Exercise 1

Hydraulic facilities for power generation and pumping

Part A

Consider the river hydroelectric scheme of Lavey on the Rhône River above Lake Geneva, commissioned in 1948.

a) Calculate the energy produced annually considering the flow duration curve (FDC) available in 1948 and a design flow rate of 250 m^3/s[1].
   i. Find the gross head of the power plant (constant).
   ii. Compute the net head.
   iii. Make an assumption on the global efficiency of the generation units at nominal flow rate.

b) Calculate the energy produced annually considering the FDC of 1990. Discuss your assumptions.

c) Comment on the contribution of upstream seasonal reservoirs to the evolution of the distribution of Lavey's energy produced annually in summer and in winter. See also the hydrographs of 1944, 1960 and 1990 on Moodle.

Reservoir	**1st impoundment**	**Volume** [hm^3]
Mattmark	1969	100
Mauvoisin	1957	211
Grande Dixence	1961	400
Moiry	1958	77.0
Les Toules	1963	20.5
Salanfe	1953	40.0
Emosson	1974	227
Zeuzier	1957	12.6

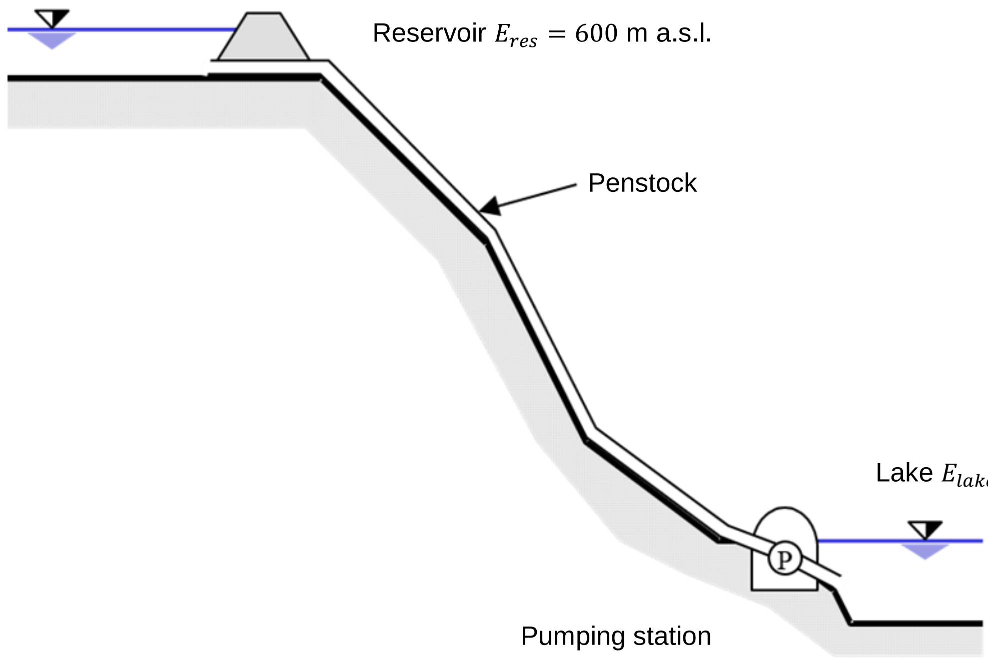
d) According to the 1990 FDC, estimate the energy produced annually considering increasing the design flow rate to 300 m^3/s.

e) Estimate the loss of production related to the ecological flow release ("residual flow") at the dam/intake section, estimated at a total of 800 l/s (constant throughout the year).

[1] Minimum ecological flow release was first introduced into the Waters Protection Act (WPA) on 24.01.1991 and enforced at Lavey dam from 2008 onwards. It was updated in in the WPA in 2013.

Part B

Consider the Lake Léman water pumping facility at Lutry, commissioned in 2001. To supply drinking water, water is pumped from the lake to an upstream reservoir at a given E_{res} level. The penstock delivers water at a velocity of 1.7 m/s at nominal flow rate over a length of 1.6 km. The penstock is a cylindrical pipe (internal diameter d_{int}=0.5 m, thickness e=10mm) made of steel (density ρ_s = 7850 Kg/m^3).



a) Calculate the head losses between the pumping plant and the reservoir. The characteristic roughness length-scale $k_s = 0.1$ mm and the kinematic viscosity of water $\nu = 1.3 \cdot 10^{-6}$ m^2/s. Local head losses are neglected, except for those at the reservoir inlet ($\xi = 1$). The Moody diagram can be found at the end of the document.

b) Draw schematically the energy head (red) and pressure (blue) lines for the steady state flow regime at nominal flow rate. Also draw the energy line for the static condition (black).

