HYDRO POWER ENGINEERING I
CODE
HWRE 3171

lecture Note

Sources of Energy

People have learned how to change energy from one form to another so that we can do work more easily and live more comfortably.

Scientists define energy as the ability to do work.

Cont'd

- **Sources of energy can be categorized as:-**
  - Renewable: Is sources can be /Rehabilitate in a short period of time
    - Solar,
    - Biomass,
    - Hydropower,
    - Wind energy
    - Geothermal

- Non-renewable:
  - Petroleum,
  - Coal,
  - Natural gas

Why Don't We Use More Renewable Energy?

- In the past, renewable energy has generally been more expensive to use than fossil fuels.
- Renewable resources are often located remote areas and it is expensive to build power lines to the cities where they are needed.

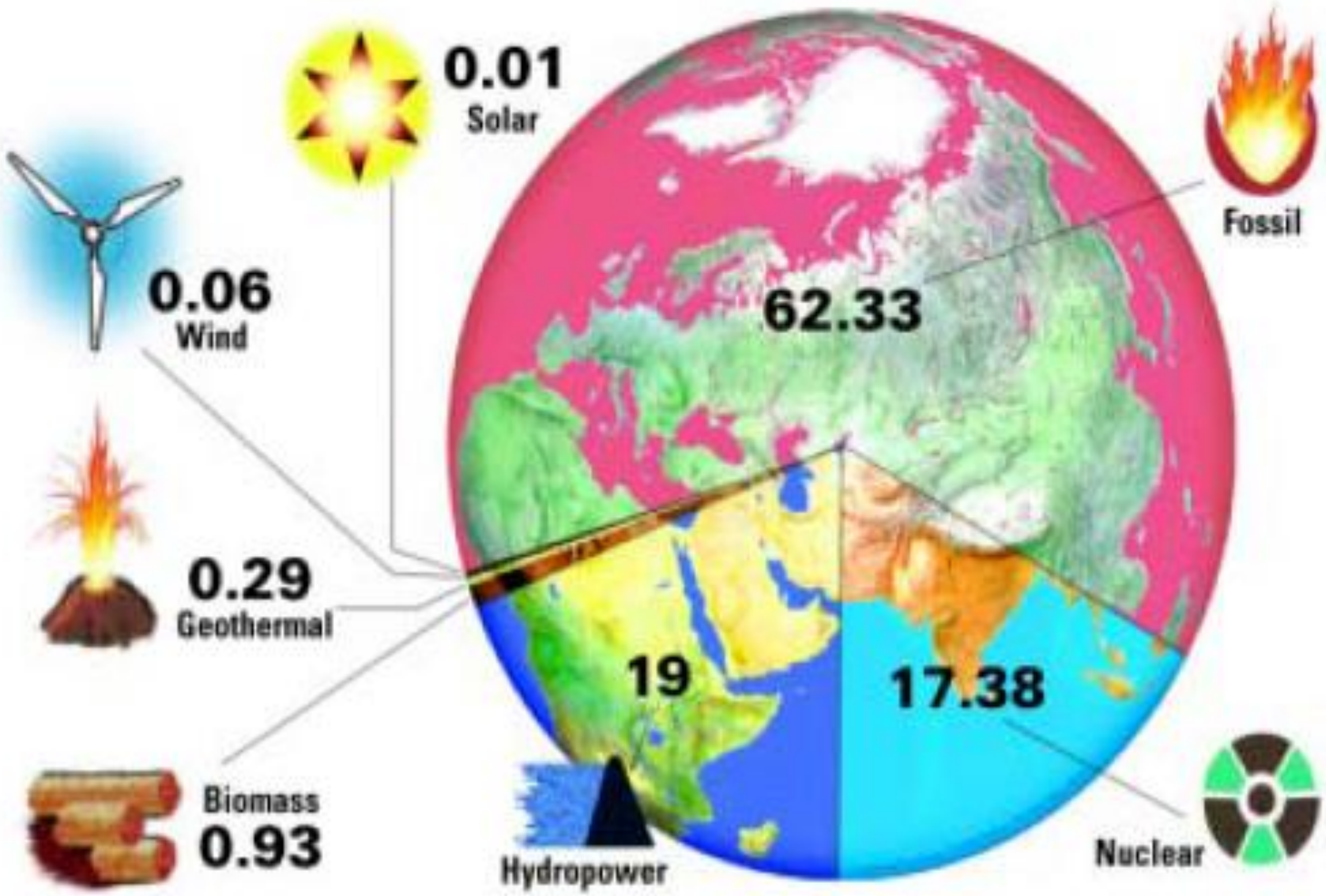
The use of renewable sources is also limited by the fact that they are not always available

- for example, cloudy days reduce solar energy,
- calm days mean no wind blows to drive wind turbines,
- droughts reduce water availability to produce hydroelectricity).

The following Two major sources of power generation may be identified on the basis of present day importance:

Conventional sources	*Unconventional sources*
Thermal power	Tidal power
Hydropower	Solar power
Thermo-nuclear power	Geothermal power
	Wind power
	Wave power

World Energy Sources contribution

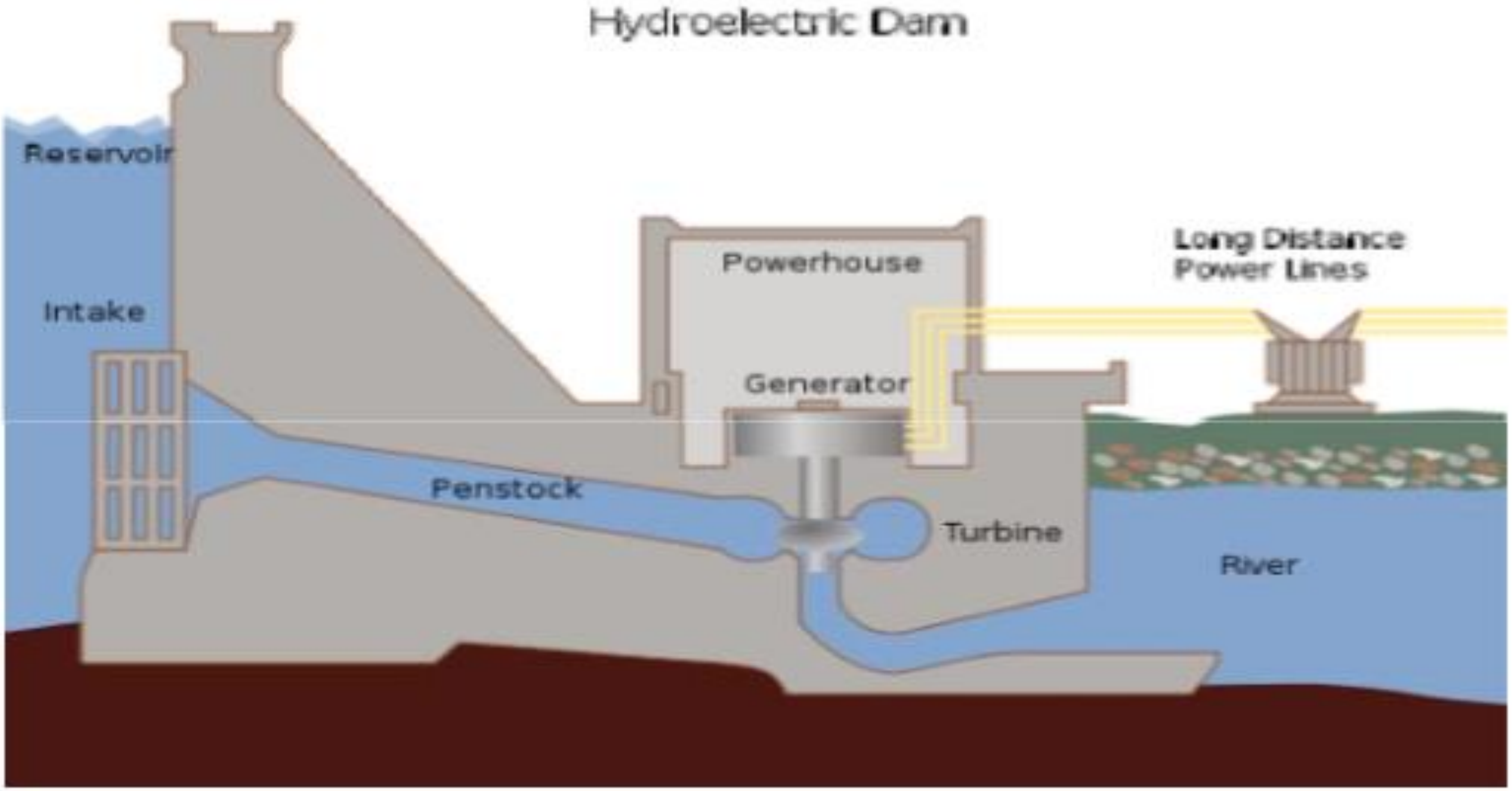


2. HYDROPOWER POTENTIAL

Hydropower Engineering

- Hydropower engineering refers to the technology involved in converting the pressure energy and kinetic energy of water into more easily used electrical energy.
- The electrical energy is obtained from the generators coupled to water turbines which convert the hydraulic energy in to mechanical energy. This means ;
- The mechanical energy is produced by running a prime mover (turbine) from the energy of flowing water.
- This mechanical energy is converted to electric power by generators which is directly coupled to the shaft of the turbine.

- Figure view



Hydroelectric Dam
Reservoir
Intake
Powerhouse
Long Distance
Power Lines
Generator
Penstock
Turbine
River

- Hydroelectricity is one of the most mature forms of renewable energy.
- providing more than 19% of the world's electricity consumption from both large and small power plants.
- Countries such as Brazil, the United States, Canada and Norway produce significant amounts of electricity from very large hydroelectric facilities.
- There are also many regions of the world that have a Significant(major) number of small hydro power plants in operation, such as

In China, more than 19,000 MW of electricity is produced from 43,000 small hydro facilities

Hydropower Potential and Its Development in Ethiopia

- It has been used in the water mills, and such practice is still under use in some rural areas of the country.
- The water power use in its more effective form, i.e. electricity generation, came to existence in the beginning of 1930's, when Abasamuel hydropower scheme is commissioned in 1932.
- This station was capable of generating 6MW and operational up to 1970.

