

Developing the residual hydropower potential on a medium sloped river stretch by standardized on-flow plants - the Italian experience

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1. Project context and background

The paper is focused on a case study in Northern Italy, in the Province of Brescia, on a ~1 km long piedmont reach of the river Mella.

The river runs from North to South in the Province of Brescia, crossing very populated and industrialised areas. The studied stretch, in particular, is located in Valtrompia, a valley at the northern end of the city of Brescia, renowned for its industrial production, with particular regard to weapons and other metallurgic products.

Therefore the Mella river flows have been exploited for a long time for industrial purposes, as witnessed by the many other HP plants located along its course, both upstream and downstream of the investigated stretch.

This stretch is characterised by a yearly average flow rate of $\sim 7 \text{ m}^3/\text{s}$ and a riverbed elevation difference of 7,50 m. Considering a possible +3 m raise of the water level by weirs, this means a total gross head of 10,50 m and consequently a hydropower potential in the order of 720 kW.

Developing this relatively low potential (which would have once been neglected, or else exploited by a traditional intake - headrace - forebay - penstock - powerhouse - tailrace scheme) in a profitable way has required, as usual, maximising performances and, more than ever, minimising costs.

In addition to the economic ones, a variety of other boundary conditions and constraints have affected the planning, designing and decision making process, as illustrated in detail in the following chapters.

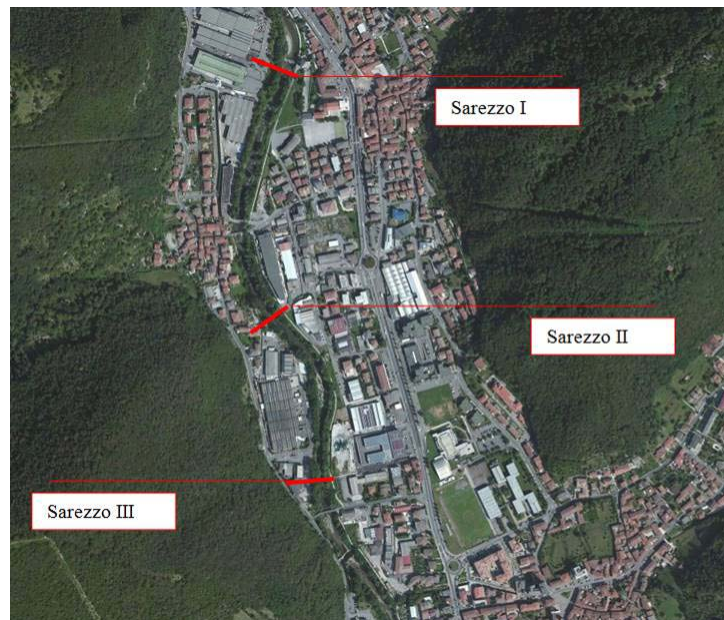


Figure 1. Map showing the main river basins and the sites identified for future hydro projects.

2. Boundary conditions and constraints

The development of a hydropower project is always a complex and iterative project.

In this case study, in particular, the design choices had to fulfil a variety of requirements and constraints, often connected to one another; therefore the solutions always had to be checked with respect to the global result, in terms of environmental impact and economic sustainability of the project.

2.1 Environmental

One of the main environmental concerns, at least in Italy, is the length of the diverted stretch and the quantification of the reserved flow which must be released in order to maintain its ecosystem in acceptable conditions.

This issue is reflected in the initial choice of developing the hydropower potential of the stretch by small plants with relatively low weirs built across three existing boulder sills, instead of building one larger plant (which would have once been the best economic choice, thanks to scale-saving) with a higher weir or longer waterways.

2.2 Authorisation

The authorisation procedure is the link between the environmental and economic issues, because it is mainly focused - at least in Italy - on the environmental impact, and its outcomes (decisions and prescriptions) strongly affect the economic and financial frame of the project.

Nowadays on-flow hydropower plants, with low head and small power, are more easily authorised than any other type; moreover, if they give water back to the river right at the downstream toe of the weir, they are (or they can be) exempted from the obligation to release the reserved flow, as there's no diverted river stretch.

2.3 Economic

In this case, as usual, the two main factors defining the economic frame of the project are the realisation costs and the energy production of the plant.

Production, in turn, depends mainly on:

- hydraulic dimensioning, i.e. the choice of the maximum diverted flow, which also affects the realisation costs, especially for low head plants, where civil and hydraulic works are a major cost item;
- plant head, therefore the choice of the weir type and height, accounting for hydraulic safety issues.

