Hydropower

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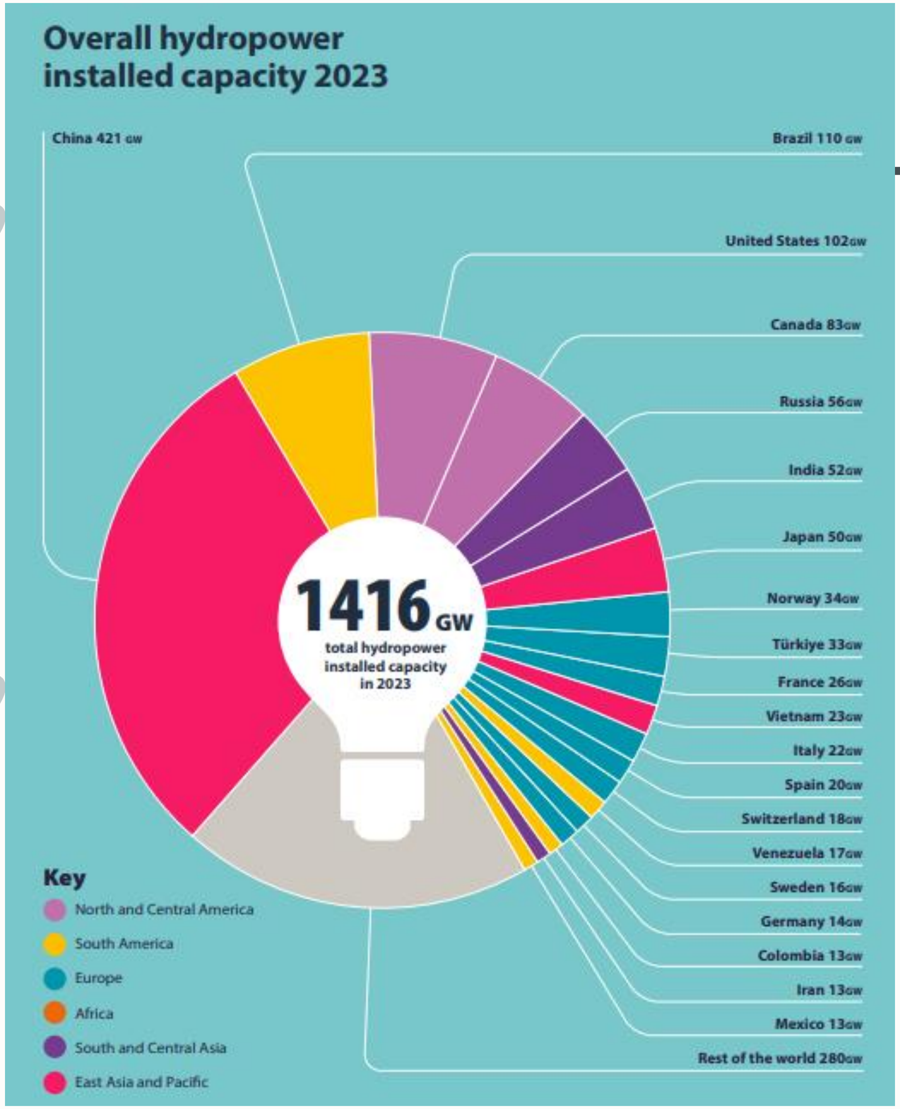
Outline

– Hydropower Overview
– Definition
– Hydropower Schemes
– Types of Hydropower Turbine
– Fundamentals of Hydraulic Engineering
– Evaluating Stream Flow
– Power Calculation
– Example: Head Loss Calculation

