Energy Resources

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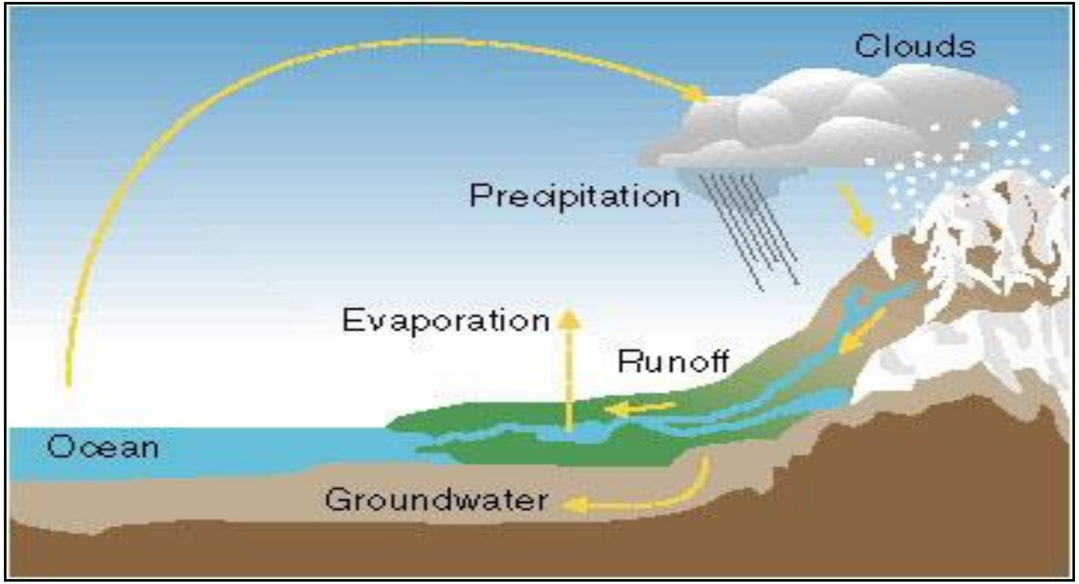
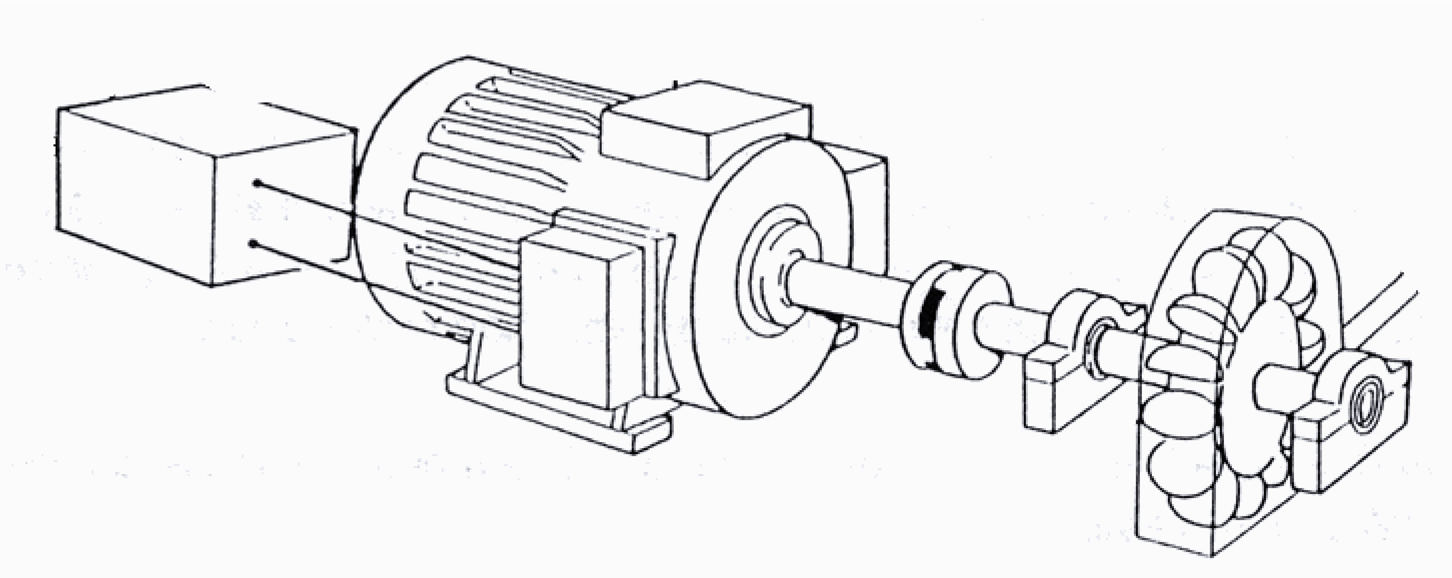
Hydro Power

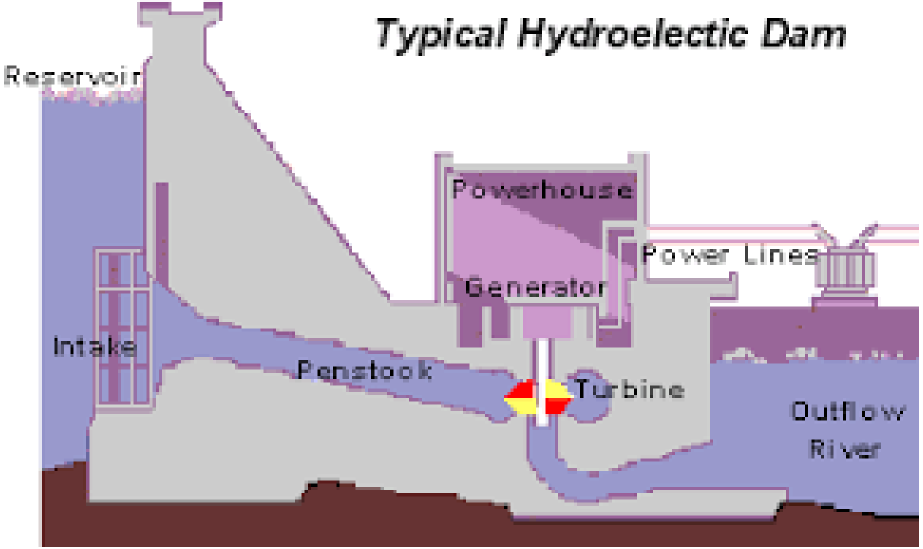


Hydropower energy is ultimately derived from the sun, which drives the **water cycle**. In the water cycle, rivers are recharged in a continuous cycle.

Hydro Power



Hydro Power



Typical Hydroelectic Dam
Reservoir
Powerhouse
Power Lines
Generator
Intake
Penstock
Turbine
Outflow
River

Hydro Power

- Hydro-power is by far the most established and widely used renewable resource for electricity generation and commercial investment.
- The capacity of total worldwide installations has grown at about 5% per year since.
- Hydro-power now accounts for about 20% of world's electric generation.
- Output depends on rainfall and the terrain.
- In about one-third of the world countries, hydro-power produces more than half the total electricity.

