Module-4

Hydroelectric plants:

Syllabus: Hydroelectric plants: Advantages & disadvantages of waterpower, Hydrographs and flow duration curves numerical, Storage and pondage, General layout of hydel power plants- components such as Penstock, surge tanks, spill way and draft tube and their applications, pumped storage plants, Detailed classification of hydroelectric plants.

4.1 INTRODUCTION

The hydroelectric or the hydel power plants, generate power using the potential energy of water available on earth's surface. The rain water collected at different altitudes on the earth's surface has potential energy with respect to the level of the oceans towards which the water flows. This energy of the rain water is utilised to drive hydraulic turbines, and in turn to run electric generators and produce electrical energy. The hydel power developed depends on the head of water and the quantity of natural rainfall. Generally, reservoirs are constructed to collect the natural rain and used to generate power throughout the year. Thus the reservoir area, which is a measure of the water collected and the height of the dam, which is the measure of the head of the water are two important factors. However, the quantity of water available depends upon the hydrological cycle and the total rain-fall received by the area in which the power plant is located.

4.2 Advantages and Disadvantages of Hydel Plants

Advantages

1) Operating cost of the plant including auxiliaries is low.

2) The maintenance of the plant is comparatively less.

3) Less labour is required to operate the plant.

4) No nuisance of smoke, exhaust gases, soot and other pollution.

5) The sites of hydel plants are usually away from the developed areas and hence the land is very cheap.

6) Load fluctuations can be met rapidly without loss of efficiency.

7) There are no stand-by losses.

8) Since no fuel used, there are no problems of handling, charging and disposal.

Disadvantages

1) Initial cost of the plant including the cost of dam is very high.

2) The feasibility of a hydel plant depends mainly on the availability of water and hence the natural phenomenon of rain and thus the problems of stopping the plant may arise during dry seasons.

3) Usually the sites will be away from the load centres, which cause loss of power and high costs in transmission lines.

4) It takes considerably long time for erection compared to the erection of thermal plants.

4.3 Hydrographs

It is a graph representing the discharge of flowing water with respect to time for a specific period. The time axis may have units of hour, day, week or month. The discharge units may be m3/sec, km^2-cm/hr or day-second-metre. Discharge hydrographs are also known as flood or run-off hydrographs) Fig. 4-5 shows typical hydrographs or discharge curves based on daily, monthly and yearly flows.

Uses of a Hydrographs

A hydrograph is useful to determine a number of parameters, such as:

1) Rate of flow at any instant during the specific recorded period.

2) Total volume of flow in a given period, as the area under the hydrograph represents the volume of water in a given duration.

3) The mean annual run-off for any of the recorded period.

4) The maximum and minimum run-off for any selected period

5) The maximum rate of run-off during the floods and duration of frequency of floods (peak of the curve indicates the flood)

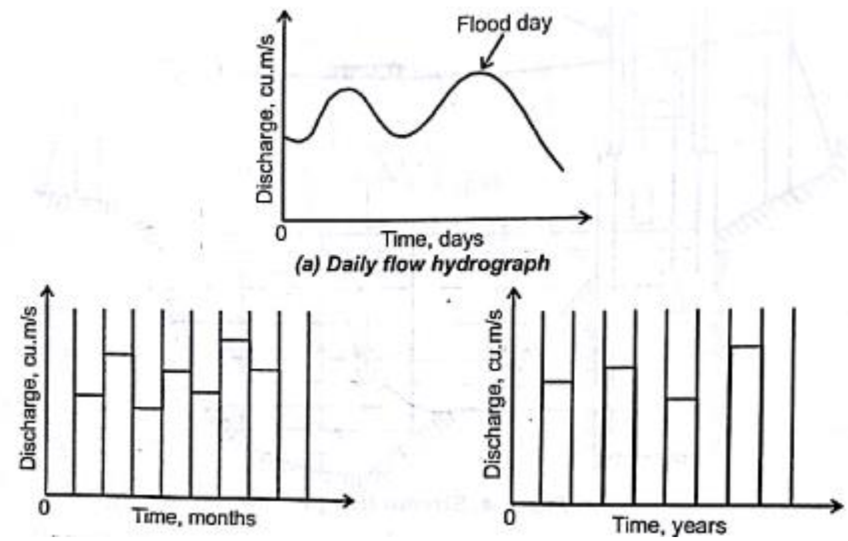


Fig. 4-5. Hydrographs or discharge curves

4.4 Unit Hydrograph

A unit hydrograph is a hydrograph with a volume of 1 cm of run-off resulting from a rainfall of specified duration and a real pattern, which is constructed using the hydrograph data. The theory of unit hydrograph was introduced by Sherman. He indicated that the time base is common to all hydrographs resulting from rainfalls of a given duration. When the rainfall distribution is similar with respect to time and area, then the ordinate of each hydrograph will be proportional to the volume of run-off.

Limitations to the use of unit hydrograph are:

1) The rainfall distribution varies from one area to another. Hence, the use of unit hydrograph is limited area of basin of about 5000 sq. km.

2) For long and narrow basins, and odd shaped basins the rainfall distribution is not even, hence unit hydrograph is not suitable.

4..5 Flow Duration Curve

This is another useful graphical representation of the run-off for a given period. The run-off data on the ordinate against the corresponding percentage of time on the abscissa represents a Flow Duration Curve. The area under the curve represents the average yield from the stream.

Fig. 4-6 shows a typical flow duration curve. the flow may be expressed as m3/sec/ week or any other convenient unit of time When the available head of water is known, then the total energy of flow can be computed. Thus by flow duration curve it is possible to estimate the total power available at the site. A flow duration curve can be used to determine the minimum and maximum conditions of flow of water. If the magnitude on the ordinate is the estimated power contained in the stream flow against the corresponding percentage of time on the abscissa, then the curve is known as Power Duration Curve.

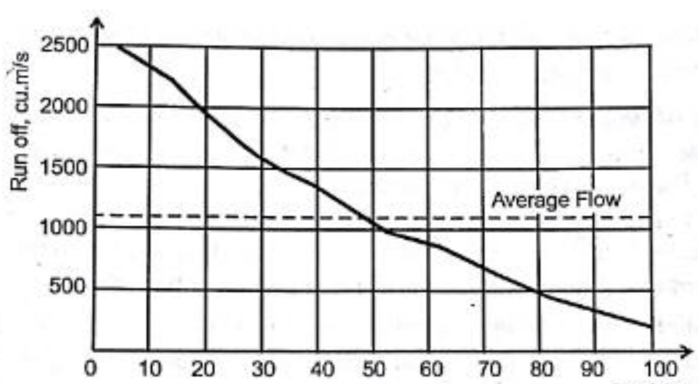


Fig. 4-6. Flow duration curve

$$V = \int_{t_1}^{t_2} Q_t . dt$$

V is the volume of run-off and Q_t is the discharge in m^3/sec as a function of time.

4.2 CLASSIFICATION OF HYDEL PLANTS

Hydel power plants can be classified as follows:-

1. Quantity of water available
   - a) Run-off river plants without pondage
   - b) Run-off river plants with pondage
   - c) Pumped storage plant
2. Head of water
   - a) Low head plant b) Medium head plant c) High head plant.
3. Nature of load
   - a) Base load plant b) Peak load plant
4. Capacity of plant
   - a) Low capacity plant (100-999 kW)
   - b) Medium capacity plant (1 MW-10 MW)
   - c) High capacity plant (above 10 MW)

4.2.1 Run-off River Plants without Pondage

In such plants water is not stored, but only the running water is used for power generation. In such power plants the power generated directly depends upon the rate of flow available. Hence, during rainy seasons some excess quantity of water may run waste without doing any power generation. During dry periods the power production will be very poor, since the water flow rate will be low.

4.2.2 Run-off River Plants with Pondage

In such plants, the excess water available during rainy seasons is stored in the reservoirs. The plant works with the normal run-off during the rainy season, while the stored water from the reservoir is utilised to supplement the low flow rate during dry periods. Power production will not be affected by the dry seasons. Hence, plants with pondage can generate a constant rate of power through out the year. If Pumped Storage Plants Such plants are most suitable for supplying sudden peak load requirements. However, such demands can be met only for a short duration. In the normal operation they can meet the average demand only.

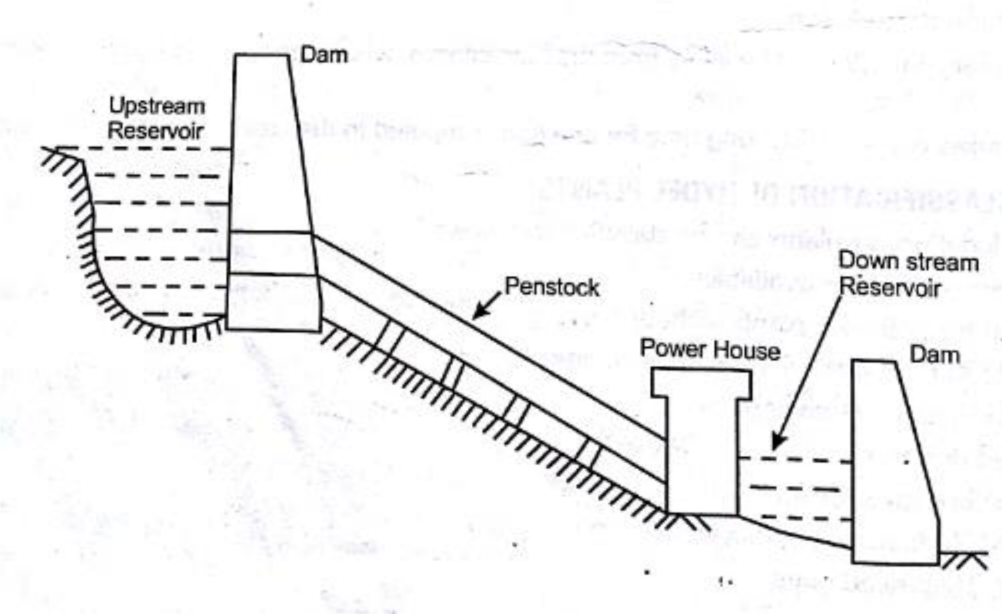


Fig. 4-8. Pumped storage plant

Fig. 4-8 shows the schematic of a pumped storage plant. Such type of plant consists of two storage reservoirs. The upstream reservoir is the main (head race) storage reservoir to which water flows from the catchment area. The second reservoir is the down stream (tail race) reservoir, in which the used water from the upstream is collected.

