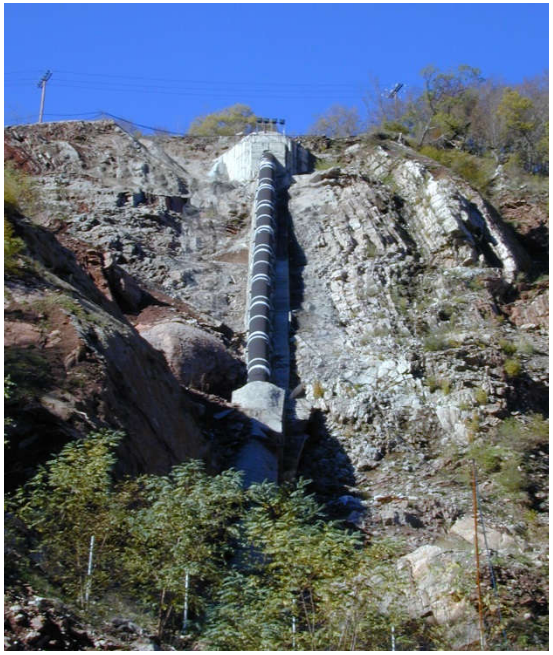
Postgraduate program: Environment and Development

Course: Energy and Environment

National Technical University of Athens

Small Hydroelectric Power Plants (SHPPs)



Nikos Mamassis, Andreas Efstratiadis, Department of Water Resources & Environmental Engineering, School of Civil Engineering, NTUA

Definition and Classification of SHPPs

- To define a HPP as **"small"**, the installed power must be under a certain limit, that is defined by national legislation.
- This limit varies considerably among different counties, but the most common values are between 10 and 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)

Types of SHPPs

Storage facility

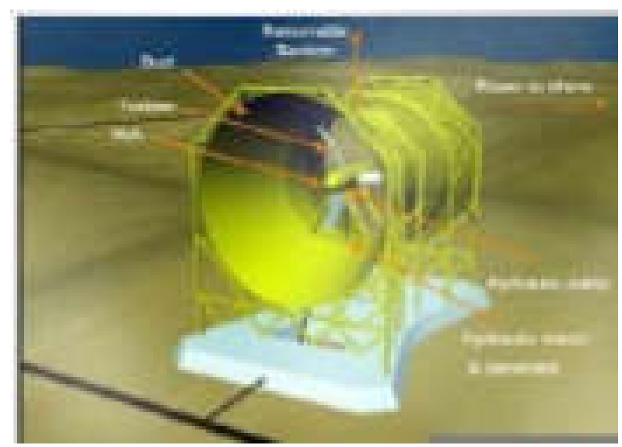
There is an impoundment and water storage facility. Several SHPPs exploit the environmental flow of large dams

Run-off-river

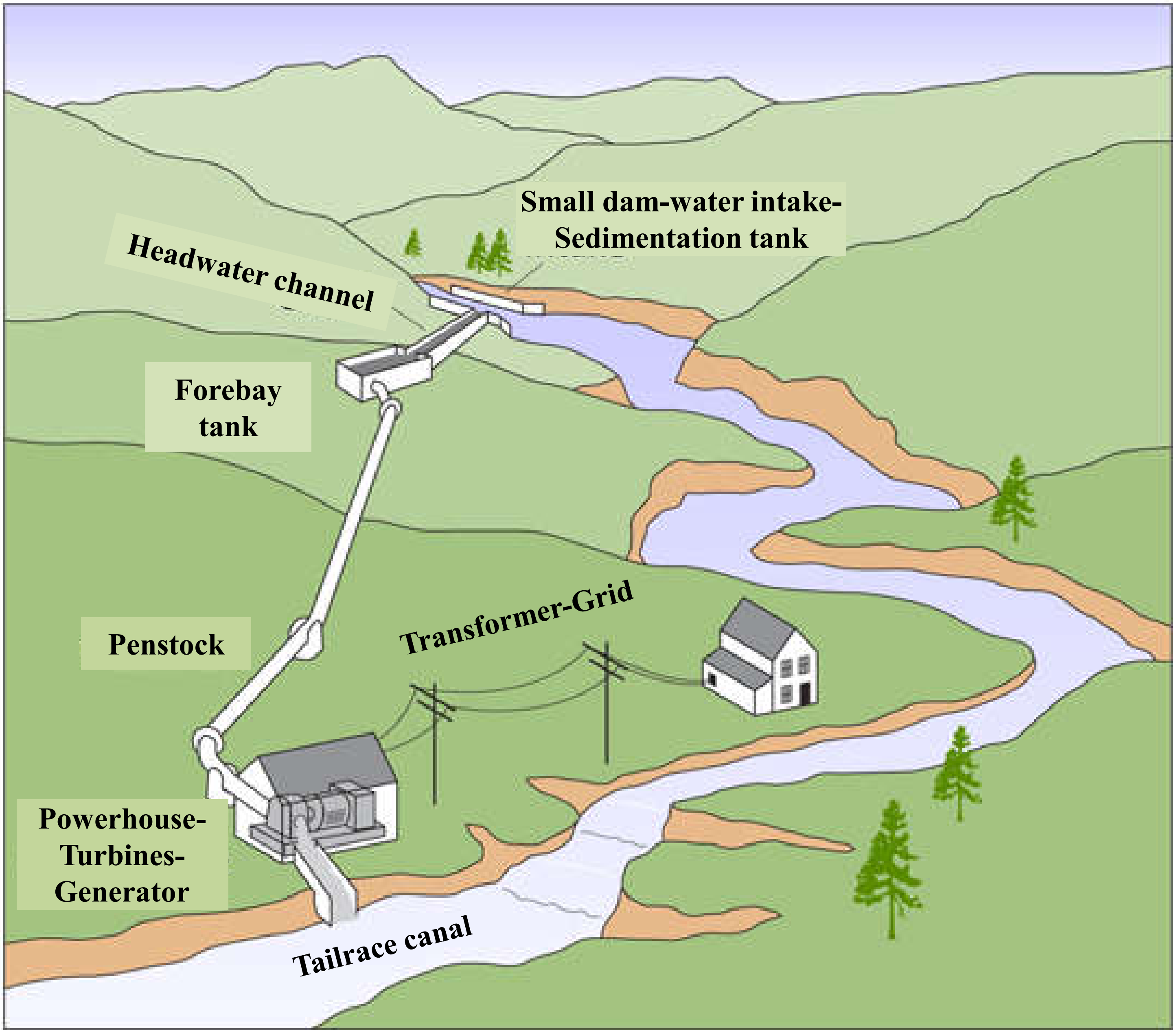
Utilizes the streamflow as it comes, without the ability to store the water. This is the most common SHPP type.

