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HS5.3.3: Innovation in hydropower operations and planning to integrate renewable energy sources and optimize the Water-Energy Nexus

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

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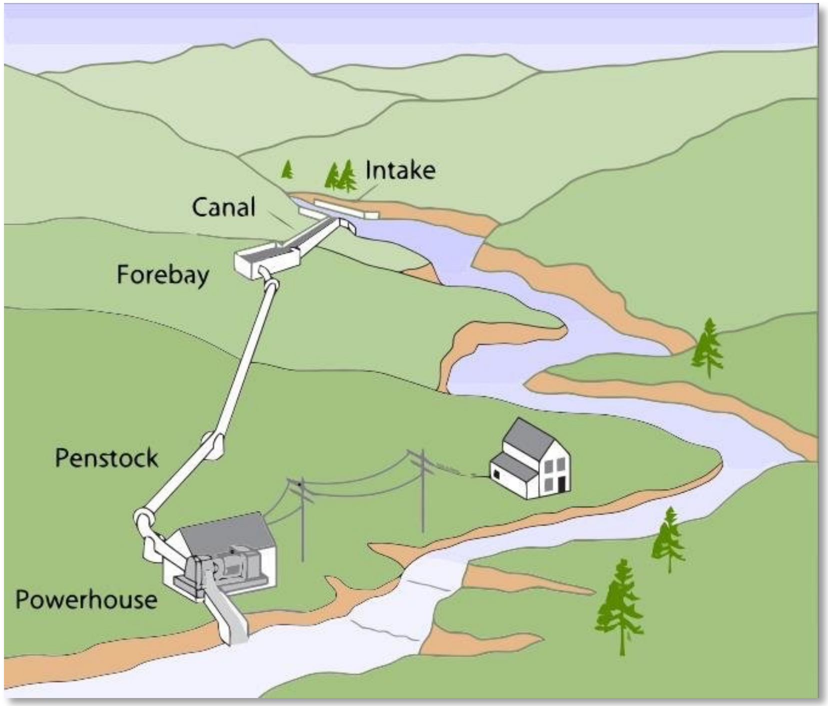
Run-of-the-river hydroelectric systems

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

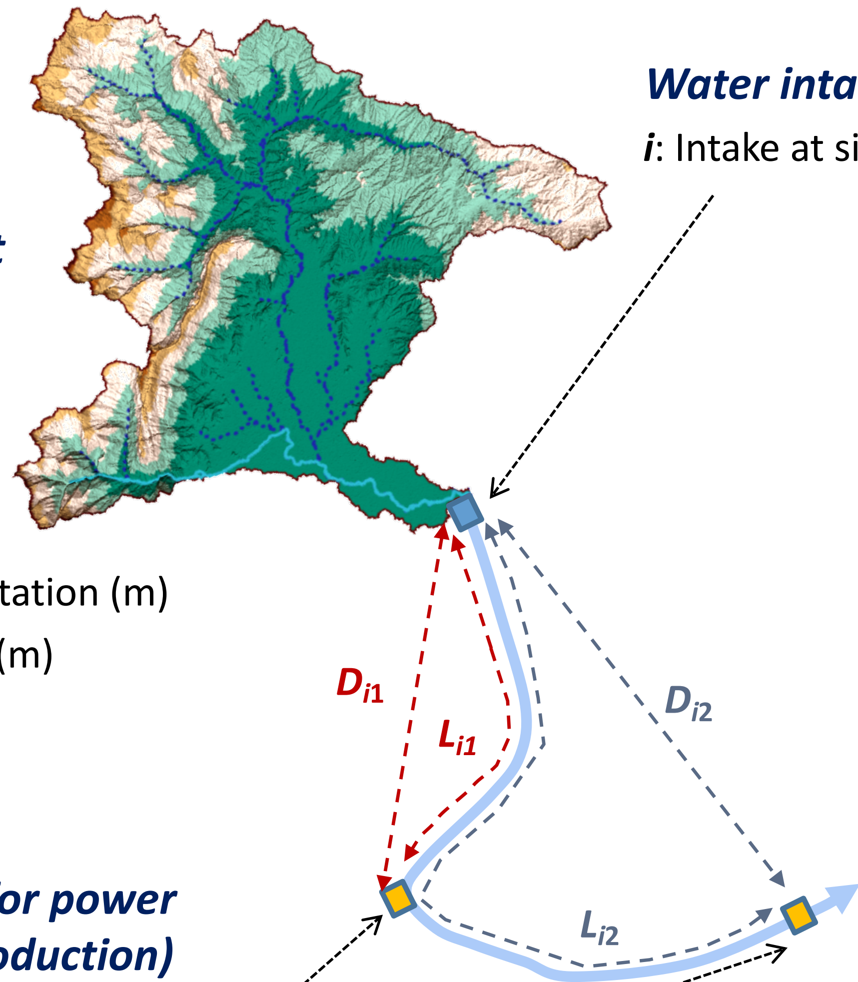


Typical layout of run-of-river systems (Algburi, 2018)

