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Hydropower potential assessment made easy via the unit geo-hydro-energy index

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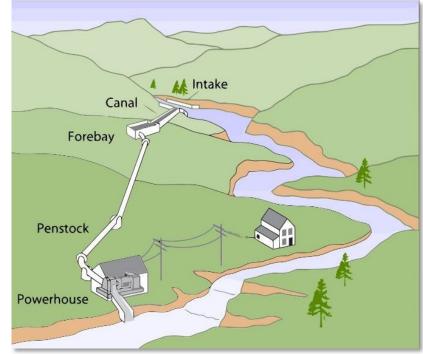
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Presentation available online: https://www.itia.ntua.gr/2102/



Run-of-the-river hydroelectric systems

- In the context of **siting** and **lay-out** of RoRs, key design objectives are (Efstratiadis et al., 2021a):
 - maximization of catchment area upstream of the intake, in order to maximize the water potential;
 - maximization the elevation difference between the intake and the power house, in order to maximize the head;
 - minimization of the diversion length, in order to minimize the hydraulic losses and the cost of conveyance works;
- The fulfilment of the above objective is highly conflicting, given that:



Typical layout of run-of-river systems (Algburi, 2018)

- As the catchment area increases, the relief becomes more mild;
- As the heads increases, the diversion length is also increasing.

Motivation: Development of spatial analysis tool for easy detection of prosperous sites for run–off–river hydropower systems

Schematic representation and definitions

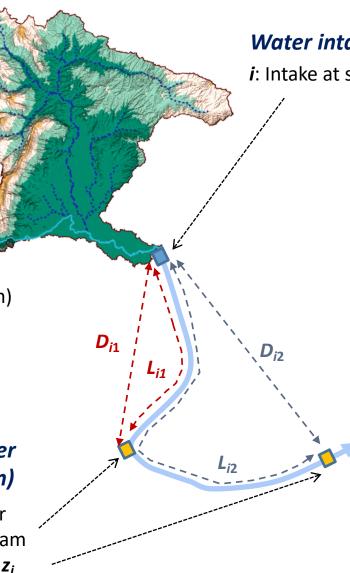
Catchment

Upstream catchment characteristics at site I_i(x_i, y_i, z_i)

A_i: Basin area (m²) *Z_i*: Mean elevation (m) *P_i*: Mean annual precipitation (m) *R_i*: Mean annual runoff (m)

Alternative sites for power house (energy production)

j(i): Alternative sites (x_j, y_j) for turbine location downstream of intake I_i, with elevation z_j



Water intake (flow diversion)

i: Intake at site (x_i, y_i) with elevation z_i

Geometrical properties

D_{ij}: Euclidean distance from the intake *i* to the alternative sites *j* for energy production (m)

 L_{ij} : Diversion distance along the river segment from the intake *i* to the alternative sites *j* for energy production (m) – by definition, $L_{ij} \ge D_{ij}$

h_{ij}: Altitude difference
between the intake *i* and
the alternative sites *j* for
energy production (m), also
referred to as gross head

From actual to unit potential energy production

Actual energy production from a turbine station located at site *j*(*i*), downstream of an intake sit *i*, and over a time interval [0, *τ*]:

$$E_{ij} = \gamma \int_{0}^{\tau} \eta \left(q_{ij}(t) \right) q_{ij}(t) h_n \left(q_{ij}(t) \right) \Delta \tau$$

where γ is the specific weight of water (9.81 KN/m³), $q_{ij}(t)$ is the discharge that is diverted to the turbines (part of total inflow arriving at the intake), $\eta(q)$ is the total efficiency of the system, which is function of discharge and also depends on the turbine type, and h_n is the net head, i.e. the gross head, after subtracting hydraulic losses.

• **Potential energy production**, on mean annual basis (hydraulic and energy losses are omitted, and all catchment's runoff is diverted to the turbines):

$$PE_{ij} = \gamma R_i A_i h_{ij}$$

• Unit potential energy production, by considering a mean annual runoff equal to 1 m (1000 mm):

$$UPE_{ij} = \gamma A_i h_{ij}$$

The value of UPE_{ij} across a hydrographic network, where all intakes I_i are located at specific distances $L_{ij} = \Delta l$, is called **unit geo-hydro-energy index** (UGHE). Its purpose is to evaluate a hydroelectric development site through easy geomorphological information.