In-stream

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



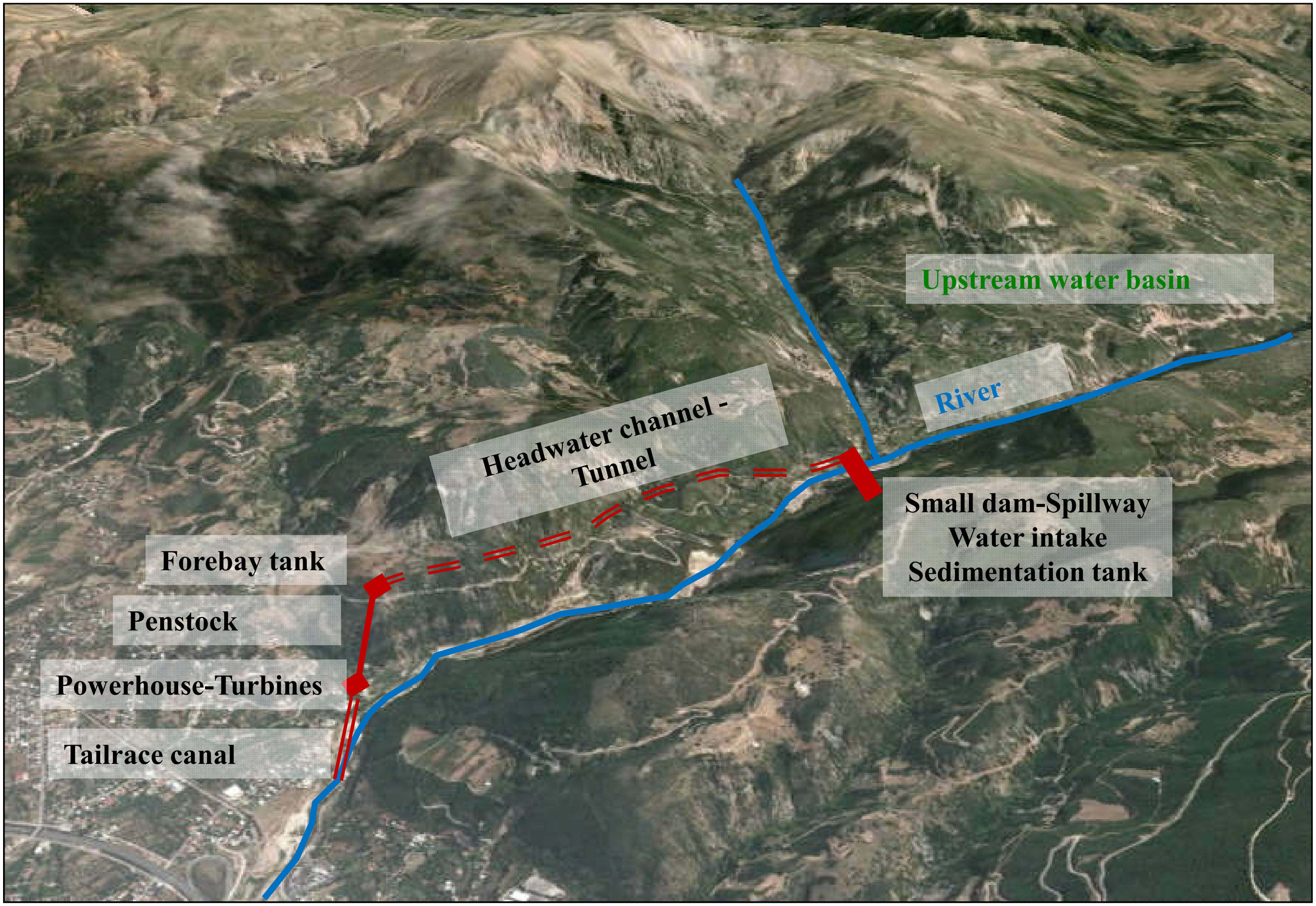
Components of a typical SHPP



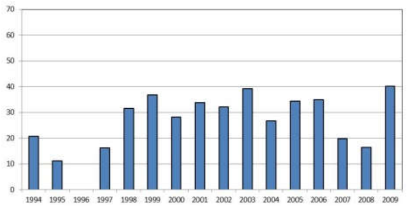
Typical SHPP

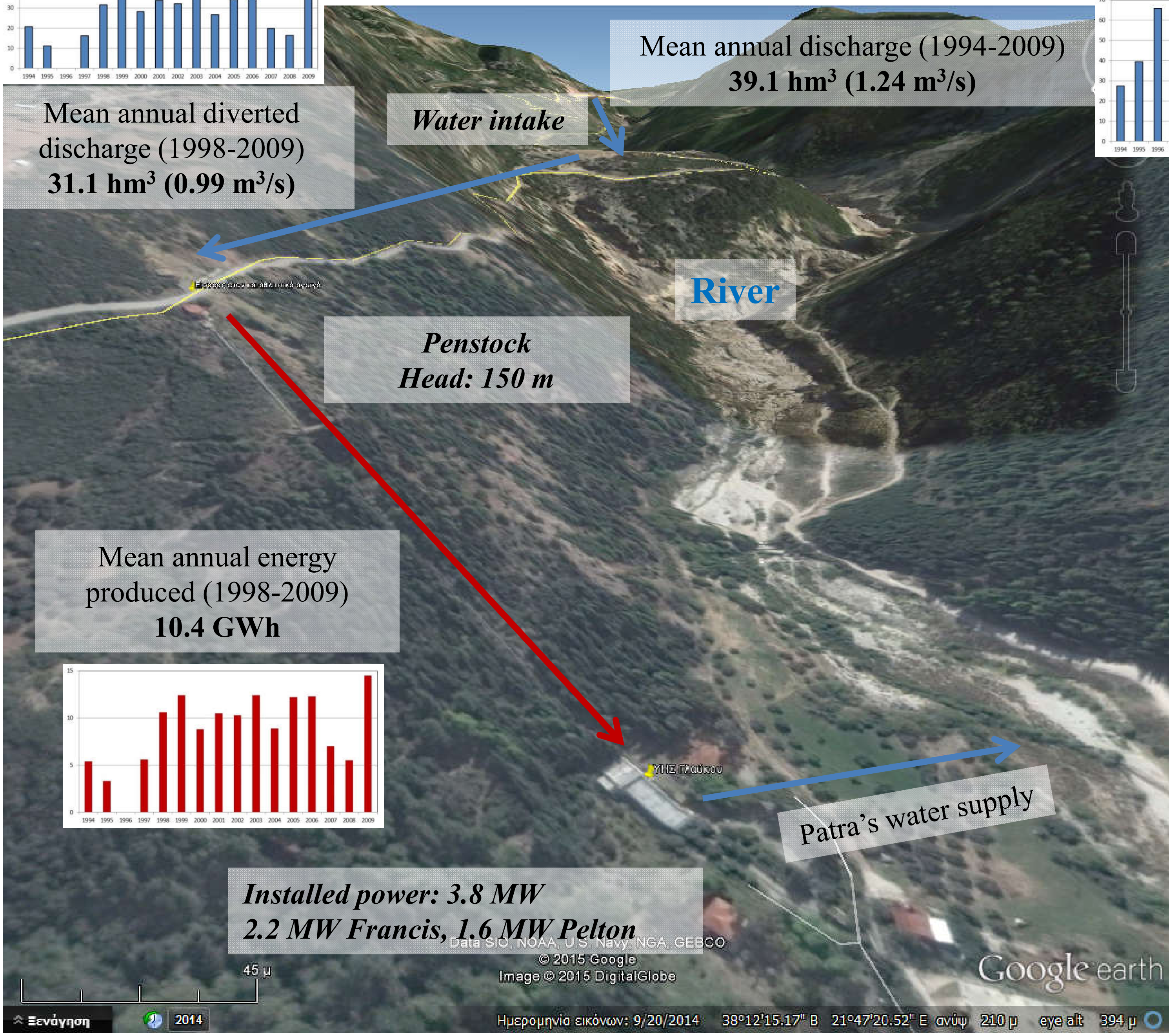
Glafkos-Patra, Greece

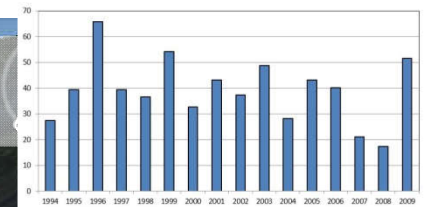
The project was constructed in 1927 and it is one of the first hydroelectric works in Greece



Typical SHPP - Glafkos



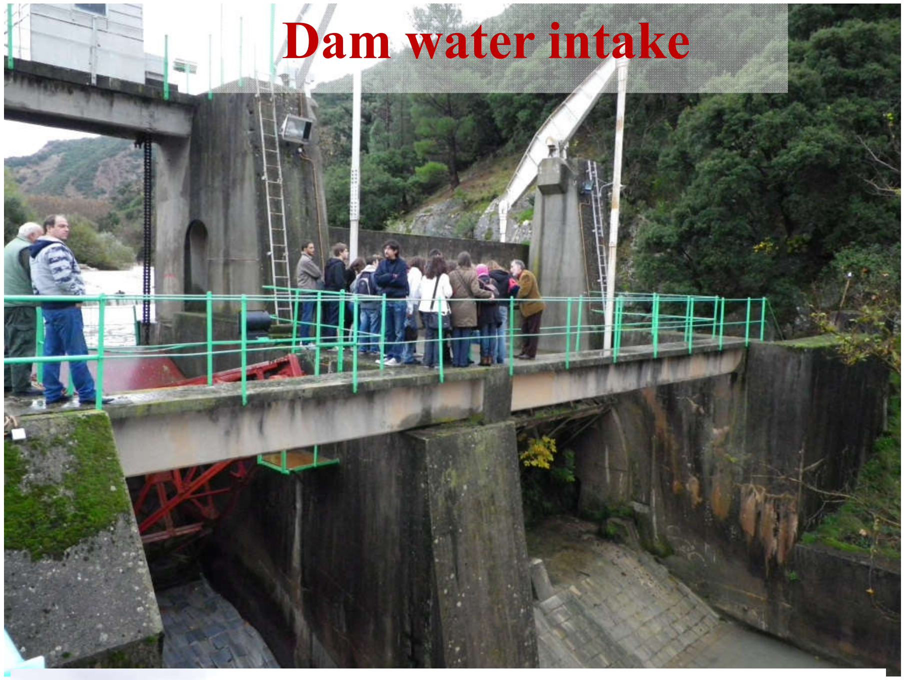




Mean annual discharge used (1998-2009)
82%

Mean capacity factor (1998-2009)
0.31

Typical SHPP - Glafkos



Dam water intake

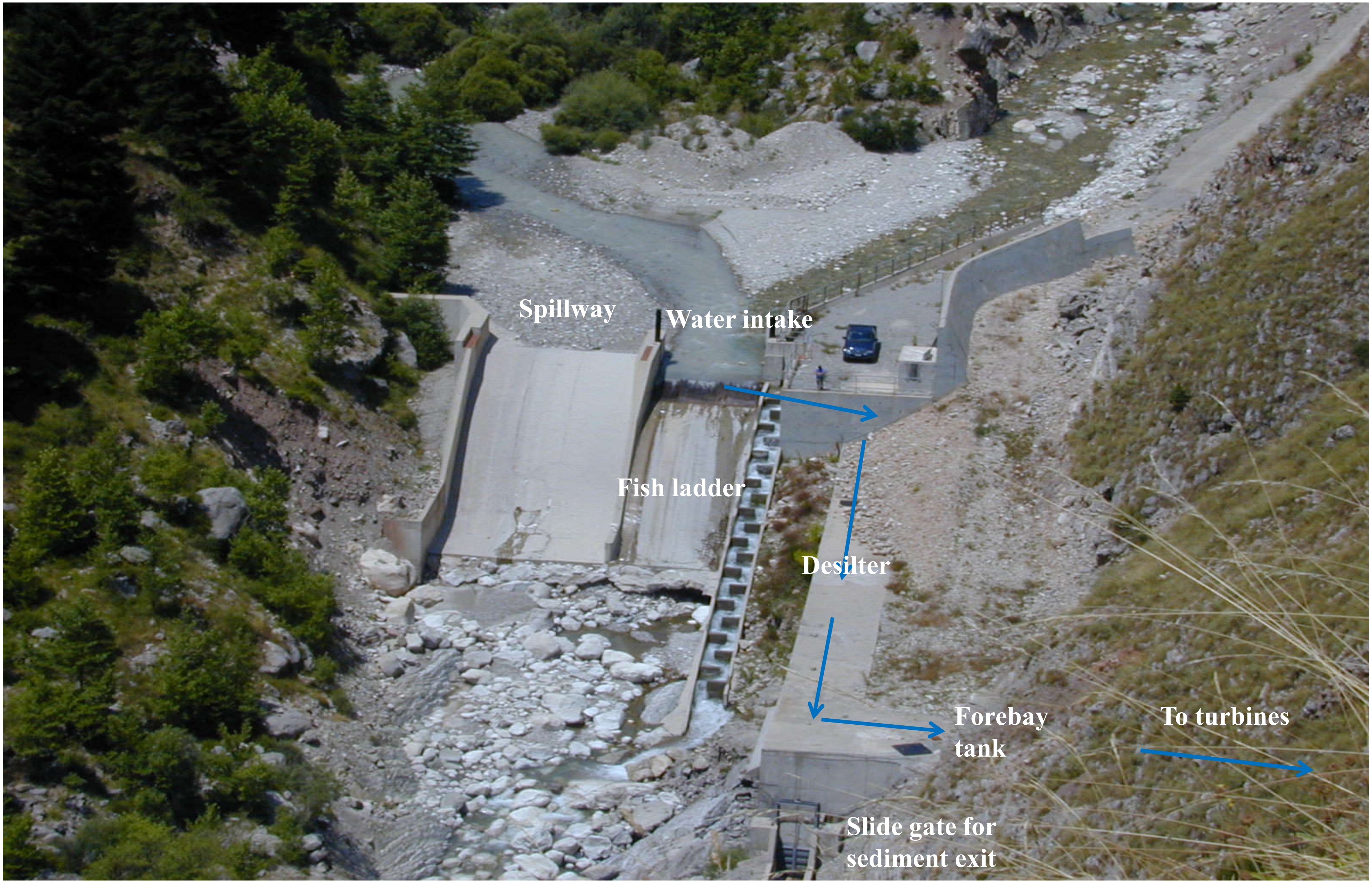
Sand trap – desilter - sedimentation tank

