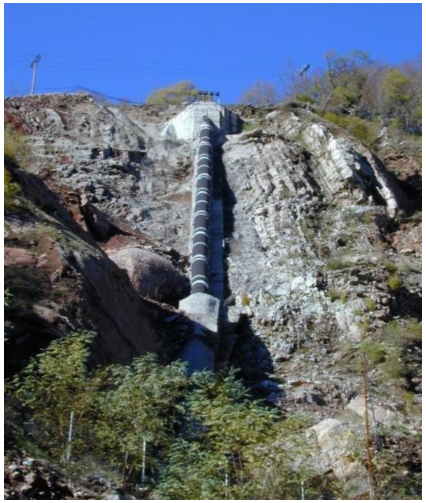
Renewable Energy & Hydroelectric Works

8th semester, School of Civil Engineering

Small Hydroelectric Projects





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Definition and classification of SHPPs

- To define a Hydropower Project (HPP) as **small**, the installed power capacity of turbines must be under a certain limit, that is defined by national legislation.
- This limit varies considerably globally, but the most common values are from 10 to 30 MW. For example, in Canada, China and New Zealand the limit is **50 MW**, in the United States and several South America countries it is **30 MW** and in Thailand and Greece it is **15 MW**.
- SHPPs can be further subdivided into **mini** (0.1-1 MW), **micro** (5-100 kW) and **pico** (<5 kW).

Storage facility

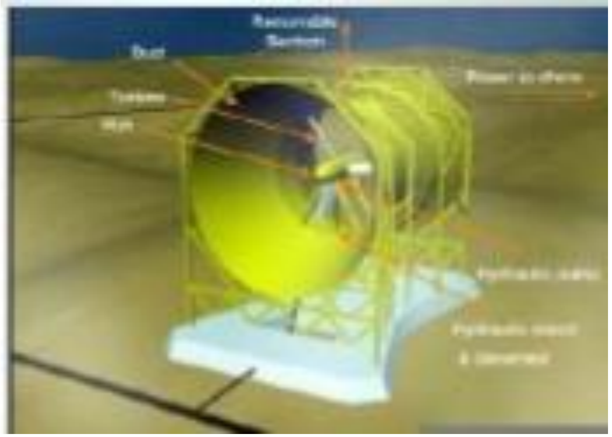
Settled downstream of large dams to take advantage of the environmental flow, which is released from an independent intake (e.g. bottom outlet)

Run-off-river

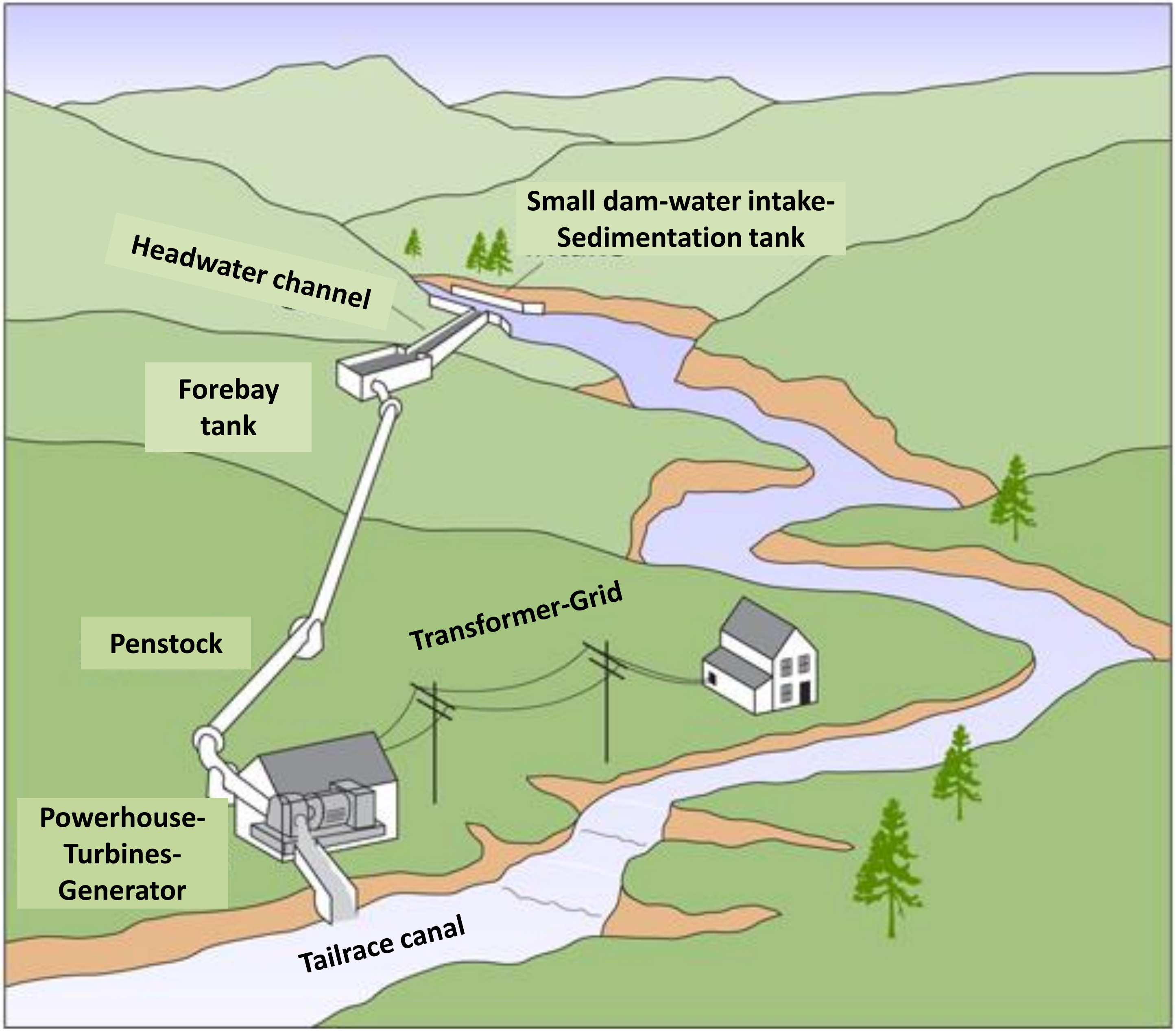
Utilizes the streamflow as it arrives, without the ability to store water. This is the most common SHPP type.

In-stream

Utilizes the streamflow velocity to produce electric energy. Very few projects of this type exist in rivers.

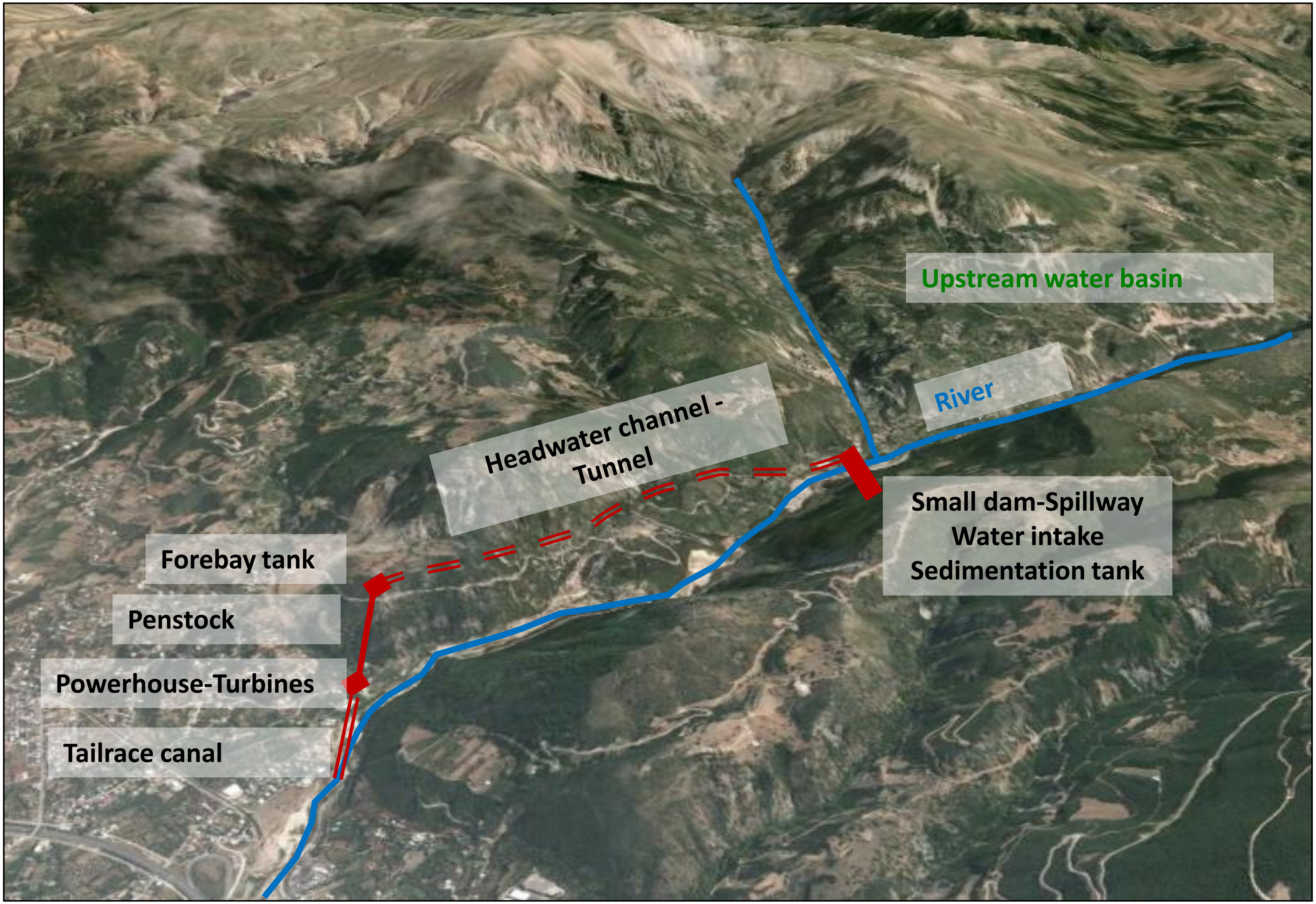


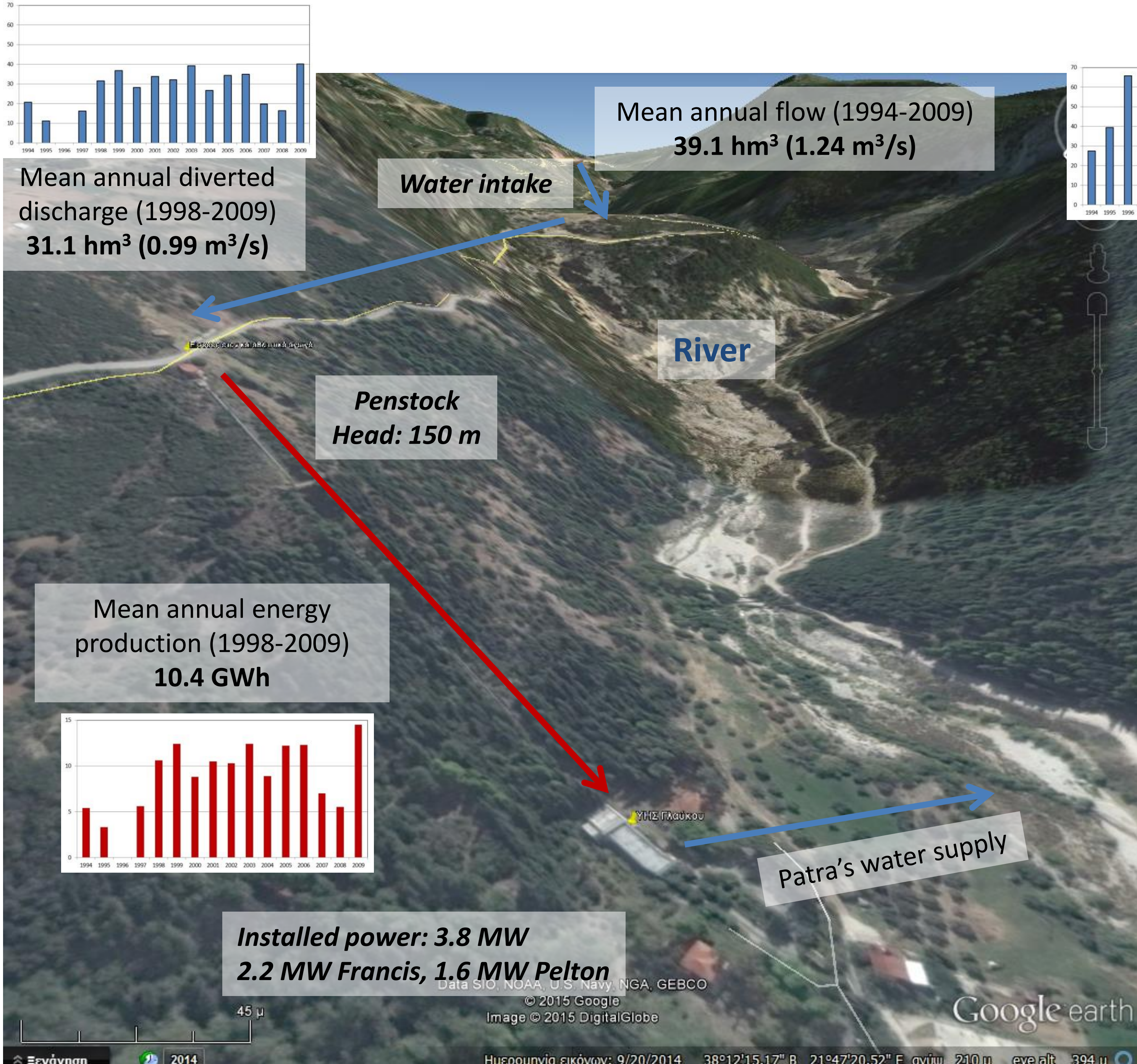
Typical layout of run-off-river plants

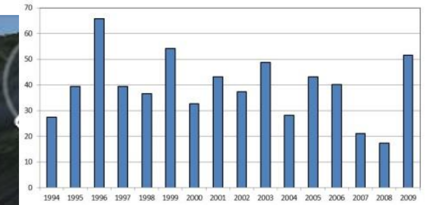


Characteristic examples: Glafkos (Patra)

