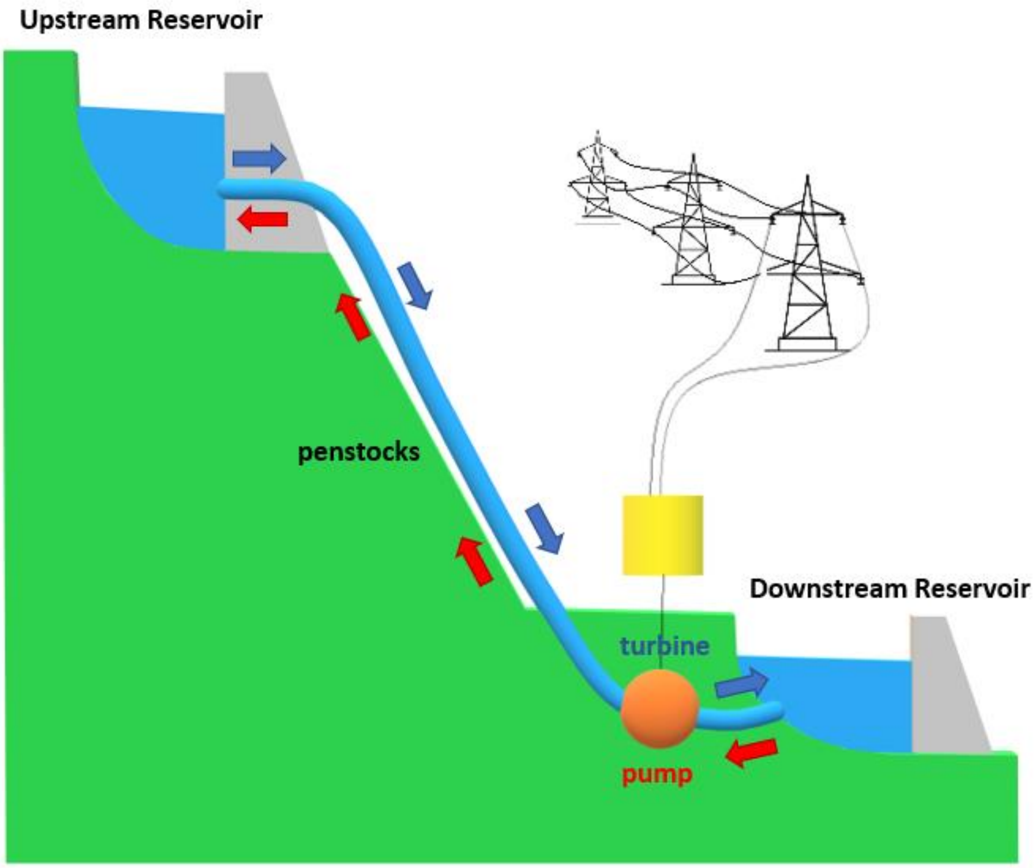
Consulting Engineers

Design and Works Supervision

PUMPED STORAGE HYDROPOWERS



FEASIBILITY STUDIES AND PROJECTS REFERENCES

GEOTECNA PROGETTI

Passion, Experience, Sustainibility…from 1972

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1. INTRODUCTION

The present Note contains **Geotecna Progetti** experiences in the pumped storage hydropowers field during the last 20 years.

2. CAPABILITY STATEMENT IN HYDRAULIC AND HYDROELECTRIC FIELD

Geotecna Progetti operates in Italy and abroad since 1972 and, in this period, has developed study and design activities on about 40 hydropowers (for an overall capacity of over 2000 MW) and on over 100 dams.

The performed technical services concern new works and/or refurbishing of existing plants, in all the steps from the prefeasibility studies to the various levels of design (including follow up during the authorization and concession path), to the construction and the commissioning.

In last 20 years **Geotecna Progetti** has participated to the design, realization and upgrade of the main Italian hydropowers and pumping storage hydropowers (Pont Ventoux-Susa, Premadio II and Nuovo Canale Viola, Campolattaro) and has been working in Africa, Latin America and Middle East.

Moreover the Company has developed a specific know-how in the identification and classification technique of possible new pumping storage hydropowers analyzing on behalf of the Italian TSO (Terna S.p.A.) existing basins in South Italy, Sicily and Sardinia.

The history of **Geotecna Progetti** in the hydraulic structures field (dams, reservoirs and hydroelectric plants) has followed the various development stages of the Italian infrastructures.

After a first period (1970-2000), in which irrigation interventions and the design and construction of several reservoirs in the South of Italy, financed by the Government through Agenzia del Sud, were prevalent, a rebalancing followed both in the geographical distribution and in the intended use of water, so that the completion of the already in progress irrigation works was accompanied by the development of new and maintenance interventions for hydroelectric customers in North Italy (Sondel, A.E.M. of Turin , A.E.M. of Milan, Edison, A.E. Bolzano).

