2. Draw a hydrograph and flow duration curve of Blue Nile flow at Kessie. Find the smallest, small, and mean flow levels

Time (Month)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Dec
Q(m^3/s)	79.75	91.85	118.622	178.3	228.186	2279.65	4803.48	2283.91	939.014	439.46	221.113

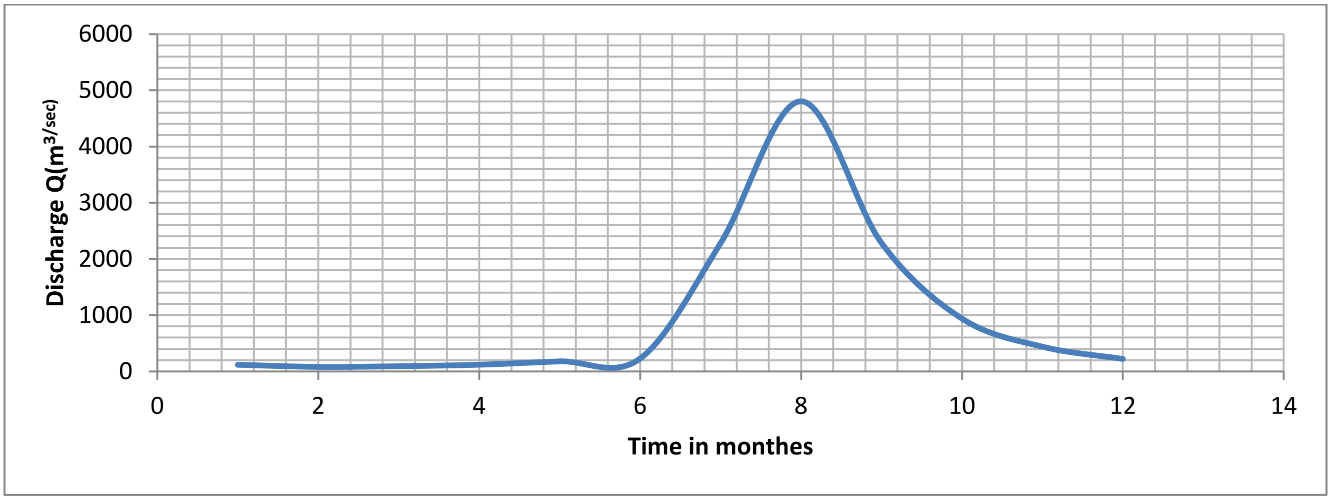


Figure 1.1 Stream Flow hydrology

Flow Duration Curve

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Q(m^3/s)	79.75	91.85	117.18	118.62	178.3	221.11	228.18	439.46	939.014	2279.65	2283.9	4803.5
%	100	91.667	83.33	75	66.67	58.33	50	41.67	33.333	25	16.67	8.33

