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A GIS integrated tool to evaluate the residual potential hydropower production at watercourse scale

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ABSTRACT

The identification of the potential hydropower at river scale (within a single basin) needs a precise analysis of the water availability in terms of annual stream discharge duration curve coupled with available geodetic falls.

The paper presents a GIS integrated numerical tool that allows for the evaluation of the residual potential hydropower energy and all possible alternatives concerning the sites for hydroelectric plants along the drainage network, taking into account the relationship between the full costs of the mini-hydro power and the benefits from selling the generated power in the national market. The tool takes into account the water resources present exploitation with its geographical location and elevation (with respect to irrigation uses, drinkable water, existing hydropower plants, etc.), and the limitation that this creates regarding the potentiality for energy production. The software is based on the topographic information (Digital Elevation Model) and the isohyets maps, with a whole analysis of the catchment, together with the regional evaluation of available discharges along the river system.

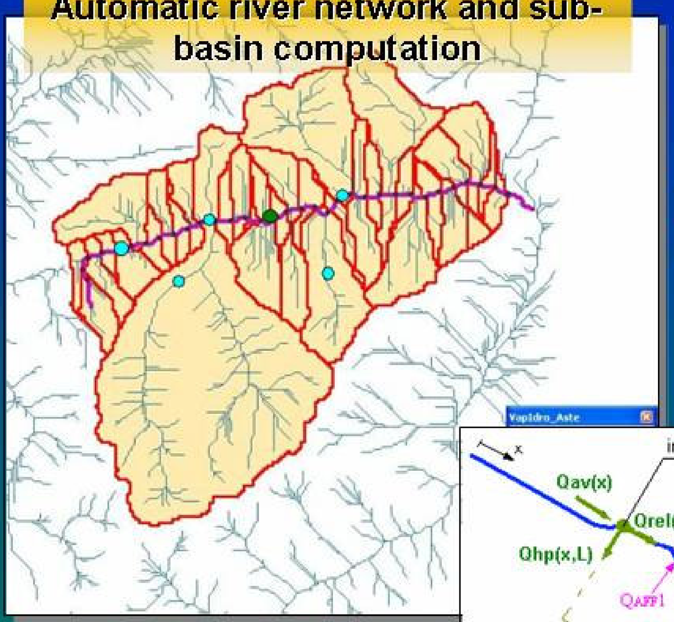
Based upon a user friendly graphical interface the tool is able to split the river into a hundreds of cross sections and to calculate the available discharges and potential hydropower production, considering constrains like minimum flow, withdrawals and restitutions scheme.

The tool shows to be a quite powerful instrument to support decision makers and stakeholders, for preparing energy plans, assess potential sites and implement small scale hydropower plants.

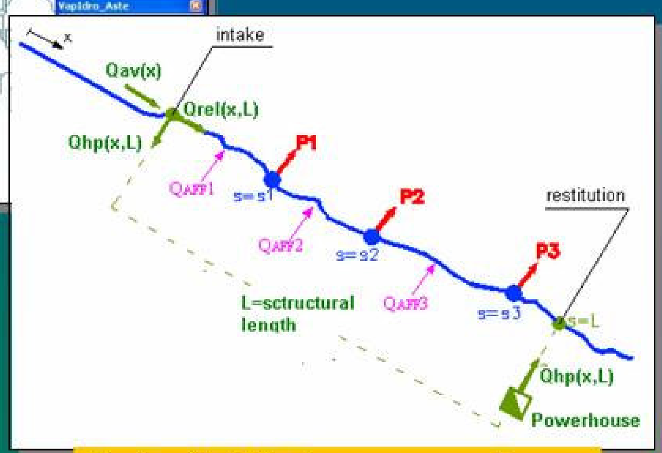
1 Withdrawal, restitutions & hydropower scheme

The VAPIDRO-ASTE tool is able to calculate automatically the river network associated to the interesting area. The user chose the a river branch where to calculate the potential hydropower production and then a series of chained sub-basins are generated by the model.