Outline of methodology

Preparation of spatial data

- Digital Elevation Model (DEM)
- Stream network (vector)
- Maps of distributed rainfall/runoff data

Discretization of stream network to determine intake and power station sites

- Distance step for intake allocation
- Diversion distance for power station allocation

Extraction of geomorphological characteristics

- Site properties (coordinates, elevation)
- Head difference
- Euclidean distance

Upstream catchment area

 Delineation of catchment boundaries upstream of each site of interest

Extraction of geomorphological and hydrological characteristics:

- Area
- Mean elevation
- Mean annual precipitation
- Mean annual discharge

Extraction of geo-hydro-energy indices

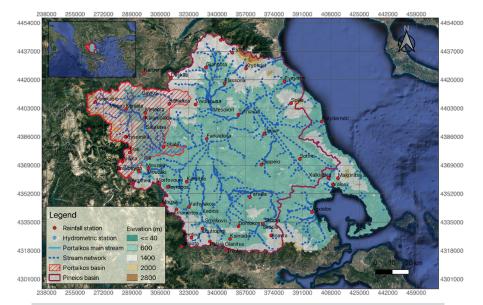
Software implementation

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			Code snippets Python and pyQGIS	

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Proof of concept: Seeking for potential sites for development of RoRs across Peneios river basin

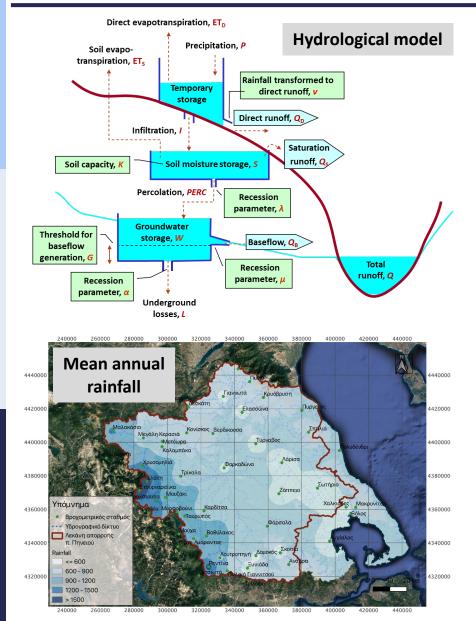
- Two levels of detail:
 - Hydrological-morphological analysis over the entire basin (11 064 km²), to detect potential sites of interest;
 - Detailed analysis and application of the proposed methodology to the upper river course (1 809 km²).
- Hydrological analysis:
 - Formulation of four hydrological response units (HRUs) over the total area (Savvidou et al., 2018);

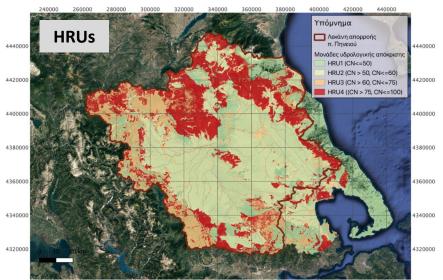


Peneios river basin, highlighting the upstream area of interest (DEM, river network, rainfall stations)

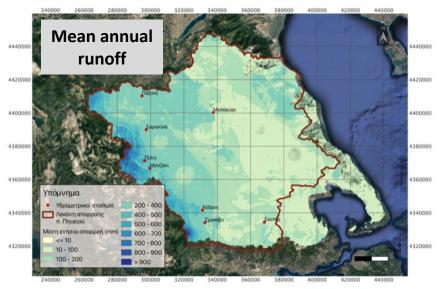
- Fitting of conceptual hydrological model at ten sub-basins upstream of hydrometric stations, by using monthly data and varying parameters per HRU and per sub-basin;
- Assignment of representative parameter values across the four HRUs (expected value of individually optimized values of the sub-basins);
- Model application over the entire river basin of Peneios, resulting to a map of distributed runoff data (Efstratiadis et al., 2021b).

Hydrological analysis



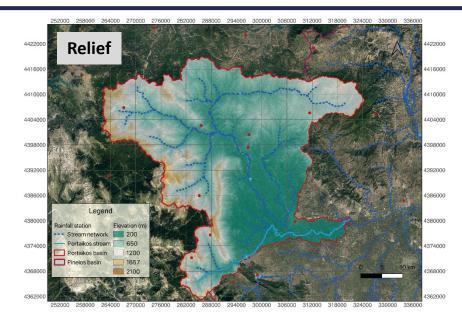


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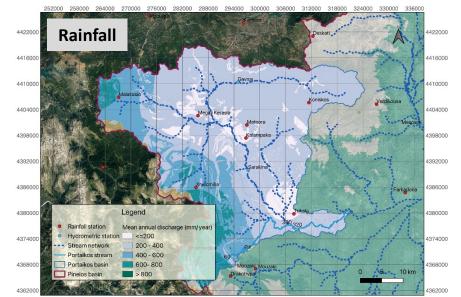


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Area of interest: Upper Peneios basin



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Runoff

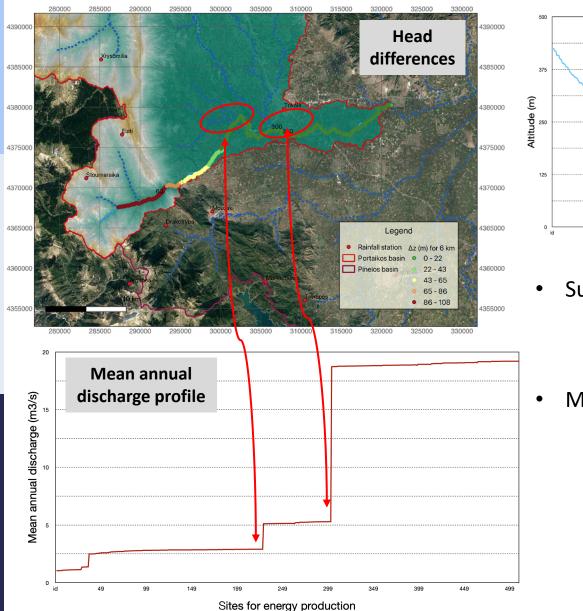


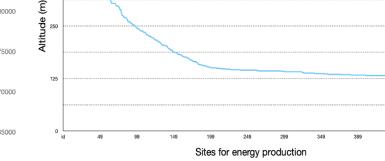
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Geomorpholigical and hydrological analysis





