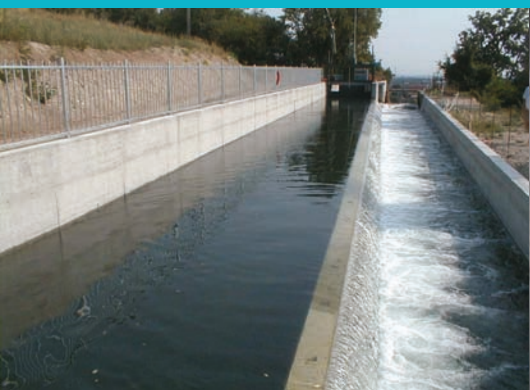


ENERGY RECOVERY IN EXISTING INFRASTRUCTURES WITH SMALL HYDROPOWER PLANTS

Multipurpose schemes – Overview and examples






SIXTH FRAMEWORK PROGRAMME

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1 Introduction

Climate change due to CO_2 emissions has been defined as the major environmental challenge to be faced nowadays by the International Community. The Rio conference in 1992, the Kyoto protocol in 1997, the European White Paper "Energy for the future: renewable sources of energy" and finally the "Directive/77/EC of the European Parliament and of the European Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market" and the recent EU Climate and Energy Package set clear community targets on CO_2 reductions with the 20/20/20 objectives for 2020 (Directive 2009/28/EC, 23.04.2009); together all these documents show impressively the political intention.

Additionally the public awareness on environmental topics has improved significantly, leading to a European environmental awareness. One of the latest manifestations of this awareness is the European Water Framework Directive, aiming at an overall protection of water, being the basis of life. But this directive tends to be in contradiction with the Renewable Electricity Directive, slowing down the development of small hydropower (SHP). However, there is no doubt about the benefits of converting energy by SHP plants. On a global level, regarding that one GWh of electricity produced by SHP means a reduction of CO_2 emissions by 480 tons, SHP means climate change mitigation and security of energy supply. Then, it implies regional development and employment. On a local level, SHP integration into the local environment, optimal use of water resource and compensation measures are now key words for SHP design and implementation, which can lead to creation of positive impacts on the local ecosystem.

Multipurpose schemes, which lead to energy recovery in existing infrastructures thanks to hydropower plants, are one of the rare issues that may respect both the "Renewable Electricity Directive" and the "Water Framework Directive". In addition, it can offer a solution to many potential issues discussed on water policy when it comes to sustainable management of the resource in sectors like agriculture, wastewater treatment or drinking water supply.

The present brochure aims at giving an overview of these schemes and presenting a collection of examples, to any interested entities, as small and large hydropower market, local, regional and national government bodies, water utilities, irrigation associations, engineering offices. Thus a large audience from specialists to non specialists of small hydropower can be concerned.

Its objective is to gather the technical knowledge and best practices on multipurpose schemes so as to:

- ► generate green electricity by an optimal use of the water resource and existing infrastructure thanks to SHPs,
- ► promote SHP in new, currently unused market segments, with two main impacts: the increase of renewable electricity generation and the stimulation of the SHP field,
- ► identify and further develop technological SHP solutions for these purposes, which have to be cost-effective, reliable, and that can be easily integrated to the existing infrastructures.

The brochure is meant to answer two main questions:

- WHERE are the potentials?
- HOW (technically) can energy be recovered by a small hydropower plant?

This second question will open on a technical points digest specific to multipurpose schemes and on a collection of examples and case studies.

For additional details, the reader is referred to the *Guide on How to Develop a Small Hydropower Plant* [1] published by ESHA and available at www.esha.be.

Finally this brochure was published within the SHAPES project which stands for SMALL HYDRO ACTION FOR THE PROMOTION OF EFFICIENT SOLUTIONS. This project was partially funded by the European Directorate for Transport and Energy (DG-TREN) within FP6, running for two and a half years since December 2007.

SHAPES overall objective was to facilitate and strengthen the co-operation between the European Small Hydropower Research and Market actors. The overall objective was to streamline future research & development and promote research and development (R&D) results in order to enhance penetration of SHP and know-how within Europe and on new markets in developing countries.

2 Where are the potentials?

Hydropower depends on two main parameters: the head (or the pressure), and the discharge. Therefore any process implying a water discharge, steady or not, and an unused pressure, is a potential energy source.

Such situation is met with water networks, dealing with:
- drinking water
- irrigation water
- raw wastewater
- treated wastewater
- runoff water (rain water, storm water, urban runoff)

But other types can also be identified:
- reserved flows or compensation ones at the foot of hydropower dams, or of water treatment plants
- fish pass system
- navigation locks and dams
- desalination plants
- cooling or heating systems

These potentials, for which electricity generation is not their primary priority, but the second, are so called **multipurpose schemes**. This implies the integration of the power plant in the existing infrastructure while guaranteeing its primary function. For example, for a drinking water network, the primary priority is to supply in quantity and quality the needed water; whilst for a desalination plant, it is to generate drinking water from sea water.

These multipurpose schemes can be so well integrated to the environment that they can lead to new recreation areas, as shown in the case study n°10, Rino SHP plant.

As multipurpose schemes are characterized by a wide range of water quality, from drinking water to waste-water, the brochure gives an overview of different techniques. However, project managers are advised to apply to SHP specialists to choose the most appropriate techniques to their sites.

2.1 Within a drinking water network

A simple drinking water network can be described as follows:
- a spring in altitude,
- a forebay,
- a penstock,
- a reservoir,
- a water supply network.

From the elevation of the sources, and as the pressure at the consumers cannot generally exceed 4 bars, there can be an excess of pressure in the networks to recover.

The main idea here is to replace the pressure breakers, used traditionally to waste the excess pressure, by turbines so as to generate electricity.

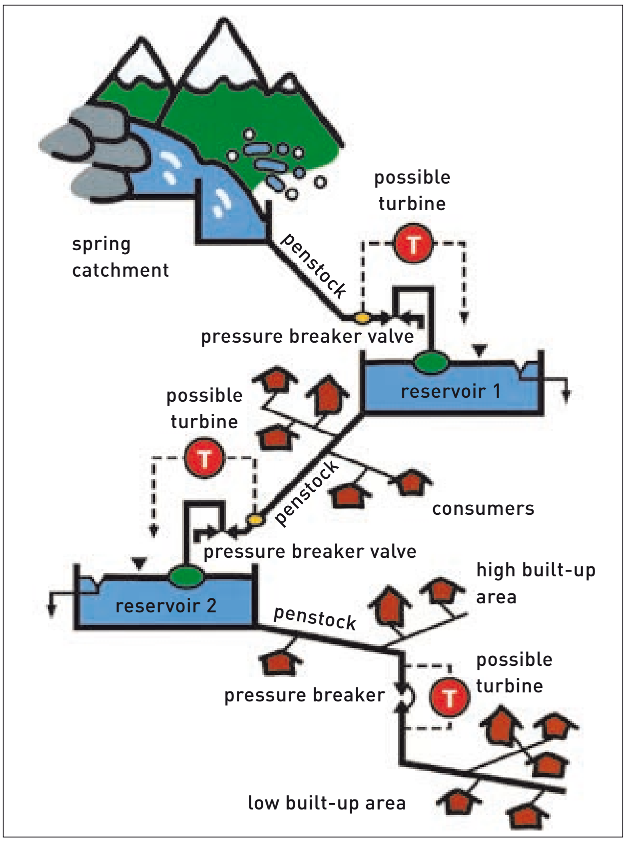


Figure 1. Example of a drinking water network and possible positions of the turbines

Different energy recovery possibilities can be identified, defined by the turbine positions:

1. on a reservoir: Water passes through the turbine before being accumulated in a reservoir. This method is the most flexible, as it permits to disconnect the turbine operation from the water supply network to guarantee at any time the primary function of the existing infrastructure.

2. within the supply network: Water passes through the turbine and carries its way through the pipe. This setting means that a pressure defined by the network requirements has to be maintained at the turbine outlet, which reaction turbines and counter pressure Pelton can achieve (cf. section 4.3).

3. before restitution to the environment: Excess water that is not supplied to the consumers passes through the turbine before discharge to the environment.

Photo 1. Trois Torrent power house, set in a drinking water network (Switzerland) (ΔZ = 242 m, Qn = 35 l/s, 70 kW, 1999)

Photo 2. St Jean power house, set in a drinking water network (Switzerland) (ΔZ = 373 m, Qn = 34 l/s, 102 kW, 2009)

When the drinking water source is underground and has to be pumped to the reservoir, no turbine integration will be possible.

The case studies n° 1, La Zour, n° 2, Schreyerbach, n° 3, Mülhau, n° 4, Poggio Cuculo, n° 5, Vienna Mauer are multi-purpose schemes set within a drinking water network.

2.2 Within an irrigation network

The potentials available within an irrigation network are similar to the ones within a drinking water network. The SHP project has to be flexible enough to maximise the electricity production the whole year and not only during the irrigation period (mostly in the summer).

The case studies n° 6, Armary, n° 7, Marchfeldkanal, n° 8, Petiva, n° 9, Esenta, n° 10, Rino are multipurpose schemes set within an irrigation network.

2.3 Before and after a wastewater treatment plant

There are two possibilities to generate electricity from wastewaters.
The first one is before the wastewater treatment plant (WWTP). In such case, the wastewater network of a built-up area will lead to a forebay equipped with a thin trash rack equipped with a rack cleaner. The wastewater is then led through a penstock to the WWTP, situated at a lower elevation, where it passes through the turbine before being treated through the usual process.
The turbine has to be set as close as possible to the elevation of the treatment basin to maximise the head.

The case study n°11 presents Profray power plant set on raw wastewaters.

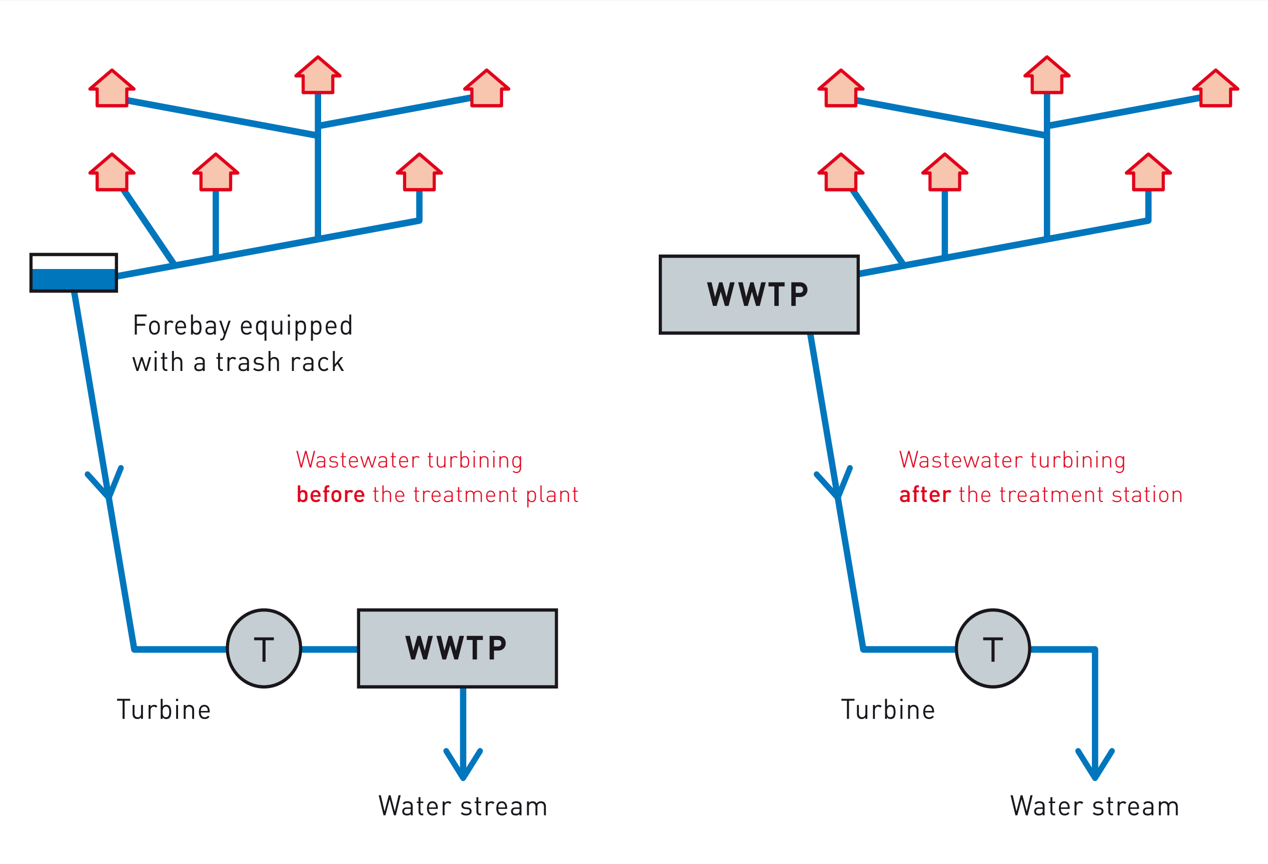


Figure 2. Turbine settings before and after the wastewater treatment plant (WWTP)

The second possibility is after the WWTP. In this case, the treated water that comes out of the WWTP is led down through a penstock to a turbine before being discharged to a water stream or a lake. To maximize the head, the turbine will then be close to this restitution.

For some sites, the hydropower project can lead to improve the cost efficiency of a longer penstock to reach a water stream where dilution can be more significant.

For the case study n°13, Seefeld SHP plant on treated wastewaters, the multipurpose project resulted in passing over a hill to reach a larger river where the treated wastewaters are discharged.

It can be noted that both possibilities can be technically implemented. As Samra project in Jordan [6] is an example of electricity production from wastewaters before and after the wastewater treatment plant.

