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Combined production of electricity and
potable water with a hybrid power plant and
a desalination unit in the island of Kasos,
Dodecanese, Greece



AEOLIAN LAND S.A.

Kasos, 20th of August 2014

Hybrid Power Plants - Introduction

Aim of a hybrid power plant

- ▶ A hybrid power plant for electricity production aims to cover an inflexible power demand, from non-guaranteed Renewable Energy Sources (R.E.S.) power plants.
- ▶ To approach the above target, the R.E.S. power plants should be combined with storage power plants.
- ▶ To ensure the uninterrupted cover of the power demand, the hybrid power plant is integrated with a back-up unit, which aims to undertake the requested power production when no power production is possible either from the R.E.S. or the storage power plant.

Aim of a hybrid power plant

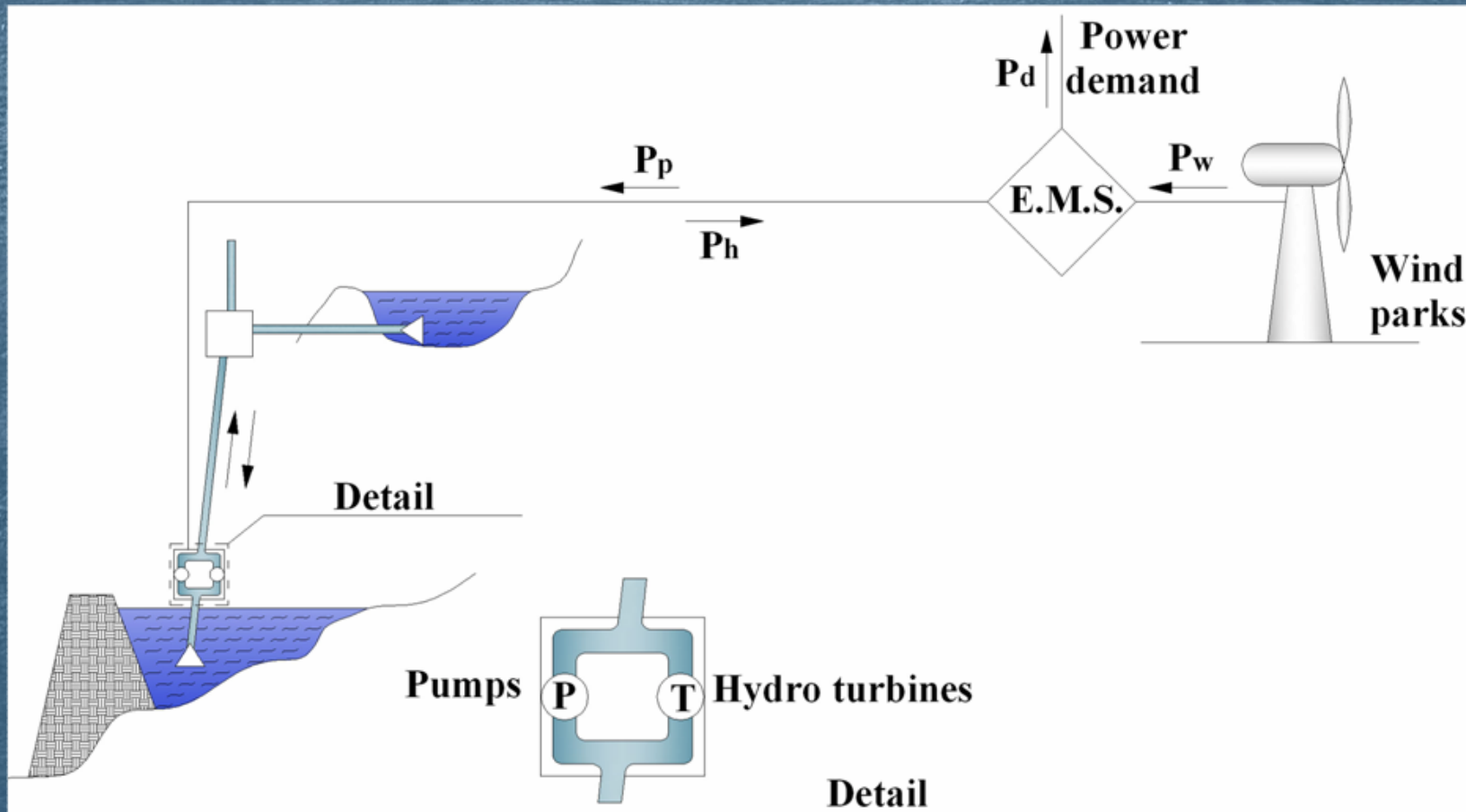
- ▶ According to the abovementioned, a hybrid power plant consists of the following discrete components:
 - ▶ non-guaranteed power production units (base units)
 - ▶ storage units
 - ▶ back-up units.

Hybrid power plants of large size

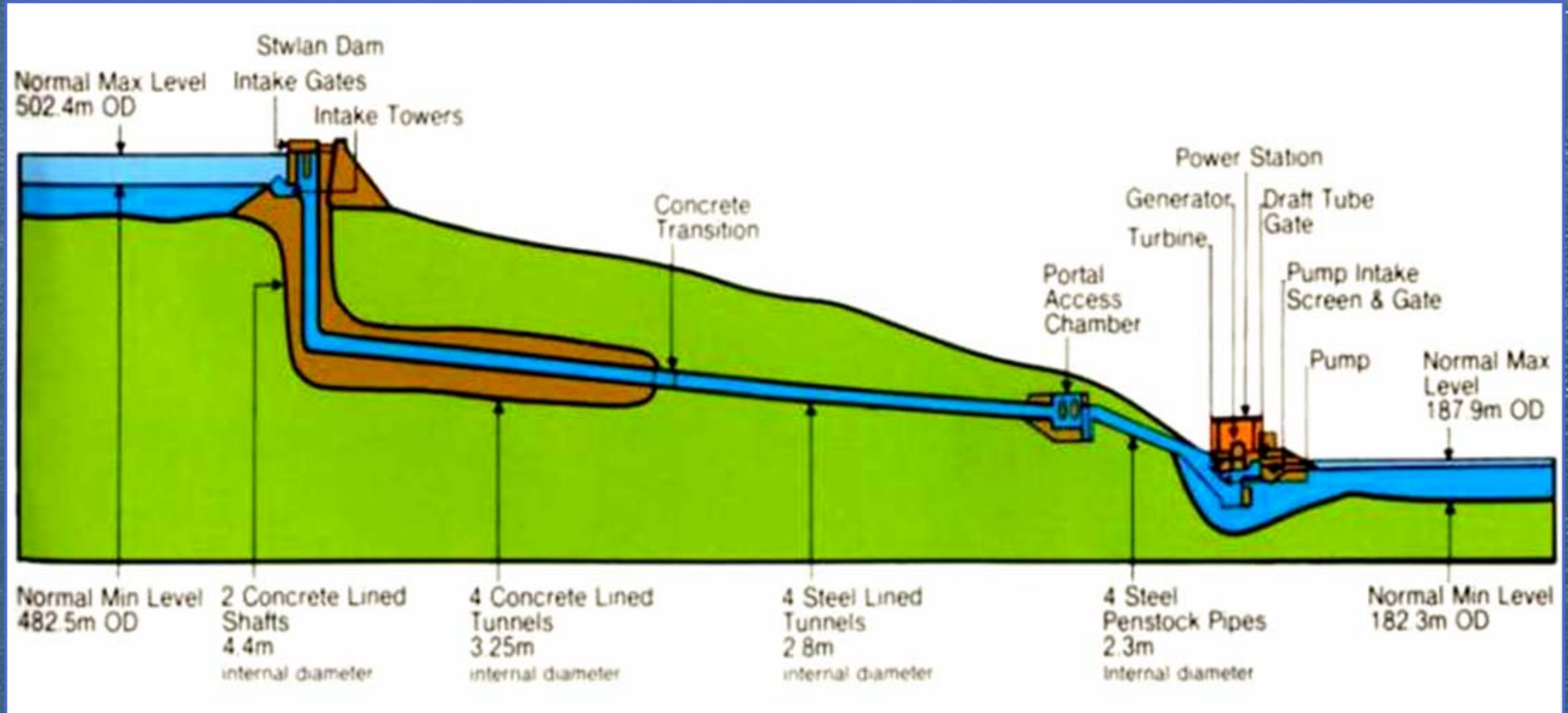
Synthesis of a hybrid power plant of large size

- ▶ The synthesis of hybrid power plants of large size (guaranteed power production higher than 1MW) is approached by composing the following most technically mature and economically competitive technologies:
 - ▶ base units: wind parks
 - ▶ storage power plants: pumped hydro storage systems (PHS).

Synthesis of a hybrid power plant of large size



What is Pumped Hydro Storage



Indicative examples of operating PHS: Goldisthal (Germany)



- ▶ Hydro turbines power: 1.060MW
- ▶ Upper reservoir capacity: $12 \cdot 10^6 \text{m}^3$
- ▶ Net head: 300m.

Indicative examples of operating PHS: Kannagawa & Kazunogawa (Japan)



Indicative examples of operating PHS: Anapo (Sicily, Italy)



- ▶ Hydro turbines power: 500MW
- ▶ Upper reservoir capacity: $5,6 \cdot 10^6 \text{m}^3$
- ▶ Lower reservoir capacity : $7,3 \cdot 10^6 \text{m}^3$
- ▶ Net head: 302m
- ▶ Penstock diameter: 6,5m.