Among the new interventions, the tender design and then the detail design on behalf of the construction concessionaire Astaldi S.p.A., winner of the tender, of the Pont Ventoux-Susa generation and pumped storage hydropower can be considered of great relevance.

In last twenty years, the interest has moved towards the maintenance and rehabilitation of existing structures on the national territory (Region Sicily, A2A and E. On), and the completion of the unfinished irrigation schemes, in some cases also with the hypothesis of implementing a pumping system on existing generation plants or on reservoir for irrigation use (A.E. Bolzano, Repower, Consorzio di Lentini, Consorzio Tirreno Reggino, Consorzio di Piacenza and IREN).

At the same time, the involvement in the design and construction of new plants abroad and in various geographical areas has grown.

In Albania and Montenegro, respectively the Hydroelectric Plant and the Dam of Skavica on the Drin River and the use of the Moraça River through the Andrjevo and Zlatika Dams and Powerplants, have been studied.

In the Iraqi Kurdistan, the detail design for the Powerplant (100 MW) and the Dam of Mandawa on a tributary of the Tigris River was developed.

In last 5 years, in the northern part of the Uganda on the Achwa River, a tributary of the Nile River, two run of river plants for about 80 MW have been designed and built.

Finally in the Dominican Republic, the detail design of the Guayubin Dam for multiple use is in progress.

The experiences of **Geotecna Progetti** are illustrated in the **Chapter 3 Pumped storage hydropowers designs** and in the **Chapter 4 Screening analyses of Pumped Storage Hydropowers.**

Some **bibliographic references** follow.

3. HYDROELECTRIC PUMPED STORAGE HYDROPOWERS DESIGNS

Geotecna Progetti is active in the field of the pumped storage hydropowers, both in study and design phase and during the construction of:

- new plants,
- refurbishment and update of existing plants,
- addition of the pumping operation in existing hydropowers.

Following a chronologic order Table 1 summarizes the main developed experiences.

Pumped storage hydropowers				
Plant	**Year**	**Installed power (MW)**	**Produced energy (GWH/year)**	**Client**
Pont Ventoux-Susa (TO) pumped storage hydropower – Detail design	1995-2005	150	400	A.E.M. Torino, now IREN S.p.A.
Naturno (BZ) hydropower plant: addition of pumping operation – Concession basic design	1997	230	300	A.E. S.p.A. Bolzano, now Alperia S.p.A.
Campolattaro (BN) pumped storage hydropower – Concession basic design	2008	550	1000	REC S.p.A.-Repower S.p.A.
Lentini (SR) pumped storage hydropower – Feasibility study	2010	500	1000	Consorzio di Lentini and REC S.p.A.-Repower S.p.A.
2 Lakes (Orta and Maggiore) (VB) pumped storage hydropower – Feasibility study	2011	28	86	Kinglor s.r.l.
Castagnara-Galatro (RC) pumped storage hydropower – Feasibility study	2012-2013	20	45	Consorzi di Reggio Calabria, now Consorzio Tirreno Reggino
Restana-Nure 4 (PC) pumped storage hydropower – Prefeasibility study	2017-2018	15	40	Consorzio di Bonifica di Piacenza and IREN S.p.A.
Monteponi-Corsi (IG) pumped storage hydropower – Prefeasibility study	2021 in progress			E.A.S. S.p.A.

Table 1. Pumped storage hydropowers designed by Geotecna Progetti

In particular, concerning Pont Ventoux-Susa Hydropower Geotecna Progetti technicians took part in the Detail design of the pumped storage hydropower and in the Construction design and follow-up during the construction from 1995 to 2005 of the main works (2 dams, 20 km of tunnels and the Underground Powerhouse).

Regarding the existing Naturno Hydropower, the Concession basic design of the addition of pumping operation from Adige River has been developed, including geological and environmental studies.

With reference to Campolattaro, Lentini and Castagnara, the Feasibility studies explored the possibility to insert in existing traditional irrigation schemes pumping and generating plants, evaluating also the financial loads and the authorization aspects.

Concerning Orta and Maggiore 2 Lakes the hypothesis to exploit the natural configuration of the 2 lacustrine basins, with an interesting natural difference in altitude, has been studied.

As an example, a short description with the main design data of some of the above-mentioned plants is reported in the following, while the Screening studies developed for Terna (Italian TSO) are illustrated in Chapter 5.

3.1 Pont Ventoux-Susa (TO) Pumped Storage Hydropower

Located in High Susa Valley, the Pont Ventoux-Susa Pumped Storage Hydropower has substituted two old run-of-river plants built in 1910 and 1923, doubling the production of electric energy with diurnal operation of the turbines and night repumping of the water.