The project development and realisation costs can be minimised not only by reducing the plant dimensions, but also by simplifying and standardising the components to be supplied. Therefore, with respect to the aforesaid factors, we decided since the first design steps that the plant head and maximum flow should be equal for the three plants, so the hydraulic and the electromechanical equipment would be the same, with a considerable saving on spare parts and supply times and costs. Thanks to the same maximum flow, also the civil works - waterways and powerhouse - of the three plants are equal. Actually the only difference, apart from negligible details, is the width of the flap gate, which is 25 m instead of 20 m in the downstream plant, due to hydraulic safety (freeboard from the nearby banks) reasons.

3. Design solutions and layout of the plants

The planning and designing process has implied a series of actions and checks.

- Topographic survey to define the geometry and elevation profile of the river stretch (bed and banks) as a base for the design process.
- Check of backwater profile (i.e. interference between plants) and, most of all, of hydraulic safety, in order to define the acceptable raising of the upstream water level. For these purposes, one-dimension hydraulic modelling was implemented, based on the riverbed features acquired by the aforesaid topographic survey, both for normal operation (weir gates raised) and flood (weir gates lowered) conditions.
- Design and dimensioning of civil, hydraulic and electromechanical works.
- Bill of quantity and computation of costs.
- Assessment of expected yearly average energy production, based on the plant head and diverted flow.
- Balance of costs, energy production and profits, depending also on the energy price and therefore on the plant size. In particular, with respect to the abovementioned gross potential roughly estimated in 720 kW, it was convenient to keep the nominal - something like average - power of the single plants under 250 kW, in order to get a higher energy price (210 instead of 195 €/MWh) and also to have direct access to incentives, i.e. without passing by the present standard procedure, which implies incentive allocation according to the order and priority of inscription into the relevant registers. Also the fact of being built across an existing sill is a priority factor for incentive access.

As a consequence of the design process described above, the three plants have the same layout.

The diversion weir consists of a fixed part - built in the place of an existing boulder sill - of reinforced concrete and of a gated part, that is a hydraulically operated 2,50 m high flap gate, whose width ranges from 20 to 25 m.

The intake is a 10 m large opening on the (hydraulic) left side, protected by an horizontal-bars screen cleaned by a horizontal-moving trash rake and followed by two very short channels - divided by a wall in order to consent the separate operation of the groups - leading to the powerhouse, which hosts two single regulated S-Kaplan turbines directly coupled to horizontal axis synchronous generators.

At the left end of the weir there's a sluicing device with a 2 m sliding gate and a small sliding gate on its top. The lower sliding gate can be lifted to flush riverbed sediment downstream, while the upper sliding gate can be lowered to discharge floating debris downstream; both these gates are also used, in combination with the turbines, to keep the upstream water level constant, while the flap gate of the weir is lowered only in case of high river flows.

Left of the plant, a fish pass made of 15 pools runs close to the left bank.

A very short tailrace gives water back to the river just downstream of the weir toe.

The plant layout is very compact, resulting in a total length of no more than 40 m and in no diverted stretch, as the toe of the weir is wetted by the water downstream.

Moreover the powerhouse (with a 11,60 x 6,90 m rectangular plan) has 5 soundproofed trap doors for access and maintenance but no overhead crane, so it is only 2,80 m high (4,20 m in the turbine room) and it remains under the surrounding ground level; the roof is made of reinforced concrete, with a waterproof sheath and gravel on top.

The transformers, control and switchgear equipments are located in another building outside of the riverbed, so the plant interference with flood flows is kept to a minimum.