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

Schematic representation and definitions

Catchment



Water intake (flow diversion)

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

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

A_i: Basin area (m^2)

Z_i: Mean elevation (m)

P_i: Mean annual precipitation (m)

R_i: Mean annual runoff (m)

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, $L_{ij} \geq D_{ij}$

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

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

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 $[0, \tau]$:

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

where γ is the specific weight of water (9.81 KN/m^3), $q_{ij}(t)$ 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

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Discretization of stream network to determine intake and power station sites
- Distance step for intake allocation
- Diversion distance for power station allocation

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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

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Extraction of geomorphological and hydrological characteristics:
- Area
- Mean elevation
- Mean annual precipitation
- Mean annual discharge

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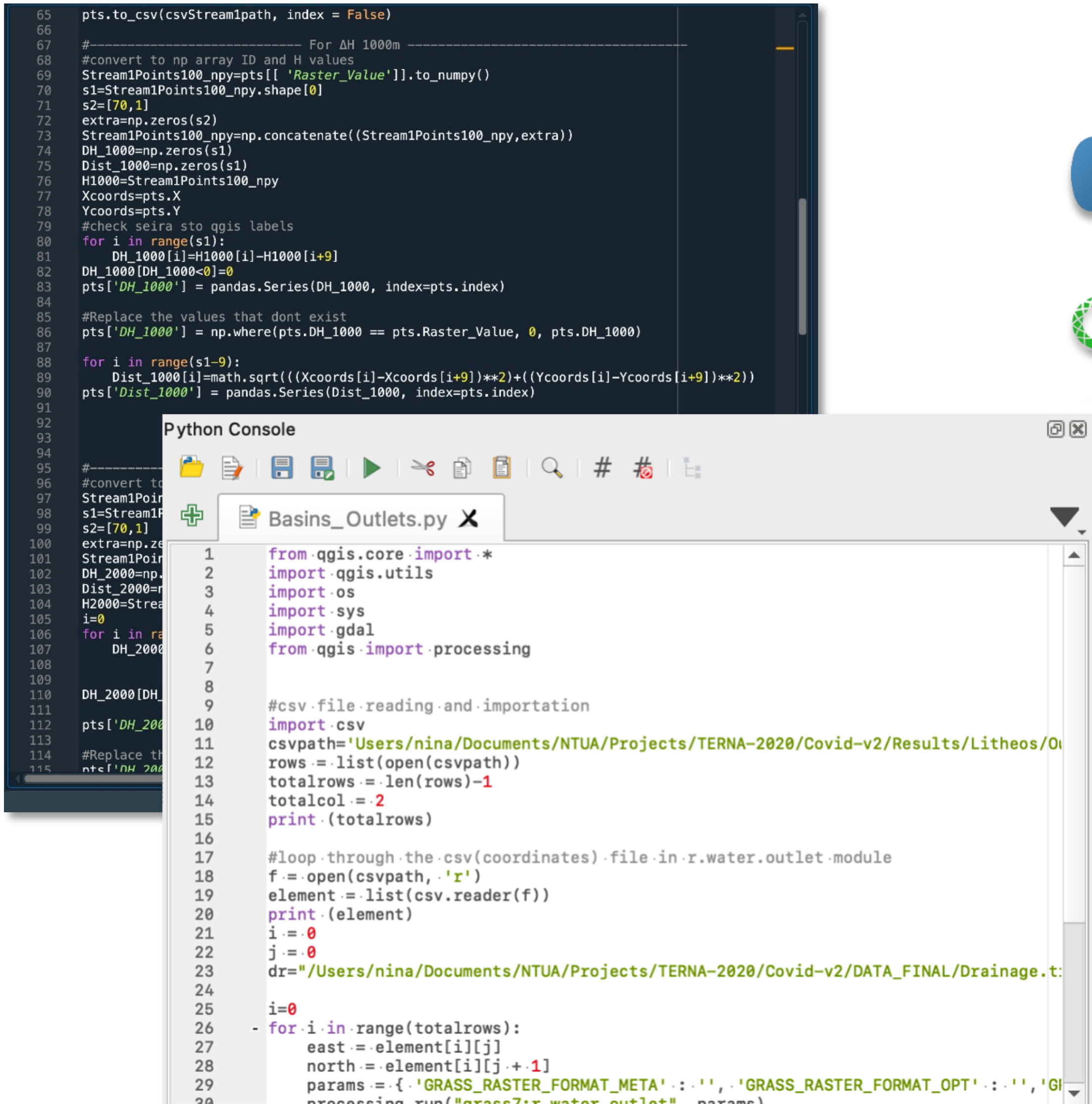
Extraction of geo-hydro-energy indices