Hydro Power

Table 8.1 Hydro-power capacity by country/region

A country/region	B technically exploitable potential/ $TWh\,y^{-1}$	C economically exploitable potential/ $TWh\,y^{-1}$	D actual generation/ TWh, 1999	E installed capacity/ GW, 1999	F under construction/ GW, 1999	G fraction harnessed = D/B/%
Africa	1890	n/a	73	20	2	4%
North America	1690	n/a	710	160	2	42%
Canada	951	523	340	67	2	36%
USA	530	376	320	80	0	60%
South America	2800	n/a	500	106	16	18%
Brazil	1490	810	285	57	11	19%
Asia	4900	n/a	567	174	71	12%
China	1920	1260	204	65	35	11%
India	660	n/a	82	22	15	12%
Japan	136	114	84	27	1	62%
Europe	2700	n/a	735	214	9	27%
Austria	60	56	41	11	0	68%
Norway	200	180	121	27	0	61%
Russia	1670	850	160	44	5	10%
UK	6	1	5	1	0	88%
Middle East	210	n/a	8	4	10	4%
Oceania	240	n/a	42	13	0	18%
Australia	35	30	17	8	0	49%
New Zealand	77	40	23	5	0	30%
World	14 400	n/a	2630	692	110	18%

Source: World Energy Council (2001)

Hydro Power (Benefits)

Hydro installations and plants are long-lasting with routine maintenance, e.g. turbines for about fifty years and longer with minor refurbishment, dams and waterways for perhaps hundred years. Long turbine life is due to the continuous, steady operation without high temperature or other stress.

Hydro Power (Drawbacks)

- Possible adverse environmental impact on fish
- Silting of dams
- Corrosion of turbines in certain water conditions
- Social impact of displacement of people from the reservoir site
- Loss of potentially productive land
- Relatively large capital costs compared with those of fossil power stations.
- Considerable civil engineering (in the form of dams, pipe work, etc.) is always required to direct the flow through the turbines.

Hydro Power (Principles)

A volume per second, *Q*, of water falls down a slope. The density of the fluid is *ρ* . Thus the mass falling per unit time is *ρ.Q*, and the rate of potential energy lost by the falling fluid is

$$P_0 = \rho Q g H$$

where g is the acceleration due to gravity, P_0 is the energy change per second (a power measured in Watts) and H is the vertical component of the water path.

Hydro Power

Question No 1

Following details are available for Ghazi Barotha Dam

Generation capacity 1450 MW (5 units each with 290 MW capacity)

Head available 69 m

Flow available 2340 m^3/s (468 m^3/s for one turbine-generator set)

Construction cost 2.1 Billion US-Dollar

Reservoir capacity 25,500,000 m^3

Calculate how much is theoretical potential and what fraction is being harnessed practically.

Hydro Power

Question No 2

Re-read question number 1, consider capital cost for twenty years time with an annual interest rate of 5%. Consider operation and maintenance cost to be about 4% of annualized cost. Calculate cost per kWh of electricity produced (Consider 1 USD=105 PKR).

Hydro Power

Question No 3

Following information is available for Tarbela dam,

Installed capacity (3478 MW, total 14 units, 10 Units of 175 MW each and 4 units of 432 MW each).

Following table summarizes annual power harnessed from this plant. Do the calculations and compare how much of installed capacity was actually harnessed from 2009-2014.

Year	Produced power (Million kWh)
2009-10	13904.541
2010-11	16006.591
2011-12	14105.331
2012-13	14788.224
2013-14	15180.791

Mention reasons why actual power production is significantly less than that of installed capacity.

Hydro Power (Principle)

Unlike some other power sources, there is no fundamental thermodynamic or dynamic reason why the output power of a hydro-system should be less than the input power P_0, apart from frictional losses which can be proportionately very small.

$$P_0 = \rho Q g H$$

The main disadvantage of hydro-power is that the site must have sufficiently high Q and H. In general this requires a rainfall >~40 $cm y^{-1}$ dispersed through the year, a suitable catchment and, if possible, a water storage site.

Hydropower resource assessment

Measurement of Head

For nearly vertical falls, trigonometric methods (perhaps even using the lengths of shadows) are suitable; whereas for more gently sloping sites, the use of level and pole is straightforward.

The power input to the turbine depends not on the geometric (or total) head H_t as measured this way, but on the available head Ha:

