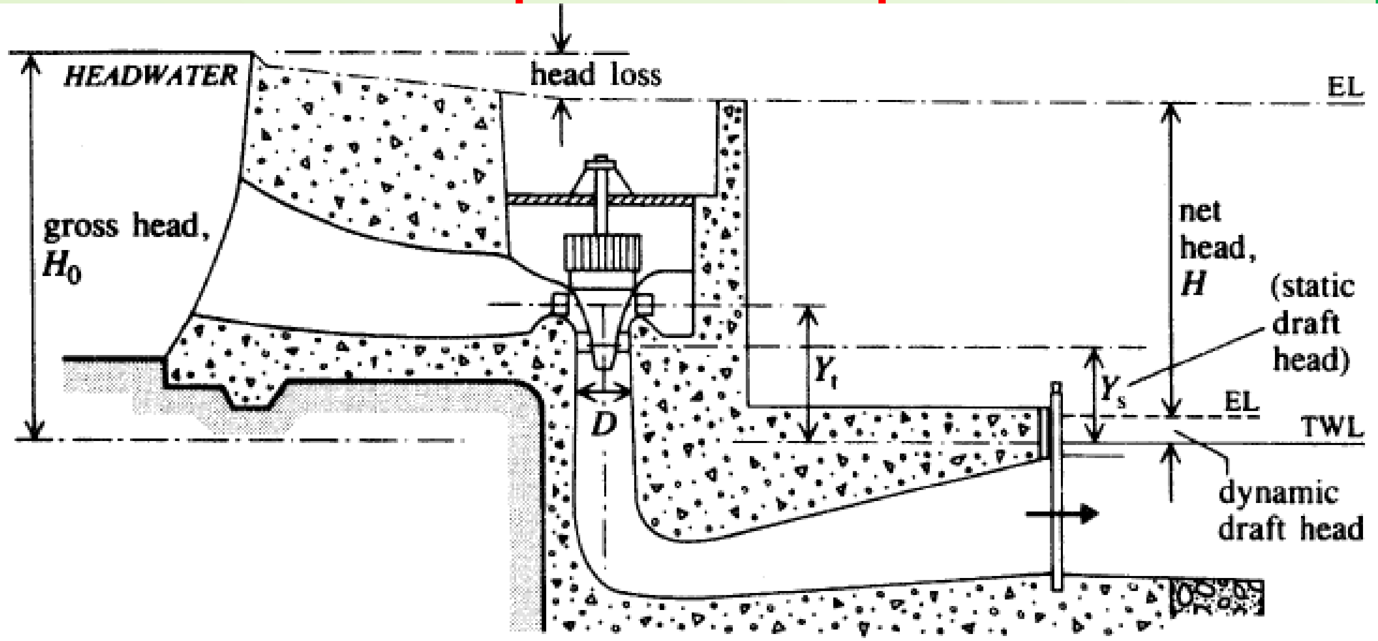
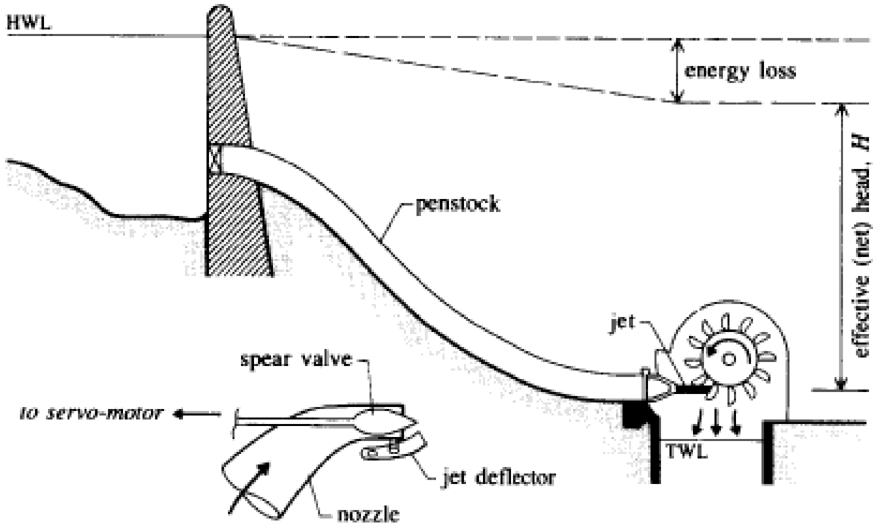
Chapter 2: Estimation of water power potential

Some fundamental definitions

- The gross head, Ho, at a hydroelectric plant is the difference in water level between the reservoir behind the dam and the water level in the tail race.
- The effective or net head, H, is the head available for energy production after the deduction of losses in the conveying system of the plant
- The water falling from a high-level source drives turbines, which in turn drive generators that produce the electricity.