- Summary hydrological data
 - Mean rainfall: 993 mm
 - Mean runoff: 169 mm
- Methodological assumptions
 - Distance step for intake allocation: 100 m (510 points, total length 50.1 km)

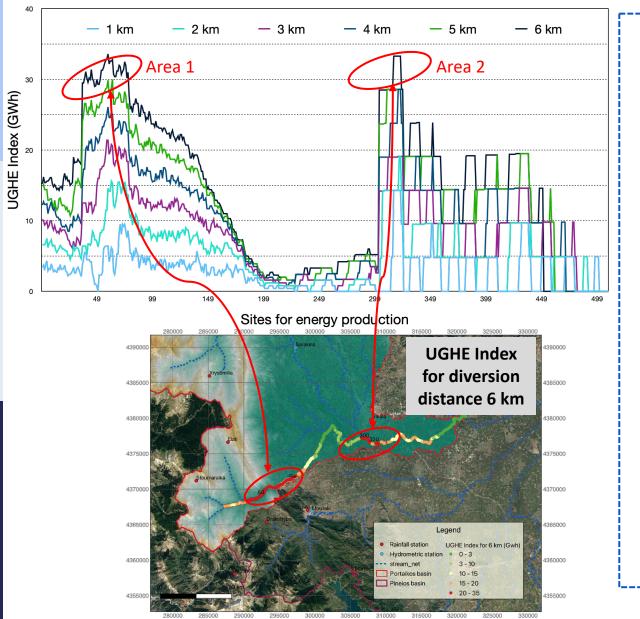
Elevation profile

along the river

 Diversion distance for power station allocation: 1 – 6 km (investigation of six cases)

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UGHE index for diversion distances from 1 to 6 km



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Two promising areas for power house siting, where UGHE is maximized

Area 1

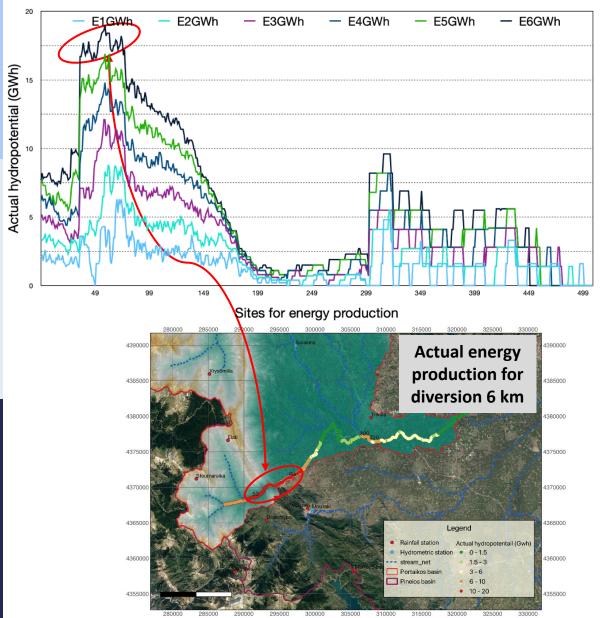
Steep relief → Maximization of head

- Head: 85 100 m
- Upstream contributing areas: 120 – 125 km²

Area 2

- Stream confluence → Maximization of upstream catchment area
- Negligible head: ~5 m
- Upstream contributing areas: ~1750 km²

Potential energy production



Mean annual runoff

- Area 1: 668 mm
- Area 2: 339 mm

Among the two promising areas, the potential energy is maximized where the product of upstream area and actual runoff is maximized.

Optimal siting

- Head: 94 m
- Mean inflow: 84.3 hm³
- Hydropower potential: 18.4 GWh

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Conclusions & future research

- Parsimonious technique in exploring suitable development sites for run-off-river hydropower systems, by considering only the geometrical properties of the stream network (distance & altitude difference) and abstract data about the runoff regime;
- Coupling of multiple computational and programming tools, **open-source code**;
- Development of methodology with augmented capabilities in data preprocessing, **geo-spatial analysis**.
- Investigation of **model sensitivity** against alternative discretizations of the stream network and against different diversion steps;
- Test of methodology across multiple river networks with varying characteristics (geomorphological, hydrological);
- Coupling with hydrological and energy conversion models to enable estimation of actual hydropower production;
- Integration of methods in a **fully automated procedure** to assess the actual hydropower potential and provide decision support for RoRs siting and design.

References

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