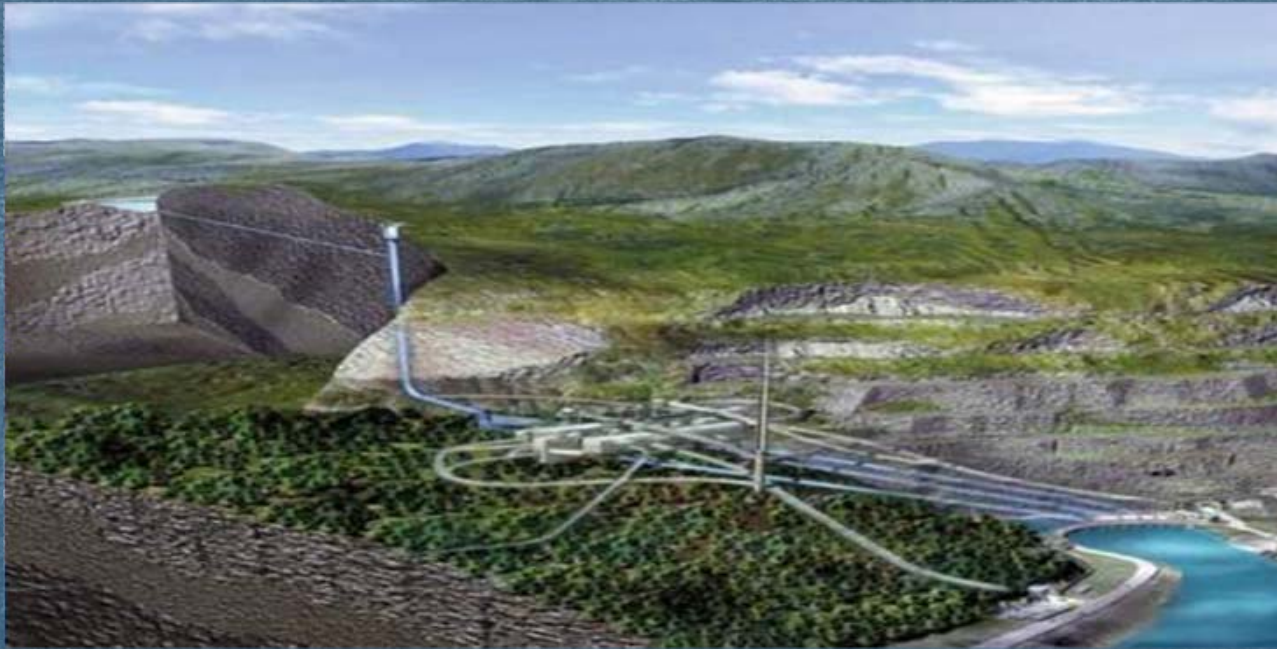
Indicative examples of operating PHS: Okinawa (Japan)



- ▶ Hydro turbines power: 32MW
- ▶ Upper reservoir capacity: $1 \cdot 10^6 \text{m}^3$
- ▶ Net head: 150m.




Indicative examples of operating PHS: : Dinorwig (Whales)



- ▶ Hydro turbines power: 1.728MW
- ▶ Upper reservoir capacity: $7 \cdot 10^6 \text{m}^3$
- ▶ Net head: 110m.

Indicative examples of operating PHS: : Raccoon Mountain (U.S.A.)




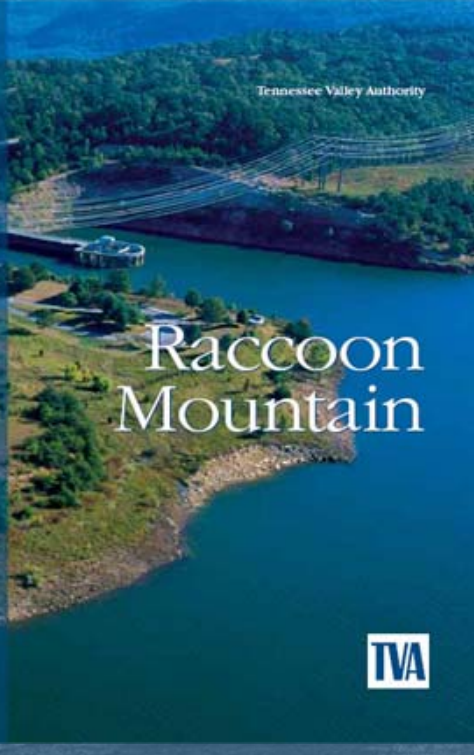


Visitor Center
Open daily except major holidays
9:00 a.m. to 5:00 p.m.

TVA is proud of Raccoon Mountain Pumped Storage Plant and the benefits it provides to local and regional residents. Enjoy your visit, and thank you for taking the time to learn more about TVA power plants. If you have additional questions, please see a Visitor Center staff member. Also visit www.tva.com for further information about the Tennessee Valley Authority, including annual and environmental reports, events, history, and facilities.

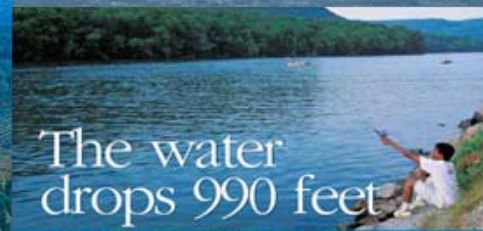
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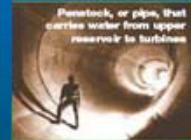
Tennessee Valley Authority

Raccoon Mountain

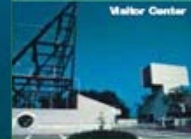


The water drops 990 feet

from the upper reservoir at Raccoon Mountain Pumped Storage Plant to the turbines deep inside the mountain. After the water is used to generate electricity, it is discharged into the lower reservoir.



Penstock, or pipe, that carries water from upper reservoir to turbines



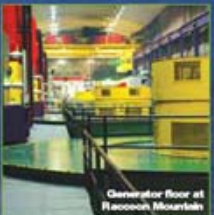
Visitor Center

Many people considered it a crazy idea when the plant was built in the 1970s. But Raccoon Mountain has proved its worth to the TVA system, providing power during periods of peak demand for electricity.


- Upper dam height 230 foot
- Upper dam length 8,500 feet
- Power capacity 4 units supplying 1,532 megawatts
- Upper reservoir length 1.2 miles
- Built 1970-78

How does a pumped storage plant work?

Water is pumped from the lower reservoir to the upper one during periods of low demand. It's stored there until power is needed, and then water is pulled from the reservoir and into a large concrete pipe that leads almost 1,000 feet down inside the mountain. The flow of water spins the turbines, which rotate a shaft inside an electromagnetic coil, producing electricity. When power generation isn't needed, the turbines operate in reverse, pumping water back up into the upper reservoir.

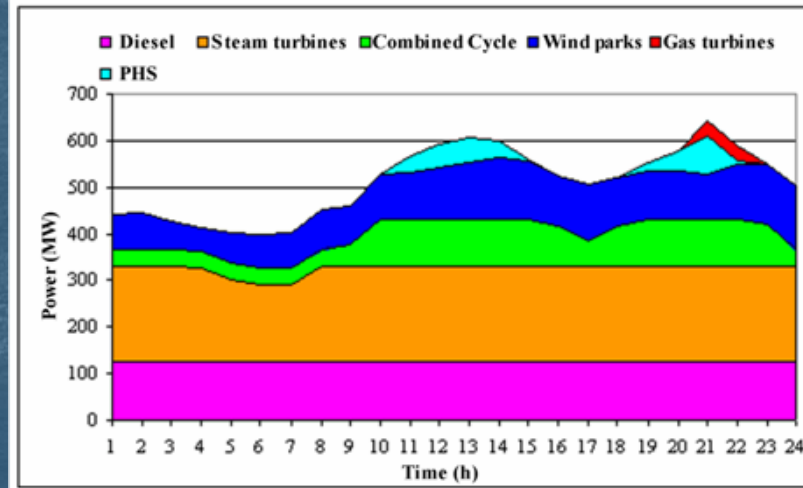
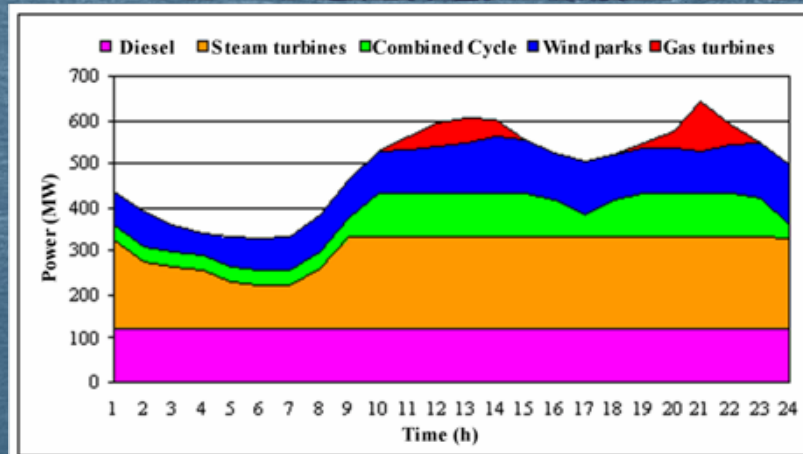


Generator floor at Raccoon Mountain



- Fishing
- Powerhouse
- Visitor Center
- Picnic Area
- Overlook
- Baseball
- Volleyball
- Boat Launch

Hybrid power plants for power peak shaving



Hybrid power plant of Kasos

The siting of the hybrid power plant's wind park in Kasos

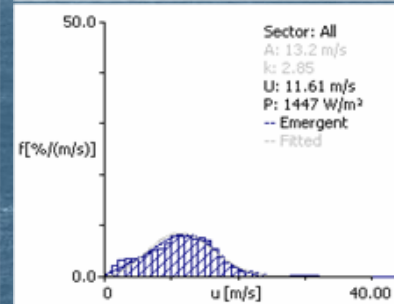
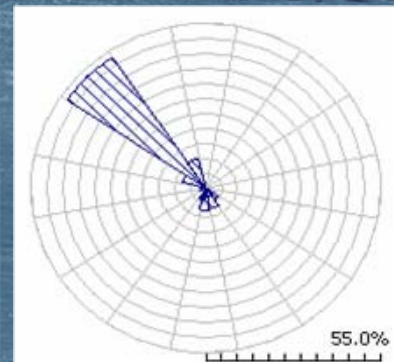