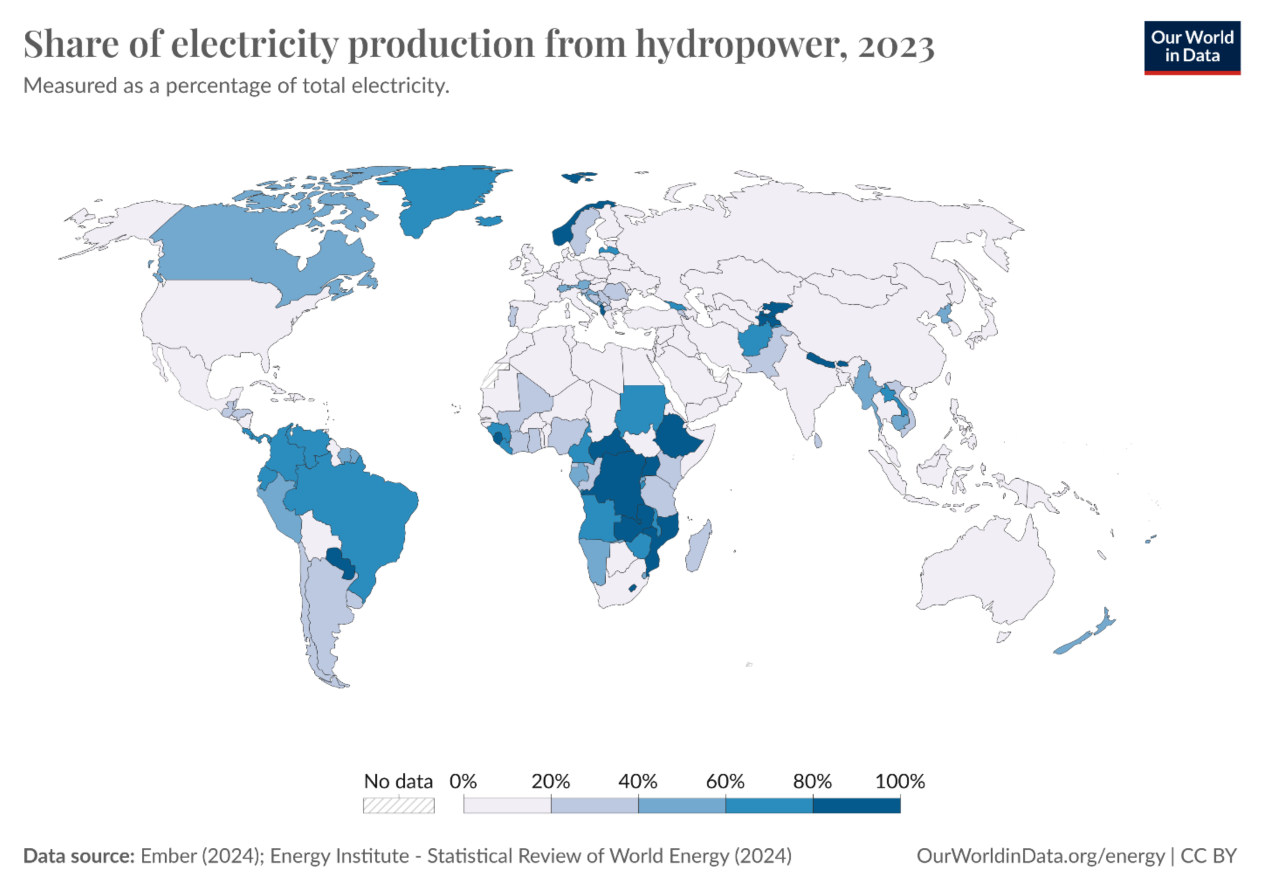
Hydropower Overview



- Hydropower currently provides over 16% of the world's electricity.
- China’s installed capacity of hydropower is 29,73% of the world’s total capacity.

