

# Use of GIS to identify potential sites for small hydroelectric plants: general concepts and example of application

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## Introduction

Small hydroelectric schemes have an interesting potential for development in Switzerland and beyond its borders, but the search for exploitable sites requires a number of things, including the ability to quickly compare the energy yield and the economic situation. The use of geographical information systems (GIS) makes this step easier, and thanks to the automation of the procedures, it is possible to cover large surfaces. That is why a methodology has been developed and integrated into a computer tool incorporated in the software ArcGIS 9.2. This tool is based on a limited amount of numerical data: a digital elevation model (DEM) and runoff data.

From the DEM, the tool recreates streams and sets up hypothetical hydropower schemes at regular intervals, symbolized by points. Each one of these points may represent the position of a power station or an intake. Input data then make it possible to estimate altitude and hydrology for each one of these positions. The tool calculates the characteristics of each potential project and selects the best according to criteria established beforehand.

In the current example, the tool was applied to the Canton of Vaud in Switzerland. The area already includes a large number of hydroelectric schemes of various sizes and features both mountains and plain zones. It makes for a good test area to see whether the tool can detect zones that already boast an installation and check the impact of the quality of the DEM on the results. It is also an easy test area because numerical runoff data exists for Switzerland.

The analysis of the results confirms the usefulness of the tool and its capacity to detect zones with interesting potential through a comparison of the sites selected automatically and existing plants. The analysis of the results also brings to light a certain number of issues linked to the input data or the method used.

## 1. Background

The company STUCKY SA in Renens, Switzerland, has been active for many years in creating small hydroelectric plants. It has gradually developed computer tools that enable one to evaluate the hydroelectric potential of streams for small hydroelectric installations with the current. The experience of the engineers in this field was recently integrated in a GIS, facilitating the identification and the comparison of potential schemes to large scales. The various stages of treatments as well as necessary calculations were automated to create a tool that is functional and easy to modify.

## 2. Data

The tool was developed in ArcGIS 9.2 software and its extension Spatial Analyst. The method is founded on a limited number of input data: the DEM and runoff data in digital form. The tool was parameterized by the analysis of feasibility studies for projects of small installations.

### 2.1 Digital elevation model

DEM allows the user to delimit a catchment area and determine its theoretical hydrographic network by computerized, reproducible and automatizable methods. Specifying the limits of the catchment area and the generated streams depends on the resolution of the DEM; the less refined the resolution is, the more they can be shifted with respect to reality. Table 1 presents three MNTs available for Switzerland.

Table 1. Examples of MNT available for Switzerland

Name	Resolution	Data acquisition	Price
SRTM	3' of arc	Radar (space shuttle)	free (Nasa)
MNT25	25 m	Digitalization of the topographic map 1:25' 000	0.52 CHF/km <sup>2</sup> + expenses of order
MNT-MO	1m	Airborne laser	60.- CHF/km <sup>2</sup> + expenses of order

## 2.2 Runoff data

Runoff data correspond to net rainfall, i.e. the part of the total rainfall that flows into the hydrographic network. It takes into account the losses, such as evaporation or infiltration. It is expressed in millimeters of water per unit of time and unit of area.

For Switzerland, annual average runoff data were developed by the Federal Office of the Environment (FOEN) and the Federal Institute of Research on Forests, Snow and Landscape (WSL) [1]. For other countries, such data may simply not exist. One can reconstitute less reliable runoff data from precipitation and evaporation data. If evaporation data are not available, it is also possible to work from rough pluviometry. The developed tool is especially designed to make comparisons between zones and highlight the best ones. Naturally the quality of the results is strongly related to the quality of the data.

## 2.3 Feasibility studies

Seventeen feasibility studies for small installation projects carried out by STUCKY SA were used. The studies made it possible to establish simple equations in order to consider unknown parameters by working from the source data (DEM and runoff data).

## 3. Method

### 3.1 Analyses of the streams' linear potential

In order to analyze the theoretical linear potential of the streams, a hydrographic network is generated from the DEM. Then hypothetical schemes, symbolized by points, are placed at regular intervals along the streams. Alternately, each of these points can represent the location of a power station or water intake. One after another, they are considered as a water intake. For a given intake, all the other points whose altitude is lower than that of the intake are potential positions for the power station. The developed tool starts by evaluating the average volume of water which could be collected annually at the intake based on runoff data (or rough rainfall if necessary) and the surface of the catchment area. Then, it calculates the water head, the installed capacity, the energy produced annually and a cost price of plant, intake and penstock that would be built with each scheme. It should be stressed that this cost price does not say anything about profitability because it is not compared with the selling price, which cannot be known at this stage. It is simply an evaluation of the production costs per kWh. The GIS tool compares the results obtained and selects the best schemes according to criteria that are defined beforehand. It proceeds in the same way for all the potential intakes. The operation of the tool is presented schematically in figure 1.