The project was constructed in 1927 and it is one of the first hydroelectric works in Greece







Mean annual discharge captured by turbines (1998-2009)
82%

Mean capacity factor (1998-2009)
0.31

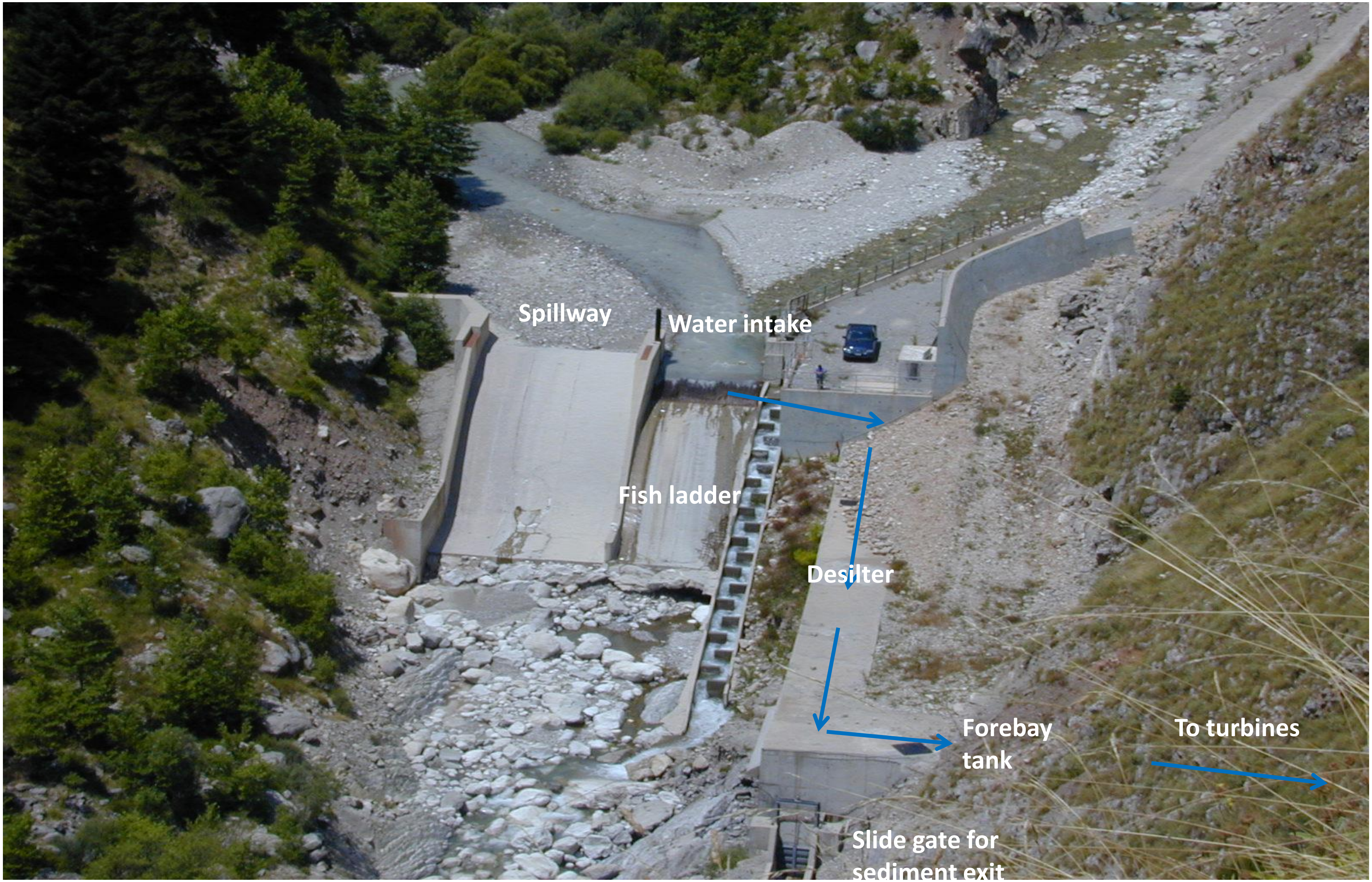
Dam water intake

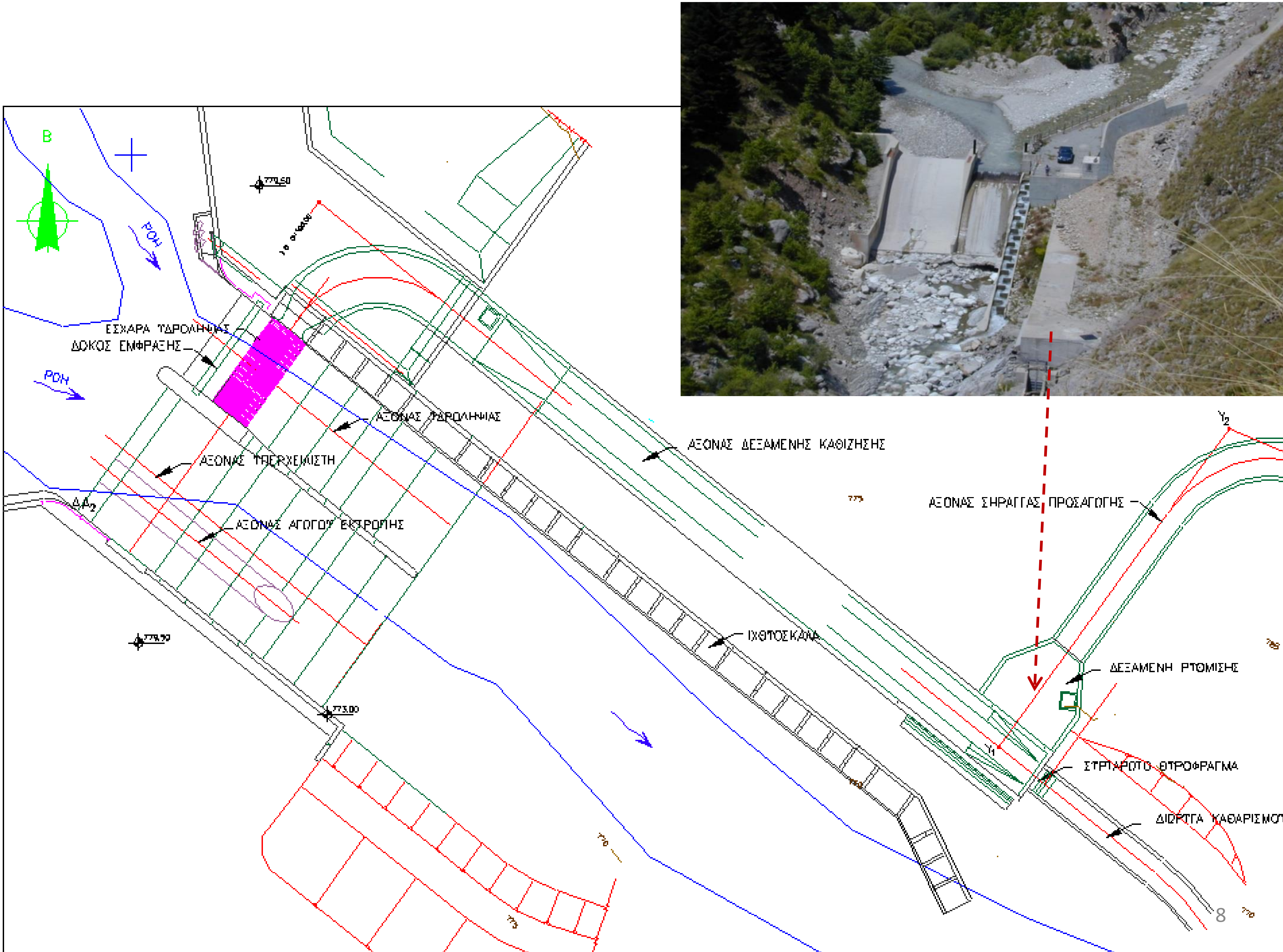
Sand trap – desilter - sedimentation tank

Penstock

Turbines

Characteristic examples: Theodoriana (Epirus, Tzoumerka)

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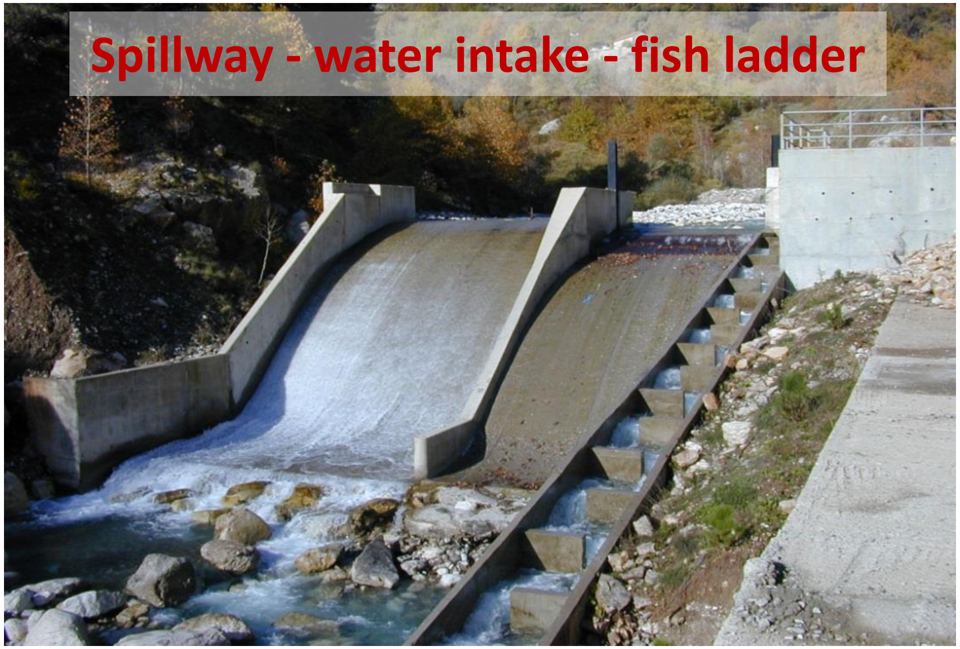
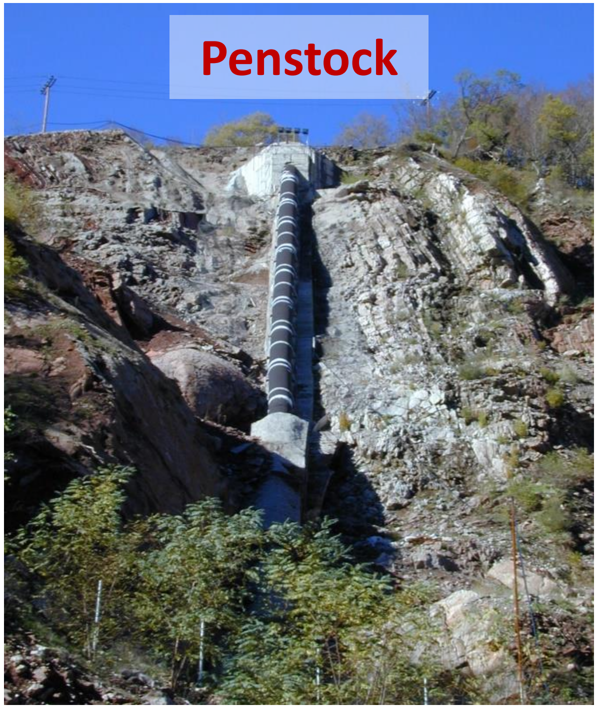

Spillway - water intake - fish ladder


Water intake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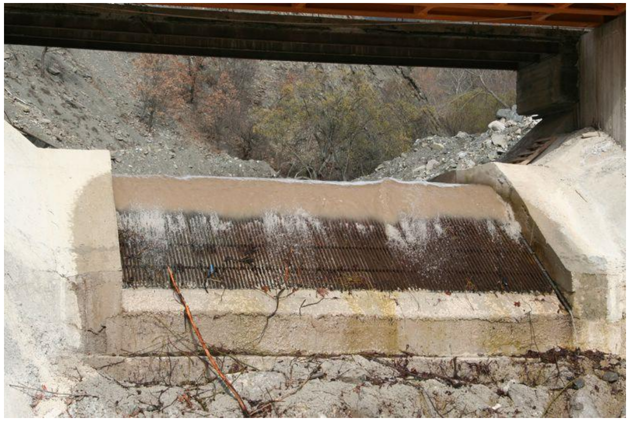
Powerhouse