CONT'D

- Hydropower is however the major source of energy in Ethiopia because of the following
  - Availability of surface water sources
  - Cheap relative to other sources available
  - Easier to tap
- HP potential of Ethiopia is huge to 650Twh annual electricity generation which is technically feasible.
- Less than 3% of the economical exploiting potential is developed so far.
- Factors hindering energy development in Ethiopia
  - low economic status of the country
  - Technological know how
  - International politics

No	Power Plant	CAP MW	system
1	Beles	460	ICS
2	Tekeze	300	ICS
3	Gibe II	420	ICS
4	Gibe I	180	ICS
5	Wakena	153	ICS
6	Fincha	134	ICS
7	Finchaa Amerit Neshe	100	ICS
8	Tis Abay I	11.4	ICS
9	Yadot	0.35	SCS
10	Koka	42	ICS
11	Awash 2	36	ICS
12	Awash 3	36	ICS
13	genale dawa III	256	ICS
14	sor	5	SCS
15	dembi	0.8	SCS

Some Hydro Project Under Study and construction

No.	Project	Status	CAP MW
1	Grand millinium	U. construciton	
2	TEKEZE II	U.Feasibility Study	450
3	BEKO ABO	U.Feasibility Study	1600
4	MENDEYA	U.Feasibility Study	2000
5	Gibe VI	U.Feasibility Study	1470
6	GIBE 5TH	U.Feasibility Study	660
7	WABI SHEBELE	Preliminary study	87
8	BIRBIR	Preliminary study	467
9	LOWER DEDESSA	Preliminary study	613
10	DABUS	Preliminary study	427
11	Beshilo	Preliminary study	700
12	TAMS	Preliminary study	1000
13	GENALE DAWA 5TH	Preliminary study	100
	Total		9572

BASIC STUDY CONSIDERATION

- A list of the studies that should be undertaken:
  - Topography and geomorphology of the site.
  - Evaluation of the water resource and its generating potential.
  - Site selection and basic layout.
  - Hydraulic turbines and generators and their control.
  - Environmental impact assessment and mitigation measures.
  - Economic evaluation of the project and financing potential.
  - Institutional framework and administrative procedures to attain the authorizations.

CONT'D

- On the basis of the experience of some countries, the following factors are required for the development of MHP:
  - Rich MHP resources and certain loads
  - Sufficient funds for the construction of MHP stations
  - Expertise in its economic exposition
  - Preferential policies from central and local governments

Advantages and Disadvantage of Hydropower

- Hydropower has the following *advantages* over other sources:

i) Hydropower has a 'perpetual' (never ending) source of energy, while thermal power has a depletable fossil fuel source. Besides hydropower doesn't consume the water.

ii) Running cost of hydropower plant is very low compared to thermal and nuclear plant.

iii) Hydropower plants can be brought in to operation in few minutes while thermal & nuclear power plants lack this capability. particularly useful in taking up short period peak loads in a power grid system.

iv) Efficiency of hydropower system is very high (90-95%), while thermal power plants have low efficiency, as low as 40%.

v) Hydropower development also provides secondary benefit such as recreation, fishing, flood control etc, where storage is contemplated.

Cont'd

- Some of the *disadvantages* of hydropower development are:

i) It is capital intensive & therefore rate of return is low.

ii) The gestation period is long. This period is low for thermal power plants.

iii) Hydropower is dependent on natural flow of streams. Since this is very variable the dependable or firm power is considerably low compared to total capacity.

Hydraulics and Hydrology of Hydropower

Hydraulic theory

Energy-work approach:

Work (W) = Force x Distance in the direction of force

Work = weight of water x the distance it falls = $W = \rho_w V_w g h$

- Where: *ρw is density of water;*
- *g- acceleration due to* gravity;
- *Vw- volume of water falling;*
- *h - the vertical* distance the water falls.

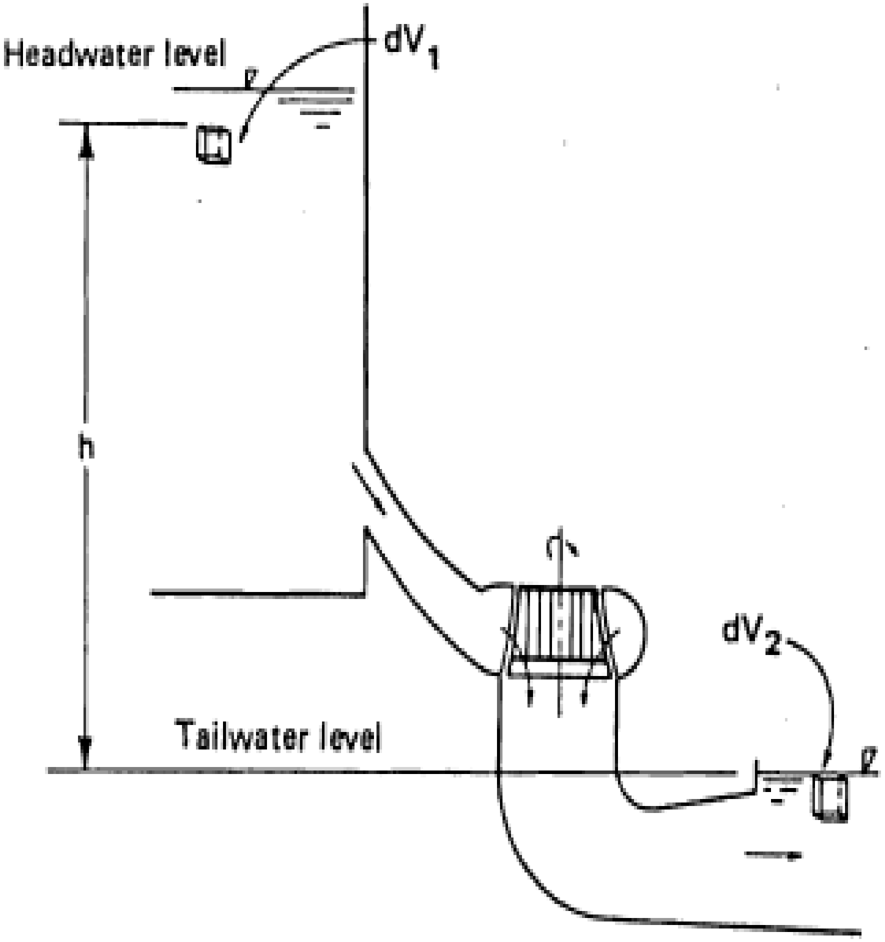
- It is conventional in hydropower computations to treat *h as the effective head that is utilized in* producing power

- Power (P) = Work / time

$$P = \frac{W}{t} = \frac{\rho_w V_w g h}{t} = \rho_w Q g h$$

$$Note\ Q = \frac{V_w}{t}$$

Where Q is discharge.



Bernoulli Equation Approach reading assignment

- **ESTIMATION OF WATER POWER POTENTIAL**

Water Power Potential: It is essential to assess the inherent power available from the discharge of a river and the head available at the site before any power plant is contemplated.

The gross head of any proposed scheme can be assessed by simple surveying techniques, where as hydrological data on rainfall and runoff are essential in order to assess the available water quantities.

The following hydrological data are necessary:

a)the daily, weekly or monthly flow over a period of several years, to determine the plant capacity & estimated output.

b) Low flows, to assess the primary, firm, or dependable power.

The potential or theoretical power in any river stretch with a difference in elevation H is computed from:

POWER

$$P_p = \gamma \cdot Q \cdot H$$

- Which is a power that can be required for useful work by overcoming friction loss in watts?

  Where H = head in m

Q = Where H = head in m

Q = discharge of streams in m^3/s

P_p= Potential (theoretical) power of the stream in KW

$$\gamma = \rho \cdot g \rightarrow \gamma = \rho.g/1000 = 9.81\ KN/m^3$$

CON

$P_p = \gamma.Q.H$ (KW) = 9.81 Q.H (KW) since

1 hp = 736 Watts

$P_p = 13.33$ Q.H (hp)

The hydraulic power P is given by

$P = \eta.\ \gamma.Q.H = 9.81\ \eta.Q.H$ (KW)

Where η = is the total efficiency

From the available stream flow data, one can obtain flow duration curve of the stream for a given site by plotting the discharge against the percentage duration of the time for which it is available.

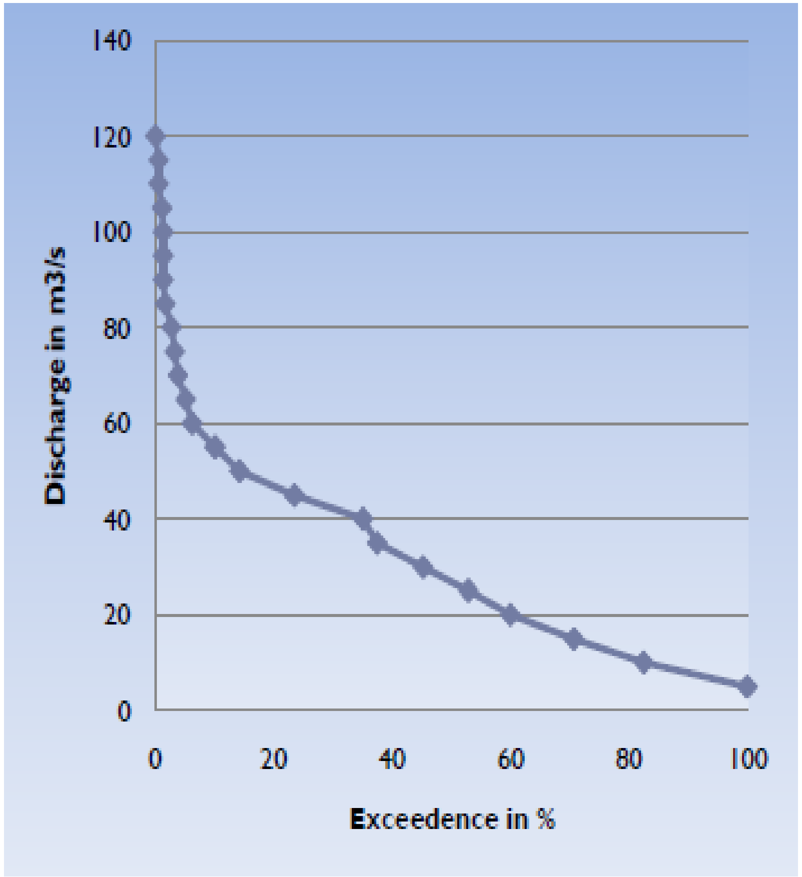
Similarly, power duration curve can be plotted since power is directly proportional to the discharge and available h

Hydrology of hydropower

- Parameters necessary in making hydropower studies are water discharge (Q) and hydraulic head (h).
- The measurement and analyses of these parameters are primarily hydrologic problems.
- Determination of the head for a proposed hydropower plant is a surveying problem that identifies elevations of water surfaces as they are expected to exist during operation of the hydropower plant.
- Because the headwater elevation and tail water elevations of the impoundment can vary with stream flow, it is frequently necessary to develop headwater and tail water curves that show variation with time, river discharge, or operational features of the hydropower project.