## 4. Application of the tool to the Canton of Vaud

The tool was applied to the Canton of Vaud, in Switzerland. The area already includes a large number of hydroelectric installations of various sizes. It is a good test area because it allows one to check if the tool detects zones that are actually exploited and which were originally of interest in terms of hydroelectricity. Moreover, the canton features both mountains and plain zones. That makes it possible to check the impact of the quality of the DEM on the results. It is also an easy test area because numerical runoff data exists for Switzerland.

### 4.1 Method

The input data used to analyze the hydroelectric potential of the Canton of Vaud are a 25 m DEM and the runoff data from the FOEN and the WSL. The data were produced from the simulation model PREVAH (Precipitation-Runoff-Evapotranspiration Hydrotope Model) and from the data provided by the hydrological atlas of Switzerland [1]. It covers all Switzerland with a 500 m grid. PREVAH makes it possible to take into account many parameters, such as

snow melt, glacier melt, interception, evapotranspiration, storage and exchanges with the water table. The results were then checked against the 1:50,000-scale topographic map.

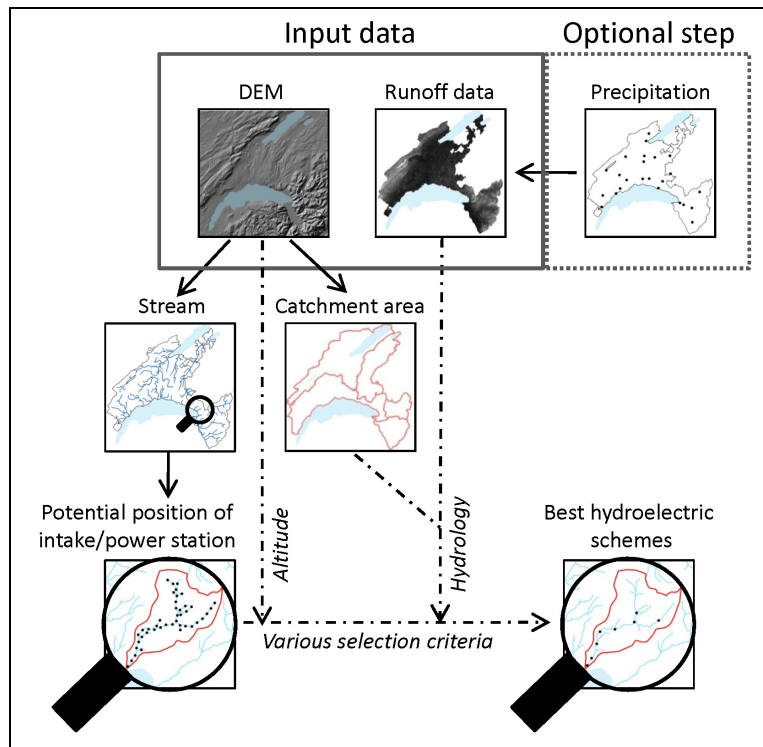


Fig 1. Operation of the tool.

The surface of the canton covers more than 2800 km<sup>2</sup>. According to the method of calculation, each water intake is tested with all the potential power stations, i.e. all the other positions whose altitude is lower than that of the intake. To limit computing time, this surface is divided into five zones delimited by the borders of the catchment area (figure 2). This division by catchment is necessary in order to consider all water reaching the intake by streaming.

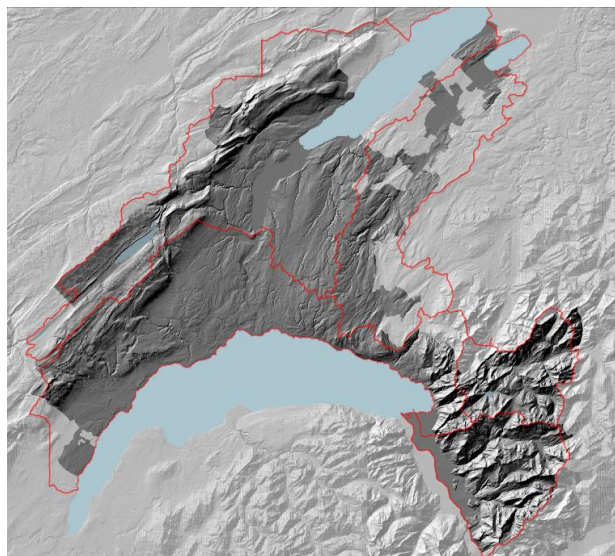


Fig 2. Canton of Vaud in dark gray and catchment area in red.