$$H_a = H_t - H_f \qquad H_f < \sim H_t/3$$

Hydro Power

Losses at canal entrance

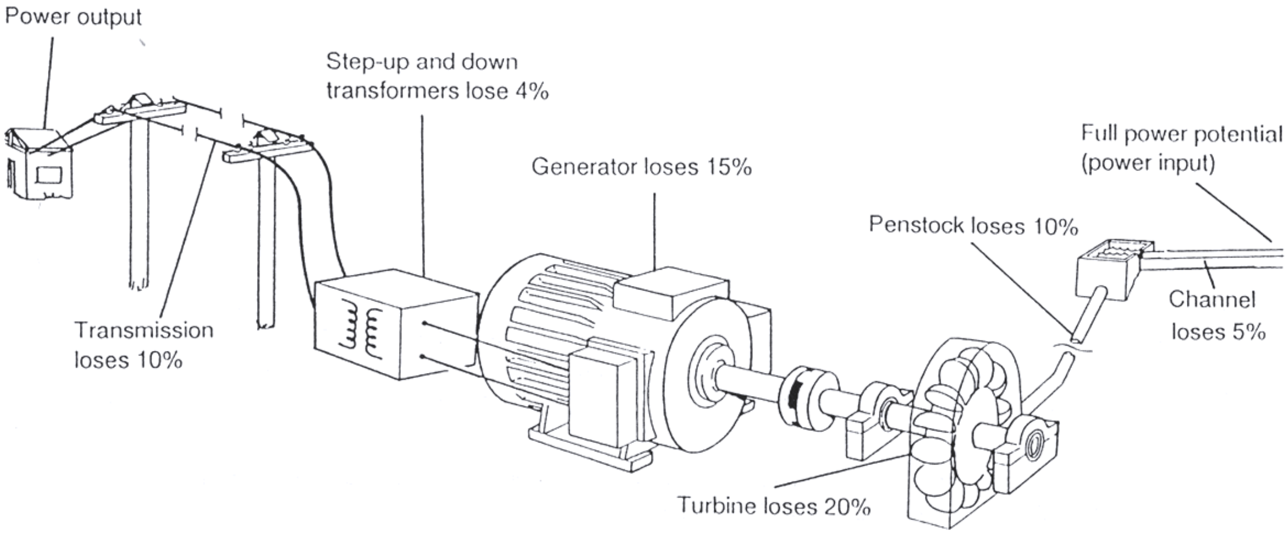
Losses due to contraction and expansion

Losses due to friction

Losses due to trash rack

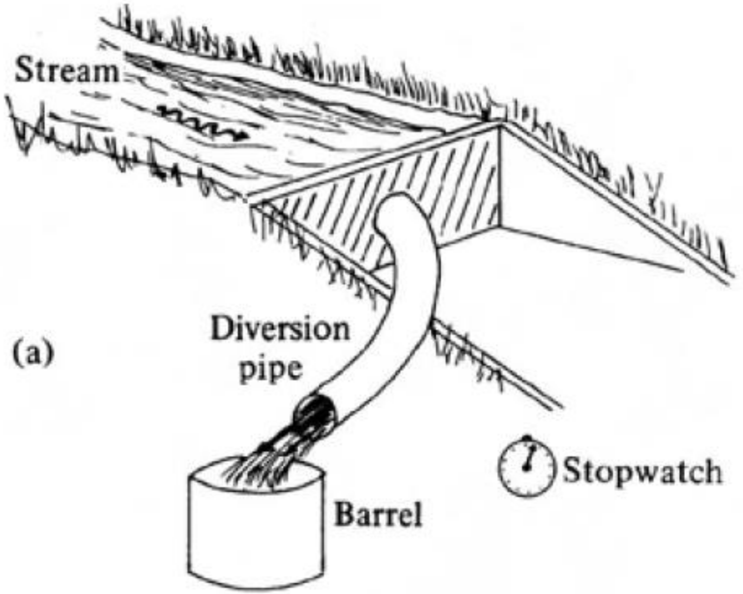
Losses due to bend

Hydro Power



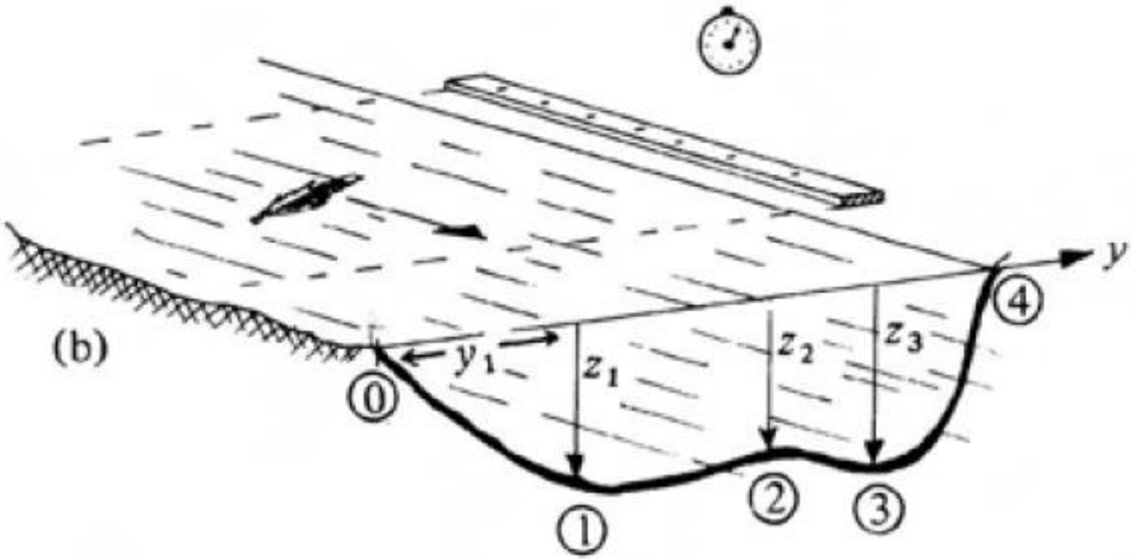
So losses overall are about 50%

Hydro Power (resource assessment)



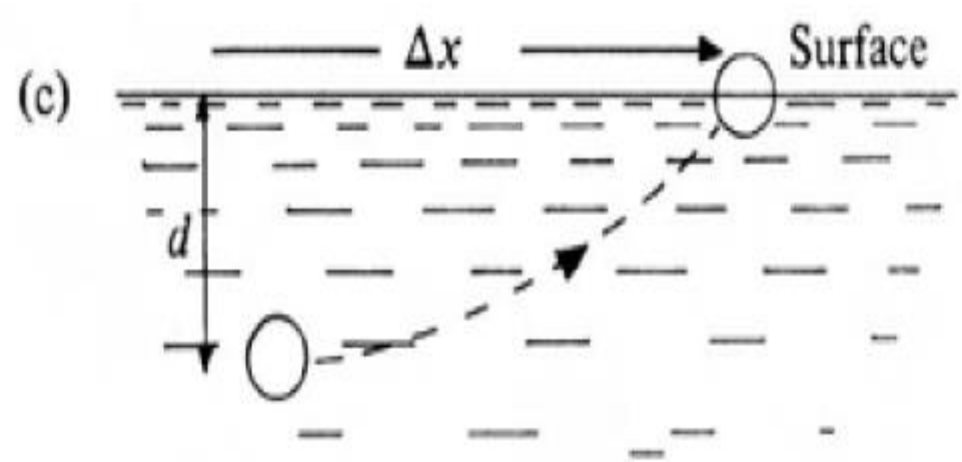
$$\text{flow rate } Q = (\text{volume passing in time } \Delta t)/\Delta t$$

Hydro Power (resource assessment)



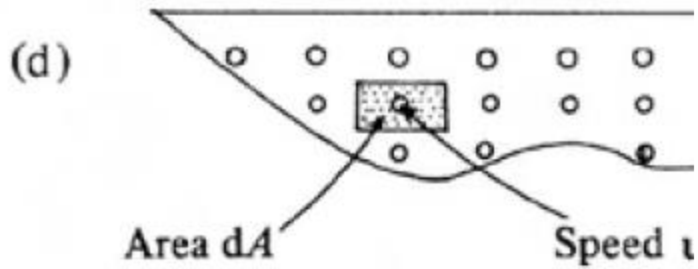
$$= (\text{mean speed } \overline{u}) \times (\text{cross-sectional area } A)$$

Hydro Power (resource assessment)

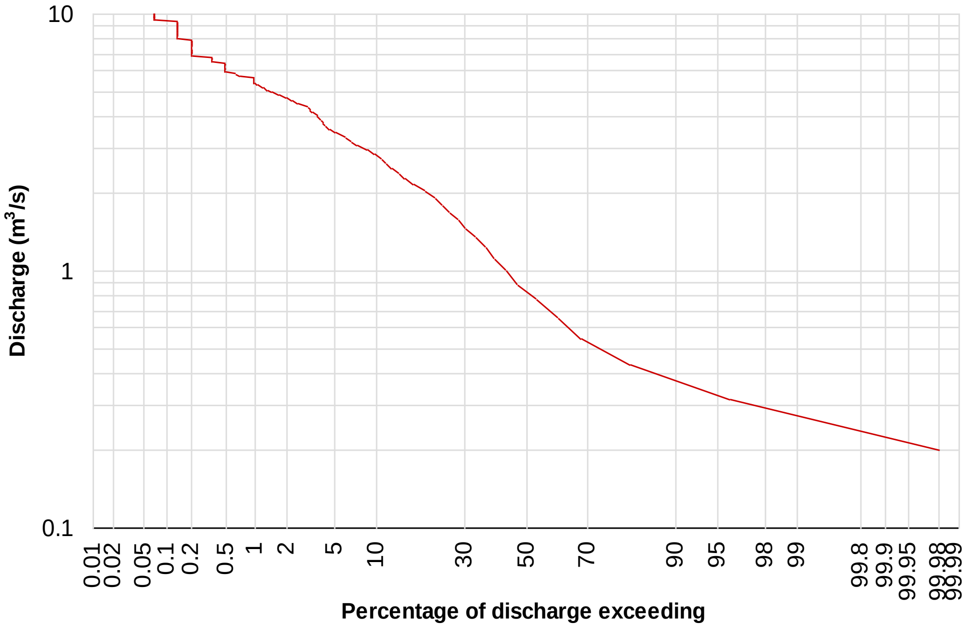


$$= \int u \mathrm{d}A$$

Hydro Power (resource assessment)

