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ITS2.5/HS5.5.2/ERE8.3/GM8.6 - The nexus between water resources management and energy, land, society and climate change (co-organized)

Optimizing the size of Hilarion dam with technical, economical and environmental parameters.

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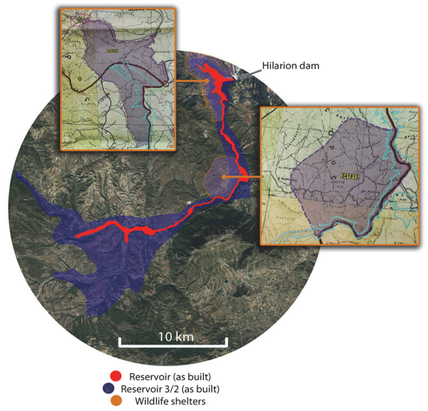
Position:
The dam of Hilarion is located in the prefecture of Kozani, on the river Aliakmonas. The project is being constructed in the area of the Monastery of Agios Ilarionas, at the exit of Medias Aliakmonas, immediately upstream of the Polyfyto reservoir. Aliakmonas dam, built over the past 35 years, has created a unique array of lakes that start from the lakes of Makrochori, Agia Varvara, Asomata and Sfikia in the prefecture of Imathia and continue in the lakes of Polyphytos and then of Hilarion.

Coordinates: 40 ° 5'49 "N 21 ° 48'10" E Budget (as built): 250 000 000 €

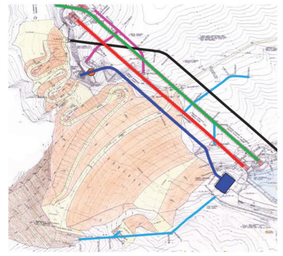


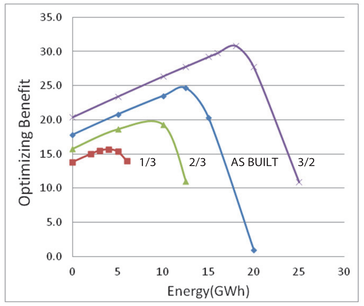

Construction of the dam


Saving the cultural heritage from the artificial lake


Hilarion dam and lake

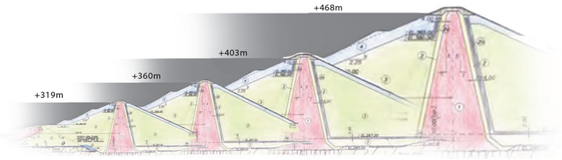

Hydroelectric power station


Technical issues:
The project consists of two diversion tunnels, an evacuated tunnel, an admission tunnel, a drainage tunnel, a tunnel, a production plant, a barrage, a dewatering basin at the level H=130m



Optimizing Benefit-Energy

No dam *1/3 (as built)* *2/3 (as built)* **AS BUILT** *3/2 (as built)*



	Do nothing	*1/3*	*2/3*	*As built*	*1.5*
Financial benefits	✗	○	✓	✓	✓✓
Technical issues	✓	✗	⊗	✓	✗
Natural ecosystem/ wildlife shelters	○	○	⊗	⊗	✗
Livestock	○	○	✓	✓⊗	✓⊗
Aquatic ecosystem /fauna	○	✓	✓	✓	✓
Primary Sector-Agriculture	○	⊗	⊗	⊗	✗
Dimitra's Bridge-Paliourias	○	○	○	○	⊗
Skoumtsas quarry	○	○	○	○	○
Bridge Panagia-Neochori,Kourounes & Loga Elatis	○	○	○	⊗	✗
Panagia Tournikiou(after the dam)	○	○	○	○	⊗
Monastery of Saint Nikanoros	○	○	○	⊗	✗
Hilarion Monastery	○	○	⊗	⊗	✗
Ag. Triada Larious	○	○	○	○	⊗
Ktio	○	○	○	○	⊗
Panagia	○	○	○	○	⊗
Sioutsa	○	○	⊗	⊗	⊗
Keramario Dimitras	○	○	⊗	⊗	✗
Panagia Tournikiou(before the dam)	○	⊗	⊗	⊗	✗
Panagia Bridge	○	⊗	⊗	⊗	✗
Ag. Kiriaki Paliourias	○	⊗	⊗	⊗	✗
Tourism & Cultural Heritage	○	⊗✓	⊗✓	⊗✓	✗✓
Antiquities	○	⊗	⊗✓	✗✓	✗✓