Flow duration curve

- **Flow Duration Curves:** is a plot of flow versus the percent of time a particular flow can be expected to be exceeded.
- A flow duration curve merely reorders the flows in order of magnitude instead of the true time ordering of flows in a flow versus time plot.
- Two methods
  - The **Rank ordered** technique and
  - The **Class-interval** technique.



The rank-ordered technique

- **The rank-ordered technique**: considers a total time series of flows that represent equal increments of time for each measurement value, such as mean daily, weekly, or monthly flows, and ranks the flows according to magnitude.
- The rank-ordered values are assigned individual order numbers, the largest beginning with order 1. The order numbers are then divided by the total number in the record and multiplied by 100 to obtain the percent of time that the mean flow has been equaled or exceeded during the period of record being considered.
- The flow value is then plotted versus the respective computed **exceedance percentage**.
- Naturally, the longer the record, the more statistically valuable the information that results.

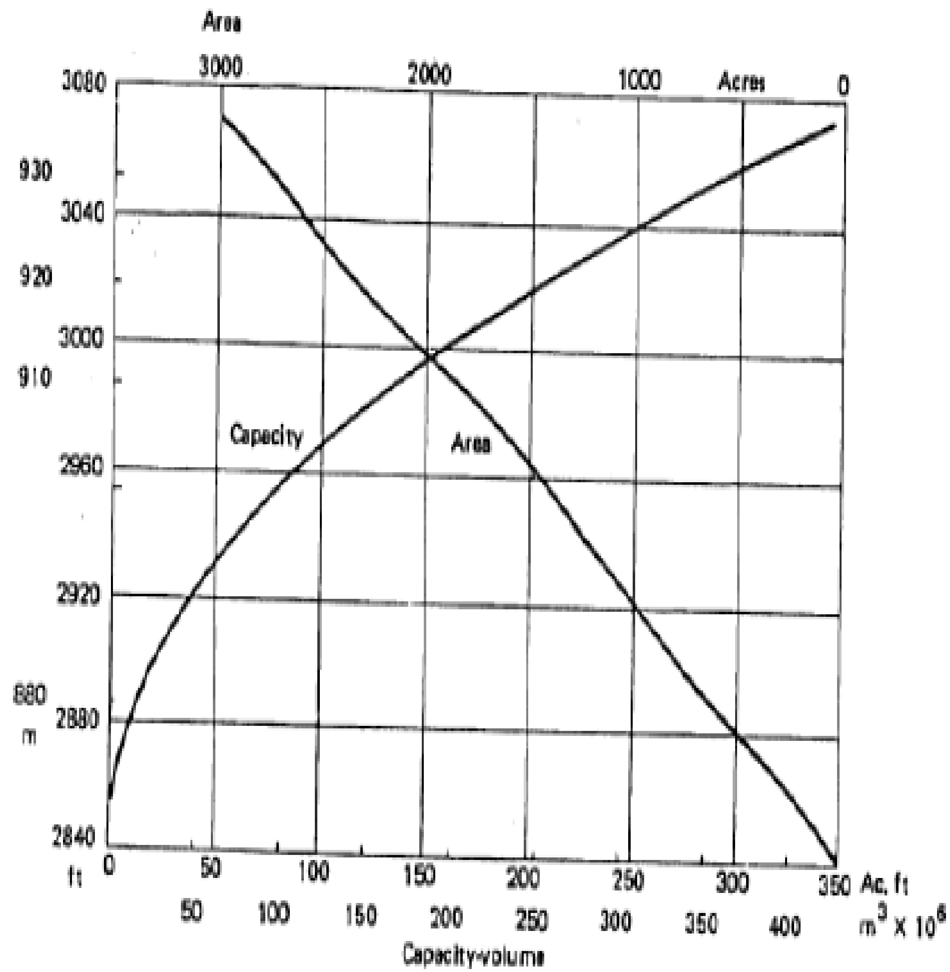
- ***Total period method:*** the entire available record is used for drawing the FDC. Thus, ten years' record would produce 120 values of monthly average flows.
  - These are first tabulated in the ascending order starting from the driest month in the entire period and ending with the wettest month of the ten-year duration.
  - The FDC would then be drawn with the help of 120 values.
- ***Calendar year method***: each year's average monthly values are first arranged in ascending order.
  - Then the average flow values corresponding to the driest month, second driest month, and so on up to the wettest month are found out by taking arithmetic mean of all values of the same rank. These average values are then used for plotting flow duration curve.

The class-interval technique

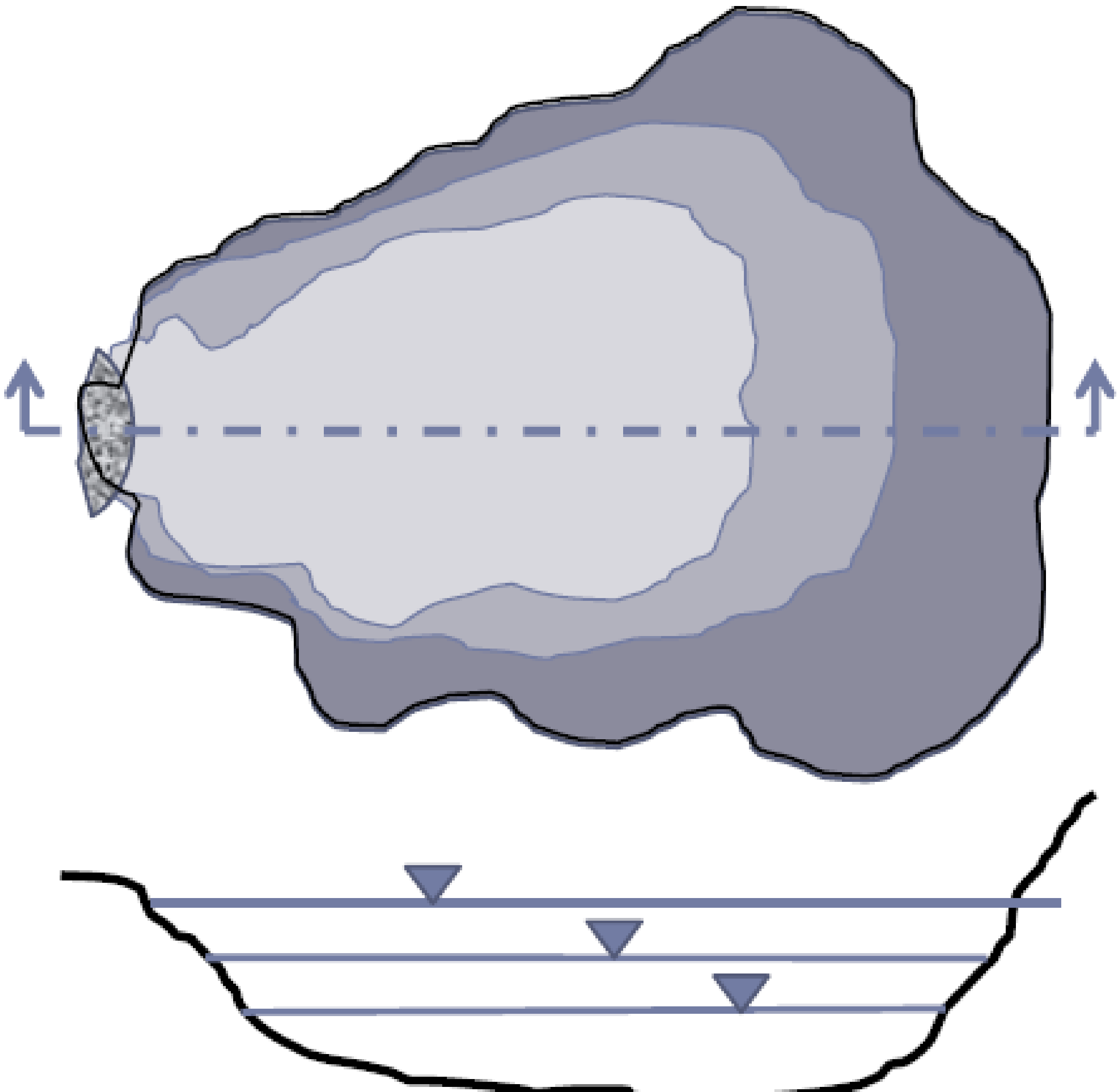
- **The class-interval technique**: is slightly different in that the time series of flow values are categorized into class intervals. The classes range from the highest flow value to the lowest value in the time series. A tally is made of the number of flows in each, and by summation the number of values greater than a given upper limit of the class can be determined.
- The number of flows greater than the upper limit of a class interval can be divided by the total number of flow values in the data series to obtain the **exceedance percentage**.
- The value of the flow for the particular upper limit of the class interval is then plotted versus the computed exceedance percent.

Area capacity curves

- Most hydropower developments involve an impoundment behind a dam. As the water in storage in the impoundment is released the headwater elevation changes and this will influence the design of the plant and the pattern of operation. Therefore, it is necessary to have a storage volume versus impoundment surface elevation curve.



Area-Capacity curve



Reservoir Rule Curves:

- When releases from reservoirs are made, the schedule of releases is often dictated by considerations other than just meeting the flow demands for power production. The needs for municipal water supply, for flood control, and for downstream use dictate certain restraints. The restraints are conventionally taken care of by developing reservoir operation rule curves that can guide operating personnel in making necessary changes in reservoir water releases.

- **Evaporation Loss Evaluation:** Where there is an impoundment involved in a hydropower development there is need to assess the effect of evaporation loss from the reservoir surface.
- **Spillway Design Flood Analysis:** Many hydropower developments require a dam or a diversion that blocks the normal river flow. This then requires that provisions be made for passing flood flows. Spillway design flood analysis treats a unique type of hydrology that concerns the occurrence of rare events of extreme flooding. It is customary on larger dams and dams where failure might cause a major disaster to design the spillway to pass the probable maximum flood. For small dams, spillways are designed to pass a standard project flood.