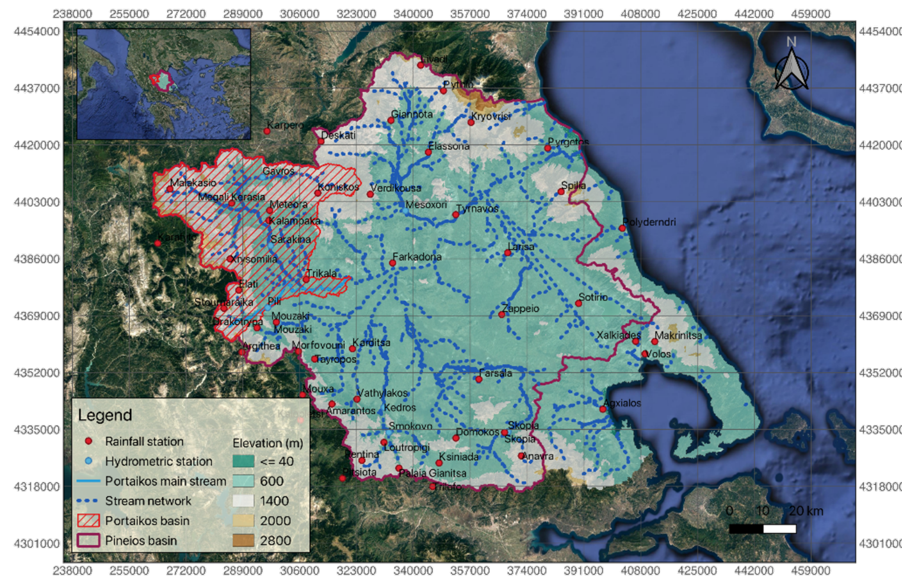
Software implementation



Code snippets Python and pyQGIS

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

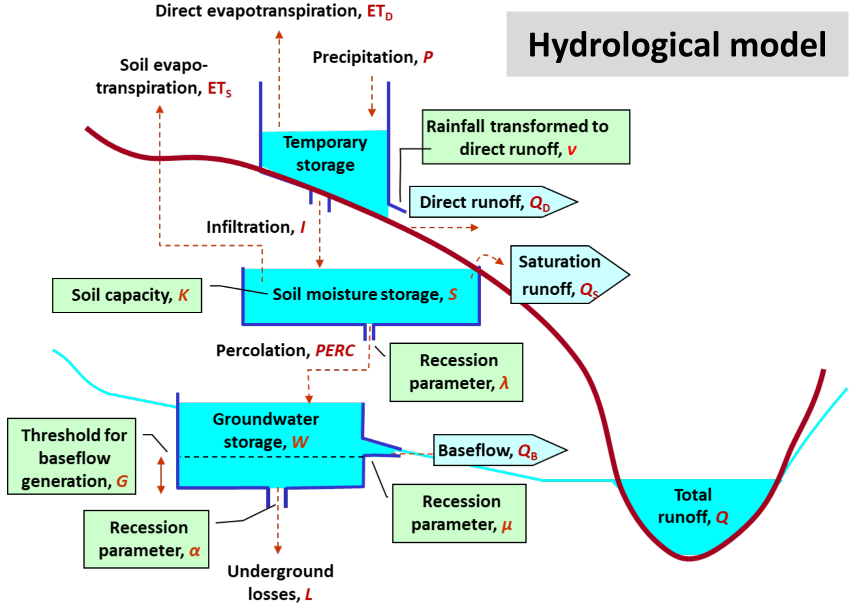
- Two levels of detail:
  - Hydrological-morphological analysis over the entire basin (11 064 km^2), to detect potential sites of interest;
  - Detailed analysis and application of the proposed methodology to the upper river course (1 809 km^2).
- Hydrological analysis:
  - Formulation of four hydrological response units (HRUs) over the total area (Savvidou et al., 2018);