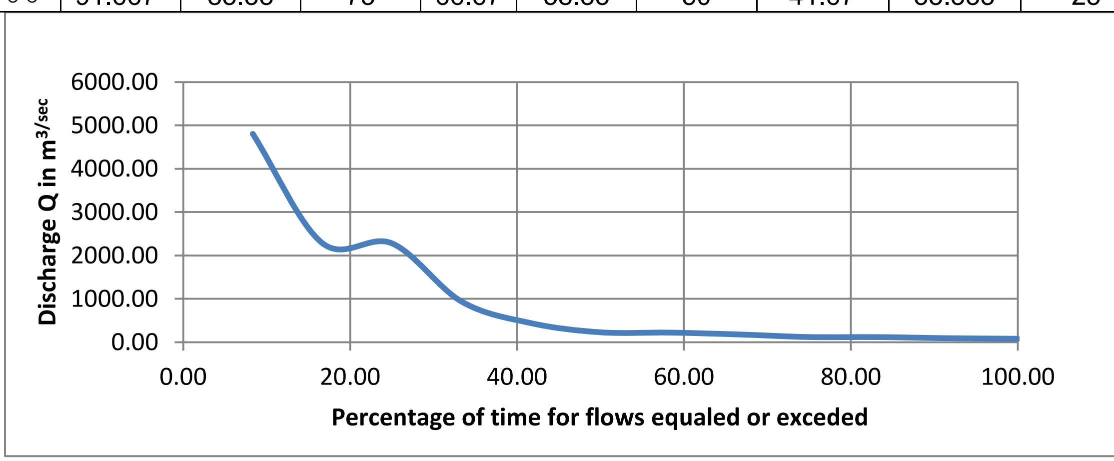


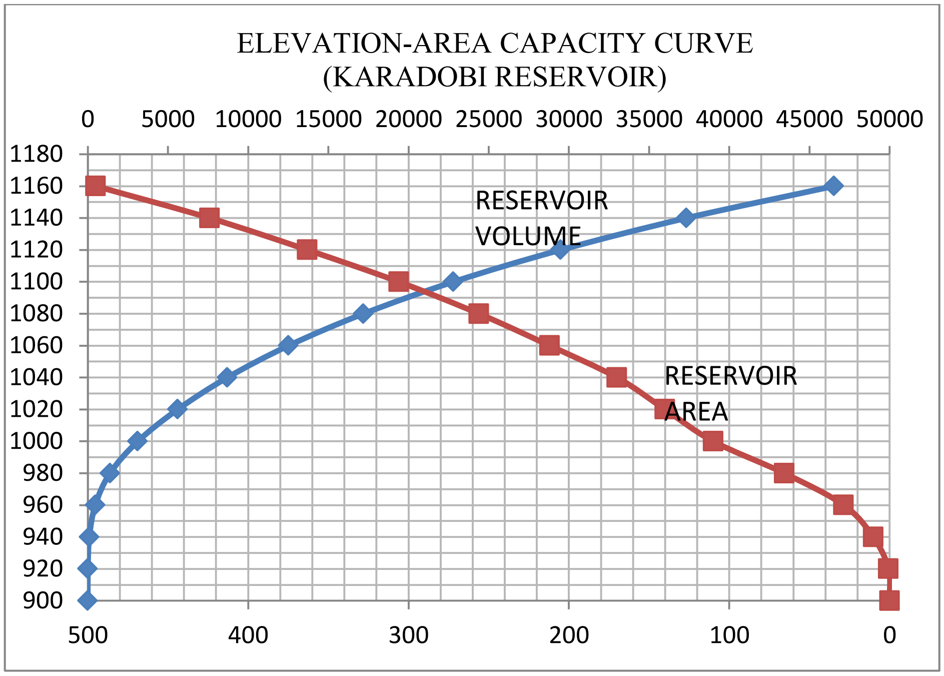
Figure 1.2. Flow duration curve

3. Plot the area duration and capacity curve of envisaged dam in the Blue Nile under the ENTRO projects, specifically the Karadobi, Mendaya or Border dams

Solution:

Karadobi elevation-area –storage data

Elevation (m)	Area (Km2)	Volume (Mm3)
900	0	0
920	0.65	4
940	10.2	93
960	28.6	466
980	65.7	1383
1000	110	3117
1020	140	5605
1040	170	8703
1060	212	12520
1080	256	17189
1100	306	22799
1120	363	29479
1140	424	37336
1160	495	46524



4. Design a settling basin for high-head power station using the simple settling theory. The basin should serve to remove particles greater than 0.4mm diameter from the water in which the sediment is mainly sand. Let the design discharge be $6m^3/s$ and assume an initial value of 3.2m for the basin depth. Take the water sediment mixture density to be γ(=1.064)

Solution:

ϒ=1.064ton/m3

d=0.4mm

Q=6m3/s

H=3.2m

Determine first the permissible flow velocity. According to Camp,

$V=44*\sqrt{d}$ for $0.1 \le d \le 1mm$

$V=44*\sqrt{0.4}=27.82cm/sec$

From graph for d=0.4mm and ϒ=1.064, ω=5cm/sec

The required length of the basin $l=h*v/\omega$

$L=3.2*28/5=17.92m$

And the width of the basin $b=Q/hv=6/(3.2*0.28)=6.696m$

Settling time, $t=D/\omega=3.2/(5/100)=64sec$

The distance conveyed by during this period

$Q*t=6*64=384m3$

And this should be equal to the capacity of the basin

$V=h*b*l=3.2*6.696*17.92=384m3$

5. A power canal with a slope of 0.0001044 and R=1.76 m is unlined with coarse sand bed material. Determine the safe velocity in the canal if the heaviest bed load in the original canal of the course is $G=0.34kg/m^3$. The water carries silt with an average diameter of 0.1 mm. Assume $d_m=2.00$ mm as size of bed material and h=2.5m.