The water in the down stream reservoir is pumped back to the main upstream reservoir, during off peak periods. This facilitates making use of the excess water during peak hours. A pumped storage plant is a peak load plant and operates in combination with other base load plants such as a thermal power plant. The off peak load capacity of the thermal plant is used for pumping water from the down stream reservoir to the main upstream reservoir. The schematic arrangement of pumped storage plant operating along with a thermal plant to meet the peak load demands, is shown in Fig. 4-9.

Advantages of Pumped Storage Plants

1) Compared to peak load plants, the initial cost of this plant is low.

2) The power plant operation is flexible, since it can operate both as peak load and base load plant.

3) Such plant can meet sudden peak hour demands, and is highly reliable in operation.

4) Since they operate at higher load factors, the overall efficiency of the plant is high.

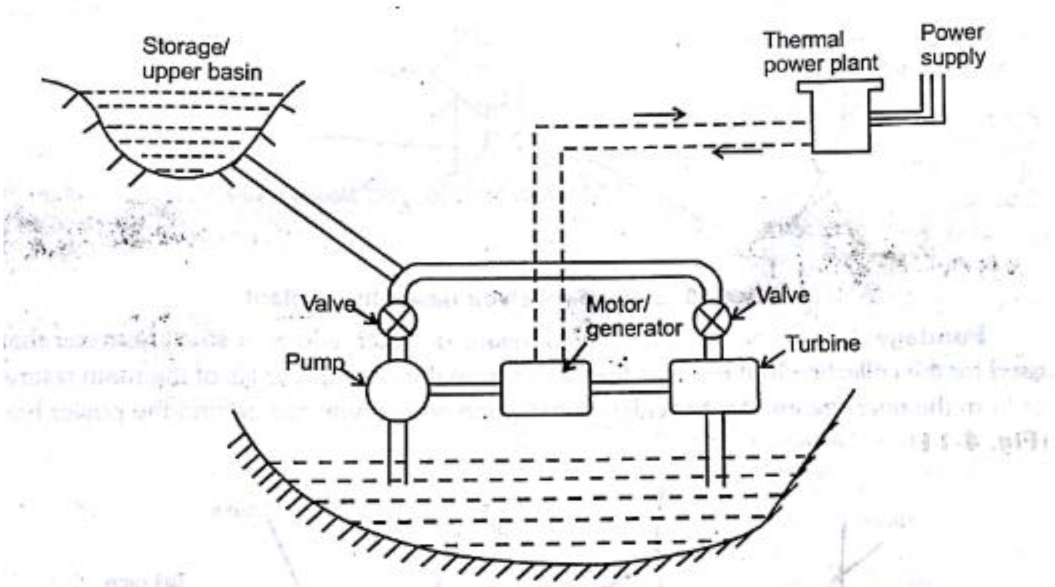


Fig. 4-9. Pumped storage plant for peak load

4.2.4 Storage and Pondage

Storage plants are the plants with facilities for storing water at their sites. However, often such plants cannot store as much water as required for the full year operation. For continuous operation, it is always preferred to have one or more reservoirs upstream. Depending upon the place of storage and the function, the reservoirs are grouped as storage and pondage.

Storage: Storage can be defined as the collection of a large quantity of run-off during mansoon seasons, which is essentially used in the dry seasons for the plant operation. This is the main or the upstream reservoir, made by the construction of a dam across the stream (Fig. 4-10).

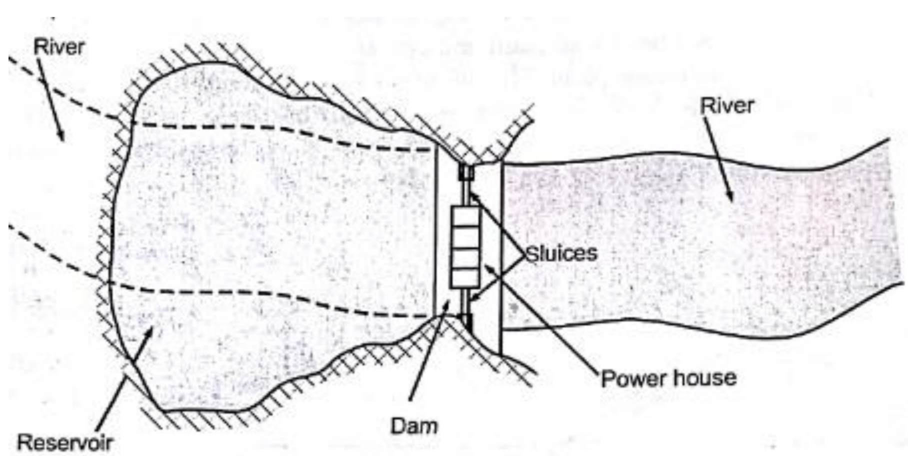


Fig.4-10. Storage reservoir based hydel plant

Pondage: It is defined as a regulating means of water, and is a small reservoir that is used for the collection of the excess flow water from the dam spill ways of the main reservoir or from the river stream. It is basically a small pond or reservoir just behind the power house (Fig. 4-11).

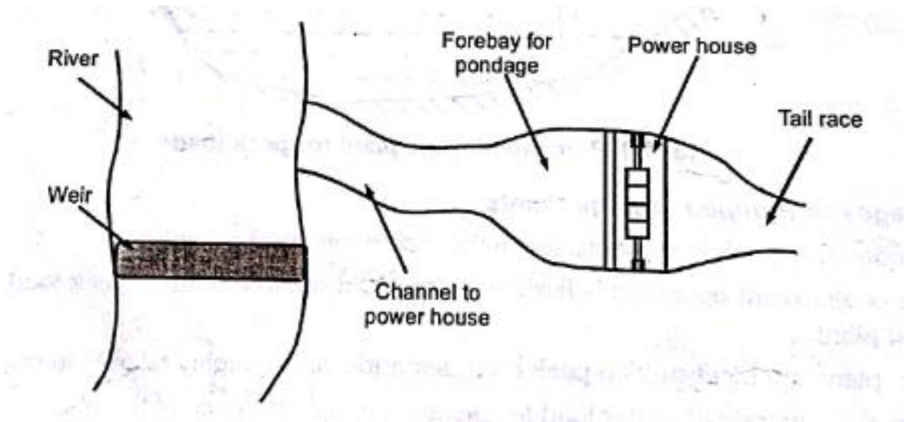


Fig. 4-11. Pondage reservoir based hydel plant

The amount of regulation obtained with pondage usually involves storing water during low loads (during low power demand periods such as early morning hours and Sundays) to aid carrying peak loads during the week. The water that would go over the dam spill-way unused during low-loads can be released and added to normal river flow to supply peak loads, usually for a few hours of duration. For fluctuating loads, pondage increases the maximum capacity that a plant can carry.

Plants with reservoirs upstream can store excess water of spring floods for release during summer to supplement the low rates of flow during this dry season. Reservoir water elevation will generally be lowest during the year at the end of the summer.

Pondage increases the capacity of a river for a brief period only, like for a week. But, _ storage increases the capacity of a river over an extended period such, like 6 months to 2 years.

4.2.5 Low Head Hydel Plant hydel plant

Hydel Plant with a water head of less than50 meter is termed &low head plant (the such plants, a small dam is constructed across a river to obtain the necessary water head:, The excess water is allowed to over the dam, while the water head is made use to run a hydraulic turbine. The water from the dam is taken through a canal to the turbine. For low head plants Francis or Kaplan turbines are used. There is no water hammer problem in such plants, hence no, surge tank is provided in the water line. The schematic arrangement of a typical low head hydel plant is shown in Fig. 4-12.

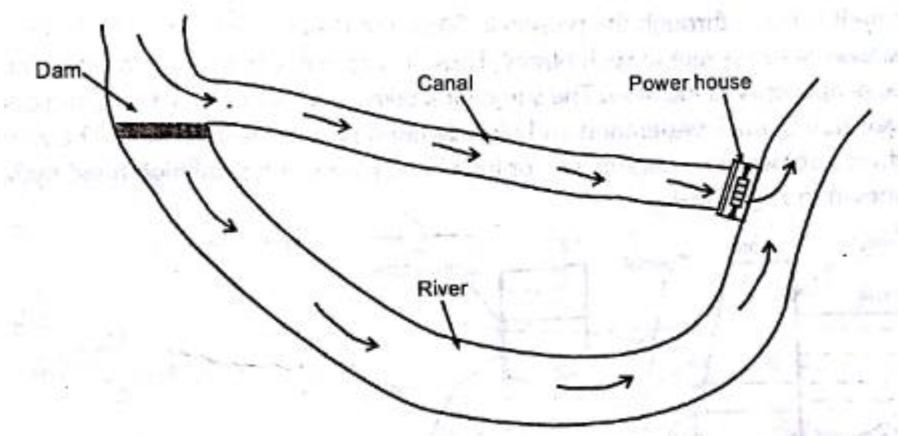


Fig. 4-12. Low head hydel plant

4.2.6 Medium Head Hydel Plant

A hvdel with a water head of in the range of 50 to 100 meters is termed a medium head plant. In this, the water is stored in a main reservoir. This water is allowed to a small pond or forebay through a canal. The water from the forebay is taken to the turbine through penstock. In such plants the forebay itself acts as the surge tank, and hence receives the excess water during the low demand periods. Francis turbine is most suitable for medium head hydel plant. The schematic arrangement of a typical medium head by n Fig. 4-13.