1. Power duration curve

- Before any power plant is contemplated, it is essential to assess the inherent power available from the ***discharge*** of the river and the ***head available at the site.***
  - The gross head of any proposed scheme can be assessed by simple surveying techniques, whereas
  - Hydrological data on rainfall and runoff are essential in order to assess the quantity of water available.
  - The hydrological data necessary for potential assessment are:
    - The daily, weekly, or monthly flow over a period of several years, to determine the plant capacity and estimate output,
    - Low flows, to assess the primary, firm or dependable power.

- Remember: From Previous section $P = \rho_w Q g h$
- The above equation is for theoretical conditions. The actual output is diminished by the fact that the turbine has losses in transforming the potential and kinetic energy into mechanical energy. Thus an efficiency term *(η), usually called overall efficiency*, must be introduced to give the standard power equation:

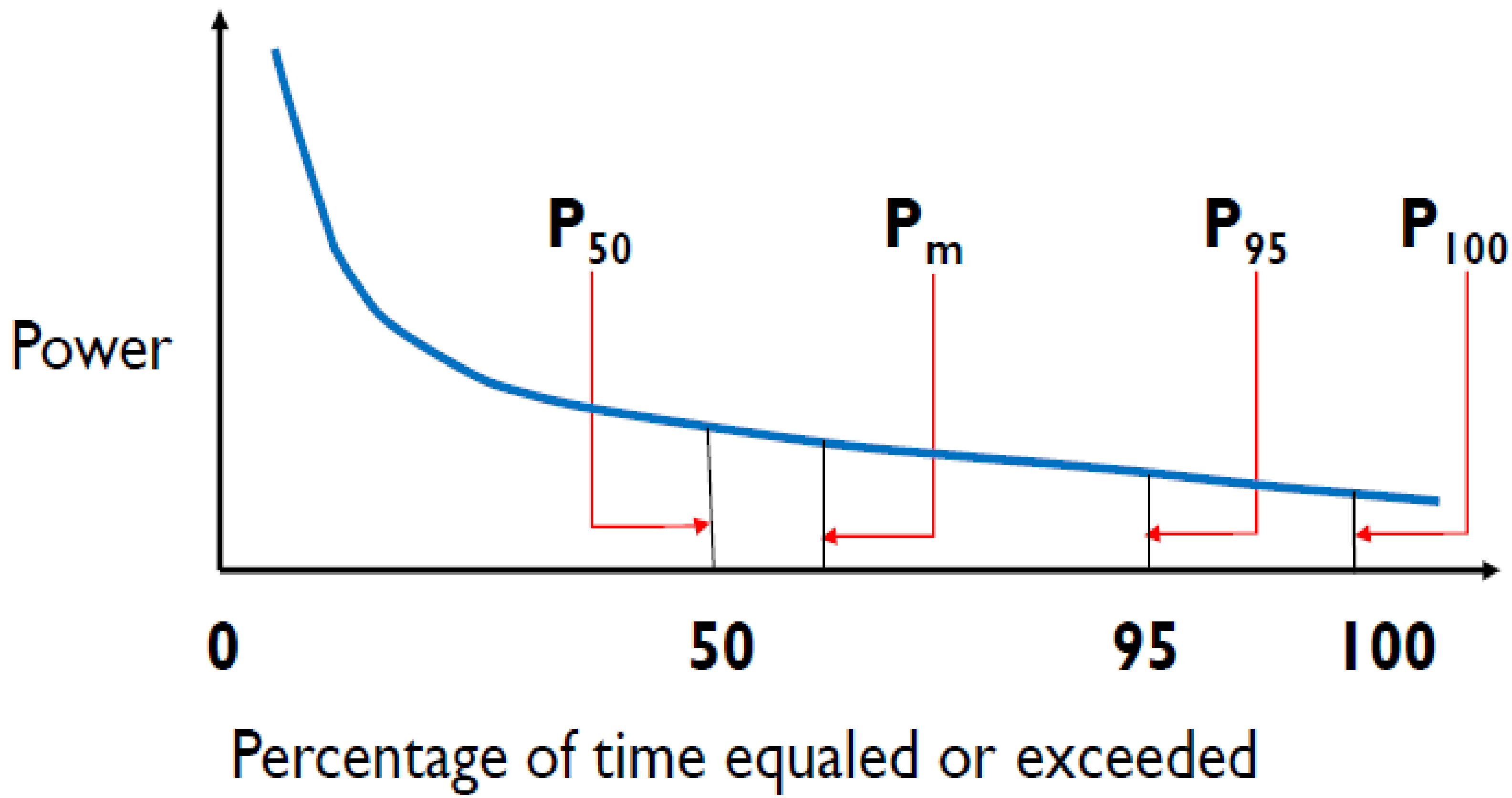
$$P = \eta \rho_w Q g h$$

- If hydraulic head and the expected losses in the penstock are known, it is possible to generate a power duration curve from the flow duration curve.
- If the river course is divided into a number of stretches, the total power can be described by

$$P = \rho_w g \sum Q h$$

- The actual use of the equation for estimating the potential (P); however, is made difficult due to the fact that the discharge of any river varies over a wide range.
- High discharges are available only for short durations in a year. Thus the corresponding available power would be of short duration.
- If the discharge rate and the percentage duration of time for which it is available are plotted, a ***flow-duration curve*** results.
- ***Power duration curve*** can also be plotted since power is directly proportional to the discharge and available head.
- ***Discharge/Power duration curve*** indicates discharge or power available in the stream for the given percentage of time.

- The available power from a run-of-river plant could be represented by a power duration curve exactly on lines analogous to a FDC;
- Generally, the head variation in a run-of-river plant is considerably less than the discharge variation.
- If the head is presumed to be constant at an average value, power duration curve would exactly correspond to FDC.
- This is very often the procedure in elementary rough calculations. If, however, a precise power duration curve is desired, then the head corresponding to any discharge is required to be known.



- ***Minimum potential*** *power* computed from the minimum flow available for 100 % of the time (365 days or 8760 hours). This is represented as $P_{100;}$
- ***Small potential*** *power* computed from the flow available for 95 % of time (flow available for 8322 hours). This is represented as $P_{95;}$

- ***Average potential*** *power* computed from the flow available for 50% of the time (flow available for 6 months or 4380 hours). This is represented as $P_{50;}$
- ***Mean potential*** *power* computed from the average of mean yearly flows for a period of 10 to 30 years, which is equal to the area of the flow-duration curve corresponding to this mean year. This is known as '*Gross river power potential*' and is represented as P_m.
- It would be more significant to find out the technically available power from the potential power; According to Mosonyi, the losses subtracted from the P values present an upper limit of utilization;
- ***Technically available power***: With conveyance efficiency of 70% and overall efficiency of the plant as 80%, a combined multiplying factor of 0.56 should be used with the average potential power, P_{50}; $P_a = 0.56 P_{50}$

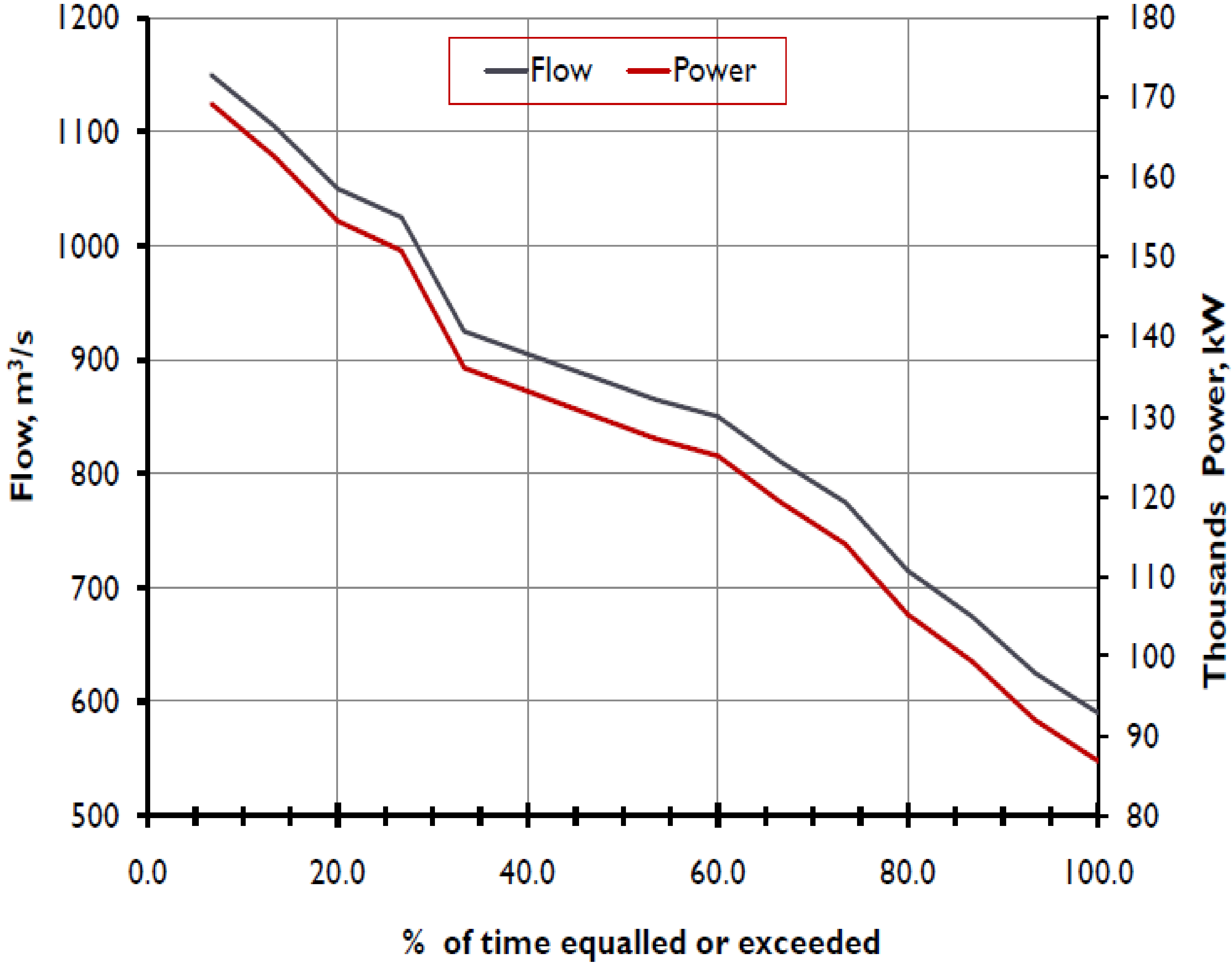
Example 1. The following is the record of average yearly flow in a river for 15 years. If the available head is 15 m, construct the FDC and power duration curve for the river.