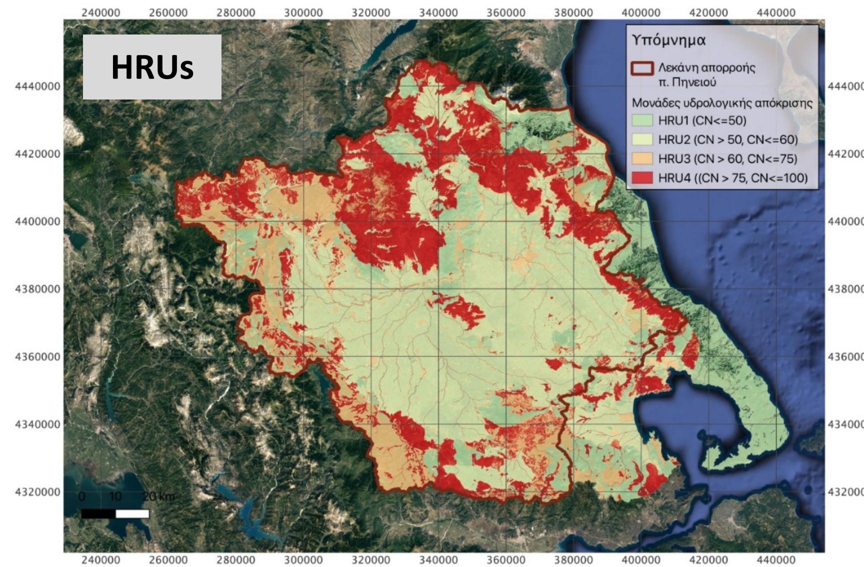


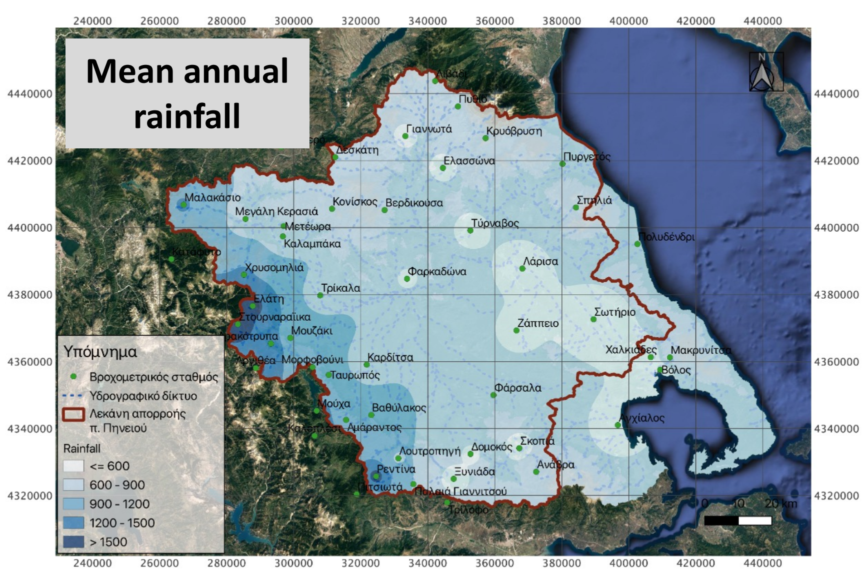
Peneios river basin, highlighting the upstream area of interest (DEM, river network, rainfall stations)

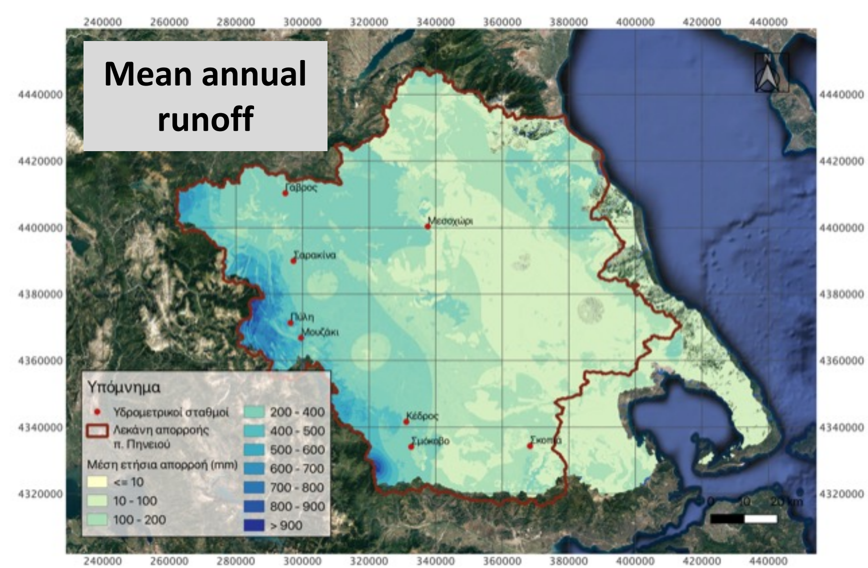
  - Fitting of conceptual hydrological model at ten sub-basins upstream of hydrometric stations, by using monthly data and varying parameters per HRU and per sub-basin;
  - Assignment of representative parameter values across the four HRUs (expected value of individually optimized values of the sub-basins);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