Penstock

Turbines

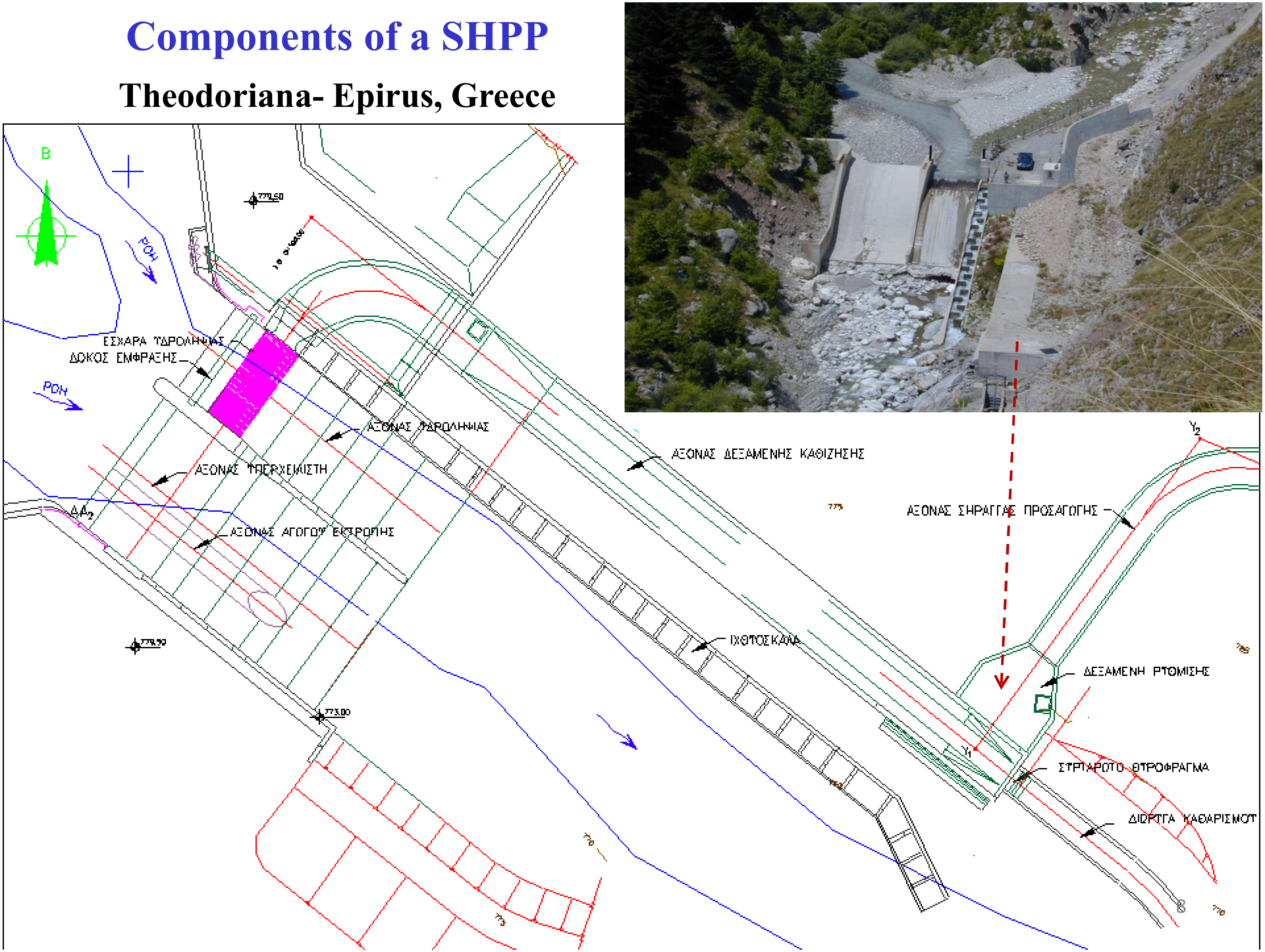
Components of a SHPP

Theodoriana- Epirus, Greece

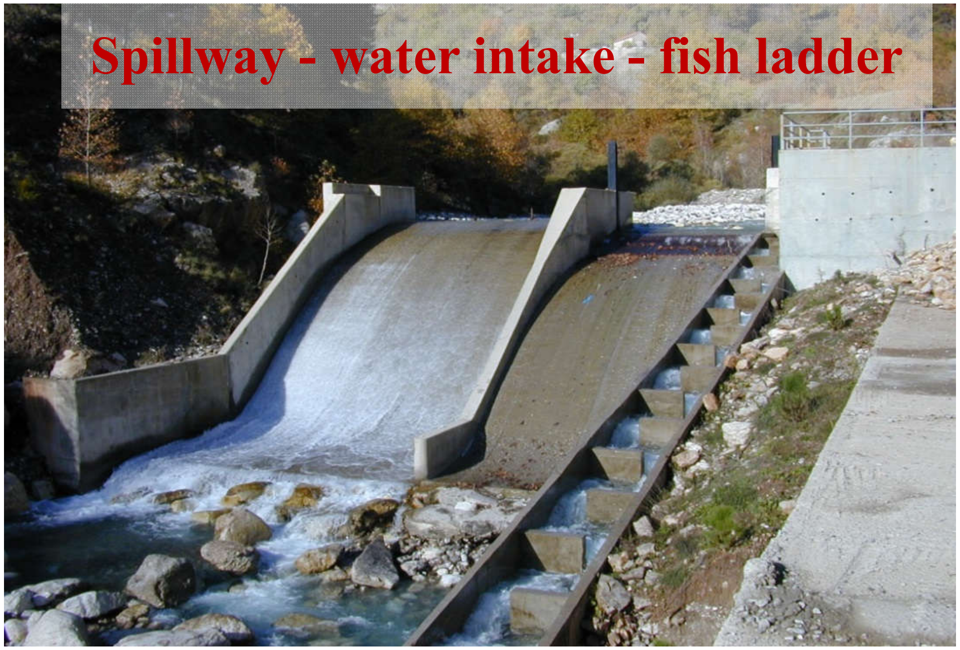


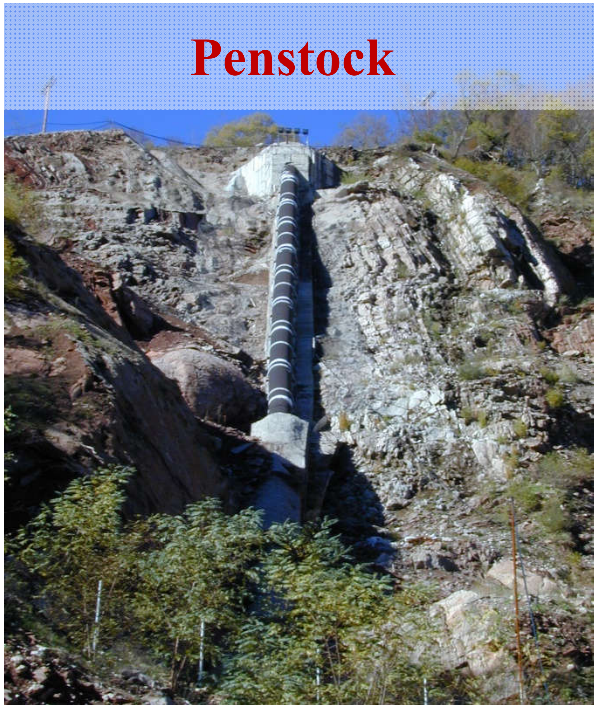
Components of a SHPP

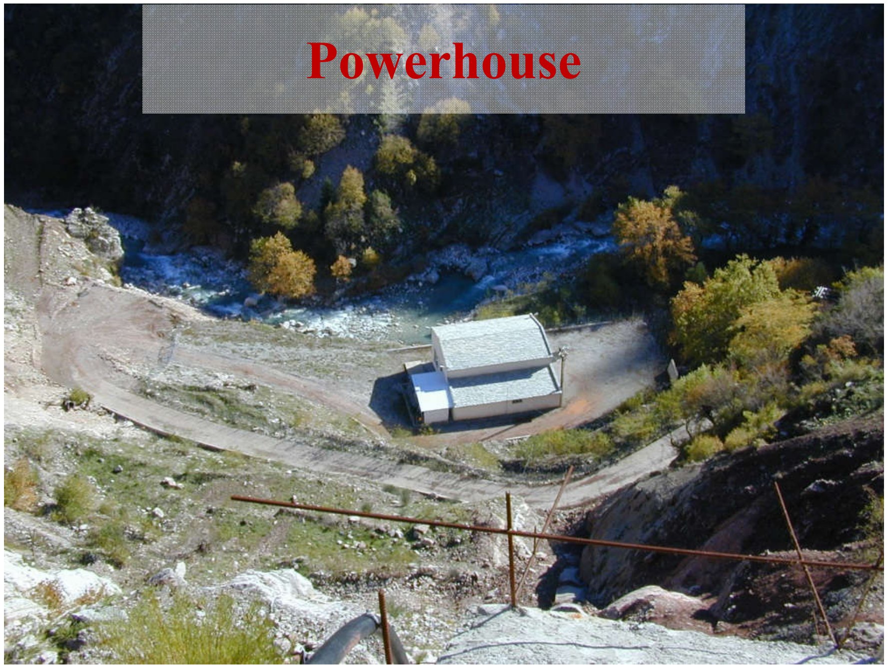
Theodoriana- Epirus, Greece



Components of a SHPP







Components of a SHPP

Thermorema - Sterea Hellas

Installed power 1.95 MW, 2003

Desilter (sand traps)

Trash rack of water intake

Headwater channel - sand traps

Forebay tank

Penstock

Photos: ΔΕΛΤΑ Project

SHPPs –Sediment management

Bed load, suspended load and floating sediment

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 that of the water flow. The main movement mechanisms are sliding, rolling or hopping

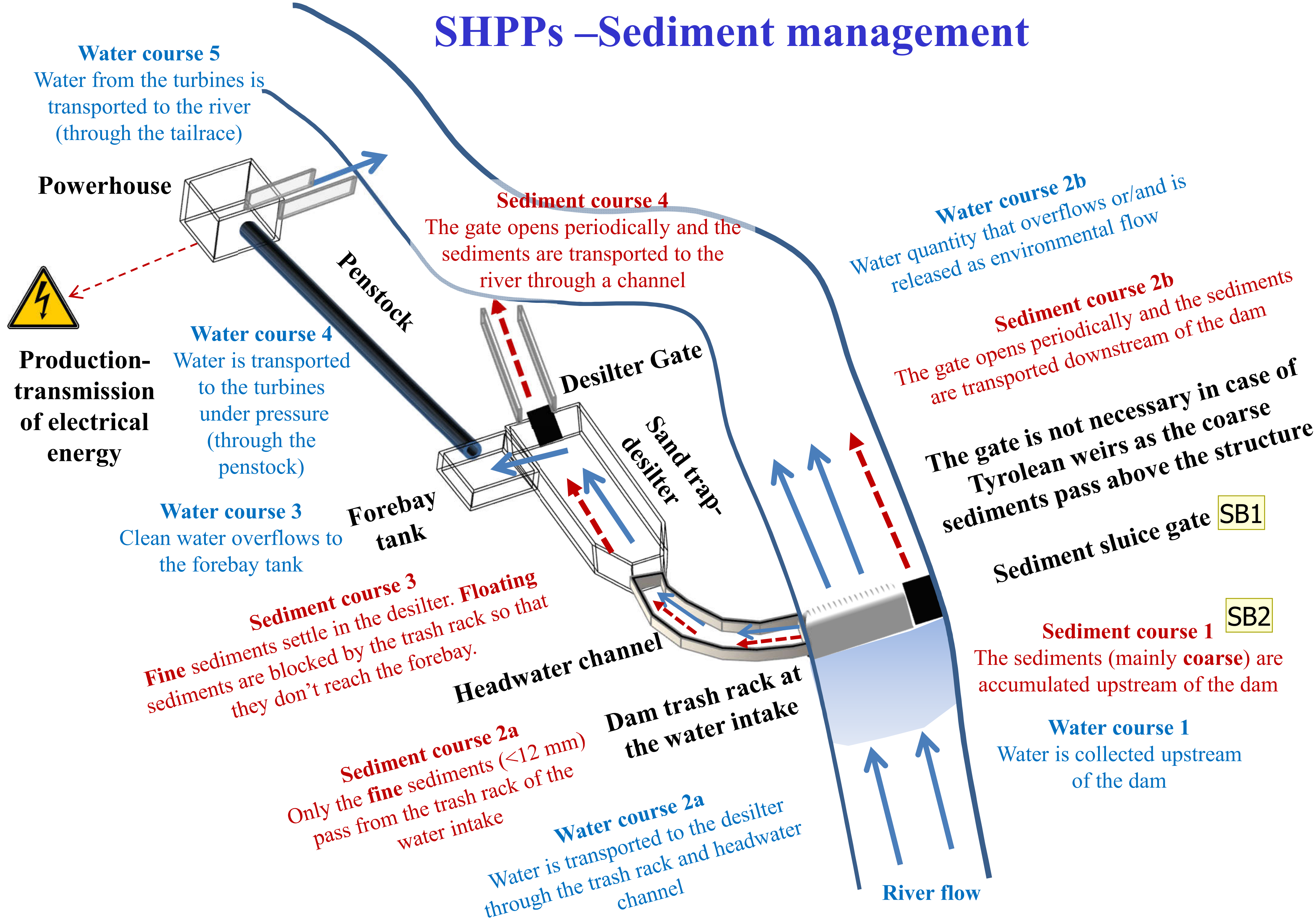
Suspended load

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

Floating sediments

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

SHPPs –Sediment management



Slide 12

SB1 The term "sediment release gate" is not used. "Sediment sluice gate" is used
Sandra Baki, 26-Mar-19

SB2 The term is "sediment transport", not "sediments' transport", same goes for "sediment course"
Sandra Baki, 26-Mar-19