(a) Nozzle flow regulation

(b) Pelton wheel

The hydraulic power is given by:

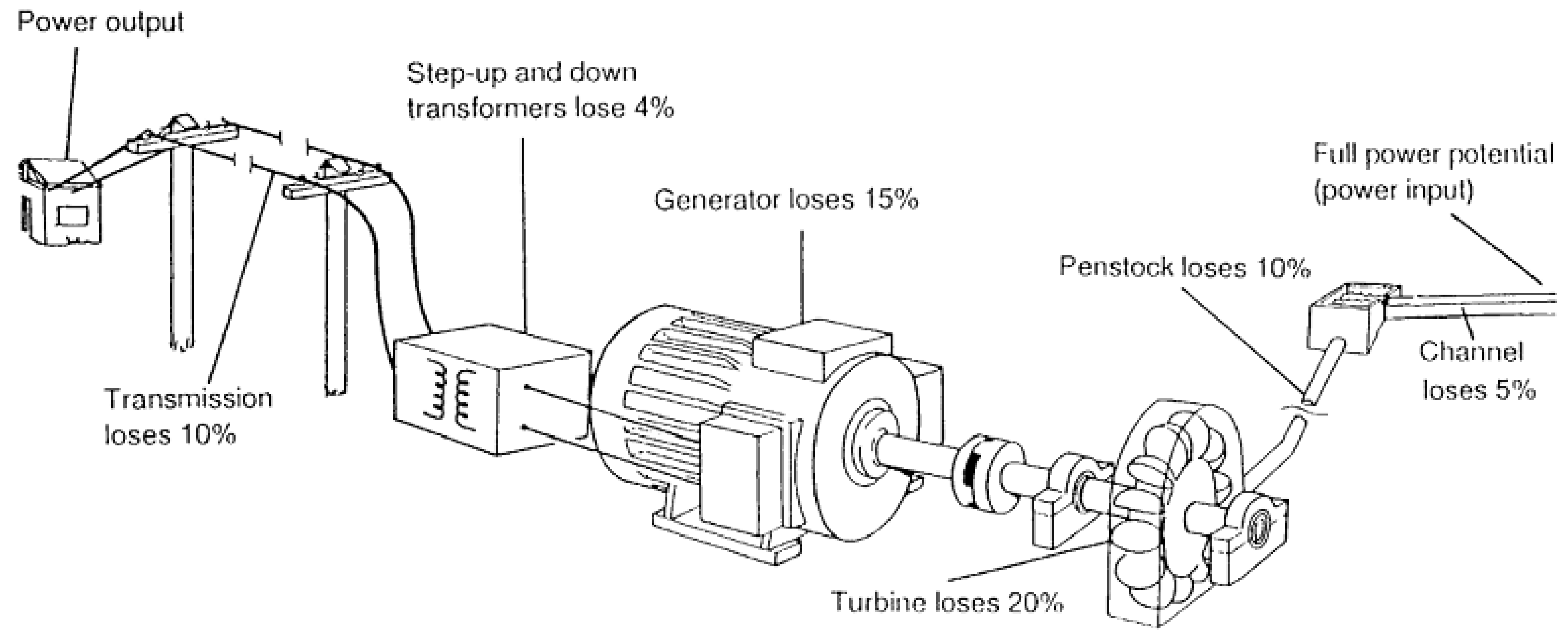
$$P = \frac{\eta \rho g Q H}{1000} \ (KW)$$

Where η is the plant efficiency

Q is the flow rate (in $m^3 s^{-1}$) under a head of H (m).

- The hydraulic efficiency of the plant is the ratio of net head to gross head (i.e. ${}^{H}/_{H_o}$)
- The overall efficiency is equal to the hydraulic efficiency times the efficiency of turbine and generator.
- The installed capacity of a hydro plant is the maximum power which can be developed by the generators at normal head with full flow.

Approximate losses in the conveying system of a plant



Some concepts and definitions

- The unit of electrical power is the kilowatt
- The unit of electrical energy, defined as the power delivered per unit time, is the kilowatt-hour (kW h).
- **Primary** or ‘firm’, power is the power which is always available, corresponds to the minimum streamflow without consideration of storage.
- Secondary, or surplus, power is the remainder and is not available all the time.
- Secondary power is useful only if it can be absorbed by relieving some other station, thus affecting a fuel (thermal) saving or water saving (in the case of another hydro-station with storage).

Estimation of 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 or digital elevation model where as hydrological data on rainfall and runoff are essential in order to assess the available water quantities.

Necessary hydrological data:

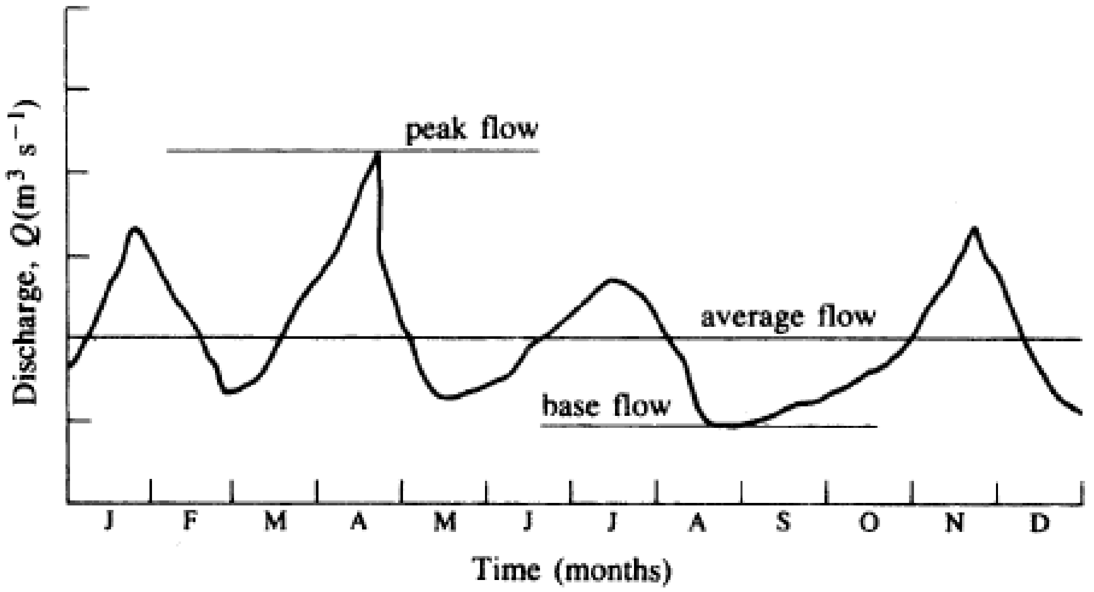
- The daily, weakly or monthly flow over a period of several years, to determine the plant capacity & estimated output.
- Low flows, to asses the primary, firm, or dependable power.