Characteristic examples: Thermorema (Sterea Hellas)

Desilter (sand traps)

Trash rack of water intake



Headwater channel - sand traps

Forebay tank

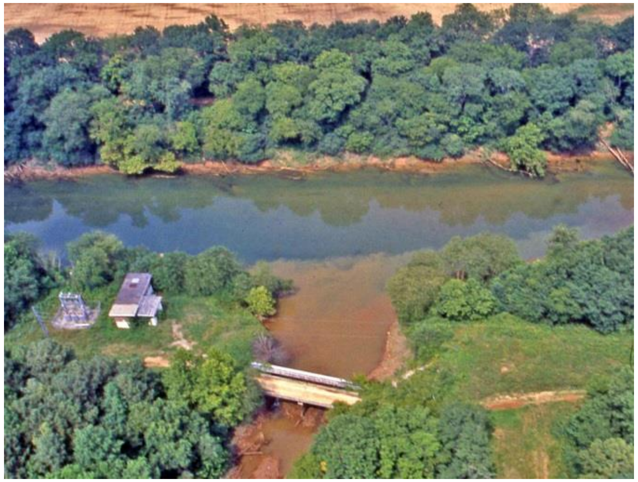
Penstock

Photos: ΔΕΛΤΑ Project

Sediment management: Definitions

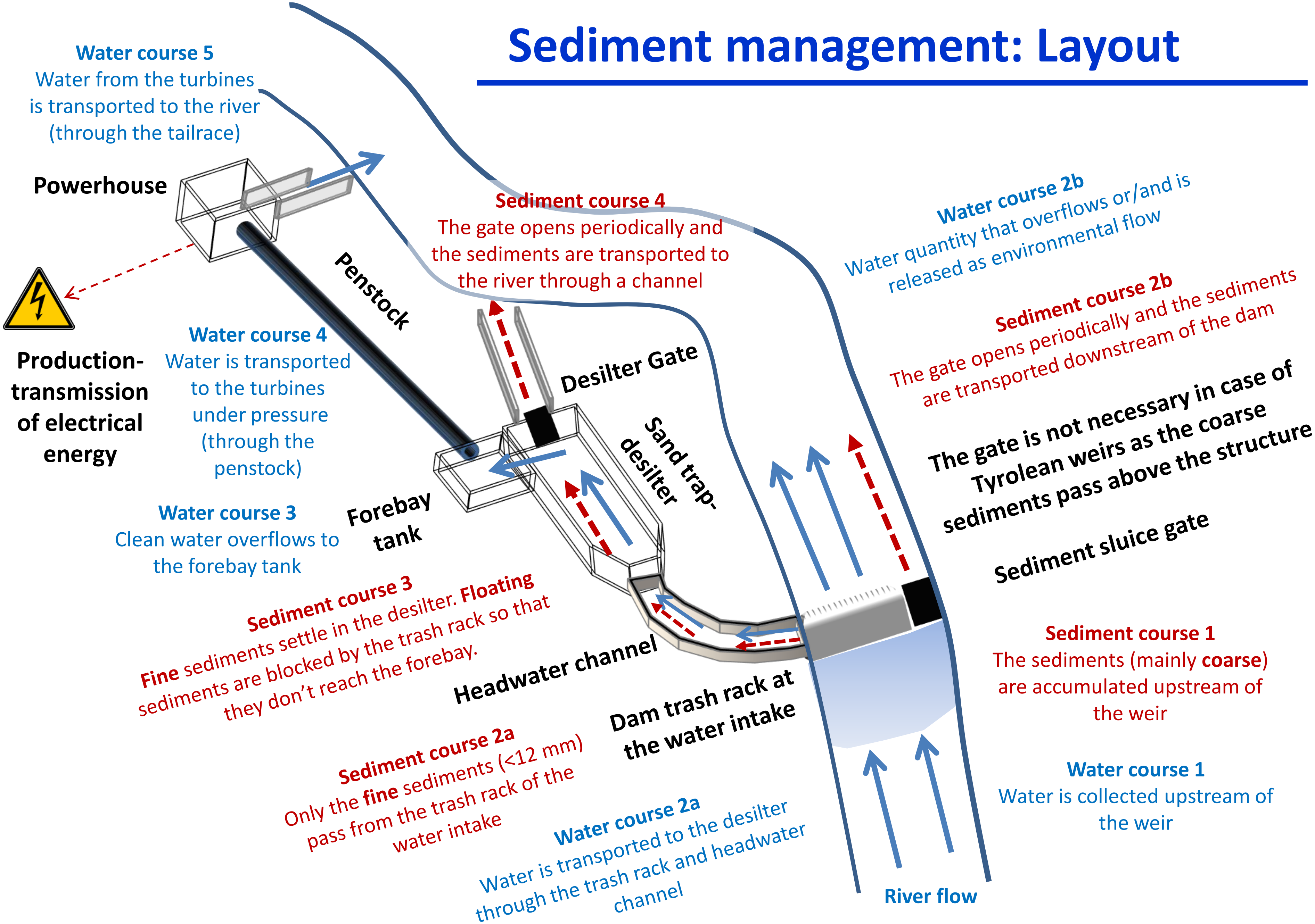
Bed load: Mainly includes stony material, such as gravel and cobbles. These are transported on or near the river bed (continuously or intermittently) with velocities lower than the flow. Main movement mechanisms are sliding, rolling or hopping.

Suspended load: Mainly includes clay, silt (diameter < 6mm) and sand. These are transported in the water body with the same velocity as the river flow.



Floating sediments: Leaves, branches, debris, garbage etc. that float in the water.

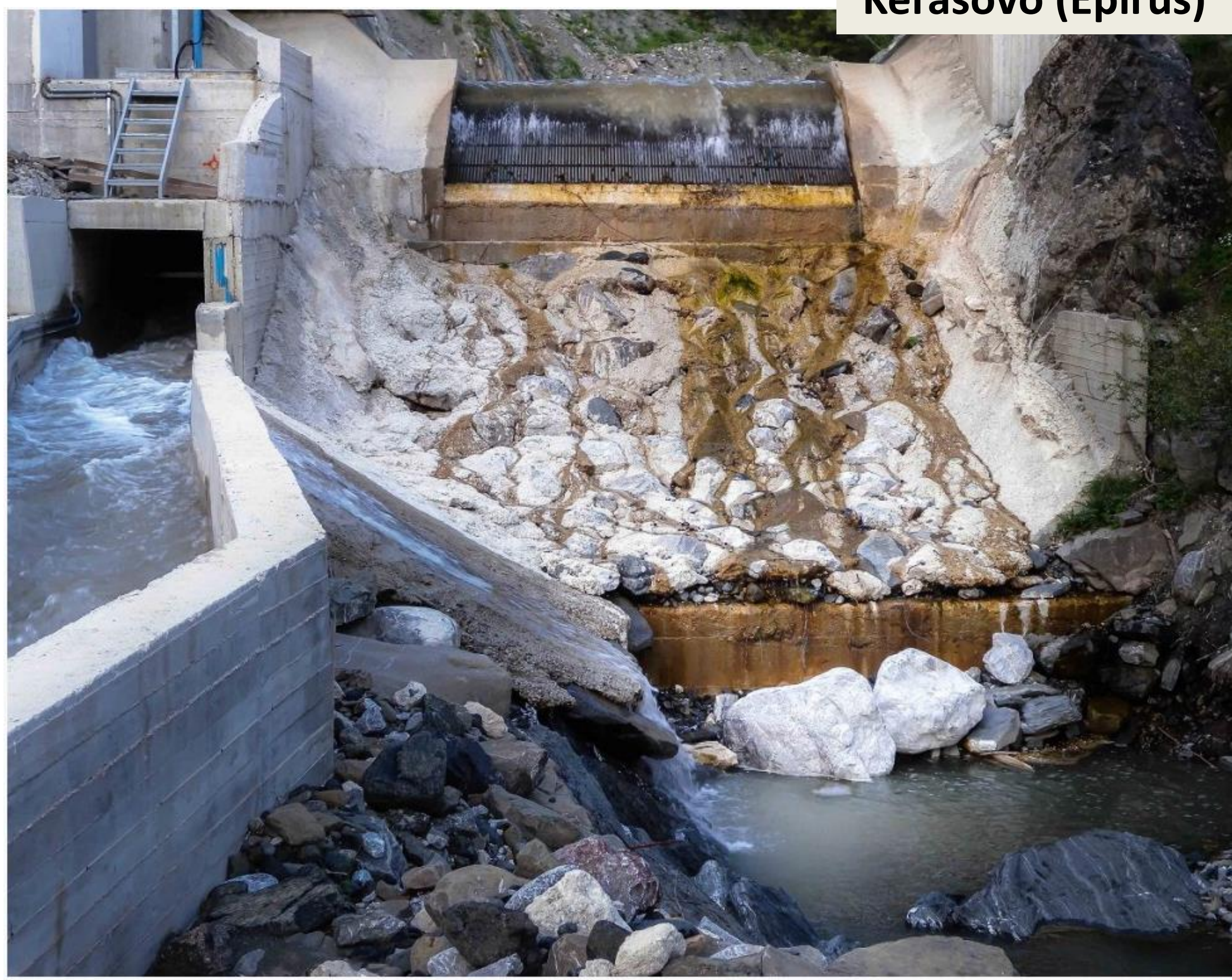
Sediment management: Layout



Drop intakes – Tyrolean weirs – water intakes for mountainous regions

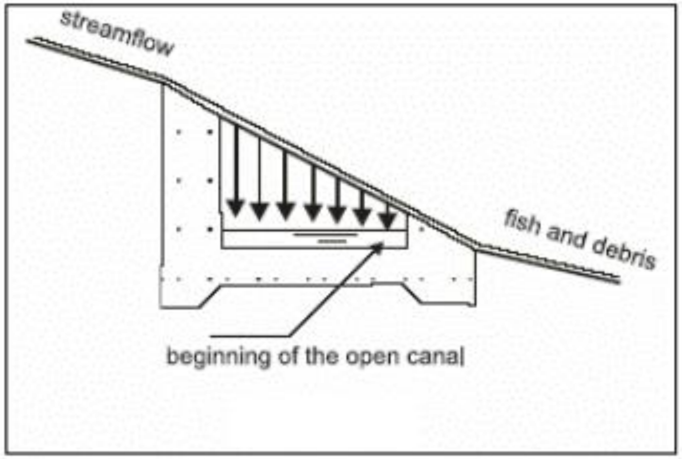
- **Tyrolean weir** is a water intake structure in which water is abstracted from the main flow through a trash rack (screen) over a gutter.
- The gutter is usually made of concrete and built into the river bed.
- The trash rack on the crest should slope downstream (15-30 degrees), to increase flow velocities and therefore prevent sediment carried by the stream from blocking it.
- From the gutter, water enters a pipeline, which drains into a sedimentation tank.

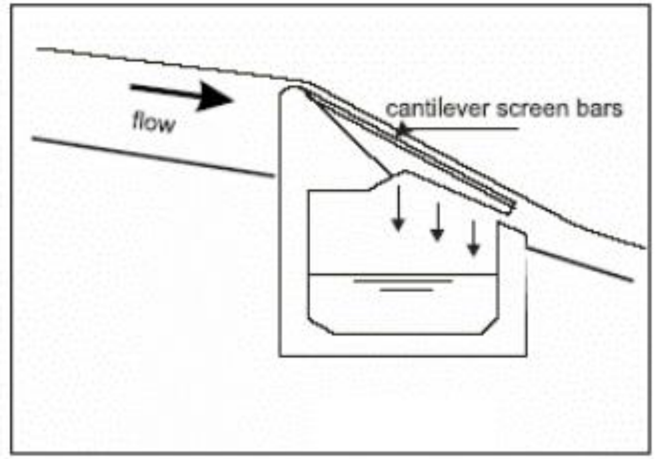
Kerasovo (Epirus)