Components of a SHPP

Drop intake - Tyrolean weir - water intake for mountainous regions

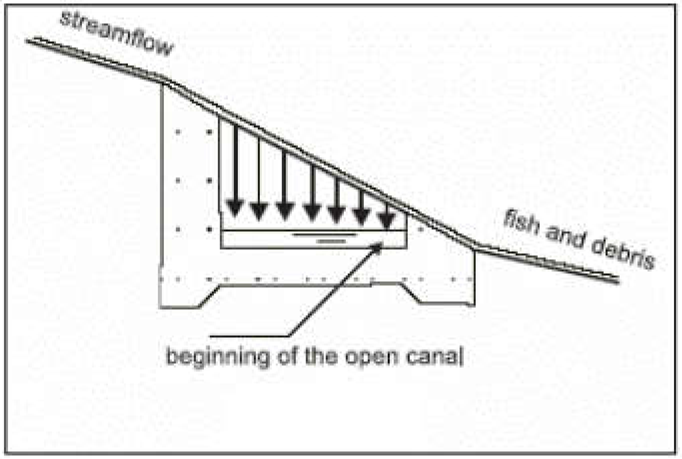
Kerasovo-Epirus

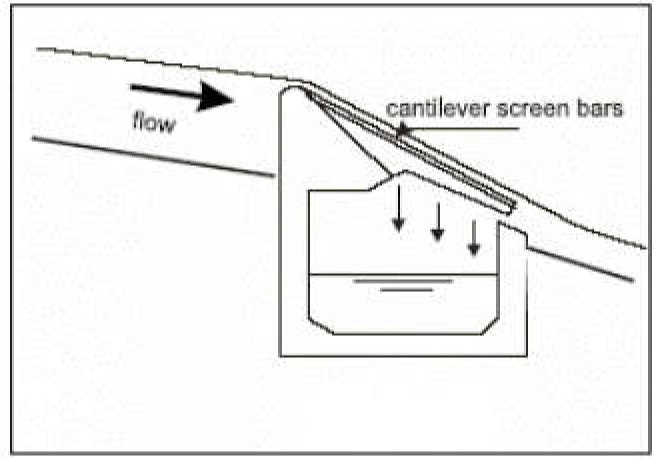
Source: http://www.sofios.gr/projects

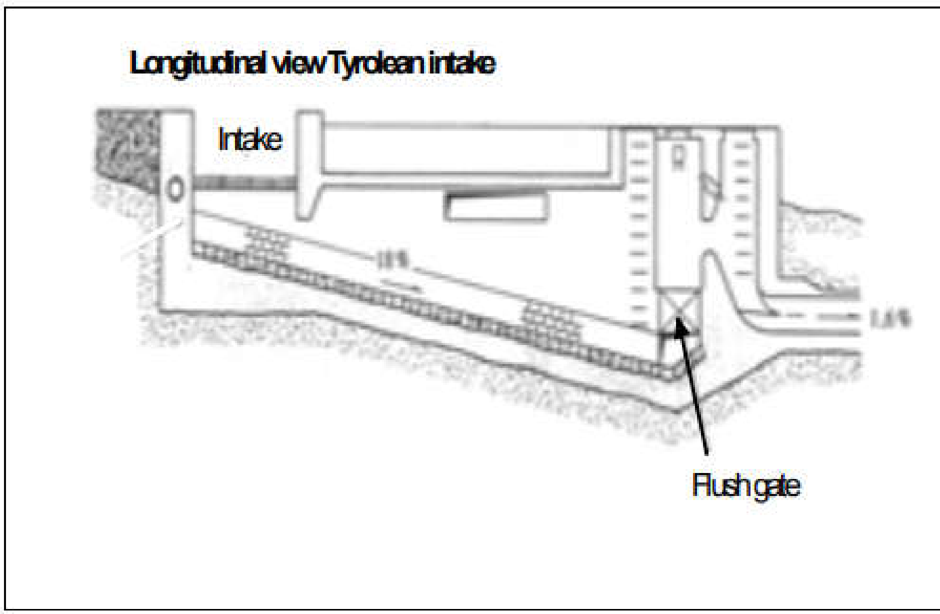
- **Tyrolean weir** is a water intake structure in which water is abstracted from the main flow through a trash rack (screen) over a gutter.
- The gutter is usually made of concrete and built into the river bed.
- The trash rack on the crest should slope downstream (15-30 degrees), to increase flow velocities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

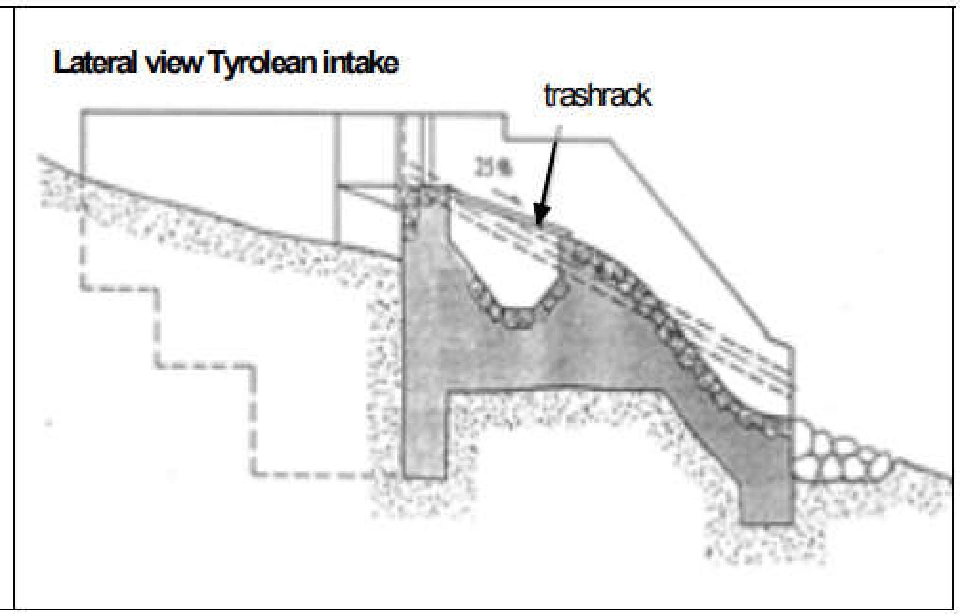
Components of a SHPP

Drop intake - Tyrolean weir - water intake for mountainous regions





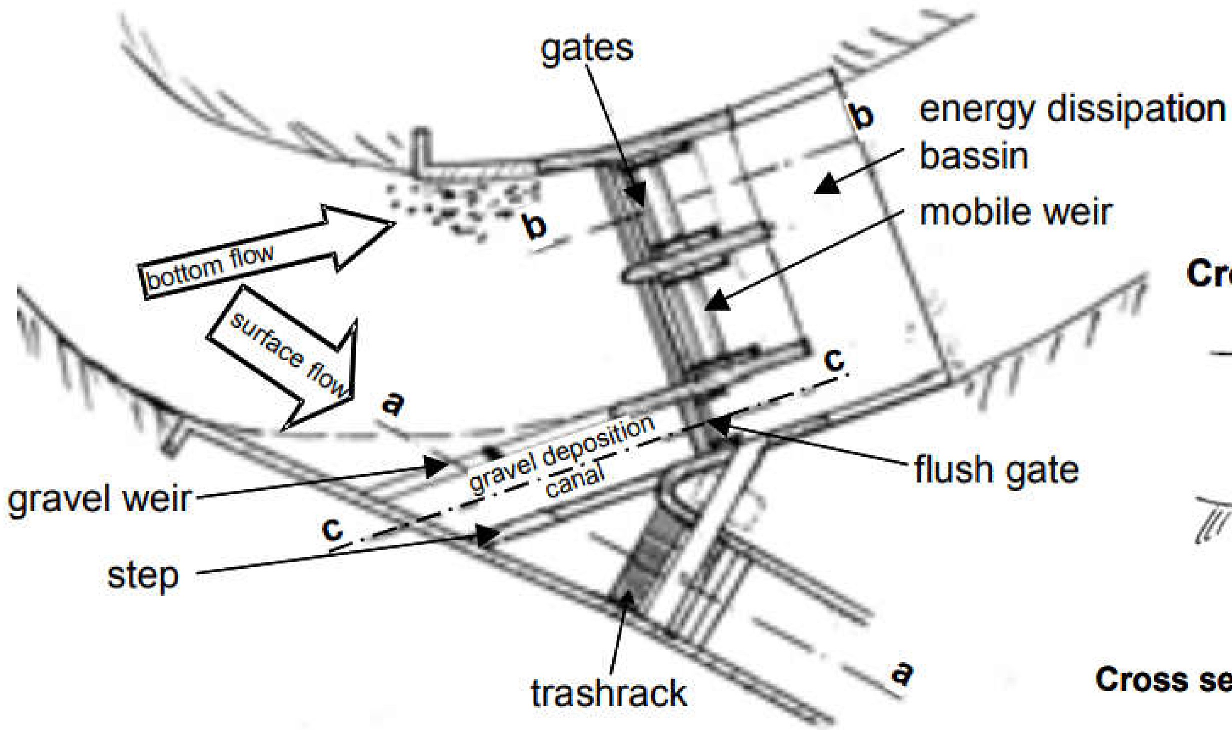




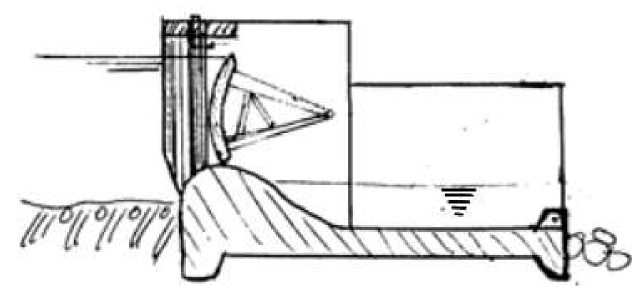
Source: Guide on How to Develop a Small Hydropower Plant, European Small Hydropower Association (ESHA), 2004

SHPPs – Lateral intake - Sediment management

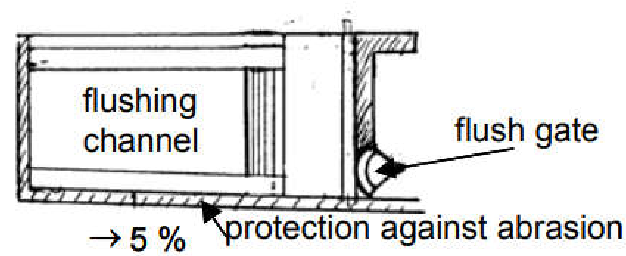
Plan view



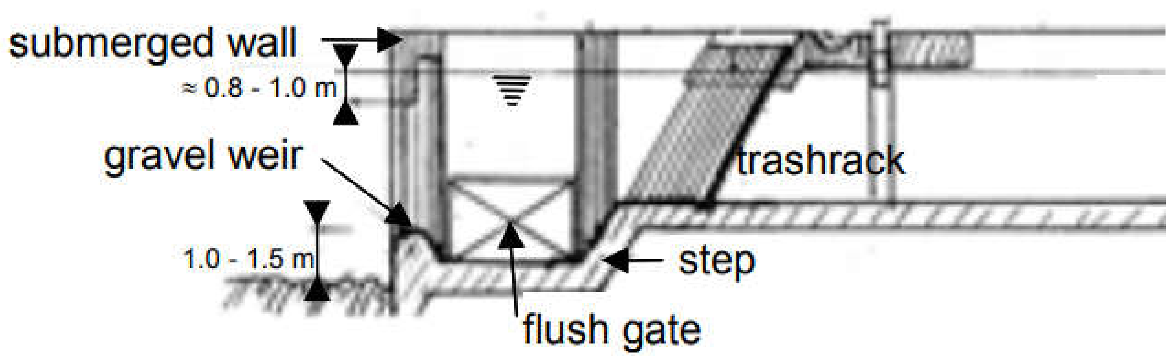
Cross section b - b : Weir /dam



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

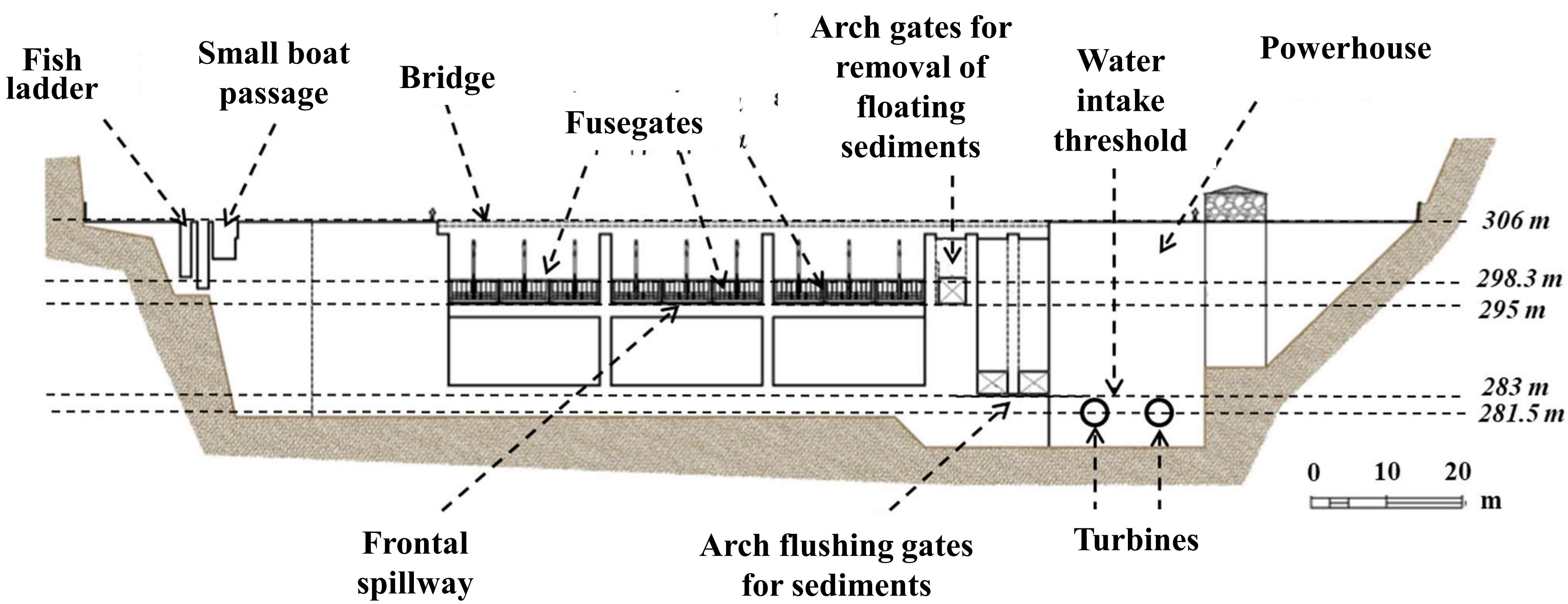
SHPPs –Sediment managment

Dafnozonara

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

Spillway and fusegates

Fish ladder and small boats passage



SHPPs as an additional project

Agia Varvara (0.92 MW)