The water is diverted at Pont Ventoux from Dora Riparia River, tributary of Po River, with a maximum flow discharge of 34 m^3/s and, after an average geodetic jump of about 515 m, it is returned to the same river about 1 km upstream of Susa Town (Figure 1).

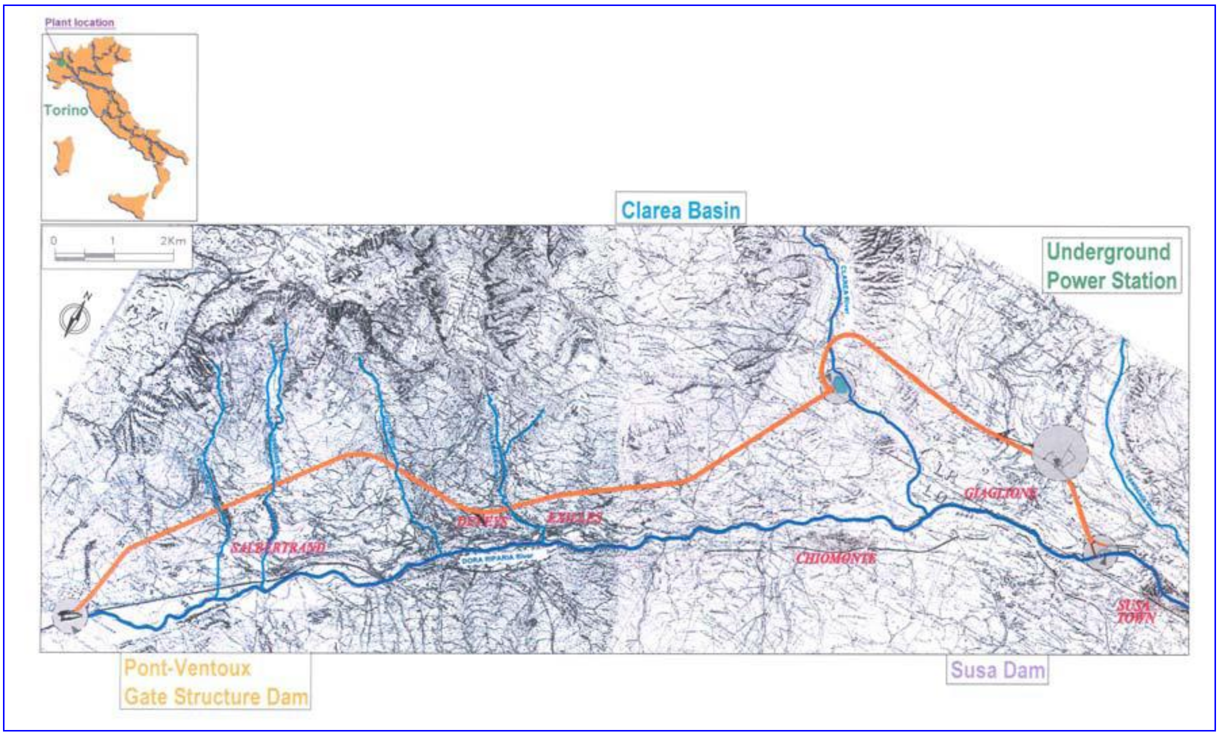


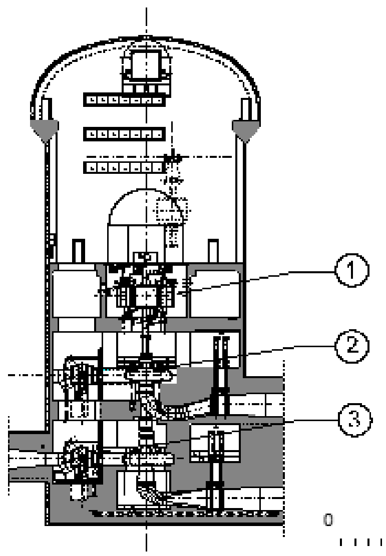
Figure 1. Pont Ventoux-Susa Pumped Storage Hydropower layout

The plant layout consists of:

- gate-structure dam, intake and ancillary works on Dora Riparia River;
- conveyance tunnel in left side of Dora Riparia River, 14 km long;
- regulation basin outside the river-bed in Clarea Valley;
- pressure tunnel, about 4 km long;
- surge shaft;
- penstock in shaft;
- underground power station, equipped with 2 Francis turbines with vertical axis; a pump is coupled with one of them;
- downstream surge shaft;
- tailrace tunnel to the demodulation reservoir created by Susa Gorge Dam.