Wind potential measurements in the wind parks' installation site



Wind mast installation position coordinates	WGS'84	Latitude	35° 24' 54.70'' B
		Longitude	26° 58' 46.40'' A
Measurements period	Since	14/5/2010	
	To	14/5/2011	
	Duration (months)	12	
Measurements height above ground (m)			22,5
Measurements position absolute altitude (m)			584,0

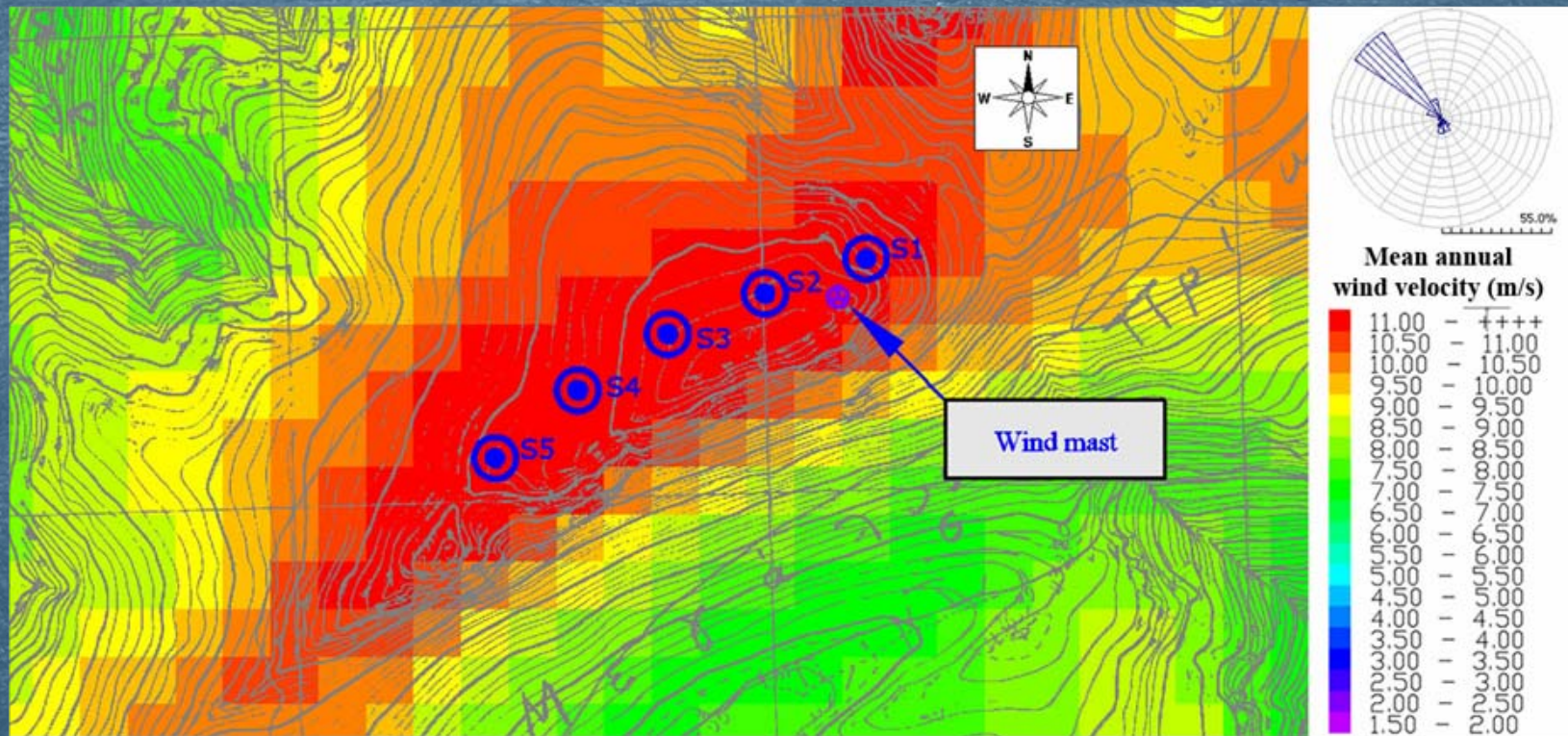
Wind potential measurements in the wind parks' installation site



Weibull parameters	C (m/sec)	13,20
	k	2,85
Averaged annual wind velocity (m/sec)		11,61
Wind power density (W/m ²)		606,5