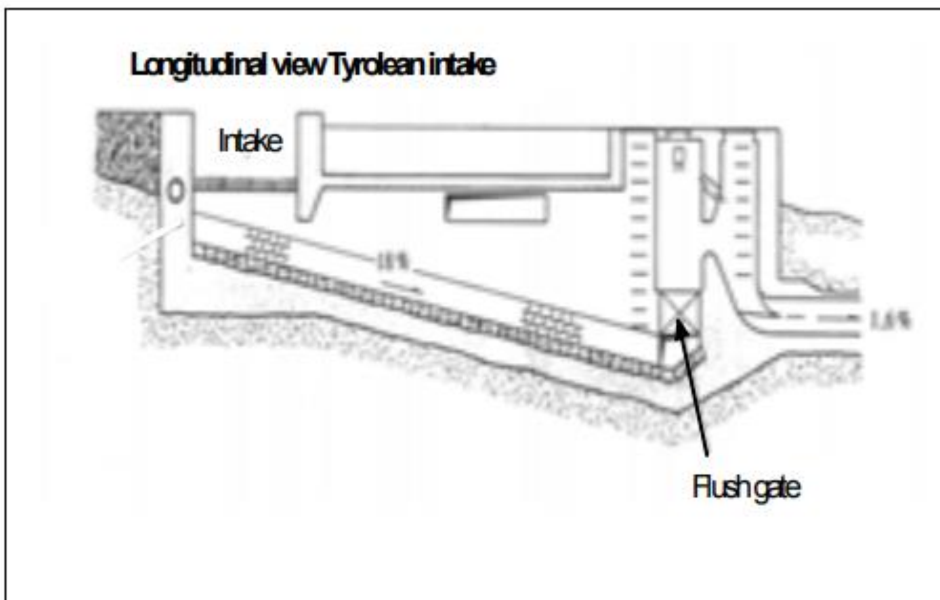


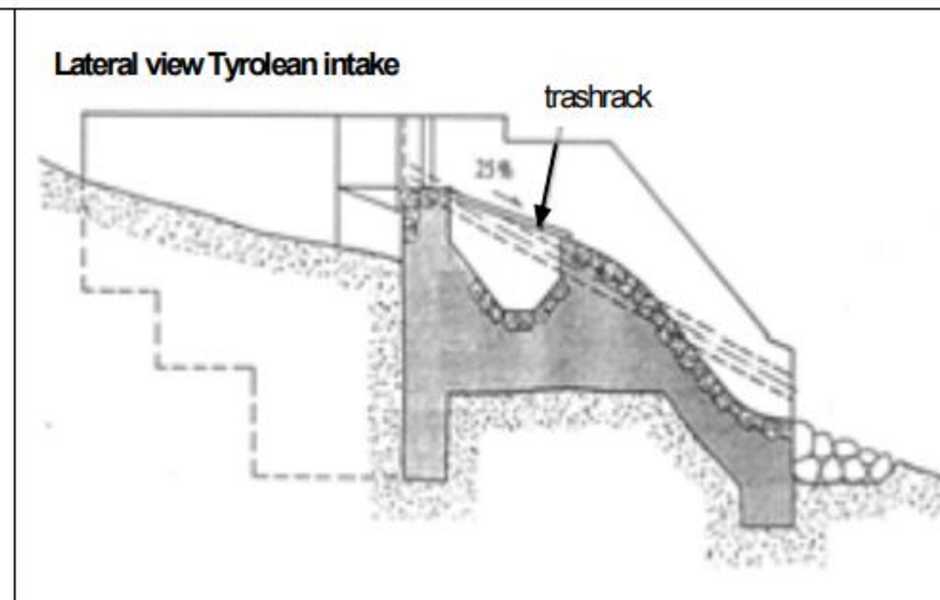
Source: http://www.sofios.gr/projects

Drop intakes – Tyrolean weirs – water intakes for mountainous regions





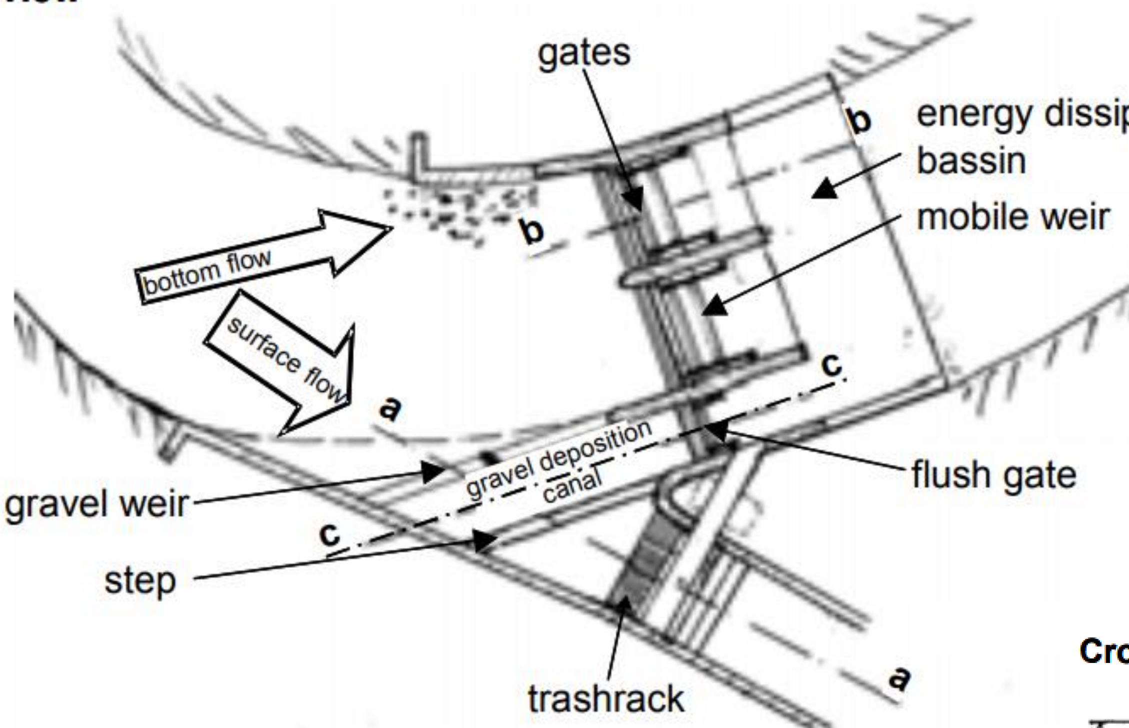




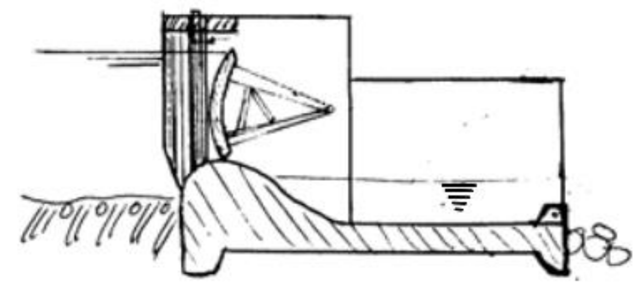
Source: Guide on How to Develop a Small Hydropower Plant, European Small Hydropower Association (ESHA), 2004

Lateral intakes

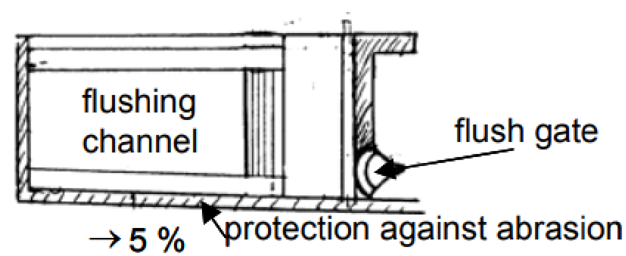
Plan view



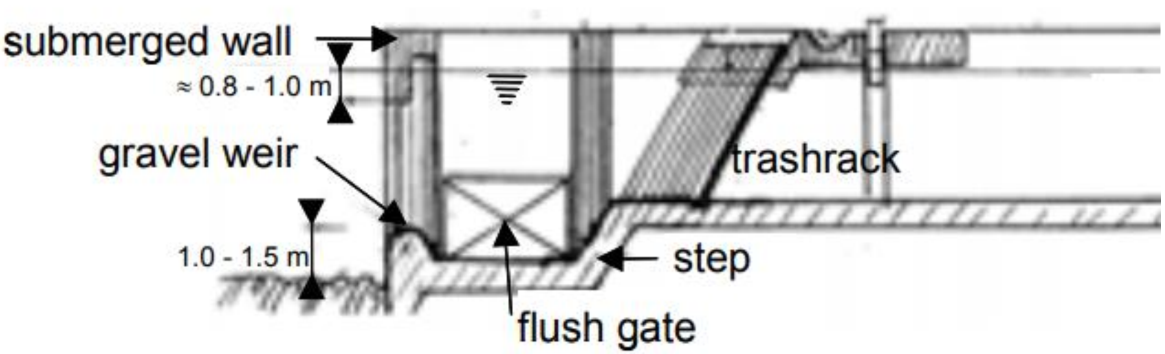
Cross section b - b : Weir /dam



Cross section c - c : Gravel weir



Cross section a - a : Intake



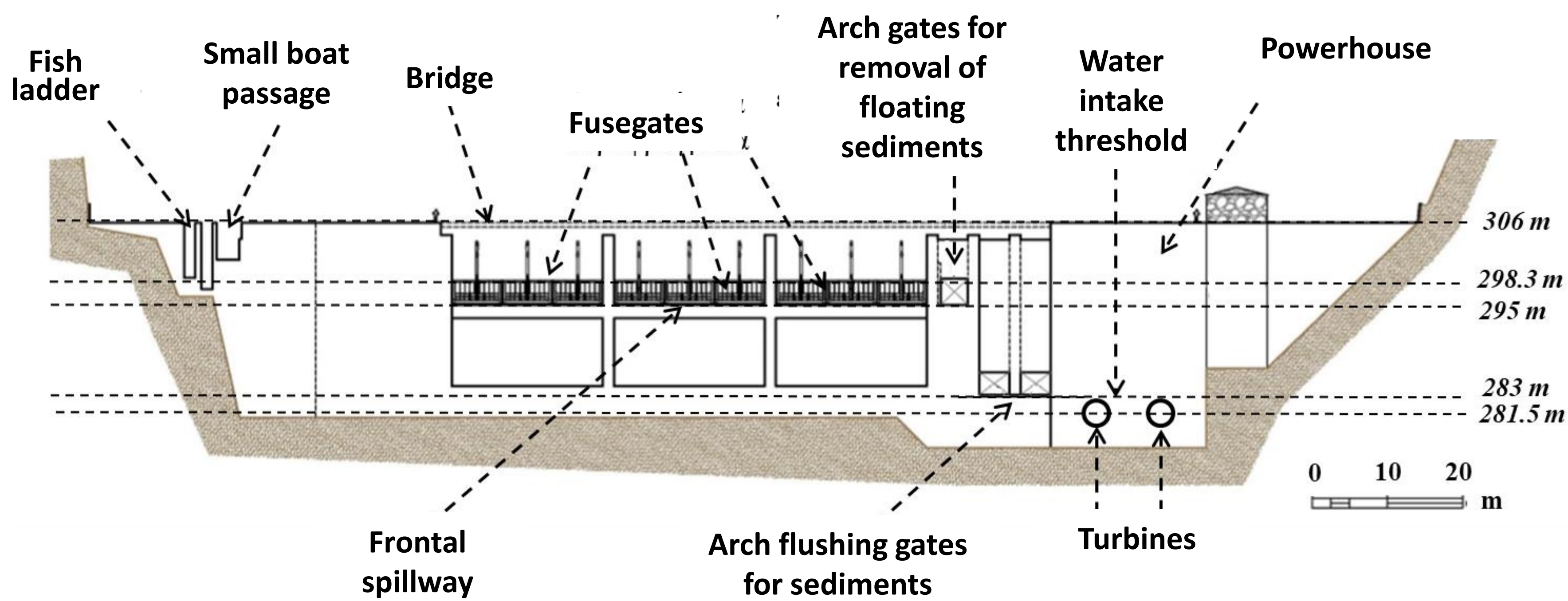
Source: Guide on How to Develop a Small Hydropower Plant, European Small Hydropower Association (ESHA), 2004

Characteristic examples: Dafnozonara (Achelous)

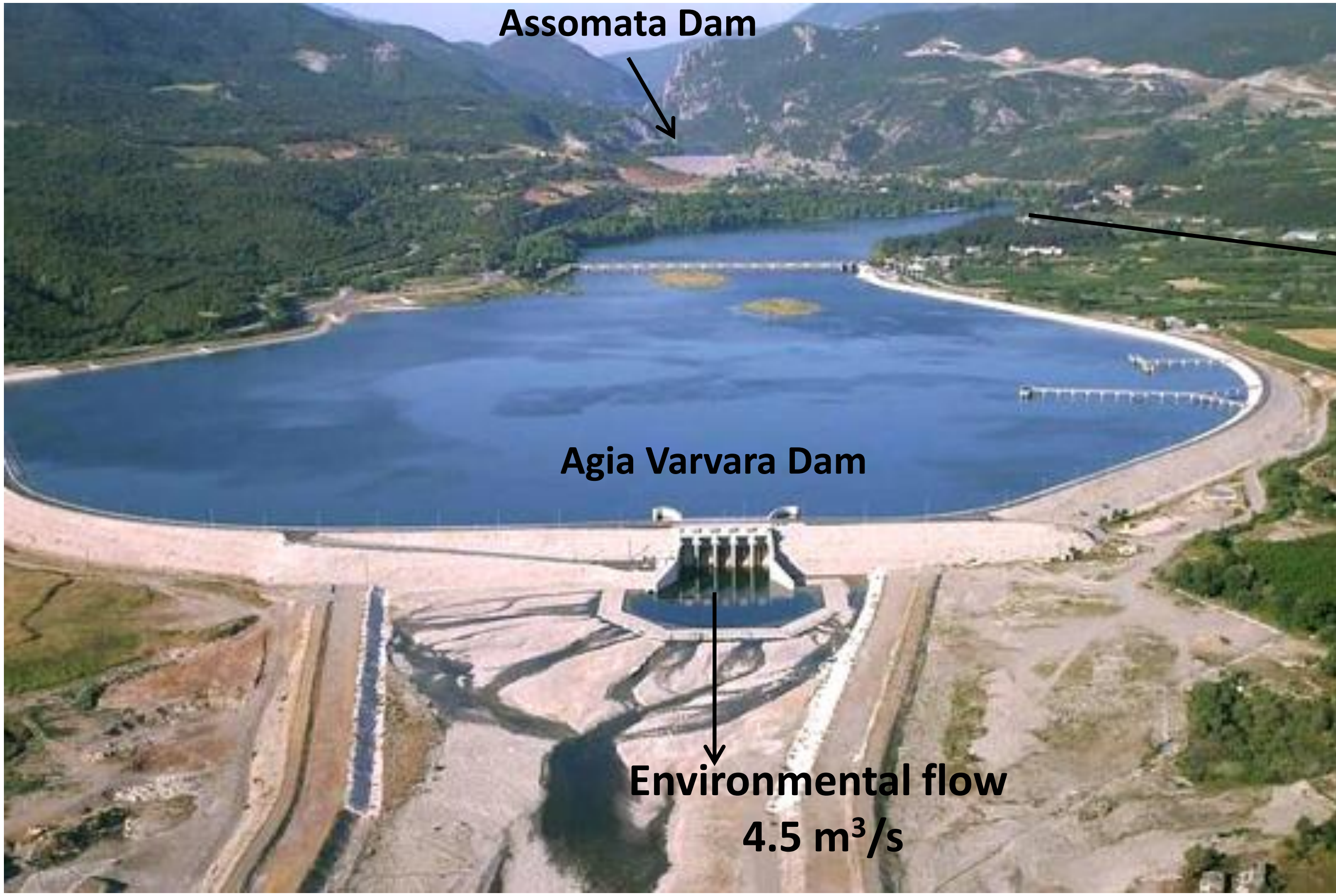
2 turbines Kaplan S-Type, power 5.93 MW (5-40 m^3/s)
Mean annual electric energy production 40 GWh