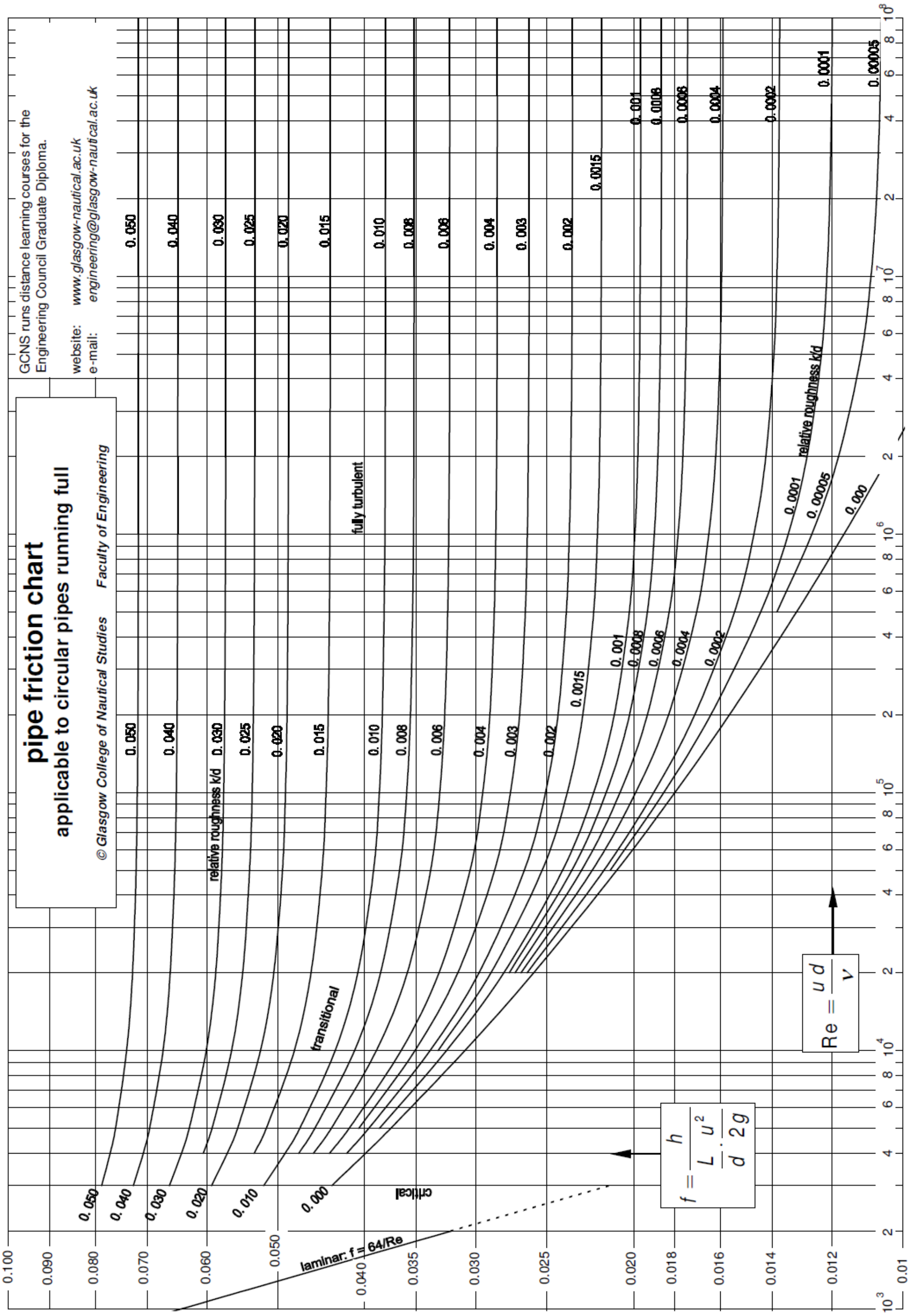
c) Estimate the total pumping power at nominal flow rate, assuming a pump efficiency of $\eta = 0.60$.

d) Calculate the total construction costs of the penstock (CAPEX), by considering a unit price of 3'600 CHF/ton for the steel and an additional cost of (900 + 230 d_{ext}) CHF/m, where d_{ext} is the external diameter of the penstock pipe.

e) Calculate the operational costs (OPEX) on an annual basis, with these assumptions:
   a. The depreciation lifetime is considered to be of n = 40 years, with a discount rate of a = 6%;
   b. The maintenance costs are estimated to be the 0.5% of the construction costs of the penstock;
   c. The energy costs of the pumping station are calculated considering an average unit cost for electricity of 6 ct/kWh, with the pumping station running for 16 h/day.

   As a reminder, the formulation for the annual cost X (the "annuity") of an initial investment X_0 is:

$$X = X_0 \frac{a(1+a)^n}{(1+a)^n - 1}$$


pipe friction chart
applicable to circular pipes running full
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Faculty of Engineering
GCNS runs distance learning courses for the Engineering Council Graduate Diploma.
website: www.glasgow-nautical.ac.uk
e-mail: engineering@glasgow-nautical.ac.uk
relative roughness k/d
fully turbulent
transitional
critical
laminar: f = 64/Re
$f = \frac{h}{\frac{L}{d} \cdot \frac{u^2}{2g}}$
$Re = \frac{u\,d}{\nu}$