Thessaloniki water supply 7 m^3/s

Source: PPC Renewables

It has been 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. It operates from 2008 and has mean annual electrical energy production of **4.5 GWh.**

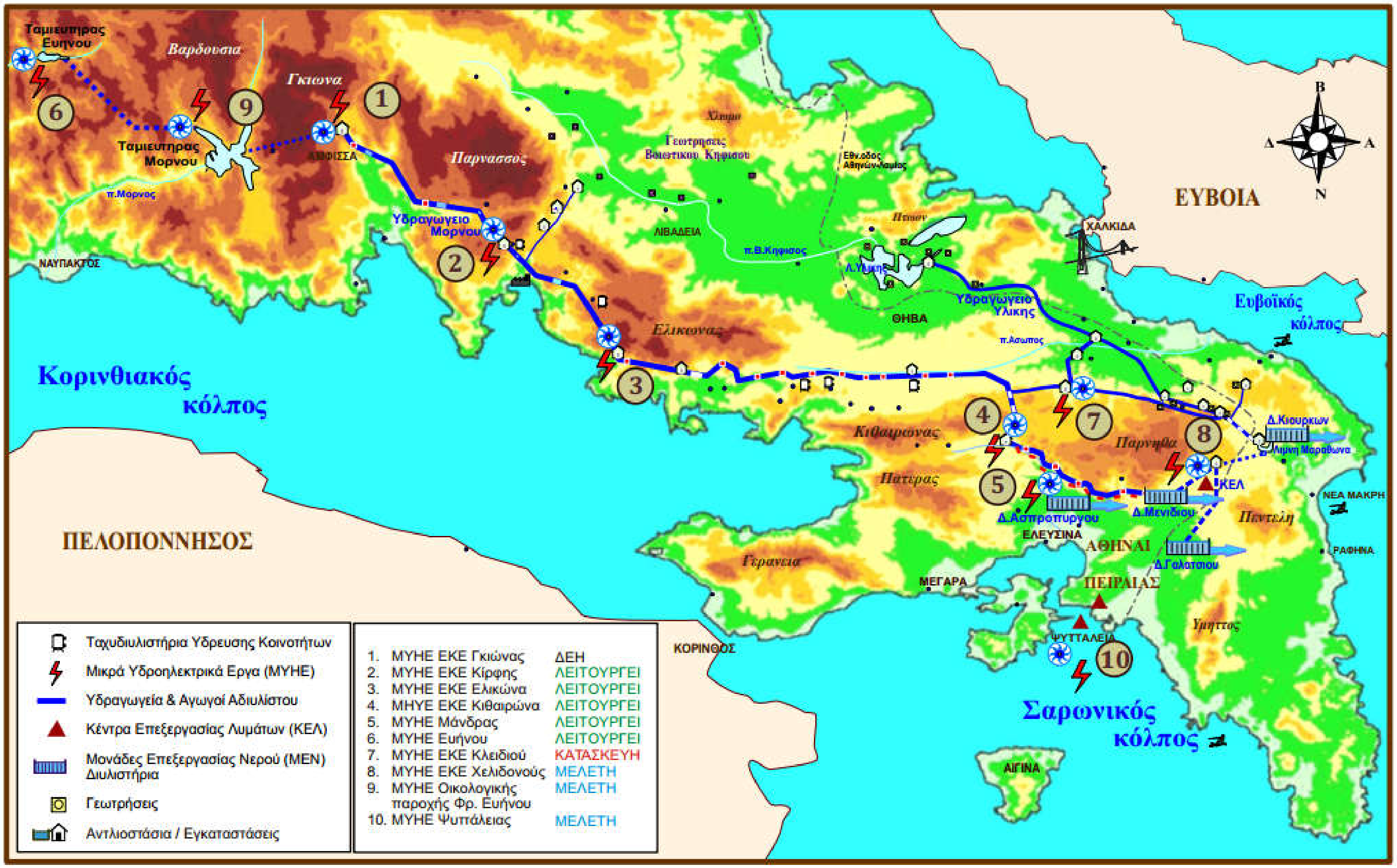
I (kW) = g * n* H (m) * Q (m^3/s)

$g = 9.81\ m/s^2$ $\quad$ $n = 0.90$ $\quad$ $Q = 4.5\ m^3/s$ $\quad$ $H = 23\ m$ $\quad$ $I = 920\ kW$

SHPPs as an additional project

Aqueducts of the Athens Water Supply System (EYDAP)

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)*

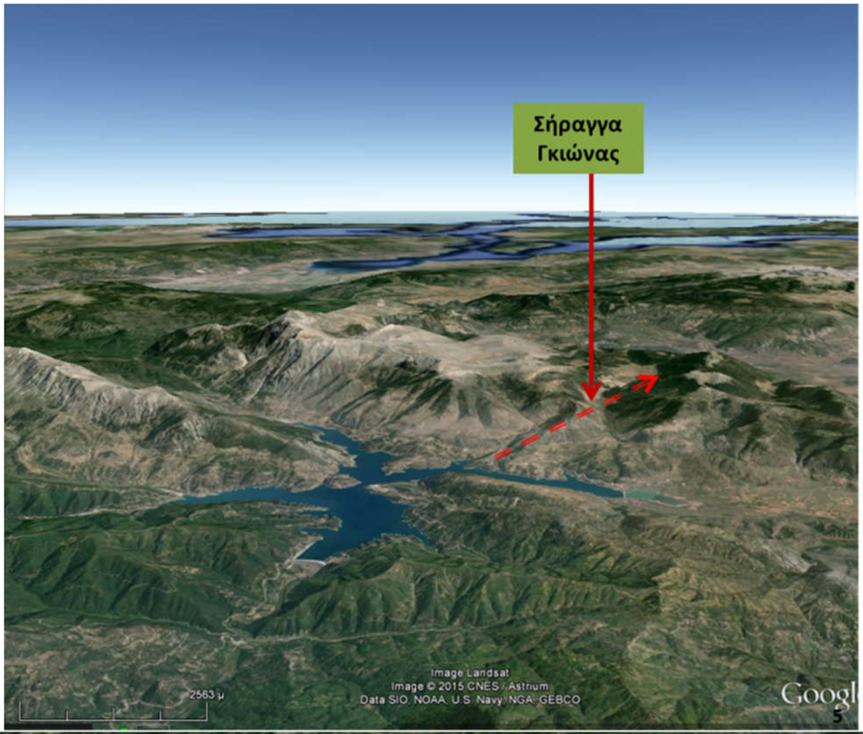
Source: EYDAP

Slide 18

SB4 I think it's better to put the Athens Water Supply System instead of only EYDAP
Sandra Baki, 26-Mar-19

SHPP as an additional project

Aqueducts of the Athens Water Supply System



The most significant SHPP on the Athens aqueduct is Giona that 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 m3/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.