Automatic river network and sub-basin computation



The structural length "L" is defined as the distance between the intake and the restitution points, measured along the river thalweg.



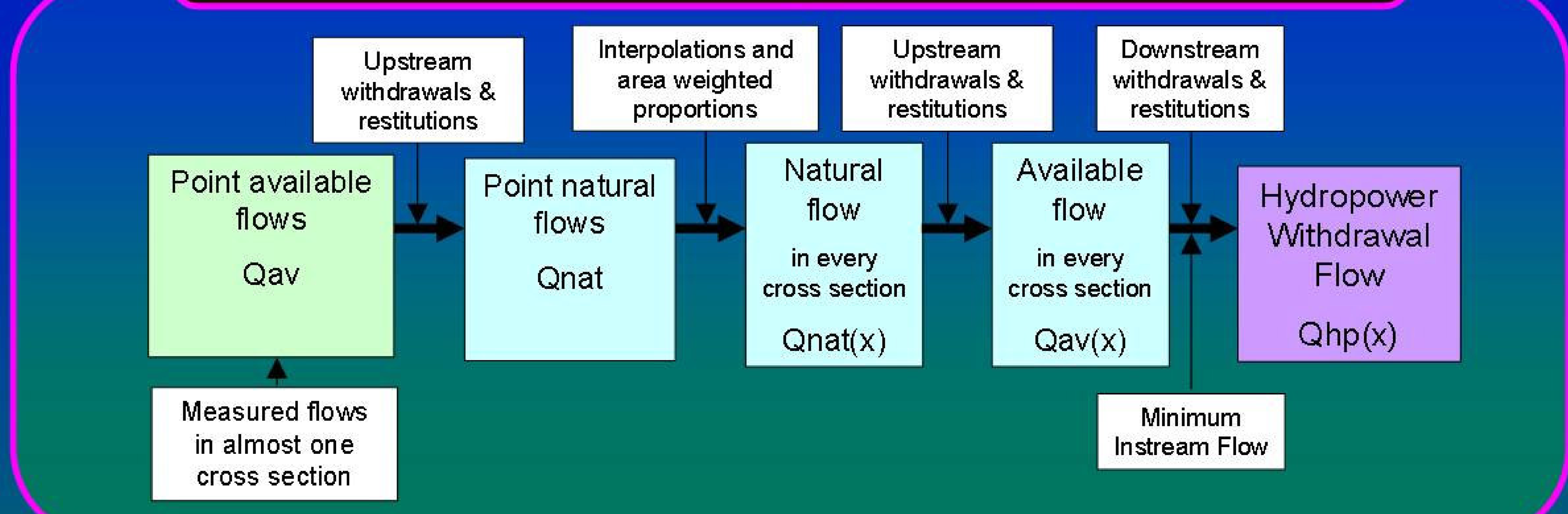
Potential Hydropower scheme

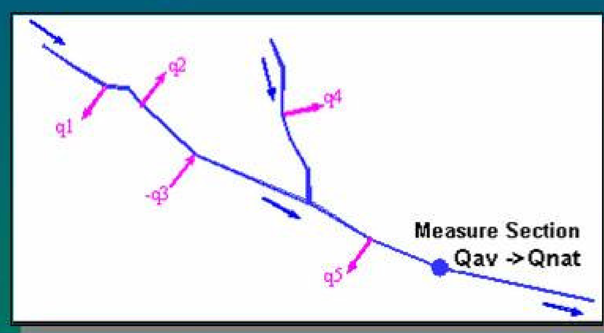
2 Hydropower withdrawal computation

It is possible to estimate the potential discharge to be used in a possible hydropower exploitation following computation and interpolation steps.