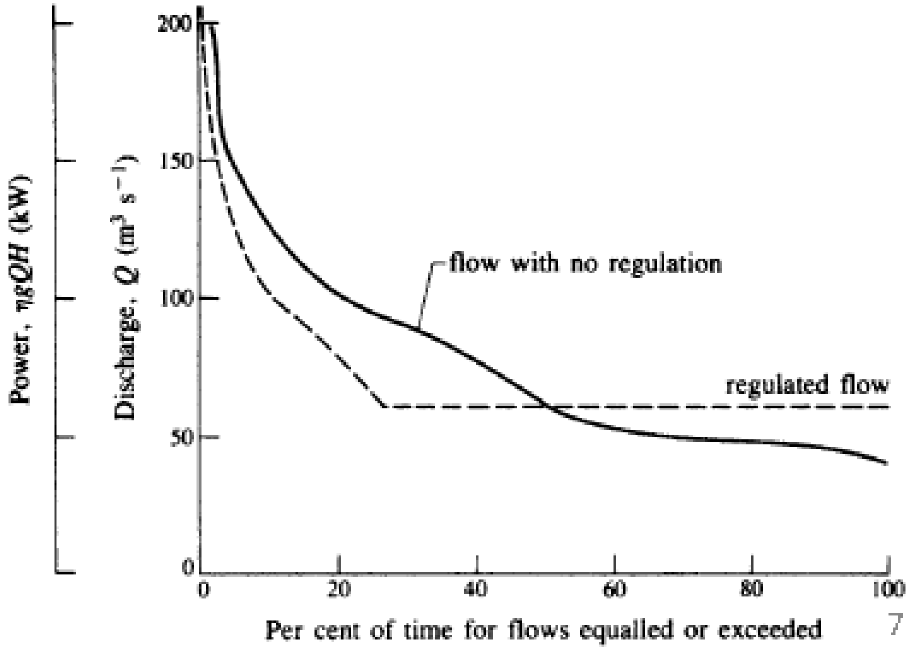
In order to evaluate the hydropower potential of a site, the following criteria are considered:

- Minimum potential power is based on the smallest runoff available in the stream at all times, days, months and years having duration of 100 percent ($Q100$)
- Small potential power is calculated from the 95 percent duration discharge ($Q95$)
- Medium or average potential power is gained from the 50 percent duration discharge ($Q50$)
- Mean potential power results by evaluating the annual mean runoff (Qm)

Flow duration studies

- A useful way of treating the time variability of water discharge data in hydropower studies is by utilizing flow duration curves
- Flow duration curve of a stream for a given site can be obtained 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 head.