2024 World Hydropower Outlook. International Hydropower Association.

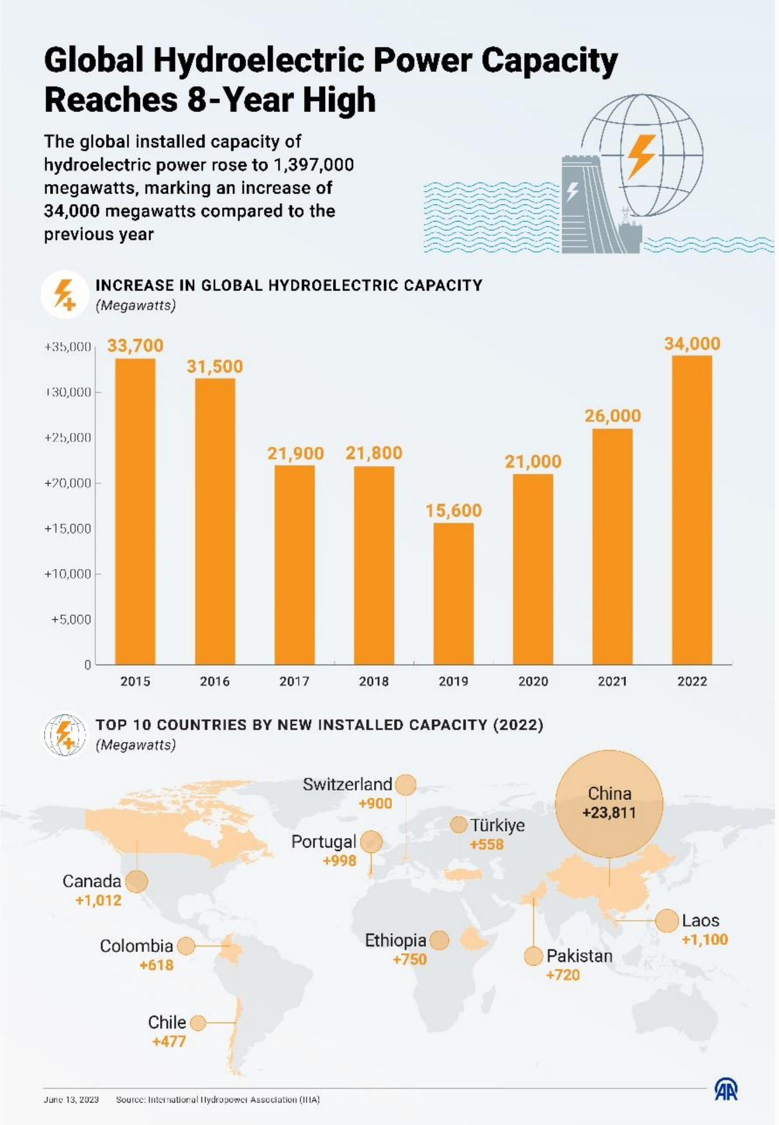
Percentage of Electricity from Hydropower



- The Central African Republic, the Democratic Republic of the Congo, Central African Republic or Ethiopia generated almost 100 percent of their electricity with hydropower in 2023.
- In 2023, Paraguay generates 100% electricity from water power. Venezuela, Ecuador, Costa Rica and Panama also primarily rely on hydropower for electricity with shares of 77, 79, 70 and 69 percent, respectively.

https://ourworldindata.org/grapher/share-electricity-hydro

Hydropower is Growing



https://www.aa.com.tr/en/economy/global-hydropower-capacity-increase-hits-8-year-high-in-2022/2921400#:~:text=Hydroelectric%20installed%20capacity%20worldwide%20reached,hydroelectric%20power%20plants%20with%20dams.

Installed Capacity of RE Power Plants in Indonesia

stagnan krn INA tdk mengembangakan tech utk angin berkecepatan rendah

Table 1; Installed Capacity of Renewable Power Plants in Indonesia (in Megawatt):

	2018	2019	2020	2021	2022	2023*
Wind	143.5	154.3	154.3	154.3	154.3	154.3
Solar	65.2	150.6	172.9	204.7	271.6	432.6
Bioenergy	1,874.8	2,098.3	2,253.2	2,284.0	3,086.6	3,144.8
Geothermal	1,948.3	2,130.7	2,130.7	2,286.1	2,355.4	2,368.4
Hydro	5,791.4	5,995.7	6,140.6	6,601.8	6,688.9	6,825.2

* Government target

Source: Ministry of Energy and Mineral Resources

https://www.indonesia-investments.com/news/todays-headlines/hydro-power-generation-in-focus-still-indonesia-s-biggest-source-of-renewable-energy/item9669