The main design data are the following and, on the right, the vertical section of the Powerhouse in cavern is reported:

- geodetic head about 515 m;
- discharges turbined by the 2 Francis turbines equal to 28.4 and 34 m^3/s;
- maximum discharge of the pumping group 13 m^3/s;
- power of the underground Powerhouse about 150 MW;
- yearly produced energy bigger than 400 GWh/year.



1 Generatore
2 Turbina
3 Pompa

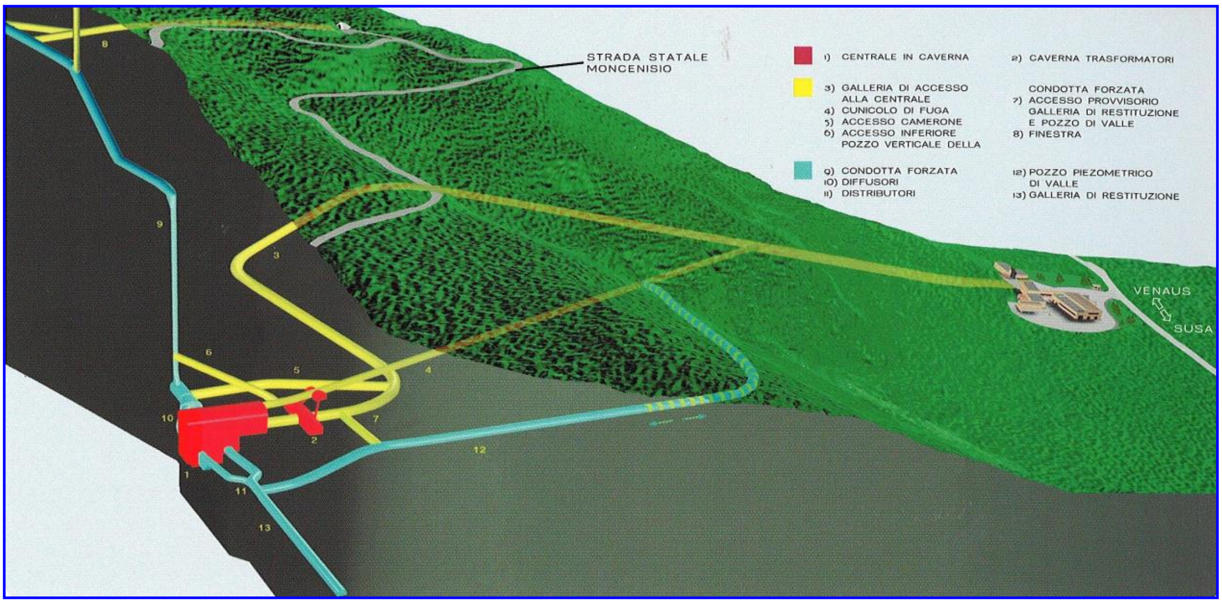


Figure 2. Giaglione Underground Powerhouse

3.2 Campolattaro (BN) Pumped Storage Hydropower

The adopted layout involves the construction of an upper reservoir in a natural hollow by Monte Calvello, with maximum water level at 880 m a.s.l. elevation and a volume of about 8 millions m^3. Such a layout gives the opportunity to exploit a maximum head of about 500 m., since the normal water level of the lower existing artificial reservoir of Campolattaro is at 377.25 m a.s.l. (125 millions m^3).
The plant consists of the following works:

- upper reservoir;
- penstock in tunnel (Φ=4.9 m, L=3910m);
- underground power station;
- tunnel under pressure (Φ=7.5 m, L=3940m) between the underground powerhouse and the lower reservoir;
- surge shaft;
- intake / tailrace works;
- connection to the high voltage electric network.

The upper reservoir is connected to the underground powerhouse, through two vertical shafts and a subhorizontal tunnel.

In the powerstation are installed several reversible groups (pump-turbine groups) at elevation about 330.00 m a.s.l. with a total electrical installed capacity of around **500 MW**.

Downstream of the groups a tunnel realizes the connection with the intake/tailrace structure in the Campolattaro Reservoir.

The access to the powerhouse is through a tunnel, with 8.5% slope, about 2.290 m long with entrance North-East of Pontelandolfo.

The time necessary to build the whole plant is estimated of about 4-5 years since the achievement of all the necessary authorizations.