Photo 3. As Samra hydropower plant and wastewater treatment plant

Photo 4. As Samra hydropower plant on the treated wastewater and the discharge into Duleil wadi

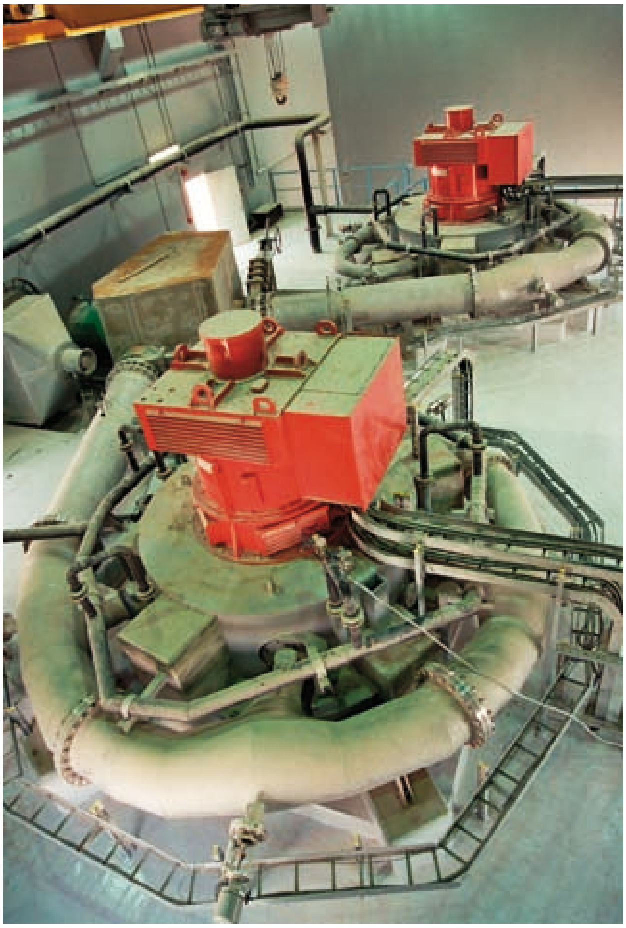


Photo 5. Two 5 nozzle Pelton turbines set on the raw wastewaters of Amman City, As Samra plants (Jordan)
(ΔZ = 104 m, Qn = 2 x 1.25 m^3/s, 2 x 830 kW, 12.5 GWh/year, 2007)

Photo 6. Two Francis turbine set on the treated wastewaters of Amman City, As Samra plants (Jordan)
(ΔZ = 42 m, Qn = 2 x 2.3 m^3/s, 2 x 807 kW, 8.6 GWh/year, 2007)

2.4 Within a runoff collection system

The potentials available within a runoff collection system are similar to the ones in a drinking water network. The main issues are the discharges irregularity, which can be managed by accumulation, and the particles carried by the water through the turbine.

2.5 On a reserved flow or compensation discharge

Reserved flows or compensation discharges have to be discharged to the rivers at the foot of dams built for large hydropower schemes or water treatment works, the amount and variability depending on national laws. The energy recovery consists in setting a SHP plant at the foot of the dam that will use the reserved flow and the difference of levels between the upstream water level in the basin and the level of the water restitution to the river.

The case studies n° 15, Alwen, and n° 16, Llys y Fran, deal with compensation discharges and water treatment works, while the case study n° 17, Le Day, deals with a large hydropower dam.

2.6 On a fish pass system

In order that fishes find the entrance of the migration system set to pass an obstacle as a dam for example, an attraction discharge is necessary. It can be created by setting a penstock from the upstream basin to the entrance of the fish pass. The energy recovery consists then in setting a turbine to use this attraction discharge and the difference of levels between the upstream basin and the fish pass entrance.

The case study n° 18, Aire-La-Ville, deals with an attraction discharge and a fish pass set in a large hydropower plant scheme.

2.7 In a navigation lock or dam

Navigation locks and dams infer regulation of water levels. Energy recovery consists then in using the difference of water levels, even during the filling and emptying of the locks. As the flood evacuation capacity has to be maintained, the machine will have either to be set as a bypass of the channel, or to be lifted higher than the upstream flood level.

The case studies n°19, Marcinelle and n° 20, L'Ame, deal with navigation locks and dams. Marcinelle SHP plant is especially equipped with a turbine lifting system to maintain the flood evacuation capacity.

2.8 In a desalination plant

Desalination plants use reverse osmosis to separate water from dissolved salts through semi-permeable membranes under high pressures (from 40 to 80 bars). The residue of liquid water containing salt, still at high pressure can be passed through a turbine in order to recover part of the energy used for the initial compression.

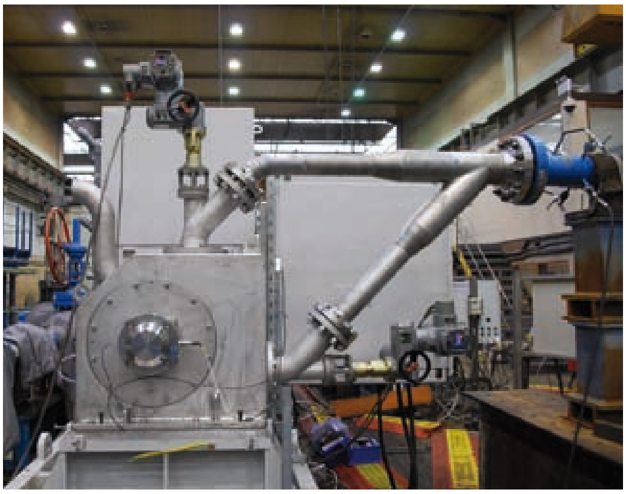


Photo 7. A 2-nozzle Pelton turbine developed for a desalination plant set in a test bench (ΔZ = 735 m, Q_n = 180 l/s, 1.1 MW)

Photo 8. The Pelton turbine is set on the same shaft as a pump (the reverse osmosis process operates with a steady discharge)

The case study n°21, Tordera, deals with the desalinated drinking water for Maresme Nord and for la Selva situated on the North coast of Barcelona.

2.9 In a cooling or heating system

Cooling or heating systems can present a pressure excess that can be recovered by hydro turbines.
For example, in a district heating system, the primary side of the heating substation is characterized by a pressure difference between the supply and return pipes. The small turbine set for energy recovery can drive (directly or not) the circulation pump of the secondary house-internal side, which ensures heat supply during power failures [7].

The case study n°22, Sangüesa, deals with a cooling system within a biomass plant.
The case studies n°23, Lomza, and n°24, Skawina, deal with turbines set on the cooling systems of heating plants in Poland [9].

3 How to start and develop a multipurpose scheme project

3.1 Main calculations

Here is a brief reminder on basic calculation.
For more details, the reader is referred to the *Guide on how to develop a small hydropower project* [1].

The electrical output power, P_e, of a hydropower plant can be defined by:

$$P_e = \rho \cdot Q \cdot g \cdot \Delta Z \cdot \eta_c \cdot \eta_t \cdot \eta_e \cdot \eta_{tr} \quad [W]$$

With:

ρ	= specific weight of water ≅ 1000	[kg/m³]
Q	= maximal discharge	[m³/s]
g	= acceleration due to gravity	[m/s²]
ΔZ	= gross head	[m]
η_c	= penstock efficiency ≥ 90%	[–]
η_t	= turbine efficiency 89% ≤ η_t ≤ 94%	[–]
η_e	= generator efficiency ≥ 92%	[–]
η_f	= transformer ≥ 97%	[–]

The efficiencies mentioned above correspond to the present state of the art for a scheme that uses optimally the water resource.
Whereas for rivers, the yearly production (kWh/year) can usually be estimated by multiplying the maximal electrical output by 4,500 hours/year, it is not possible to define this factor for multipurpose schemes. Regarding the 24 case studies, the operation at full load varies between 2,200 and 8,700 hours/year.
The average electrical consumption of a European household is estimated here at 4,500 kWh/year [8].

3.2 Recommended steps for developing a SHP project

The following table lists the recommended steps of a SHP project from site identification to commissioning. Due to cost efficiency constraints, it may be reduced for sites which output is lower than 15 kW.

	Steps	Goal
1	Site identification	To define the main site characteristics and specificities and to involve the main entities concerned by the existing infrastructure (cf. § 3.3)
2	Preliminary analysis	To evaluate the technical, environmental and economic (with an accuracy of circa 30%) feasibility of the project: is it worth going further?
3	Feasibility study	To evaluate the technical, environmental and economic (with an accuracy of circa 25%) feasibility of the project and define the final solution
4	Implementation project	To achieve the specifications for the whole design of the SHP plant (equipments and civil works), and the final plans with a focus on the water quality and on the integration into the existing infrastructure (cf. § 3.4 and 4.1)
5	Public information	To reduce the risk of future public opposition
6	Public inquiry	To obtain the necessary authorisations peculiar to each country
7	Call for tenders and final design	To achieve a call for tenders to equipment suppliers and civil engineering firms, to propose the award, to achieve the final drawings of the schemes
8	Implementation and commissioning	Turbine manufacturing, civil works, erection on site

Table 1. Recommended steps of a SHP project in an existing infrastructure, for an output higher than 15 kW

3.3 Site identification

As mentioned in the previous table, the first step to start a multipurpose project consists in creating collaboration between the infrastructure owner and SHP specialists and collecting information.

Here is a first checklist:

- **Definition of the primary function of the existing infrastructure and of its specificities,**
- **Maps and drawings to define the position and role of all the infrastructures components,**
- **Head or pressure definition:**
  - What is the upstream water level? What is its elevation?
  - What is the downstream water level? What is its elevation?
  - What are their yearly evolutions?
- **Pipes characteristics: length, internal diameter, nominal pressure, roughness, age, state, head losses regarding discharges,**
- **Hydrology:**
  - Are there any flow meters in the water network?
  - Definition of the flow duration curve with daily data, the compilation on 10 years being an optimum (cf. figure 3),
  - Are there any seasonal variations?
  - For water networks: evolution of the inhabitants
  - For drinking water networks: sources discharges, number of consumers, consumption data and their evolution,
- **Water quality, as defined in section § 4.1**
- **Evolution of the existing infrastructures (projects? extension?)**
- **Where could the power house be set?**
- **Is there an electrical grid close to the existing infrastructure?**

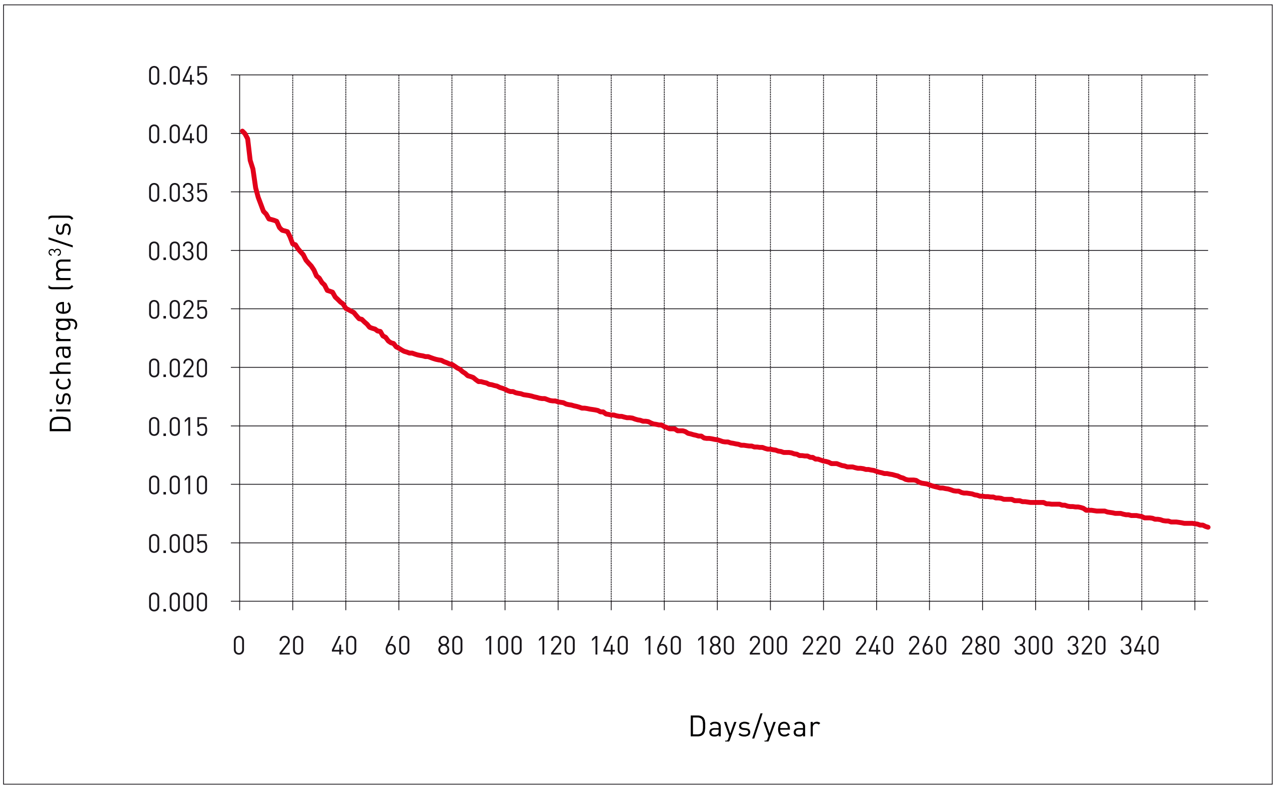


Figure 3. Example of flow duration curve

Each SHP project is specific to the scheme where it has to be integrated. It is mainly defined by a nominal discharge, a gross head and head loss in the infrastructure as detailed in the Table 2. Then, the yearly average evolutions of the discharges and heads will lead to the production calculation.

Topic	Acronym	Units	Definition
Nominal discharge	Qn	m^3/s	The nominal discharge depends on the flow duration of the site, so as to optimise the production all over the years (cf. figure 3).
Gross head	ΔZ	m	The gross head is defined by the difference in levels between the upstream water level at the collecting chamber or reservoir or penstock forebay and the downstream water level at the reservoir, at the treatment plant or at the discharge river.
Head losses	Hr	m	Head losses are energy losses within the infrastructure (penstock, channels, grids) (cf. § 4.2).

Table 2. Main parameters to define a hydropower site

3.4 Main requirement: integration to the existing infrastructure

Once the feasibility study has demonstrated the project viability, the implementation project will lead to define the whole design of the SHP plant, with a focus on the integration to the existing infrastructure. In other words, the SHP plant must not impact on the primary function of the site. Table 3 gives a list of basic recommendations.

Infrastructure requirements	Recommended technique
Water quality	The SHP plant must not impact on the water quality, unless it leads to its improvement, while optimising the equipment efficiencies and lifetime (cf. § 4.1).
Discharges at the turbine outlet	The turbine is designed from the flow duration curve of the scheme (cf. figure 3) so as to optimise the production. A bypass is set to reach the infrastructure discharge requirements at any times. Storage is avoided, apart when required for the existing infrastructures (cf. § 4.3.2 and 4.8).
Pressure at the turbine outlet	For heads >60 meters, if the needed turbine outlet pressure has to be higher than the atmospheric one, the Pelton turbine is at a higher elevation, or a counter pressure turbine is set (cf. § 4.3.5.1).
Flexibility	The turbine has high efficiencies for the optimal range of pressure and discharges, defined by the existing scheme (cf. § 4.3.2).

Table 3. Technical recommendations for the integration of the SHP plant into the existing infrastructure

3.5 Economic aspects specific to multipurpose schemes

The selected case studies show a wide range of investment: from 90,000 to 3,945,000 €, showing how each multipurpose project is specific. However, a few common principles can be mentioned.
First, the economic calculations distinguish the investments due only to the hydropower plant from the ones due to the primary function of the existing infrastructure. For example, a 312 mm diameter penstock can be sufficient for the network, but as it may result in high head losses (cf. § 4.2), a 380 mm diameter pipe will be necessary for the hydropower project. Then only the cost difference between both penstocks (supply and setting) will be considered in the economic analysis of the SHP project.
Then, maintenance and operation costs will be reduced with sustainable equipment especially designed for the site. If the generator is connected to the national grid, the selling price will depend on the small-hydropower regulation proper for each country.
Finally, by creating a source of income, a hydropower project can be a good opportunity to improve the existing scheme.