Hydrological analysis

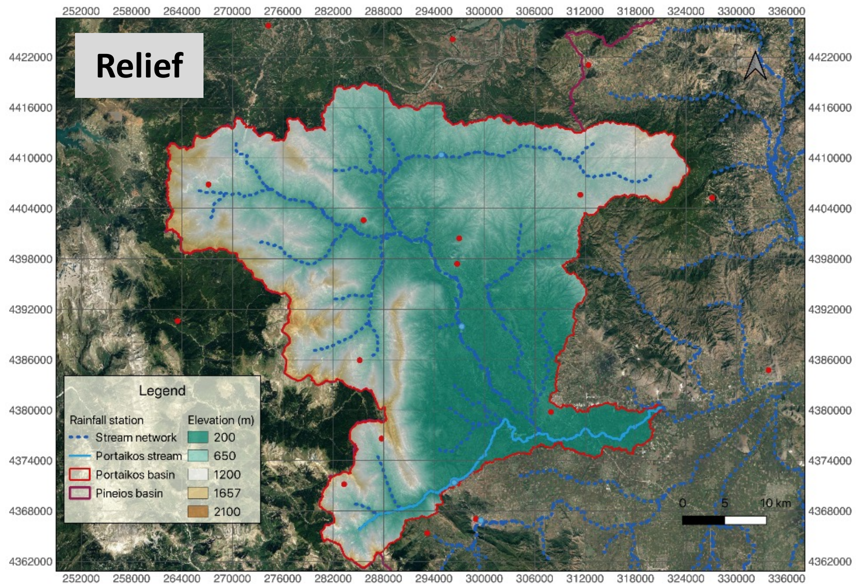


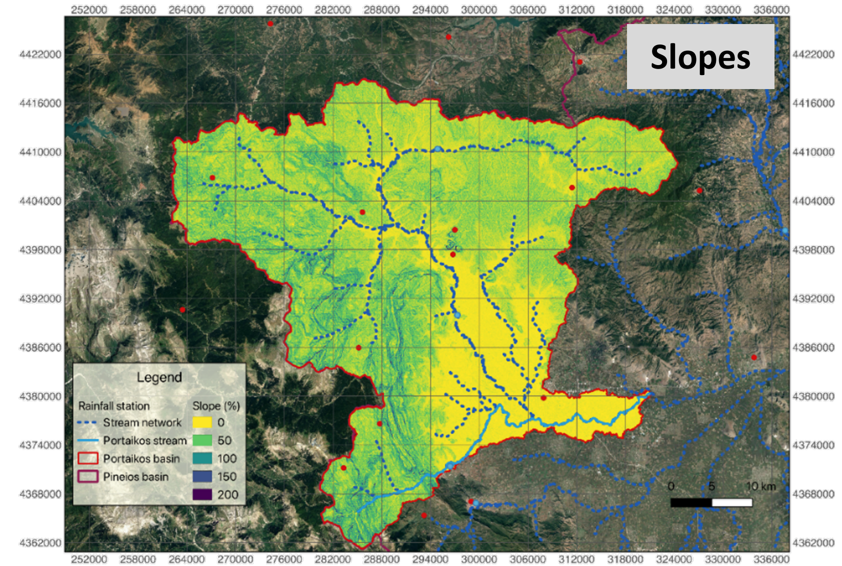


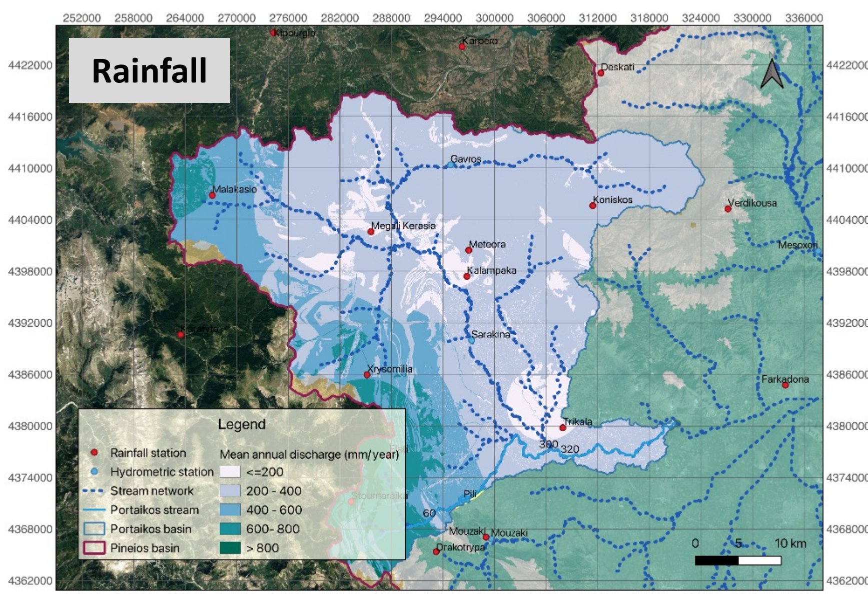