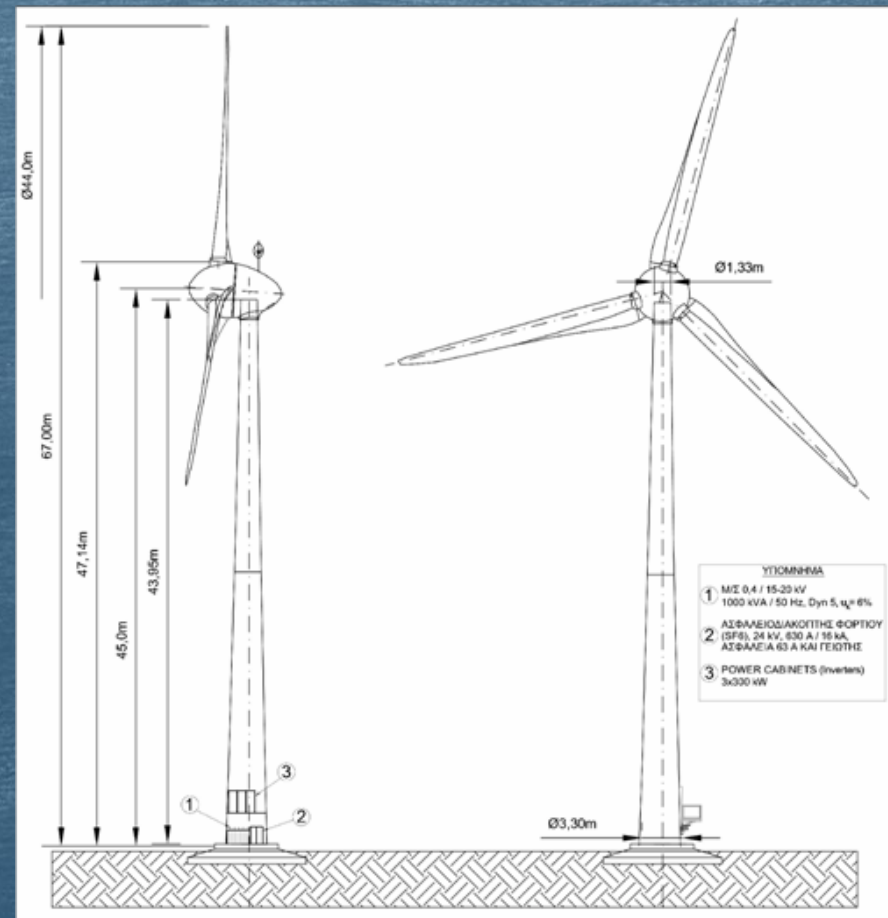
Wind potential map

Wind park siting

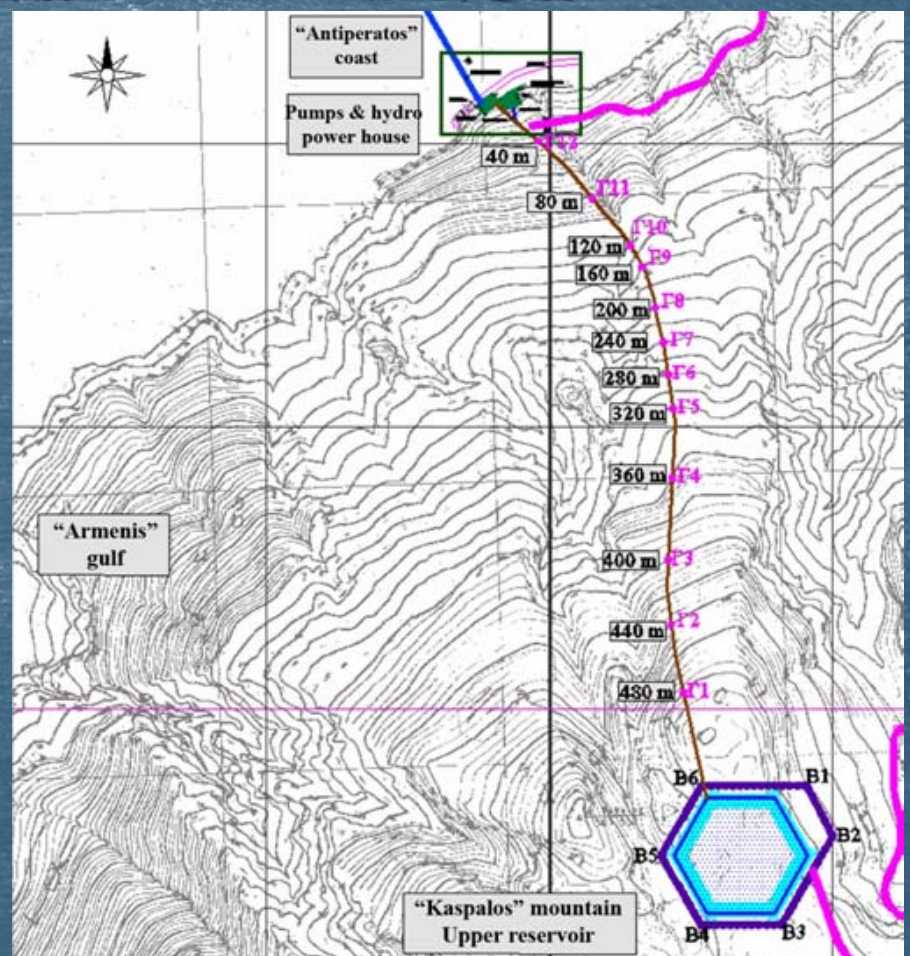


- ▶ Wind park nominal power 4,5MW
- ▶ Five wind turbines Enercon E-44 / 900kW

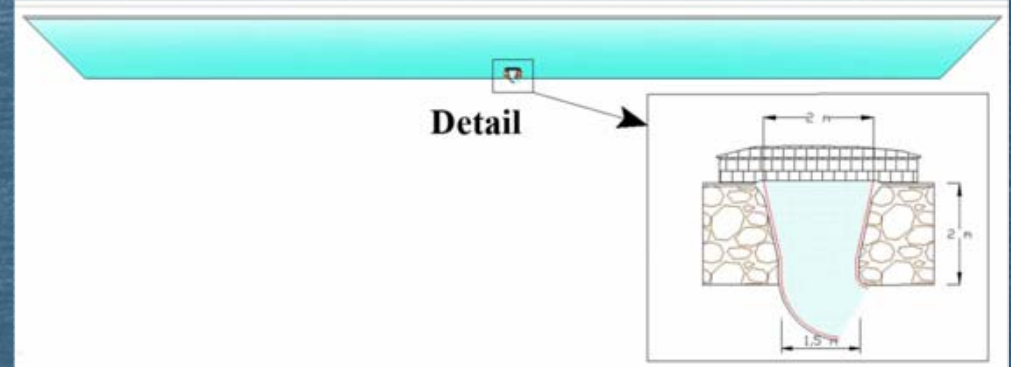
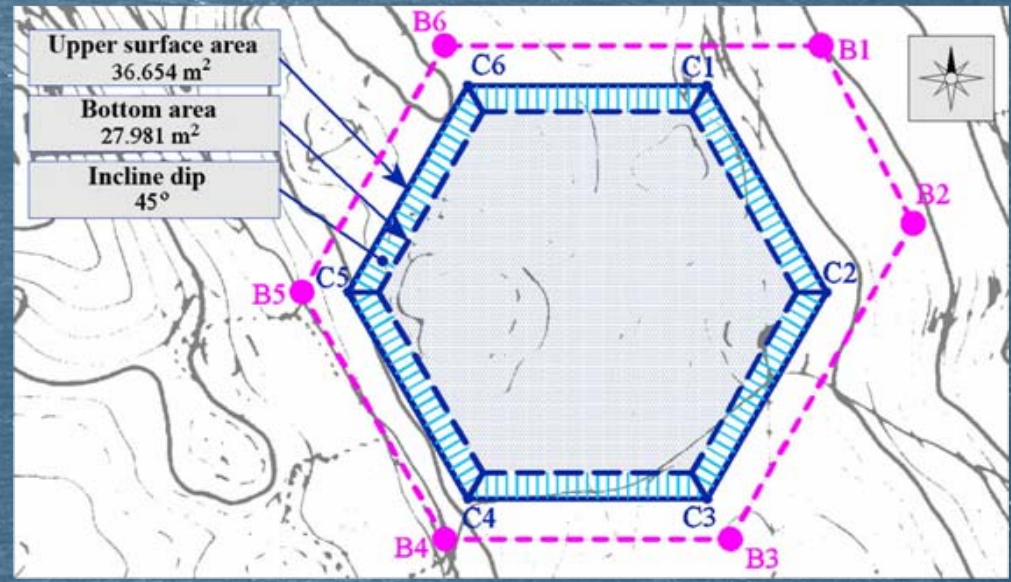
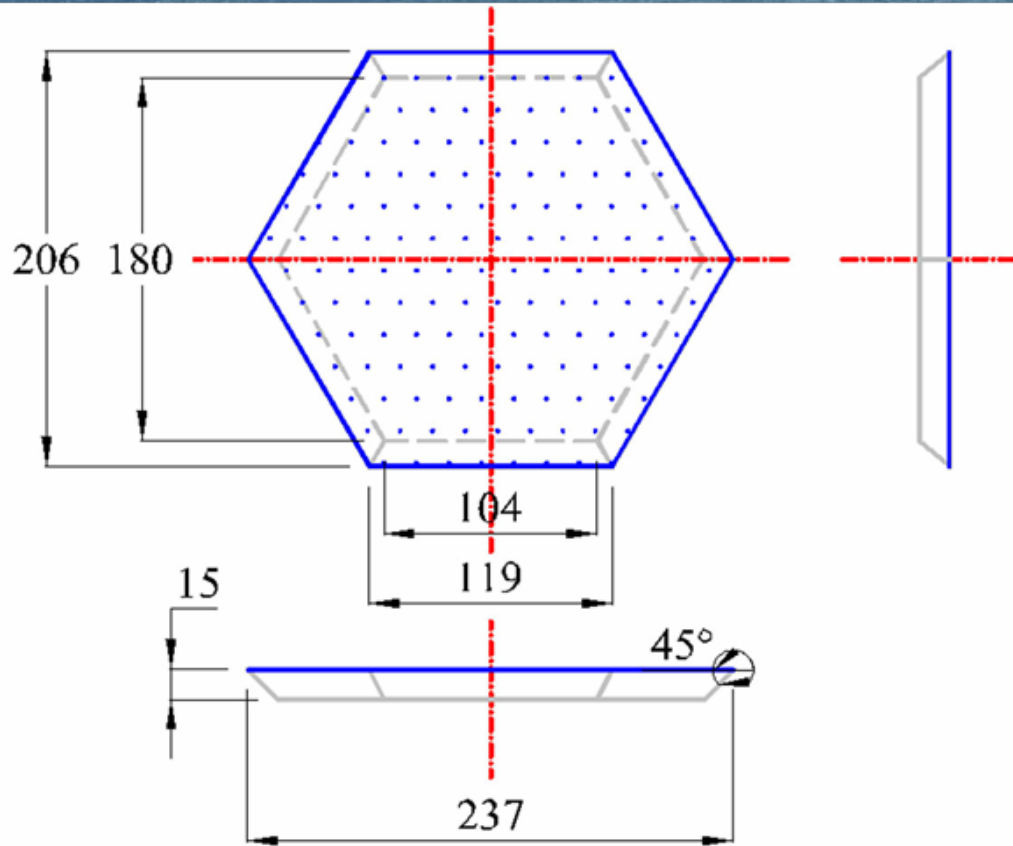
The selected wind turbine model