Potential of RE in Indonesia

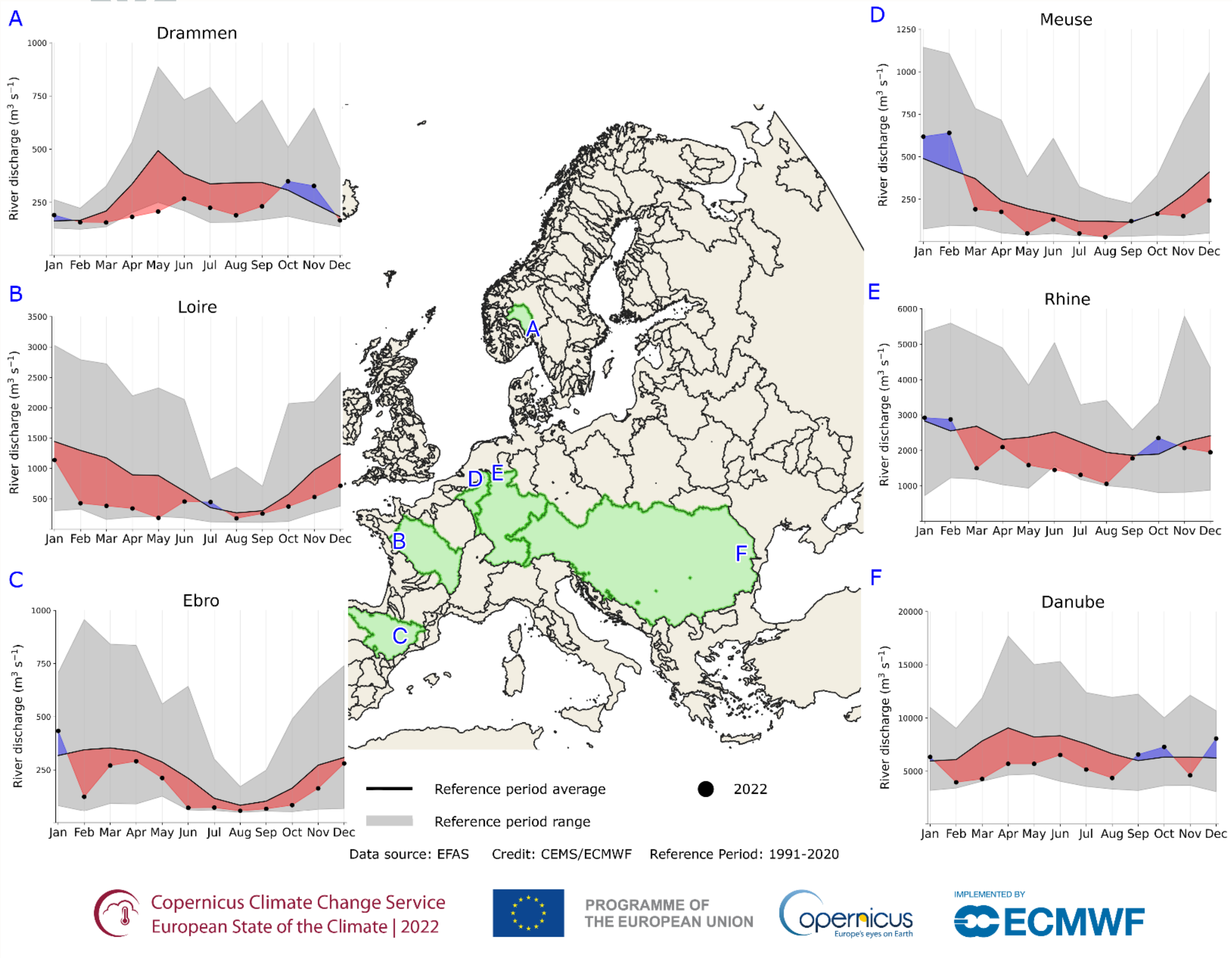
Table 3; Estimated Potential of Renewable Energy Sources in Indonesia:

Renewable Energy Source	Estimated Potential (in GW)	In Use/Tapped Potential (in GW)
Solar	3,295.0	0.27
Wind	155.0	0.15
Hydro	95.0	6.69
Bioenergy	57.0	3.09
Geothermal	24.0	2.34
Total Renewables	**3,686.0**	**12.55**

Source: Energy and Mineral Resources Press Release 060.Pers/04/SJI/2023 (04.02.2023)

https://www.indonesia-investments.com/news/todays-headlines/hydro-power-generation-in-focus-still-indonesia-s-biggest-source-of-renewable-energy/item9669