4 Technical recommendations for SHP plants set in existing infrastructures

The first recommendation, as for any projects, is the design as a whole at an early stage. In addition to this general principle, this section has the objective to list a selection of technical recommendations for multipurpose schemes, with a focus on integration to the existing infrastructures.

4.1 Water quality and its impacts on the SHP plant design

A SHP plant must not impact on the water quality, unless it leads to its improvement, while optimising the equipment efficiencies and lifetime. Especially while defining the penstock and turbine, attention will be paid on the mechanical resistance and manufacturing easiness of the selected materials but also on their corrosion and abrasiveness behaviour.

Table 4 lists some technical consequences of the water characteristics on the SHP plant design.

It can be noted that the following infrastructures use water which quality is similar to rivers:

- irrigation water network
- reserved flows or compensation ones at the foot of hydropower dams, or of water treatment plants
- fish pass system
- navigation locks and dams

For cooling/heating systems, a priori the water quality does not imply a specific design for the turbine. Nevertheless, its temperature has to be considered.

Water quality	Recommended technique	Brochure section	Existing infrastructure: Drinking water network	Irrigation water network	Raw wastewater network	Treated wastewater network	Runoff collection system	Reserved flow	Fish pass	Navigation lock	Desalination plant	Cooling/heating system
Gravels and stones	Setting of a grid at the forebay		X	X	X		X	X	X	X		
Sand particles	Setting of a de-silted set before the forebay		X	X	X		X	X	X	X		
	Pelton runner built with mounted bucket to unset and replace the buckets	4.3.4										
Drinking water	All parts in contact with water in stainless steel		X									
	Electrical actuators to replace all oil ones		X									
Chlorinated water	Sacrificed anodes to prevent from erosion		(X)		X	X						
Salt	All parts in contact with water in stainless steel										X	
Organic wastes (bacteria)	Increase of the penstock internal diameter, to limit head losses due to the deposits on the wall created by bacteria	4.2			X	X						
Fat	Fat removing system at the forebay				X							
Fibrous and filamentous matters (plants, strings...)	Setting of a screening system equipped with a trash rack at the forebay.			X	X		X			X		
	Suppression of all obstacles where the materials could accumulate. For Pelton turbines, it means no nozzle guide vanes and no deflector.	4.3.4			X							
	Progressive flow speed increase within the turbine, to avoid trash accumulation	4.3.4			X							
	Integration of hand holes in the casing to clean the machine	4.7			X							
	For Kaplan turbines, special cleaning programme based on the closure of the downstream valve.	4.7		X	X			X		X		
Wastewater	All parts in contact with water in stainless steel				X							

Table 4. Technical recommendations due to water quality for SHP plant design

Photo 9. Screening system for wastewater at the forebay (Profray power plant, Switzerland, case study n°11)

Photo 10. 6 mm grid for wastewater at the forebay (Profray power plant, Switzerland, case study n°11)

4.2 Penstock and head losses

At the start of a SHP project in an existing infrastructure, a first issue is to define if the existing penstocks and channels are suitable for electricity production, which implies mainly to check their mechanical resistance (nominal pressure for a penstock) and head losses.

In general, head losses are acceptable if at nominal discharge they are lower than 10% of the difference in levels, or in other words if the penstock efficiency is higher than 90%. Indeed, this corresponds to the present state of the art for equipment that uses optimally the water resource.

To sum up, head losses in a penstock depend on:

- Its shape: singularities as elbows, forks tend to increase head losses
- Its internal diameter
- Its wall roughness and its evolution due to its degradation or/and to wall deposits.

It may be recalled here that energy loss due to friction in a penstock can be estimated as being inversely proportional to its diameter to the power of five. For instance, a diameter increase of 20% leads to a head losses decrease of 60% *.

When considering a wastewater network, the pressure due to the difference of levels between the forebay and the treatment plant (WWTP) has to be reduced, which tends to select a penstock with a small diameter. Thus the pipe carries wastewaters while wasting the pressure useless for the treatment process. On the contrary, if the objective is to produce electricity, the pressure has to be maximal where the turbine is set. Therefore, a penstock with a larger diameter has to be selected to minimise head losses.

When dealing with raw or treated wastewaters, a possible deposit of wastes on the penstock walls due to organic wastes has to be considered. Observations show that this deposit can easily exceed 1 to 2 mm.

Table 5 presents how important the choice of the penstock diameter is, and points out its clogging impact. Calculations have been achieved using Colebrook formula for an 860 m length penstock, a discharge of 280 l/s and a gross head of 115 m. The results are expressed as the penstock energy efficiency, ratio between the gross and net heads.

Penstock diameter	Polluting load thickness	Head losses	Penstock energy efficiency
mm	mm	mm	%
312	0	22.7	80.3
312	2	44.2	61.6
380	0	8.5	92.6
380	2	15.5	86.5

Table 5. Head losses in a penstock regarding its diameter and clogging

* *The Guide on how to develop a small hydropower project* [1] details the different means to calculate head losses and optimal internal penstock diameters.

As shown by the above-mentioned values, a small diameter change (+ 21%) does not only result in reducing head losses (and thus the production loss), but also in reducing the dependency from the clogging thickness. It can be noted that 312 mm and 380 mm are standard diameters, and that excavation and setting costs will be similar for both variants. Moreover, the energy efficiency of the 380 mm penstock without clogging fulfils the SHP performance requirements. It can be added that head losses can be directly mesured on site using, for example, a piston pressure gauge, connected to the turbine inlet.

Finally, as for the whole hydropower area, head losses in pipes or channels have to be considered in the cost efficiency of a multipurpose project. Indeed, only a technical and economic calculation, based on the production gain and the cost difference between the variants, permits to select the optimal equipment.

4.3 Turbines

4.3.1 Main types of turbines

The following table presents the four main types of turbines. It shows that they are suitable to all multipurpose schemes (considering that dams and locks higher than 60 meters are rare to set a Pelton turbine). Reverse pumps are often found in drinking water networks, when the available output is lower than 100 kW, thanks to their affordable price. However, as seen in section 4.3.2, they are not suitable to multipurpose schemes.

Turbine type	Operation range	Multipurpose schemes									
		Drinking water network	Irrigation network	Raw wastewater network	Treated wastewater network	Runoff collection system	Reserved flows and compensation discharges	Fish bypass system	Navigation locks and dams	Desalination plants	Cooling/heating systems
Pelton	60 –1000 meters	X	X	X	X	X				X	
Francis	20 –100 meters	X	X	X	X	X	X	X		X	
Kaplan	1.5 – 30 meters	X	X	X	X	X	X	X	X		X
Reverse pumps	For outputs lower than 30 kW	X	X	X	X	X	X	X	X	X	X

Table 6. The four main types of turbine

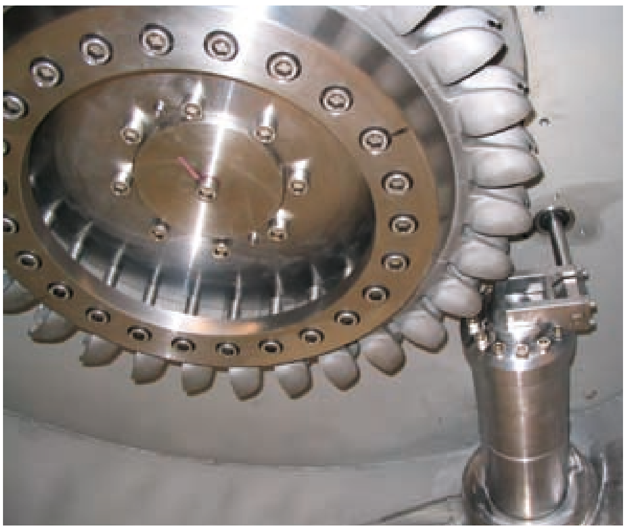


Photo 11. Pelton runner with one nozzle, set on the drinking water of Haut Intyamon (Switzerland) (ΔZ = 502 m, Qn = 40 l/s, 163 kW, 2006)

Photo 12. Kaplan runner with 8 blades at the workshop, set on the drinking water of Arezzo (Italy) (case study n°4)

Photo 13. Francis turbine with a spiral casing set on the drinking water of Vallorbe (Switzerland)
(ΔZ = 11 m, Qn = 400 l/s, 41 kW, 156,000 kWh/year, 1929)

Photo 14. Reverse pump set on the treated wastewater of Nyon (Switzerland) (case study n°14)

4.3.2 Discharges, flexibility and performances

The SHP plant operation must not impact on the primary function of the existing infrastructure. Thus, the turbine has to be as much flexible as possible regarding the available pressures and discharges, while guaranteeing high performance on the largest operation ranges.

The turbine design is based on the site flow duration curve (cf. figure 3), a crucial tool to optimize the production and the viability of the project. Indeed, the discharges can evolve with the spring hydrology and/or with human activities.

The case study n° 11, Profray SHP plant set on raw wastewater, is an interesting example of oversized project. First, it can be noted that the commune is characterized by a population of 7000 inhabitants that reaches more than 30,000 during the winter season. In 1993, it was chosen to design the turbine for the maximal discharge of the wastewater treatment plant, 240 l/s. Therefore, the turbine was only operating a few days per year at its nominal discharge. Moreover, during the dry season, the limited available discharges had to be stored at the forebay to allow electricity production. This storage resulted in an important generation of decanted deposits. An accumulation of grease at the surface was also observed, leading to form a crust that had to be regularly removed. Furthermore, such wastewater storage made the further treatment more difficult.

Finally, the new turbine was designed for 100 l/s, leading to a production increase of 45% (851,000 kWh/year instead of 585,000 kWh/year), although the new nominal discharge is 2.4 times lower.

Some multipurpose schemes deal with steady discharges, as for the following case studies:

- n° 18, Aire la Ville, dealing with an attraction discharge for fish to find the entrance of the upstream migration system,
- n° 15, Alwen, and n° 16, Llys y Fran, dealing with a compensation discharge for water treatment schemes.

Then, SHP plants at the foot of large hydropower dams generally work with a steady reserved flow. However, the case study n° 17, Le Day, deals with a reserved flow that doubles during the summer season.

For the case study n° 4, Poggio Cuculo, the turbine works with three different drinking water discharges along the year depending on the season and if it is day or night. This variation is due to the price of the electricity consumed by the water treatment plant.

Turbine type	Discharge control device	Minimal discharge
Pelton	One to five adjustable nozzles	At least 15% of the nominal discharge per nozzle
Francis	Adjustable guide vanes	Circa 50% of the turbine nominal discharge
Kaplan	Fixed or adjustable guide vanes, adjustable runner blades	At least 20% of the turbine nominal discharge
Reverse pump	No device	85–90% of the machine nominal discharge

Table 7. The four main turbines and their flexibility

High performances depend on the site definition and on the whole design of the SHP plant. Therefore the project manager is recommended to go through all the analysis steps listed in table 1 in collaboration with small-hydropower specialists, and to ask the suppliers to justify the efficiencies of their equipment.

As shown on table 7 and figure 4, Pelton and Kaplan turbines are especially recommended for their flexibility regarding discharges.

On the contrary, **a reverse pump** is not recommended regarding its lack of flexibility due to the absence of regulation device, leading to:

- a cyclical operation, that infers:
  - numerous starts and stops, leading to an untimely wear of the equipment,
  - a buffer reservoir designed for at least one operation hour,
- a problematical synchronisation,
- a specific design to operate with high performances as a turbine, which reduces its low investment advantage.

The case study n° 14, Nyon SHP, commissioned in 1993, is composed of a reverse pump. Although it has been especially designed for the site, its lack of flexibility is so that the operator has launched a study to replace it with a Pelton turbine.

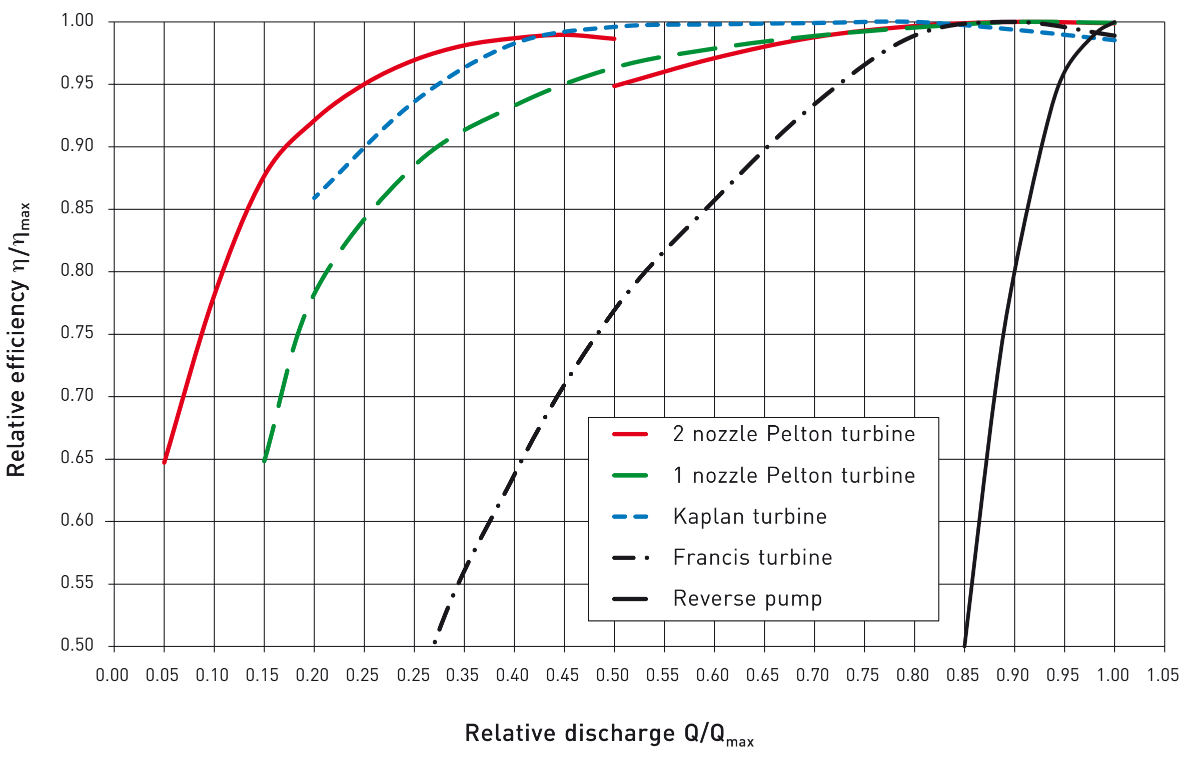


Figure 4. Evolution of the relative efficiencies regarding the discharges for Pelton, Kaplan and Francis turbines, and reverse pumps

4.3.3 Drinking water quality and turbines

To demonstrate that turbines can respect water quality, or in other words that drinking water can pass through the turbine before being consumed, a comparison with pumps can be achieved, as shown in Table 8.