$$\mathbf{I\ (kW) = g * n * H\ (m) * Q\ (m^3/s)}$$

$g = 9.81\ m/s^2$ $\quad$ $n = 0.90$

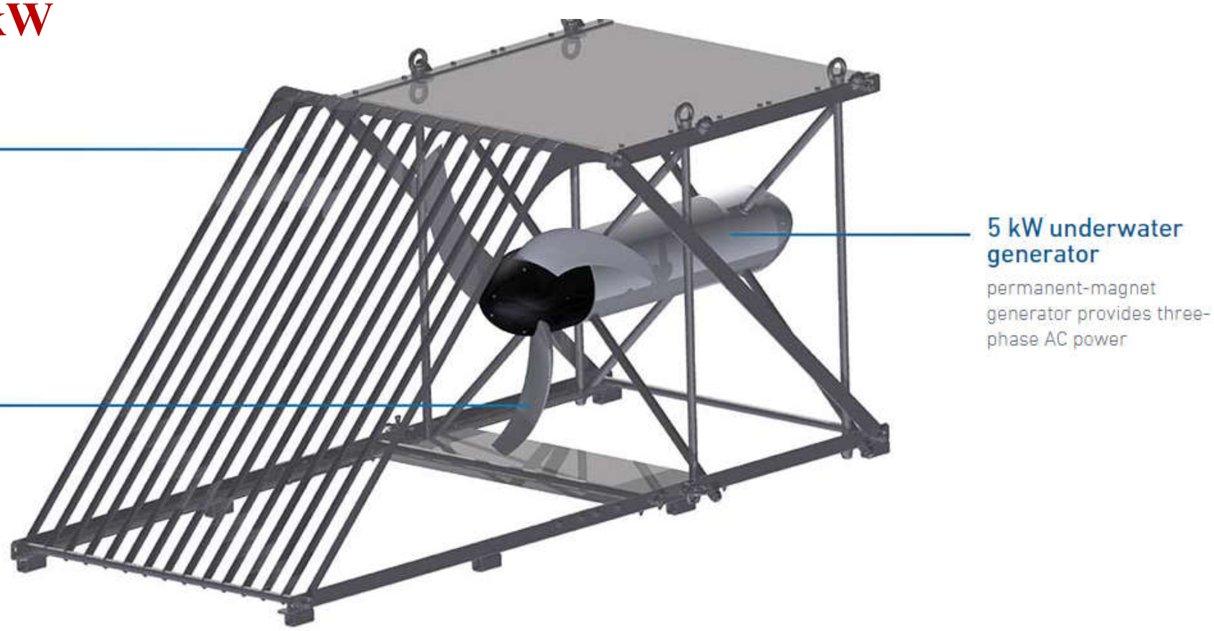
$Q = 14.5\ m^3/s$ $\quad$ $H = 66.1\ m$

I= 8.5 MW

In-stream projects

River current turbines

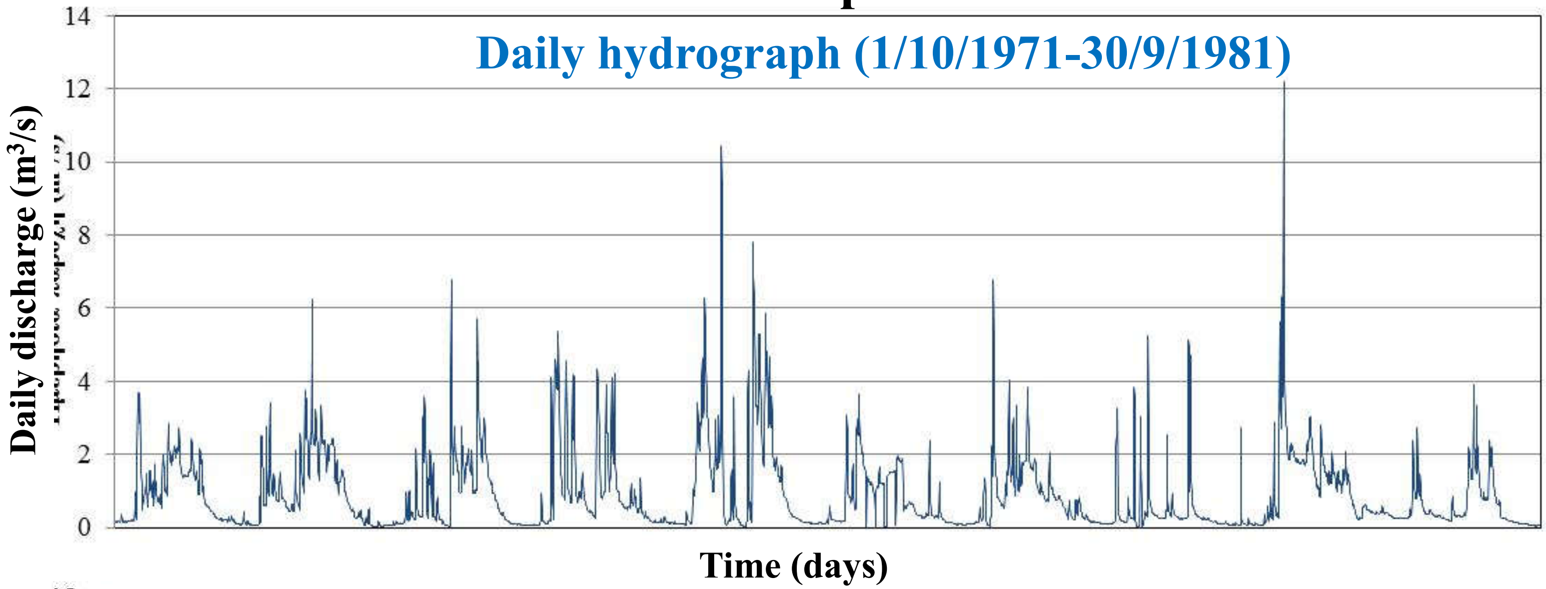
Smart free stream: **5 kW**

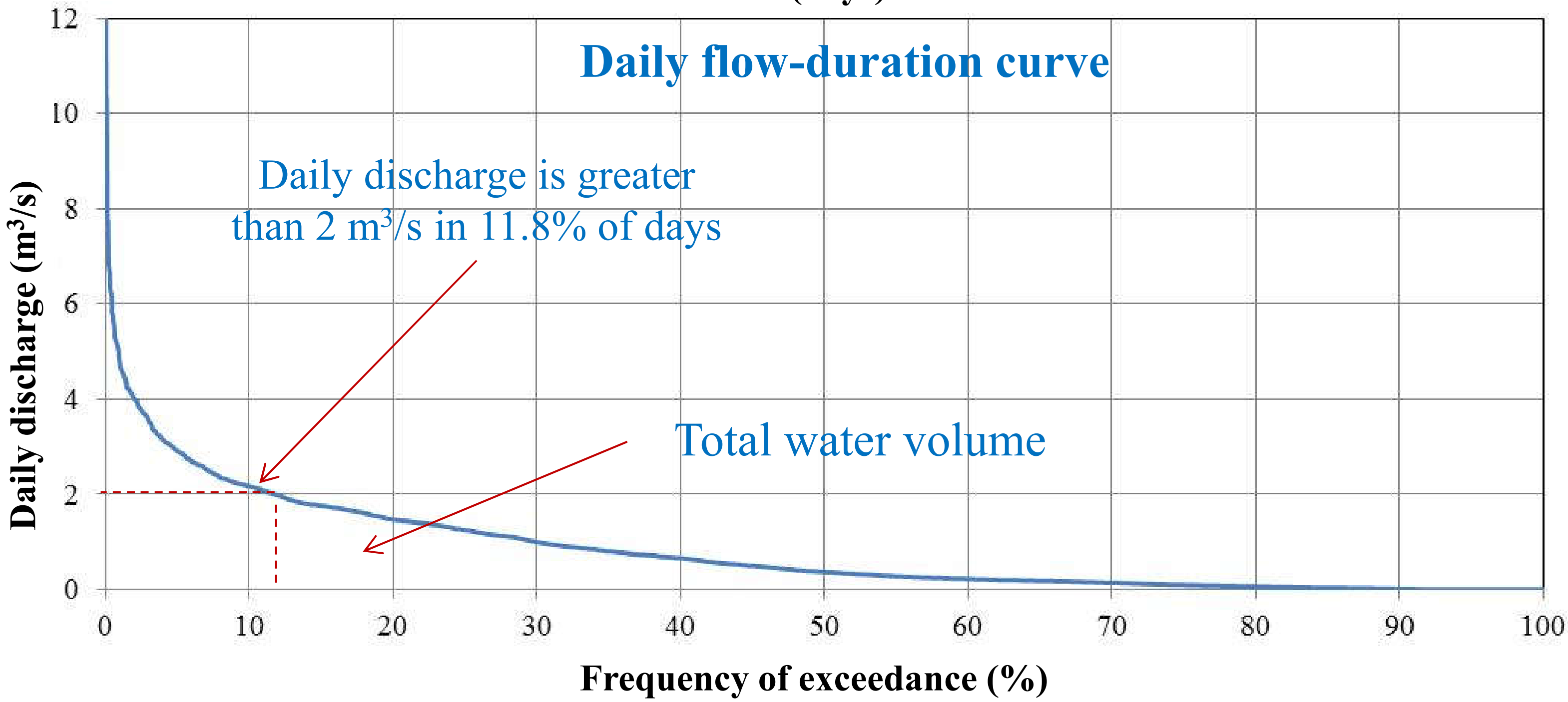


HydroQuest River: **80 kW**, Minimum water head: **4.2 m**, Nominal current flow velocity: **3.1 m/s**

Design of SHPPs

Water potential





Design of SHPPs

Environmental flow

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

- the historical flows of the river (water flow regime)
- the 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 environmental flow 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 lt/sec in any case.*

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

The first known flow regulation rule

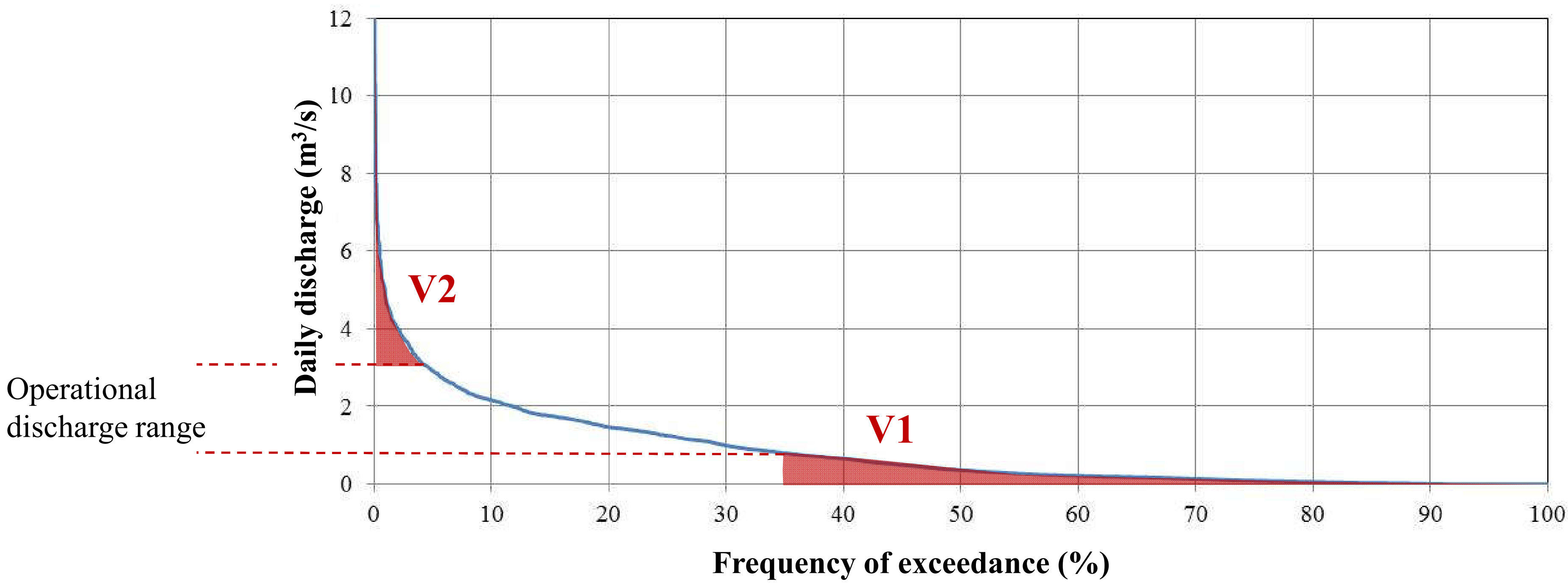
It is saved in an epigraph of the 5th century BC in the ancient city of Gortyn in Crete. The city is crossed by the river Lithaios, which dominates the valley of Messara

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 of SHPPs

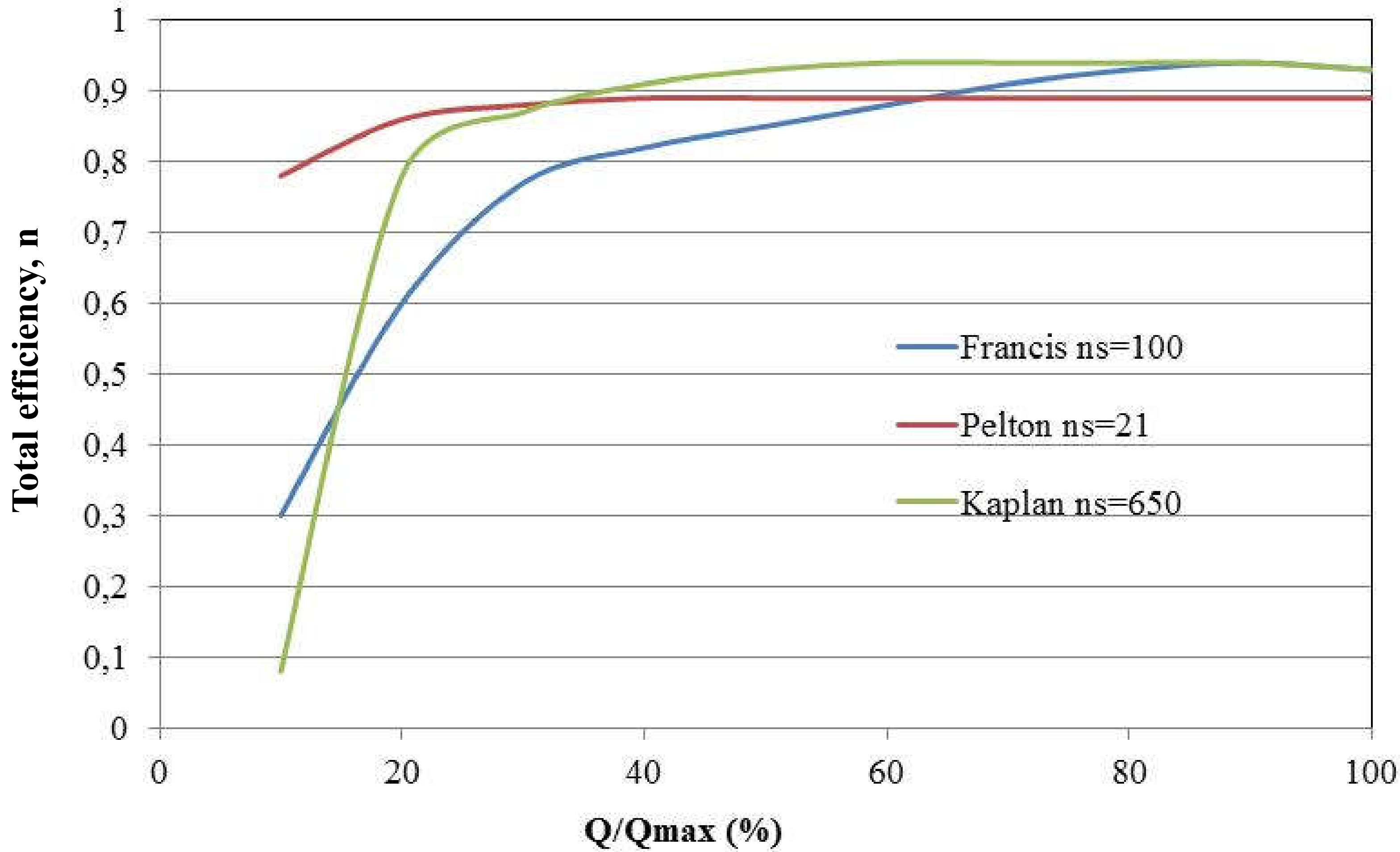
Limitations

- 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 V1 and V2 are not exploited for energy production. The volume V1 depends on the minimum operational discharge of the smallest turbine and volume V2 depends on the maximum operational discharge of the largest turbine
- The minimization of volumes V1 and V2 is achieved with the combination of several turbines with different installed power
- 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%