PHS siting



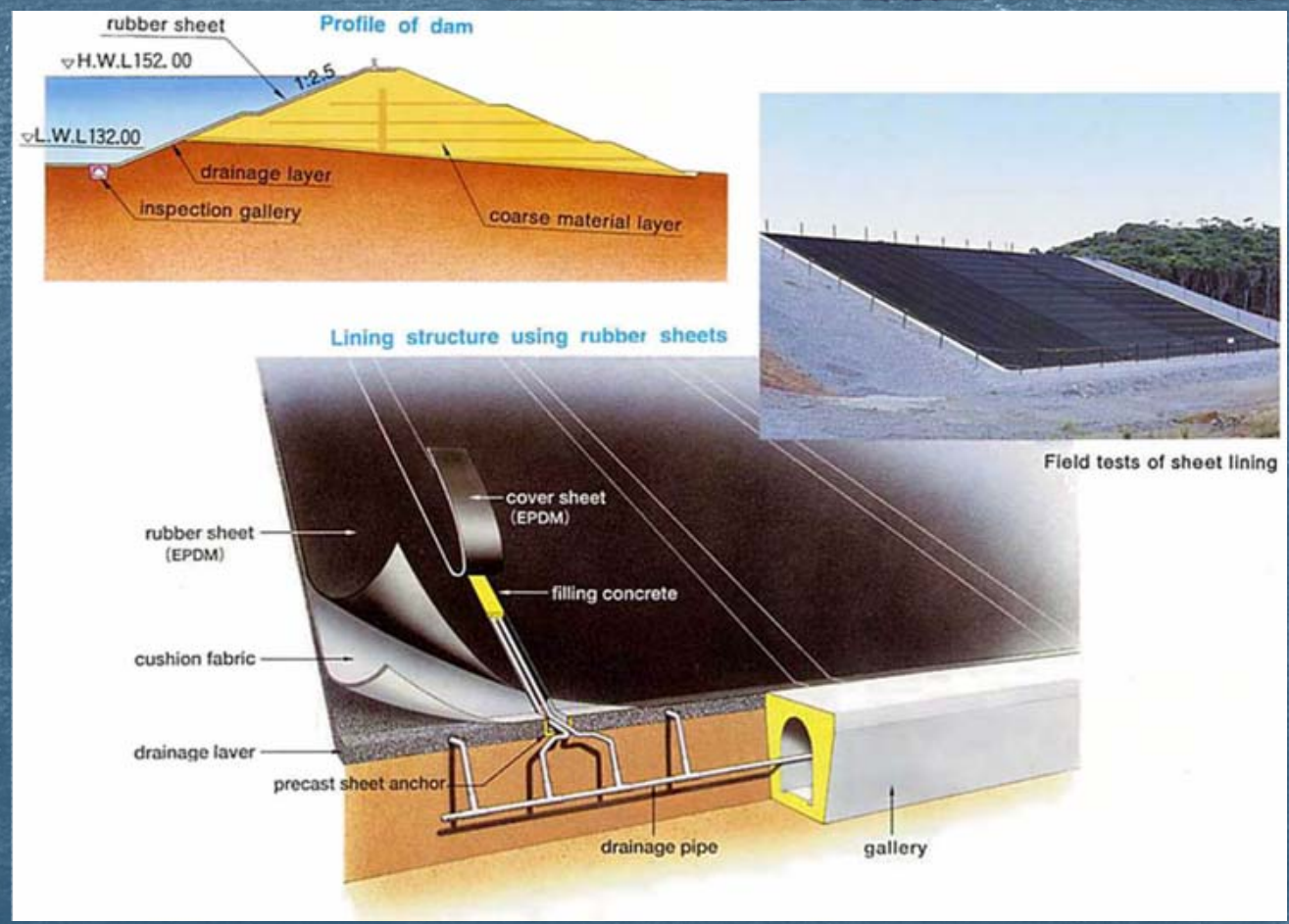
Upper reservoir design



The upper reservoir installation area



Sealing of upper reservoir



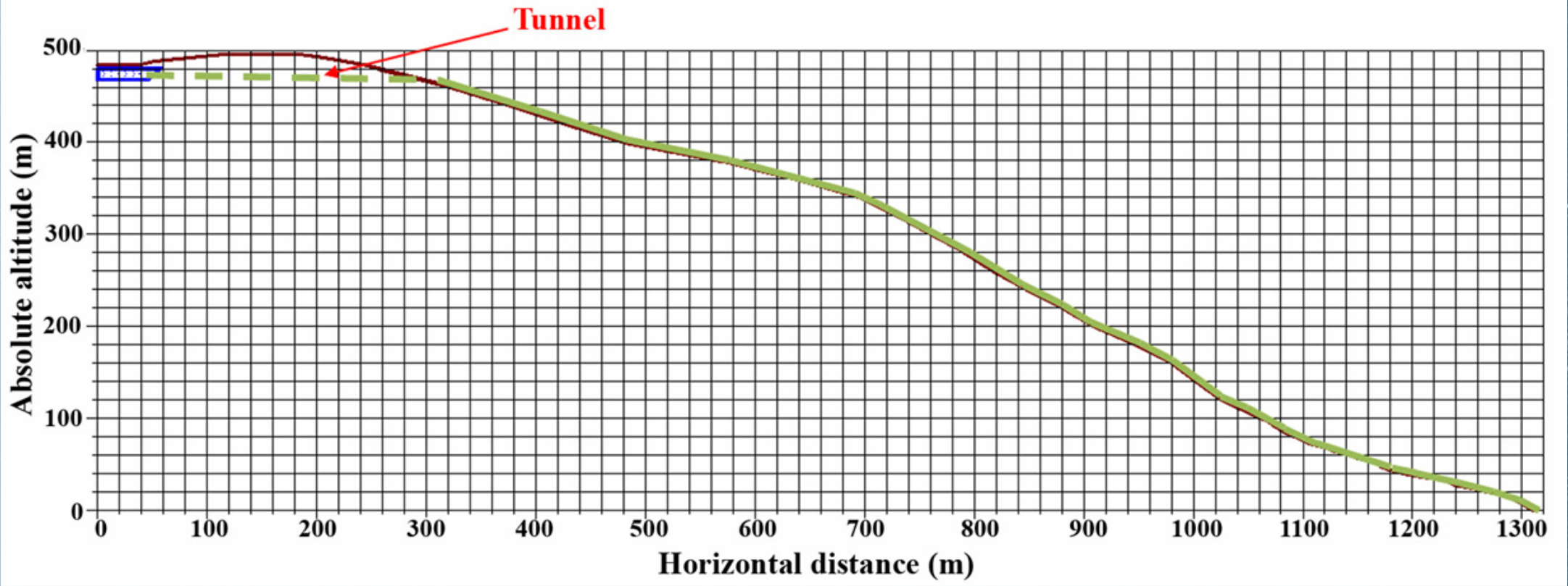
Fundamental features of upper reservoir

Total capacity (m ³)	483.313
Effective capacity (m ³)	465.062
Maximum absolute altitude of the reservoir's surface (m ²)	36.654
Area of the reservoir's bottom (m ²)	27.981
Installation area absolute altitude (m)	480
Bottom's absolute altitude (m)	465
Maximum reservoir's depth (m)	15
Slope of the reservoir's sides (°)	45
Total digging works volume (m ³)	86.394