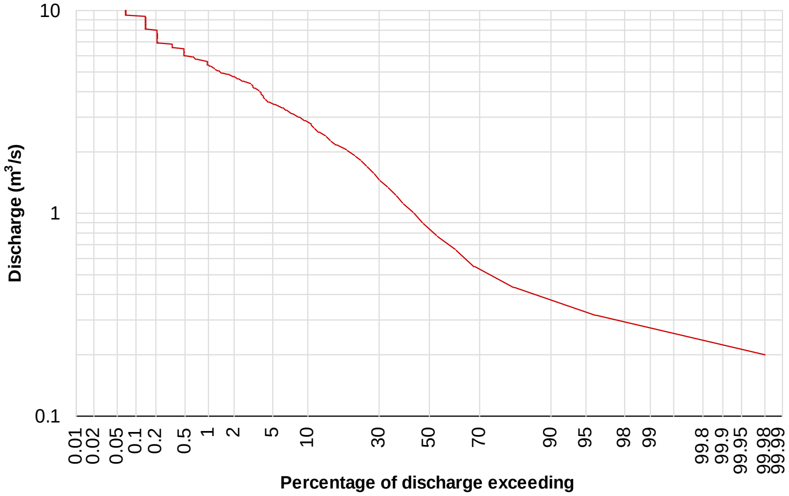


Hydro Power



10
1
0.1
Discharge (m3/s)
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
30
50
70
90
95
98
99
99.8
99.9
99.95
99.98
99.99
Percentage of discharge exceeding

Hydro Power



$$P = (Q\rho gH)(0.5e)(24\times 365)$$

$$= (0.33\times 1000\times 10\times 1)\times(0.5\times 0.95)\times(24\times 365)$$

$$= 13{,}731\,\text{kWh/m}_{\text{head}}$$

$$\approx 14{,}000\,\text{kWh/m}_{\text{head}}$$

Hydro Power

$$C_{unit\,energy} = \frac{C_{annual} + C_{\mathrm{O\&M}}}{(24 \times 365) P_{installed}\, f_{plant}}$$

$C_{unit\ energy}$ = Unit energy cost

C_{annual} = Annualised cost

$C_{\mathrm{O\&M}}$ = Operation and maintenance cost

$P_{installed}$ = Installed power

f_{plant} = Plant factor

Hydro Power

$$C_{annual} = C_{capital} \frac{i(1+i)^n}{(1+i)^n - 1}$$

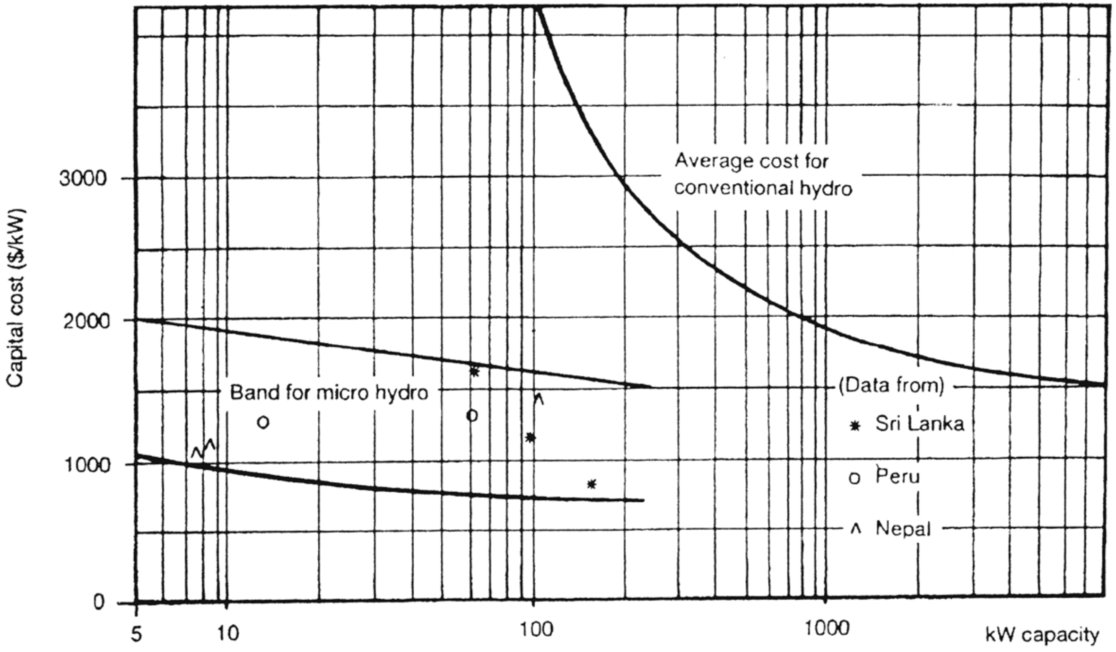
C_{annual} = Annualised cost

$C_{capital}$ = Capital cost

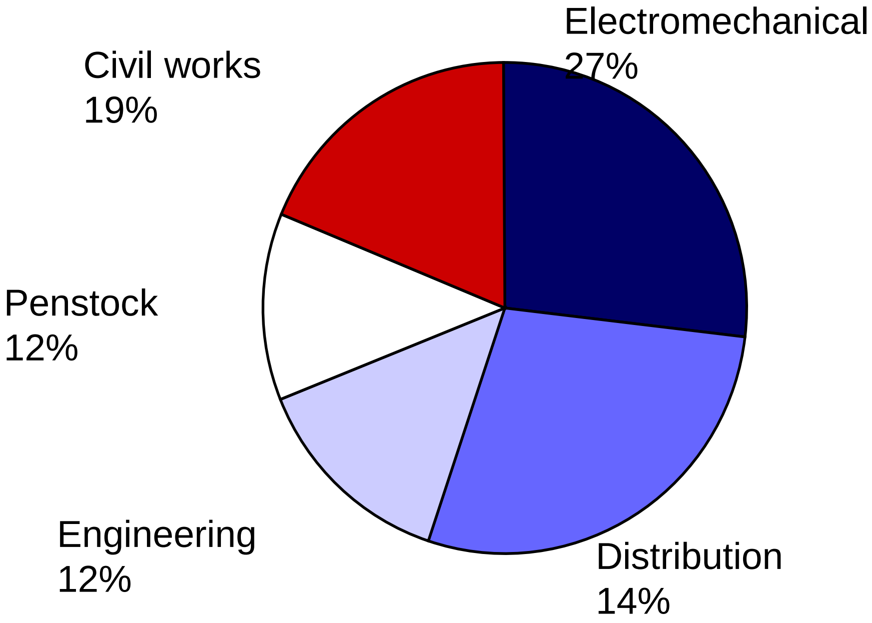
i = Interest rate

n = number of years

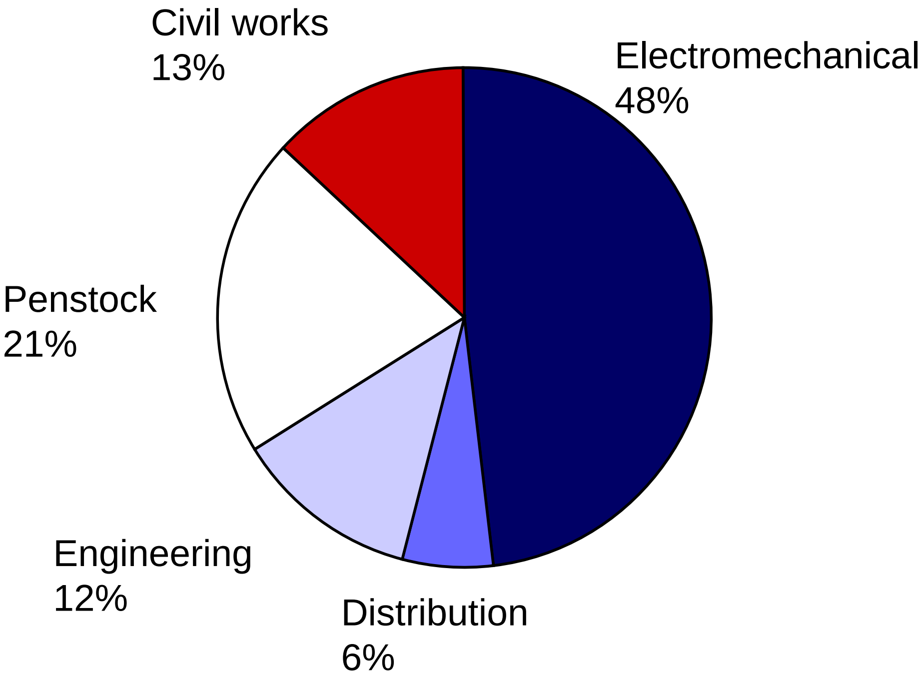
Hydro Power


Capital cost ($/kW)
3000
2000
1000
0
5
10
100
1000
kW capacity
Average cost for conventional hydro
Band for micro hydro
(Data from)
Sri Lanka
Peru
Nepal

Hydro Power



Nepal



Sri Lanka

Hydro Power (Pakistan)

Table 3
Existing hydel power stations in Pakistan [44].