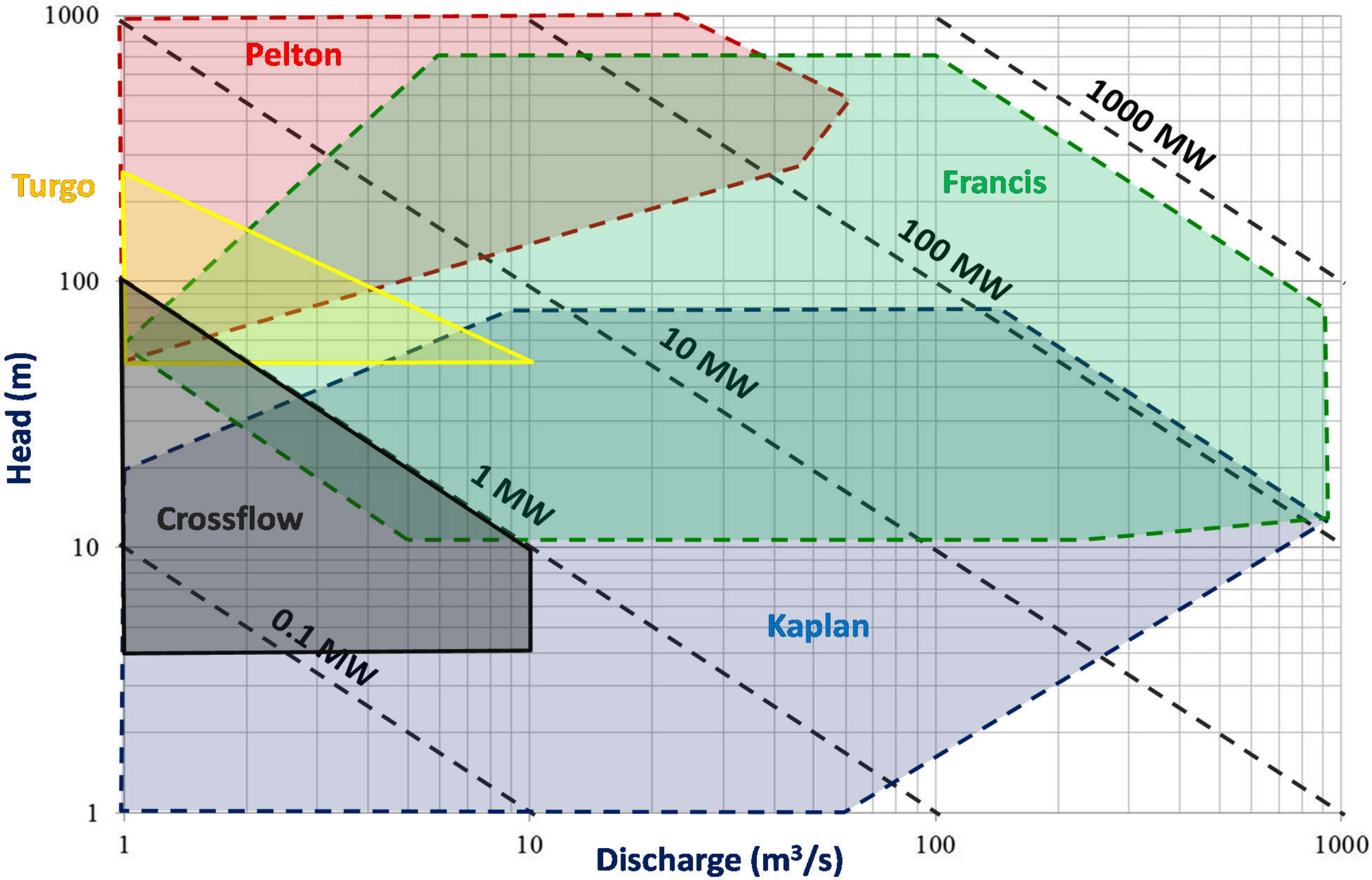
Design of SHPPs

Efficiency curves



Design of SHPPs

Operational ranges of different turbine types



Design of SHPPs

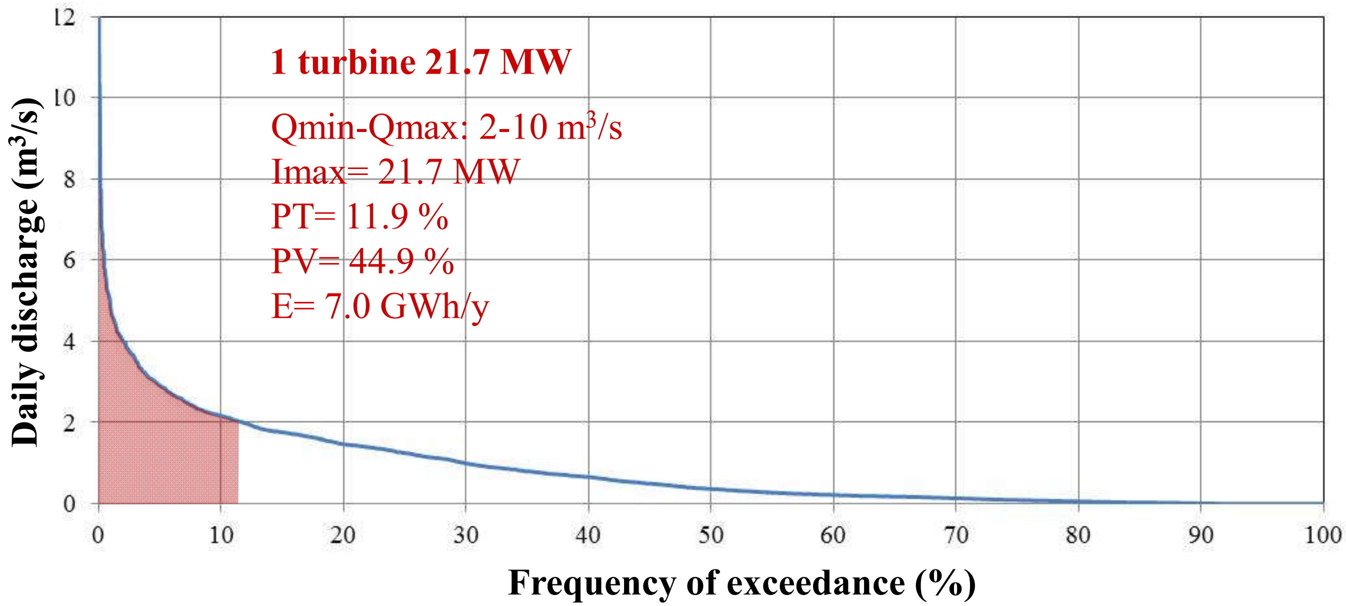
Data

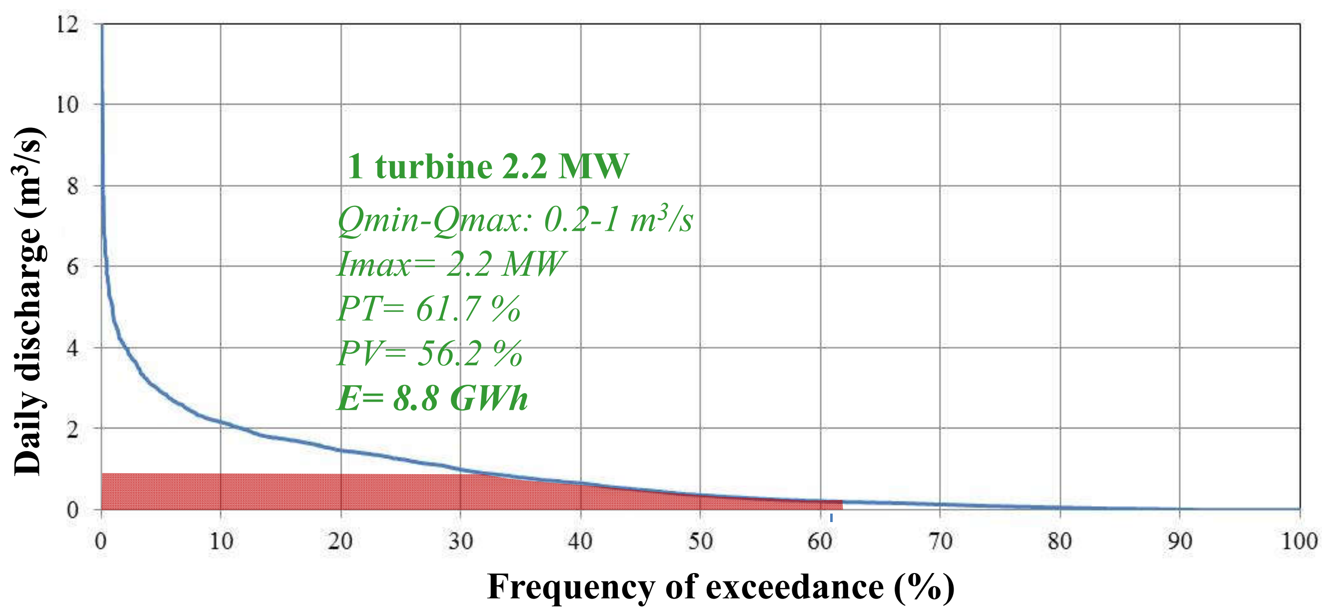
H=260 m
ρ=1000 kg/m^3
g=9.81 m/s^2
n=0.85

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

Turbine Selection





Legend

Qmin, Qmax: Minimum, maximum exploitation discharge (m^3/s)

SB5

Imax: Power in maximum exploitation discharge (MW)

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

PV: Percentage of water volume used (%)

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

Slide 26

SB5 Not sure of this term, maybe there is something else used?
Sandra Baki, 26-Mar-19

Design of SHPPs

Selection of turbines

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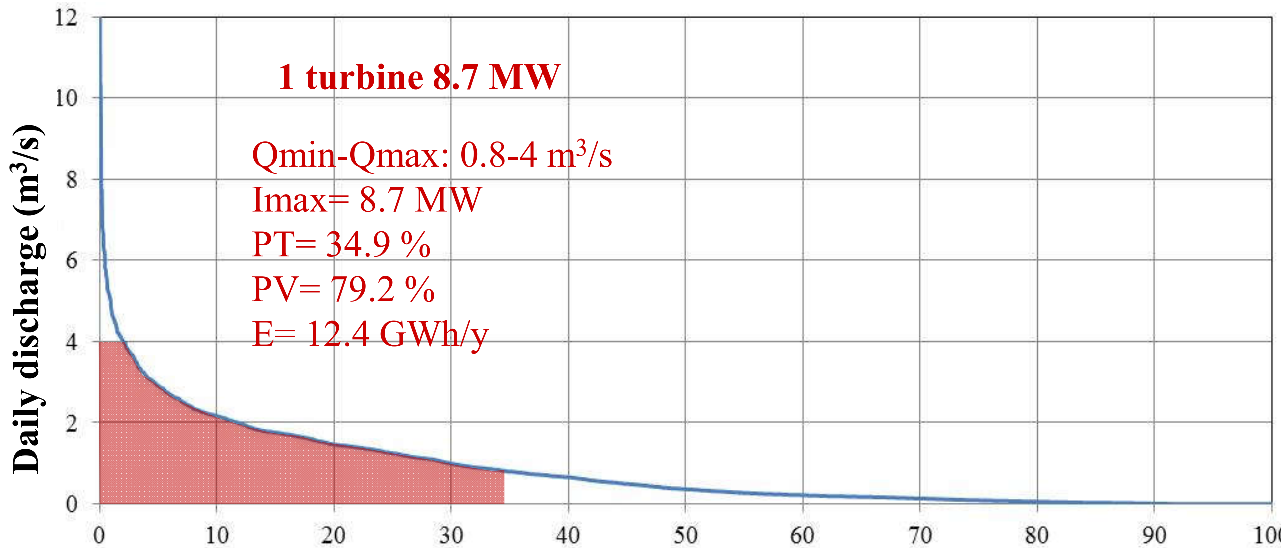

