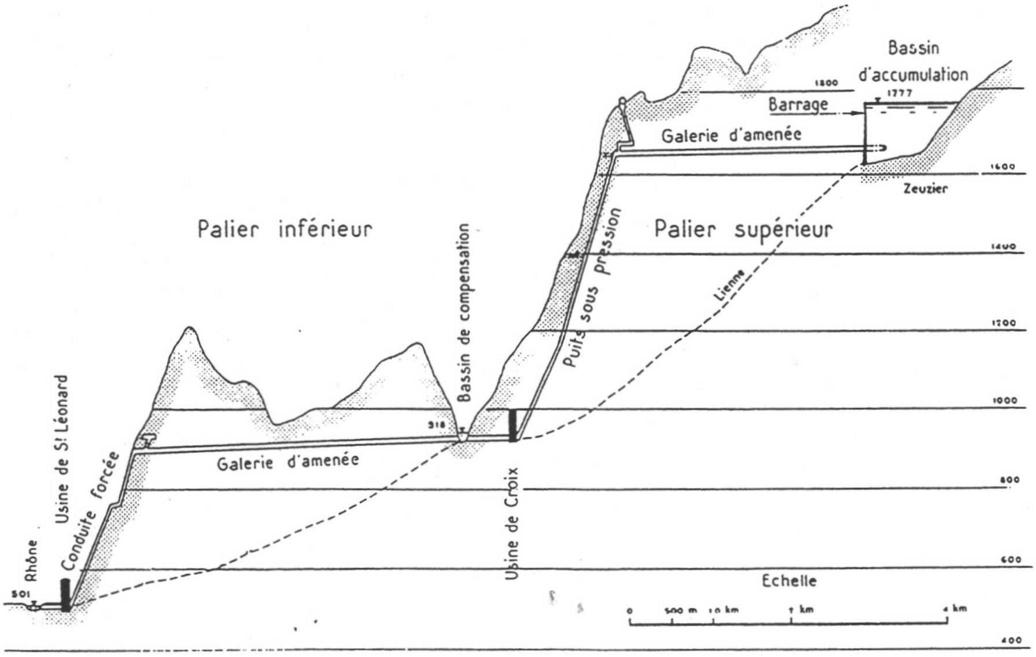
Exercise 2: Pumped-storage facility

Preliminary design and operation of a pumped-storage facility



Introduction

Consider a two-stage hydroelectric scheme with a main reservoir X, whose output contributes to the winter electricity supply due to its seasonal storage regime. The possibility of building a new reservoir not far away is being considered. This would represent an additional opportunity for winter supply, but this function is not sufficient to justify the investment. The promoter is looking into the possibility of using the same facility to provide services to the power grid through daily pumped storage cycles. The storage curves for the main reservoir X (lower reservoir) and the natural reservoir Y (upper reservoir) are defined below.

Storage curve of reservoir X

N [m.s.m] = f(V [hm³])	Polynomial factors
a0	1.672E+03
a1	7.229E+00
a2	-5.486E-01
a3	3.072E-02
a4	-9.387E-04
a5	1.437E-05
a6	-8.633E-08

Storage curve of reservoir Y

N [m.s.m] = f(V [hm³])	Polynomial factors
a0	2.452E+03
a1	6.241E+00
a2	1.364E-01
a3	-1.459E-01
a4	1.854E-02
a5	-9.466E-04
a6	1,739E-05

Question 1

Consider a daily non-stop pumped storage strategy (never stopped, either in turbine "T" state or in pump "P" state). Consider an hourly time step (the state can change at any fixed time).

(1) Considering a daily cycle of 8 hours of generation for 16 hours of pumping, and the following table representing the sale/purchase price of electricity, find the optimum pumping / generations cycle, while checking that it is hydraulically feasible. Fill in the "state" column of the Excel table with the letters P or T.

Time	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Price [CHF/kWh]	0.09	0.08	0.07	0.14	0.17	0.19	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.15	0.16	0.18	0.20	0.22	0.26	0.24	0.17	0.12	0.09	0.08

Consider a daily pumping / generation volume of 0.5, 1, 2 and 4 hm^3 respectively and calculate the necessary generation and pumping flows.

(2) Using the storage curves above, determine the optimum water levels of the 2 reservoirs at midnight, given that the maximum operating levels of the 2 reservoirs are 2480 m.s.m. and 1777 m.s.m. respectively. We will assume that reservoir X constantly sends 25 m^3/s to power station X to produce electricity and receives 25 m^3/s from the river upstream. The water level in the reservoir is therefore constant in the absence of a pump-generation cycle. (Hint: The optimum water level is that which allows the maximum level of the reservoir to be reached during the day). Deduct these values for the 4 P/T volumes considered.

(3) Discuss the acceptability of the reservoirs drawdown rates

(4) The heights of power stations Y and X are 1770 m.s.m. and 918 m.s.m. respectively. A total efficiency of 85% is considered for the generation mode (including the efficiency of the turbine, the generator and the head losses in the pipes). An efficiency of 87% is assumed for pumping mode (motor, pump and head losses). Calculate the total daily energy production of the 2 power stations for the 4 P/T volumes considered.
Calculate daily income for the 4 scenarios.

(5) Which one is the most economically advantageous?