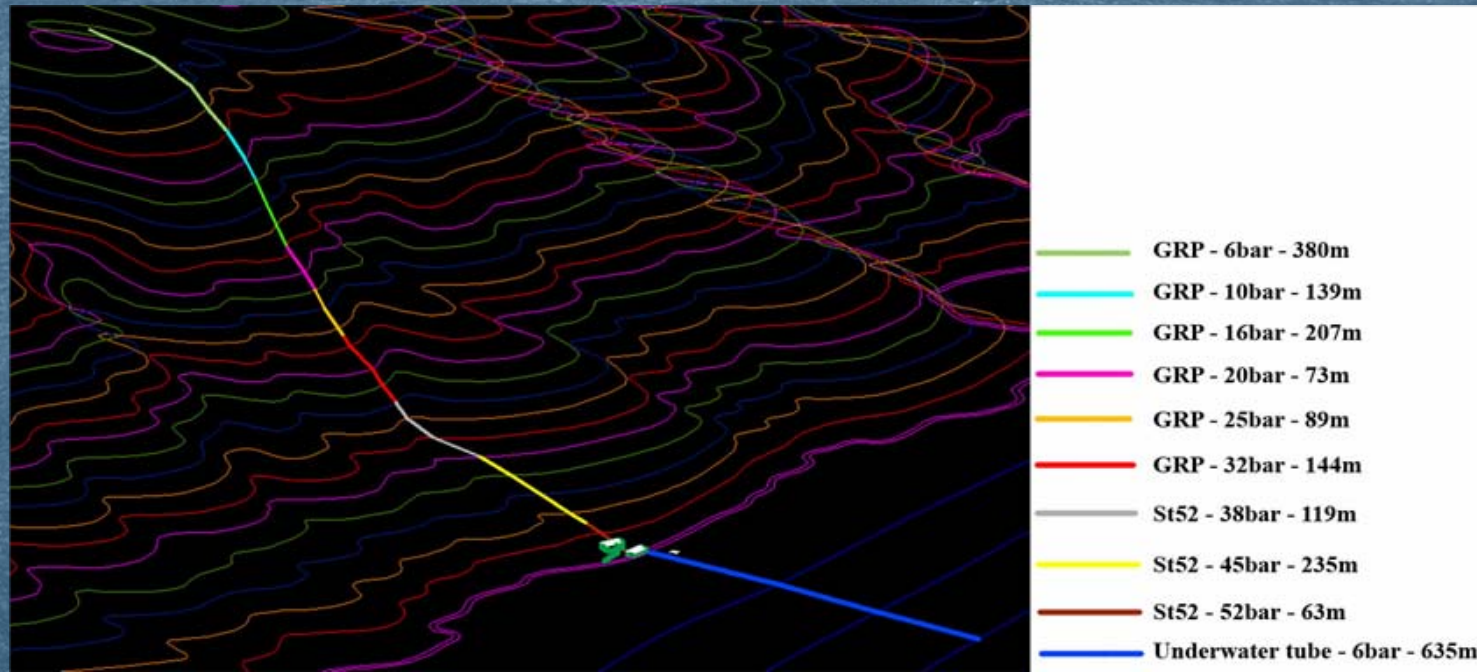
Penstock installation



Penstock vertical cross-section view



Penstock route 3-D view

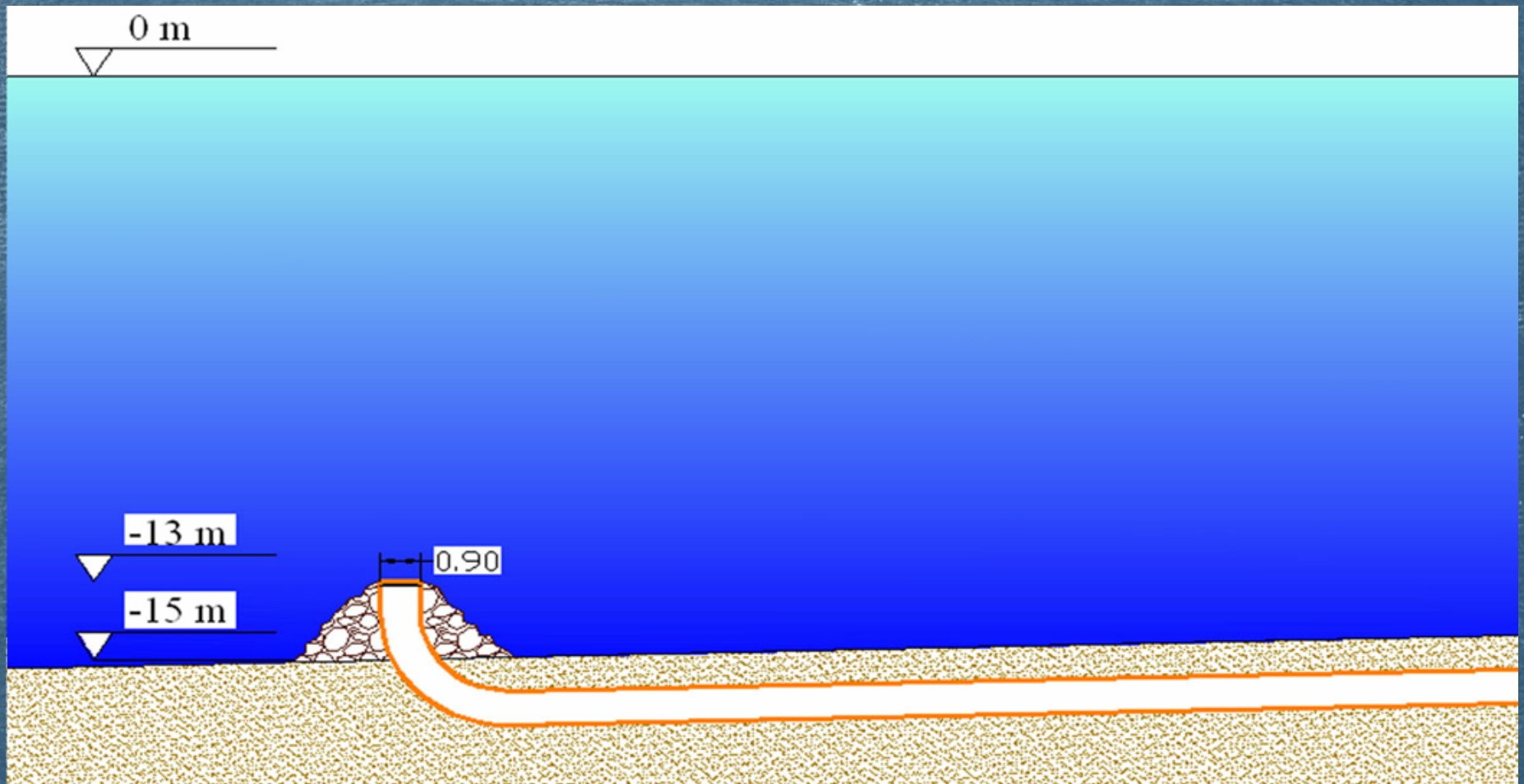


Total length of GRP tubes (m)	1.032,74
Total length of steel tubes (m)	417,07
Total tubes length (m)	1.449,81
Tubes inner diameter (m)	0,90

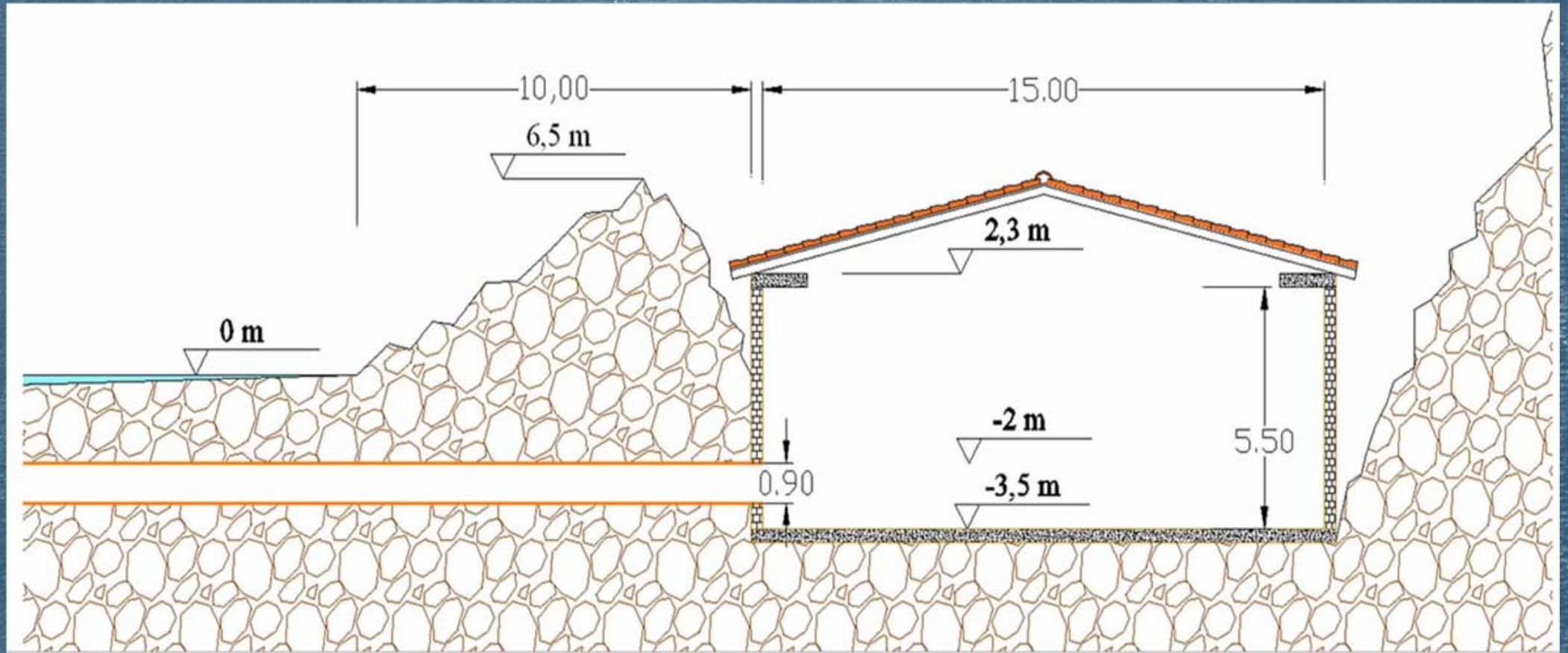
Example of penstock installation from the PHS in El Hierro, Canary islands, Spain