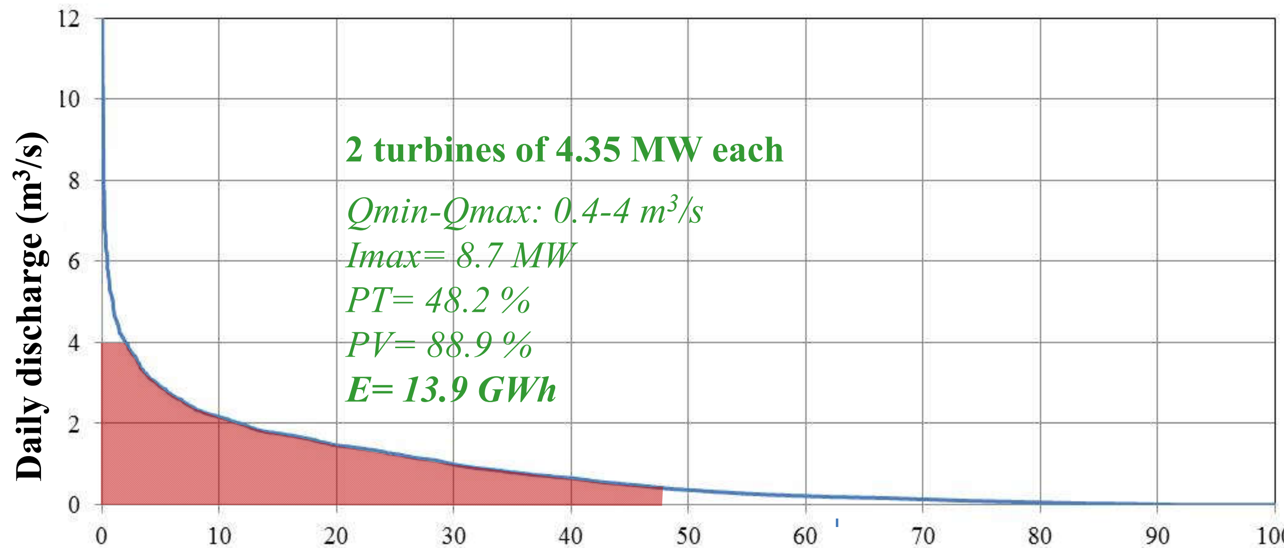

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Design of SHPPs

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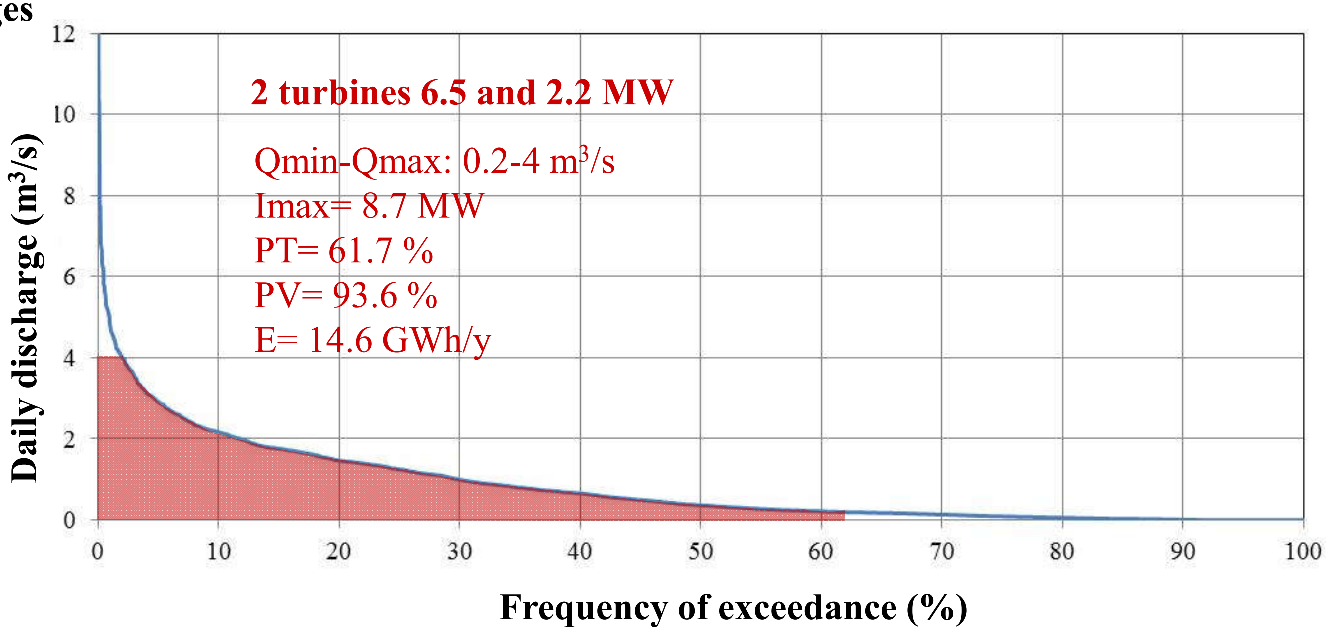
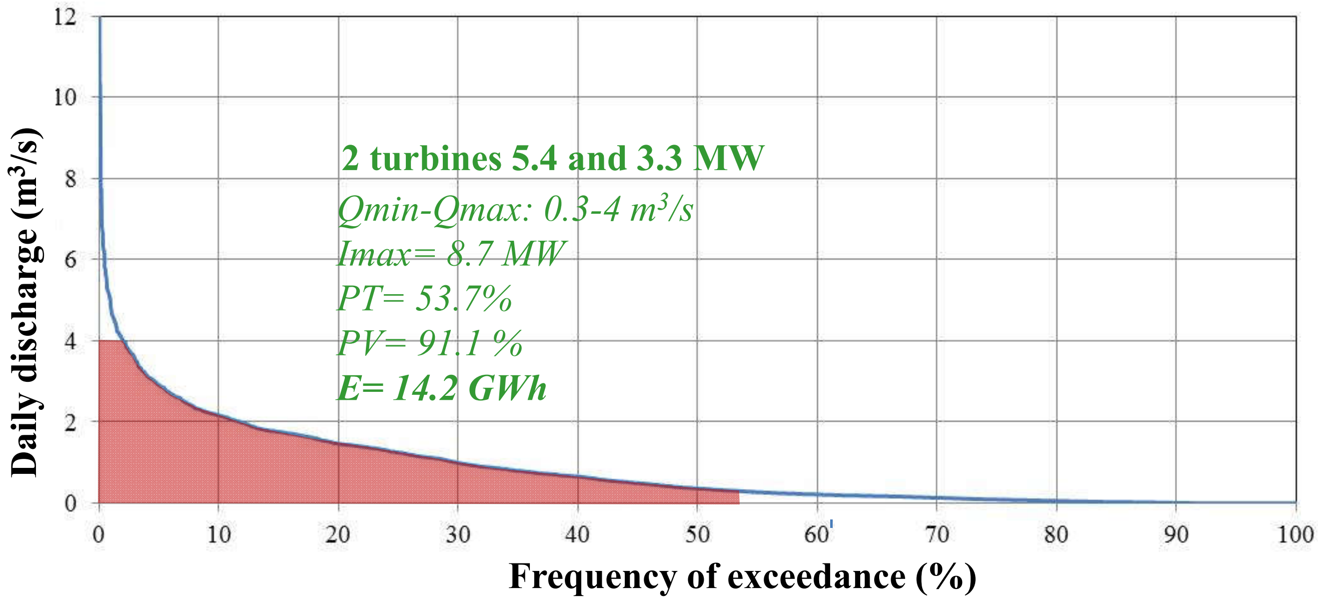
Selection of turbines





Legend

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Design of SHPPs

Flow duration curve application

$$P(Q) = 1 - F(Q) = (1 + Q/10)^{-5}$$

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

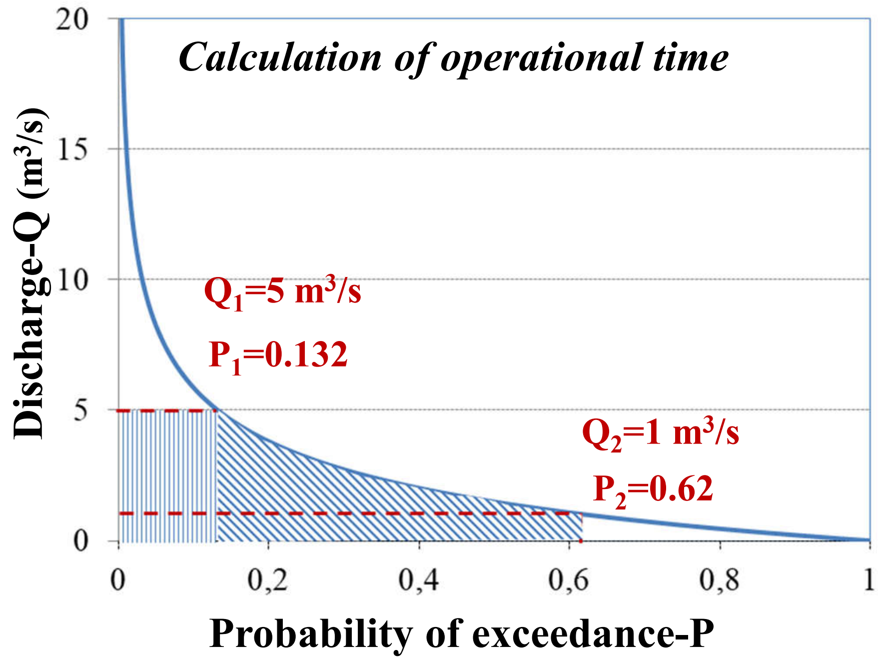
The inverse function is given by the formula:

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

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

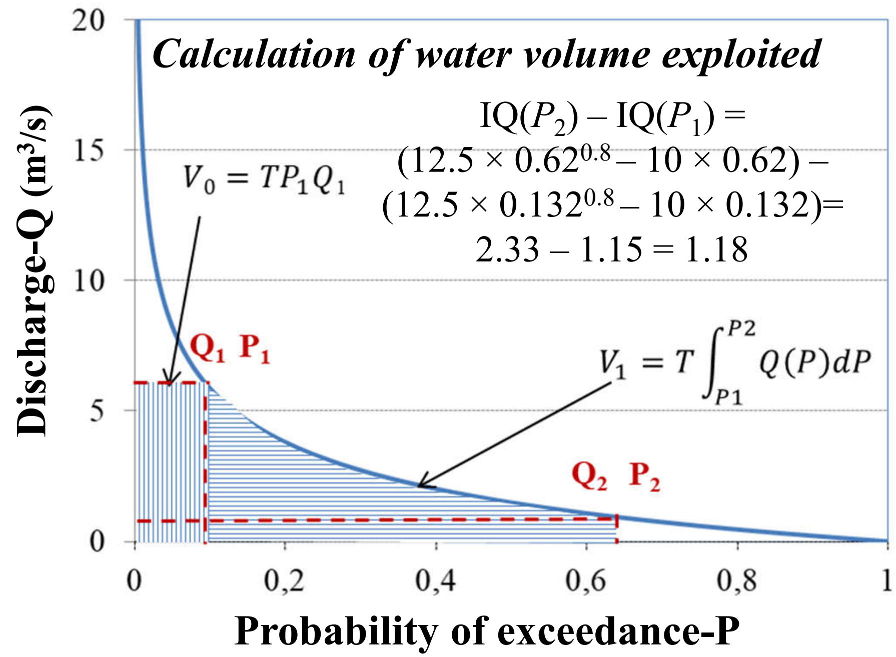
$$\mathrm{IQ} := \int Q(P)\mathrm{d}P = 12.5P^{0.8} - 10P$$

A turbine with an operation discharge range of 1 - 5 m^3/s, is examined



Operational time: **62%**

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



For one-year operation, T =31.56×10^6 s

$V_0 = 31.56 \times 0.132 \times 5 =$ **20.8 hm^3**

$V_1 = 31.56 \times 1.18 =$ **37.1 hm^3**

Exploitation of hydraulic energy

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