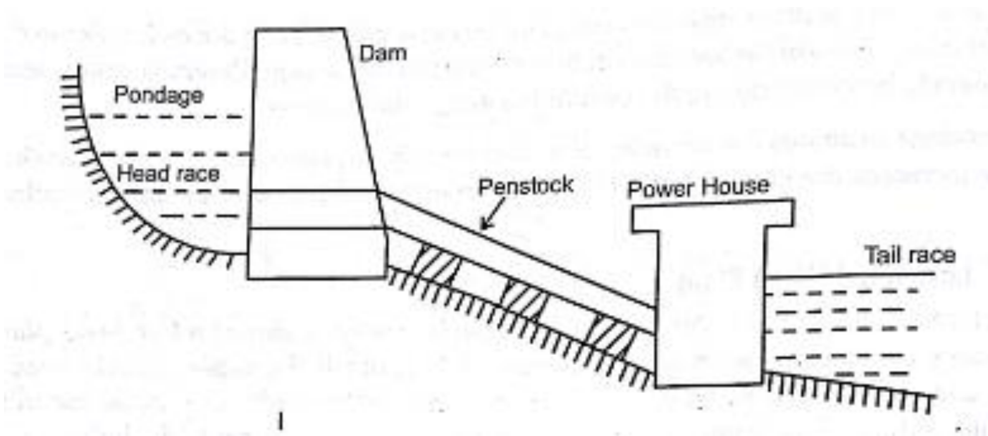


Fig. 4-13. Medium head hydel plant

4.2.7 High Head Hydel

Plant hydel plant with a water head of more than 100 meters is termed a high head plant. In this case, the water from the main reservoir is carried through tunnels up to the surge tank, ord. Where it is taken through the penstock. Since the water head is very high, the effect of water hammer is too severe in such plants. Thus, it is essential to provide a surge tank in the water line at appropriate location. The surge tank takes care of the increasing and decreasing water levels during the low-demand and high demand periods, respectively. The Francis and Pelton wheel turbines are most suitable for high head plants. A typical high head hydel power plant is shown in Fig. 4-14.

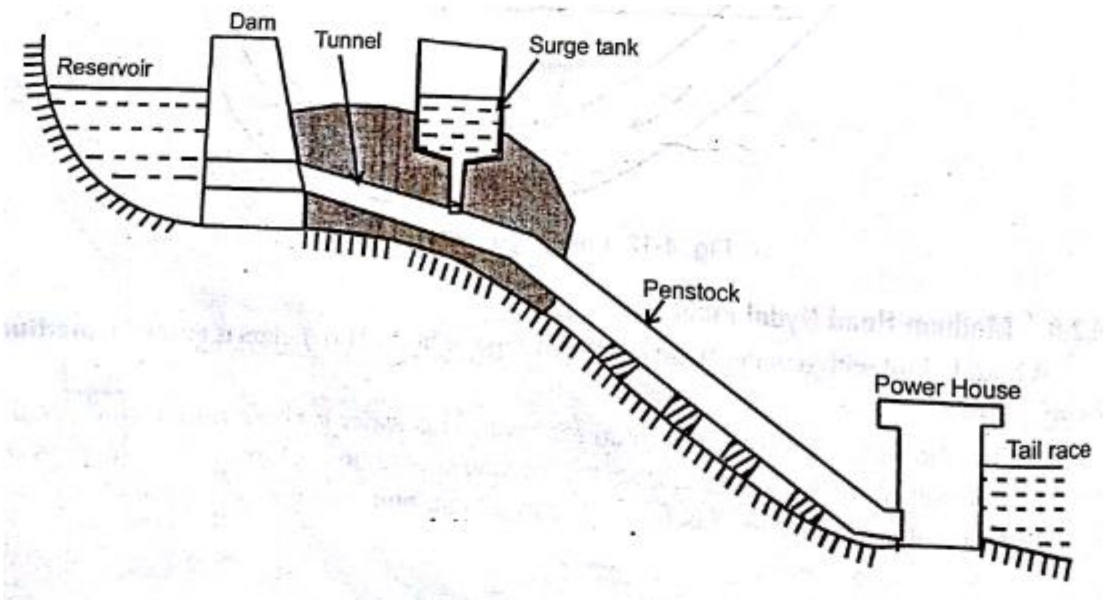


Fig. 4-14. High Head Hydel

4.3 GENERAL LAYOUT OF A HYDEL PLANT

Fig. 4-15 shows the general layout of a storage type hydel power plant with necessary components and protective devices. The main components of a storage type hydel power plant arc as follows:

1. Catchment area
2. Storage Reservoir
3. Dam
4. Penstock
5. Forebay
6. Power house
7. Draft tube
8. Trash rack
9. Spill way
10. Surge tank

The last three units are the protective devices, which help in the safe functioning of the hydel plant.

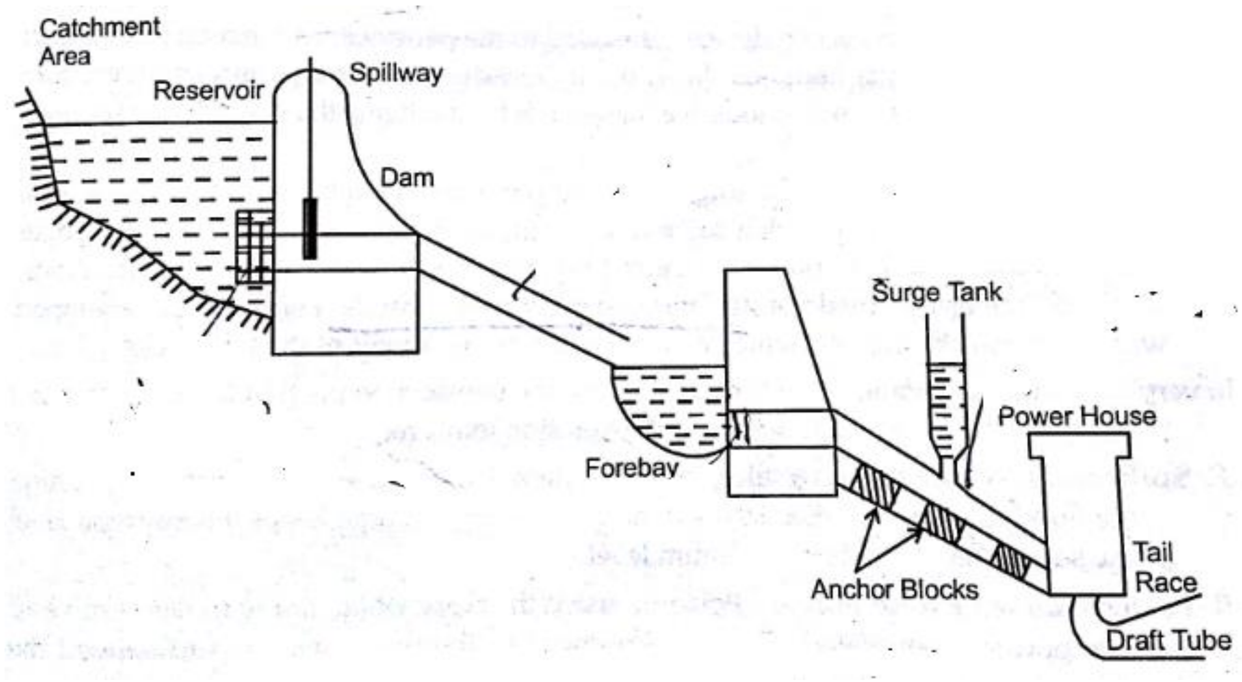


Fig. 4-15. General layout of a hydel power plant

The different components and their functions are briefly discussed below.

1. Catchment Area: The complete area around the reservoir, around the river and the river basins near the reservoir is termed the catchment area. A larger catchment area results in better run-off into the reservoir. The reservoir capacity and the dam size are dependent on the size of the catchment area and the intensity of the rainfall.

2. Reservoir: The main purpose of reservoir is to store water during rainy season and supply the same during dry season. The reservoir is located at a region of heavy rain fall, with sufficient catchment area. 3. Dam: The function of a dam is to increase the height of water level behind it, hence to increase the reservoir capacity. The -darn also helps to increase the working head of the power plant.

4. Trash Racks: The water intakes from the dam or from the forebay are provided With trash racks to prevent the entry of debris. The debris if allowed may damage the wicket gates and turbine runners, or choke-up the nozzles of the impulse turbine, thus hampering the plant operation. If the winter is severe, arrangements to heat the trash racks by electrical means are made to prevent the clinging of ice around it. Sometimes bubbling arrangement is made near the trash racks, which brings them in contact with warm water and minimises the icing problem.

5. Forebay: It serves as a regulating reservoir and temporary storage pond. It receives the excess water when the load on the plant is reduced and provides water for initial increment of an increasing load, while the water in the canal is being accelerated. Thus, forebay is a naturally provided storage which is able to absorb the flow variations. This can also be considered as the naturally provided surge tank as it performs the work of a surge tank.

6. Surge Tank: It is a protective device connected to the penstock. Its function is to protect penstock against water hammer effects during low demand periods and avoid vacuum effect during high demand periods. It achieves this by stabilizing the velocity and pressure in the penstock.

7. Penstock: A pipe between the surge tank and prime mover is known as penstock. The structural design of a penstock is same as other pipes, except for that it is made stronger inside, to withstand high pressures caused by water hammer during load fluctuations. Penstocks are usually made of steel through reinforced concrete. Penstocks are equipped with head gates at the inlet which can be closed during repair of the penstocks. In very cold weather conditions, it is better to bury the penstock to prevent the ice formation in the pipe and to reduce to number of expansion joints required.

8. Spillway: It is considered as a safety valve of a clam. It must have the capacity to discharge major floods without damage to the dam and at same time keeps the reservoir level below some predetermined maximum level.

9. Power House / Prime Mover: Power house is the place where prime mover is run and electric power is generated. The main purpose of the prime mover is to convert the kinetic energy of water into the mechanical energy to produce electric current. These are Pelton, Kaplan and Francis turbines.

10. Draft Tube: This essential part of reaction turbine installation. It supplements the action of the runner by utilizing most of the remaining kinetic energy of the water at the discharged end of the runner.

4.4.2 Spillways:

It is a safety device constructed with the dam. It functions when the dam faces flood problems. If allows the passage of excess water from the reservoir, whenever the level raises above the predetermined safer level, thus avoiding the damage to the darn. The different types of spill ways are:

1) **Ogee Spillway:** Fig. 4-17a shows a ogee spillway. It is the crust of the dam, designed in such a way that, whenever the reservoir level reaches the safe limit the water starts flowing out. This is the simplest spillway and widely used for concrete dams.

2) **Chute Spillway:** A chute spillway is shown in Fig. 4-17b. In this type of spillway, the excess water during floods flows-out of the dam and gets discharged through concrete channels constructed along the sloping dam as shown in figure. This type of spillway is suitable for earthen dams.