After having created the theoretical streams corresponding to the DEM, points representing the potential positions of the civil works are placed every 100 m. To eliminate aberrant schemes, the 1:50,000 topographic map is used to carry out an initial check; indeed, the methodology used to create the theoretical waterways automatically involves errors in the following two cases:

- In flat zones, the theoretical waterways are badly reconstituted because the thalwegs of the natural streams are not sufficiently indicated. In these areas, the software creates a large number of parallel features which do not correspond at all to reality (figure 3, left).
- In karstic areas, water does not stream sufficiently to create permanent waterways. In this case, the thalwegs do not correspond to waterways (figure 3, right).

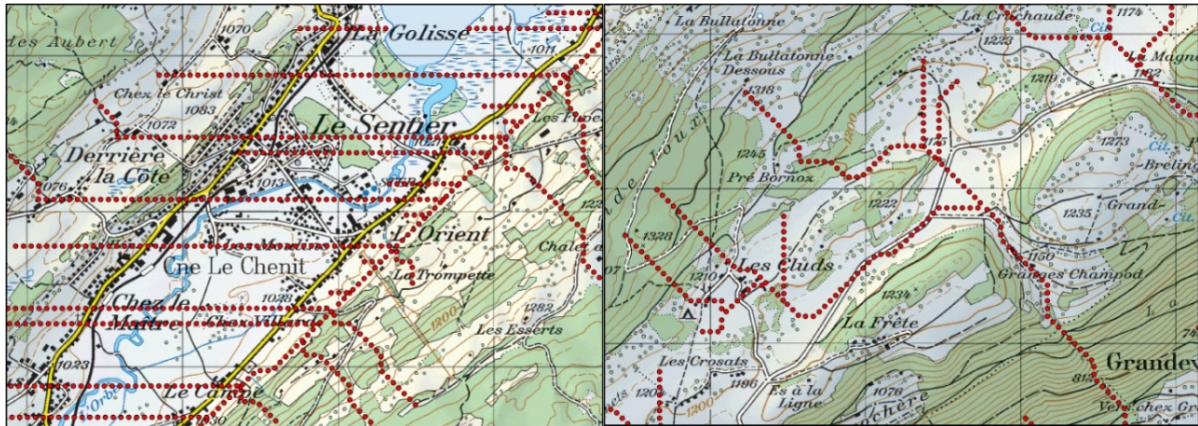


Fig 3. Typical errors due to the methodology used to create the theoretical waterways. Left: reconstituted waterways in flat zones. Right: nonexistent rivers in karstic areas.

The points which were added automatically to these places are therefore removed before starting the calculations.

A second presorting of the potential positions of constructions is carried out in certain zones where the natural flow is strongly disturbed by the existence of hydroelectric installations. It is the case in particular of the Orbe, whose waters are turbinéd downstream from Lake Joux and whose rhythm of operation is unknown. Indeed, the automatically calculated parameters were fixed for installations with the current and are thus not adapted in such cases.

The selection criteria used in this example are the minimization of the cost price and the maximization of the installed capacity. As explained above, this price does not express profitability but allows one to evaluate the production costs per kWh of a scheme compared with others. The economic criteria used to calculate the annual loan repayment are the following:

- loan = 80% of the total costs of installation
- loan maturity = 25 years
- interest rate = 5%

For the calculation of the installed capacity, the efficiency of the plant is estimated at 0.81 and the head losses to 10% of the total head.

## 4.2 Results

First of all, it should be noted that several existing schemes or schemes under detailed study were singled out by GIS analysis, proof that the tool is able to detect the sites having the best potential and that it is well adapted to this area. Checking the results highlighted certain important problems, however:

The method used to select power stations only ensures that they are located at a lower altitude than that of the water intake. Thus, certain installations have intakes and power plants that are not located in the same valleys. This configuration may be of interest when the potential for production is sufficiently important to cover the additional expenses generated by the tunnel. However, these costs are not integrated in the method of calculating and the

estimate of the cost price is thus distorted. Schemes in this configuration are thus eliminated, even though they might be of interest.