Solution:

Given

S=0.0001044m/m
R=1.76m
d=0.1mm

dm=2.00mm
h=2.5m
G=0.34Kg/m3

Required

Safe velocity

Solution

Minimum velocity

According to E.A: Zamarian, the requirements silting or non solting of unlind canal is given by:

$$Go = \frac{700V}{wo}\sqrt{\frac{RSV}{w}}$$

Where V= mean velocity given by $V = C\sqrt{(RS)}$ according to Chezy-Manning's equation

$$C = \frac{1}{n}(R^{(1/6)})$$

n=0.03 for an unlined canal with a bed material gravelly or sandy loam which approaches our canal's bed material.

$$C = \frac{1}{0.02} * (1.76)^{\frac{1}{6}} \;\; = 55$$

Then V=36.36*$\sqrt{1.76 * 0.0001044}$=0.5m/sec

And ω will be ω =1cm/sec for d=0.1mm and γ=1.064 from fig 4.20

ω_o=2 because ω <2cm/sec

Then $Go = 700 * \frac{0.5}{2}\sqrt{1.76 * 0.0001044 * \frac{0.5}{1}} = 1.68Kg/m3$

G<G_o i.e 0.38kg/m3<1.68kg/m3 implying no siltation or deposition

Maximum flow velocity

Critical bottom velocity (w.r.t. erosion) is given by:

$$V_b = 22.9 * dm^{(\frac{4}{9})}\sqrt{Ss - 1}$$

Where Ss=2.65

V_b=22.9*0.002^(4/9)*(2.65-1)^0.5=2.38m/sec.

Hence 0.5m/sec -2.38m/sec can be taken as safe velocity.

Let take 1.0 m/sec as a safe velocity through the canalwithout scouring and siltation .

6. Determine the seepage loss from a power canal constructed in a sandy soil of medium fineness by the Davis and Wilson, Etchevery and Kostyakov methods discussed. The following data are given:

Trapezoidal canal: bottom width, b= 11.0 m

Water depth, D=2.5m

Side slope 2H: 1V

Mean velocity =0.5m/s

Effective size of soil particle, d_m=0.1mm

Permeability coefficient, k=1x10^{-5} m/s

Solution:

A= 2.5*(11+2*2.5)=40m2

P=11+2*2.5*(4+1)^0.5=22.18m

Q=VA= 0.5*40m3/s

→According to Davis and Wilson seepage losses from power canal

q= $\frac{C}{10,000}P\sqrt[3]{h}$

From table 5.5 C=50 for sandy soil of medium fineness

q= $\frac{50}{10,000} * 22.18 * \sqrt[3]{2.5} = 0.15$ m3/s-km

→According to B.A Etchivery

For effective size of soil particle, dm=0.1mm, specific seepage is between =0.23-0.3

Taking the average value , q= 0.27m^3/day-m^2

→According to A.N. Kostyakov(USSR)

q= $\frac{C}{100}Q$ q in m3/sec-km

values of C for moderate permeability

C=1.9/(Q^0.4)=1.9/(20^0.4)=0.5732

q= 0.5732/(100)*20= 0.114m3/sec-km

7. A tunnel with steel lining embodied in 40 cm concrete has an internal diameter of 300 cm. If E_{st} = 2.1 x 10^6 kg/cm^2, Ec = 2.1 x 10^5 kg/cm^2, σ_{sta}= 1200 kg/cm^2. The rock is crystallized schist of mediocre quality with E_r = 60,000 kg/cm^2 and $\Delta = \Delta_1 + \Delta_2$ = 0.5 mm = 0.05cm and internal pressure is 25 kg/cm^2. Determine the plate thickness of lining.

The load distribution factor,according to the following equation, with due regard to ln x=2.3log$x$

$$\varepsilon = \frac{1}{p}\frac{\sigma_{sta} - E_{st}(\frac{\Delta 1 + \Delta 2}{r})}{\frac{E_{st}}{E_c}\ln\left(\frac{r2}{r1}\right) + \frac{E_{st}}{E_c}\left(\frac{m+1}{m}\right)}$$

$$\varepsilon = \frac{1}{25}\frac{1200 - 2{,}100{,}000(\frac{0.05}{150})}{\frac{2{,}100{,}000}{210{,}000}\ln\left(\frac{180}{150}\right) + \frac{2{,}100{,}000}{60{,}000}\left(\frac{6+1}{6}\right)} = 0.468$$

The necessary plate thickness is, according to

$\delta = \frac{(1-\varepsilon)pr}{\sigma_{sta}}$= (0.532*25*150)/1200=1.6625cm=<u>16.63mm</u>

Steel plate of 17mm thickness are used.