Spillway and fusegates

Fish ladder and small boats passage



SHPPs as additions: Agia Varvara (Aliakmonas)

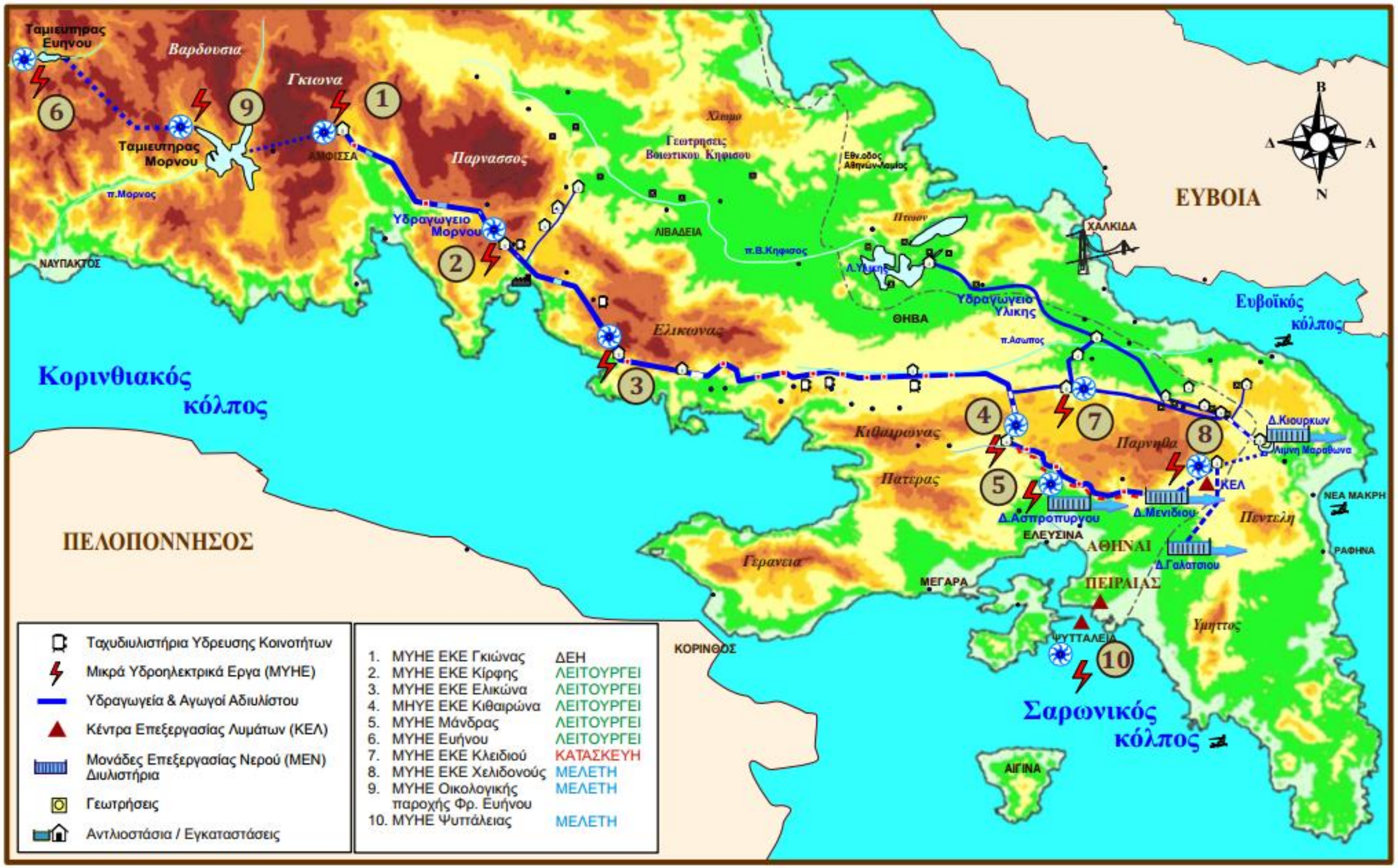


Source:
PPC Renewables

It is constructed at the foot of the Agia Varvara regulatory dam. The SHPP belongs to the Public Power Corporation (PPC) and exploits the environmental flow of Aliakmon river. It includes a Kaplan S-type horizontal-axis turbine of 23 m head and 0.92 MW capacity. It operates from 2008 and has mean annual electrical energy production of **4.5 GWh.**

SHPPs as additions: Athens water supply system

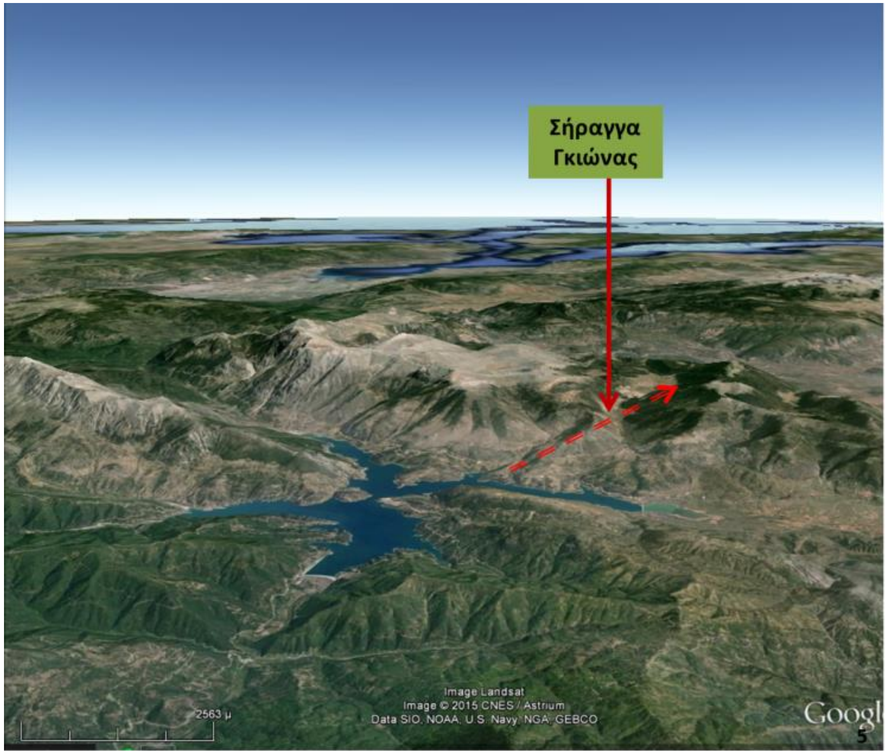
The Water Supply and Sewage Company of Athens (EYDAP) has constructed several SHPPs along the aqueducts that convey the water to Athens. In each SHPP location, the water is diverted to a lateral canal where electrical energy is produced and the water is then returned to the main canal.



Athens Water Supply System SHPPs: ***Evinos Dam (820 kW), Kirfi (760 kW), Elikona (650 kW), Kitheronas (1.200 kW), Mandra (630 kW), Klidi (590 kW)***

Source: EYDAP

SHPPs as additions: Giona (Mornos aqueduct)

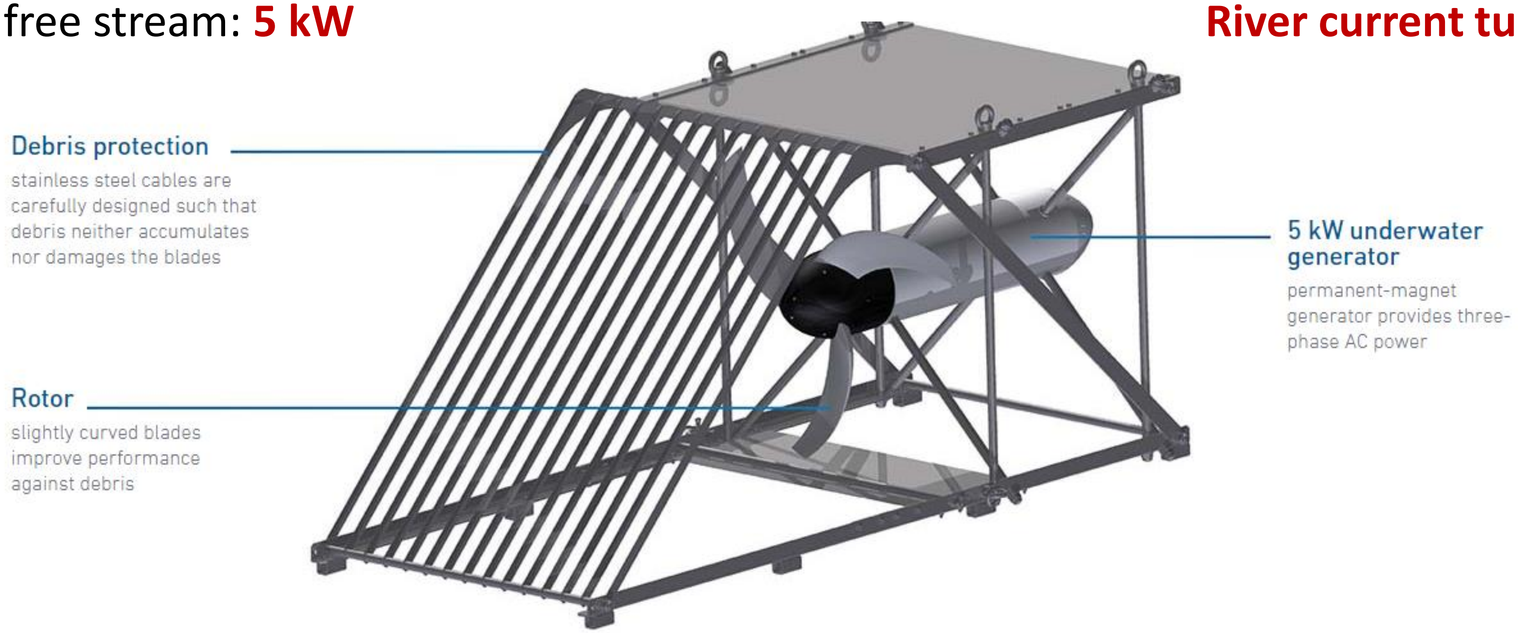


The largest SHPP across Mornos aqueduct is Giona, which operates since 1987. It is located near the city of Amfissa, belongs to the PPC and exploits a part of the water volume transported to the city of Athens. The operational discharge fluctuates from 7.8 to 14.5 m^3/s, and the head from 30.0 to 66.1 m. The installed power is 8.67 MW and the mean annual electrical energy production is about 34 GWh.