River Discharge



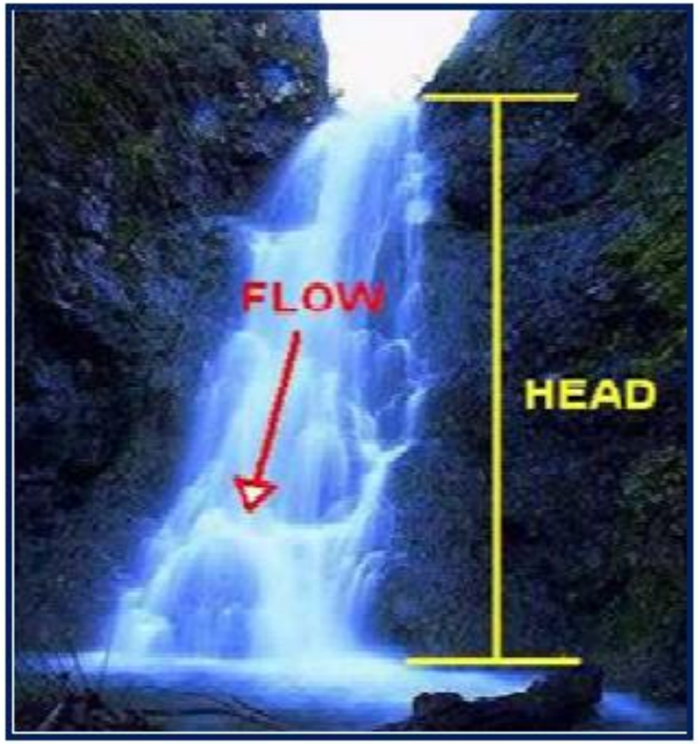
River discharge as monthly averages for the (A) Drammen, (B) Loire, (C) Ebro, (D) Meuse, (E) Rhine and (F) Danube river catchments.

Colored areas indicate deviations from the average for the 1991–2020 reference period, with blue indicating higher discharge and red indicating lower discharge. Averages for 2022 are shown as black dots. The range between monthly minimum and maximum discharges during the reference period is shown by the grey shaded area, and the average of the reference period is shown as the solid black line.

Data source: EFAS. Credit: Copernicus EMS/ECMWF.

https://climate.copernicus.eu/sites/default/files/custom-uploads/ESOTC2022/europe/river_discharge/C3S_ESOTC22_RIVER_FIG4.pdf

Definition (cont'd)



- Hydropower engineering refers to the technology involved in converting the pressure energy and kinetic energy of water (often referred as "head") into more easily used electric energy.
- Hydropower schemes are generally classified according to the "head":
    - High head: 100-m and above
    - Medium head: 30 - 100 m
    - Low head: 2 - 30 m

These ranges are not rigid but are merely means of categorizing sites.

Definition

- Hydropower based on capacity
    - Large: > 100 MW
    - Medium: 25 – 100 MW
    - Small: 1 – <25 MW
    - Mini: 100 kW – 1 MW
    - Micro: 5 – <100 kW
    - Pico: <5 kW

- Hydropower schemes can also be defined as:
    - Run-of-river schemes
    - Schemes with the powerhouse located at the base of a dam
    - Schemes integrated on a canal or in a water supply pipe

Definition

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❖ mini hydro, MHP – under 1 MW

❖ small hydro, SHP – under 10 MW

❖ large hydro, LHP – above 10 MW

Run-of-river Schemes (cont'd)

- **Run-of-the-river hydroelectric systems/schemes** are hydroelectric systems that harvest the energy from flowing water to generate electricity in the absence of a large dam and reservoir, which is how they differ from conventional impoundment hydroelectric facilities (https://energyeducation.ca/encyclopedia/Run-of-the-river_hydroelectricity).
- Run-of-river schemes are where the turbine generates electricity as and when the water is available and provided by the river. When the river dries up and the flow falls below some predetermined amount or the minimum technical flow for the turbine, generation ceases.

Run-of-river Schemes
High-head Scheme

Forebay: A reservoir or canal from which water is taken to run equipment (such as a waterwheel or turbine).

Weir: a dam in a stream or river to raise the water level or divert its flow.