8. Check the lining of 12 mm thick steel plate backed by 40cm thick concrete layer in pressure tunnel of 400 cm internal diameter operating under a head of 200m. E_{st} = 2.1 x 10^6 kg/cm^2, Ec = 2.1 x 10^5 kg/cm^2, σ_{sta} = 1200 kg/cm^2, m=6, rock is dolomite wi77th E_r = 100,000 kg /cm^2, $\Delta = \Delta_1 + \Delta_2$ = 1mm = 0.10cm.

Solution:

$$\varepsilon = \frac{1 - \frac{E_{st}}{p}\frac{\delta}{r}(\frac{\Delta}{r})}{1 + \frac{E_{st}}{E_r}\frac{\delta}{\mathrm{r}}2.3\log\left(\frac{r2}{r1}\right) + \frac{E_{st}}{E_r}\frac{\delta}{r}\left(\frac{m+1}{m}\right)}$$

First computing:
Est/p=105,000
δ/r=1.2/200=0.006
Δ/r=0.00005
Est/Ec=10
Log(r2/r)=log(240/200)=0.079
Est/Er=2,100,000/100,000=21
(m+1/m)=1.1667

Substituting the above values in the following formula:

$$\varepsilon = \frac{1 - 105{,}000 * 0.006 * 0.00005}{1 + 10 * 0.006 * 2.3 * 0.08 + 21 * 0.006 * 1.167} = \frac{1 - 0.0315}{1.158} = 0.836$$

Circumferential stress in the lining steel is

$$\sigma_{sta} = \frac{(1-\varepsilon)pr}{\delta} = \frac{(1-0.836)*20*200}{1.2} = 546.67kg/cm2\text{=54.67Mpa}$$

The stress developed in the pipe is less than the ultimate stress of the steel;
i.e. $\sigma_{st} < \sigma_{sta}$ (546.67Kg/cm2<1200Kg/cm2) hence no need of steel of greater ultimate strength.

9. A surge chamber 8m in diameter is situated at the downstream end of a low pressure tunnel 10km long and 3m in diameter. At a steady discharge of 36 m^3/s the flow of the turbines is suddenly stopped by closure of the turbine inlet valves. Determine the maximum rise in level in the surge chamber and its time of occurrence.

Solution:

D=8m
Lt=10km
Dt=3m
Q=36m3/sec
Zmax=?
T=?

$$Z\text{=Vo}\sqrt{\frac{L.At}{g.As}} * \sin\frac{2\pi t}{T}$$

$$Zmax = Vo\sqrt{\frac{L.At}{g.As}}$$

$$\text{At=}\frac{\pi Dt^2}{4} = \frac{\pi 3^2}{4} = 7.069m2$$

$$As = \frac{\pi Ds^2}{4} = \frac{\pi 8^2}{4} = 50.24m2$$

Vo=Q/At=36/7.069=5.093m/s

$$\text{Zmax=5.093*}\sqrt{\frac{10000*7.069}{9.81*50.24}} = 60.995m$$

$$\text{T=2}\frac{\pi}{r} = 2\pi * \sqrt{\frac{L*As}{g*At}} = 2\pi * \sqrt{\frac{10000*50.24}{9.81*7.069}} = 534.53sec$$

→t=T/4=534.53/4=<u>133.63sec</u>

10. A surge chamber 100m² in area is situated at the end of a 10,000m long, 5m diameter tunnel; λ=0.01. A steady state discharge of 60m³/s to the turbines is suddenly stopped by the turbine inlet valve. Neglecting surge chamber losses, determine the maximum rise in level in the surge chamber and its time of occurrence. Use dimensionless parameters method and finite difference methods.