Year	1956	1957	1958	1959	1960	1961	1962	1963	1964
Flow (m^3/s)	905	865	1050	1105	675	715	850	775	590

Year	1965	1966	1967	1968	1969	1970
Flow (m^3/s)	625	810	885	1025	1150	925

- **Solution:** The yearly flow values are arranged in ascending order (see table below). The power corresponding to each flow values are calculated assuming the head (=15 m) to be constant. Then, FDC and power duration curves are plotted on the same graph.

Rank	Flow in desending order	Power(9.81*QH(KW)	Percentage of time exeeded
1	1150	169223	6.7
2	1105	162601	13.3
3	1050	154508	20.0
4	1025	150829	26.7
5	925	136114	33.3
6	905	133171	40.0
7	885	130228	46.7
8	865	127285	53.3
9	850	125078	60.0
10	810	119192	66.7
11	775	114041	73.3
12	715	105212	80.0
13	675	99326	86.7
14	625	91969	93.3
15	590	86819	100.0



Flow
Power
Flow, m³/s
Thousands Power, kW
% of time equalled or exceeded
1200
1100
1000
900
800
700
600
500
180
170
160
150
140
130
120
110
100
90
80
0.0
20.0
40.0
60.0
80.0
100.0

Example 2: Draw the flow and power duration curve…

Month	Flow (m^3/s)	Head(m)	Efficiency
January	65	83.5	0.87
February	50	83.5	0.83
March	42	83.5	0.75
April	40	83.5	0.70
May	40	83.5	0.60
June	115	83.5	0.50
July	400	80	0.88
August	340	81.6	0.89
September	270	83	0.90
October	155	83.5	0.90
November	115	83.5	0.88
December	85	83.5	0.87

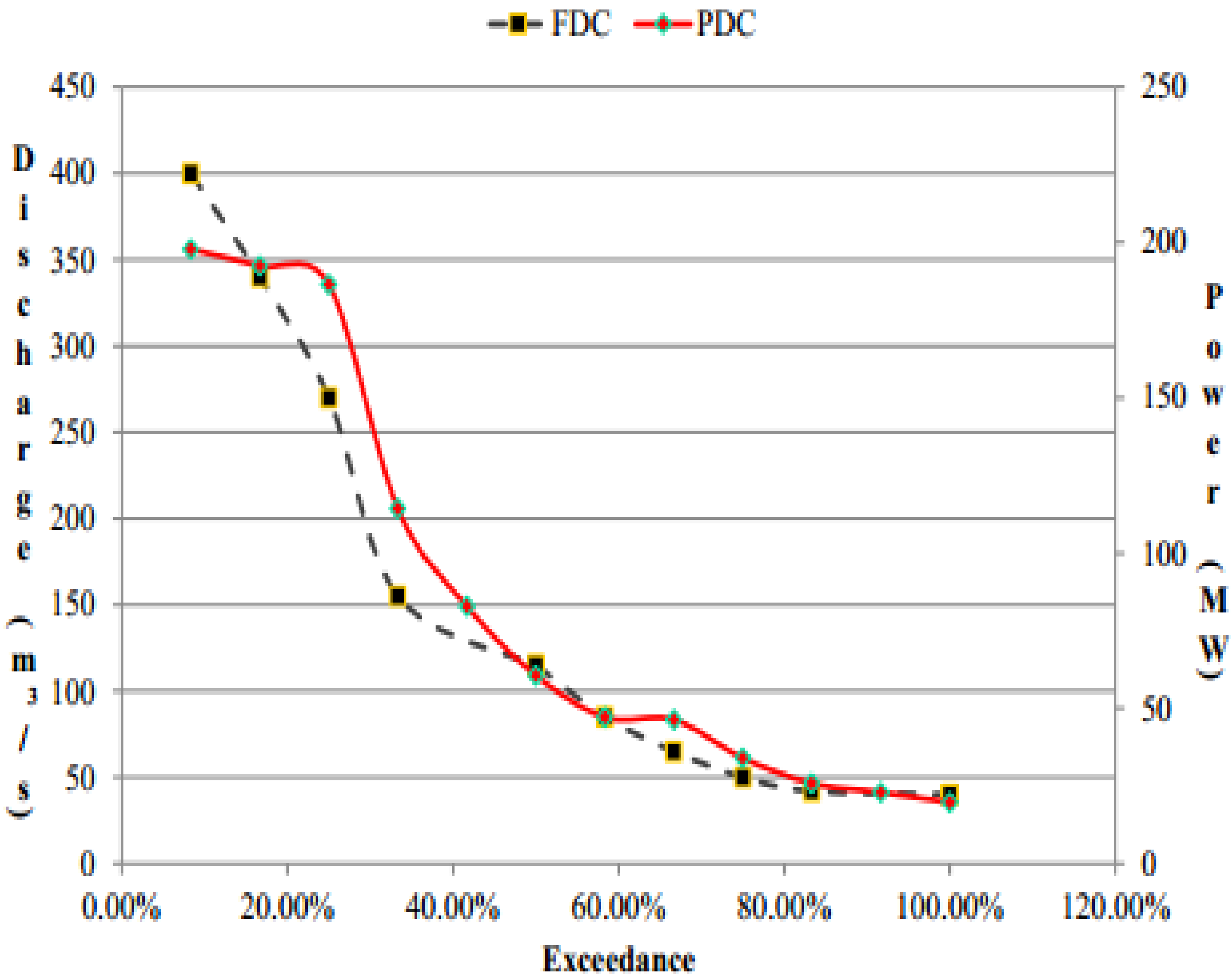
$Q_c = 270\ m^3/s$

$\rho = 1000\ kg/m^3$

$g = 9.81\ m/s^2$

Solution

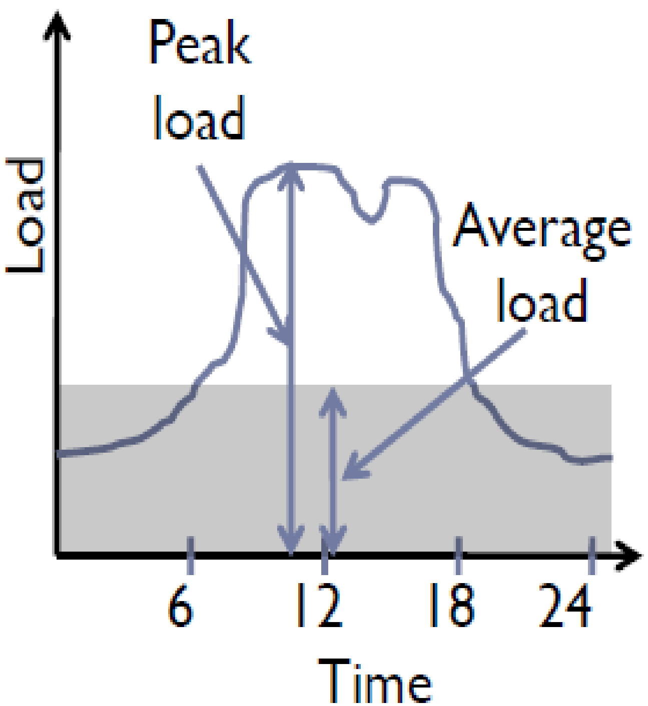
				FDC					PDC		
Mon	Q Sorted	Head	EFF	Rank Q	Exce. %	Q for P	P (MW)	Mon	Rank P	Exce. %	P sorted
Jul	400	80	0.88	1	8.3	265	183.07	Sep	1	8.3	197.86
Aug	340	81.6	0.89	2	16.7	267.7	190.73	Aug	2	16.7	190.73
Sep	270	83	0.9	3	25.0	270	197.86	Jul	3	25.0	183.07
Oct	155	83.5	0.9	4	33.3	155	114.27	Oct	4	33.3	114.27
Jun	115	83.5	0.5	6	50.0	115	47.10	Nov	5	41.7	82.90
Nov	115	83.5	0.88	6	50.0	115	82.90	Dec	6	50.0	60.58
Dec	85	83.5	0.87	7	58.3	85	60.58	Jun	7	58.3	47.10
Jan	65	83.5	0.87	8	66.7	65	46.32	Jan	8	66.7	46.32
Feb	50	83.5	0.83	9	75.0	50	33.99	Feb	9	75.0	33.99
Mar	42	83.5	0.75	10	83.3	42	25.80	Mar	10	83.3	25.80
Apr	40	83.5	0.7	12	100	40	22.94	Apr	11	91.7	22.94
May	40	83.5	0.6	12	100	40	19.66	May	12	100	19.66



FDC
PDC
Discharge (m3/s)
Power (MW)
Exceedance
450
400
350
300
250
200
150
100
50
0
250
200
150
100
50
0
0.00%
20.00%
40.00%
60.00%
80.00%
100.00%
120.00%

2. Load terminologies

- **Load** is the amount of power delivered or received at a given point at any instant.
- **Average Load** is the total load produced divided by the number of hours in the time period of interest.



- **Peak Load** is the maximum instantaneous load or a maximum average load over a specified period of time.
- ***Base load*** is the total load continuously exceeded;

Load Factor

- The degree of variation of the load over a period of time is measured by the **load factor**, which may be defined as the average load divided by the peak load within the given time range.
- The load factor measures variation only and does not give any indication of the precise shape of the load-duration curve.
- The area under the load curve represents the energy consumed in kWh; Thus, a daily load factor may also be defined as the ratio of the actual energy consumed during 24 hours to the peak demand assumed to continue for 24 hours.
- Load factor gives an idea of degree of utilization of capacity;
- Thus, an annual load factor of 0.4 indicates that the machines are producing only 40% of their yearly production capacity.