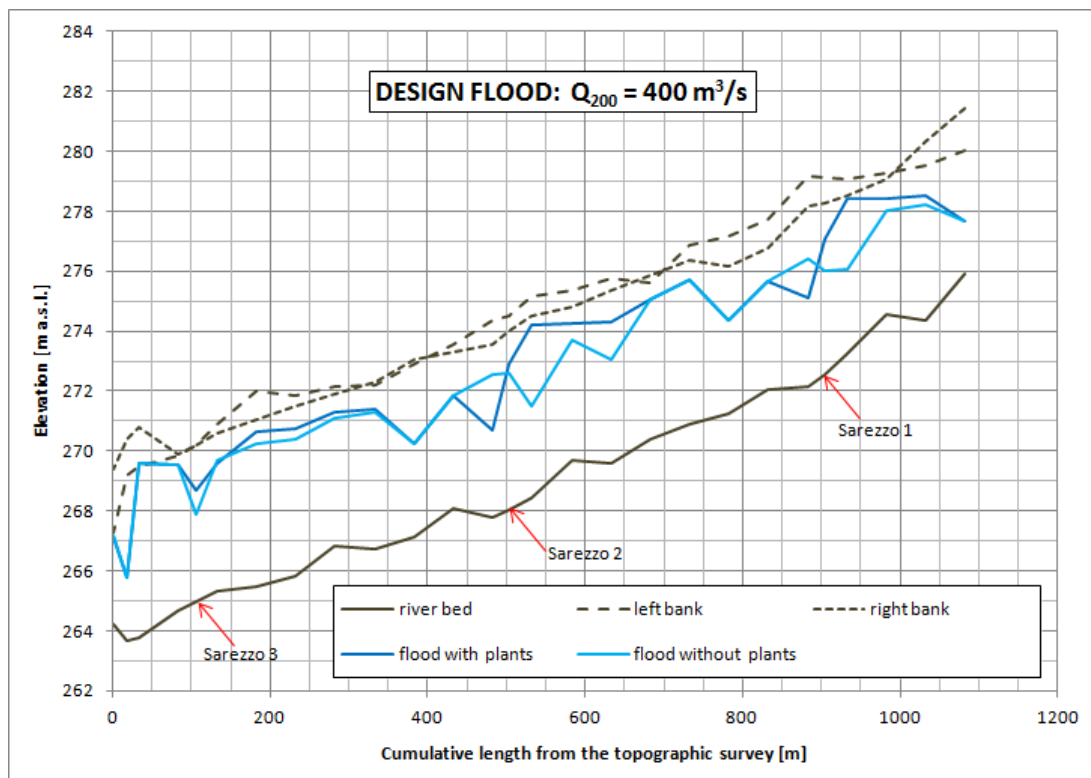


Figure 2. Elaboration of the hydraulic model output, showing the hydraulic profile of the design flood before and after the HPPs realization. The hydraulic model was implemented to assess the hydraulic safety and consequently determine the necessary width of the weir, given the acceptable water raise (by the gated part) for preventing backwater influence between one plant and another, resulting from the hydraulic model in normal operation conditions. The chosen dimensions and elevations implied small modifications of the natural (before realisation) flood profile, requiring only local and limited raising of the existing banks.

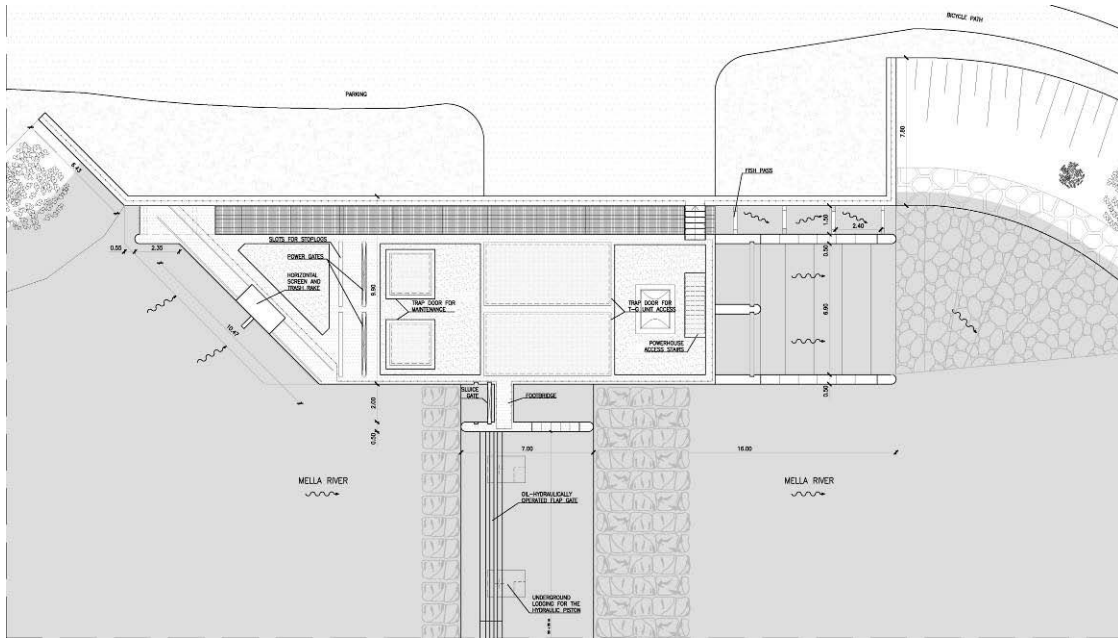


Figure 3. Layout of the three HPPs - plan view.