3) **Shaft Spillway:** Fig. 4-17c shows a shaft spillway. In this, water flows through a horizontal tunnel to the penstock from the reservoir. In the dam a vertical shaft is constructed connecting the horizontal tunnel. Whenever the water level exceeds the safe limit, excess water starts flowing through the vertical shaft as shown in figure.

4) **Siphon Spillway:** Fig. 4-17d shows a siphon spillway. When the water level reaches A-A the siphon starts working and siphons out water up to B-B. This type is suitable for small capacity reservoirs.

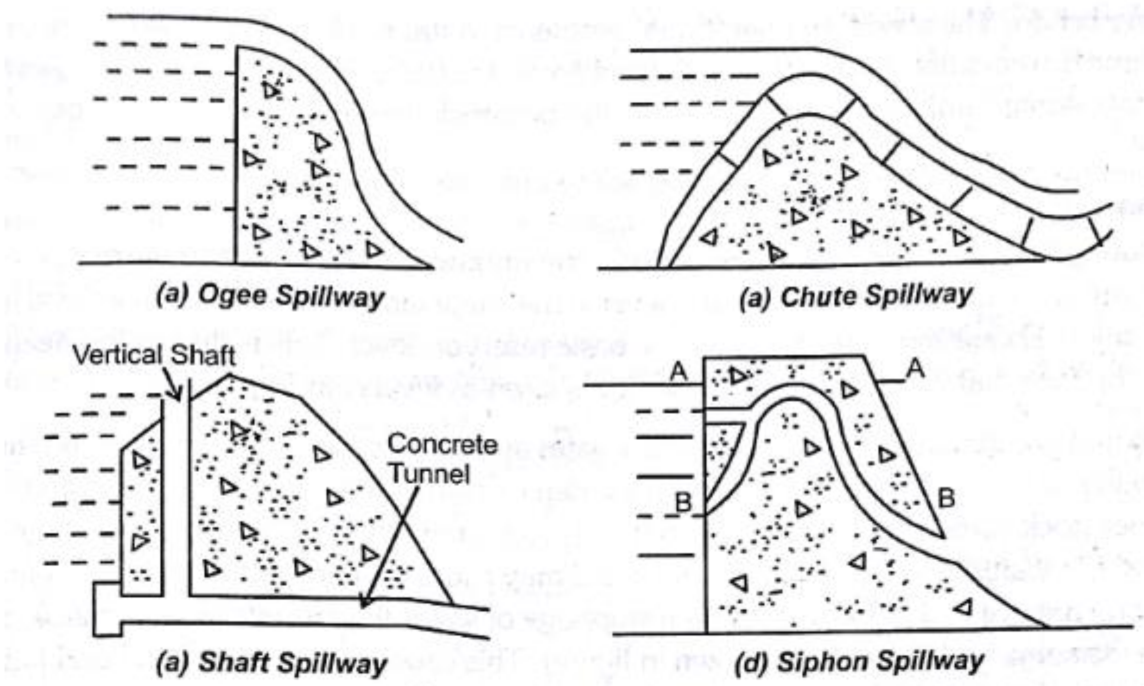


Fig. 4-17. Spillways

4.4.3 Penstocks

Penstocks are the pipelines that connects between the water source (such as the reservoir, forebay, water way) and the hydraulic turbine. These are usually large circular pipes with diameters ranging form 1 meter to 8 meters. Penstocks are usually made of steel or concrete pipes.

Care should be taken to keep the entry to the penstock at the dam or the forebay at a low level, submerged always under the water. If the entry is open to air, it may take air along and create aeration prob1lAms in the prime mover, thus affecting the performance.

The penstocks should be laid in such a way that there are no sharp bends. Sharp bends cause frictional losses and reduce the effective water head. Generally penstocks are exposed type, since they are economical and easy to repair and maintain. However, covered penstocks can be used when the regions are prone to sliding rocks, snow, earth and such dangers, so as to avoid damage to the pipe line.

4.4.4 Water Hammer - Surge Tanks

Whenever there is a sudden fall in the demand, the governor closes the penstock valve to a minimum. This sudden closure of the valve increases the pressure inside the penstock due to the kinetic energy of the water which is high enough to damage the penstock pipe. This effect is termed Water Hammer. Also, whenever there is a sudden rise in the load demand the gates are opened instantly by the governor, thereby creating vacuum in the penstock pipe. This causes to bubbling and foaming action. This leads to operational problems in the turbine. These problems can be overcome by providing a surge tank in the penstock line. Basically, a surge tank is a cylindrical Open top storage unit, which connected to the penstock line and located very close to the turbine.

Function of Surge Tank

During the normal demand/flow periods, the turbine gates are open to normal position, since there are no fluctuations in the water level in the surge tank. The normal water level in the surge tank is always lower than that of the basic reservoir level. This is due to the head loss due to the frictional losses in the flow line. It is shown as level A in Fig. 4-18. During low demand periods, the turbine gates are closed partly and water flow is reduced to keep the turbine speed constant. Due to sudden closure of the flow path, the flowing water in the penstock comes to a halt thereby building pressure in the line. If there is no surge tank this creates a water hammer in the penstock and may cause damage to the pipe line. With the surge tank present in the line, this sudden stoppage of water flow results in an increase in the level in the surge tank (level B, as shown in figure). This causes a retarding head and reduces the velocity of water in the penstock thereby avoiding water hammer effect.

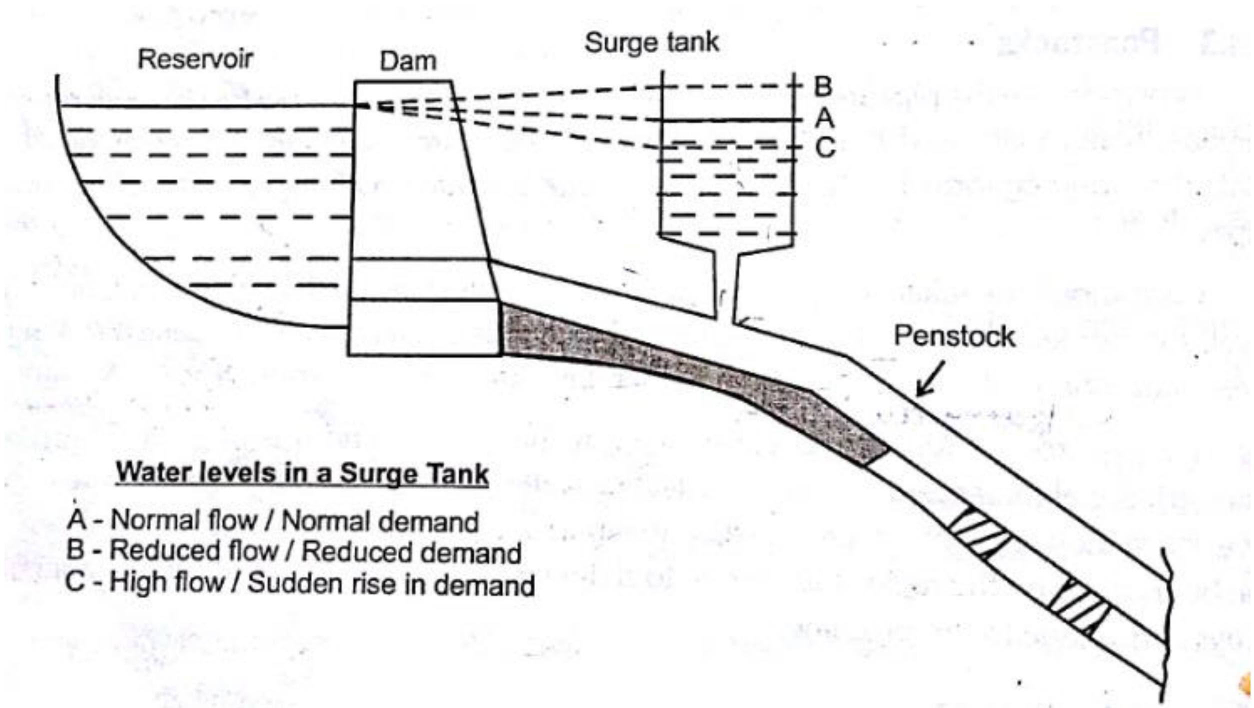


Fig. 4-18. Function of a surge tank

Similarly, when the demand is normal, the gate is opened to the normal position, so that the flow velocity on the penstock reaches the normal value. For this, the required water is supplied by the surge tank, and the water level in the surge tank suddenly reduces and fluctuates up and down till its motio7n is damped down by friction.

When there is a sudden rise in the load, additional water required is supplied by the surge tank thus avoiding the possibility of vacuum formation in the penstock. During this the water level suddenly drops down below the normal as the water excess water is supplied by the surge tank. This is indicated as level C in Fig. 4-18.

Types of Surge Tanks

Different types of surge tanks are used in the power plants depending upon the design and topographical requirements. Some important types of surge tanks are as follows:

a) Cylindrical Surge tank

This is the simplest design. It is simply a plain cylindrical tank connected to the penstock line through a short connecting conduit (Fig. 4-19a). The tank size is kept to a level so as to maintain a stable flow to the turbine, and minimum fluctuations in the water level. However, this design is not a common design due to its slow response to demands and also it is expensive. This is not a commonly used design in hydel plants.