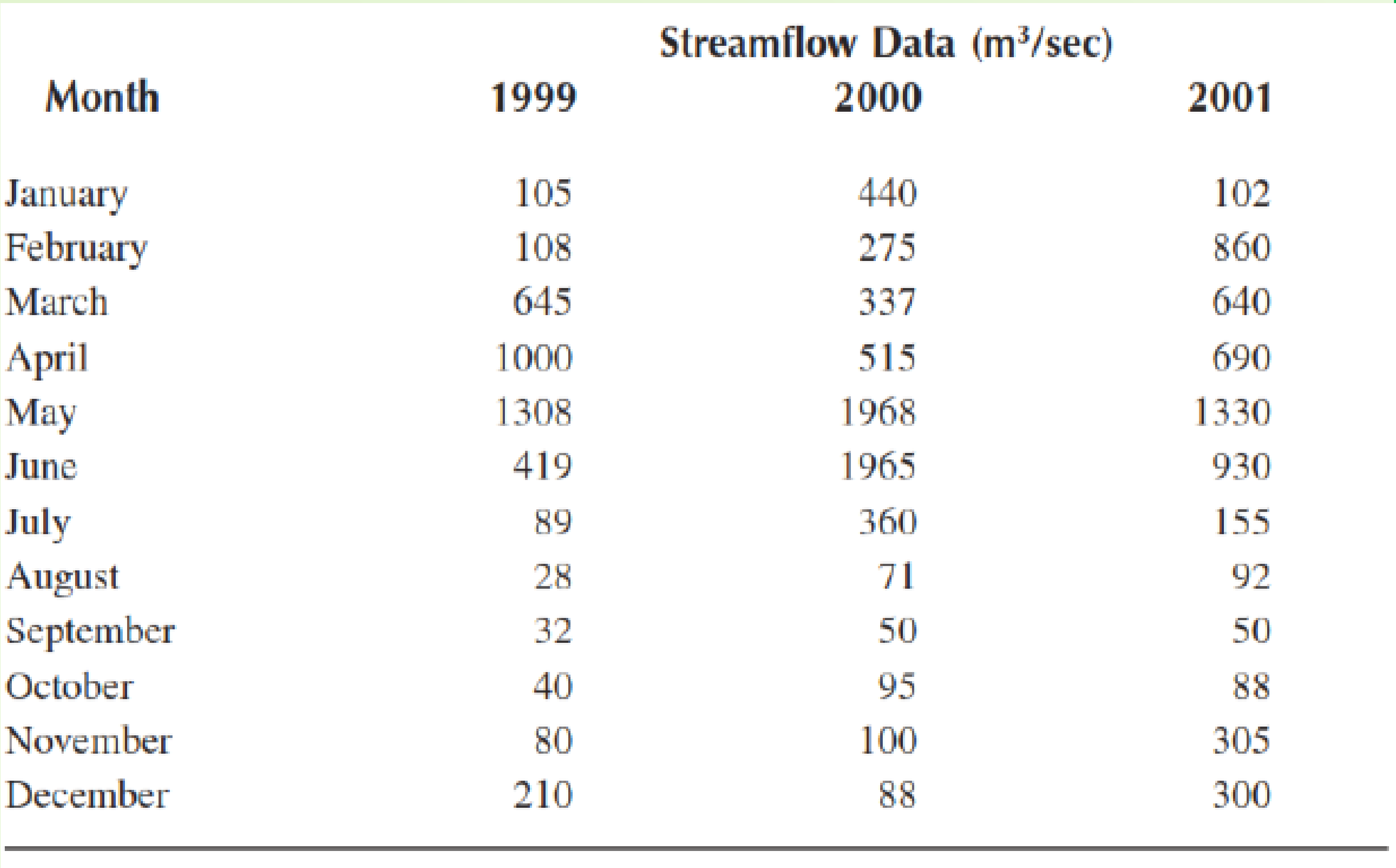




Example

The table (right side) provides the monthly streamflow data for a gauging station for the years 1999 to 2001. Plot the flow–duration curve for this river.

The head available at the site is about 10 m and plant efficiency is about 70%. Assume that the turbine discharge capacity is 500 m3/sec find the firm energy that is expected with 90% probability of exceedance.

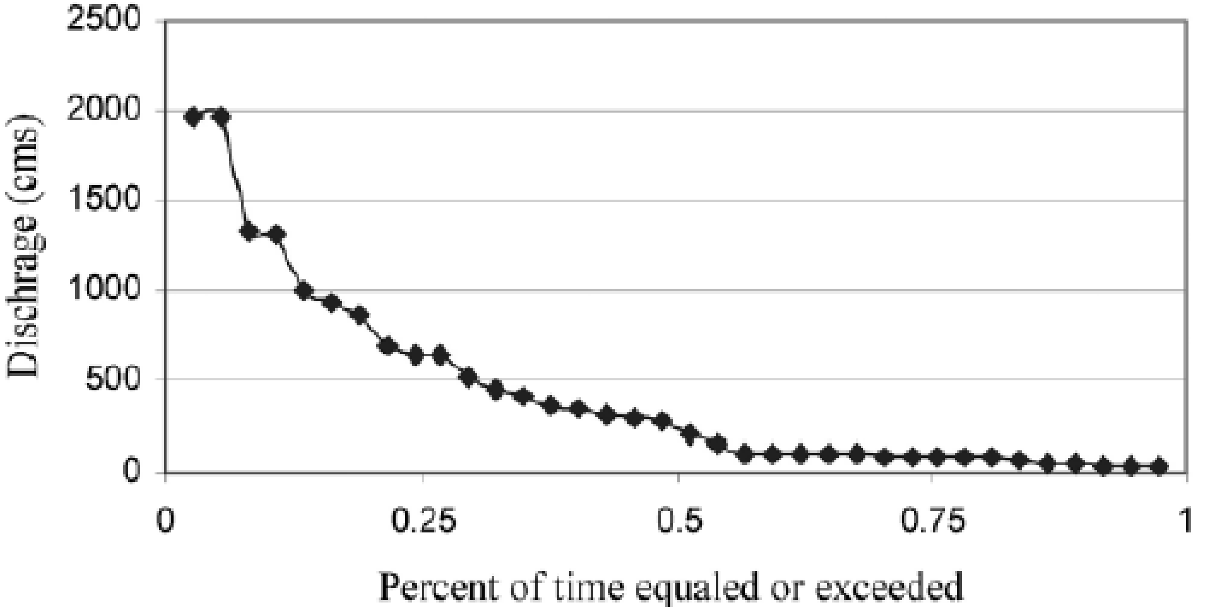


	Streamflow Data (m^3/sec)		
Month	**1999**	**2000**	**2001**
January	105	440	102
February	108	275	860
March	645	337	640
April	1000	515	690
May	1308	1968	1330
June	419	1965	930
July	89	360	155
August	28	71	92
September	32	50	50
October	40	95	88
November	80	100	305
December	210	88	300

- Solution: To develop the flow–duration curve, the observed streamflows should be arranged in descending magnitude.
- The data are ranked from 1 to 36. The probability of exceedence is then estimated by the following relation:

$$P_{ei} = \frac{i}{N+1}$$

where i is the rank of the data and N is the total number of data (36 in this example).



Technically Available Power

Hydropower potential is commonly divided into three:

- Theoretical

The gross theoretical potential is the sum of the potential of all natural flows from the largest rivers to the smallest rivulets, regardless of the inevitable losses and unfeasible sites.

- Technical

From technical point of view, extremely low heads (less than around 0.5m), head losses in water ways, efficiency losses in the hydraulic and electrical machines, are considered as infeasible. Hence, the technically usable hydro potential is substantially less than the theoretical value.

- Economic

Economic potential is only that part of the potential of more favorable sites which can be regarded as economic compared to alternative sources of power like oil and coal. Economically feasible potential, therefore, would change with time, being dependent upon the cost of alternate power sources.