	Pump station	Turbine station
Inlet valve	yes	yes
Discharge regulation device	**no**	**yes**
Runner linked to a rotating shaft	yes	yes
Shaft gaskets	yes	yes
Casing and runner in contact with water	yes	yes
Greased-for-life roller bearings	yes	yes
Electrical machine	**yes (engine)**	**yes (generator)**
Electrical panels	yes	yes
Medium voltage/high voltage transformer	Yes, if needed	Yes, if needed
Usual building materials of the hydraulic machine	Cast, black steel, stainless steel, bronze	Cast, black steel, stainless steel, bronze
Automatic by pass	**no**	**yes**
Water access	Disassembly necessary	Disassembly necessary

Table 8. Comparison between a pump and a turbine station

4.3.4 Adaptations to raw wastewater

The main difficulty with raw wastewaters is linked with fibrous and filamentous residues that are not caught by the forebay grids (vegetal fibres, strings, threads, etc). Such materials can be blocked by any obstacles in the flow, as for example in the guide vanes of a reaction turbine. Then, some other wastes can cling at them and agglomerate, which can lead to a partial or total clogging of the turbine and of its control systems.

For **Francis turbines**, the guide vanes and the fixed blades of the runner are obstacles for the wastes. The cleaning of a jammed turbine can imply its whole dismantling, and the replacement of a few pieces, reducing the availability of the power plant, and thus, the kWh cost price.

Kaplan turbines face the same set of problems. But it is possible to remove the fibrous wastes by closing regularly the downstream security valve (creation of a wave back).

On the contrary, **Pelton turbines** geometry is ideal for these applications. Indeed, the simplification of the turbine shapes by choosing progressive flow acceleration reduces waste accumulation. Figure 5 shows the principle of a 4-nozzle Pelton turbine with such a simplified manifold composed of standard pipes, elbows and tees.

Furthermore, it is recommended to avoid:

- nozzle guide vanes (cf. Photo 15)
- deflectors, which implies that another security system has to be integrated to prevent any turbine runaway.

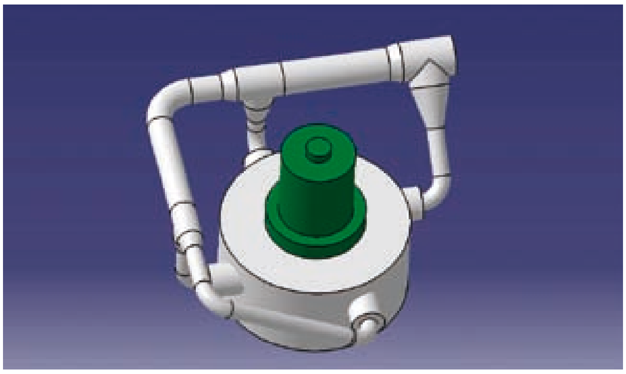


Figure 5. 4-nozzle Pelton turbine with a progressive flow acceleration to prevent waste from accumulating in the manifold

Photo 15. A nozzle guide vane, worn out by limestone

Once these usual design precautions are considered, the only possible blockage risk (but rare) concerns the nozzle tip liner. Finally, compared to a Francis turbine, the cleaning of a Pelton turbine is simple. It can be achieved thanks to a hand hole to get in the machine without dismantling it.
Regarding wear by abrasiveness, for **Pelton turbines**, it concerns the needle, the nozzle and, especially, the internal face of the buckets. As far as suitable manufacturing layouts have been achieved, the interchange-ability of the needles and the nozzles should not be a problem. On the contrary the replacement and the reparation of the buckets are not as simple. One solution is the runner with mounted buckets: the buckets are set together by screwing and pre-stress between two massive rings and can be easily dismantled and replaced.

Photo 16. Achievement of a Pelton runner with mounted buckets (St Jean SHP plant, Switzerland, set in a drinking water network, ΔZ = 373 m, Qn = 34 l/s, 102 kW, 2009)

Photo 17. Pelton bucket worn out by sand particles (case study n°11, Profray)

4.3.5 Turbine setting

Whereas section 2 described turbine setting regarding each multipurpose scheme, this section aims at detailing the possible positions of turbine regarding their types.

4.3.5.1 Pelton turbines and counter pressure turbines

As a Pelton runner operates in the air, at atmospheric pressure, the reservoir which receives the turbine outlet is set high enough from the consumers to guarantee them a sufficient pressure.
When the setting of a reservoir is not possible, and a turbine outlet pressure higher than the atmosphere is required for the existing infrastructure, a counter pressure turbine can be set. For this turbine type, the runner rotates in an air volume maintained at the requested required pressure.

Photo 18. Counter pressure Pelton turbine (Mels SHP plant, Switzerland, set in a drinking water network, ΔZ = 415 m, Qn = 13 l/s, 41 kW, 2008)

Photo 19. Counter pressure Pelton turbine (Fällanden SHP plant, Switzerland, set in a drinking water network, ΔZ = 140 m, Qn = 16 l/s, 17 kW, 2008)

4.3.5.2 Kaplan turbines and cavitation

Kaplan turbines can be directly set as a bypass of the pressure breaker or of a valve. Figure 6 shows a turbine directly set as a bypass of the initial regulating valve.

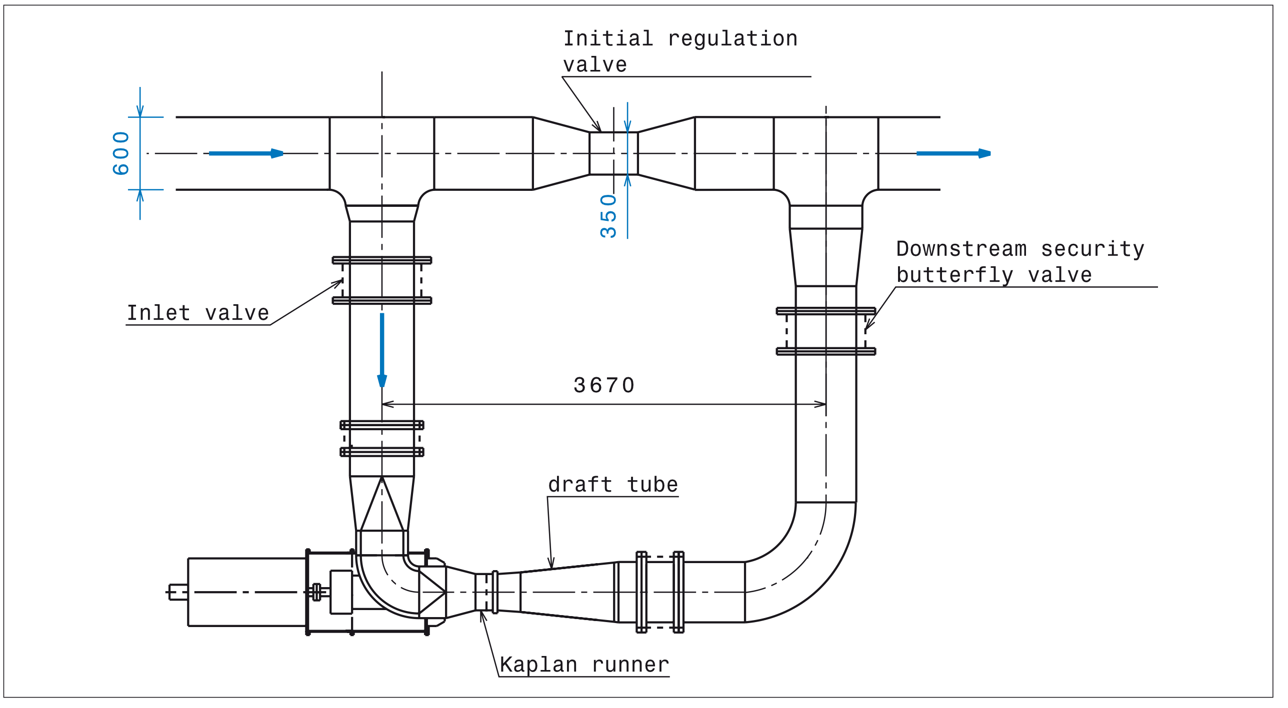


Figure 6. Setting of a Kaplan turbine as a bypass of an existing valve in a drinking water network, Poggio Cuculo SHP plant (case study n°4) (cotations in mm)

However, the setting of Kaplan turbines is limited by cavitation. This phenomenon can appear for any turbine, but especially for Kaplan turbines.

Cavitation is the transformation of liquid water into steam, through a pressure decrease. When the flow accelerates after meeting a turbine blade, its inlet edge for example, the local pressure may fall below that of water vaporization at the surrounding temperature. A bubble of vapour forms on the blade's extrados, which extends progressively as ambient pressure drops. Pursuing its movement along the blade, the bubble reaches a spot where pressure rises, beyond that of vaporization. The vapour bubble then implodes (collapses) generating considerable kinetic energy densities, which can sometimes lead to catastrophic pitting of the blade's surface. Grapes of bubbles form over the area where condensation takes place. The phenomenon is usually noisy, and always fluctuates strongly. The cavitation pocket itself, however, does not modify turbine performance or erode the blades, provided of course it is stable and not too large.

Finally, the vapour bubble implosion close to the blade is responsible for its erosion, and for the deterioration of the turbine performances. And as this phenomenon is a vicious circle, the erosion keeps on growing, while the production keeps on decreasing.

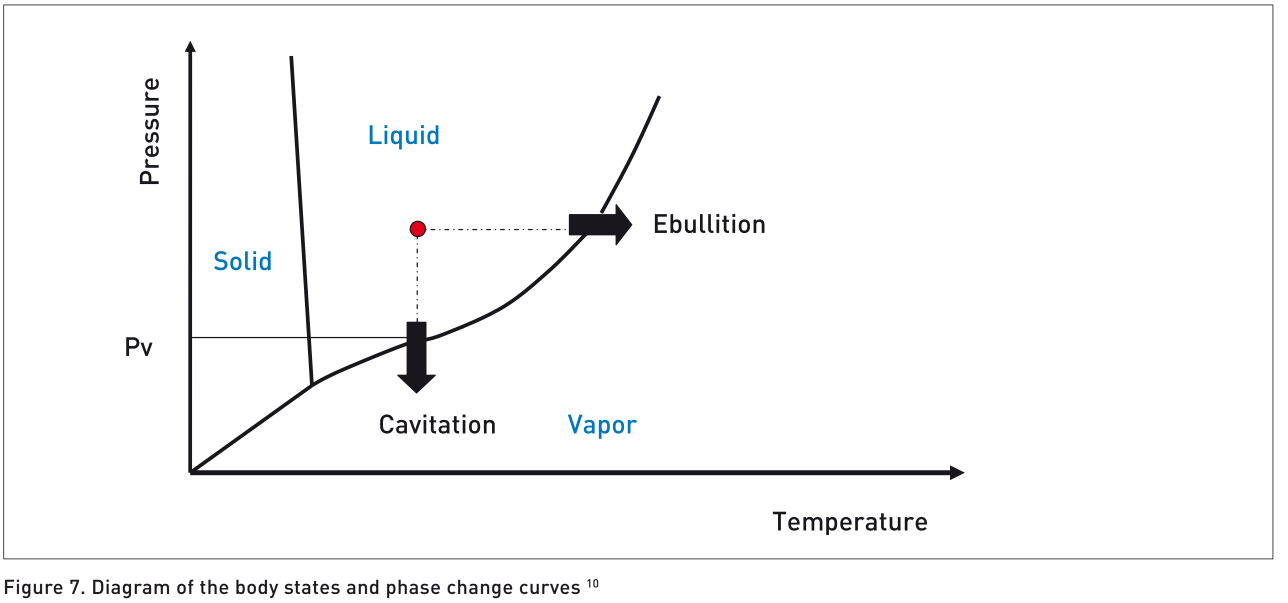


Figure 7. Diagram of the body states and phase change curves [10]

Photo 20. Cavitation on blades

Photo 21. Kaplan turbine blade, manufactured without hydraulic laboratory techniques, eroded by cavitation after a few months operation

But cavitation is not a fatality. Laboratory tests permit to identify turbine cavitation behaviour, and to improve it by an appropriate design. Then the manufacturers of these laboratory-developed turbines can define with accuracy the maximal height regarding the downstream water level at which the runner can be set without cavitation damages.

For the case study n° 4, Poggio Cuculo SHP, with a gross head of 28 meters, cavitation could have been a strong constraint. But thanks to the water treatment configuration, the turbine could be set 2 meters under the water level in the downstream reservoir.

4.4 Regulation

Generally, the turbine is regulated on the upstream water level in the forebay, so that it remains steady. The process can be defined by the following steps:

- When the upstream level tends to raise, the turbine opens up to increase its discharge up to the nominal one. If the upstream level keeps on raising, the surplus can pass through the bypass.
- When the upstream level tends to go down, the turbine closes itself to take less discharge. If the upstream level keeps on going down, the turbine is shut down.

By controlling the needle stroke for Pelton turbines, the vanes or blades opening for Francis, and Kaplan turbines, the turbine can turn to be an efficient and convenient device to regulate discharges.

For the case study n° 6, Armary SHP, the regulation enables the turbine operation even during the irrigation season. For the case study n° 4, Poggio Cuculo SHP, the turbine is used as a regulation device thanks to the blade opening control.

4.5 Security system

In case of load rejection (due to a storm for example) resulting in disconnection of the turbine from the electrical grid, the machine has to stop automatically. Such shut down must be achieved so as to any water hammer in the penstock and avoid runaway speed. Indeed, these phenomena could lead to important equipment damage.
The first requirement is that the SHP plant has to be equipped with an emergency power supply. The second depends on the type of turbines:

- **Francis turbine** shut down is achieved by closing the guide vanes and the upstream valve with adapted speeds.
- **Kaplan turbine** shut down is achieved by closing the adjustable guide vanes, the runner blades and the downstream valve with adapted speeds.
- **Reverse pump** shut down is achieved by closing the upstream or downstream valve with adapted speeds.
- For **Pelton turbines**, deflectors are a simple and secure solution. Nevertheless, they are not recommended for raw wastewater, as they might be caught into wastes. In such cases, the turbine is designed to resist to runaway speed, and a special monitoring is achieved to regulate the valves closures.

However, for the case study n°11, Profray power plant set on raw wastewater, the turbine is equipped with deflectors, which are regularly checked thanks to hand holes set in the casing.

Photo 22. A deflector of Profray SHP plant before the commissioning (case study n°11)

Photo 23. A deflector in the raw wastewater of Profray SHP plant (case study n° 11)

The case study n° 2, Schreyerbach power plant, presents two important security systems: an electromagnet linked to the deflector, and an inlet valve controlled by a counterweight.