Solution:
As=100m2
Lt=10000
Dt=5m
ʎ=0.01
Qt=60m3/sec

Neglecting head loss
At=$\frac{\pi D^2}{4} = \frac{\pi 5^2}{4} = 19.63m2$
Vo= Q/At=60/19.63=3.06m/sec

$$Zmax = Vo\sqrt{\frac{L.At}{g.As}}$$

Zmax=3.06* $\sqrt{\frac{10000*19.63}{9.81*100}} = 43.24m$

T=2$\frac{\pi}{r} = 2\pi * \sqrt{\frac{L*As}{g*At}} = 2\pi * \sqrt{\frac{10000*100}{9.81*19.63}} = 452.8sec$

→t=T/4=452.8/4=113.2sec

Including friction
Dimension less parameter

$F_T = \frac{ʎL}{2gd} = \frac{0.01*10000}{2*9.81*5}$
=1.019

$Z^{+}max = \frac{Z}{Zmax}$
$Z^{+}max = (1-1/3K^{+}o)^2$
$Ko^{+} = Po/Zmax$
$Po = F_T Vo^2$
$= 1.019*(3.06)^2 = 9.542$
Zmax = 9.54/43.24=0.22<0.7

$Z^{+}max = (1-1/3*0.22)^2 = 0.86$

Z=Z^{+}max*Zmax= 0.86*43.24=37.1m

Z2+=$\frac{-1}{1+\frac{7}{3}ko^{+}} = \frac{-1}{1+\frac{7}{3}*0.22}$ =-0.66

Z2=-0.66*43.24=-28.57m

Direct successive method

a$\Delta V^2 + b\Delta V + c = 0$

$$\Delta V = \frac{-b + \sqrt{b^2 - 4ac}}{2 * a}$$

$a = \pm FR/4$

$$b = \frac{L}{g\Delta t} + \frac{A_T}{4A_s, m}\Delta t \pm (F_R Vi - \frac{F_s A_T Q_m}{{A_S}^2})$$

$$c = Zi + \frac{A_T}{ZA_{s,m}}Vi\Delta t - \frac{Qm}{2A_{s,m}}\Delta t \pm (F_R Vi^2 + \frac{F_s Q_m}{A_s}(-ZViA_T + Q_m))$$

$$F_R = F_s\left(\frac{A_T}{A_s}\right) + F_T$$

$$a = \frac{F_R}{4} = \frac{1.019}{4} = 0.254$$

$$b = \frac{10000}{9.81 * 10} + \frac{19.63}{4 * 100} * 10 + (1.019 * 3.06)$$

= 105.53

$$c = -9.542 + \frac{19.43}{4 * 100} * 3.06 * 10 - 0 + 1.019 * 3.06^2 = 1.454$$

$$\Delta v = \frac{-105.53 + \sqrt{(105.53)^2 - 4 * 0.254 * 1.454}}{2 * 0.254}$$

$\Delta V = -0.013m/s$

Vi+1=3.06-0.013=3.047m/s

Vm=3.06-0.013/2=3.054m/s

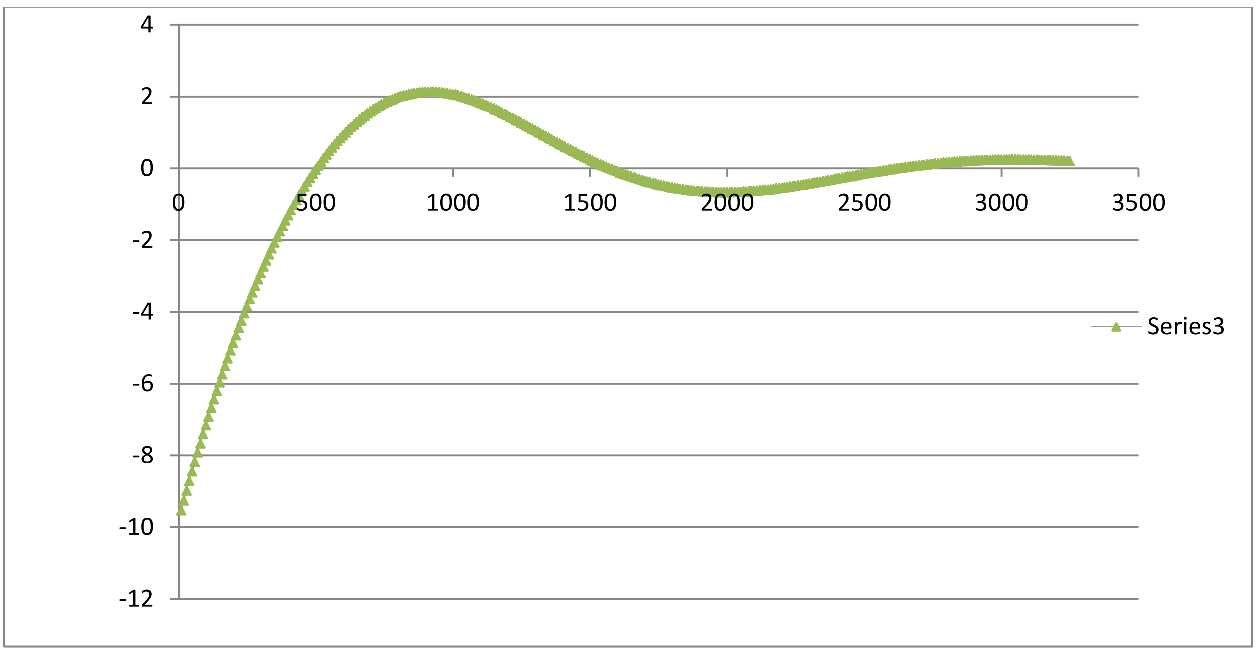
$$\Delta Z = \frac{A_T}{A_s}Vm * \Delta t$$