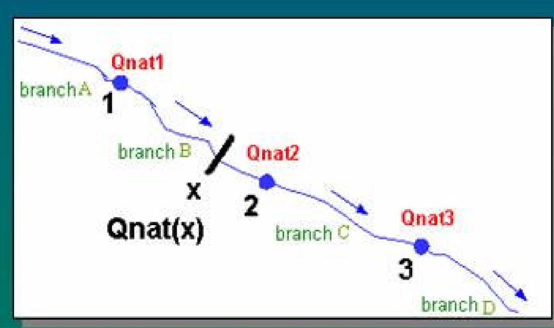
The interpolation process uses a double transformation of the river flow data, first the "naturalization process" of the river measured point flows, interpolation of the natural values and then a final transformation of available flows for every cross section.

Process to calculate the hydropower withdrawal flow





Flow measure cross section and upstream withdrawal/restitution scheme



Watercourse scheme with 3 point natural flow sections and Qnat(x) computed in A, B, C and D

$$Qmax(s) = Qav(s) - MIF(s)$$

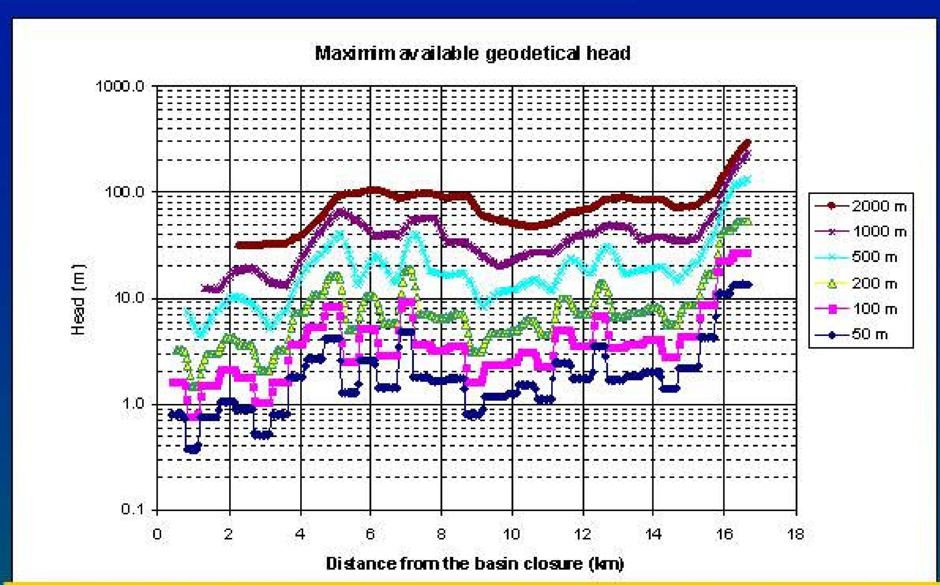
$$Qhp(x,L) = min|_{[s=0,L]} (Qmax(s))$$

Qmax(s) maximum withdrawal flow
MIF minimum instream flow
Qhp(X,L) hydropower withdrawal flow

Formulation of the hydropower withdrawal flow

3 Evaluation of Geodetic and Net Heads

The Digital Elevation Model coupled with GIS tools, permits to obtain the ground elevation pattern and consequently the geodetic heads, related to a particular "structural length" (L), for any cross section "x" along the river stream. It has been examined the available geodetic heads with 50, 100, 200, 500, 1000 and 2000 m structural lengths.



Available geodetic heads in a logarithmic scale.

The Geodetic Head corresponds to the Gross Head, while the Net Head is obtained considering the hydraulic losses:

$$Hnet(x,L) = Hgross(x,L) - DH(L)$$

where:

L structural length (m);
Hgross(x,L) Gross Head (m), function of x and L;
Hnet (x,L) Net Head (m), function of x and L;
DH(L) hydraulic losses in channel and penstock.

4 Computing the residual potential and the installable hydropower

The most favourable conditions for hydroelectric production are related to significant geodetic heads combined with Hydropower Withdrawal discharges.