4.6 Electrical connection

Most of the time, the SHP plant is connected to the local electrical grid, for financial and practical reasons. But if necessary, the energy recovery can be used directly for self consumption (as in desalination plants).

4.7 Maintenance

The maintenance and its cost depend on the water quality and on how the whole design of the SHP plant has been adapted to it, as described in Table 4.
For **drinking water networks**, the maintenance is limited, whereas it can be important for non-adapted SHP plants using **raw wastewater**. To make this maintenance easier, the machine design integrates, for example, hand holes for a direct access to wastes.
It can be noted that most of the time, the wastewater treatment plant staff is in charge of the SHP maintenance.

For the case study n° 11, Profray SHP, in operation since 1993 on raw wastewater, the average usual maintenance amounts to about 40 hours per year. The maintenance frequency is based on the electrical output evolution. Indeed, when the output is lower than the foreseen one for the available discharge, it means that the waste accumulation is not acceptable anymore and the turbine has to be cleaned.

Photo 24. Two open hand holes to reach the deflectors Profray SHP plant (case study n° 11)

Photo 25. A hand hole with its cover, Profray SHP plant (case study n° 11)

4.8 Bypass

A bypass of the turbine may be required to guarantee the primary function of the existing infrastructure at any time. For water networks for example, it has to be systematically set. It can be used when the turbine is not operating due, for example, to a too low discharge or to maintenance needs. It can also be used when the discharge needed for the existing scheme is higher than the turbine nominal one. In such situation, the turbine uses its maximal discharge, whereas the surplus flows through the bypass (if the head losses are still acceptable for the turbine).

As it replaces the turbine, the bypass has different functions: to regulate the discharges and/or the water levels, and to reduce the pressure.

Different instruments exist for pressure reduction in a pipe. They have to be suitable for a continuous operation, and automatically and manually controllable. Here are some examples:

- **Decompression valve**

Direct inflow in the water network through a decompression valve is possible but not an optimal solution. It is preferred to separate the pressure systems strictly by the creation of a free water level (cf. figure 8).
The configuration of a decompression valve (as the Clayton valve) that discharges into a reservoir is usual.

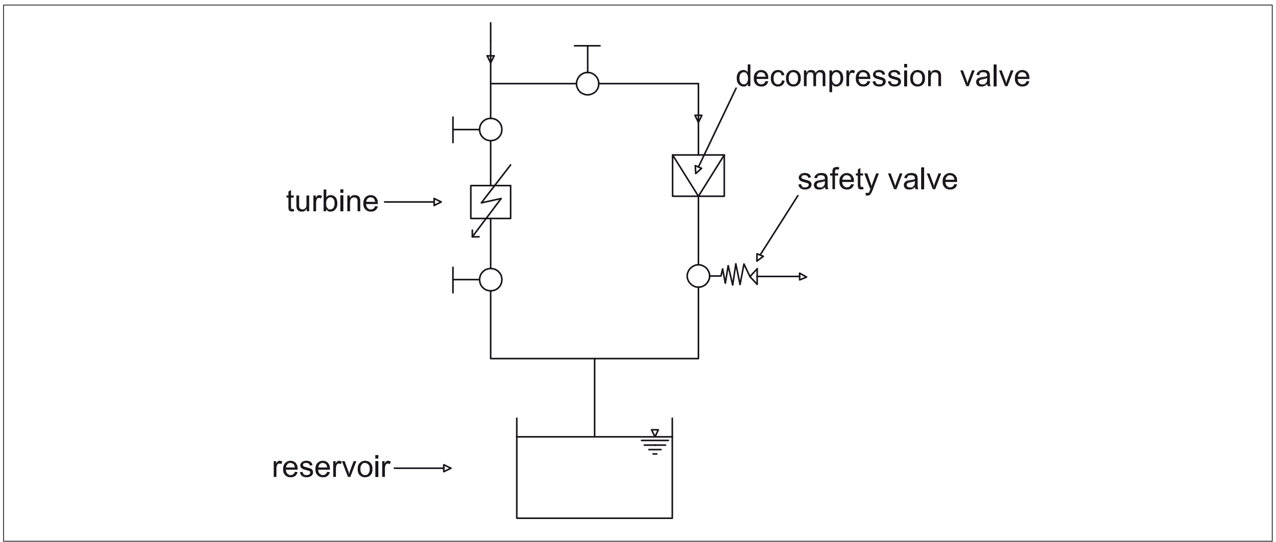


Figure 8. Bypass composed of a decompression valve with a reservoir

- **Adjustable nozzle system**

For high heads, a Carnot pressure breaker may be the best tool (cf. figures 9 and 10). It is composed of an adjustable nozzle placed into a long tube immersed in a reservoir. Such device allows to maintain the upstream water level, to regulate the bypassed discharge, while wasting the excess pressure. The nozzle control system is integrated in the process control system of the existing infrastructure and the SHP plant.

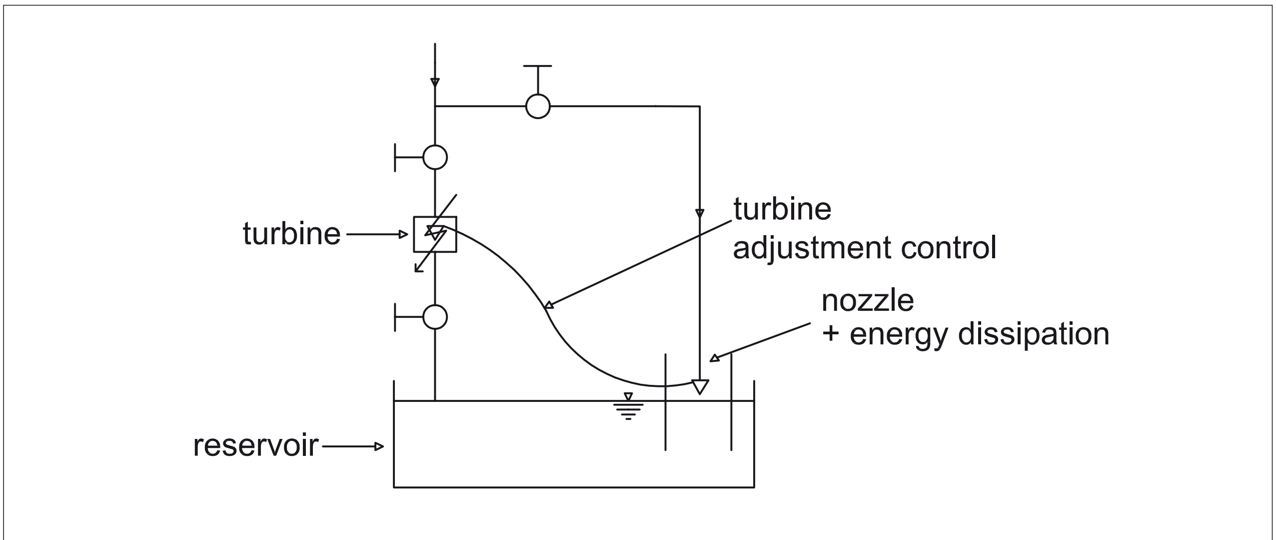


Figure 9. Bypass composed of an adjustable nozzle for high heads

When the SHP plant is equipped with a single-jet Pelton turbine, the Carnot pressure breaker can be equipped with a similar nozzle, leading to regulation simplification and cost reduction.

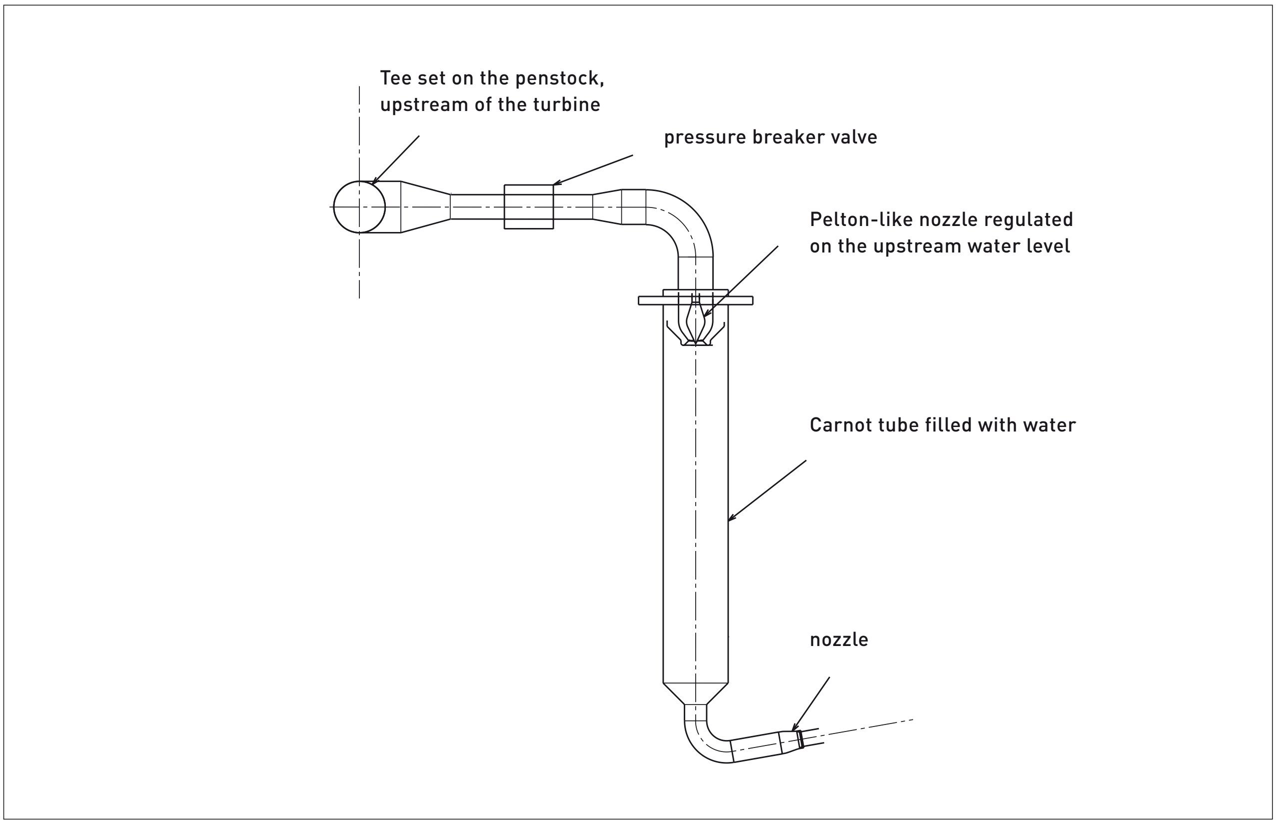


Figure 10. Carnot pressure breaker

Photo 26. A Carnot bypass equipped with an adjustable nozzle set against the reservoir wall
(St Jean SHP plant, Switzerland, set in a drinking water network, ΔZ = 373 m, Qn = 34 l/s, 102 kW, 2009)

Photo 27. The Carnot bypass in operation
(Schreyerbach, case study n°2)

For the case study n° 19, Marcinelle, a special device can lift both turbines out of the navigation lock. Then a crane sets them on the bank, and the regulation schemes operate as before the turbines integration.

5 Case studies

The following table presents a selection of European case studies that are then developed one by one through cards.

Existing infrastructure	Case study	Power plant name	Country	Nominal discharge (m³/s)	Gross head (m)	Electrical output (kW)	Electrical production (kWh/year)	Equivalent per number of European households *
Drinking water network	1	La Zour	Switzerland	0.30	217	465	1,800,000	400
	2	Shreyerbach	Austria	0.02	391	63	550,000	120
	3	Mühlau	Austria	1.60	445	5750	34,000,000	7,560
	4	Poggio Cuculo	Italy	0.38	28	44	364,000	80
	5	Vienna Mauer	Austria	2.00	34	500	3,000,000	670
Irrigation network	6	Armary	Switzerland	0.09	105	68	454,000	100
	7	Marchfeldkanal	Austria	6.00	2	70	500,000	110
	8	Petiva	Italy	18.50	6	875	5,000,000	1,110
	9	Esenta	Italy	4.50	24	860	4,300,000	960
Irrigation network and tourist area	10	Rino	Italy	0.78	446	2800	14,000,000	3,110
Raw wastewater network	11	Profray	Switzerland	0.10	449	380	851,000	190
Raw wastewater and runoff network	12	La Louve	Switzerland	0.12	180	170	460,000	100
Treated wastewater network	13	Seefeld	Austria	0.25	625	1192	5,500,000	1,220
	14	Nyon	Switzerland	0.29	94	220	700,000	160
Water treatment works and compensation discharge	15	Alwen	United Kingdom	0.16	26	26	200,000	40
	16	Llys y Fran	United Kingdom	0.16	25	29	220,000	50
Hydropower dam and reserved flow	17	Le Day	Switzerland	0.60	27	126	580,000	130
Hydropower dam and fish pass	18	Aire la Ville	Switzerland	2.00	21	348	2,720,000	600
Navigation lock and dam	19	Marcinelle	Belgium	30.00	3	650	2,000,000	440
	20	L'Ame	France	10.80	2	145	650,000	140
Desalination plant	21	Tordera	Spain	0.11	685	720		
Cooling system (biomass plant)	22	Sangüesa	Spain	1.16	11	75	500,000	110
Temperature control system (heating plant)	23	Lomza	Poland	0.09	31	20	40,000	10
Steam block cooling system (thermal power plant)	24	Skawina	Poland	23.30	8	1560	6,390,000	1,420

Table 9. European case studies of multipurpose schemes

* The average electrical consumption of a European household is estimated at 4,500 kWh/year.

Multipurpose scheme n°1

Existing infrastructure	**Drinking water network**
Power plant name	**La Zour**
Location	**Savièse, Switzerland**
Commissioning year	**2004**
Multipurpose scheme definition	The primary function of this multipurpose scheme is to supply drinking water, while the second is to produce electricity from the drinking water.
Site description	The drinking water system of Savièse commune had to be upgraded in anticipation of population growth, increases in per-capita water consumption, and glacier retreat. In the scope of this project, two small hydro schemes (250 kW and 330 kW) were commissioned in 2001, La Zour scheme in 2004 and a fourth one in 2009. Moreover the commune plans a further scheme on its irrigation network.  **The reservoir and the power house**  **The setting of the runner and the generator**  **Inside the power house**  **The runner and its 3 jets**
Comments	The performance of the three first hydro plants are to the level expected. The fact that the commune has recently ordered a fourth turbine demonstrates the technical and economic attractiveness of these kinds of SHP developments. However the outputs (and the income from the electricity sales) could have been even higher if more attention had been paid to analysing of the penstock head losses and considering the available discharges during the detailed design phase.
Nominal discharge	0.300 m^3/s
Gross head	217 m
Electrical output	465 kW
Electrical production	1,800,000 kWh/year, or the electricity consumption of circa 400 European households
Investment	
Involved enterprises	Mhylab (CH): hydraulic design, Gasa SA (CH): manufacturer
Operator	Savièse commune

Multipurpose scheme n°2

Existing infrastructure	**Drinking water network**
Power plant name	**Schreyerbach**
Location	**Aldrans-Innsbruck, Austria**
Commissioning year	**2006**
Multipurpose scheme definition	The primary function of this multipurpose scheme is to supply drinking water, while the second is to produce electricity from this drinking water.
Site description	The Schreyerbach integrated water and power plant was installed in an existing spring-fed drinking water supply system so as to make use of the natural head of almost 400 m. The combined plant was designed with absolute priority for the drinking water supply over power generation including full system availability. A by-pass of the turbine will guarantee the drinking water supply if ever the turbine is not operating.