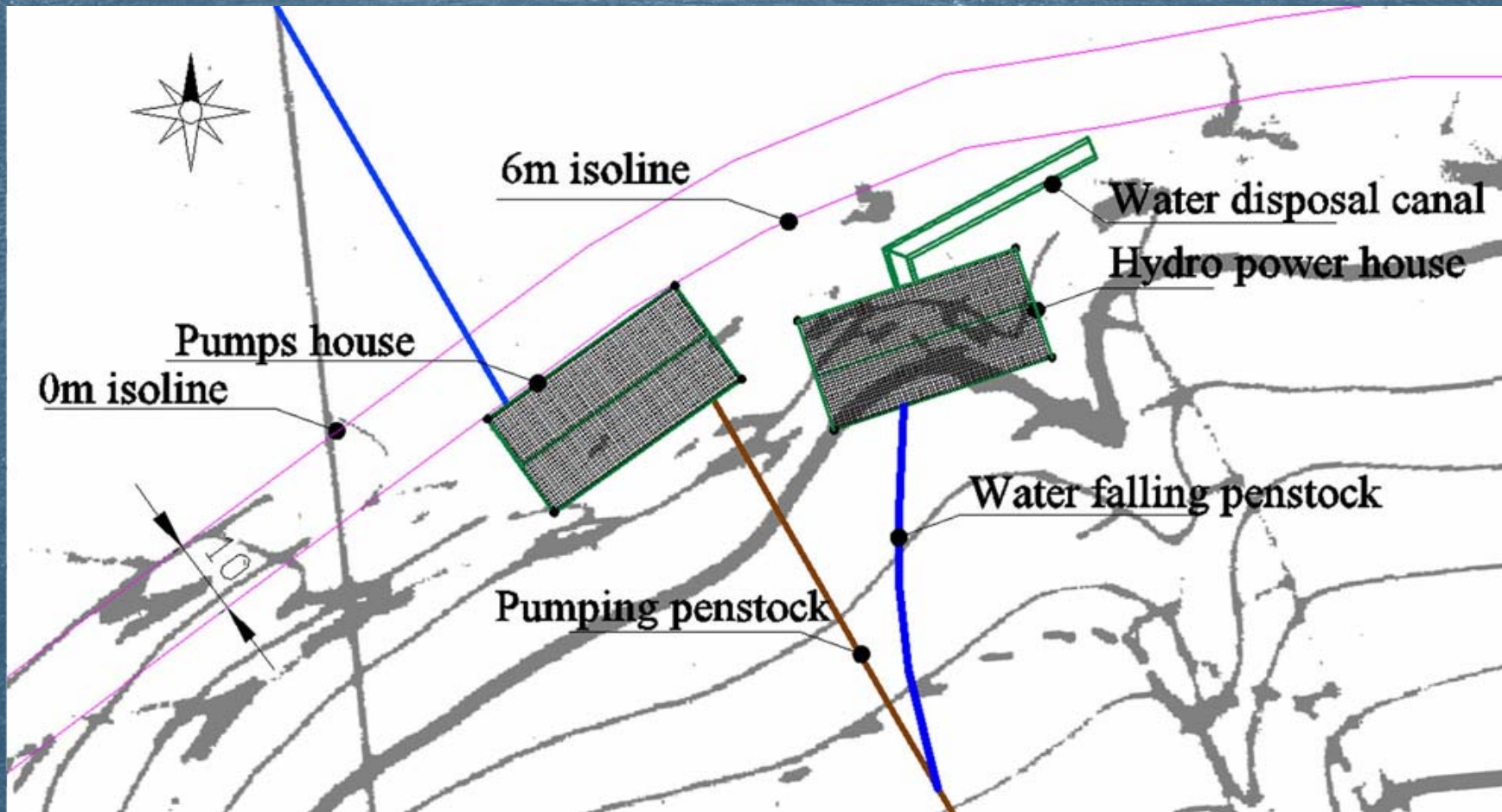
Underwater penstock installation



Pumps station suction side



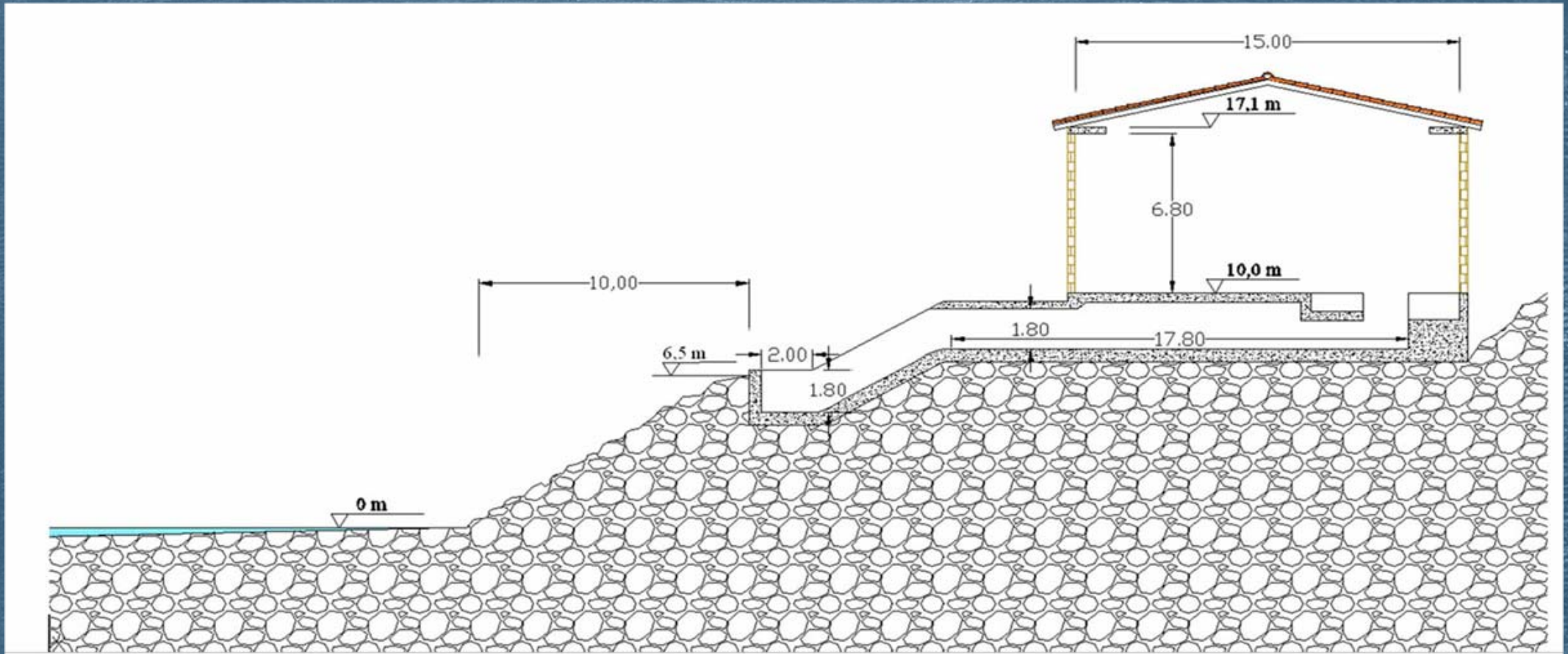
Pump station and hydro power plant siting



Pump station and hydro power plant installation area



Hydro power plant vertical cross-section view



Hydro turbines and pumps nominal power

Type	Model	Nominal power per unit (kW)	Number of units	Total nominal power (kW)
Hydro turbine	Pelton, horizontal shaft	2.075	2	4.150
Pump	Multi-stage, horizontal shaft	560	8	4.480

Guaranteed power production

	Day power demand peak period	Night power demand peak period	Total time of guaranteed power production per day
Winter period (from 15 th of October to 15 th of April)	10:00 – 16:00	16:00 – 21:00	11
Symmer period (from 15 th of April to 15 th of October)	10:00 – 17:00	17:00 – 21:00	11

Guaranteed power production: 4MW

Annual energy production

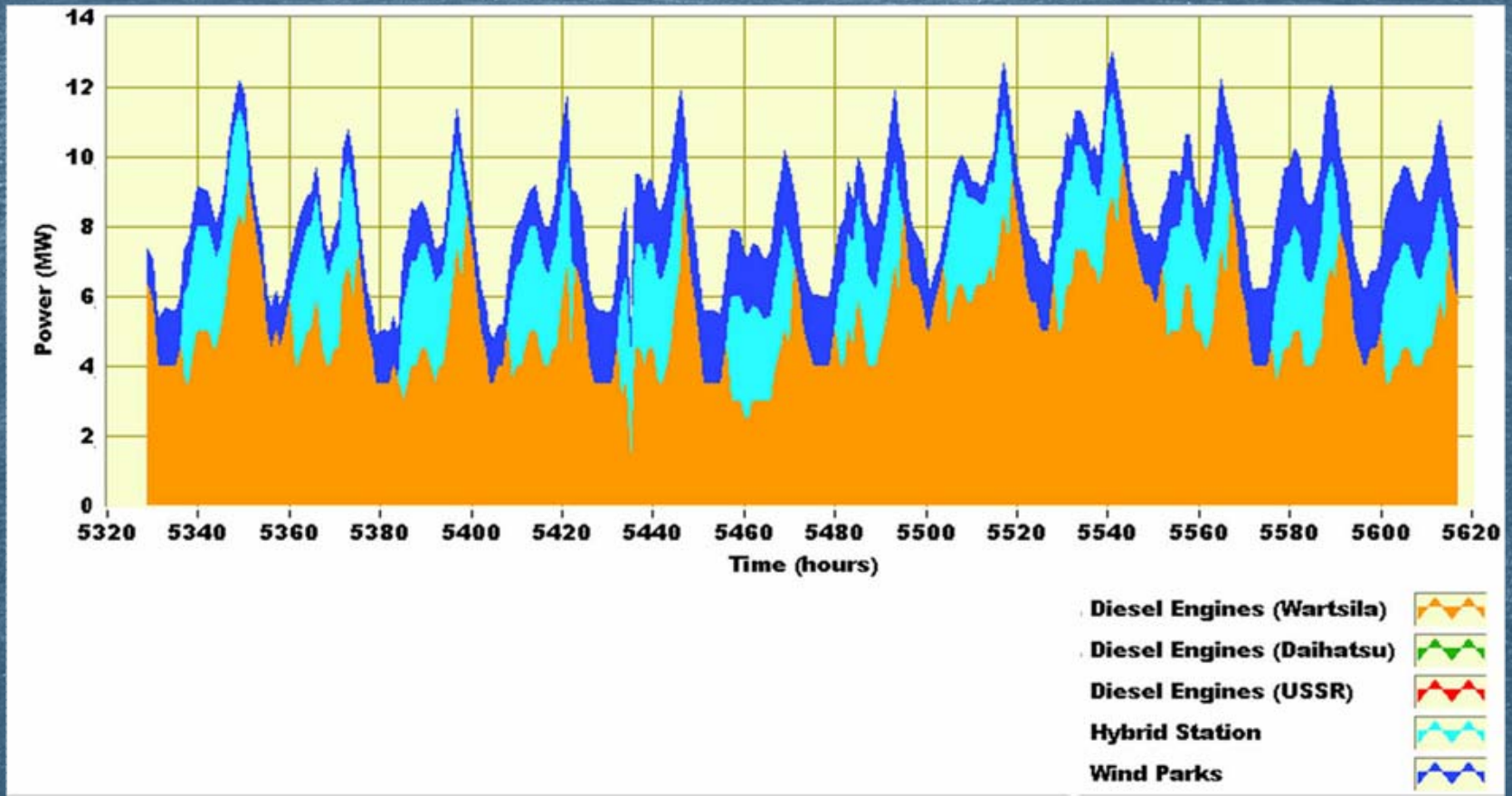
The perspective of desalination

Wind park's annual electricity production (MWh)	20.714
Hydro turbines annual electricity production (MWh)	11.478
Annual energy storage from the wind parks (MWh)	17.922
Annual energy storage from thermal generators (MWh)	0.00
PHS overall efficiency (%)	64,05
Wind park annual electricity production surplus (MWh)	2.792

Given that the wind park's electricity annual surplus is estimated at 2.792MWh and the electricity annual rejection from the existing wind parks is estimated at 1.761MWh, the possibility for potable water production via a desalination plant is estimated annually at 1,8 millions m³ by exploiting the above electricity surplus from the wind parks, assuming a specific electricity consumption by the desalination unit of 2,5kWh/m³ of potable water.