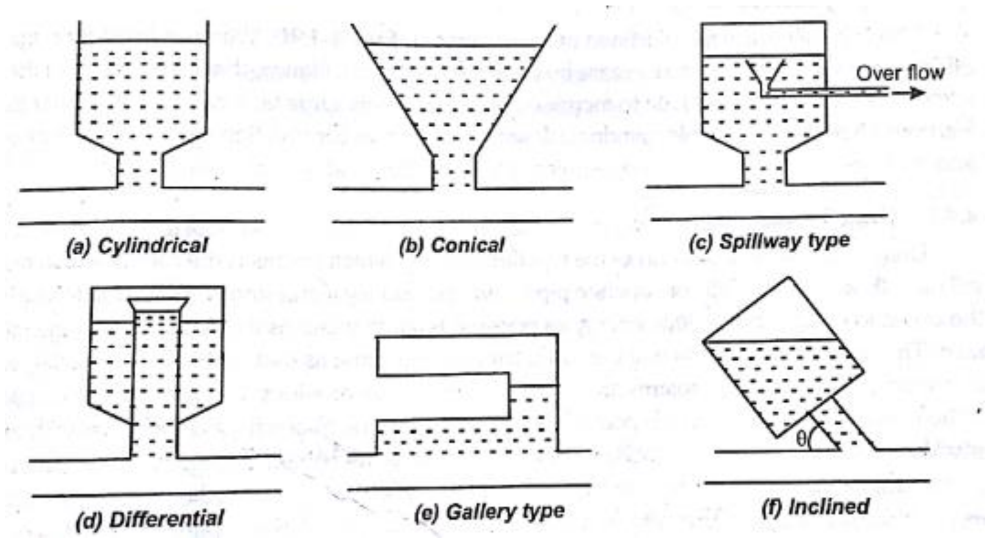


Fig. 4-19. Types of surge tanks

b) Conical Surge tank

It is a conical shaped vessel connected to the penstock (Fig. 419b). it is a better design than the cylindrical surge tank. Since it has an increasing area of cross section, it can handle the water fluctuations more effectively. Also, it has a considerably faster response to load fluctuations.

c) Spillway type Surge tank

This is a closed cylindrical vessel with a bell mouth spill way connected to it (Fig. 4 19c). The tank is designed to meet the water demand from the stock available in it, while the excess water during low demand periods over flows out of the surge tank through the spill way,

d) Differential Surge tank

This is cylindrical tank with a central riser with small ports at the lower end (Fig. 4-19d). Water movement in the tank is through the ports. It responds effectively to the variations in load demands, and also the oscillations in the wafer level are minimal.

e) Gallery type Surge tank

This is special surge tank design. It has two separate water galleries (Fig. 4-19e). The upper gallery stores the water when the load on the turbine drops, while the lower gallery supplies water when there is a sudden increase on the turbine load.

t) Inclined Cylindrical Surge tank

This is a cylindrical tank inclined at some angle q (Fig. 4-19f). With this inclination the effective area of water surface increase by an amount cosec q. Hence, the actual height of the surge tank can be reduced. Due to increased water area, this surge tank can respond faster to load variations than the simple cylindrical design. However, its construction is difficult, expensive and preferred only when the topographical situations demand for such requirements.

4.4.5 Draft Tubes

Draft tube is an integral part of the reaction turbine, which connects the runner exit to the tail race. It can be a metallic or concrete pipe having gradually increasing cross section towards the outlet to ensure that as little energy as possible is left in water as it discharges into the tail race. The area of the draft tube at the top is circular and same as that of the turbine outlet, so that shock and aeration problems are minimum. Draft tube provides a negative suction head at the runner outlet by which it is possible to install the turbine above the tail race level without any loss of head. Since the velocity of the water leaving the runner is quite high, the kinetic energy will be lost if water is allowed to discharge freely. The draft tube reduces outlet velocity and increases the useful pressure head thereby increasing the turbine output. The different types of draft tubes used in hydel plants are illustrated schematically in Fig. 4-20.

1) Straight divergent tube (Fig. 4-20a), is used in low specific speed vertical shaft Francis turbines. It has a circular inlet and rectangular outlet. The cone angle should be less than 8° for optimum turbine performance. It gives a better speed regulation when the turbine load drops down.

2) Moody spreading tube (Fig. 4-20b) has two split section at the outlet. This section reduces the whirl action of water flowing at high velocity.

3) Simple elbow tube (Fig. 4-20c) has circular cross section throughout.

4) Elbow type draft tube has a circular inlet and a rectangular outlet (Fig. 4-20d) .

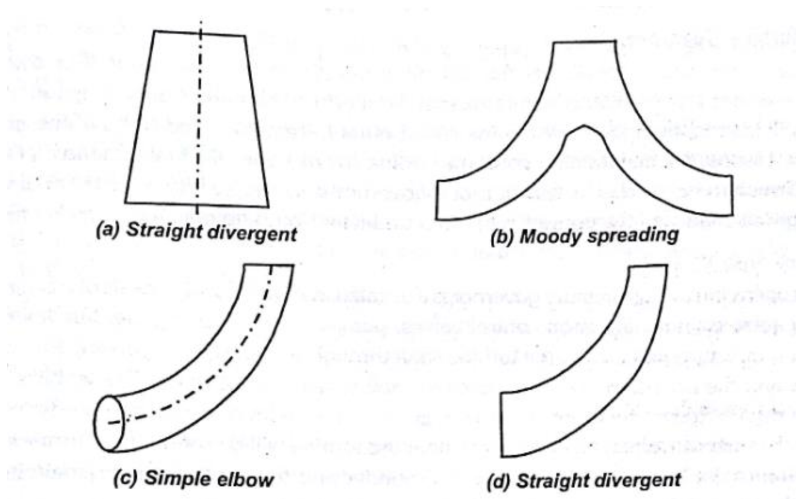


Fig. 4-20. Types of draft tubes

List of formula

$$\text{power } P = \frac{\rho g Q H \eta}{10^3} \text{ kW}$$

or

$$P = \frac{\rho g Q H \eta}{10^6} \text{ MW}$$

$\rho \rightarrow$ density of water 1000 kg/m³

$g \rightarrow$ Acceleration due to gravity, 9.81 m/s²

$Q \rightarrow$ Discharge m³/sec

$H \rightarrow$ Head available (m)

$\eta_0 \rightarrow$ overall efficiency.

(a) $\text{mean discharge} = \frac{\text{Total discharge}}{\text{Total. No. of month}}$

* if millions of m³/month

$$Q = \frac{10^6 \,(\text{mean dischage})}{30 \times 24 \times 60 \times 60}$$

* if million of m³/year

$$Q = \frac{10^6 \,(\text{mean discharge})}{365 \times 24 \times 60 \times 60}$$

Q] Two 20° involute spur gears have a module of 8mm the

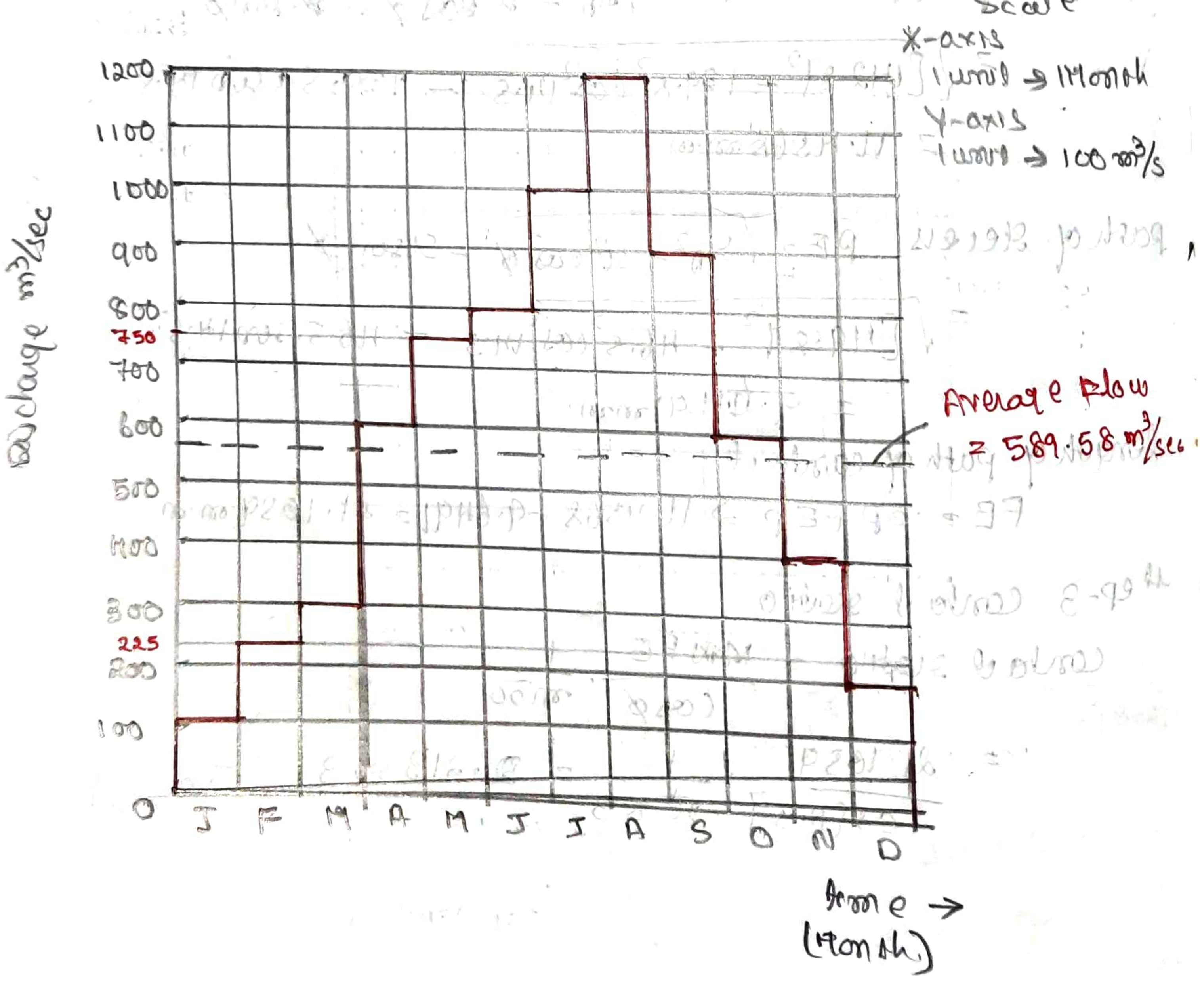
Q] At a particular site, the mean monthly discharge is as follows

Month	Discharge, m^3/s	Month	Discharge, m^3/s
January	100	July	1000
February	225	August	1200
March	300	September	900
April	600	October	600
May	750	November	400
June	800	December	200