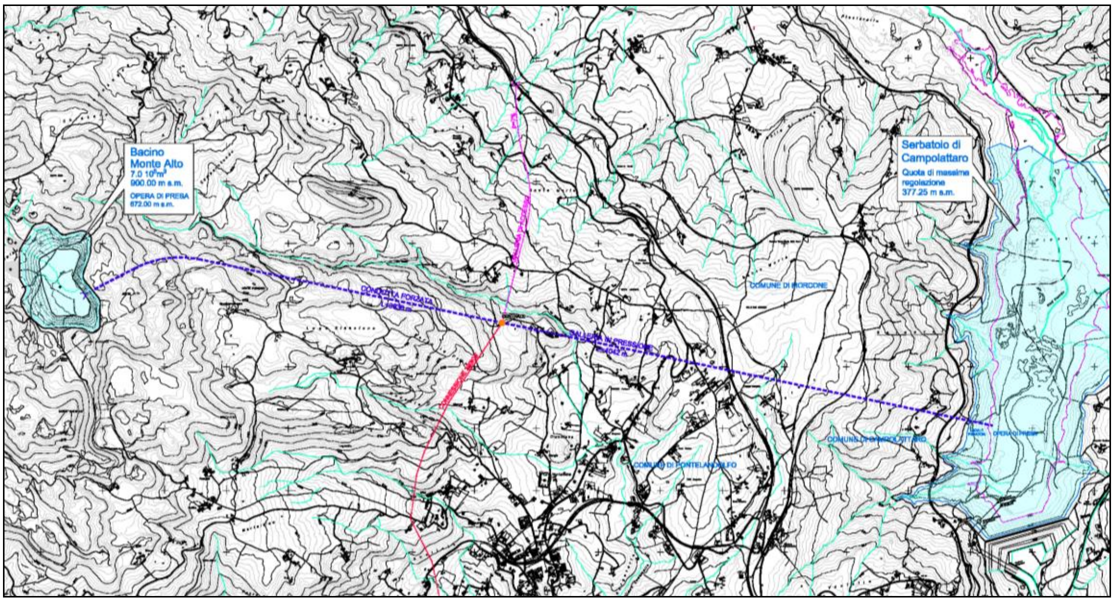


Figure 3. Campolattaro Pumped Storage Hydropower layout

4. SCREENING ANALYSES OF PUMPED STORAGE HYDROPOWERS

The activities carried out by **Geotecna Progetti** in last years consist of screening analyses of existing reservoirs identified in the geographical area of interest in order to evaluate their potential use for pumping purposes (with the use of GIS tools).

The Studies, based on public data traceable on the Internet, have examined the possibility both of interconnecting pairs of reservoirs and of associating with each of them a new reservoir, characterized by the maximum difference in height, to be built within a radius of 10 km and in compliance with the environmental and hydrogeological restrictions.

Using parametric costs from literature and/or related to previous experiences, the relative cost for each plant has been evaluated. Rankings have been then established on the basis of evaluation criteria with reference to various parameters as capacity, cost, restrictions and authorization time, in order to select the sites worthy of further investigations through pre-feasibility and feasibility studies.

4.1 Methodology

The location mainly in the North of Italy of the pumped plants limits their use for the resolution of system and overgeneration criticalities generated by non-programmable renewable plants.

The latter, in fact, are located in sites meteorologically suitable for wind or solar production, namely in the South of the country and in the Islands, where the grid meshing is historically less developed. This situation has determined the so-called "local" congestions.

Furthermore, in perspective, the progressive growth of intermittent renewable plants increases the need of resources in reserve, in the hours of maximum production from wind or solar, and of balancing, in the hours characterized by high discontinuity of production of the same (e.g. coverage of the evening peak).

The Italian territory, due to its geomorphological characteristics, has important reservoirs in all the regions, which are suitable for hosting new hydroelectric storage plants.

These reservoirs, currently used for the water supplying for civil, irrigation and industrial uses, could be equipped, at least in part, with pumped plants to exploit residual capacities, for example through the creation of a reservoir upstream or downstream of the existing one with adequate elevation drop, or by the connection of two existing impounds with different water level through a conduit or a tunnel.

Indeed, many reservoirs are today under-used, due to limitations of the operating parameters for the progressive deterioration of the safety conditions for the delay or lack of investments, which could be indeed turned on by the additional destination.

In particular, with reference to the pumped plants, the potentiality in the areas mentioned above and represented in Figure 4 was already identified in 2010.