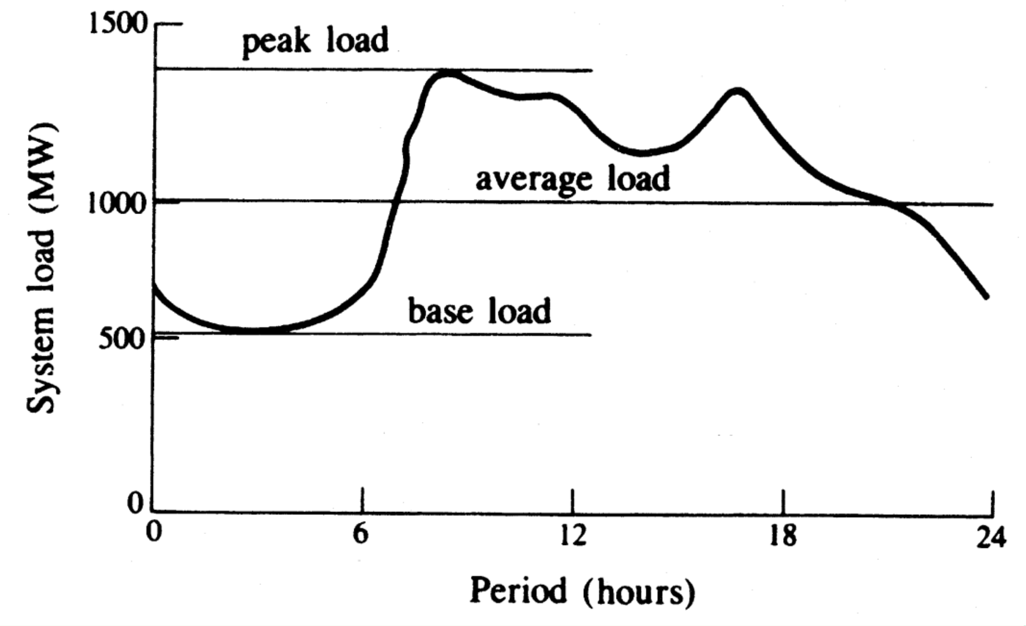
- The upper value of net power capable of being developed technically is computed from the potential waterpower by introducing reduction factors to account for losses in conveyance & in energy conversion.
- The EEPCo puts the factor to be about 0.75 to 0.80.
- Thus $Pm = (0.75 \ to \ 0.8)\gamma QmH$, Where Qm is arithmetic mean discharge.

Power Demand

- Demand for electrical power varies from hour to hour during the day, from day to day, and from year to year.
- The power demand is defined as the total load which consumers choose, at any instant, to connect to the supplying power system.
- The system should have enough capacity to meet the expected demand, in addition to unexpected breakdowns and maintenance shutdowns.
- A daily load curve for a typical domestic area is shown in the following slide.

- **Load** is the demand for electricity which can be expressed in terms of energy demand (average power demand) or capacity demand (peak power demand).
- **Base load** is the minimum load of a power system in a specific period of time.
- **Peak load** is the maximum load in a specific period; the peaking portion of the load is usually defined as the load that occurs at the peak demand hours, which is about 8 hours a day.
- **Intermediate load** is that portion of the load between the base load and the peaking portion of the load.
- **Load factor** is the ratio of average power demand to peak power demand for a specific period that can be computed on a daily, weekly, monthly, or annual basis.

$$\text{Load Factor} = \frac{\text{energy consumed (say during 24 } h)}{(\text{max. demand}) * 24\ h}$$



- Load factor gives an idea of degree of utilization of capacity.
- Thus an annual load factor of say 0.4 indicates that the machines are producing only 40% of their yearly maximum production capacity.

An Electric demand Load Factor Calculation Example

Monthly Energry Use 4000 KWh
Monthly Peak Electric Demand 35 KW
Days in the Month 30
Hours in a Day 24 days
Power Load Factor =4000/(35*30*24) = 15.9%

- A single station connected to an industrial plant may have a load factor of, for example 80%.
- In a country where the supply is distributed through a national grid system for a diversity of uses, the annual load factor may be of the order of 40%.
- Low load factors represent a degree of inefficiency, as sufficient capacity in the form of generating machinery must be installed to meet the peak demand while, on average, a considerable part of this machinery is standing idle.
- Thermal plants are more efficient to run at full load and hence are suitable for generating continuously near capacity to carry the base load.
- Hydroelectric plants are therefore very suitable for meeting variations in load with little waste of power.

Firm and Secondary Power

Firm or primary power

- is the electric energy that should be made available to a customer to meet any or all of the agreed-upon portion of that customer's load requirements.
- For hydropower plants, it usually can be estimated based on the energy output of the plant in the most critical period (low flow) of the historical records.

Secondary power is all power available in excess of firm power.

Plant (Capacity) factor is the ratio of the average output of a plant for a particular time period to its installed capacity.

- Capacity factor of hydroelectric plants varies depending on the availability of its fuel, water. Some existing hydro plants that are run as base load due to continuous and abundant supply of water have a high capacity factor that is comparable to thermal plants.
- For some plants, which are dam-type and not much have plenty of water supply could only have a capacity factor of around 40% and could go to less than 20% during extreme dry season.
- Hydro plants with low capacity factor are usually run as peaking plant -operates only during peak demand to take advantage of the high price of electricity.
- Of course, if the availability of water is low, you could still design a hydro plant with high capacity factor by reducing the rated capacity (installed capacity).