SYMBOLS

Very bad	Bad	Neutral	Good	Very good
✗	⊗	○	✓	✓

Methodology

In an exploration of how the scale of a hydroelectric project relates with its technical, economic and environmental characteristics five different scenarios the project of Hilarion dam in Greece are examined. These scenarios include the existing as-built scenario of Hilarion dam, a scenario in which no dam is built and three different scenarios for with alternative sizes of Hilarion dam. In these three scenarios it is assumed that the dam location remains the same with the as-built scenario and alternative dam heights are examined: 1/3, 2/3 and 3/2 of the height of the original Hilarion dam.

For the investigation of the technical and economic characteristics of each scenario a simulation of the hydroelectric reservoir operation was developed. Utilizing the monthly observed inflows from measurements at Hilarion dam, for hydrological years 1962-63 to 2011-12, we:

- Plotted the monthly time series of simulated water level, reservoir storage, outflows through the turbines, spill losses and generated hydroelectric energy.
- Computed and plotted the power-duration curve.
- Estimated the mean annual benefit from the reservoir operation, assuming firm energy price 0.10€/kWh, secondary energy price 0.05 €/kWh, and penalty cost for energy deficit 1.0€/kWh.
- Estimated the monthly energy target that maximizes the aforementioned profit.
- Repeated calculations assuming alternative values of the maximum pool level (and the dam height) and provide a scatter plot of the useful storage capacity and the maximized profit from hydropower generation.

The minimum and maximum elevations of the existing reservoir of Hilarion dam are +365.0m and +403.0m, respectively, while the outlet elevation of the power station is +293.0m. The storage curve of the reservoir is approximated by the power function:

$$s = 2.392 \times \left(\frac{z}{z_0}\right)^{16.376}$$

where:
s is the water volume (hm^3),
z is the water level of the reservoir (m),
z_0 = +290.0 m is the elevation of the river bed at the dam site.

The monthly energy generation is estimated by:

$$E = 0.00238\, V\ \ h$$

where
E is the energy (GWh),
V is the monthly water release through the turbines (hm^3),
h is the gross head (m).

The monthly capacity of the penstock is 430 hm^3 , which is considered, for simplicity, constant (i.e. independent of the head). Apart from energy production, the reservoir fulfills the maintenance of a constant environmental flow 4.5 m^3/s downstream of the dam, which is released through an independent intake. For the given data, we formulated the monthly simulation model of the reservoir (in spreadsheetFor the different scenarios of dam height the maximum and minimum reservoir sizes where calculated proportionately.

For the investigation of the environmental impacts of the five different scenarios, data from the environmental impact assessments (EIA) reports of the Greek PPC were used [1, 2] , to evaluate quantitatively how recorded impacts from original Hilarion dam are differentiated. In the maps, layouts and calculations from the EIA studies were utilized in the following ways:

- From the layout of rehabilitation works of Hilarion dam the boundaries of local of villages, who would be inundated from a larger reservoir were located.
- From the orientation map, it seems that two wildlife sanctuaries are affected at a certain rate (reduced for smaller versions) in all cases, while in the case of a larger barrier a third retreat (341 386) is also affected.
- From the land coverage map, the extents of natural grassland, broadleaf forests, and agricultural areas affected in each scenario of Hilarion hydroelectric project were estimated.
- From the land use map, the locations of the thirteen points of historical and archaeological value in the general area of the project were pinpointed. Their locations were used to conclude on how many of these locations would be affected in each scenario.
- Additional information on reservoir volume, environmental impacts and impact to cultural heritage were extracted from the chapter of investigation of alternative solutions from the Hilarion dam bv the PPC [1l.