(6) Do the 4 scenarios seem feasible from an equipment point of view?

(7) Note that a non-stop pumped-storage strategy is not the most beneficial. Explain why and suggest a solution that would be more optimal (without doing any calculations).

Question 2

We will now consider a pumping / generation volume of 2 hm^3.

(1) Determine the maximum flow rates in pumping mode and in generation mode.

(2) Propose a solution for equipping the powerhouse.

(3) A manufacturer offers pumps that guarantee a maximum head of 800 m at a flow rate of 15 m^3/s. Under these conditions, the datasheet specifies a head loss of 1 m at the pump inlet and a required NPSH of 15 m. Determine the submersion required for the pumps to avoid cavitation. The NPSH available can be found with the following formula.

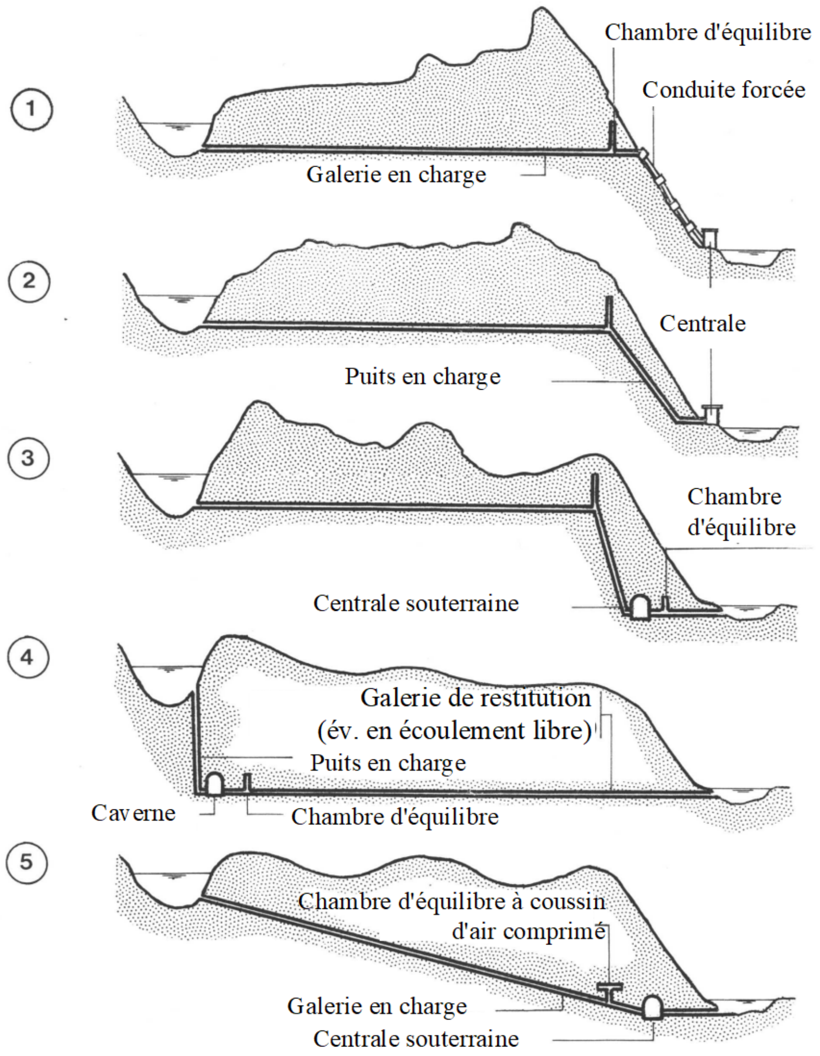
$$NPSH_A = \frac{p_0}{\rho g} - \frac{p_v}{\rho g} + (z_0 - z_i) - h_f$$

(4) Calculate the optimal pump setting level.

Question 3

Also for the chosen option

(1) Compare the different solutions for the layout of the main installations in the longitudinal profile shown in the following figure. Which one seems the most optimal for the layout for this exercise?



(2) Assuming we use layout (1) in the previous figure, and using the following gradient profile, determine the total investment (GC+ EHM+ LT) with clearly formulated assumptions. Orders of magnitude are given in the following table.

GC	Headrace	220 CHF/m^3
	Penstock	400 CHF/m^3
	Lake covering	15 CHF/m^2
	Water intake	15 Mio CHF
	Downstream water discharge	23 Mio CHF
	Powerhouse	300 kCHF/MW
	Construction installations	20% sub-total construction
EHM	Hydromechanical equipment	400 kCHF/MW
LT	High voltage power line	400 CHF/m
	Studies	10% sub-total construction + installation
	Contingencies	20% total

Suggestions:

(a) Compute the energy losses in the headrace and penstock as follows:

$$\Delta H = f\,\frac{L}{D}\,\frac{\overline{u}^2}{2g}$$

Where "f" is the friction coefficient (aka Darcy-Weisbach), which you can assume to be 0.20. Rewrite this expression as a function of the flow rate Q and limit the pressure drop to 10m. Determine the pipe diameter.

(b) Assume that a high-voltage line already exists at power station X, located about 5 km from the planned site of pumped-storage power station Y.

(c) Consider that the water surface area of reservoir Y at its maximum level is 30 ha.