S.No	Name of Project	Installed capacity (MW)
1	Tarbela	3478
2	Ghazi Barotha	1450
3	Mangla	1000
4	Warsak	240
5	Chashma	184
6	Malakand	19.6
7	Dargai	20
8	Rasul	22
9	Shadiwal	13.5
10	Chichoki Malian	13.2
11	Nandipur	13.8
12	Kurram Gari	4
13	Reshun	2.8
14	Renala	1.1
15	Chitral	1
16	Jagran-I	30.4
17	Kathai	1.6
18	Kundel Shahi	2
19	Leepa	1.6
20	Northern Area	94
21	Small/Micro Hydel Stations	3
	Total	6595.032

Hydro Power (Pakistan)

Table 5
Under construction hydropower projects in Pakistan [56].

Sr #	Name of Project	Hydropower (MW)	Progress/Completion
1.	Mangla Dam Raising Mirpur, AJK	Addition 644 GWh	Substantially completed
2.	Gomal Zam Dam FATA	17.4	65% (Dec 2010)
3.	Satpara Dam Gilgit Baltistan	15.8	91% (Dec 2010)
4.	KHAN KHWAR Besham, KPK	72	97% Dec 2010
5	DUBER KHWAR Kohistan, KPK	130	77% (Aug 2011)
6.	ALLAI KHWAR–Battagram, KPK	121	54% (Oct 2011)
7.	JINNAH HYDROPOWER, Jinnah Barrage	96	95% (Jun 2011)
8.	NEELUM JHELUM Neelum, AJK	969	16% (Oct 2015)
	Total	1421.2	

Hydro Power (Systems)

Hydropower systems may be **divided into two ways:**

Based on its **construction methods.**

There are three types of hydropower systems based on construction methods:

- **Impoundment.**
- **Diversion or run of river.**
- **Pumped storage.**

Based on their size

- **Large hydropower (> 30 MW)**
- **Small hydropower (100 kW-30 MW)**
- **Micro hydropower (<100 kW)**

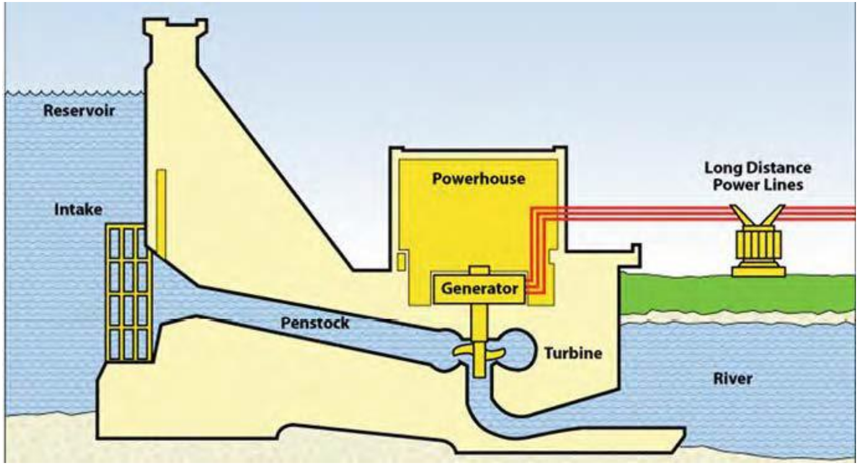
Hydro Power (Systems)

Impoundment

Most of the large hydropower systems are impoundment type.

A dam is used to store river water in a reservoir. Water released from the reservoir flows through a turbine to generate electricity.

The water may be released either to meet changing electricity needs or to maintain a constant reservoir level.



Hydro Power (Systems)

Dam

A dam is built to raise the water level of the river to create a falling water system. This also controls the flow of water.

The reservoir of a dam basically stores the energy in the form of potential energy. When water flows down from the reservoir into a turbine, this potential energy is converted to kinetic energy that rotates the turbine blades.

The main factor that needs to be considered is the ability of the dam to withstand the pressure of water build up behind it.

Hydro Power (systems)

Spillways

When dams are designed, provision must be made to cope with large floods. Spillways are pathways for floodwater to flow over or around the dam so that the dam itself is not breached.

Hydro Power (systems)

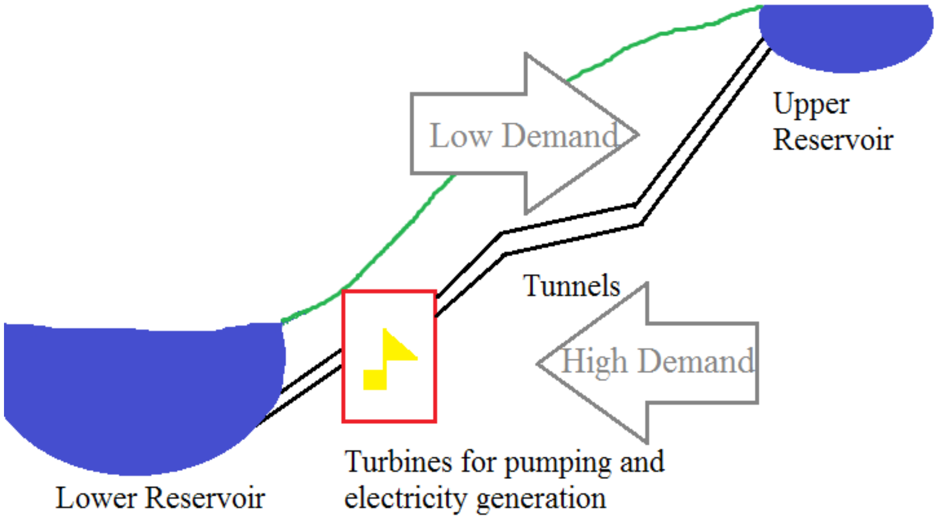
Run of the River

Run-of-the-river plants derive energy from a water flow with minimal disruption of the flow or the surroundings.

Normally, such systems are built on small dams that impound little water. They may not cause changes in the water quality.

They do not normally affect downstream habitat or terrestrial habitat. Other concerns, such as ladder rejection by fishes, are not problems.

Hydro Power (systems)



Pumped Storage

Pumped-storage hydropower systems are operated differently from conventional hydroelectric systems.

Although these systems use falling water to generate power in the same manner as a conventional hydroelectric system, water, after falling through the turbine, is collected in a reservoir (called lower reservoir).

A reversible turbine that works in both directions is used at the pumped storage facility. When demand for electricity is low, the turbine is operated in the reversible mode to pump the water back to an upper reservoir.

Water from the upper reservoir is released to generate power during periods of peak demand.