1. Department of hydroelectric development (1994) Environmental Impact Assessment study of HE project of Hilarion in mid Aliakmon (readjustment). Public Power Corporation S.A. - Hellas, Athens

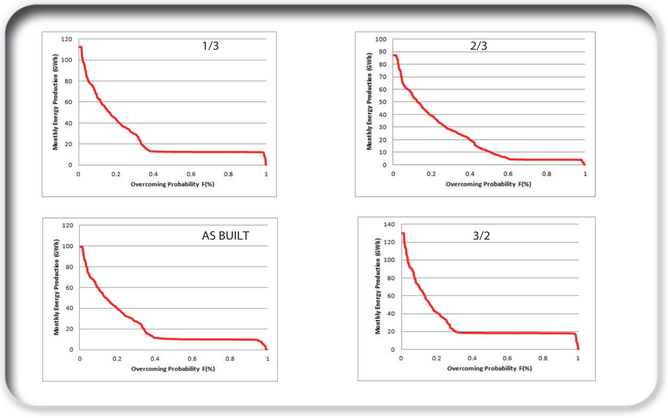
2. Hydroelectric Generation Department (2013) Update of the Environmental Impact Assessment Study numbered 130437/30-06-2003 K.Y.A/E.Π.O of the project "Hilarion HEP", as was modified, in the river Aliakmon in the borders of the regions of Kozai and Grevena. Public Power Corporation S.A. - Hellas, Athens

Alternatives studied by PPC

Alternative solutions, which were studied by the project owner (PPC), are presented:
I. Construction of a hydroelectric project at the position Palionon with maximum reservoir operating level at 403m and a hydroelectric station at the position Panagia.
II. Construction of a hydroelectric project at the position Palionon with maximum reservoir operating level at 403m, a hydroelectric station at the foot barrier of the dam and a hydroelectric project at Hilarion with maximum reservoir operating level at 305m.
III. Construction of a hydroelectric project at the position Elatis with maximum reservoir operating level at 403m, intake tunnel and a hydroelectric station at the position Panagia.
IV. Construction of a hydroelectric project at Elatis with maximum operating level at 403m and a hydroelectric project with maximum operating level at 350m.

The first and the second alternative solutions were rejected due to the following reasons:
• The dam was placed in a too narrow gorge with steep slopes.
• The quality of the rock mass was good, the permeability was small but extensive surfaces in slopes required strengthening with concrete buttress walls.
• The position of Panagia is known to be very seismic and has frequent earthquakes.
• Access to the Aianis-Chromios road for the construction of diverging tunnels was foreseen. The length of the road is approximately 4 km, of which 2 are inside the gorge. To accomplish that significant construction-related difficulties would be faced, which will lead to longer construction time, increased expenses and heavier impact to the environment.

The third and the fourth alternative solutions were rejected due to the following reasons:
• The quality of the rock mass was good, the permeability was small but, similarly to the first and second alternatives, extended surfaces in slopes required strengthening with concrete buttress walls.
• Severe waterproofing problem had to be dealt with, resulting in longer construction time and increased rick of landslides.



Energy-Time 1962-2012
The Energy-Time 1962-2012 chart shows the change of energy in relation to an indicative duration of operation of the project measured in months (from 1962 to 2012).So,it allows estimating :
• the energy production above target (surplus or secondary energy)
• the energy deficit with respect to target

Energy(GWh)	Cost (€/kWh)
secondary	0.05
target	0.10
deficit	1.0

The evaluation of a hydroelectric reservoir is made on the basis of simulated energy, E, which allows estimating:
• the probability of fulfilling the target energy (reliability), empirically computed as the percentage of time steps for which E ≥ E*
• the energy production above target E* (surplus or secondary energy)
• the energy deficit with respect to target E*

Conclusions

1/3
Target 4 GWh
(low target)
secondary (too much)- losing money -
NON-profitable solution

2/3
Target 10 GWh
secondary 40 %
highly economic value, not important environmental impacts
NON-profitable solution

As built
Target 12.5 GWh
secondary 38%
highly economic value, not important environmental impacts

3/2
Target 18 GWh 67%
secondary 30%
highly economic value, a lot of environmental impacts

Acknowledgments:
1. Special thanks to Dr. Andreas Efstratiadis for his guidance and support in this research
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