$$\Delta Z = \frac{19.63}{100} * 3.054 * 10 = 5.994m$$

Zi+1=-9.542+5.994=-3.548

t	0	10	20	30
V	3.06	3.054		
Z	-9.542	-3.548		

Direct solution method of finite element method



11. A hydropower scheme has a surge tank at the end of a 2020m long tunnel, 4.22 m in dia. The surge tank, rectangular in section, may be assumed of a circular x-section, 15.85m in dia. Penstock systems can be represented by a single penstock, 380 m long and 3.41 m diameter, friction factor for tunnel and penstock is 0.018 and 0.03 respect. And C in penstock is 1370 m/s. at steady state, the head reservoir level is 457.0m with a discharge of 26.2 m^3/s.

Compute the water hammer pressure, levels of maximum upsurge and down surge for sudden load rejection using dimensionless parameters.

Evaluate the natural frequency of oscillation using

Analytical solution

Numerical solution (including friction, neglect surge tank throttle loss). You may apply one of the numerical techniques (Finite difference, direct or successive estimates or Runge-Kutta method.) using fortran programming. Present the result graphically showing time variation of oscillation for both a) and b).

12. In a pumped storage hydropower project, water is delivered from the upper impounding reservoir through a low pressure tunnel and four high pressure penstocks to the four-pump turbine units. The elevation of the impounding reservoir water level is 500m AOD, and the elevation of the d/s reservoir WL is 200m AOD. The max. reservoir storage which can be utilized continuously for a period of 48 hours is 15 $*10^6$ m^3.

The low-pressure tunnel is constructed as follows:

Length = 4 km; diameter = 8m; friction factor = 0.025. The high pressure penstocks (4 nos.) are constructed as follows: length of each penstock = 50 m; diameter = 2m, friction factor = 0.015, turbine efficiency when generating = 90%; generator efficiency (16 poles, 50Hz) = 90% turbine efficiency when pumping = 80% barometric pressure = 10.3 m of water; Thoma's cavitations coefficient σ=0.043 $(N/100)^2$.

Determine the maximum power output from the installation.

Estimate the specific speed and specify the type of turbine.

Determine the safe turbine setting relative to the d/s reservoir water level.

If a simple surge chamber of 6 m in diameter is provided at the end of the low-pressure tunnel, estimate:

The max. upsurge and down surge in the surge chamber for sudden load rejection of one units and

The maximum down surge for sudden demand of one unit.

Solution:

The discharge available 15*10^6/48*60*60=86.8m^3/s.

The power output is calculated as follows:

velocity in tunnel =86.8/(π/4)8*8=1.73m/s

Therefore:-

head loss in tunnel =$\lambda LV2/2gD$=2.13m,

discharge per penstock =86.8/4=21.7m3/s

velocity in penstock =21.7/(π/4)2*2=6.91m/s

Therefore:-

head loss in penstock = $\lambda LV2/2gD$=9.73m,

gross head at turbine =500-200=300m,

and so

net head = 300-2.13-9.73=288.14m,

output/turbine =$\eta\rho gQH/10^6$= 0.9*1000*9.81*21.7*288.14/10^6=55MW,

total output =4*55=220MW.