Schemes having the best potential were studied in detail. The catchment area of the water intakes of these schemes was thus reconstituted using DEM, then compared with the 1:50,000 topographic map. In the flat zones, the quality of the DEM was particularly important. Indeed, when the slopes are very slight and the thalwegs not easily seen, the topography is not always correctly represented by the DEM and the software does a poorer job estimating catchment areas. The user needs to be vigilant and check the results in the zones where the topography is relatively flat. The quality of the DEM is thus an element that becomes increasingly critical particularly if one wants to evaluate zones of flat topography, whether estimating the catchment areas or the head. In a first test, the free DEM of NASA (3' of arc) was used on the Canton of Vaud. The results were of relatively good quality in the mountainous areas but poor in the flat zones.

The method used to estimate hydrology from the net rain implies that the ground is impermeable and that the totality of the rain that does not evaporate flows on the ground into the rivers. This method thus overestimates the flows. The runoff data established by FOEN and WSL for Switzerland were fixed to measured data of flows to limit this problem [1]. However, estimation of the flows according to this method remains problematic for the areas where the real catchment cannot be taken into account, as is the case in the karstic areas of the Jura (North East of the canton). It should also be noted that the results represent the natural flow of the rivers (without urbanization). The sites retained in the karstic areas were thus eliminated. As to the problem of urbanization and the present use of water, the current tool does not allow one take it into account during calculations. Moreover, this information is generally unknown.

Finally, the scheme selection processes are not always restrictive enough. Several schemes, for example, are very close to each other, distant only by a few hundred meters, with very similar results. This does not really matter as the objective of the GIS tool is not to identify precisely the location of the proposed schemes, but rather zones of interest. However, in such cases, the increased number of installations in a given zone makes consulting the results on the maps more complicated. The user needs to spend more time sorting them to obtain easy-to-read maps. In the actual state of the tool, taking into account the other inconveniences listed above, a larger number of schemes concentrated in particular areas also constitutes a safeguard against the elimination of potentially interesting locations when checking the results for software-induced mistakes.

After the results were checked and various improbable schemes, whether unrealizable or uninteresting, were eliminated, there remain 177 schemes, including 120 which have more than 1 GWh of annual production. Among these, the best production is estimated at 12 GWh per year. Site visits must then take place at some of these locations in order to define the best locations for the intake and the power plant and to prepare more detailed studies.

## 5. Conclusion and prospects

The results show that the tool developed completely corresponds to the objective: it evaluates correctly and quickly the hydroelectric potential of relatively large areas. The fact that the tool indeed predicted installations that either exist or are currently under study proves that it is well adapted. After the results were checked and selected, 120 sites of more than 1 GWh of annual production were highlighted. This result is very encouraging about the efficiency of such a computer-aided site identification approach.

The stage of validation shows the importance of the quality of the DEM, in particular in gently sloping areas. A stage of manual checking of the identified sites is however essential for eliminating incoherent results.

One must also bear in mind that the results currently do not take into account existing water use. It is thus necessary to have certain knowledge of the area in order to eliminate those zones that are already equipped or where water is used for other purposes.

Finally, further development and refinement of the tool is foreseen, in order to include, in particular, the costs associated with the distance between the power plants and HV electrical network. In the long term, it is also foreseen that the tool will be able to combine several water intakes in a single scheme.

## Reference

1. **Plaundler, M. and Zappa, M.**, "Die Mittleren Abflüsse über die ganze Schweiz. Ein optimierter Datensatz im 500x500m Raster", *Eau énergie air* 5 (2006).

## **The Authors**

**Joanne Félix** obtained her diploma in Environmental Natural Sciences in 2006 at the University of Lausanne. She started a MAS in Hydraulic Engineering at the EPFL in Lausanne. During this time, she was also completing an internship at the offices of STUCKY SA in Renens, where she developed the computer tool presented in the article as the practical research work for her Master's degree. Since obtaining her Master's in 2009, she has worked as a design engineer in the same company.

**Antoine Dubas** has twenty-four years of experience in energy and infrastructure projects. Initially trained as a geologist, he switched to infrastructure rehabilitation in Africa and the Balkans, particularly in the water and energy sectors. Since 2002, he has been Director in charge of Business Development and Project Finance for STUCKY Ltd, working mainly on hydropower projects. He is also developing several small and large hydropower projects in Switzerland, Peru and several other countries.