$\frac{1200}{12}$ 2100

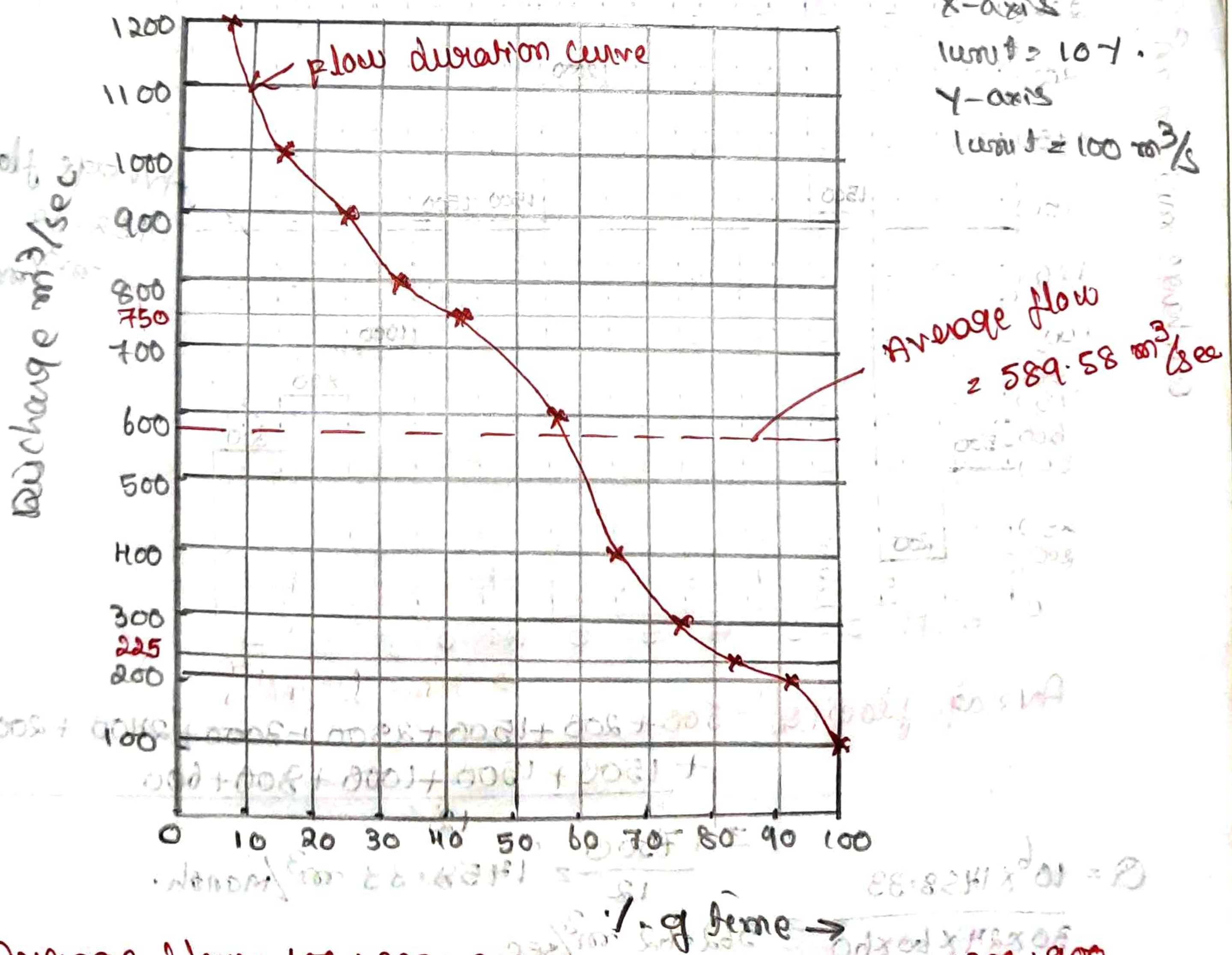
Draw the hydrograph and flow duration curve

Sol Hydrograph



Discharge, m^3/s (a)	length of time, Months (b)	(c) % of time $= \frac{(b)}{12} \times 100$
100	12	$\frac{12}{12} \times 100 = 100\%$
200	11	$\frac{11}{12} \times 100 = 91.7$
225	10	83.83
300	9	75
400	8	66.7
600	7	58.3
750	5	41.7
800	4	33.3
900	3	25
1000	2	16.7
1200	1	8.3

Flow duration curve.



Scale
X-axis
1unit = 10%.
Y-axis
1unit = 100 m^3/s

Average flow $= 100 + 225 + 300 + 600 + 750 + 800 + 1000 + 1200 + 900 + 600 + 400 + 200 \, / \, 12 = 589.58\ m^3/sec$

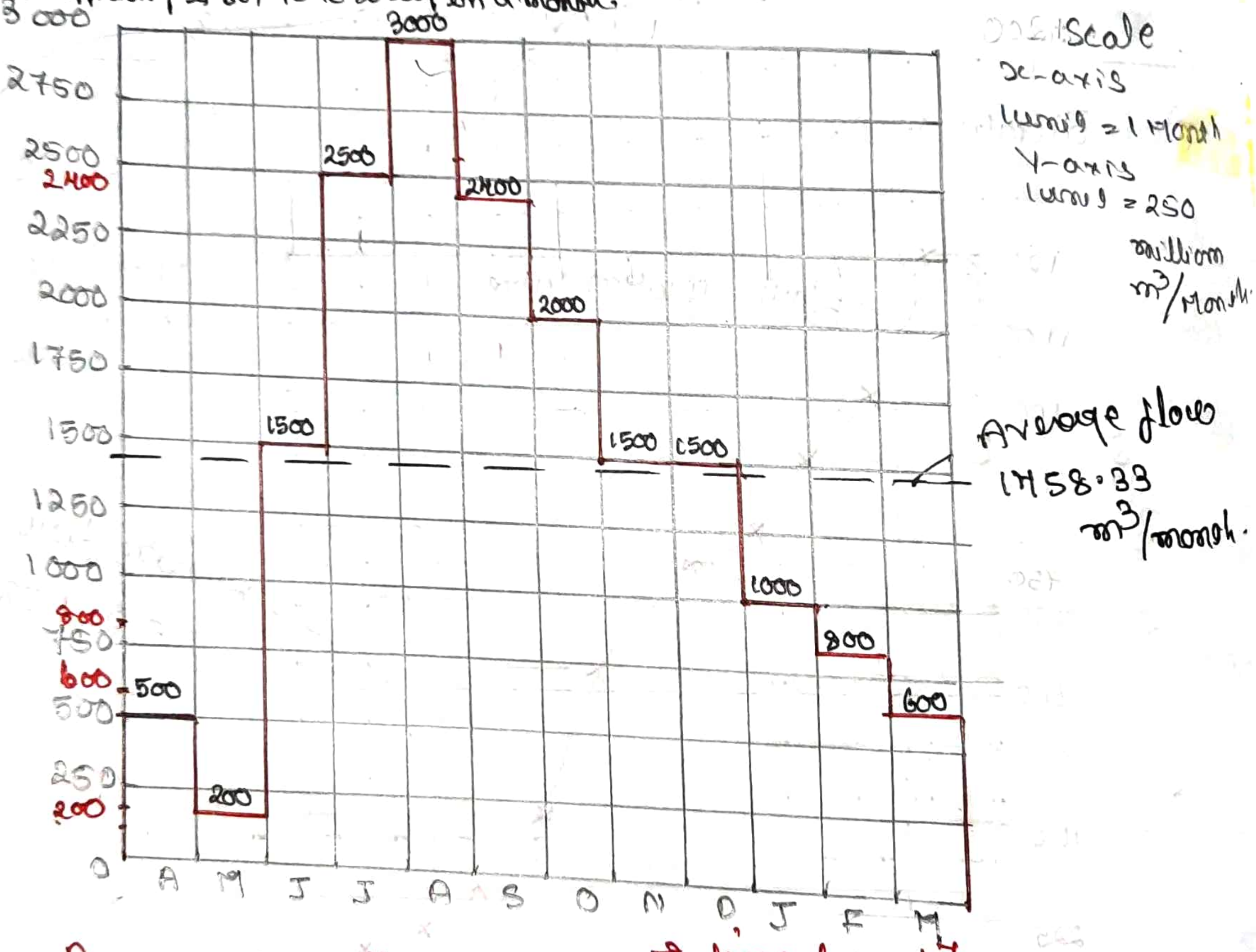
Q) Mean monthly discharge for 12 months at a particular site of a river is tabulated below

Month	Discharge in million of m^3 per month	Month	Discharge in million of m^3 per month
April	500	October	2000
May	200	November	1500
June	1500	December	1500
July	2500	January	1000
August	3000	February	800
September	2400	March	600

Scale. $\frac{3000}{12} = 250$

a) (i) Draw the hydrograph and flow duration curve for the given discharge and find the average monthly flow

ii) Calculate the power available at mean flow of water, if the available head is 80m and overall efficiency is 80%. Take 30 day in a month.