Load Predictions

Power is needed for a variety of purposes,

- Domestic
- commercial,
- industrial,
- municipal,
- agricultural,
- public transport etc.

- The energy demand (local, regional, trans-regional) is subject to considerable temporal fluctuations
- These variations could be from hour to hour within a day, from day to day within a week/month, from month to month within a year, etc.

These seasonal fluctuations depend on:

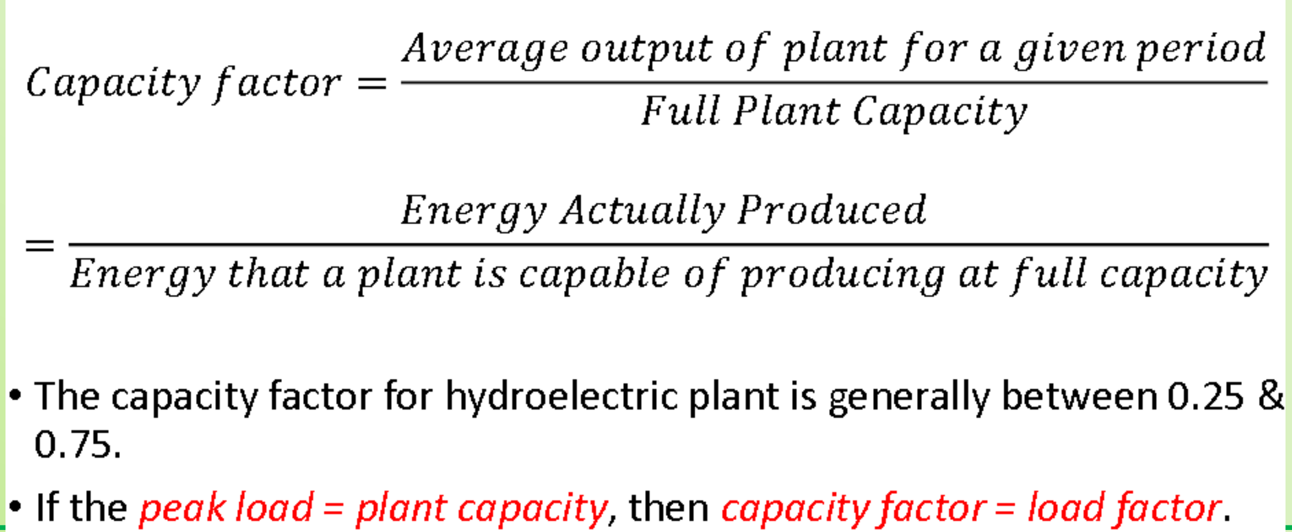
- Weather, season;
- Vacation times;
- Cyclical business activity.

Daily fluctuations are due to:

- Rhythm of work time and free time;
- Weather;
- Traffic

To cover the fluctuating energy demand, the following types of power plants are interconnected to each others and work together:

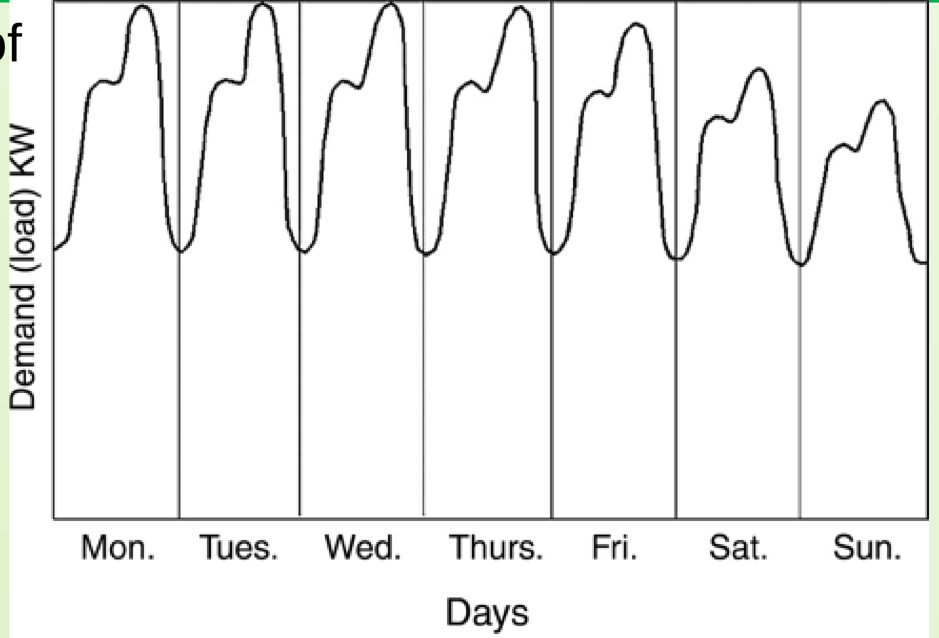
- Base load power stations
- coal, oil
- nuclear and
- run-of-river scheme power stations
- Average load power stations
- Temporary gas and reservoir power stations
- Peak load power stations
- pumped storage and
- peak load hydro power stations