The powerhouse and the town of Innsbruck in the valley

The single-jet Pelton turbine

The bypass and the reservoir house

The bypass set on the reservoir

Comments	The eighty year old original gravity penstock was replaced with a new one. The single-jet stainless steel Pelton turbine and the bypass were set and integrated into a combined process control system. The by pass, comprising an adjustable jet, is constantly available and used for energy dissipation. Two important security devices are incorporated into the plant: an electromagnet linked to the deflector, and an inlet valve controlled by a counterweight.
Nominal discharge	0.02 m^3/s, which is the maximal authorized diversion discharge of the spring.
Gross head	391 m
Electrical output	63 kW
Electrical production	550,000 kWh/year, or the electricity consumption of circa 120 European households
Investment	400,000 € overall costs (planning included)
Involved enterprises	IKB AG, Wasser Tirol – Wasserdienstleistungs-GmbH (AT), IB Kirchebner (AT), Troyer (IT): manufacturer
Operator	IKB AG Innsbruck

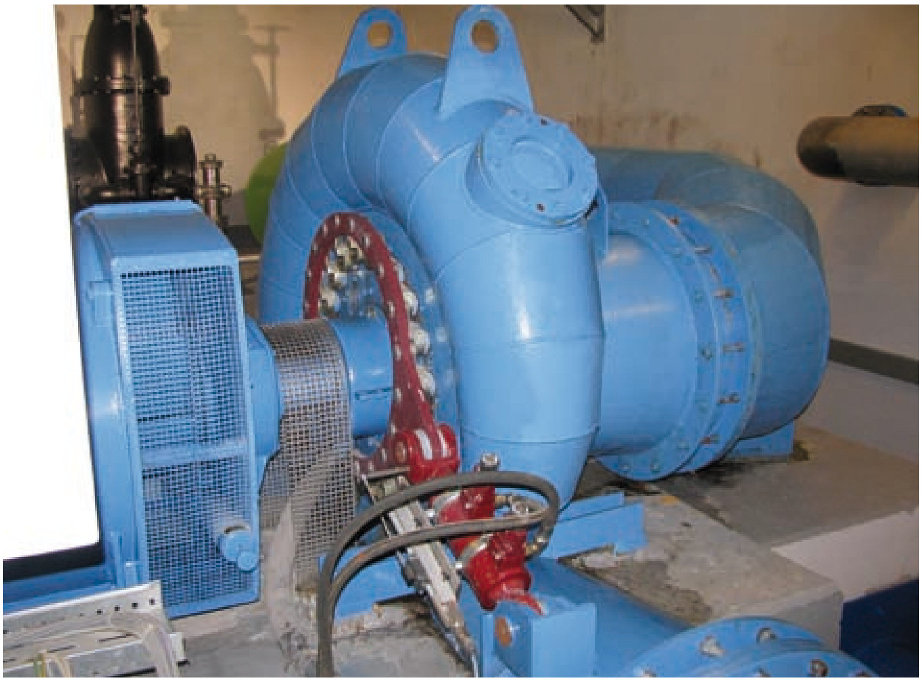
Multipurpose scheme n°3

Existing infrastructure	**Drinking water network**
Power plant name	**Mühlau**
Location	**Innsbruck, Austria**
Commissioning year	**1952**
Multipurpose scheme definition	The primary function of this multipurpose scheme is to supply drinking water, while the second is to produce electricity from this drinking water.
Site description	Mühlau plant that collects water in a tunnel more than 1.6 km long (the average time the water takes to pass through and into the tunnel the rock mass is estimated at 10 years), supplies drinking water for the major part of Innsbruck. The hydropower plant was designed with absolute priority for the drinking water supply over power generation including full system availability with the turbine shut down. With a generating capacity of 6 MW, it is one of the biggest drinking water power plants in Austria.  **Spring gallery**  **Drinking water turbine (2-nozzle Pelton turbine)**
Comments	Two redundant penstocks lead to two twin-jet Pelton turbines. To guarantee the continuity of the drinking water supply, a bypass with energy dissipation was installed. The turbines and the bypass are integrated in a central process control system for automatic operation.
Nominal discharge	1.6 m^3/s
Gross head	445 m
Electrical output	5,750 kW
Electrical production	34,000,000 kWh/year, or the electricity consumption of circa 7,560 European households
Investment	
Involved enterprises	Voith (De): manufacturer, IKB AG Innsbruck (At)
Operator	IKB AG Innsbruck

Multipurpose scheme n°4

Existing infrastructure	**Drinking water network**
Power plant name	**Poggio Cuculo**
Location	**Arezzo, Italy**
Commissioning year	**2010**
Multipurpose scheme definition	The primary function of this multipurpose scheme is to supply drinking water, while the second is to produce electricity from the drinking water.
Site description	Poggio Cuculo water treatment plant supplies drinking water to the Arezzo basin in Italy. It operates with three different raw water discharges supplied by a large upstream reservoir, depending on the electricity price: 280 l/s during the day, 360 l/s during the winter night and 380 l/s during the summer night. The water treatment works consumes more than 2 millions kWh/year of electrical energy. As the difference of levels between an intermediate reservoir and the water treatment plant is 28 meters, a turbine has been set as a bypass of the former regulation valve. The raw water discharges through the hydro turbine before entering the water treatment works for processing.  **From the water treatment plant**  **The regulation valve, used as the turbine bypass**  **The 8-blade runner at the workshop**
Comments	Although the pipeline related head losses are considerable for the 3 operational discharges (an efficiency of 45% for 380 l/s), the existing pipe work could not be changed for administrative and cost reasons. However, thanks to a runner with 8 adjustable blades and variable turbine rotation speed, the turbine can be operated with good hydraulic efficiency under any of the three operating discharges. Moreover the turbine has become the discharge regulation device for the treatment works inlet, thanks to automation of the runner blade adjustment.
Nominal discharge	3 discharges: 0.380 m^3/s, 0.360 m^3/s, 0.280 m^3/s
Gross head	28 m
Electrical output	44 kW
Electrical production	364,000 kWh/year, or the electricity consumption of circa 80 European households
Investment	200,000 € for the turbine, the generator and the valves
Involved enterprises	Mhylab (CH): engineering and hydraulic design, Desgranges Sàrl (Fr): manufacturer, Suez Environment: shareholder
Operator	Nuove Acque (IT): drinking water supplier

Multipurpose scheme n°5

Existing infrastructure	**Drinking water supply system**
Power plant name	**Drinking water power plant Vienna Mauer**
Location	**Vienna, Austria**
Commissioning year	**2006**
Multipurpose scheme definition	The primary function of this multipurpose scheme is to supply drinking water, while the second is to produce electricity from the drinking water.
Site description	The drinking water supply works for Vienna is large and old. The water for the works originates from an alpine region. The new drinking-water turbine, a Francis spiral casing one, is configured to bypass the original pressure reduction system.  **The Francis turbine**
Comments	Together with the new installation the old building has been renovated as a historical museum.
Nominal discharge	2 m^3/s
Gross head	34 m
Electrical output	500 kW
Electrical production	3,000,000 kWh/year, or the electricity consumption of circa 670 European households
Investment	1,250,000 €
Operator	Magistrat der Stadt Wien, MA 31. Wasserwerke

Multipurpose scheme n°6

Existing infrastructure	**Irrigation network**
Power plant name	**Armary power plant**
Location	**Aubonne, Switzerland**
Commissioning year	**2006**
Multipurpose scheme definition	The primary function of this multipurpose scheme is irrigation at a sufficient pressure, while the second is to produce electricity the whole year with the remaining discharge.
Site description	Historically, the Armary, a small water stream, was used to irrigate the lands of Allaman castle. Before the hydro scheme implementation, the farmers used diesel driven pumps to irrigate their fields during the summer season. In 2006, a penstock was installed as a bypass to the stream, still fed with a reserved flow, connected to a turbine and to spraying devices in the fields (145 hectares) for irrigation. In this way, water is available for the farmers' spraying equipment at the required pressure (10 bar). Therefore, pumping is no longer necessary, which has reduced CO_2 related emissions. Water is also available all year round for the hydro plant.  **The intake**  **Outside of the plant**  **The power house**  **The 2-nozzle Pelton turbine**
Comments	The turbine discharge regulation is the water level of the forebay. Using this parameter allows the turbine to operate automatically even during the irrigation season. When the farmers are irrigating their fields, the forebay level drops causing the turbine discharge to be reduced or even stopped. As the turbine is equipped with two jets, it operates with good efficiency even with low discharges.
Nominal discharge	0.090 m^3/s
Gross head	105 m
Electrical output	68 kW
Electrical production	454,000 kWh/year, or the electric consumption of circa 100 European households
Investment	400,000 €
Involved enterprises	Mhylab (CH): hydraulic design, Gasa Sa (CH): manufacturer
Operator	Groupement Arrosage Armary

Multipurpose scheme n°7

Existing infrastructure	**Irrigation channel**
Power plant name	**Marchfeldkanal**
Location	**Wehr 4, Deutsch Wagram, Austria**
Commissioning year	**2007**
Multipurpose scheme definition	The primary function of this multipurpose scheme is irrigation, while the second is to produce electricity from the irrigation discharges.
Site description	The existing irrigation channel system is about 20 km long and comprises 8 weirs equipped with flap gates to regulate the water level. The highest weir (number 4) was selected to implement a small hydropower plant upon. All the irrigation operational requirements have been safeguarded. The system is an unusual one in that it uses a so-called "hydraulic coupling". Both turbines are connected indirectly to a unique generator via oil hydraulic pumps. The hydraulic pumps drive a hydraulic motor, which then drives the electrical generator.  **Situation: the weir**  **Fish bypass channel**  **Turbines setting**  **Both turbines**
Comments	The purpose of the hydraulic coupling is to replace the two-speed increasers and two generators by two pumps, one motor/generator and an oil pressure unit. The hydraulic circuit gives freedom to locate the motor/generator at a distance of 10 meters from the turbines, on the bank of the water course. The first advantage of this arrangement is that the size of the complete installation is substantially reduced. The second advantage is that the location of all the electrical equipment is on the bank well clear of flooding and easily accessible. Due to the additional stages in the energy conversion process, losses are increased, something that was underestimated at the start of the project. The overall efficiency may be between 60-70%. The annual output is due to the considerable discharges available in the channel which is itself fed by the Danube river.
Nominal discharge	6 m^3/s
Gross head	2 m
Electrical output	70 kW
Electrical production	500,000 kWh/year, or the electricity consumption of circa 110 European households
Investment	
Involved enterprises	Guggler water turbines (AT), Niederranna, Federspiel Ökotechnology consulting (AT)
Operator	Betriebsgesellschaft Marchfeldkanal (AT)

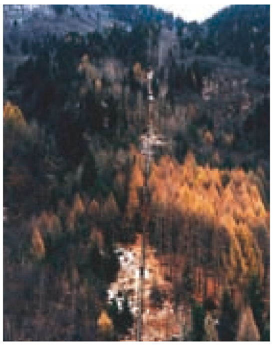
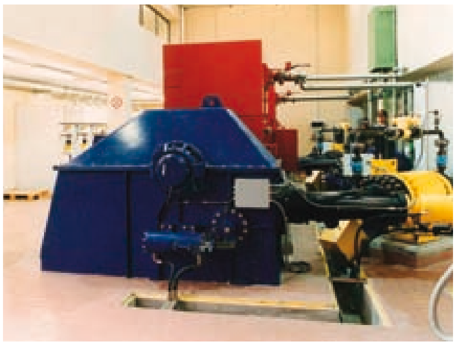
Multipurpose scheme n°8

Existing infrastructure	**Irrigation canals network**
Power plant name	**Petiva**
Location	**Santhià (Vercelli), Italy**
Starting up year	**2010**
Site description	A mobile weir on an artificial irrigation channel creates a small impoundment. From the forebay at the impoundment, water is usually conveyed to two of the three groups in the power station. During the irrigation season, part of the impounded water is diverted to an irrigation canal (Cavo Bargiggia) that feeds the third group of the plant and then goes on to its course. The current works aim to refurbish the existing structures and substitute the current three groups with three submersible compact Kaplan turbines (fixed wicket gates and adjustable runner blades).  The forebay  The floodgates and the forebay  The tailrace to Cavo Bargiggia  The tailrace to the main irrigation canal
Comments	Thanks to this special scheme, the power plant operates all year round without impacting on the irrigation network management.
Nominal discharge	18.5 m^3/s
Gross head	5.9 m (groups 1 and 2) – 5.3 m (group 3)
Electrical output	875 kW
Electrical production	5,000,000 kWh/year, or the electricity consumption of circa 1,110 European households
Investment	2,500,000 € – all inclusive (not only the hydro units)
Involved enterprises	Studio Frosio (IT): project engineering, STE: main contractor, Zeco: turbine and generator units
Operator	Associazione Irrigazione Ovest Sesia (Italy)

Multipurpose scheme n°9

Existing infrastructure	**Irrigation canals network**
Power plant name	**Esenta**
Location	**Esenta (Brescia), Italy**
Commissioning year	**2002**
Multipurpose scheme definition	The primary function of the scheme is irrigation, while the second is to produce electricity from the irrigation discharges.
Site description	The plant exploits the 25 m gross head drop on an existing irrigation canal. The head-race channel fed by a side-channel spillway, conveys water to a short, buried pipeline (diameter 1.6 m). The power house structure is partly buried due to its proximity with the village of Esenta.  **The headrace channel during the irrigation season**  **Excavations for the pipeline and the foundations of the power station**  **The setting of the spiral case of the turbine**  **Esenta Power Plant**
Comments	Previously, the energy in the 25 m head drop was dissipated in a discharger that is now used as a bypass. Because of the proximity of Esenta village, careful attention was paid to operational noise levels – these were successfully limited to acceptable levels by careful specification of the plant (a Kaplan turbine directly coupled with a synchro-nous generator).
Nominal discharge	4.5 m^3/s
Gross head	24 m
Electrical output	860 kW
Electrical production	4,300,000 kWh/year, or the electricity consumption of circa 960 European households
Investment	1,535,000 €
Involved enterprises	Studio Frosio (Italy): project engineering, Voith Siemens Hydro (Germany): manufacturer
Operator	Consorzio Idroelettrico di Esenta (Italy)