Capacity factor

- The capacity factor is the ratio of the energy actually produced by the plant for any given period of time to the energy it would be capable of producing at its full capacity for that period of time.
- The extent of use of the generating plant is measured by the capacity factor, frequently also termed plant factor or use factor. If during a given period a plant is kept fully loaded, it is evident that it is used to the maximum extent, or operated at 100% capacity factor.
- The factor is equal to the average load divided by the rated capacity of the plant.
- Capacity factor and load factor become identical when the peak load is equal to the capacity of the plant. The relationship between the two factors is evidently

$$Capacity\ \ Factor = \frac{Peak\ \ Load \times Load\ \ factor}{Rated\ capacity\ of\ the\ plant}$$

- For example, if a plant with a capacity of 100MW produces 6,000,000 kWh operating for 100 hours, its capacity factor will be 0.6, i.e.

$$C.F. = \frac{6000000}{100000 \times 100} = 0.6$$

- The capacity factor for hydroelectric plants generally varies between 0.25 and 0.75.
- The capacity factor would be identical with load factor if the peak load were equal to the plant capacity.
- Thus, in the above example, if the maximum load was 75 MW instead of 100 MW, then

$$L.F. = \frac{6000000}{75000 \times 100} = 0.8 \ againest \ C.F. = 0.6$$

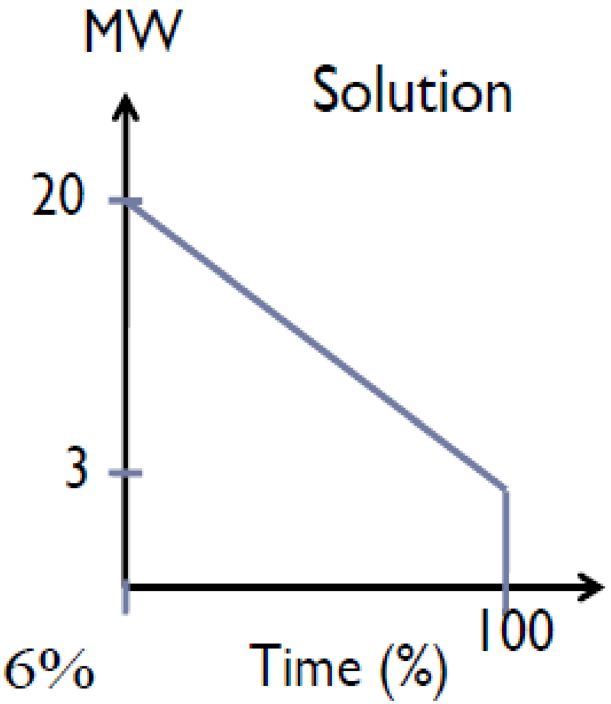
Utilization Factor

- The utilization factor measures the use made of the total installed capacity of the plant. It is defined as the ratio of the peak load and the rated capacity of the plant.
- ***Utilization Factor***: is the ratio of the quantity of water actually utilized for power production to that available in the river. If the head is assumed to be constant, then the utilization factor would be equal to the ratio of power utilized to that available.
- The factor for a plant depends upon the type of system of which it is a part of. A low utilization factor may mean that the plant is used only for stand-by purposes on a system comprised of several stations or that capacity has been installed well in advance of need.
- In the case of a plant in a large system, high utilization factor indicates that the plant is probably the most efficient in the system. In the case of isolated plants a high value means the likelihood of good design with some reserve-capacity allowance.
- The value of utilization factor varies between 0.4 and 0.9 depending on the plant capacity, load factor and storage.

Example 2

- Consider the yearly load duration curve for a certain load center to be a straight line from 20 to 3 MW. To meet this load, three hydropower units, two rated at 10 MW each and one at 5 MW are installed. Determine:
  - Load factor (LF)
  - Capacity factor (CF)
  - Utilization factor (UF)

Solution



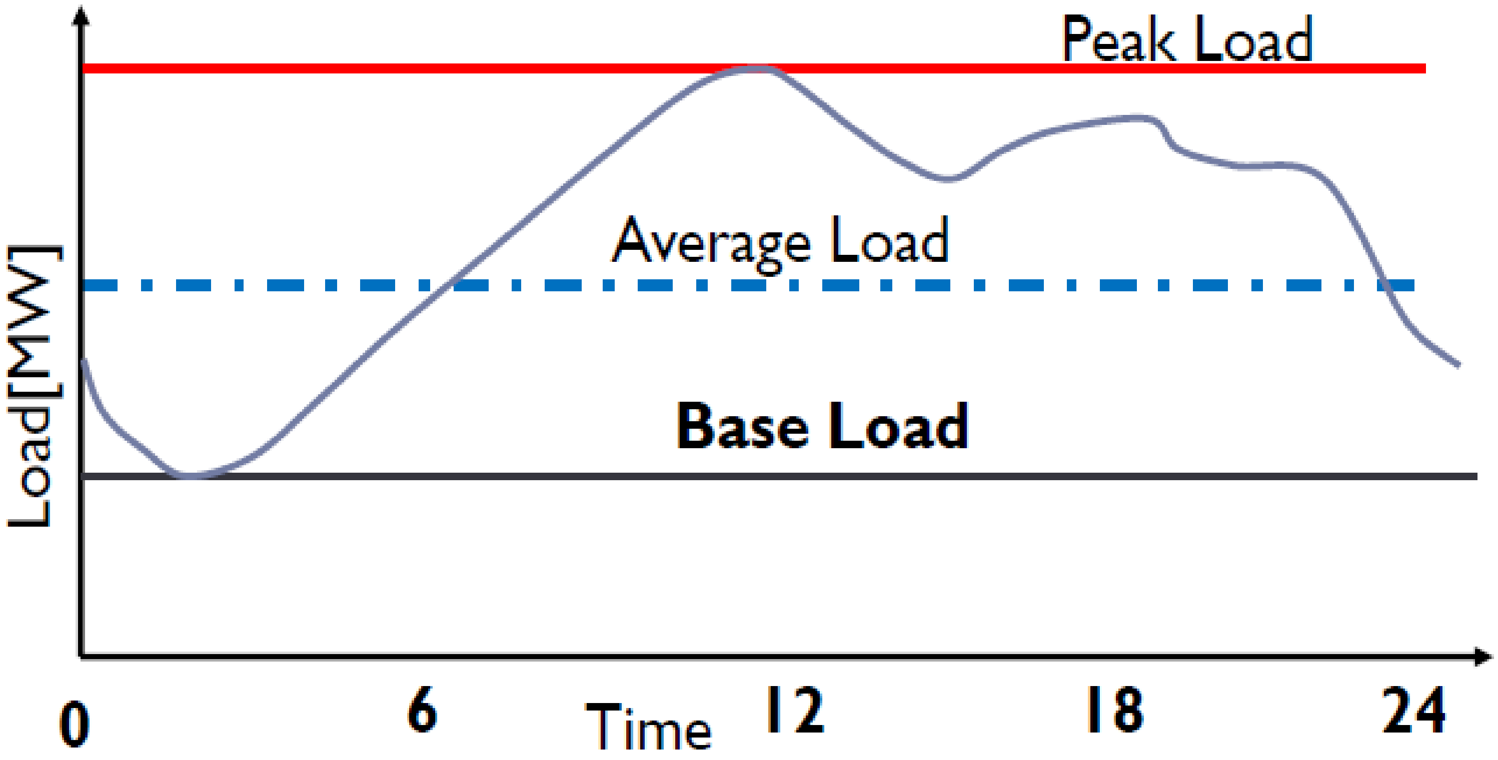
$$LF = \frac{\frac{3+20}{2} \times 100\% \times t}{20 \times 100\% \times t} \times 100\% = 57.5\%$$

$$CF = \frac{\frac{3+20}{2} \times 100\% \times t}{(10+10+5) \times 100\% \times t} \times 100\% = 46\%$$

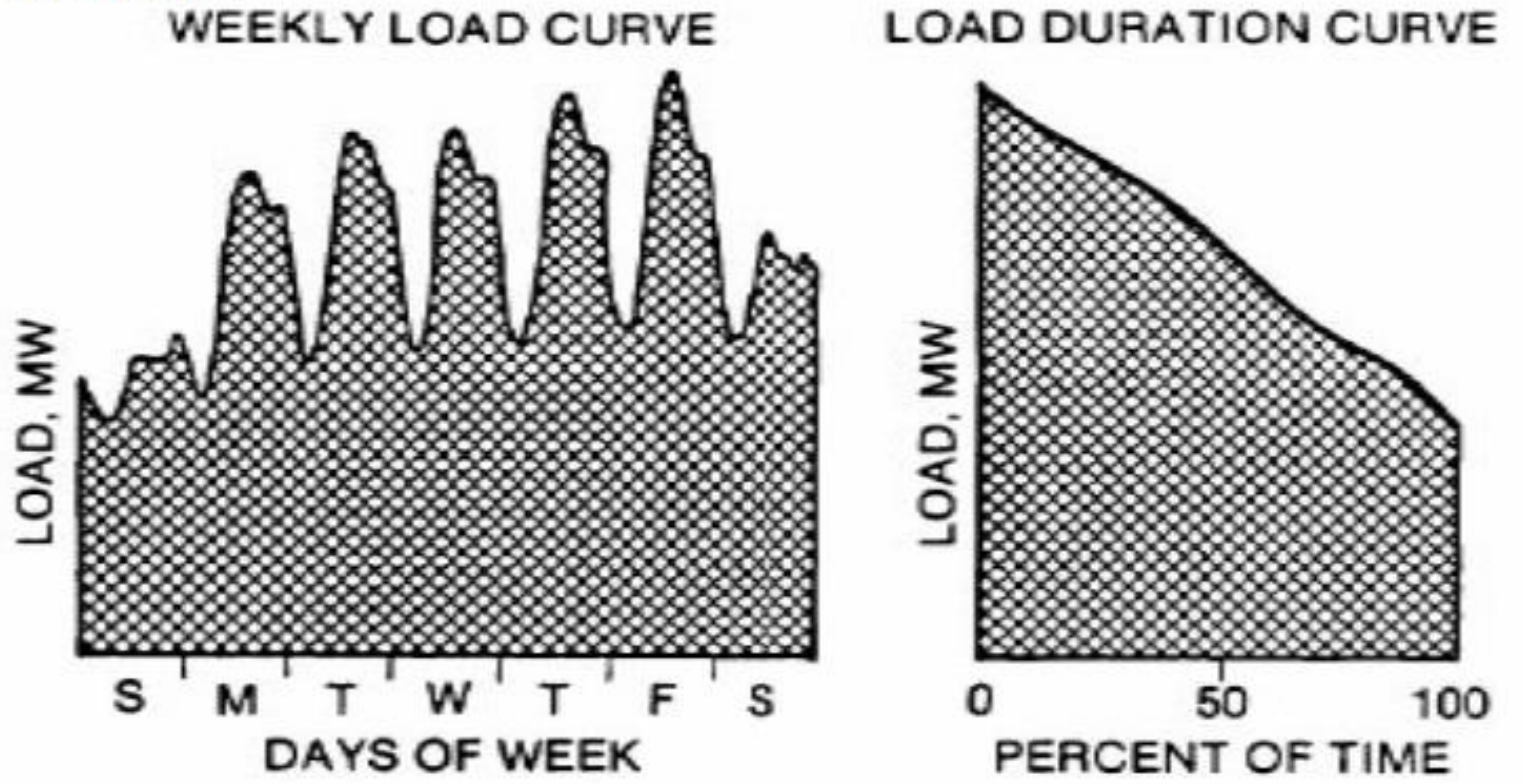
$$UF = \frac{20 \times 100\% \times t}{25 \times 100\% \times t} \times 100\% = 80\%$$