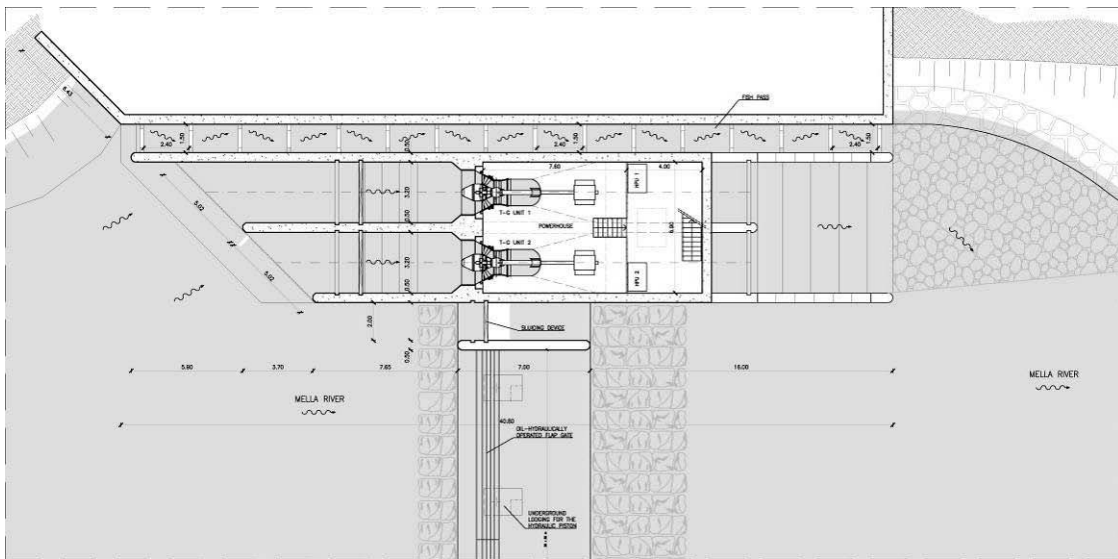


Figure 4. Layout of the three HPPs - plan section.

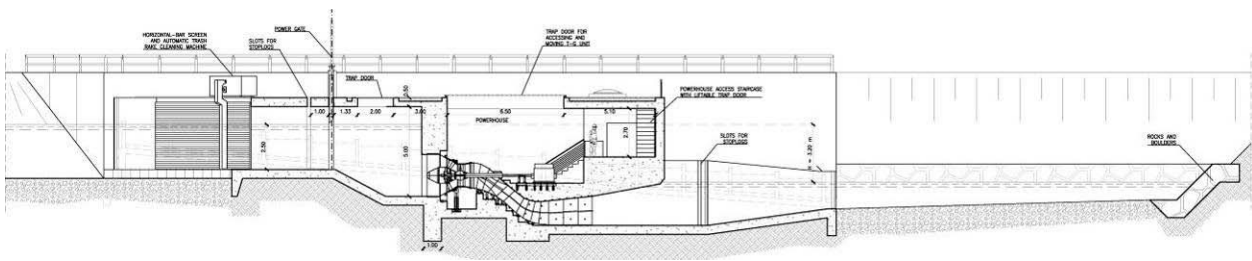


Figure 5. Cross section along the plant waterways.

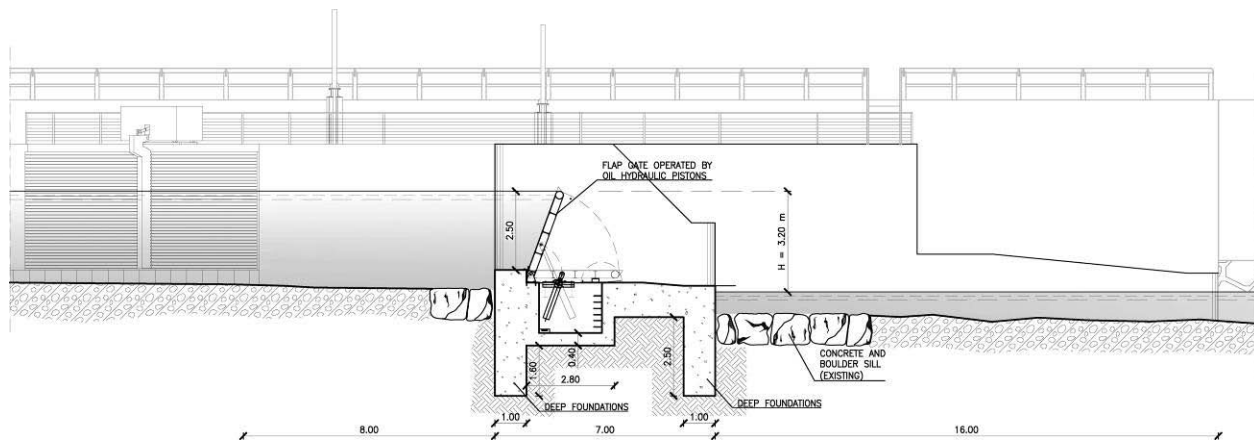


Figure 6. Cross section along the weir.