Multipurpose scheme n°10

Existing infrastructure	**Irrigation network and tourist area**
Power plant name	**Rino**
Location	**Rino di Sonico (Brescia) – "Parco dell'Adamello", Italy**
Commissioning year	**1996**
Multipurpose scheme definition	The primary function of this multipurpose scheme is irrigation, while the second is to produce electricity from the irrigation discharges, while creating a recreation area.
Site description	The multipurpose use of water in an Alpine Park (hydroelectric production, tourist attraction and irrigation) makes the Rino hydroelectric plant an interesting example of how to balance the exploitation of natural resources with considerable environmental constraints. The small basin permits transfer part of the daily production from the off-peak hours to the peak ones. This has been designed to be an attractive place for the tourist activities (angling, picnic, recreation). The plant was designed to exploit the variation of water levels in the basin, which is kept between precise limits in July and August so that it can be utilised for angling. Two horizontal-axis Pelton turbines are used. The tourist use of the basin has been improved by the construction of a recreation area nearby (wood, picnic sites, fountains, toilets block). The tail race of the hydroelectric plant supplies screened de-silted and regulated water to a sprinkler irrigation plant.  **Recreation area around the basin**  **The penstock**  **A view of the power station**  **The inside of the power station with 2 Pelton turbines**
Comments	The success of this project, being in a park environment, shows that carefully designed small hydro development is compatible with sensitive management of the environment and with other enterprises (such as agriculture and tourism). The aim of the project was not only to respect these activities but, when possible, to enhance them.
Nominal discharge	0,780 m^3/s (average)
Gross head	446 m
Electrical output	2,800 kW
Electrical production	14,000,000 kWh/year, or the electricity consumption of circa 3,110 European households
Investment	3,945,000 € (in 1996)
Involved enterprises	Studio Frosio (IT): project engineering, Voith Siemens Hydro (DE): manufacturer
Operator	Franzoni Filati S.P.A (IT)

Multipurpose scheme n°11

Existing infrastructure	**Raw wastewater network**
Power plant name	**Profray**
Location	**Bagnes, Switzerland**
Commissioning year	**2007**
Multipurpose scheme definition	The primary function of this multipurpose scheme is to collect and treat wastewaters, while the second is to produce electricity from the raw wastewaters.
Site description	The wastewater from the outlets of the Verbier ski resort are collected in a storage basin of 400 m^3, equipped with a 6 mm trash rack to remove floating material. This basin is now also used as a forebay for a hydro scheme where the power house is located 2.3 km distant below within the treatment plant. After passing through the hydro turbine, the wastewater discharges into the treatment works inlet before finally being reintroduced to a nearby water stream. A bypass of the turbine is incorporated to guarantee that the wastewaters reach the treatment process, whether or not the hydro plant is operational, and for times when the works operational discharges need to be greater than the turbine maximum discharge.  **The valley and the wastewater treatment plant where the turbine is set**  **The runner and one of its two nozzles**  **The turbine and the generator during the erection**
Comments	The power plant which was originally commissioned in 1993 was refurbished and improved in 2007. After 14 years in service, the control panel was out of date and in need of upgrading. The generator bearings needed to be replaced and sand in the discharge had resulted in significant abrasion of the runner and nozzle surfaces (and consequent decrease in efficiency). In addition to this maintenance related work, the first turbine was somewhat oversized as it was designed for the wastewater treatment plant (WWTP) maximal discharge of 240 l/s. Thus the turbine was operating at its nominal discharge only a few days per year and therefore this was not optimal from the point of view of annual energy generation. The new machine, designed for 100 l/s, results in a production increase of 45%. The first turbine had been in service for 14 years, with limited maintenance (about 40 hours per year), carried out by the treatment plant staff. The main operational issues connected to the turbine include: no x-cross liner for the nozzles, hand holes to clean the turbine, suppression of obstacles and zones where the wastes could accumulate.
Nominal discharge	0.100 m^3/s
Gross head	449 m
Electrical output	380 kW
Electrical production	851,0000 kWh/year (average 2008-2009) or the electricity consumption of circa 190 European households
Investment	375,000 €
Involved enterprises	Mhylab (CH): hydraulic design, Gasa SA (CH): manufacturer
Operator	Services Industriels de Bagnes (CH)

Multipurpose scheme n°12

Existing infrastructure	**Raw wastewater and run off network**
Power plant name	**La Louve**
Location	**Lausanne, Switzerland**
Commissioning year	**2006**
Multipurpose scheme definition	The primary function of this multipurpose scheme is to separate the discharges of a river from the main sewer, while the second is to produce electricity from this river.
Site description	Historically Lausanne's wastewater was discharged into a stream that itself discharged into Lake Geneva. At the end of the 19th century, the stream and the wastewater structures were buried in a tunnel under Lausanne. Then in 1964, a wastewater treatment plant was built near the lake. In the light of projected population growth, the capacity of the treatment plant became an issue, especially during storms, considering that the water stream did not need to be treated. A proposal was put forward to separate the stream water from the wastewater to decrease the volume of water that needed to be treated. This was facilitated by building an intake and collecting the discharges of La Louve river in a penstock pipe that was installed in the existing tunnel. The penstock pipe terminates in a power house close to the lake which houses the hydro turbine, generation and control equipment.  **La Louve intake**  **The penstock inside the wastewater tunnel under Lausanne city**  **The Pelton turbine, generation and control equipment**
Comments	The La Louve hydro scheme has met the original objective of increasing the efficiency of the wastewater treatment, improving the quality of the discharges into Lake Geneva and renewable electricity production.
Nominal discharge	0.120 m^3/s
Gross head	180 m
Electrical output	170 kW (max)
Electrical production	460,000 kWh/year, or the electricity consumption of circa 100 European households
Investment	430,000 €
Involved enterprises	Mhylab (CH): hydraulic design, Gasa Sa (CH): manufacturer, Ville de Lausanne: contracting authority
Operator	Ville de Lausanne (CH)

Multipurpose scheme n°13

Existing infrastructure	**Treated wastewater network**
Power plant name	**Plobb, Seefeld**
Location	**Seefeld Zirl, Austria**
Commissioning year	**2005**
Multipurpose scheme definition	The primary function of this multipurpose scheme is to discharge treated wastewaters to a river that can fulfil the dilution criteria, while the second is to produce electricity from these treated wastewaters.
Site description	To reach the Inn river, the treated wastewater from Seefeld sewage treatment works needs to be pumped to pass over a hill and then discharges to the hydropower plant. After the turbine, the water passes through a de-foaming plant and then into the Inn river, meeting the dilution criteria for treated wastewater. To guarantee these discharges, a permanently available bypass with energy dissipation is installed. The turbine and its bypass are integrated in a central process control system for automatic operation.  **The power house**  **The treated wastewater turbine**
Comments	The project feasibility is justified by the site topology. The hill between the sewage plant and the Inn River is a relatively small percentage of the over gross head available (head for the pumps: 94 m / head for the turbine: 625 m). Note that the electricity generation from this scheme exceeds both the pump energy consumption (1,500,000 kWh/year) as well as the wastewater treatment plant consumption (500,000 kWh/year) so that excess local generation can be exported onto the grid network. Additionally, by discharging the treated wastewater into a larger receiving stream, the local ecology is improved. The architecture of the power house is unusual and meaningful: a water droplet.
Nominal discharge	0.25 m^3/s
Gross head	625 m
Electrical output	1,192 kW
Electrical production	5,500,000 kWh/year or the electricity consumption of circa 1,220 European households
Investment	2,200,000 € (overall costs water catchment and power station)
Involved enterprises	Geppert (At): manufacturer, TIWAG (At), Wasser Tirol (At)
Operator	TIWAG, Wasser Tirol

Multipurpose scheme n°14

Existing infrastructure	**Treated wastewater network**
Power plant name	**Nyon wastewater treatment plant (WWTP)**
Location	**Nyon, Switzerland**
Commissioning year	**1993**
Multipurpose scheme definition	The primary function of this multipurpose scheme is to manage wastewaters, while the second is to produce electricity from the treated wastewaters.
Site description	In the 1990s, due to a lack of space near Lake Geneva, the new WWTP of Nyon City was built 110 meters higher on the plateau. Since then wastewaters are collected in a basin close to the lake, pretreated, and then pumped to the WWTP where they are treated. Then they pass through a turbine before their discharge to the lake.  **The pumps that bring the wastewaters to the treatment plant**  **The reverse pump that generates electricity from the treated wastewaters**
Comments	The electricity production represents half of the pumps consumption, and the third of the water treatment one. The turbine is here a reverse pump especially designed for the site. As it works with a fixed discharge, the frequent automatic operations to start up and shut down the reverse pump (circa 10 times per 24 hours) require especially sturdy drive systems, that are relatively expensive. For example, the upstream butterfly valve has already been changed due to strong cavitation. Moreover, the neighbours complain about the noise and the vibrations due to these operations. Finally the operator has launched a study to replace the reverse pump with a Pelton turbine, with the objective to gain flexibility, reduce noise and vibrations and increase production.
Nominal discharge	0.293 m^3/s
Gross head	94 m
Electrical output	220 kW
Electrical production	700,000 kWh/year, or the electricity consumption of circa 160 European households
Investment	500,000 € (penstock not included)
Involved enterprises	Bonnard & Gardel (CH): engineering, Sulzer Pumpen (CH): manufacturer
Operator	City of Nyon

Multipurpose scheme n°15

Existing infrastructure	**Water treatment works and compensation discharge**
Power plant name	**Alwen compensation scheme**
Location	**Cerrigydrudion, Conwy, Wales**
Commissioning year	**2007**
Multipurpose scheme definition	The primary function of this multipurpose scheme is to divert water from a river to process for drinking water, while the second is to produce electricity from the fixed compensation discharge (raw water) that runs at the foot of the dam.
Site description	In the United Kingdom, abstractors of water normally have an abstraction license from the Environment Agency, that defines a compensation flow to be maintained in the river at all times. Alwen water treatment scheme that went out of commissioned in the 1980s, is composed of a dam built on a river to accumulate water that will then be treated before consumption. As a compensation discharge of 160 l/s is required, and thanks to the difference of levels between the reservoir water levels and the foot of the dam, a turbine has been set that generates around 200,000 kWh/year.  **Alwen Water Treatment dam**  **The turbine**
Comments	The main requirement of the scheme development was that the compensation flow should be guaranteed at all times whether or not the hydro plant was operating. This meant that controls on discharges into the turbine and bypassing the turbine needed to be fully automated. Automation was achieved by actuation of existing valves and the installation of a new valve equipped with a "failsafe" actuator. A second requirement was that the system had to be cost efficient in spite of the low output and annual production and thus the tight financial budget. A cross flow turbine was then chosen due to its low investment cost and its suitability to run with the fixed discharge (only the head may vary). A third requirement was that the control equipment needed to be integrated onto the water treatment works telemetry system and central control. This is because the power house is more than half a kilometre from the water treatment works buildings.
Nominal discharge	0.16 m^3/s (fixed)
Gross head	26 m
Electrical output	26 kW
Electrical production	200,000 kWh/year, or the electricity consumption of circa 40 European households
Investment	Circa 90,000 €
Involved enterprises	Dulas Ltd
Operator	United Utilities (UUOSL) and Welsh Water (DCC)

Multipurpose scheme n°16

Existing infrastructure	**Water treatment works and compensation discharge**
Power plant name	**Llys y Fran compensation scheme**
Location	**Pembrokeshire, Wales**
Commissioning year	**2008**
Multipurpose scheme definition	The primary function of this multipurpose scheme is to store water from a dam that can then be used for processing drinking water, while the second is to produce electricity from the fixed compensation discharge (raw water) that runs at the foot of the dam.
Site description	In the United Kingdom, abstractors of water normally have an abstraction license from the Environment Agency, that defines a compensation flow to be maintained in the river at all times. Llys y Fran water treatment scheme, located near the Preseli mountains in Pembrokeshire, is composed of a dam built on a river to accumulate water that will be then treated before consumption. As a compensation discharge of 160 l/s is required, and thanks to the difference of levels between the reservoir water levels and the foot of the dam, a turbine has been set that generates around 220,000 kWh/year.  **Llys y Fran dam**  **The hydro plant and control panel before refurbishment**  **After refurbishment: the new control panel and the restored turbine**
Comments	The existing hydro scheme commissioned in the early 1970s was under utilised, mainly because of a lack of automation. The main issues dealt with were working on an operational site where the priority lay with delivering raw water for treatment, whilst at the same time, making sure that the compensation discharge was not affected. In 2008, the hydro plant operation was refurbished and automated, whilst the compliant grid connection was facilitated.
Nominal discharge	0.16 m^3/s (fixed)
Gross head	25 m
Electrical output	29 kW
Electrical production	220,000 kWh/year, or the electricity consumption of circa 50 European households
Investment	
Involved enterprises	Dulas Ltd.
Operator	United Utilities (UUOSL) and Welsh Water (DCC)

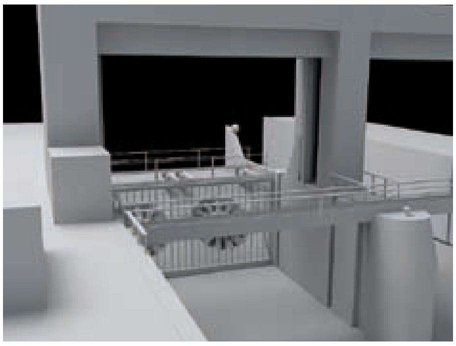
Multipurpose scheme n°17

Existing infrastructure	**Hydropower dam and reserved flow**
Power plant name	**Le Day**
Location	**Le Day, Switzerland**
Commissioning year	**2011 (expected)**
Multipurpose scheme definition	The primary function of this multipurpose scheme is to produce electricity from a large hydropower plant while letting a reserved flow at the foot of the dam, while the second is to produce electricity from this reserved flow before its restitution to the river.
Site description	Le Day dam was built in the 1950s on the Orbe river to feed the underground power plant of Les Clées (27 MW) and Montcherand (14 MW). At the foot of the dam are located the valve chamber and the penstock that leads to Les Clées power plant. In Switzerland, from the federal law on water power use (from 1916 and revised in 2008), to let a reserved flow at the feet of dams becomes mandatory five years at the latest after the concession expiry. Although the concession is here valid until 2034, the operator respects already the recommendations from the cantonal water authority by letting a reserved flow of 400 l/s to the water stream. Recently the authority has defined again the reserved flow regarding the seasons. Finally, the reserved flow will be 600 l/s from July to September and 300 l/s the rest of the year, which represents the same annual amount of water as the current situation. The project is then to use this reserved flow and the gross head between the back water level and the dam foot to produce electricity.  **Le Day back water and its spill way**  **The foot of the dam where the small power plant will be installed**  **The current reserved flow into the Orbe river (400 l/s)**
Comments	As the head varies between 17 and 27 meters, a Kaplan turbine with variable speed will be set. The hill chart of the turbine is here an essential tool as it permits to optimise the production by guaranteeing high performance and operation without cavitation erosion for the two discharges and head variations. This project has then two positive impacts: it permits to recover a part of the green electricity production lost by the large power plant while favouring the local ecosystem.
Nominal discharge	0.6 m^3/s from July to September, and 0.3 m^3/s from October to June
Gross head	From 17 to 27 meters
Electrical output	126 kW
Electrical production	580,000 kWh/year, or the electricity consumption of circa 130 European households
Investment	
Involved enterprises	Mhylab (CH): engineering, Romande Energie Renouvelable (CH): project manager
Operator	Romande Energie