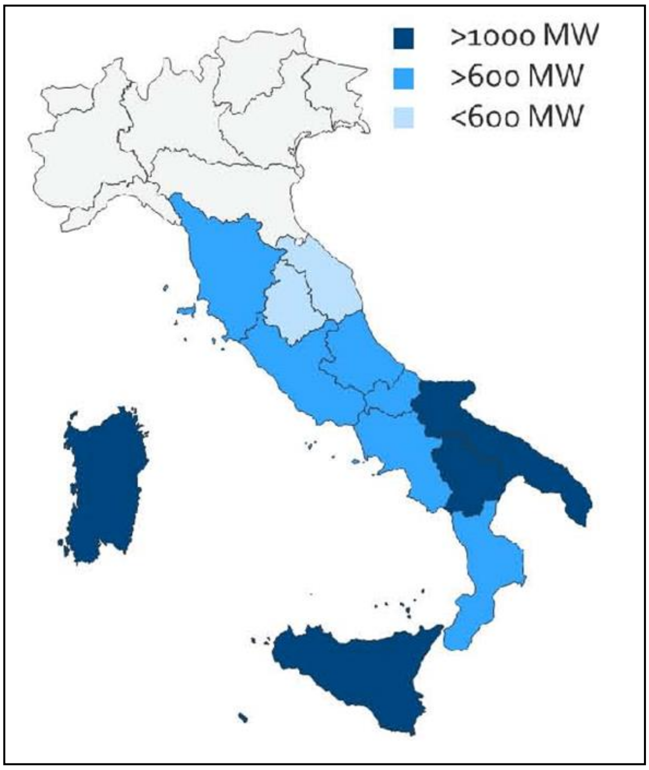


Figure 4. Energy storage potential through new pumped hydroelectric plants

In the following years, preliminary studies for both fresh water and sea water pumped hydro plants were developed by RSE, operating in a GIS environment.

Firstly, the Italian territory has been analysed in order to identify suitable areas, within a distance of 10 km from existing reservoirs, to build an upper or a lower reservoir with a minimum head of 100 m, excluding the protected areas.

Then, with similar methodology, the shoreline has been scanned in order to identify roughly flat areas, within a distance of 1 km from the sea, to build an upper reservoir with a minimum head of 100 m.

Finally, the application of a methodology for the assessment of the nationwide storage potential for underground hydroelectric pumped plants has been developed.

Once the residual water availability of an existing reservoir has been ascertained, the research for suitable areas to locate a new impound in combination for hydroelectric pumping can be carried out with the support of IT tools. They can be implemented in a GIS environment and managed through the common functions of geographic information systems, which allow the spatial representation of georeferenced databases of specific interest (e.g. topographic, geological, geomorphological, hydrogeological, instability, land use, environmental constraints digital maps, etc.).

The approach used for the GIS analysis considers that, in the context of a circular search area with a defined radius centred on the existing dam (generally 10 or 20 km), the parts of territory subject to environmental constraints (e.g. National Parks, Protected Natural Areas, Wetlands, urbanized areas, industrial areas, areas of agricultural development, etc.), as well as those with a high ground slope (e.g. slopes with an inclination> 30°), or affected by hydraulic risk (flooding), geomorphological (landslides), seismic hazards (e.g. presence of capable faults) have to be initially excluded.

Removing within the circular area of research the zones affected by the above-mentioned constraints, it is possible to identify, by difference, the areas considered "suitable" for the location of a new reservoir (Figure 5).

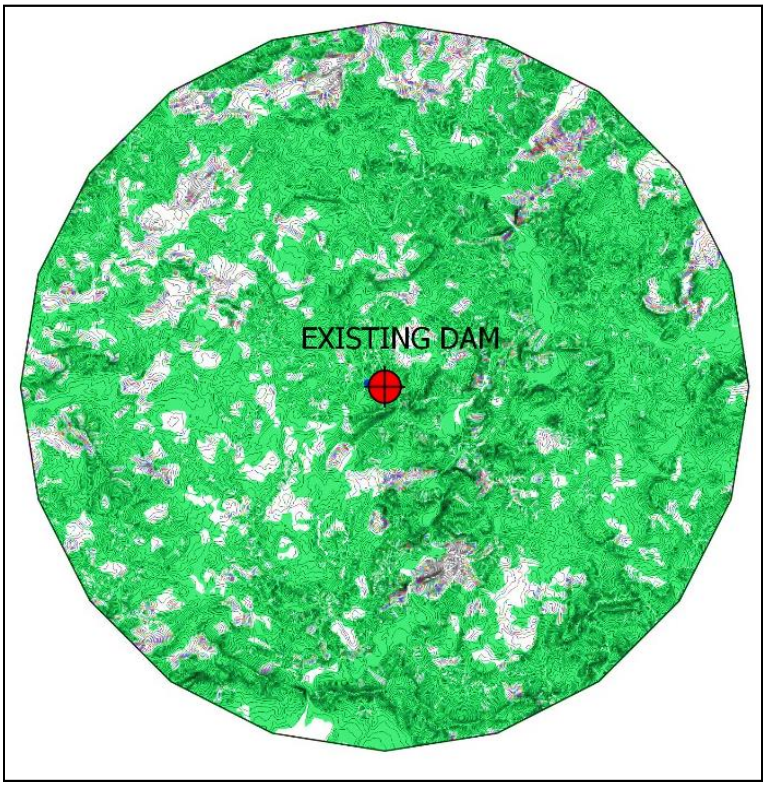


Figure 5. Example of representation of "suitable" areas (green) for the location of a new impound in combination with an existing dam

The possible locations of a new pumped reservoir are then subsequently researched within the above-mentioned "suitable" areas.