3. Load Duration Curve

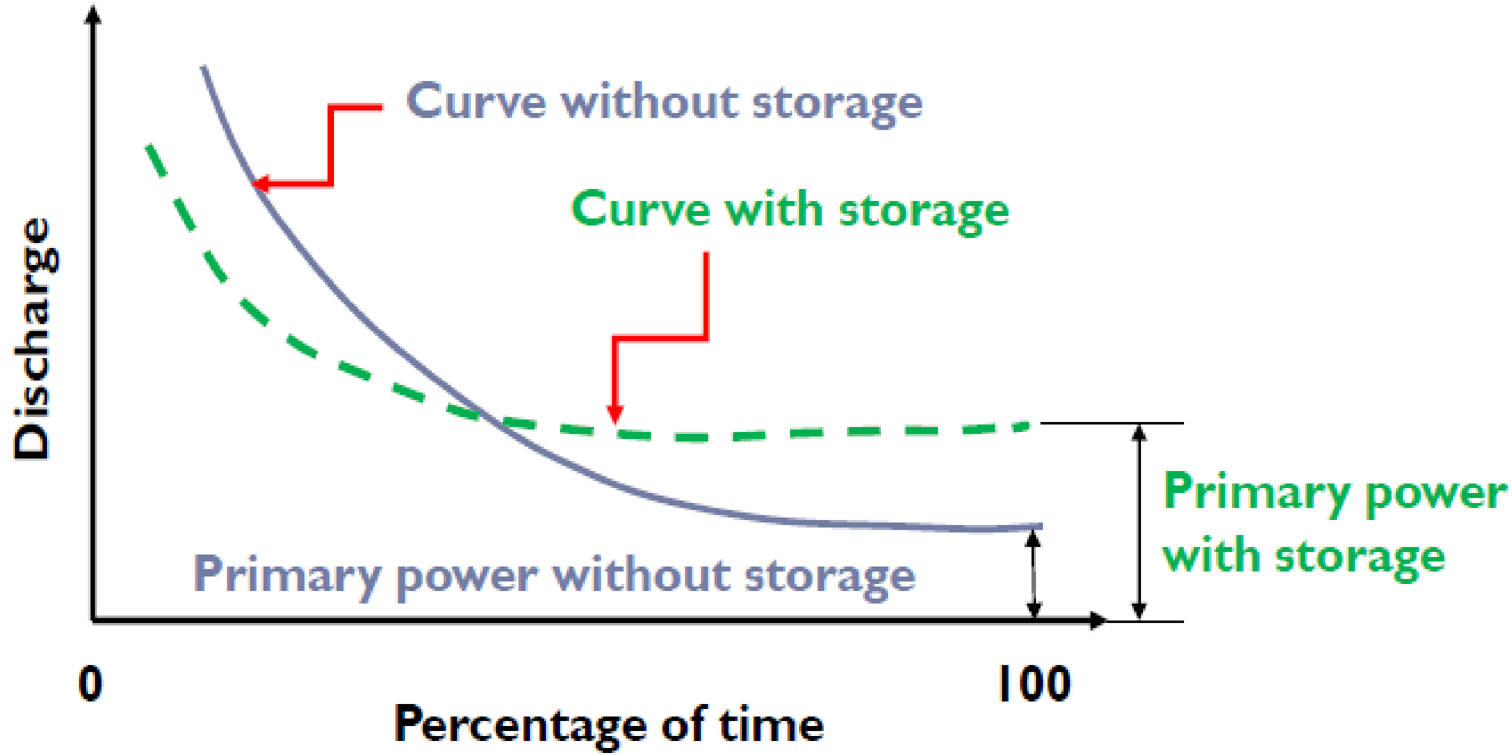
- **Load Curve:** A load curve is a graph of load consumption with respect to time and directly gives an indication of power used at any time (daily, weekly, monthly, annually, etc.)
- ***Daily Load Curve*** is a curve drawn between load as the ordinate and time in hours as the abscissa for one day.



- ***Firm Power***: The firm or primary power is the power which is always ensured to a consumer at any hour of the day and is, thus, completely dependable power. Firm power would correspond to the minimum stream flow and is available for all the times;



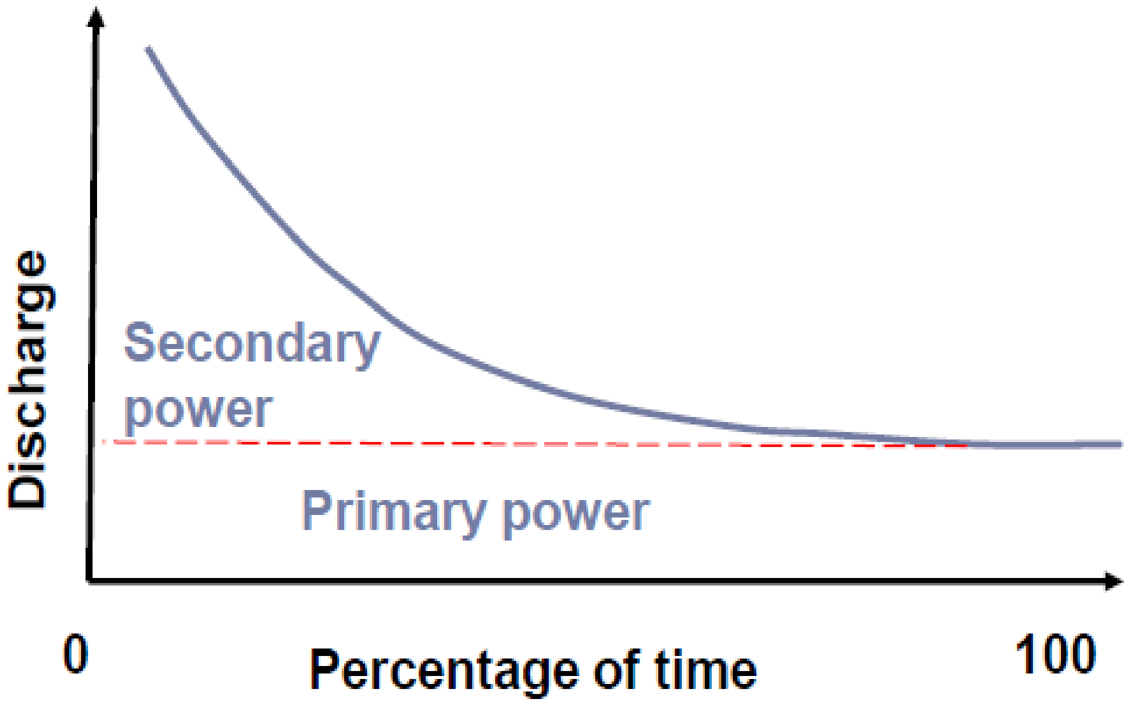
- The firm power could be increased by the use of pondage (storage).



- ***Secondary power***: *Also known as surplus or non-firm power*, is the power other than the primary power and is, thus, comparatively less valuable

- The secondary power is useful in an interconnected system of power plants.

- At off-peak hours, the secondary power may be called upon to relieve the interconnected stations thus affecting economy.
- The secondary power may also be used to take care of the current demand by following a load-duration plan



Example 3 : The following data are obtained from the records of the mean monthly flows of a river for 10 years. The head available at the site of the power plant is 60 m and the plant efficiency is 80%.

Mean monthly flow range (m^3/s)	*No. of occurrences (in 10-yr period)*
100-149	3
150-199	4
200-249	16
250-299	21
300-349	24
350-399	21
400-449	20
450-499	9
500-549	2

1. Plot the FDC and PDC
2. Determine the mean monthly flow that can be expected and the average power that can be developed.
3. Indicate the effect of storage on the FDC obtained.
4. What would be the trend of the curve if the mean weekly flow data are used instead of monthly flows?

Table: Flow duration analysis of mean monthly flow data of a river in a 10 yr period (Example 3)

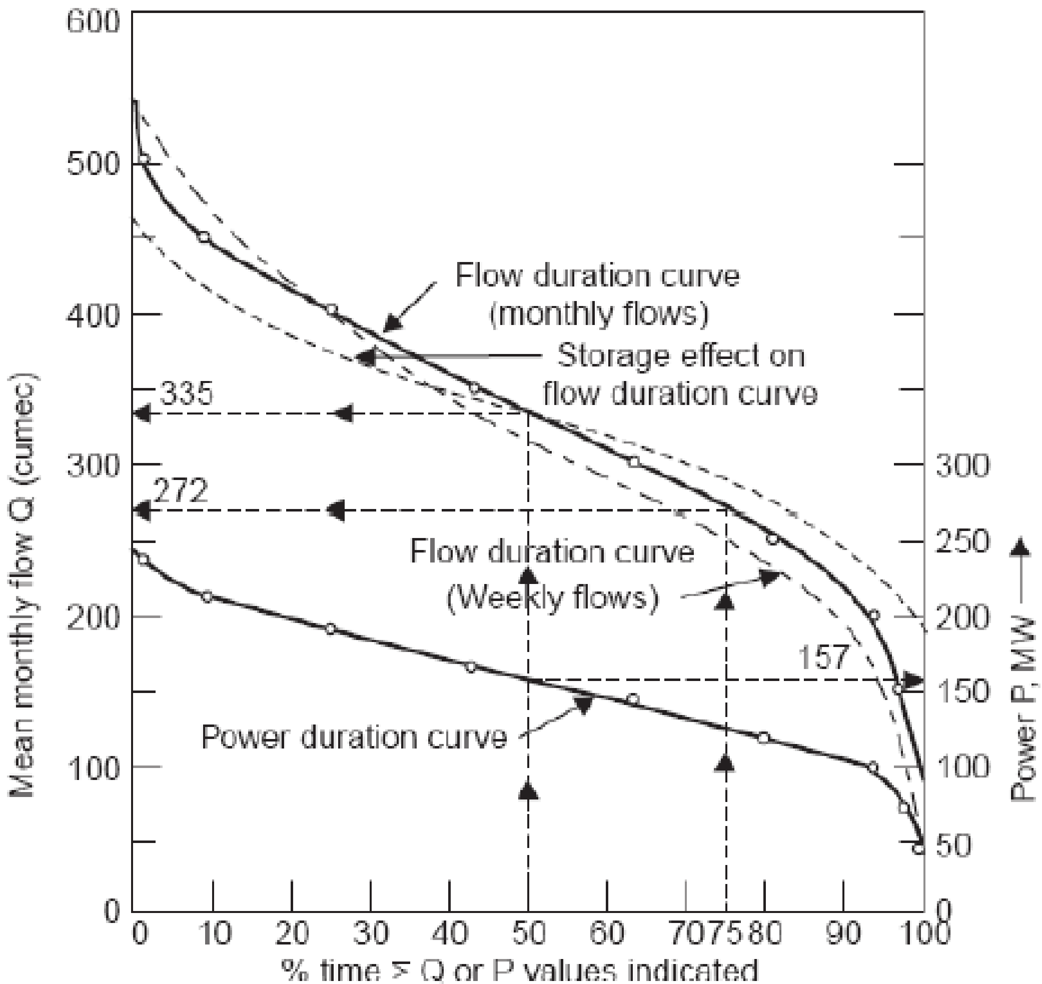
Mean monthly flow C.I. (m^3/s)	*No. of occurrences (in 10-yr period)*	No. time equaled or exceeded (m)	% of time lower value of CI equaled or exceeded = (m/n) x 100%	Monthly P = 9.81x60x0.8xQ (MW) Q is lower value of CI
100-149	3	120	100	47.2
150-199	4	117	97.5	70.8
200-249	16	113	94.2	94.4
250-299	21	97	80.8	118
300-349	24	76	63.3	142
350-399	21	52	43.3	165
400-449	20	31	25.8	189
450-499	9	11	9.2	212
500-549	2	2	1.7	236
	Total n =120			