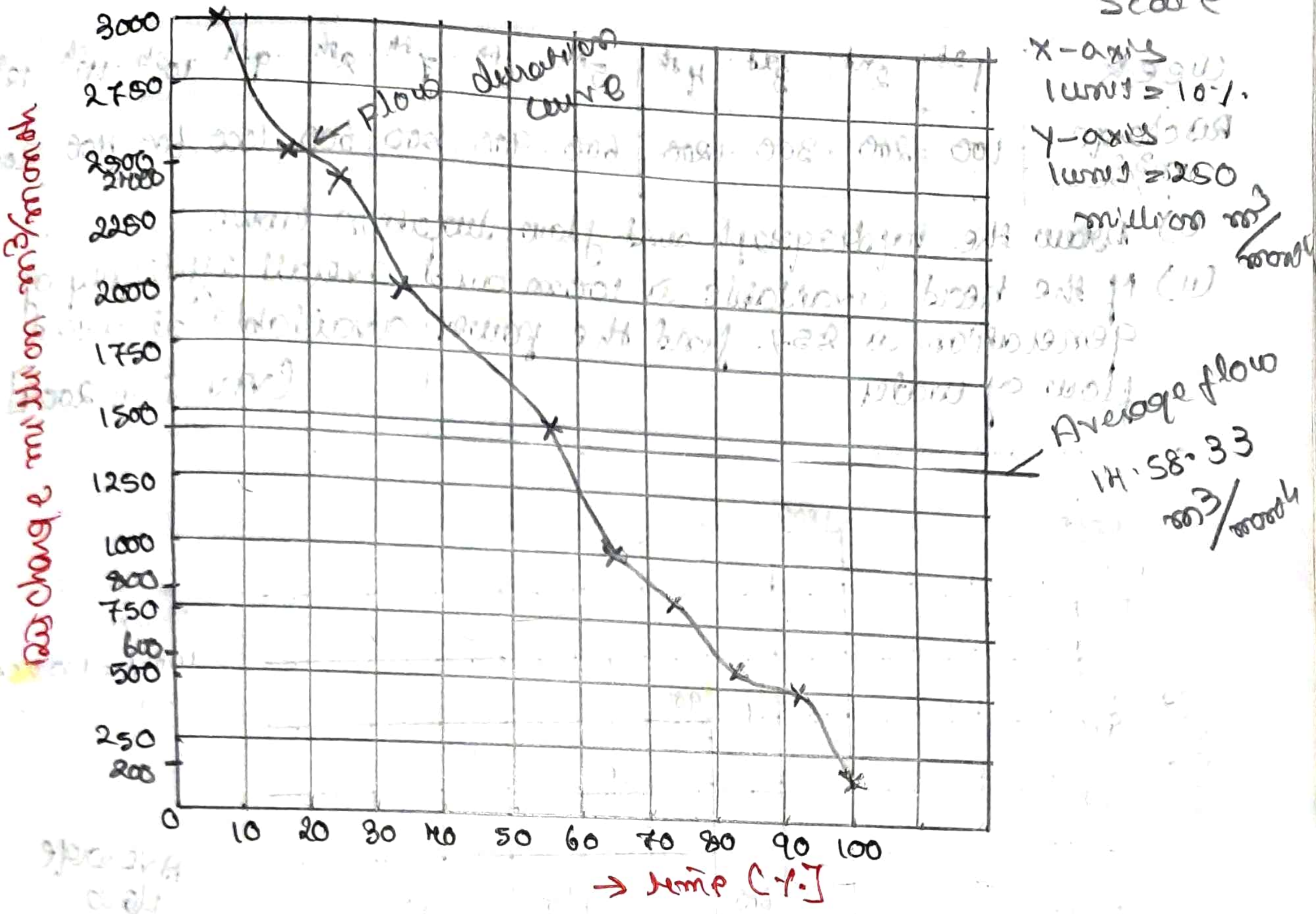


Average flow (Q) $= \frac{500+200+1500+2500+3000+2400+2000+1500+1500+1000+800+600}{12}$

$= \frac{17500}{12} = 1458.33\ m^3/month.$

$Q = \frac{10^6 \times 1458.33}{30 \times 24 \times 60 \times 60} = 562.62\ m^3/sec$

Flow duration curve



Discharge m³/month (a)	length of time, month (b)	(c) % of time = $\frac{(b)}{12} \times 100$
200	12	100
500	11	91.7
600	10	83.33
800	9	75
1000	8	66.7
1500	7	58.3
2000	4	33.3
2400	3	25
2500	2	16.7
3000	1	8.3

power $P = \frac{\rho g Q H \eta}{10^6} = \frac{1000 \times 9.81 \times 562.62 \times 0.80 \times 80}{10^6} = 353.23\ MW$

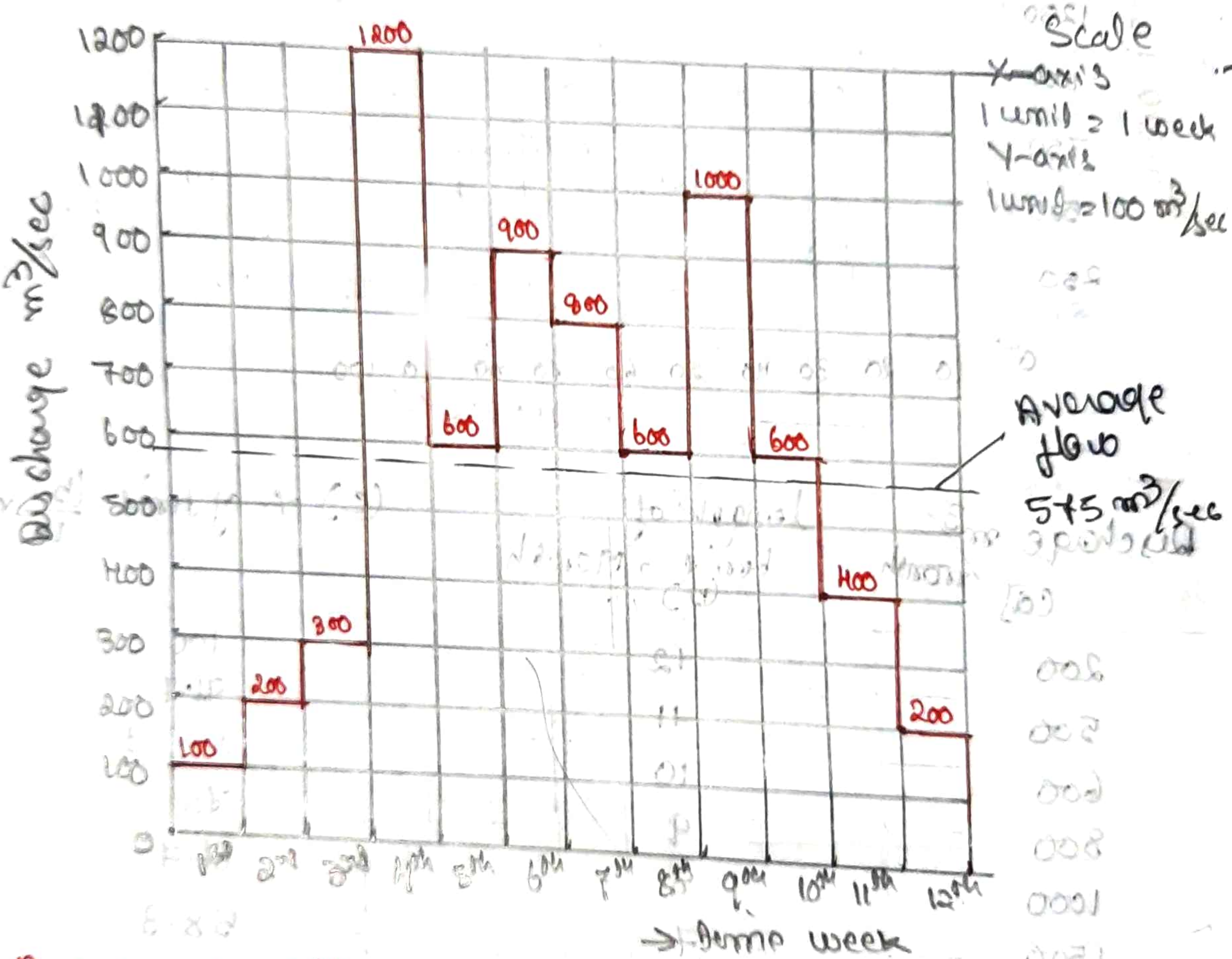
Q] the mean weekly discharge for 12 weeks of a river is given below

Week	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
Discharge m^3/sec	100	200	300	1200	600	900	800	600	1000	600	400	200

(i) Draw the hydrograph and flow duration curve

(ii) If the head available is 100m and overall efficiency of generation is 85%. find the power available at mean flow of water [VTU, Jan 2009]

Sol Hydrograph

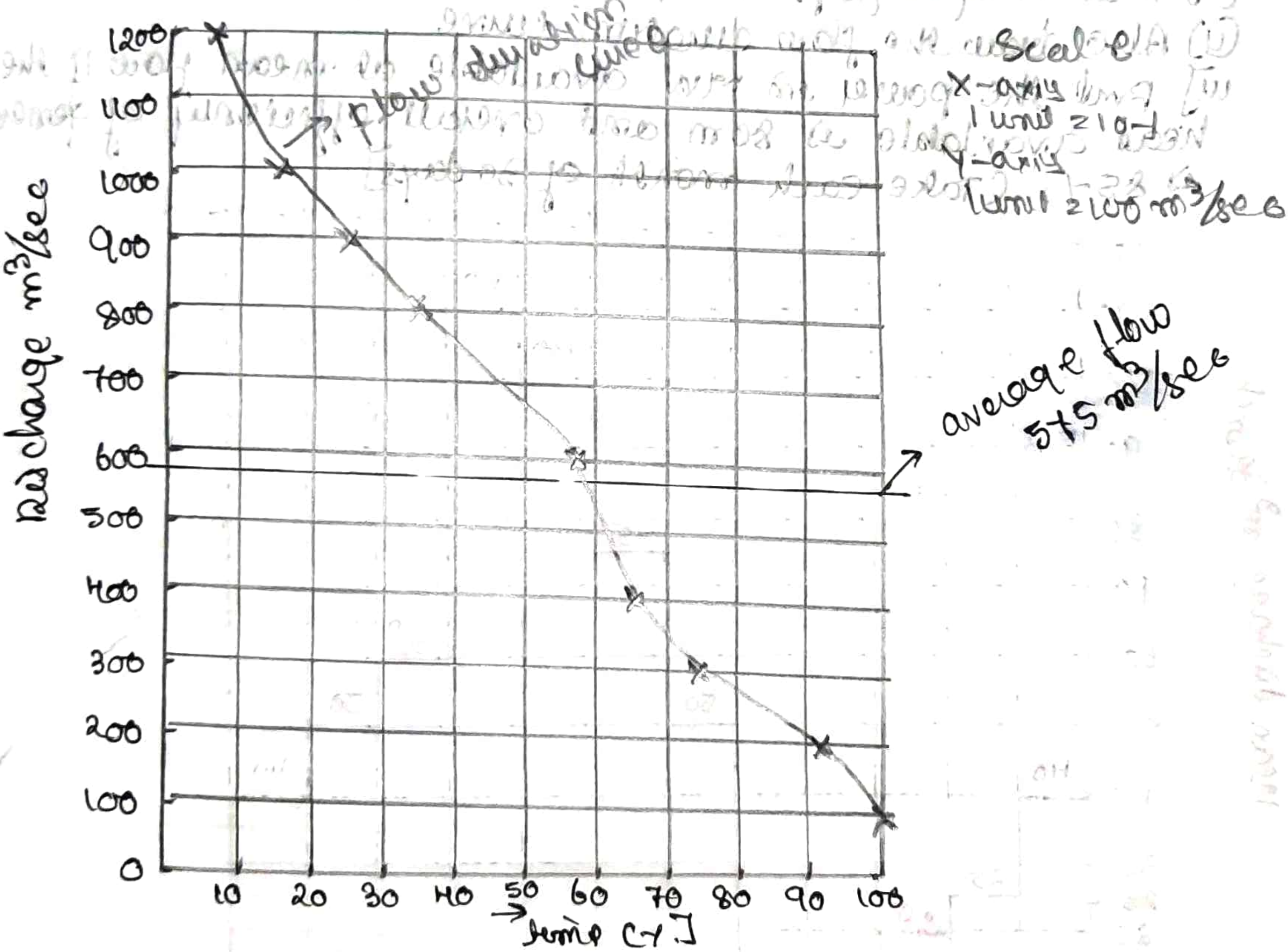


Average flow $(\bar{Q}) = \dfrac{100+200+300+1200+600+900+800+600+1000+600+400+200}{12}$