For this purpose, a raster base is developed for the research area consisting of a grid of points (pixels) each characterized by a value of the ratio elevation drop/distance (Δ/D) with respect to the existing dam. The best locations of the new impound are then selected coinciding with the points having the maximum values of this index.

In this way, the possible "optimal" positions of the new reservoir which allow, in combination with an existing dam, to create a pumped system that maximizes the ratio between the producible energy and the construction costs can be selected.

The construction, by successive steps, of such a raster base, indispensable to set up the research according to the above described criteria, requires the elaboration of maps of elevation drop and distance of each cell (pixel), with respect to the plane-altimetric position of the existing reference dam (Figure 6), through the GIS functions that perform mathematical operations among the rasters of the terrain topography.

For this purpose, the digital terrain model provided by NASA (STRM Shuttle Radar Topography Mission), consisting of a regular mesh of elementary cells extending 3"x 3" of arc (indicatively corresponding to 90 mx 90 m cells), or even higher resolution DEM models, can be used as a topographical database.

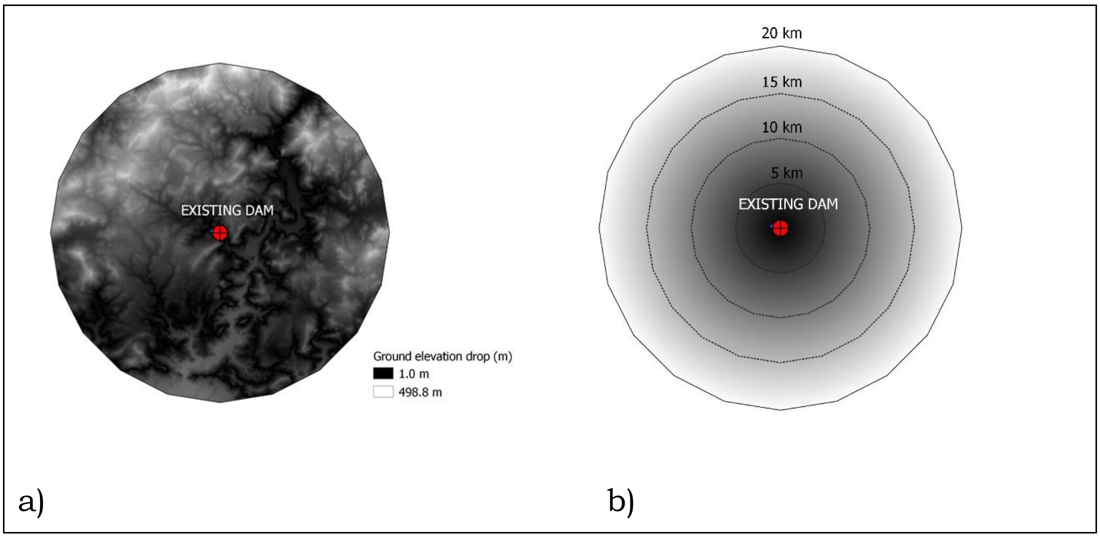


Figure 6. Raster maps realized to represent a) the ground elevation drop Δ and b) the distance D from the existing dam

In addition, it is necessary to exclude from the research the suitable areas that present an elevation, referred to an existing dam, lower than a given limit value (usually ± 100 m), generally considered as a minimum value of acceptability for sustainability purposes and interest of an hydroelectric pumped plant.

As an example, Figure 7 illustrates the final processed map showing the elevation drop / distance ratio Δ/D in relation to an existing reservoir, processed considering only elevation drop values > 100 m.

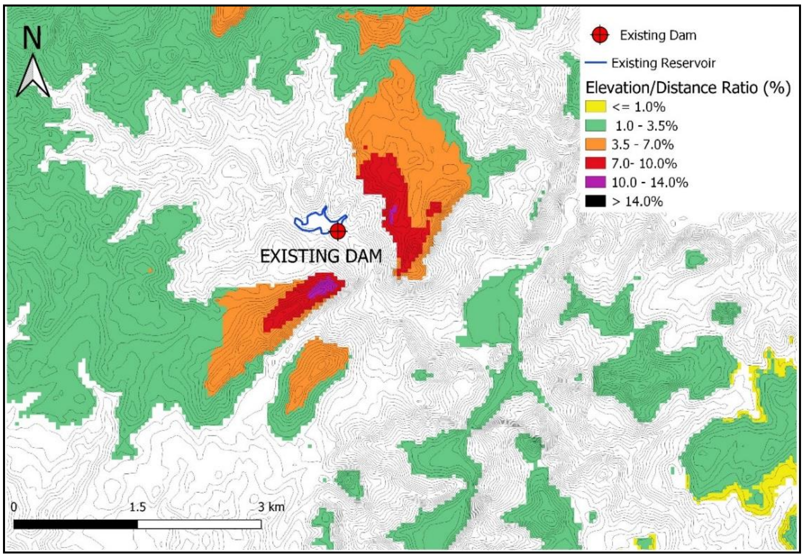


Figure 7. Example of raster map processing, with representation of the ratio Δ/D evaluated in relation to an existing reservoir