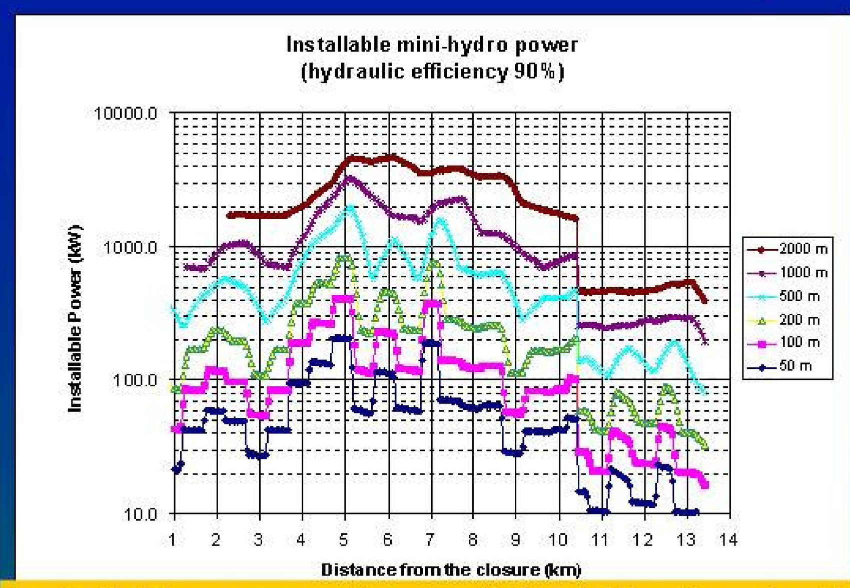
The Residual Hydropower Potential at each section of the watercourse, and for various structural lengths (from 50 to 2000 m), is evaluated using the following simplified formulation:

$$E(x,L) = \eta t \; 9.81 \; Qhp(x,L). \; Hnet(x,L). \; 8760$$

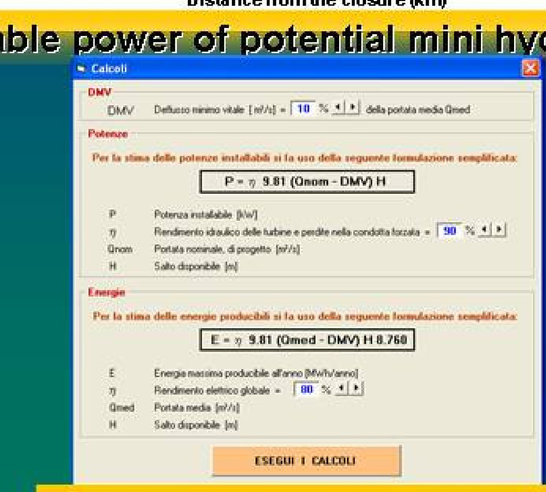
E(x,L) Maximum Available Energy (kWh/year), in function of x and L;
ηt electric global efficiency
Qhp(x,L) mean annual hydropower discharge (m^3/s)
Hnet(x,L) hydraulic net head (m)

$$P(x,L) = E(x,L) / Kh$$

P (x,L) installable power in a given section "x" for a structural length "L" (kW)
Kh yearly continuous hours at a maximum equivalent power to produce the potential energy (h/year)