The net output of the generators is 0.9*220=198MW. The generator

speed, $N=120f/p$= 120*50/16=375 rev/min (acceptable synchronous speed). Therefore

the specific speed, Ns=$Np^{1/2}/H^{5/4}$=*375*(55000)^0.5/(288.14)^1.25*=76. A Francis-type turbine is suitable

(efficiency, specific speed, and head match this type).

The turbine setting:

Ys =B-σH,

σ = 0.043*(76/100)^2=0.0248,

and therefore

Ys =10.3-0.0248*288=3.16 m or 203.16m AOD.

The distributor elevation

Yt $=Y$s-0.025DNs$^{0.34}$

The approximate runner diameter

$D = 4.43(Q/N)^{1/3}$ =1.72m.

Therefore:

Yt=3.16+187=3.347 m or 203.35m AOD.

The surge chamber calculations are as follows:

area of surge chamber, As = 3.14*9= 28.27m^2;

area of tunnel, At = 3.14*16=50.26m2;

length of tunnel, Lt = 4000m.

Therefore:

$r = (gA\text{t}/L\text{t}A\text{s})^{1/2} =$ ((9.81*50.26)/(4000*28.27))^0.5=0.066

For one unit rejection or demand, Q0 = 21.7m3/s and P_o =2.13m. Therefore

Zmax =Q0/Asr = 21.7/(28.27*0.066)=11.63m

and

K^*_0=P0/Zmax =2.13/11.63= 0.183.

Upon sudden rejection, the maximum upsurge , Z^*max = 1-2k$^*_0$/3+k$^{*2}_0$/9=0.88. Therefore

Zmax =0.88*11.63=10.23m.

The maximum downsurge (equation (12.33)), Z^*min = -1-0.125K$^*_0$=-0.7. Therefore

Zmin =-0.7*11.63=8.14m.

Upon sudden demand, Z^*min =-1.023. Therefore

Zmin =-1.023*11.63=-11.9m.

13. The following data refer to a proposed hydroelectric power plant. Turbines: total power to be produced = 30MW; normal operating speed = 150 rpm; net head available = 16m. Draft tube: maximum kinetic energy at exit of draft tube = 1.5% of H; efficiency of draft tube = 85%; vapor pressure ≤ 3 m of water; atmospheric pressure = 10.3 m of water.

What size, type, and number of units would you cleat for the proposed plant?

Starting from the first principles, determine the turbine setting relative to the tail water level.

Solution: For a low-head, high-discharge plant, Kaplan-type units are suitable.

Assuming a specific speed of, say, 500, the power per machine

$=(N_s H^{5/4}/N)^2$ =((500*16^1.25)/150))^2 = 11377kW.

Therefore the number of units is 30,000/11,377=2.64. Therefore, choose

three units, each having an installed capacity of 10MW. Note that the

number of units depends on other factors such as the variability of power demand, breakdown-maintenance works, the availability of national grid power supply in case of emergencies, etc.

The specific speed

$NS=150*\sqrt{10000/(16)^{5/4}} = 468$

The discharge per unit is 10,000/0.94*9.81*16 (assuming an efficiency of 94% from the Table) = 67.75m3/s. Therefore the runner diameter,

$D = 4.57(Q/N)^{1/3}$ = 4.57*(67.75/150)^(1/3)=3.50 m, and the inlet velocity (i.e. the exit velocity at the runner) is

67.75/(π/4)*3.5*3.5 = 7.04m/s; hence the inlet velocity head is 2.53 m.

The exit velocity head is 1.5*16/100 = 0.24m.

Applying Bernoulli's equation between the inlet of the draft tube and the tailwater level.

$$Ys = pa/\rho g - p\sqrt{\rho g} - \left(V1^2/2g - V2^2/2g - hfd\right)$$

=10.3-3-0.85(2.53-0.24) = 5.35m above TWL

From Thoma's cavitation limiting conditions,

Ys =B-σH

σ = 0.58 (from Table for Ns=468),

giving *Y*s =1.02m above TWL. In the absence of further data, Thoma's criterion may be adopted.