Of course, the interest focuses on the positions where the ratio is maximum, even if also the distance and other factors affect the classification.

4.2 Screening analyses

Possible new pumping storage hydropowers screening analyses		
Geographical area	Year	Client
Possible new pumping storage hydropowers in South Italy - Technical and economic feasibility studies/Survey, analysis and classification considering 41 existing basins for irrigation.	2018-2019	TERNA S.p.A
Possible new pumping storage hydropowers in Eastern Sicily (Italy) - Technical and economic feasibility studies / Survey, analysis and classification considering 19 existing basins.	2019	TERNA S.p.A
Possible new pumping storage hydropowers in Sardinia (Italy) - Technical and economic feasibility studies / Survey, analysis and classification considering 58 existing basins.	2021 ongoing	TERNA S.p.A.
Possible 6 new pumping storage hydropowers in the Central-Northern Calabria (Italy) - Technical and economic feasibility studies	2021 ongoing	A2A S.p.A.

Table 2. Screening analyses of possible new pumping storage hydropowers developed by Geotecna Progetti in regions with high growth of not programmable renewable plants

4.2.1 ANBI reservoirs in Calabria, Campania, Basilicata, Molise, Puglia and Sicilia (South of Italy)

The present Project has considered 41 existing reservoirs in South Italy (Campania, Molise, Calabria, Basilicata, Puglia, Sicilia Regions) currently used for irrigation uses.

The sites have been deeply investigated analysing possible stability, sedimentation, geotechnical, environmental problems and the residual capacity availability.

Having discarded the problematic impounds for the 39 residual judged adequate, the connection of two existing impounds and the creation of a reservoir upstream or downstream of the existing one have been examined.

The research for suitable areas to locate a new impound in combination for hydroelectric pumping has been carried out with the support of IT tools.

For each possible plant an optimal power and a specific lay-out have been determined.

Assuming parametric works costs (derived from international databases) the overall economic values for construction and operation of each plant have been estimated.

On the basis of a ranking considering several factors (sedimentation, environmental constraints, power, costs etc.) a general classification has been developed.

The first and the second plant in the ranking, respectively in Puglia and Basilicata, present a power of about 100 MW, while the third and fourth, both in Basilicata, vary between 1200 and 250 MW.

4.2.2 Reservoirs in the Eastern Sicilia

Sicily, due to its geomorphological characteristics, has important reservoirs, which are suitable for hosting new hydroelectric storage plants.

Indeed, some impounds are today under-used, due to limitations of the operating parameters for the progressive deterioration of the safety conditions for the delay or lack of investments, which could be indeed turned on by additional destinations.

These reservoirs, currently committed to the water supplying for civil, irrigation and industrial uses, could be equipped, at least in part, with pumped plants to exploit residual capacities, alternatively:

- through the creation of a reservoir upstream or downstream of the existing one with adequate elevation drop,
- by the connection of two existing impounds with different water level through a conduit or a tunnel.

The present Project has considered 19 existing reservoirs in Eastern Sicily currently used for several uses.

The sites have been deeply investigated analysing possible stability, sedimentation, geotechnical, environmental problems and the residual capacity availability.

Having discarded the problematic impounds for the 15 residual judged adequate, the connection of two existing impounds and the creation of a reservoir upstream or downstream of the existing one have been examined.

The research for suitable areas to locate a new impound in combination for hydroelectric pumping has been carried out with the support of IT tools.

For each possible plant an optimal power and a specific lay-out have been determined.

Assuming parametric works costs (derived from international databases) the overall economic values for construction and operation of each plant have been estimated.

On the basis of a ranking considering several factors (sedimentation, environmental constraints, power, costs etc.) a general classification has been developed.

The first plant in the ranking presents a power of about 500 MW with a cost of 1.21 Millions of €/installed MW.

4.2.3 Reservoirs in Sardegna

In July 2020 Geotecna Progetti, in joint venture with Fichtner, won a tender announced by Terna and related to the technical-economic feasibility studies of hydroelectric pumping plants to be researched within the 58 existing basins located in Sardinia.

The activities are in progress.

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