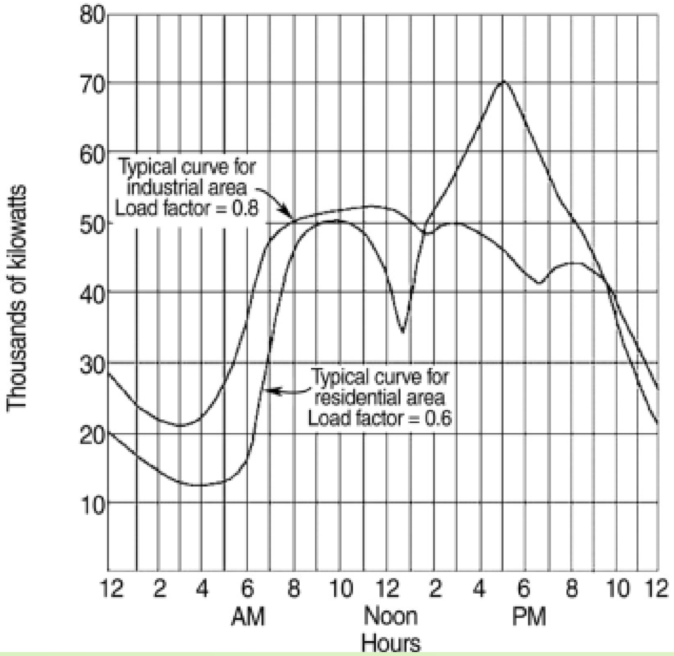


$$Capacity\ factor = \frac{Average\ output\ of\ plant\ for\ a\ given\ period}{Full\ Plant\ Capacity}$$

$$= \frac{Energy\ Actually\ Produced}{Energy\ that\ a\ plant\ is\ capable\ of\ producing\ at\ full\ capacity}$$

- The capacity factor for hydroelectric plant is generally between 0.25 & 0.75.
- If the *peak load = plant capacity*, then *capacity factor = load factor*.





Example

- As of 2010, Three Gorges Dam is the largest power generating station in the world by nameplate capacity.
- In 2009, not yet fully complete, it had 26 main generator units of 700 MW and two auxiliary generator units of 50 MW for a total installed capacity of 18,300 MW.
- Total generation in 2009 was 79.47 TW·h, for a capacity factor of just under 50%:

$$\frac{79,470,000\ \mathrm{MW{\cdot}h}}{(365\ \mathrm{days}) \times (24\ \mathrm{hours/day}) \times (18,300\ \mathrm{MW})} = 0.4957 \approx 50\%$$

- Hoover Dam has a nameplate capacity of 2080 MW and an annual generation averaging 4.2 TW·h. (The annual generation has varied between a high of 10.348 TW·h in 1984, and a low of 2.648 TW·h in 1956.) Taking the average figure for annual generation gives a capacity factor of:

$$\frac{4,200,000\ \mathrm{MW{\cdot}h}}{(365\ \mathrm{days}) \times (24\ \mathrm{hours/day}) \times (2,080\ \mathrm{MW})} = 0.23 = 23\%$$

For assumed constant head

$$Utilization\ factor = \frac{Quantity\ of\ water\ actually\ used\ for\ power\ production}{Quantity\ of\ water\ available\ in\ the\ river(reservoir)}$$

$$Utilization\ factor = \frac{Power\ utilized}{Power\ available}$$

- For hydroelectric plants, this factor varies from 0.4 to 0.9 depending on plant capacity, load factor & storage.

Load Prediction and Demand Assessment

- Estimation of future power loads of a specific system is a primary step for hydropower development planning or operation management studies.
- Load predictions are usually based on the rate at which the energy consumption has increased over the past few years.
- Three methods have been used for estimating future power loads (American Society of Civil Engineers, 1989)

Methods of estimating future power loads

- Trend analysis: based on extending historical trends and modifying the projections to reflect expected changes
- End-use analysis: based on the expected use of electricity by different users
- Econometric analysis: based on the relationships between electricity demand and various factors that influence demand.

- Each of the forecasting methods uses a different approach to determine electricity demand during a specific year in a particular place
- Each forecasting method is distinctive in its handling of the forecast ingredients

The factors which actually influence the power demand

- Population
- Income
- price, etc.–*the independent variables*;
- power demand itself –*the dependent variables*; and

How much power demand changes in response to

- population
- Income
- price, etc., changes –*the elasticity's*

Trend Analysis

- Trend analysis extends past growth rates of power demand into the future
- It focuses on past changes or movements in demand and uses them to predict future changes in the demand

The advantage of trend analysis is that

- simple, quick and inexpensive to perform
- It is useful when there is no enough data to use more sophisticated methods or
- when time and funding do not allow for a more elaborate approach.

The disadvantage of trend analysis is:

- It produces only one result (future power demand)
- It doesn't help analyze why power demand behaves the way it does, and
- it provides no means to accurately measure how changes in energy prices or government policies, for instance, influence the demand.

End-Use Analysis

- The basic idea of end-use analysis is that the demand for power depends on what it is used for (the end-use)
- For instance, by studying historical data to find out how much power is used for individual electrical appliances in homes, then multiplying that number by the projected number of appliances in each home and multiplying again by the projected number of homes, an estimate of how much power will be needed to run all household appliances in a geographical area during any particular year in the future can be determined.
- Using similar techniques for power used in business and industry, then adding up the totals for residential, commercial, and industrial sectors, a total forecast of power demand can be derived.

Advantage

- It identifies exactly where power goes and how much is used for each purpose.

Disadvantage

- It assumes a constant relationship between power and end-use, for example, power used per appliance but, in actual case, energy saving technology or energy prices will undoubtedly change with time, and the relationship will not remain constant
- It requires extensive data.