Hydro Power (systems)

Pumped storage systems actually are net users of electrical energy. The generation and pumping cycles are usually 90% efficient. When other losses, such as friction loss, turbine efficiency, etc., are considered, the overall efficiency is generally around 75%.

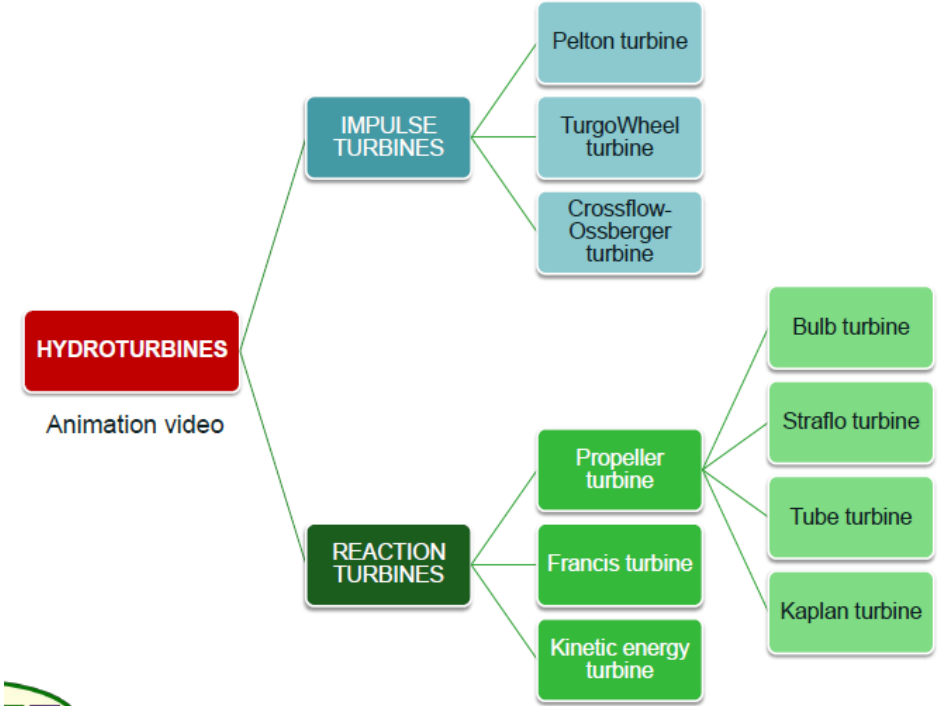
There are several benefits of a pumped storage system: Improved energy regulation and operation of the supply grid.

Creates environmental benefits such as reduced gaseous emissions and has little environmental impact during its operation.

Allows flexible and rewarding commercial operations across a variety of electrical power supply scenarios.

About 127,000MW of pumped-storage hydro capacity is already operating around the world.

Hydro Power (Turbines)



Animation video

Hydro Power (Turbines)

Impulse Turbine

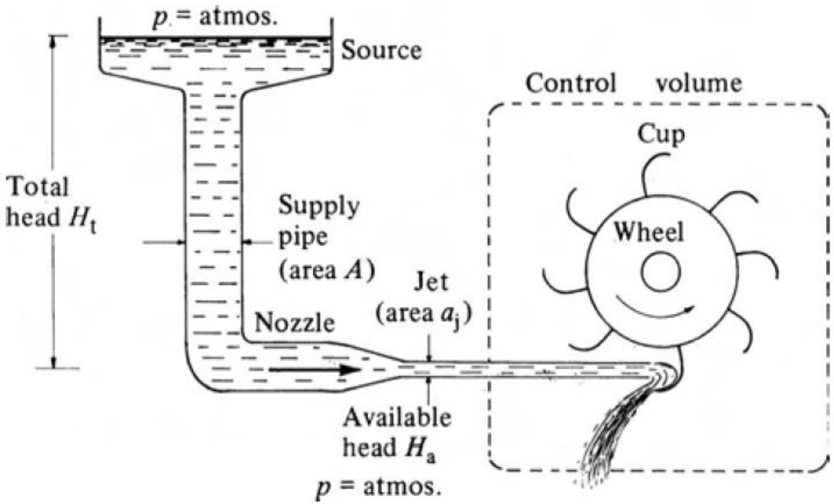
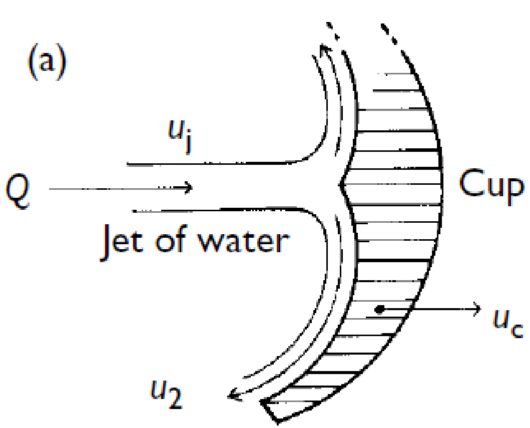


Figure 8.3 Schematic diagram of a Pelton wheel impulse turbine.

The potential energy of the water in the reservoir is changed into kinetic energy of one or more jets. Each jet then hits a series of buckets or 'cups' placed on the perimeter of a vertical wheel.

Hydro Power (Turbines)



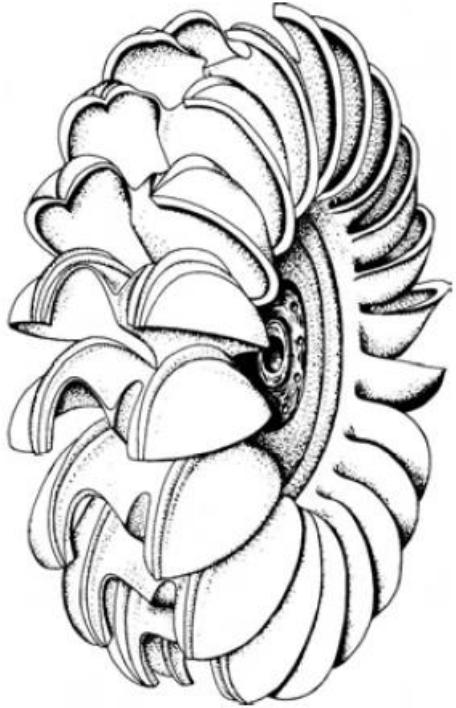
$$F = 2\rho Q_j (u_j - u_c)$$

$$P_j = F u_c = 2\rho Q_j (u_j - u_c) u_c$$

$$u_c / u_j = 0.5$$

$$P_j = \frac{1}{2} \rho Q_j u_j^2$$

Hydro Power (Turbines)



Although the ideal turbine efficiency is 100%, in practice values range from 50% for small units to 90% for accurately machined large commercial systems.

$$u_j^2 = 2gH_a$$

$$Q = nau_j = nQ_j$$

$$P_m = \eta_{mn} P_j = \eta_{mn} \frac{1}{2} \rho Q u_j^2 = \eta_{mn} \frac{1}{2} \rho (auj) u_j^2$$

$$= \frac{1}{2} \eta_m n a \rho (2gH_a)^{3/2}$$

Hydro Power (Turbines)

It is usually easier to increase the number of nozzles n than to increase the overall size of the turbine, but the arrangement becomes unworkably complicated for $n \geq 4$.

For small wheels, $n = 2$ is the most common.