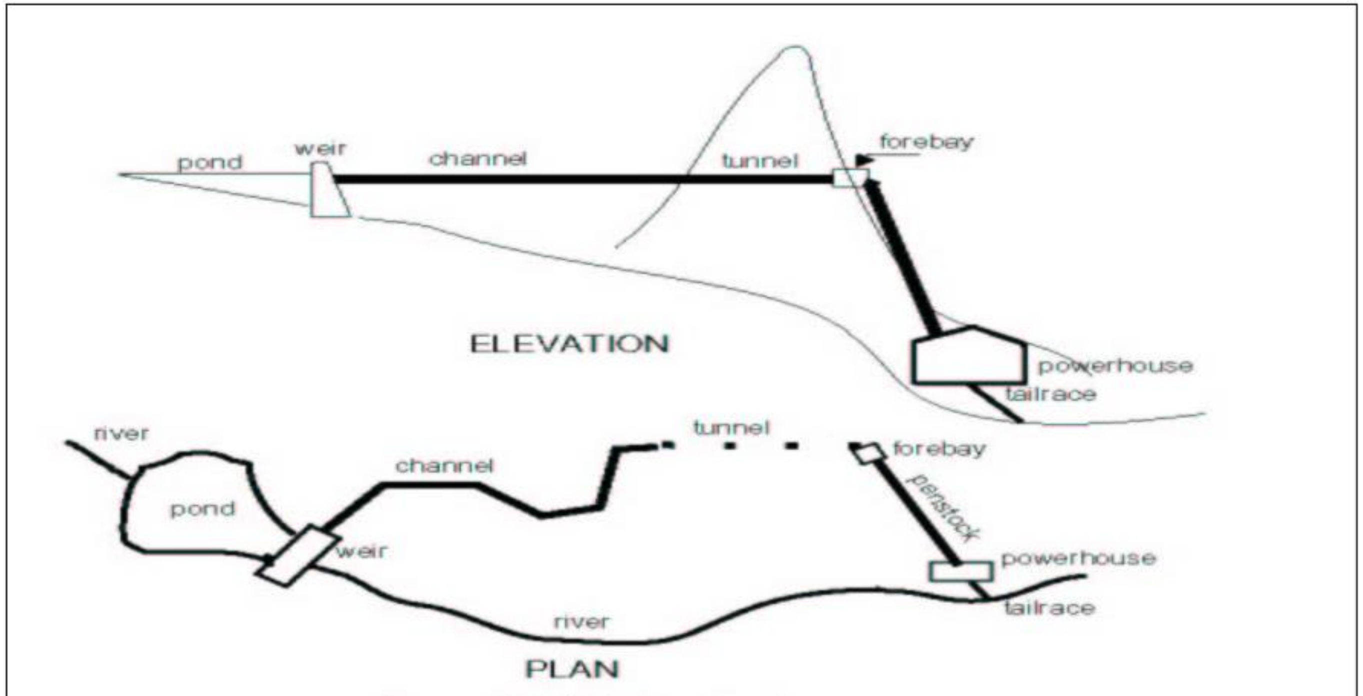


figure 1.1 high-head scheme

Run-of-river Schemes
High-head Scheme

Penstock: A closed conduit or pipe for conducting water to the powerhouse.

Power house: The structure that houses generators and turbines.

Tailrace: A channel that carries water away from a hydroelectric plant or water wheel.