Econometric Analysis

- Econometric analysis uses economics, mathematics, and statistics to forecast power demand.
- It is a combination of trend analysis and end-use analysis, but it does not make the trend analyst's assumption that future power demand can be projected based on past demand.
- Moreover, unlike end-use method, it can allow for variations in the relationship between power input and end-use.
- Econometric analysis uses complex mathematical equations to show past relationships between demand and the factors which influence the demand.
- For instance, an equation can show how power demand in the past reacted to population growth, price changes, etc
- For each influencing factor, the equation can show whether the factor caused an increase or decrease in a power demand.
- The equation is then tested and fine tuned to make sure that it is a reliable as representation as possible of the past relationships
- Once this is done, projected values of demand-influencing factors (population, income, prices) are put in to the equation to make the forecast.

Advantage

- It provides detailed information on future levels of power demand, why future power demand increases or decreases, and how power demand is affected by all the various factors
- It is flexible and useful for analyzing load growth under different scenarios.

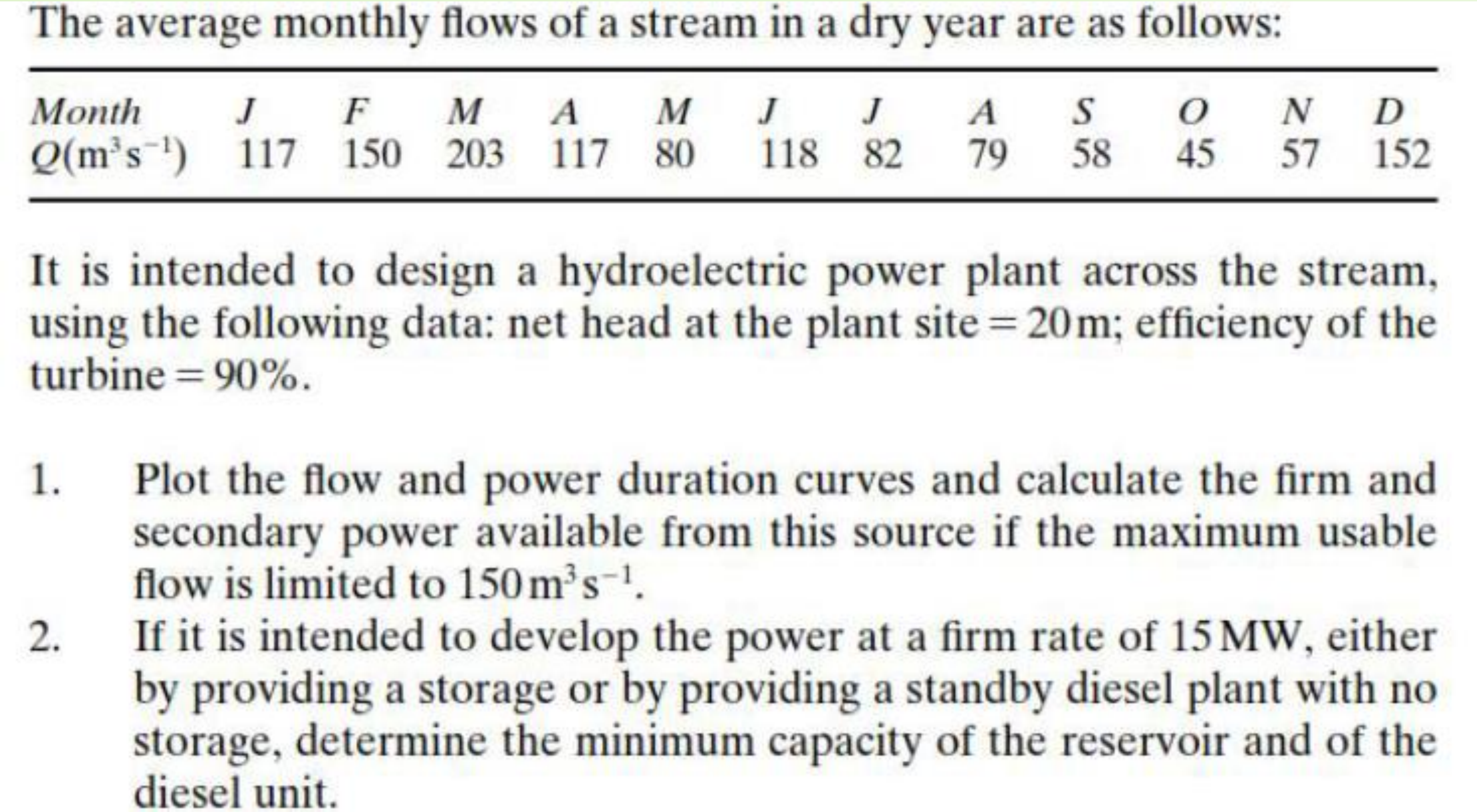
Disadvantage

- The assumption that the changes in the power demand caused by changes in the factors influencing that demand remain the same in the forecast period as in the past. However, this constant elasticity assumption is hard to justify in reality.

Demand Forecasting

- Short-term forecasting is usually done
- operation planning of existing power plants
- Medium-term forecast
- basis for expansion program of power generation facilities
- Long-term forecast helps
- formulation of the country’s perspective plan for power generation

Example



The average monthly flows of a stream in a dry year are as follows:

Month	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
$Q(\mathrm{m^3 s^{-1}})$	117	150	203	117	80	118	82	79	58	45	57	152

It is intended to design a hydroelectric power plant across the stream, using the following data: net head at the plant site = 20 m; efficiency of the turbine = 90%.

1. Plot the flow and power duration curves and calculate the firm and secondary power available from this source if the maximum usable flow is limited to $150\,\mathrm{m^3 s^{-1}}$.
2. If it is intended to develop the power at a firm rate of 15 MW, either by providing a storage or by providing a standby diesel plant with no storage, determine the minimum capacity of the reservoir and of the diesel unit.