(*i*) The flow duration curve is obtained by plotting *Q* vs. percent of time in the Fig. (*Q* = lower value of the CI.).

(*ii*) The power duration curve is obtained by plotting *P* vs. percent of time, see the Fig.

2. The mean monthly flow that can be expected is the flow that is available for 50% of the time *i.e.*, 335 m^3/s from the FDC drawn.

The average power that can be developed *i.e.*, from the flow available for 50% of the time, is 157 MW, from the PDC drawn.



3. The effect of storage is to raise the flow duration curve on the dry weather portion and lower it on the high flow portion and thus tends to equalize the flow at different times of the year, as indicated in Fig. above.

4. If the mean weekly flow data are used instead of the monthly flow data, the flow duration curve lies below the curve obtained from monthly flows for about 75% of the time towards the drier part of the year and above it for the rest of the year as indicated in Fig. above

In fact the flow duration curve obtained from daily flow data gives the details more accurately (particularly near the ends) than the curves obtained from weekly or monthly flow data but the latter provide smooth curves because of their averaged out values.

- **Pondage:** While storage refers to large reservoirs to take care of monthly or seasonal fluctuations in the river flow, pondage usually refers to the small storage at the back of a weir, in run-of-river plants, for temporarily storing water during *non-working hours, idle days and low load* periods for use during hours of peak load demand.
  - Run-of-river plants are feasible for streams which have a minimum dry weather flow or receive flow as regulated by any storage reservoir upstream.
- Pondage is needed to cover the following four aspects:
  - To store the idle day flow.
  - For use during hours of peak load.
  - To balance the fluctuations in the stream flow.
  - To compensate for wastage (due to leakage) and spillage.

Classification of Hydropower Plant

- Hydropower plants can be classified into different types based on the various criteria, as follow.

a) classification based on storage(hydraulic) characteristics

i. Run-off river plant
ii. Storage plant
iii. Pumped storage plants
iv. Tidal plants

Cont….

i. Run-off river plant

- Is located on a perennial river in which adequate discharge is available through out the year.
- The plant uses the water as it comes in the river with out storing it.
- These plant are those which utilise the minimum flow in a river.
- A weir (or a barrage) is usually constructed across the river to maintain the required water level and the head for the power plant located on its side or downstream.

Cont….

- The run-off river plants are generally low head plants usually have a small pondage on the upstream to store some water during off-peak hours, which is later utilised during peak hours.
- The power stations constructed on diversion canals (irrigation & power canals) called diversion canal plants, can also be placed in this category.

Cont….

ii. Storage plants

- In storage (or reservoir) plants, a dam is constructed to create a large reservoir to permit carry over storage from the rainy season to the dry season.
- These plants can be designed for a constant flow much greater than the minimum natural flow
- The power house may be located at the foot of the dam or it may be located much away from the dam (on the downstream side)
- In such a case a power house is located at the end of the tunnels which carry water from the reservoir.

Cont….

- When the power house is located near the dam, as is generally done in low head installations; it is known as concentrated fall hydroelectric development. But
- When the water is carried to the power house at a considerable distance from the dam through a canal, tunnel or penstock; it is known as a divided fall development.

Cont….

iii. Pumped storage plants

- A pumped storage plant generates power during peak hours, but during the off-peak hours, water is pumped back from the tail water pool to the head water pool for future use.

Iv. Tidal plant

- Tidal plants are designed to make use of high tides occurring in the sea for the generation of power.
- These plants are constructed on the sea shore, and therefore do not require any storage of water.

Cont….

b) classification based on load (use) to meet the demand for electrical power.

i. base-load plant

- A base load plant is designed to take care of the base load of the power system. It is capable of supplying continuous power to the system through out the year.
- Both run-off river plants and storage plant can work as base load plants. however, if a runoff-river plant with out poundage is designed as a base-load plant, the design discharge should be taken as corresponding to the minimum flow of the river.

Cont....

ii. Peak-load plants

- A peak-load plant is designed to take care of the peak load of the power system. It operates only during the period of the peak load.
- Pumped storage plants are usually designed as peak-load plant

Cont....

c) Classification based on head on turbines

- Low head plants (head < 15 m)
- Medium head plants (head between 15 – 50 m)
- High head plants (head between 50-250 m)
- Very high head plants (head > 250 m)

d) Classification based on Plant capacity:

- Micro hydropower plant (has a capacity < 5MW)
- Medium capacity plant (has a capacity 5MW to 100MW)
- High capacity plants (has a capacity 100 to 1000MW)
- Super Hydropower plant (has a capacity >1000MW)

Principal Components of Hydroelectric Scheme

- A hydroelectric development scheme ordinarily includes:
- ✓ a storage or diversion structures,
- ✓ intake structure,
- ✓ conveyance system which carry the water from the reservoir to the power house. It may includes canals, pipes, penstocks or tunnels
- ✓ Powerhouse which is a building for housing the equipment required for generation of power such as turbines generators.

Cont….

- In addition to these
  - trash racks at the entrance to penstock, canal and penstock gates,
  - A forebay,
  - A surge tank and other accessories may be required and also
  - A tailrace channel which is a channel from power house back to the river must be provided , if the power house situated at such a place that the draft tubes can not discharge water directly in to the river.

Conveyances in Hydropower

Tunnels Vs. Canals

Fore bay design

Penstocks and Spiral Cases

Draft Tubes

- **Power Canal:** In very simple low-head installations the water can be conveyed in an open channel directly to the runner. Power canal settings of turbines do require a protective entrance with a trash rack.
- **Head Race:** Head race may be a power canal, a pressure tunnel, or a pipe, which in most cases conveying water from intake structure to surge tank, fore bay or pressure shaft, depending on the arrangement of the scheme.

- ***Canals:***
- **Canals are appropriate choice when the general topography of the terrain is moderate with gentle slopes.**
- **However, when the ground is very steep and rugged, it becomes uneconomical to construct canals as it follows longer distances and/or needs provision of cross-drainage works and deep cuts and fills at a number of appropriate locations.**
- **In such cases, it is advisable to go for tunnels or pipes.**
- **The choice, in fact, has to be made based on economic analysis.**
- **Where the topography of the region presents special formations, the alternating use of open canal and open-surface tunnel sections may ensure the most economical development.**

Canal Design:

Involves determination of the following:

- **Carrying capacity: velocity of water &roughness coefficient**
- **Canal slopes**
- **Cross-sectional profile of the canal**

Carrying Capacity and Velocity:

The discharge is computed from continuity equation as **Q=VA**

The roughness coefficient (n):

is specified from the bed material type

- Chezy's equation $V = C\sqrt{RS}$

- To determine the value of C we can use

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

$$V = \frac{1}{n} R^{2/3} S^{1/2} = M R^{2/3} S^{1/2}$$

Apart from the hydraulic computations, the flow velocities in the canal or other water conduits in general are determined according to *economic point of views* (investments, head losses, wear and tear of material, danger of erosion and silting).

The velocity must be high enough to prevent sedimentation. It has to be low enough to prevent bed erosion for unlined and wear by abrasion for lined-canals.

Maximum velocity		Maximum velocity		Minimum velocity
Bed Material	V_{max} (m/s)	Bed Material	V_{max} (m/s)	V_{min} (m/s)
		Clay	2.0	To keep any sediment from settling, the minimum velocity in a canal should not be less than 0. 3 m/s.
Sand	0.4	Gravel	3.0	
Sandy loam	0.6	Masonry	3.5	
Loam	0.6	Asphalt	4.0	
Clayey loam	0.8	Concrete	5.0	

Power Canal Slopes:

- In plain areas use slope between 5 to20 cm/km. In mountainous areas slopes are as steep as 1 to 2 m/km. The canal bed slope can also be estimated using the Manning's equation:

$$S = \frac{n^2 V^2}{R^{4/3}}$$

Cross-sectional Profile

- The material in which the canal is constructed generally dictates its cross-sectional profile.
- The common cross-sections used for canals are
- *semi-circular*
- *trapezoidal and*
- *rectangular* cross-sections

- ***Freeboard Allowance:***
- For earth canal the lower limit is 35 cm and the upper limit is 140 cm. Generally the *free board = [0.35+0.25h]* m. Where h is depth of flow. Allowances should be made for bank settlements.
- For lined canals, the top of the lining is not usually extended for the full height of the free board. Usually it is extended to 15cm to 70cm above the design water level.
- **Water Loss in Power Canals**
- Water losses are due to
  a) Seepage
  b) Evaporation
  c) Leakage at gates
- Generally b) and c) are generally of minor importance.