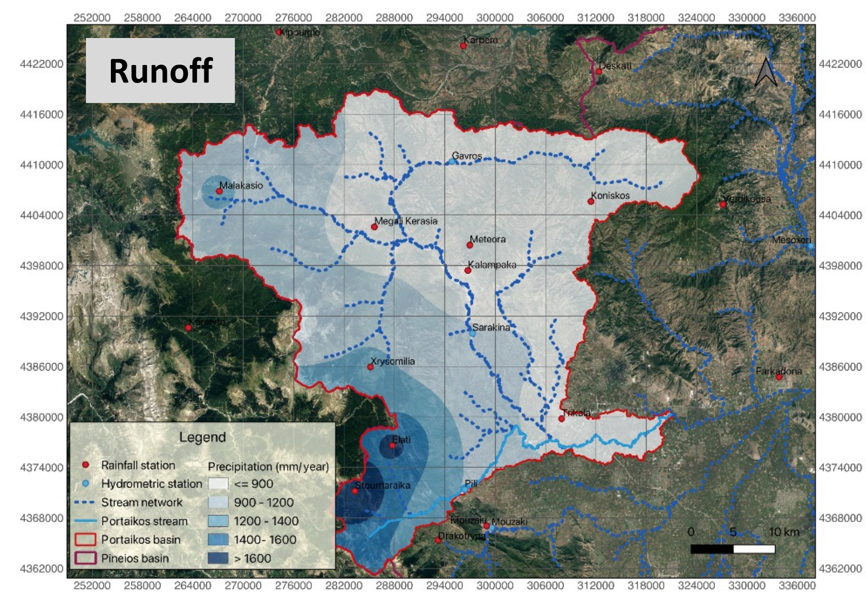


Area of interest: Upper Peneios basin

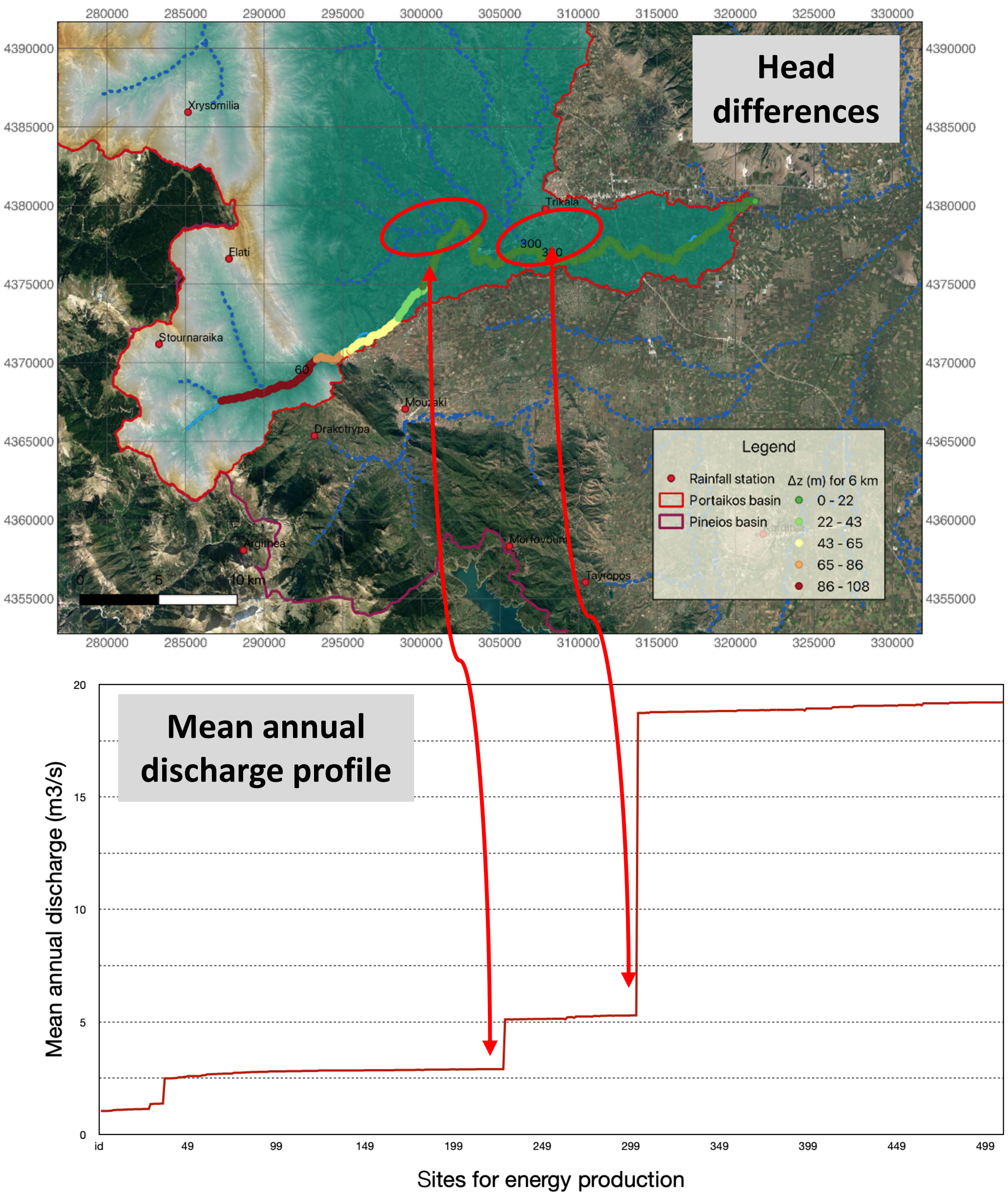