In-stream projects

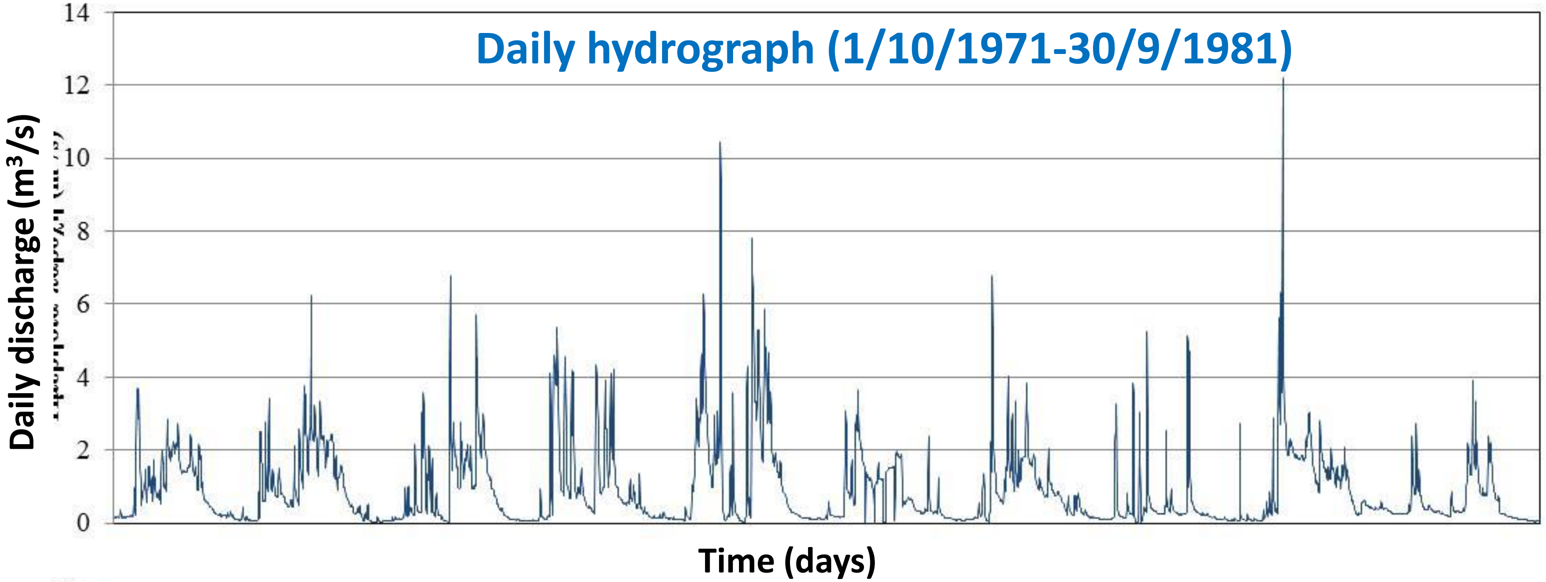
Smart free stream: **5 kW**

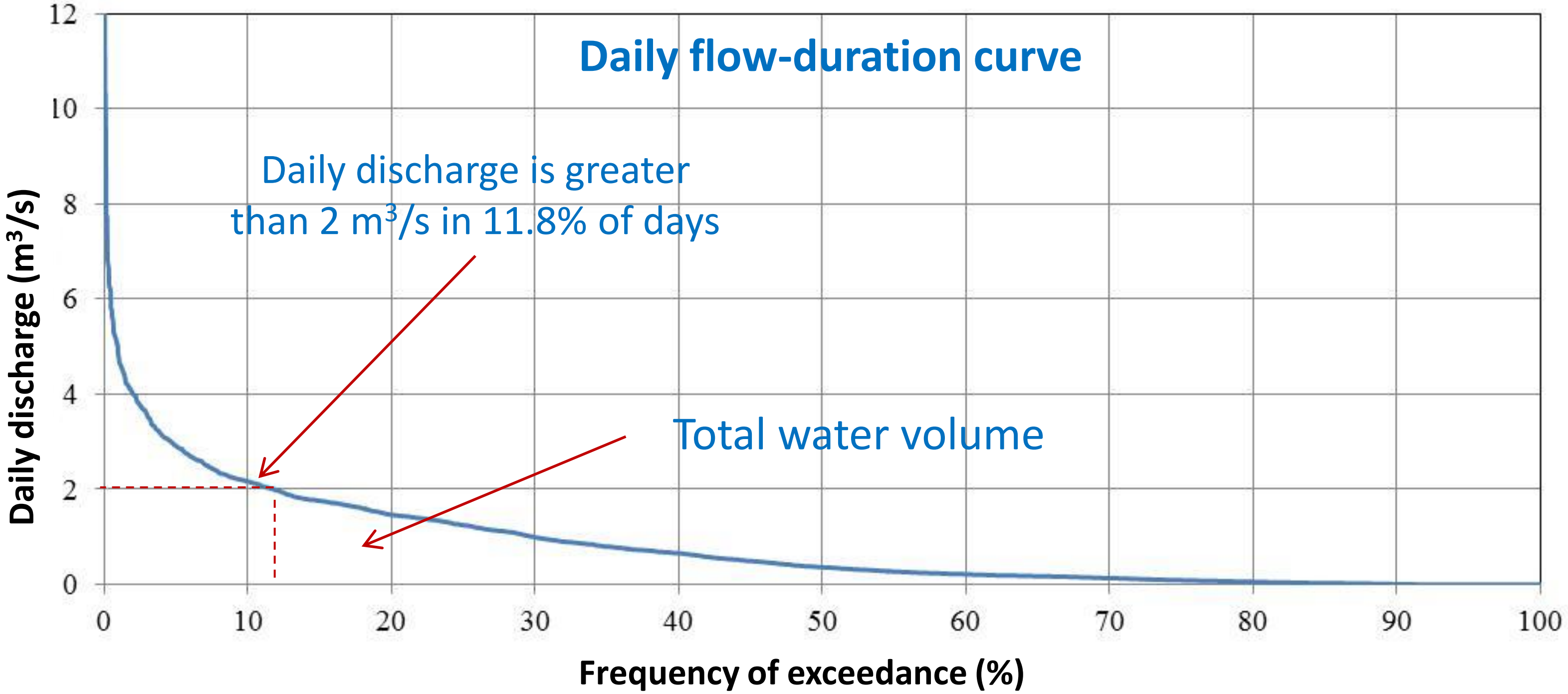
River current turbines



HydroQuest River: **80 kW**, Minimum water head: **4.2 m**, Nominal current flow velocity: **3.1 m/s**

Design issues: Flow duration curves





Design issues: Environmental flows

The main methodologies for the estimation of environmental flow are based on:

- historical streamflow data (water flow regime)
- geometrical characteristics of the river cross sections
- the preservation of the river as (a) habitat for specific species, (b) wetland and (c) natural landscape

Practically, the EF can be estimated considering the:

- statistical characteristics of flow time series (as a percentage of the annual low-flow period or by taking into account the flow duration curve)
- wetted perimeter in specific river cross sections
- required water volumes for the preservation of specific species and wetlands

According to Greek legislation, the minimum environmental flow downstream of SHPPs must be defined as the maximum of the following:

- *30% of the mean discharge of summer months (June, July, August) or*
- *50% of the mean discharge of September or*
- *30 L/s in any case.*

The environmental flow must be increased, in case of an important ecosystem downstream

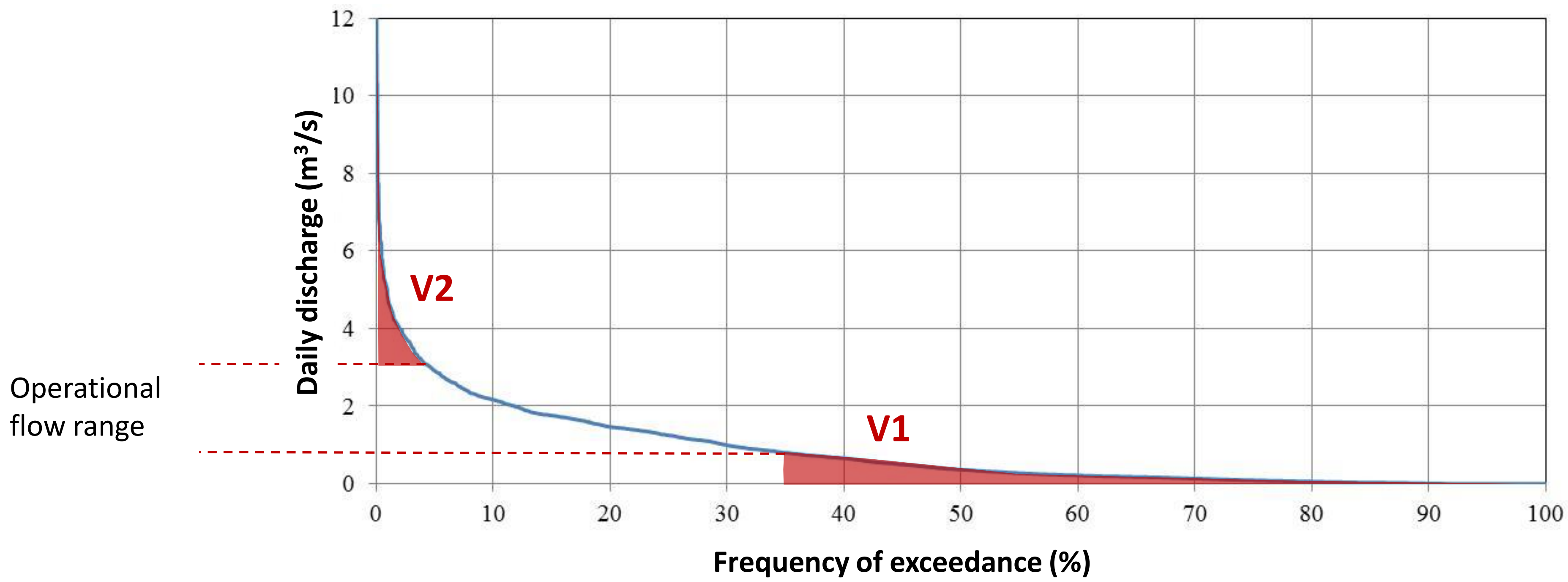
The first known flow regulation rule

It is saved in an epigraph of the 5th century BC in the ancient city of Gortyn in Crete. The city is crossed by the river Lithaios, which dominates the valley of Messara

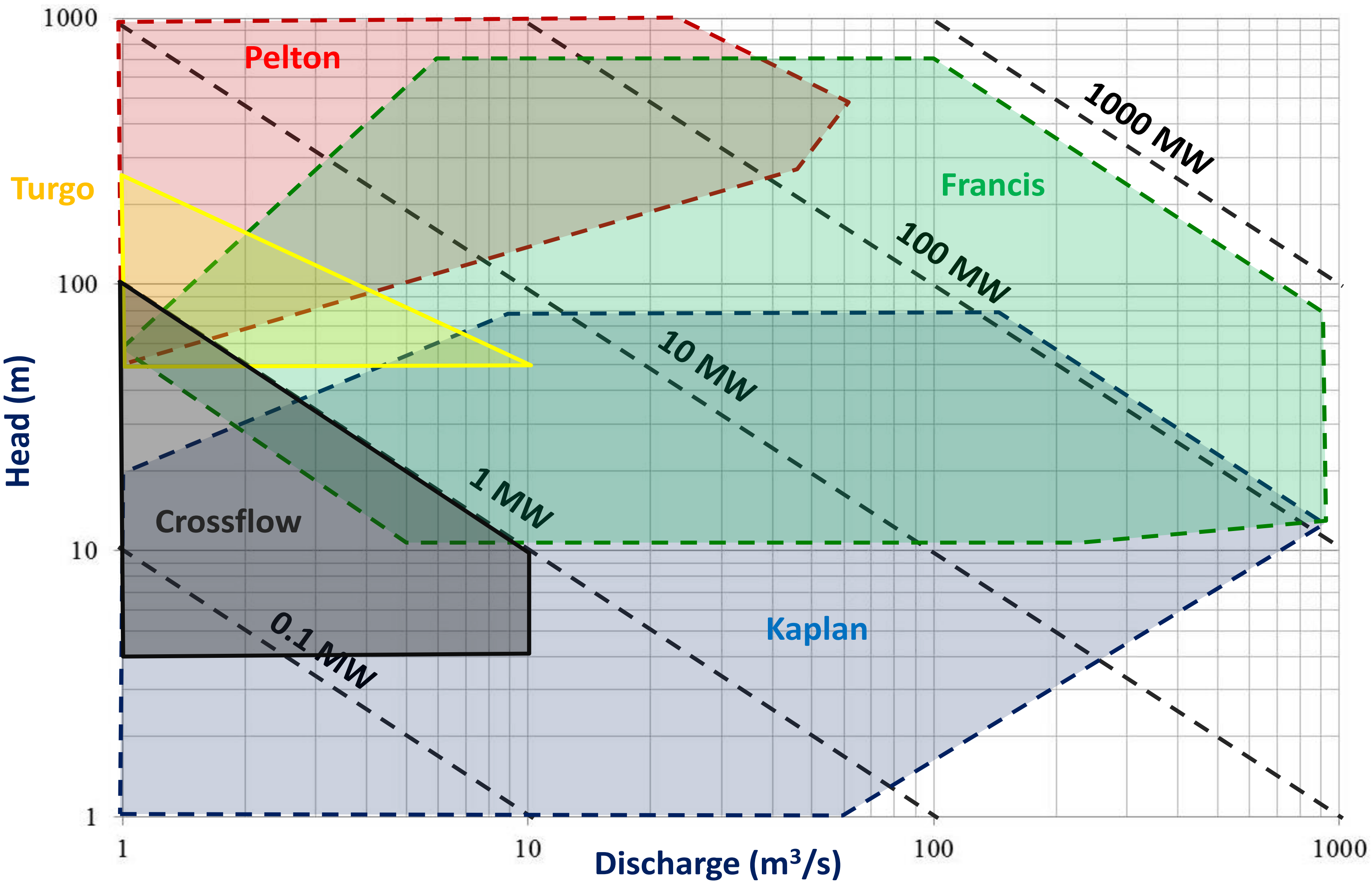
Gods. If anyone makes the flow run from the middle of the river towards his own property, it is without penalty for the person so doing. He is to leave the flow as wide as the bridge that the agora holds, or more but no less.