Installable power of potential mini hydro plants

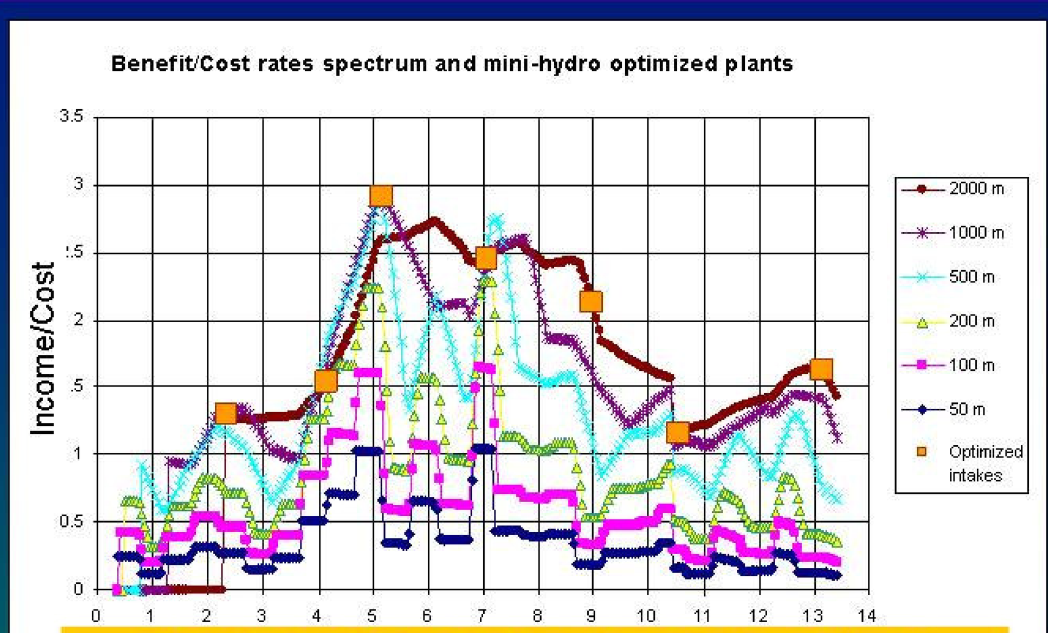


Residual potential hydropower data input mask

5 Optimized economic analysis of the hydropower exploitation

The choice of the most appropriate sites for the hydropower exploitation depends upon the relationship between the construction and maintenance costs of the full system and the income from energy selling plus the additional grants, such as the Green Certificates.

- Computation of the cost of the full system, for all the considered scenarios with different structural developments
- Calculation of the income from produced energy selling in the electrical market (including Green Certificates)
- Choice of the more profitable solutions, considering the relationship between benefit and cost, for the various positions

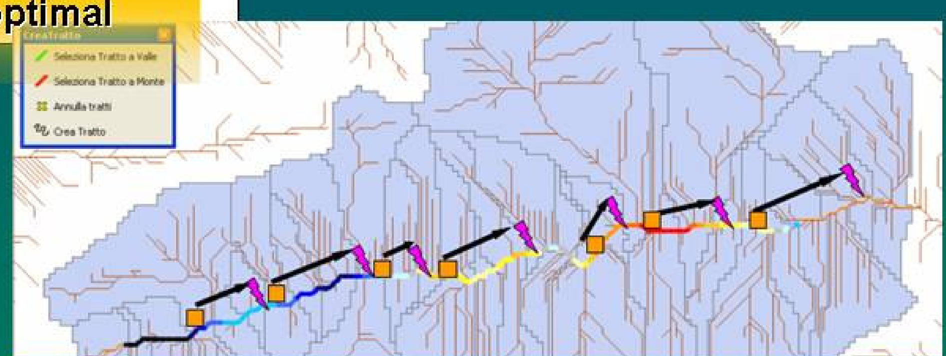


The Income/Cost spectrum and the optimal hydropower exploitation

The whole optimization process takes into account a chain of hydropower plants with different L and "x" (two freedom degrees optimization).

The optimized configuration is obtained maximizing the energy production and the income/cost ratio of the total chain.

Channel
Penstock
Intakes
Restitutions (powerhouse)



The optimal hydropower exploitation in a GIS frame

6 Conclusions

A GIS integrated numerical tool for the analysis of the mini-hydro residual potential sites at a river scale is developed. An optimization analysis considering the power generation and the benefit/cost relationship maximization is performed with the tool.

Is in progress the data acquisition regarding two case studies in Lombardia and Basilicata regions in Italy, to validate the application of the residual potential hydropower tool in watercourses.

The tool shows to be a quite powerful instrument to support decision makers and stakeholders, for the energy plan preparation, the assessment and the implementation of small scale hydropower plants.