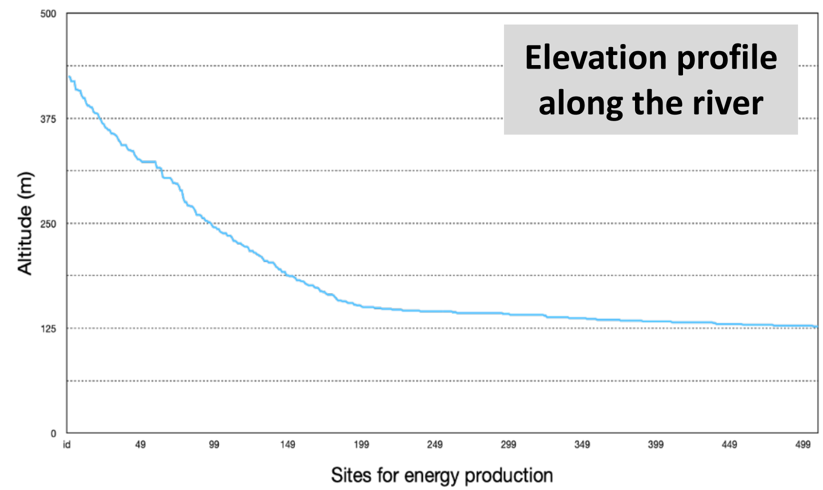






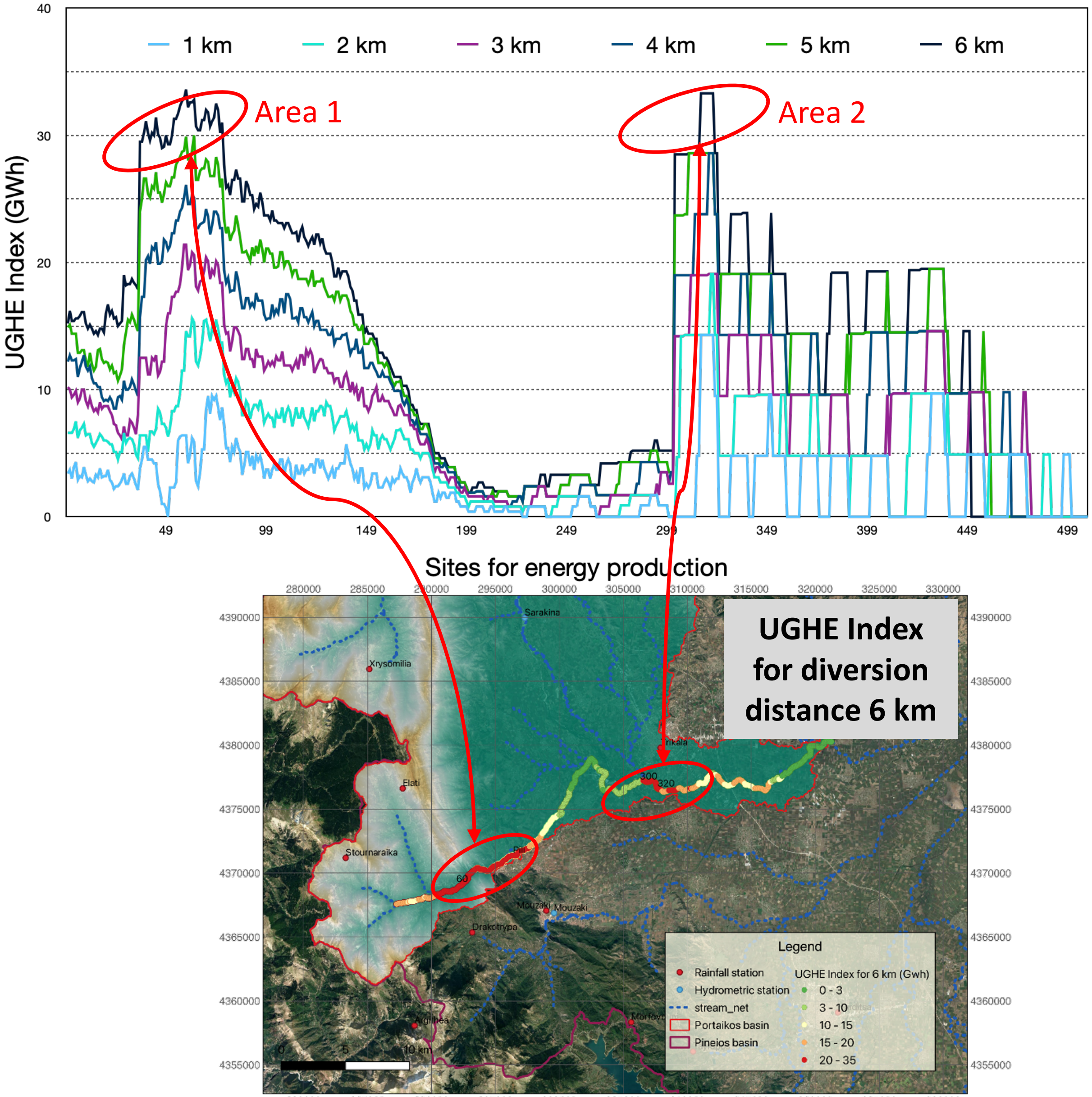
Geomorpholigical and hydrological analysis