Design issues: Limitations

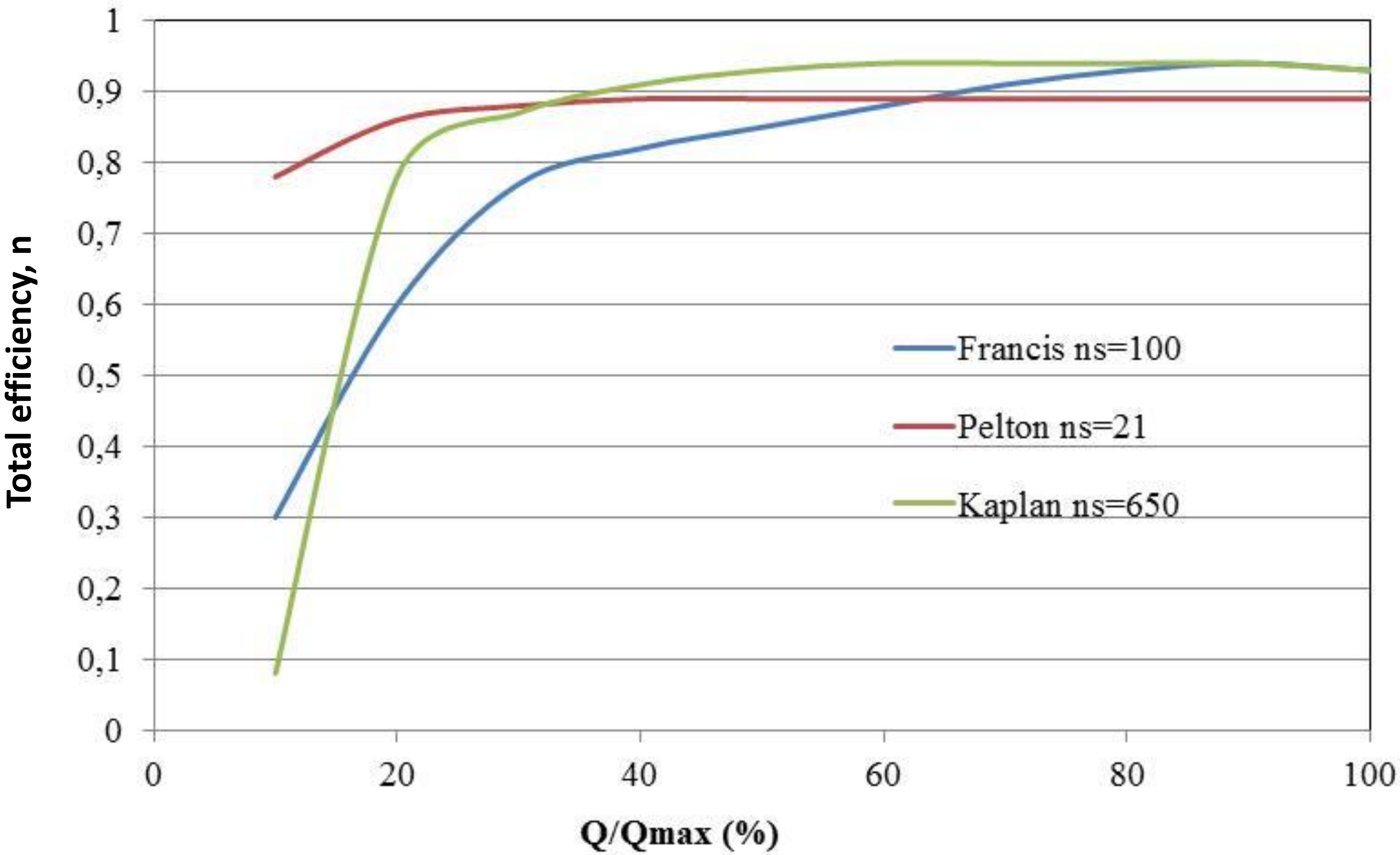
- The turbine exploits a range of discharges between the nominal discharge (maximum) and a minimum discharge that is usually 10% to 30% of the nominal discharge. The exact percentage depends on the type of the turbine (Pelton-Francis-Kaplan)
- The volumes V_1 and V_2 are not exploited for energy production. V_1 depends on the minimum flow of the smallest turbine and V_2 depends on the maximum of the largest one
- The minimization of V_1 and V_2 is achieved through the combination of several turbines with different installed power capacities
- According to Greek legislation the design of SHPPs must ensure: **(a) the exploitation of at least 75% of the available water volume; and (b) an operational time greater than 30%**



Design issues: Turbine selection



Design issues: Turbine efficiency curves



Turbine selection: Numerical example 1

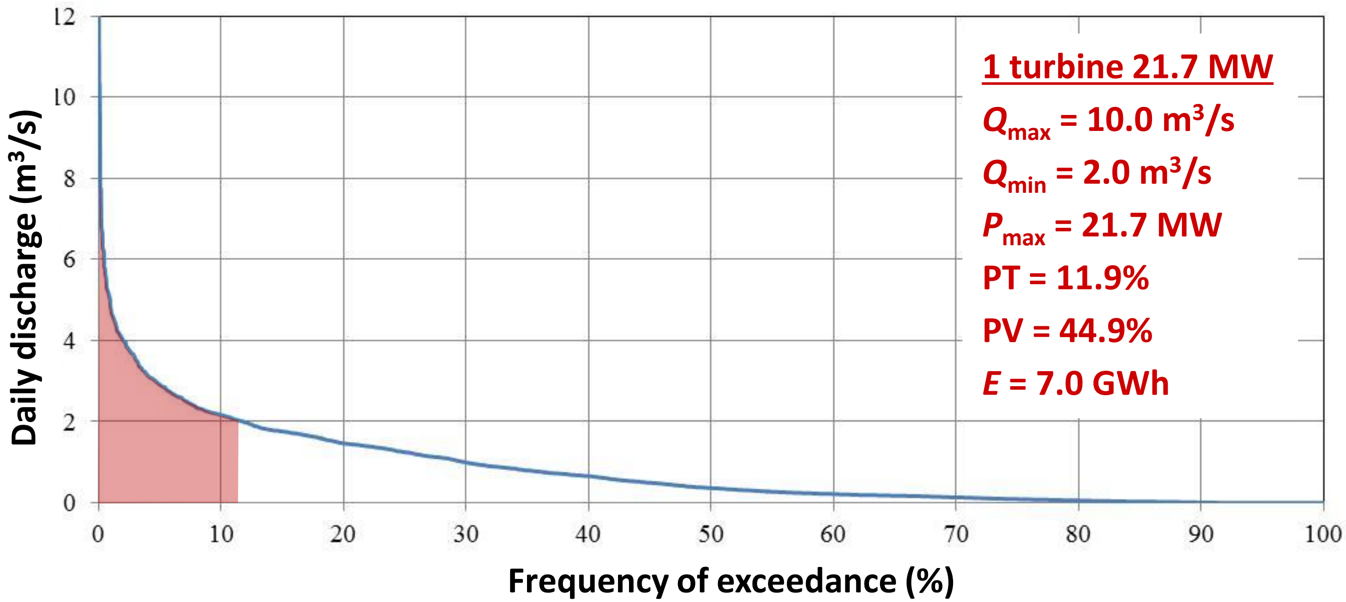
Data

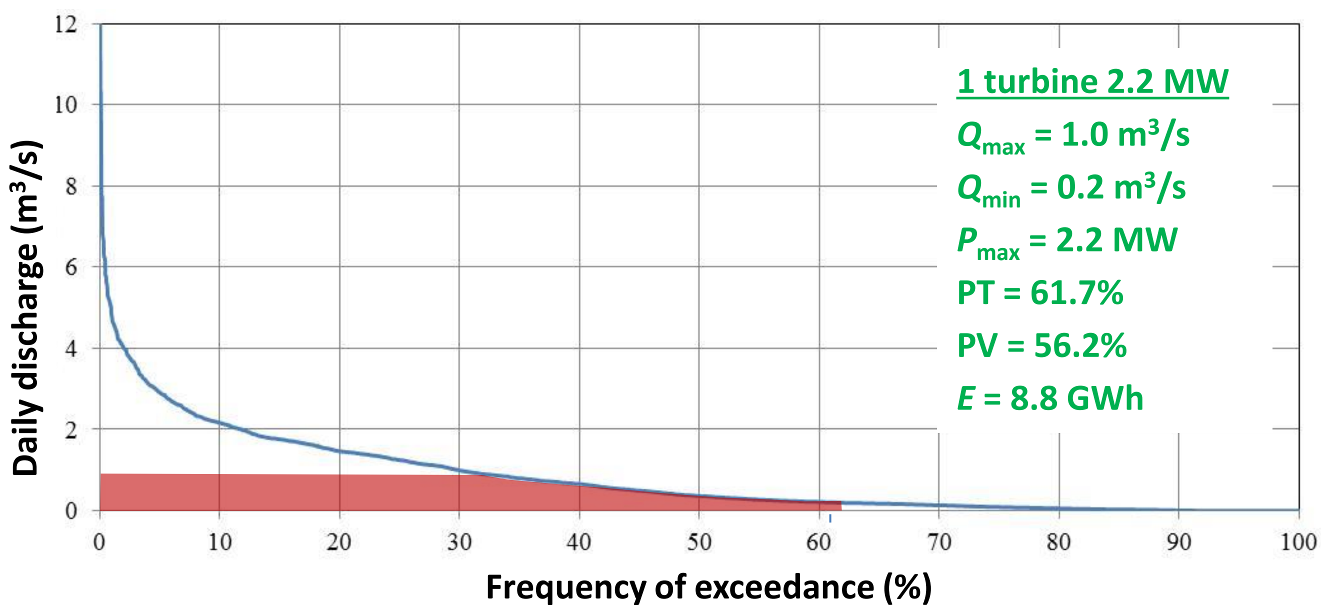
H = 260 m

η = 0.85

Theoretical power for various discharges

Q (m³/s)	I (MW)
0.5	1.1
1	2.2
1.5	3.3
2	4.3
2.5	5.4
3	6.5
4	8.7
5	10.8
10	21.7





Legend

Q_{min}, Q_{max}: Minimum, maximum exploitation discharge (m³/s)

P_{max}: Power in maximum exploitation discharge (MW)

PT: Percentage of operation time in a typical year (%)

PV: Percentage of water volume used (%)

E: Total annual electrical energy produced (GWh/y)