Hydro Power

$$P = FR\omega$$

Thus for a given output power, the larger the wheel the smaller its angular velocity. Since $u_c = R\omega$, and $u_c = 0.5u_j$ by (8.8), and using (8.10)

$$R = \frac{0.5(2gH_a)^{1/2}}{\omega} \qquad (8.15)$$

$$r^2 = \frac{P_m}{\eta_m \rho n \pi (gH_a)^{3/2}\sqrt{2}}$$

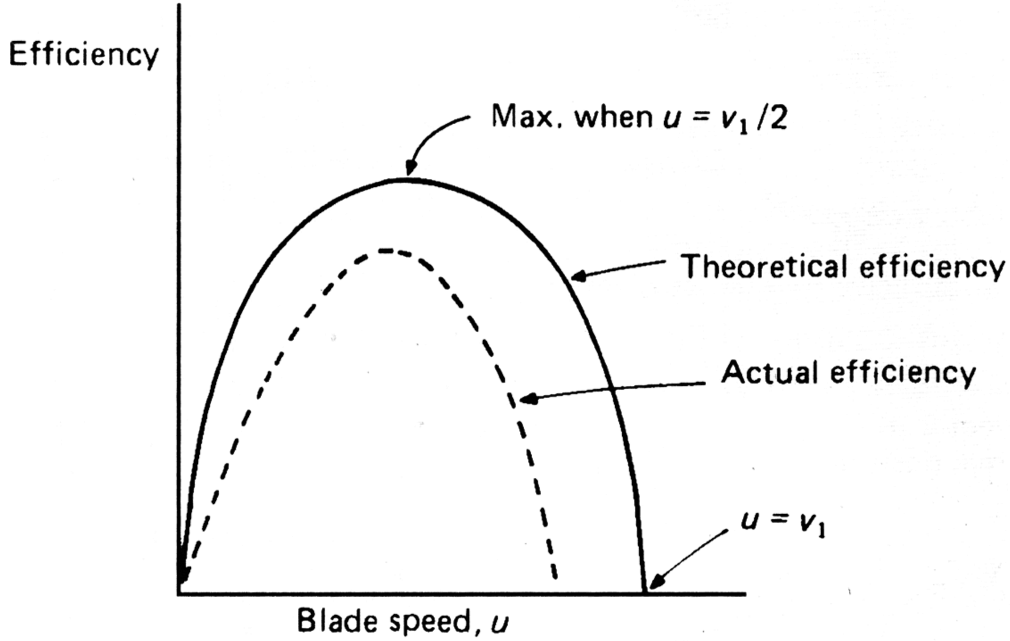
$$\mathcal{S} = \frac{P_m^{1/2}\omega}{\rho^{1/2}(gH_a)^{5/4}}$$

Combining (8.15) and (8.16), we find

$$N_s = \frac{P^{1/2}\nu}{H_a^{5/4}}$$

$$r/R = 0.68(\eta_m n)^{-1/2}\mathcal{S}$$

Hydro Power (Turbines)

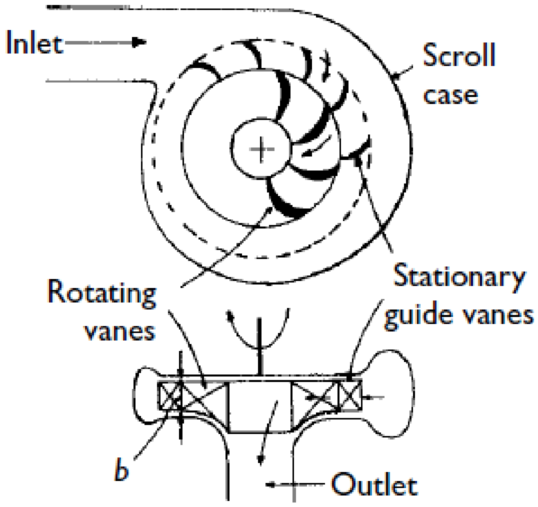


Hydro Power (Turbines)

If the ratio u_c/u_j is the same for two wheels of different sizes but the same shape, then the whole flow pattern is also the same for both. It follows that all non-dimensional measures of hydraulic performance, such as m and , are the same for impulse turbines with the same ratio of uc/uj. Moreover, for a particular shape of Pelton wheel (specified here by r/R and n), there is a particular combination of operating conditions (specified by) for maximum efficiency.

Hydro Power (Turbines)

Reaction Turbine



(b) Francis: reaction

Hydro Power (Turbines)

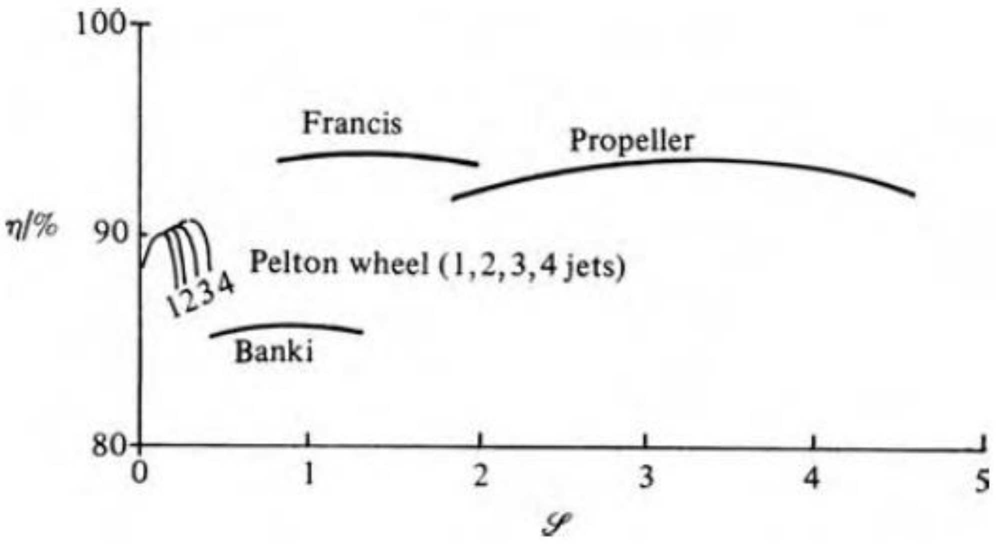
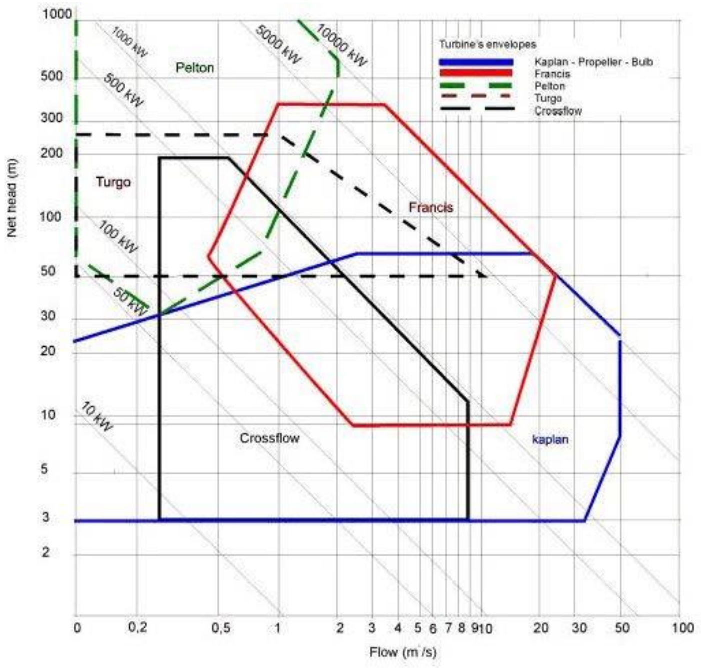