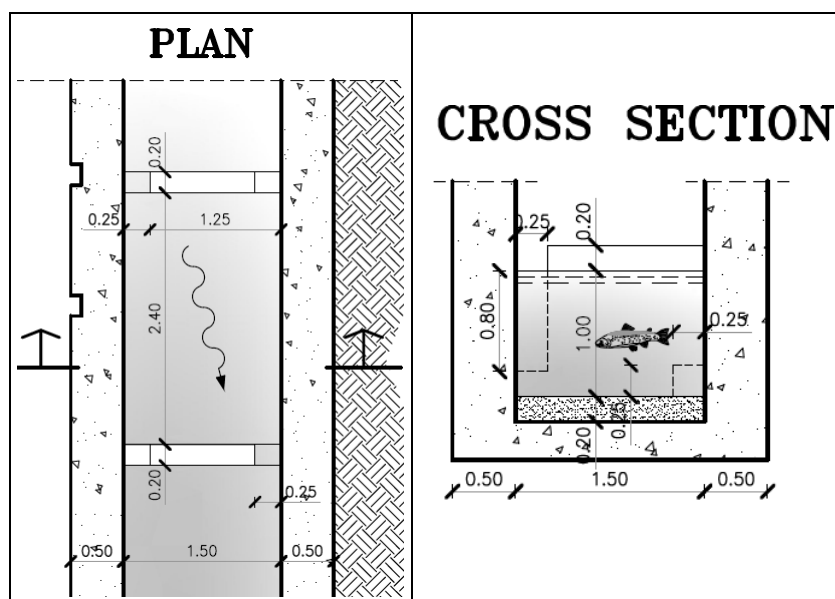


Figure 7. Plan and section details of the fish pass.

HPP	Sarezzo 1	Sarezzo 2	Sarezzo 3	
Maximum diverted flow rate	20	20	20	m ³ /s
Average diverted flow rate	6,79	6,79	6,79	m ³ /s
Average gross head	3,20	3,20	3,20	m
Nominal power of the plant	213,02	213,02	213,02	kW
Turbine installed capacity	500	500	500	kW
Generator installed capacity	625	625	625	kVA
Expected yearly average energy production	1,49	1,49	1,49	GWh
Cost of design and realisation	1.920.000	1.950.000	2.050.000	€
Cost/capacity ratio	3.840	3.900	4.100	€/kW
Cost/energy ratio	1,29	1,31	1,38	€/kWh
Incentivised tariff	210	210	210	€/MWh
Expected yearly income	313.000	313.000	313.000	€
Upstream water level in normal operating conditions	276,20	272,00	268,60	m a.s.l.
Downstream water level in normal operating conditions	273,00	268,80	265,40	m a.s.l.
Fixed part (reinforced concrete sill) elevation	273,70	269,50	266,10	m a.s.l.
Weir gate width	20	20	25	m
Weir gate height	2,50	2,50	2,50	m
Sluice opening width	2,00	2,00	2,00	m
Lower sluice gate height	2,00	3,20	2,70	m
Upper flushing gate height	1,00	1,00	1,00	m

Table 1. Summary of the main technical and economic features of the three HPPs.

4. Final and general remarks

The experience of these three plants can be, or rather must be, repeated in other contexts. Actually the situation and the constraints faced by the project development are getting more and more common, at least in Italy, where these low and very low head small hydropower plants are the best (and easiest to be authorised and implemented) solution to harvest the residual potential of already exploited rivers. This is due to a series of common causes, which have also affected the design process of the three examined plant, in particular:

- “best” sites (e.g. high heads) already exploited for a long time;
- incentivising frame more favourable for small (in terms of rated power) on-flow plants built across existing weirs;
- ever-growing environmental concerns, requirements and constraints, with particular regard to the diverted river stretches.

Consequently it's worth trying to draw some lessons from the Mella river case study.

- flood levels and backwater profiles must be checked, at least in a preliminary way, since the very first steps of the design process;
- production maximisation is a *constrained* optimisation process, not only for the abovementioned boundary conditions and constraints, but also because it must account for standardisation in order to reduce costs and therefore achieve the best global result, defined by the combination of incomes and costs.

These conclusions are valid for the Italian context, but also for most European countries and in general wherever hydropower has already been developed for a long time.

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