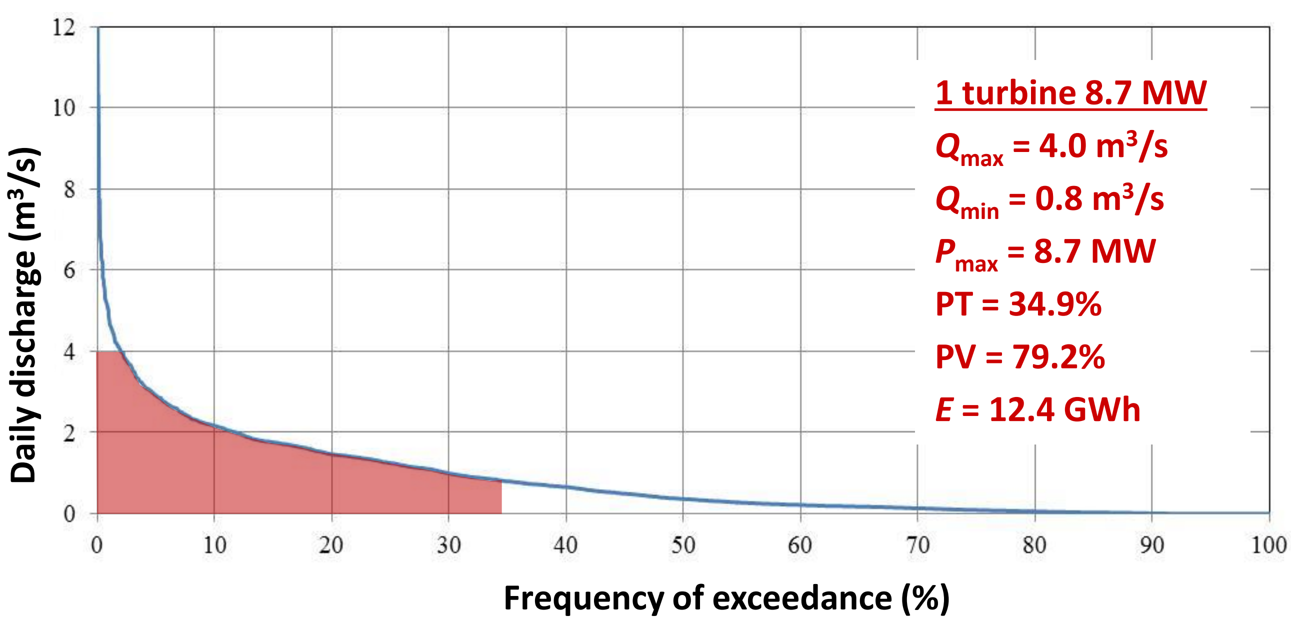
Turbine selection: Numerical example 2

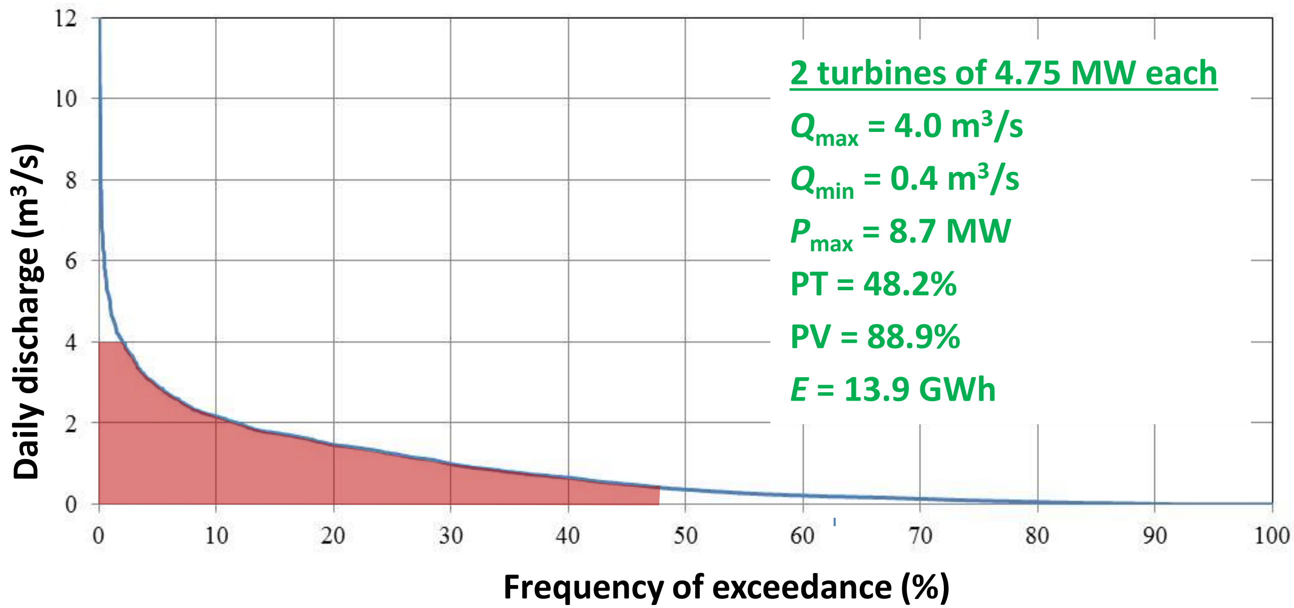
Data

H = 260 m
η = 0.85

Theoretical power for various discharges

Q (m^3/s)	I (MW)
0.5	1.1
1	2.2
1.5	3.3
2	4.3
2.5	5.4
3	6.5
4	8.7
5	10.8
10	21.7





Legend

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P_{max}: Power in maximum exploitation discharge (MW)

PT: Percentage of operation time in a typical year (%)

PV: Percentage of water volume used (%)

E: Total annual electrical energy produced (GWh/y)

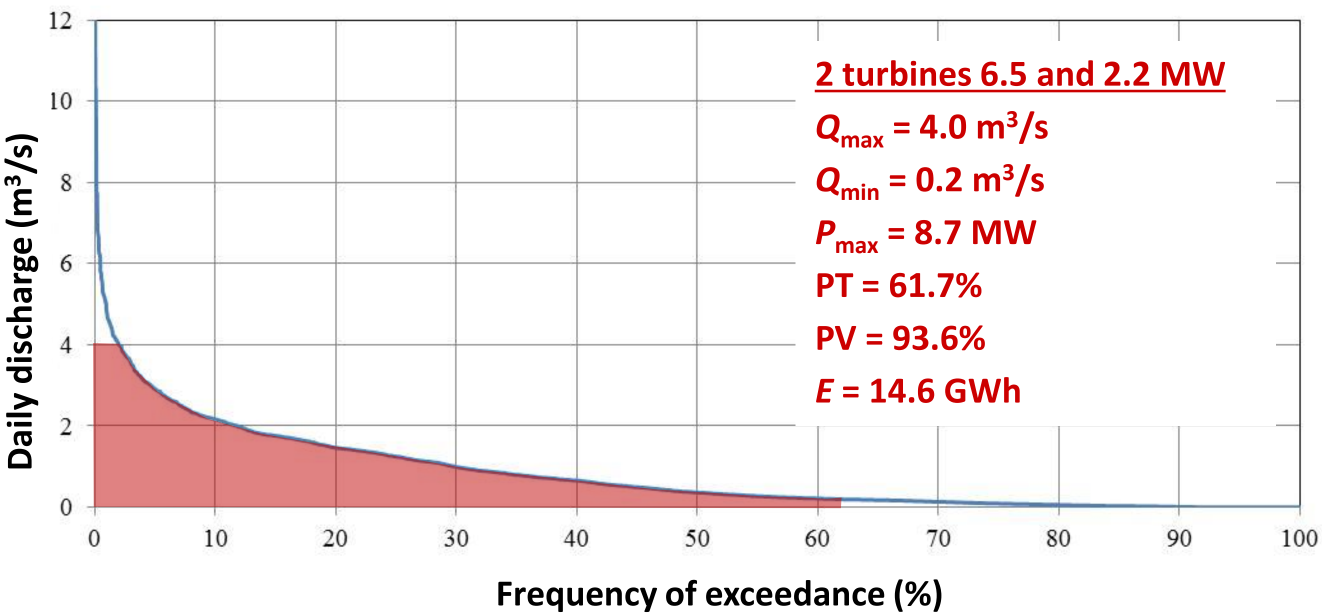
Turbine selection: Numerical example 3

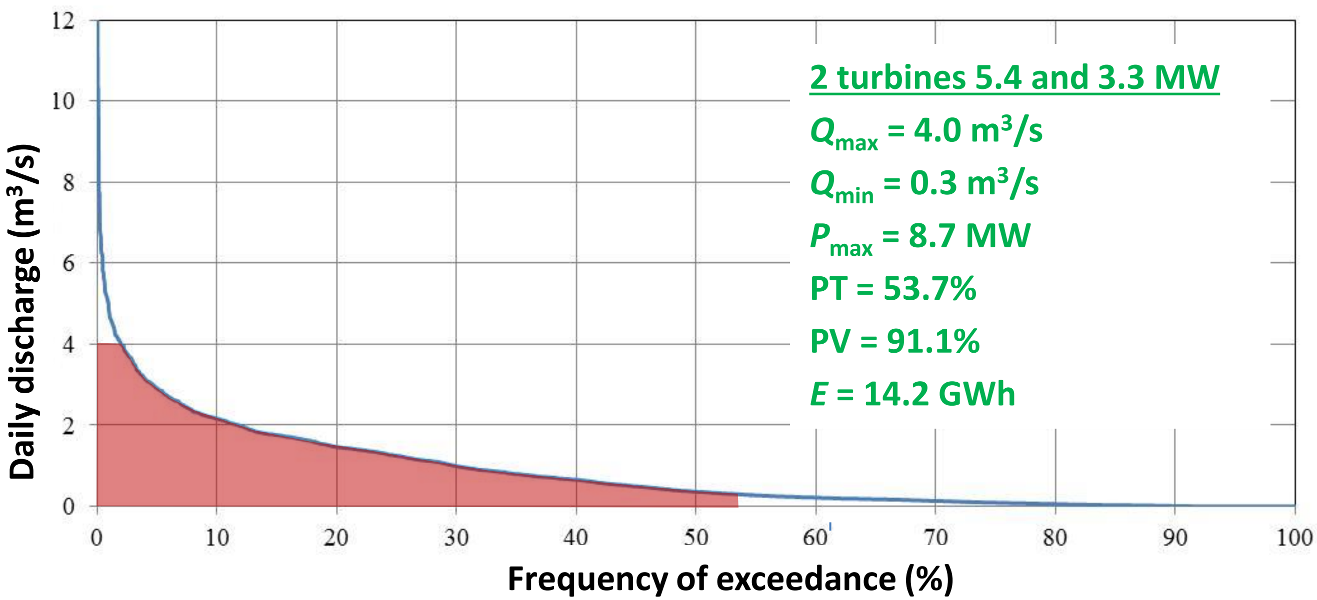
Data

H = 260 m
η = 0.85

Theoretical power for various discharges

Q (m^3/s)	I (MW)
0.5	1.1
1	2.2
1.5	3.3
2	4.3
2.5	5.4
3	6.5
4	8.7
5	10.8
10	21.7





Legend

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Analytical flow duration curves

Theoretical flow duration curve formula: $P(Q) = 1 - F(Q) = (1 + Q/10)^{-5}$

Q discharge in m^3/s ***P*** probability of exceedance of the value Q ***F*** probability function

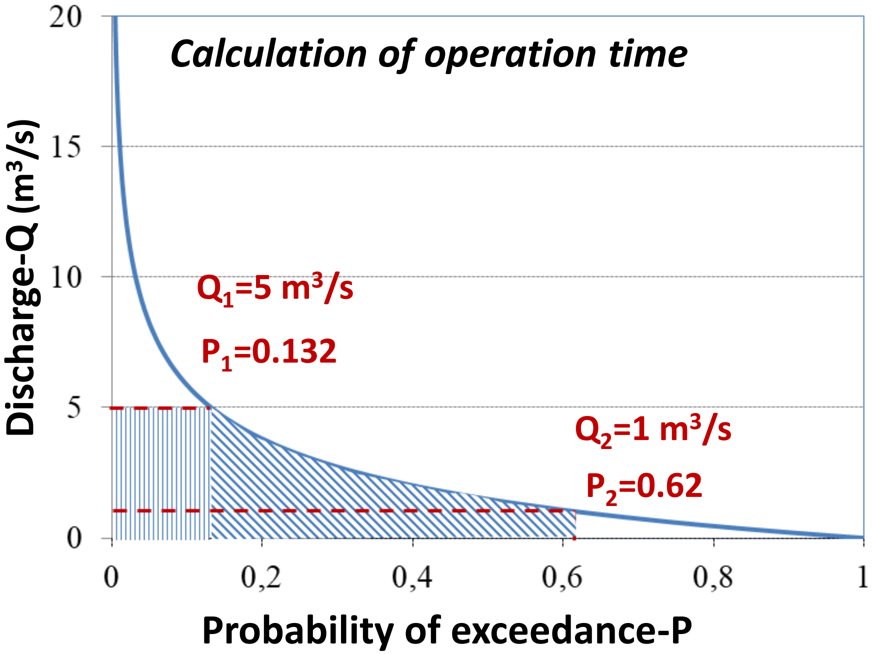
The inverse function is given by the formula:

$$Q(P) = 10(1/P^{0.2} - 1)$$

The integral of the flow duration curve to P is given by the formula:

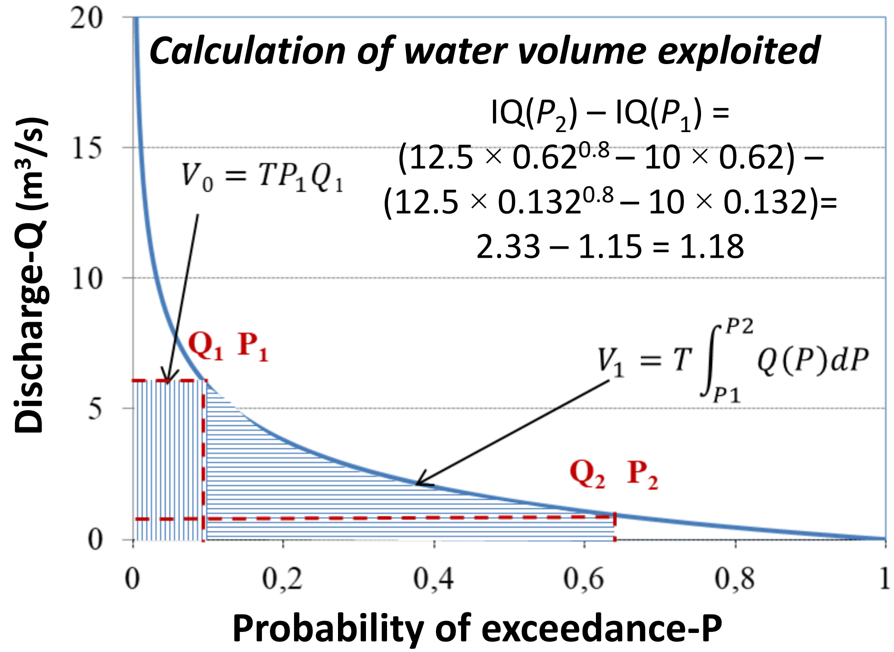
$$\mathrm{IQ} := \int Q(P)\,\mathrm{d}P = 12.5P^{0.8} - 10P$$

A turbine with an operation discharge range of 1 - 5 m³/s, is examined



Operational time: **62%**

Operational time at maximum discharge: **13.2%**



For one-year operation, $T = 31.56 \times 10^6$ s

$V_0 = 31.56 \times 0.132 \times 5 =$ **20.8 hm³**

$V_1 = 31.56 \times 1.18 =$ **37.1 hm³**

Alternatives of hydraulic energy

Source: http://www.lifo.gr/guests/viral/56837