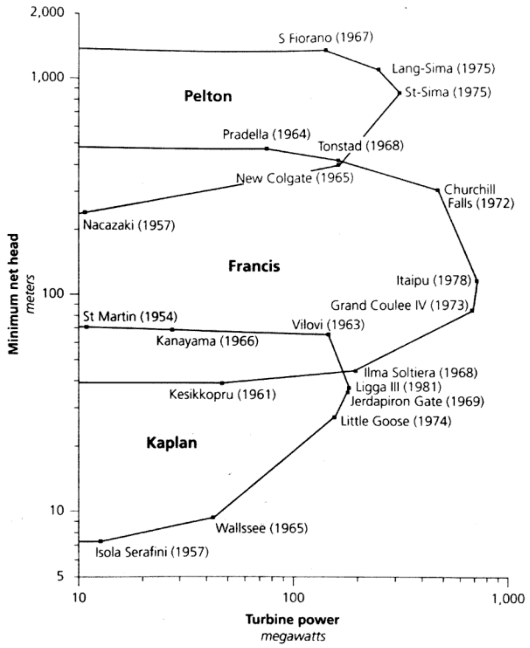
Figure 8.7 Peak efficiencies of various turbines in relation to shape number. Adapted from Gulliver and Arndt (1991).

Hydro Power (Turbines)

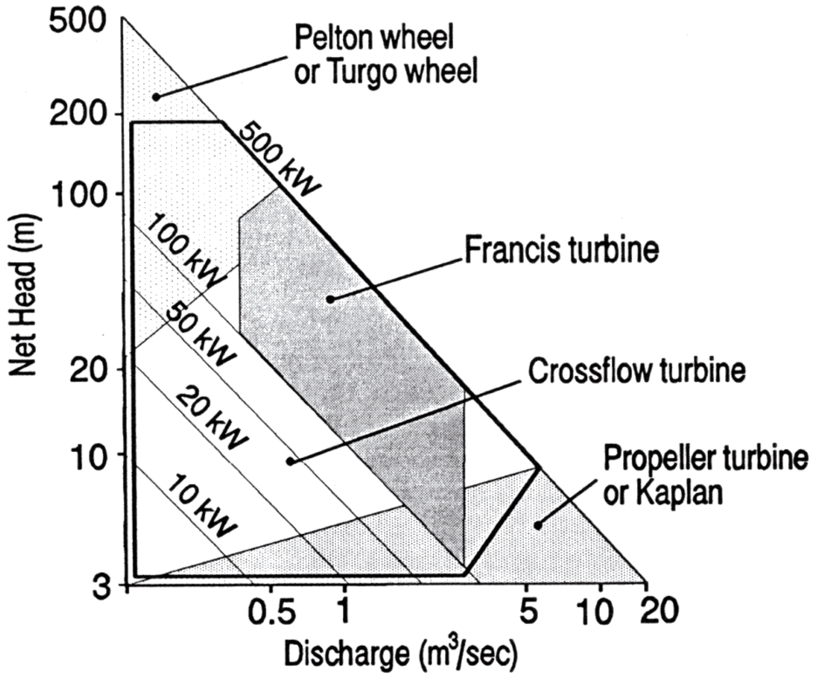
The selection of a turbine depends on several factors. Each turbine operates most efficiently at a certain pressure and flow range. However, often times, the working head determines the turbine types for a specific application.



Hydro Power



2,000
1,000
100
10
5
S Fiorano (1967)
Lang-Sima (1975)
St-Sima (1975)
Pelton
Pradella (1964)
Tonstad (1968)
New Colgate (1965)
Churchill Falls (1972)
Nacazaki (1957)
Francis
Itaipu (1978)
Grand Coulee IV (1973)
St Martin (1954)
Vilovi (1963)
Kanayama (1966)
Ilma Soltiera (1968)
Ligga III (1981)
Kesikkopru (1961)
Jerdapiron Gate (1969)
Little Goose (1974)
Kaplan
Wallssee (1965)
Isola Serafini (1957)
Minimum net head meters
10
100
1,000
Turbine power megawatts



500
200
100
20
10
3
Net Head (m)
Pelton wheel or Turgo wheel
500 kW
100 kW
50 kW
20 kW
10 kW
Francis turbine
Crossflow turbine
Propeller turbine or Kaplan
0.5
1
5
10
20
Discharge (m3/sec)

Hydro Power (Social and Environmental aspects)

It produces about 20% of the world's electric power.

In at least twenty countries, including Brazil and Norway, hydro-power accounts for over 90% of the total electricity supply.

Hydroelectric systems are long lasting with relatively low maintenance requirements.

For hydro plant with ample supply of water, the flow can be controlled to produce either base-load or rapidly peaking power as demanded.

Hydro Power (Social and environmental aspects)

Most large dams (i.e. those *>15m high) are built for* more than one purpose, apart from the significant aim of electricity generation, e.g. water storage for potable supply and irrigation, controlling river flow and mitigating floods, road crossings, leisure activities and fisheries.

Over one million people were displaced by the construction of the Three Gorges dam in China, which has a planned capacity of over 17 000MW; yet these displaced people may never consider they are, on balance, beneficiaries of the increased power capacity and industrialization.

Hydro Power (Social and environmental aspects)

Some dams have been built on notoriously silt-laden rivers, resulting in the depletion of reservoir volume.

Hydro-power, like all renewable energy sources, mitigates emissions of the greenhouse gas CO_2 by displacing fossil fuel that would otherwise have been used. However, in some dam projects, in an effort to save construction time and cost, rotting vegetation (mostly trees) have been left in place as dam fills up, which results in significant emissions of methane, another greenhouse gas.

Classification of hydroelectric power plant

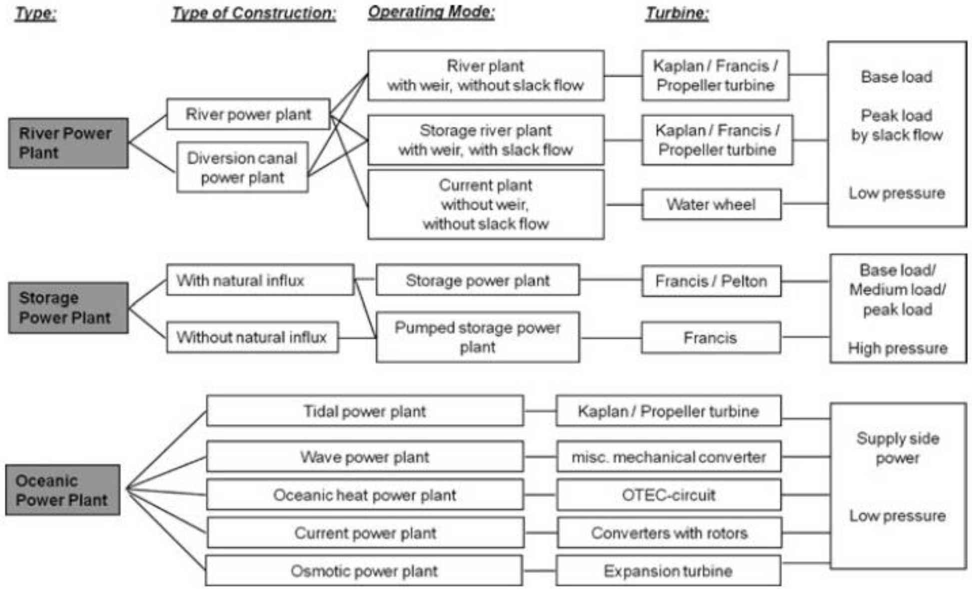


Fig. 1.3 Overview of hydropower plants

Thank You