Multipurpose scheme n°18

Existing infrastructure	**Hydropower dam and fish pass**
Power plant name	**Aire-la-Ville small SHP – Verbois dam**
Location	**Aire-La-Ville, Switzerland**
Commissioning year	**2003**
Multipurpose scheme definition	The primary function of this multipurpose scheme is the fish upstream migration, which is helped by an attraction discharge, leading to electricity production.
Site description	The Verbois large hydropower plant (100 MW, 466 GWh/year) is sited on a dam across the river Rhône near Geneva. The maximum head achievable in the dam is 21 m. In 1999 a fish pass was installed (the longest of Switzerland with 350 m), comprising 107 pools, supplied by a discharge of 710 l/s. To help fish to locate and navigate their way to the fish pass entrance, an additional discharge of 2 m^3/s was deemed to be necessary at its entrance downstream and this would be required all year round. A proposal was made to exploit this discharge and the head in the dam with a small hydro scheme, by arranging for an intake upstream of the dam with a penstock pipe routed parallel to the fish pass, and the turbine discharging near the entrance to the fish pass. Since 2003, the upstream fish migration has been guaranteed for 26 species, while the production of electricity has been facilitated.  Verbois power plant and dam  Verbois fish pass and the SHP  The Francis turbine set on the attraction discharge, close to the fish pass entrance
Comments	A Francis turbine is well suited to this site, as the discharge is fixed, and the head variation is low.
Nominal discharge	2.0 m^3/s (fixed)
Gross head	21 m
Electrical output	348 kW
Electrical production	2,720,000 kWh/year, or the electricity consumption of circa 600 European households
Investment	3,800,000 € for the SHP and its civil engineering
Involved enterprises	GEOS Ingénieurs Conseils SA (CH): engineering, JMC Engineering (CH): electro mechanical design, Geppert (AT): turbine manufacturer, SIG (Services Industriels de Genève) (CH): automation and project manager
Operator	SIG (Services Industriels de Genève)

Multipurpose scheme n°19

Existing infrastructure	**Navigation lock and dam**
Power plant name	**Marcinelle**
Location	**Sambre River, Belgium**
Commissioning year	**2010**
Multipurpose scheme definition	The primary function of the dam and the big gates upstream of the hydro turbines is the fine regulation of water levels for navigation purpose of the Sambre River located in Belgium, while the second is to produce electricity.
Site description	An existing water level and flood regulation dam has been fitted with two VLH turbines DN 3550 of 325 kW capacity each (Kaplan type), located immediately downstream of the left bank regulating gates.  Downstream view of the existing gates  Side view of the existing gates & the lock  Turbines in working position from upstream  The site in operation
Comments	One of the main challenge has been the design of a supporting structure that allows a complete lifting of all equipments upstream of flood level of turbines and rakes in order to maintain the flood evacuation capacity of the dam. This structure will be lifted every month for safety checking.
Nominal discharge	30 m^3/s (2 x 15 m^3/s per turbine)
Gross head	3 m
Electrical output	650 kW (2 x 325 kW)
Electrical production	2,000,000 kWh/year, or the electricity consumption of circa 440 European households
Investment	1,000,000 € for the electromechanical equipment including the device to lift the two groups
Involved enterprises	MERYTHERM – MJ2 Technologies (FR)
Operator	HYDRO B

Multipurpose scheme n°20

Existing infrastructure	Navigation lock and dam
Power plant name	L'Ame
Location	Mayenne River, France
Commissioning year	2009
Multipurpose scheme definition	The primary function of the dam is the fine regulation of water levels for navigation purpose of the Mayenne River located in France, while the second is to produce electricity.
Site description	The Mayenne River is navigable and equipped with 16 locks & dams. The l'Ame project is the second fitted with VLH turbine (Kaplan type) on this river. A program to equip the 14 remaining locations is being developed.  General view of the dam  The turbine in operating position seen from downstream  Upstream view of the turbine with closed gates  Downstream global view of the dam and the turbine
Comments	The main challenge in this case is to fit in 19th century infrastructures with a small visual impact and a high fish friendliness due to the presence of silver eels.
Nominal discharge	10.8 m^3/s
Gross head	1.8 m
Electrical output	145 kW
Electrical production	650,000 kWh/year, or the electricity consumption of circa 140 European households
Investment	520,000 € for the electromechanical equipment including the upstream gates
Involved enterprises	MJ2 Technologies (FR) – SHEMA – Hydrostadium – EIFFAGE
Operator	SHEMA (EDF small hydro subsidiary)

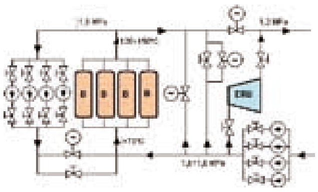
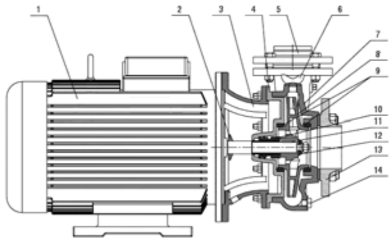
Multipurpose scheme n°21

Existing infrastructure	**Desalination Plant**
Power plant name	**Tordera**
Location	**Blanes (Spain)**
Commissioning year	**2002**
Multipurpose scheme definition	The primary function of this multipurpose scheme is to supply drinking water and recover the aquifer.
Site description	Tordera desalination plant generates drinking water for Maresme Nord and for La Selva, situated on the North coast near Barcelona. The plant takes sea water from wells, which implies that less water is taken from the aquifer and sea intrusion can be stopped. Currently 10 Hm^3 of drinking water per year are generated and 20 Hm^3 are planned for next year. The reverse osmosis is the process used to separate water from dissolved salts through semi-permeable membranes under high pressures. Here four groups are set, each one composed of a pump, a motor and a 1-jet Pelton turbine on the same axis. The pumps are used to increase the water pressure (up to 70 bars) so that the water (without salt) can cross the membranes, while the turbines recover the energy from the concentrate outlet of the reverse osmosis, inferring smaller motors.  **The four groups**  **The Pelton turbine, the motor and the pump on the same axis**  **A dismantled Pelton turbine**
Comments	As the highest cost in a desalination plant (about 60-70%) is due to energy consumption, even a very small save in energy is interesting. Thus, currently, works are achieved to replace the turbines for new isobaric chambers (ERI) with a higher efficiency.
Nominal discharge	0.107 m^3/s (x 4)
Gross head	685 m
Electrical output	720 kW (x 4)
Electrical production	
Investment	
Involved enterprises	ACA (Water Catalan Agency) (ES), Acciona Agua (ES), Aqualia (ES)
Operator	Explotación ITAM Tordera (ES), UTE (Joint venture: 50% Acciona Agua + 50% Aqualia)

Multipurpose scheme n°22

Existing infrastructure	**Cooling system within a biomass plant**
Power plant name	**Sangüesa**
Location	**Sangüesa, Navarra, Spain**
Commissioning year	**2006**
Multipurpose scheme definition	The primary function of this multipurpose scheme is to generate energy from biomass, while the second is to produce electricity from the cooling system.
Site description	This hydropower project was part of a scheme to improve the cooling system at the Sangüesa Biomass plant. Condenser cooling needs a back pressure to operate, which necessitates a tower of balance of 10.5 meter high.  **The Francis turbine**  **The turbine in operating position seen from downstream**  **The biomass plant and its tower of 10.5 meters**
Comments	The output from the hydro plant was not as high as hoped for and this is attributed to, amongst other things, excessive head losses in the pipe at the entrance to the turbine. As the biomass plant and the turbine operate together, the turbine needs operate in continuous service for around 8,000 hours/year, which is what is typically achieved by biomass plants.
Nominal discharge	1.155 m^3/s
Gross head	10.7 m
Electrical output	75 kW
Electrical production	500,000 kWh/year, or the electricity consumption of circa 110 European households
Investment	300,000 €
Involved enterprises	Acciona Energy (Spain): hydraulic design, Ingehydro (Spain): manufacturer
Operator	Acciona Energy

Multipurpose scheme n°23

Existing infrastructure	**Municipal heating plant**
Power plant name	**Lomza**
Location	**Lomza, Poland (North Eastern)**
Commissioning year	**1997**
Multipurpose scheme definition	The primary function of this multipurpose scheme is to supply water at a temperature and a pressure suitable for a municipal heating, while the second is to produce electricity from the cold-mixing bypass of the boiler block.
Site description	Due to technological reasons, the boiler block supplies water at a temperature over 120°C, which is too high for the needs of the municipal heating network. Therefore unheated water has to be mixed with the outlet of the boiler system. As the pressure of the unheated water is by 0.4 to 0.6 MPa higher than the one of the boiler block outlet, this by-pass was equipped with a throttling valve. In 1997, this task was taken over by an energy recovery installation with a centrifugal pump [9]. Precautions were taken in order to divert smoothly the water stream to a bypass conduit in case of a unit shut-down. A throttling orifice was used to keep the discharge constant.  **Simplified schematic of the heating plant hydraulic circuit (B= Boiler, ERU= Energy Recovery Unit)**  **The centrifugal pump unit used for energy recovery purposes**  **The installation during commissioning**
Comments	The installation was developed in the scope of a research project of the Polish Committee on Scientific Research. Erection and commissioning costs were covered by the heating plant operator. The installation had been operating from 1997 until the control system battery failure in 2005. A repeated coding of the control unit and new commissioning tests were considered too expensive in view of a planned removal of the "cold-mixing" need, after the general plant rehabilitation. Nevertheless, the plant operator was satisfied with the 338 MWh of electricity recovered during the operation period.
Nominal discharge	0.092 m^3/s
Gross head	30.5 m
Electrical output	20 kW
Electrical production	40,000 kWh/year or the electricity consumption of circa 10 European households
Investment	
Involved enterprises	MPEC Lomza (PL), IMP PAN (PL), LFP (Leszno Pump Manufacturers), Governor Ltd.
Operator	Municipal Heating Enterprise Lomza (MPEC Lomza)

Multipurpose scheme n°24

Existing infrastructure	**Skawina Thermal Power Plant (500 MW)**
Power plant name	**Skawina**
Location	**Skawinka river coast, close to its estuary to Vistula, Cracow, Poland**
Commissioning year	**1959**
Multipurpose scheme definition	The primary function of this multipurpose scheme is to provide cooling of the steam block condensers, while the second one is to produce electricity by recovery of mechanical energy from the discharged cooling water.
Site description	The hydropower plant (HPP) was planned together with the thermal one (ThPP). The ThPP uses cooling water from Laczany Channel that bypasses a 20 km long segment of Vistula river and serves also for navigation purposes. After passing through the cooling system of the ThPP, water is led to the HPP by two concrete channels. The final portion of these channels is open with side walls used as spillways. The plant is equipped with a single hydraulic unit (Kaplan turbine and generator). After leaving the HPP, water is discharged through a 30 m long tailrace channel to Skawinka river.  The two inlet channels of the power plant  Inside the power plant: the Kaplan turbine and its generator  The powerhouse during turbine overhaul  The power transformers
Comments	Planning energy recovery together with a major industrial installation was a proper strategy. Nevertheless, selecting an outlay with a single unit was not the optimum solution, contributing probably to insufficient maintenance and rather poor technical unit conditions. Indeed, due to a high water temperature (over 30°C) and severe pollution of Vistula river, the turbine is subject to cavitation and corrosion threat. Then, the turbine is situated too high as the tailrace channel has still a substantial slope. Thus the erection of a low-head installation at the outlet to Skawinka river was considered some time ago. Due to green certificate and green energy quota system in Poland, the owner may be interested in a much more promising opportunity of using the substantial head at the Laczany Channel outlet.
Nominal discharge	23.3 m^3/s
Gross head	7.9 m
Electrical output	1560 kW
Electrical production	6,390,000 kWh/year or the electricity consumption of circa 1,420 European households
Investment	
Involved enterprises	Skawina Thermal Power Plant, HYDROPROJEKT, Ganz Mavag: turbine manufacturer, AEG: generator supplier
Operator	Skawina Thermal Power Plant

6 Conclusions

The equipment used for multipurpose schemes do not differ much from the traditional ones used for water streams, apart from the specific conditions of each infrastructure that have to be considered all along the project steps.

Regarding environment, as the hydropower plant has to be integrated to the existing infrastructure, the impacts are mainly due to its primary function. One can even mention that the environmental impact is positive as the SHP plant implies an energy recovery.

Nevertheless, nowadays and worldwide, the multipurpose schemes equipped with small hydropower plants are limited. For example, no one has been identified in Estonia, Lithuania and Latvia. Moreover there is a lack of data in Europe concerning the operating and remaining potential, apart from Switzerland, as shown in table 10. This implies that the remaining potentials can be interesting!

Water network type	Potential type	Number of sites	Output (kW)	Production (MWh/year)	Electricity consumption equivalent households
Drinking water	Operating	90	17,800	80,000	17,780
	Remaining	380	38,890	175,000	38,890
Raw wastewater	Operating	1	380	850	190
	Remaining	86	7,100	32,000	7,100
Treated wastewater	Operating	6	700	2,900	640
	Remaining	44	4,200	19,000	4,200

Table 10. Multipurpose schemes in Switzerland: operating and remaining potential (Copyright: Swiss Energy, 2003) [3, 4, 5]

The limited number of operating sites is mainly due to the **lack of information** on the possibility to recover energy. Moreover, in some countries, one second obstacle would be the **lack of simple administrative procedures** adapted to small hydropower. For example, the doubts on the quality of the turbine water outlet notably during and after a maintenance operation have slowed down the SHP development on drinking water networks in France. On the contrary, the procedure in Switzerland is simple, mainly because the water network and the SHP plant are generally owned and operated by the water office of the commune or city. Then, it can be pointed out that a power plant on the drinking water network of Lausanne * was already erected in 1901.

Finally, thanks to the remaining potential in Europe, based on energy recovery in existing infrastructures, small hydropower has still a role to play among renewable energies.

* This power plant, called Sonzier, still operates nowadays, with an output of 1.6 MW and a yearly production of 6,600,000 kWh, or the electricity consumption of 1,470 European households.

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