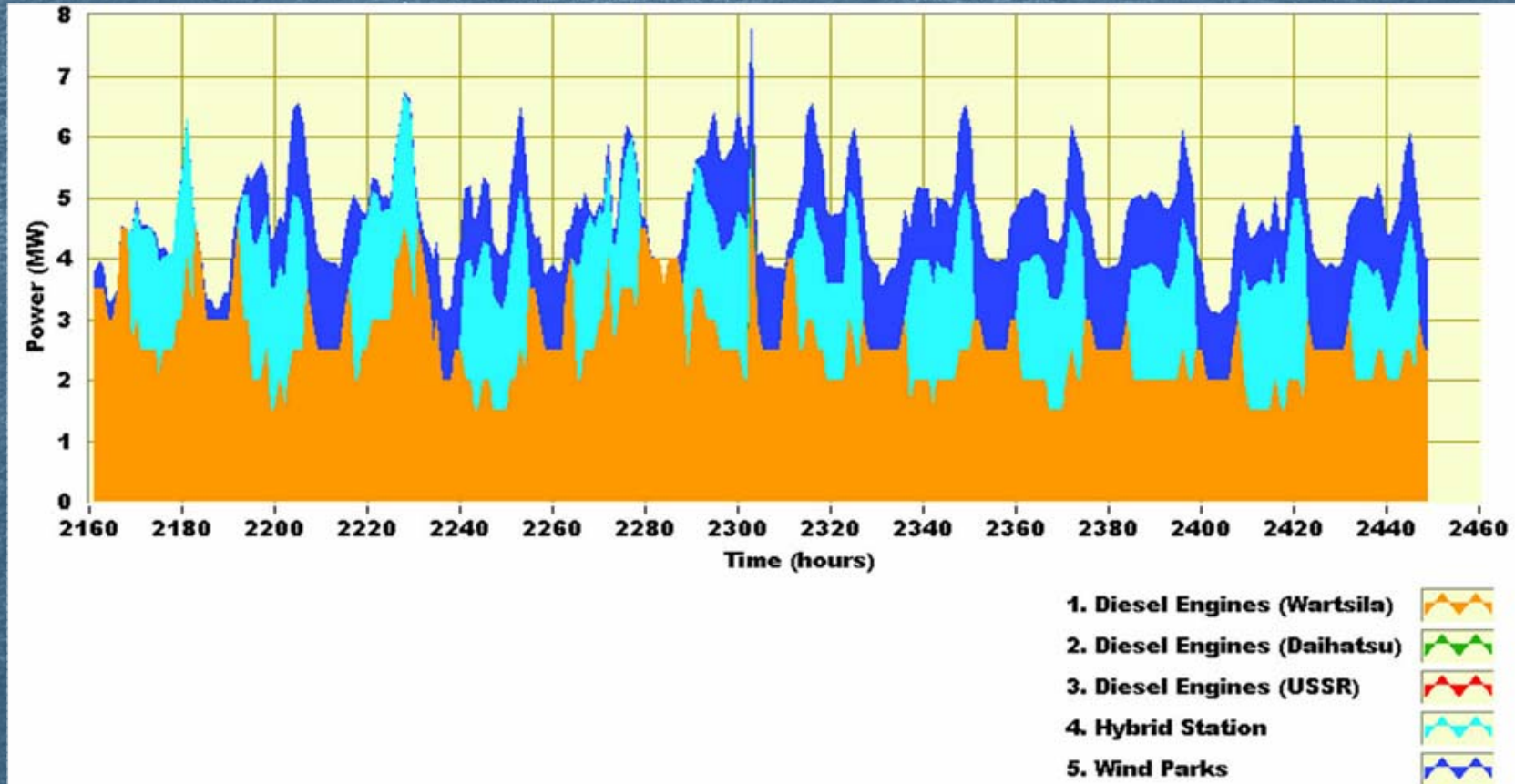
Power production synthesis

High power demand season (August)

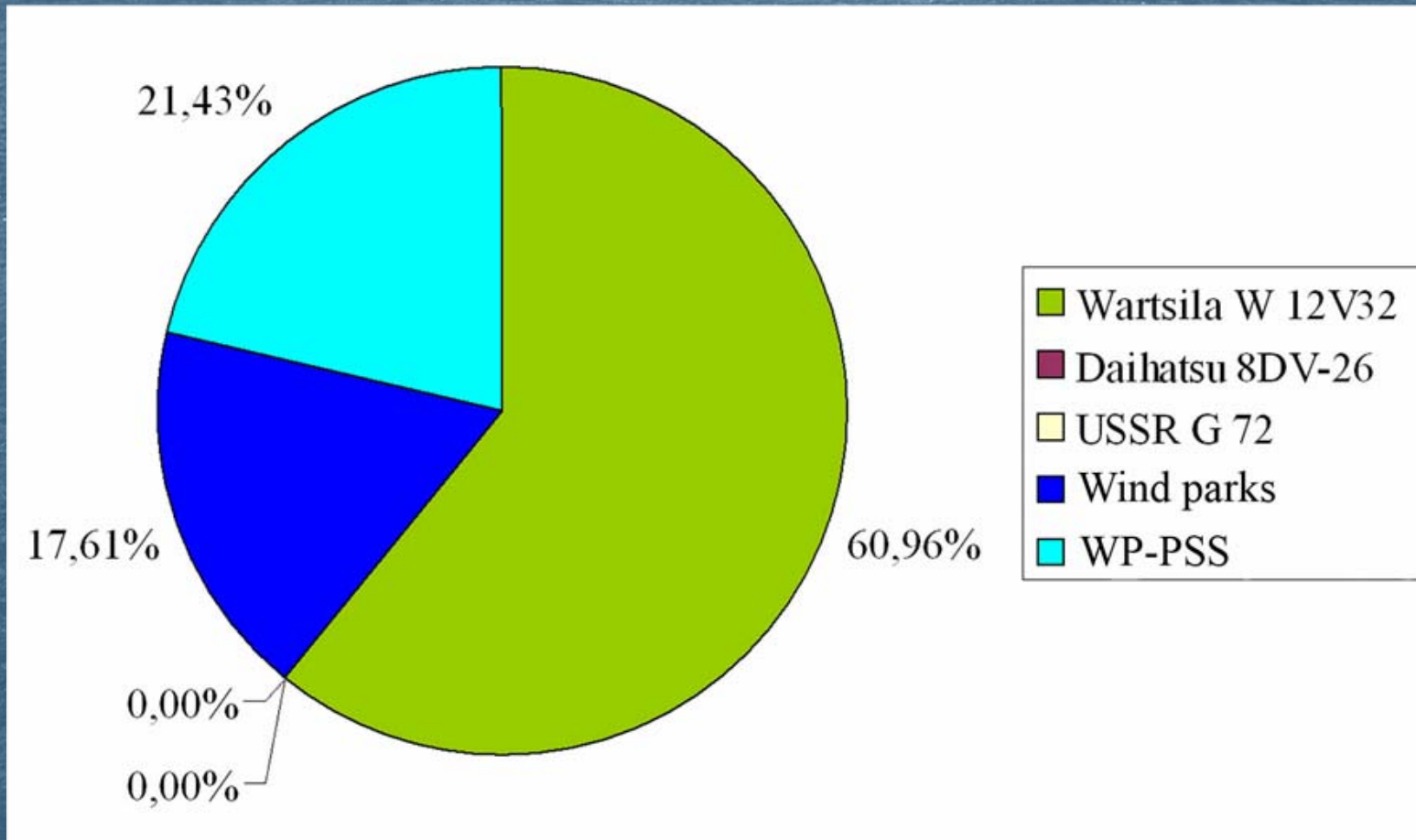


Power production synthesis

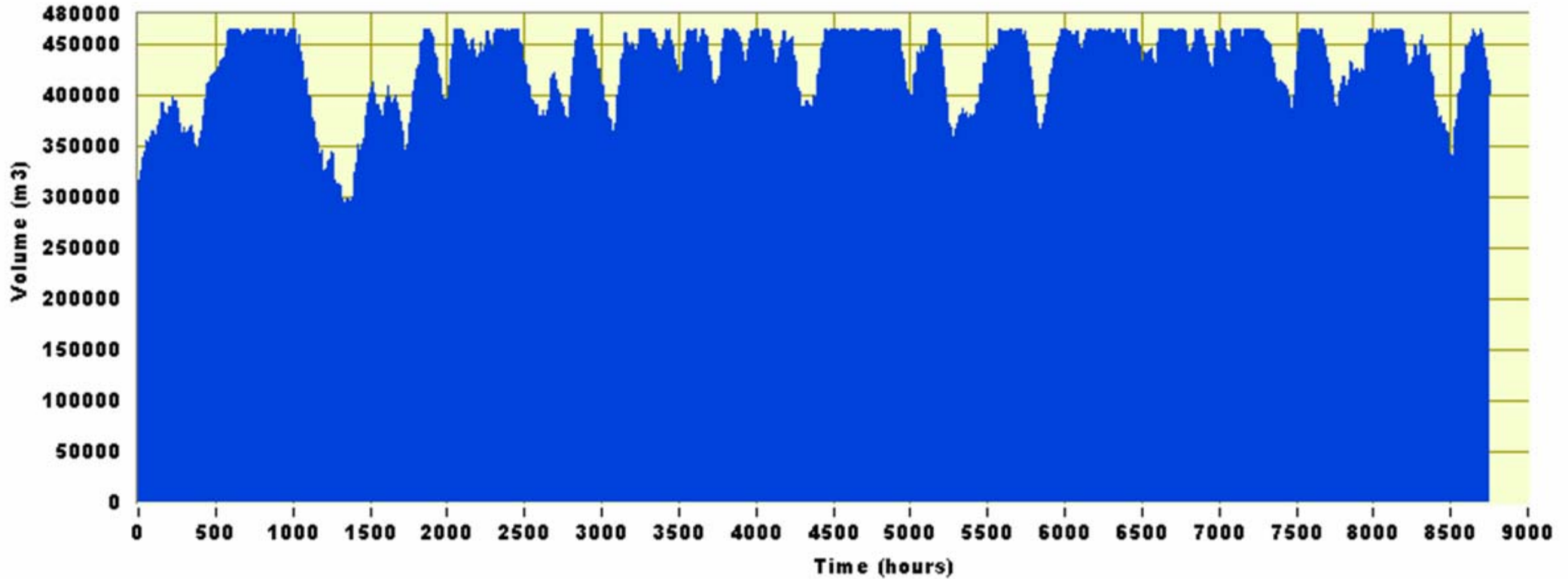
Low power demand season (April)



Percentage distribution of the annual electricity production



Upper reservoir stored water volume annual variation



Hybrid power plant set-up cost

No	Set-up cost component	Cost (€)
1	Wind park	4.800.000
2	Hydro power plant	2.800.000
3	Pump station	2.240.000
4	Upper reservoir	4.300.000
5	Penstock	2.400.000
6	New roads construction	600.000
7	Connection grid	800.000
8	Other infrastructure works	900.000
9	Buildings	500.000
10	SCADA	2.200.000
11	Consulting and licensing	300.000
12	Other costs	500.000
	Total cost	22.340.000

Benefits for the island of Kasos

- ▶ Contribution to the energy supply security.
- ▶ Availability of abundant potable water with low cost.
- ▶ Public compensation rates for the Municipality of Kasos of about 110.000 annually.
- ▶ Five permanent work positions.
- ▶ Disposal of around half of the project's budget locally in the island of Kasos, during the set-up of the project.
- ▶ Improvement of the existing infrastructure of electricity and roads networks.

Thank you for your attention

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