$= 575\ m^3/sec$

Discharge, m^3/s (a)	Length of time, weeks (b)	(c) % of time $= \frac{[b]}{12} \times 100$
100	12	100
200	11	91.7
300	9	75
400	8	66.7
600	7	58.3
800	4	33.3
900	3	25
1000	2	16.7
1200	1	8.3

flow duration curve



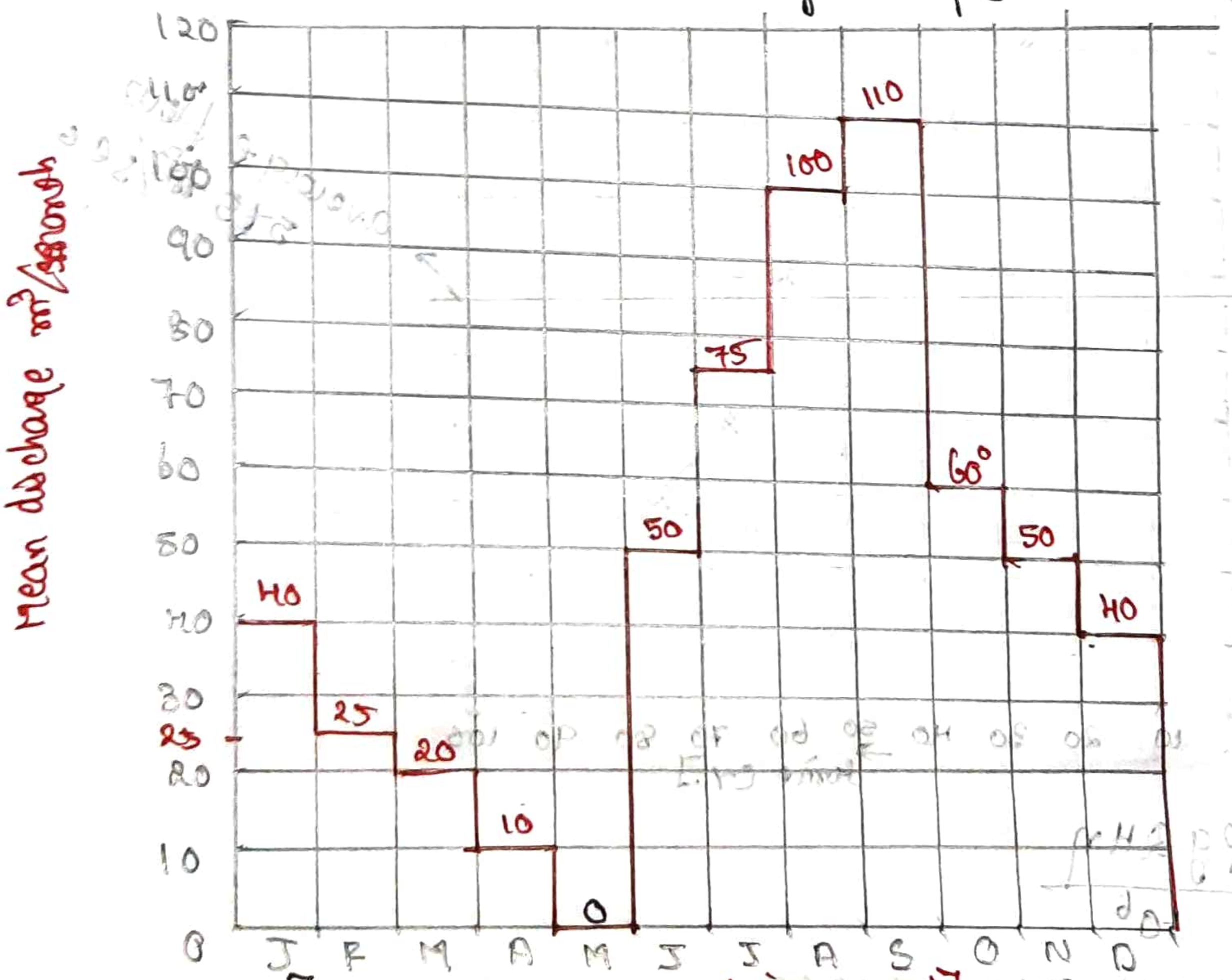
$$\text{Power } P = \frac{\rho g Q H \eta}{10^6}$$

$$= \frac{1000 \times 9.81 \times 575 \times 100 \times 0.85}{10^6} = \underline{\underline{479.46 \text{ MW}}}$$

Q] The run-off data of a river at a particular site is tabulated below

Month	Mean discharge per month (million of cu m)	Month	Mean discharge per month (million of cu-m)
January	40	July	75
February	25	August	100
March	20	September	110
April	10	October	60
May	0	November	50
June	50	December	40

(i) Draw a hydrograph and find the mean flow.
(ii) Also draw the flow duration curve
(iii) Find the power in MW available at mean flow if the head available is 80m and overall efficiency of generation is 85%. [Take each month of 30 days]



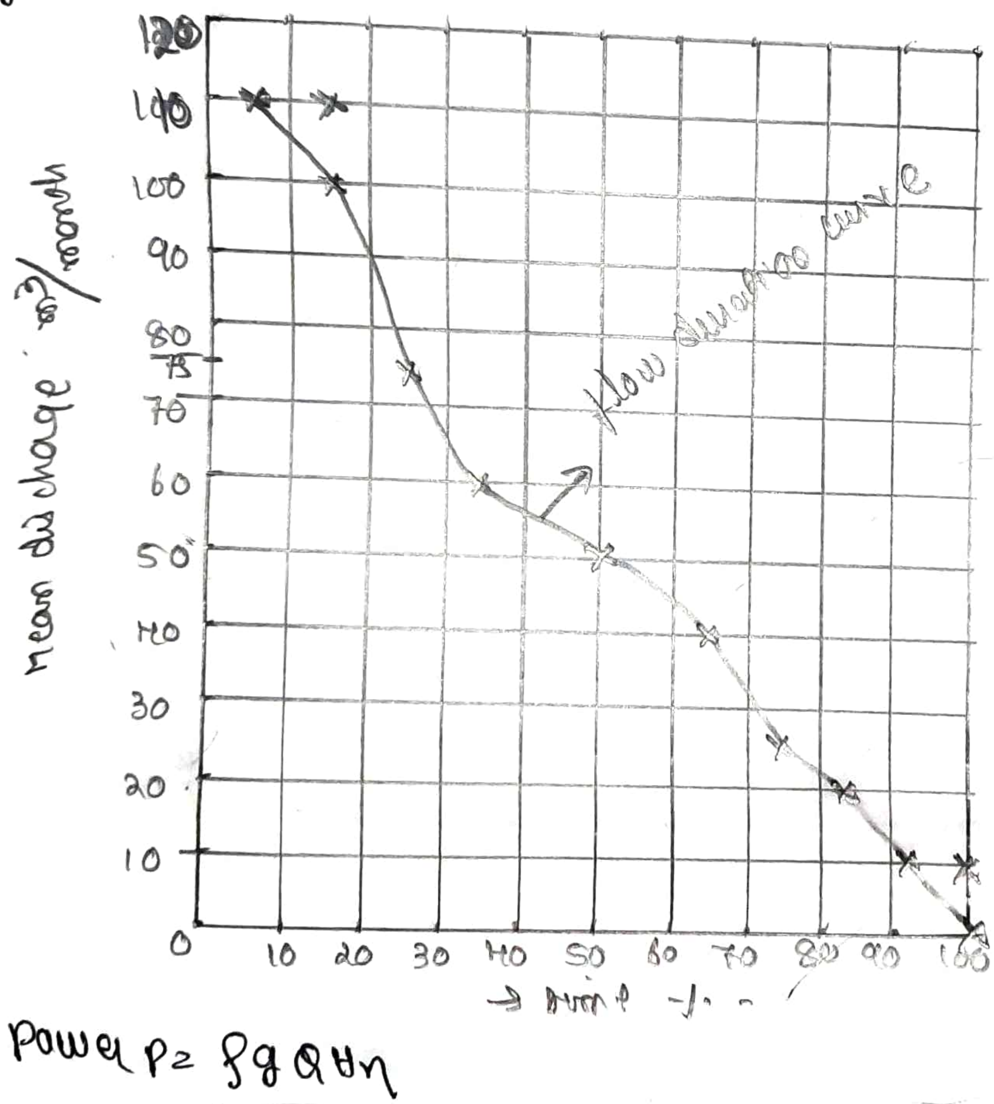
(a)

$$\text{average flow} = \frac{40+25+20+10+0+50+75+100+110+60+50+40}{12} = 48.33\ m^3/\text{month}$$

$$Q = \frac{10^6 \times 48.33}{30 \times 24 \times 60 \times 60} = 18.645\ m^3/\text{sec}$$

Discharge m^3/month (a)	length of time, month (b)	(c) % of time = (b)/12 × 100
0	12	100
10	11	91.7
20	10	83.3
25	9	75
40	8	66.7
50	6	50
60	4	33.3
75	3	25
100	2	16.7
110	1	8.3

- flow duration curve



Scale
X-axis
1 unit = 10 %.
Y-axis
1 unit = 10 m^3/month.

$$\text{Power } P = \frac{\rho g Q H \eta}{10^6}$$

$$= \frac{1000 \times 9.81 \times 18.645 \times 80 \times 0.85}{10^6} = 12.4819 \text{ kW}$$