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

UGHE index for diversion distances from 1 to 6 km



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

Area 1

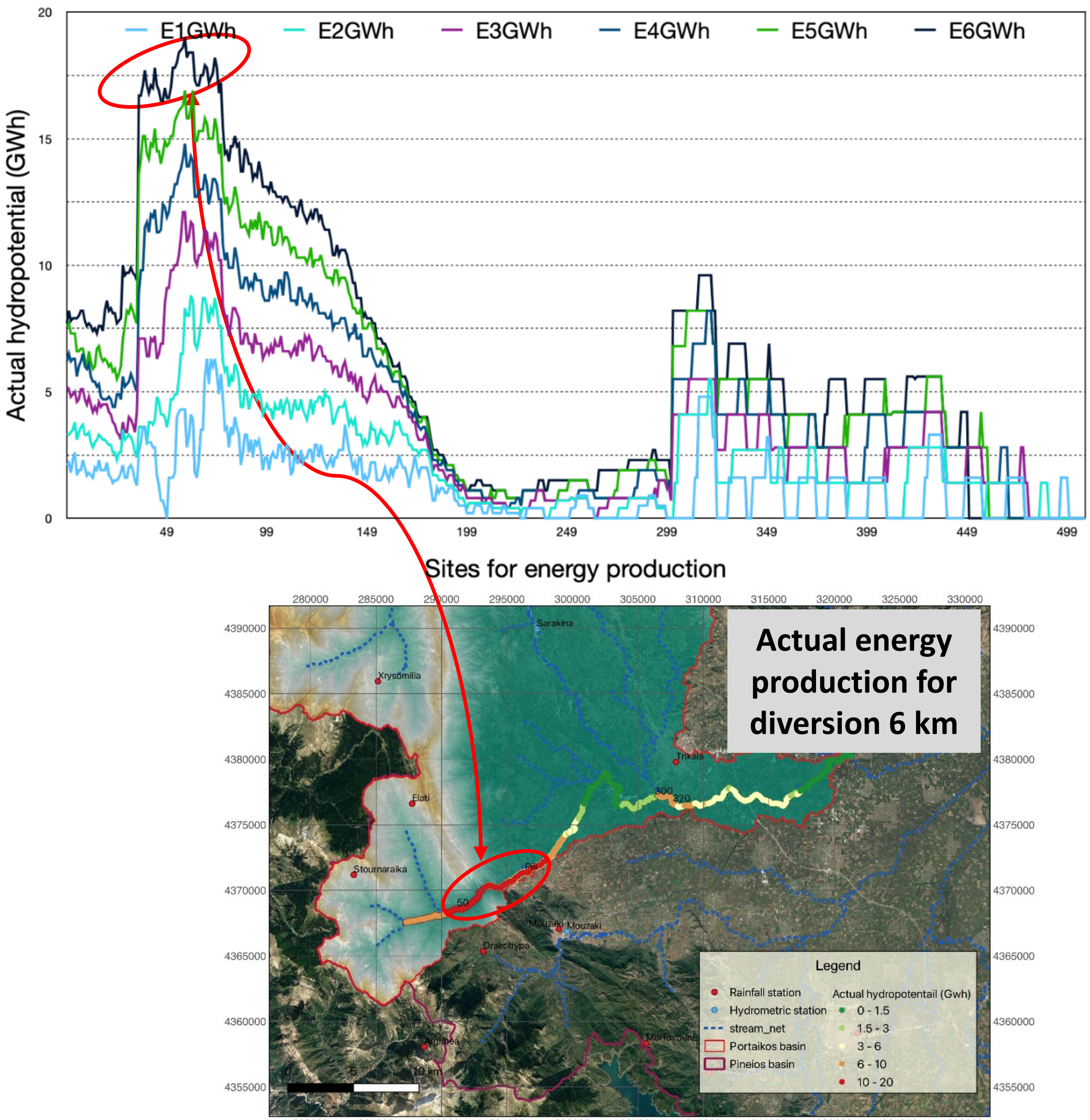
- **Steep relief → Maximization of head**
- Head: 85 – 100 m
- Upstream contributing areas: 120 – 125 km^2

Area 2

- **Stream confluence → Maximization of upstream catchment area**
- Negligible head: ~5 m
- Upstream contributing areas: ~1750 km^2

Risva et al., Hydropower potential assessment made easy via the unit geo-hydro-energy index

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 hm^3
- Hydropower potential: 18.4 GWh

Risva et al., Hydropower potential assessment made easy via the unit geo-hydro-energy index

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 pre-processing, **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.

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