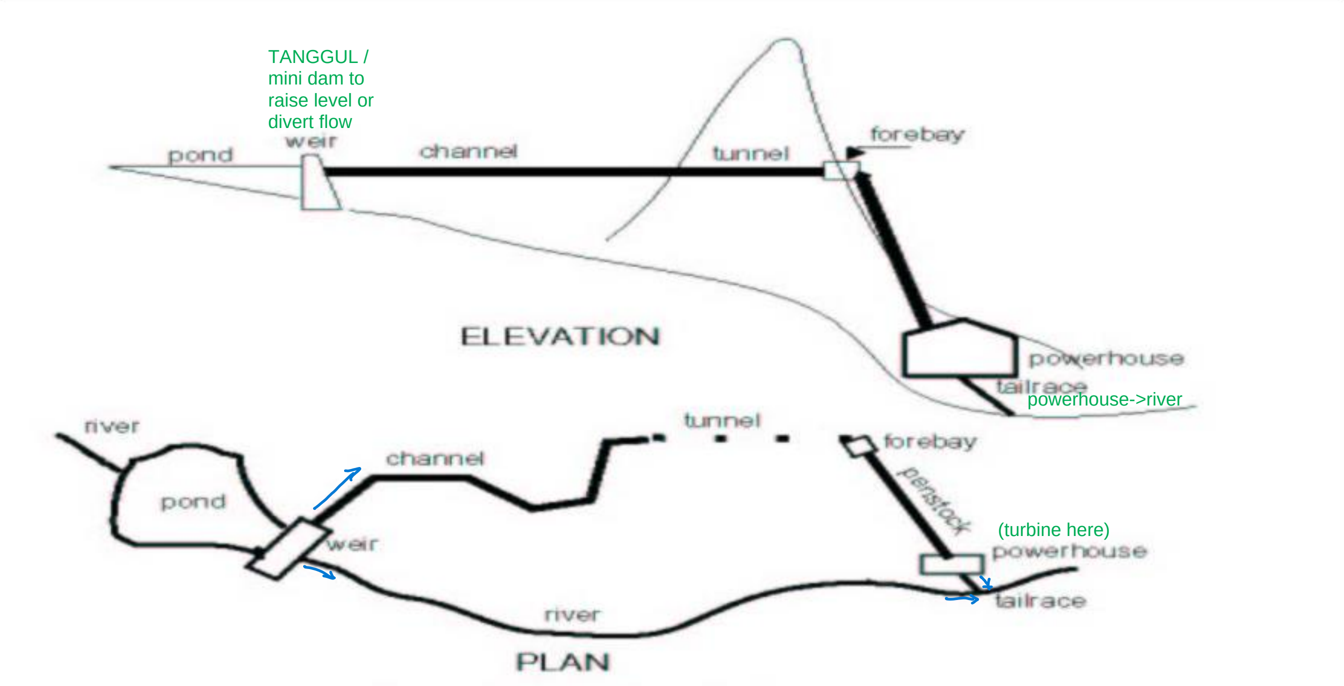


figure 1.1 high-head scheme

Run-of-river Schemes
Low-head Scheme with Penstock

- Low head schemes are typically built in river valleys.

- Two technological options can be selected:
    1. The water is diverted to a power intake with a short penstock, as in the high head schemes.

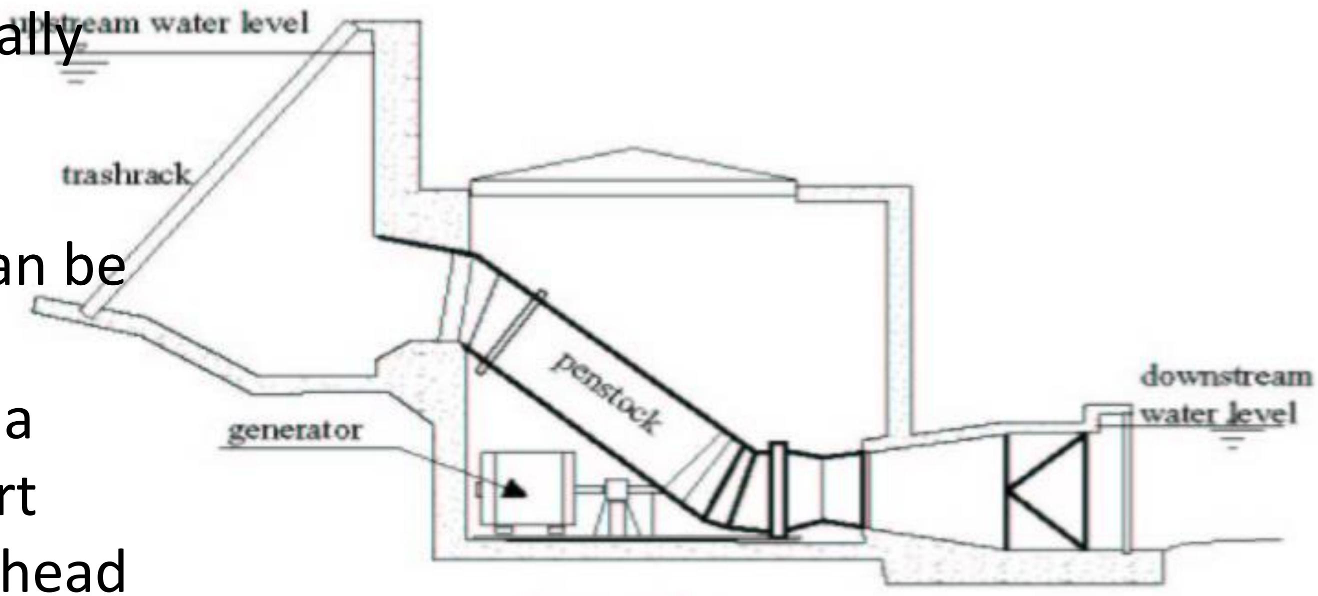
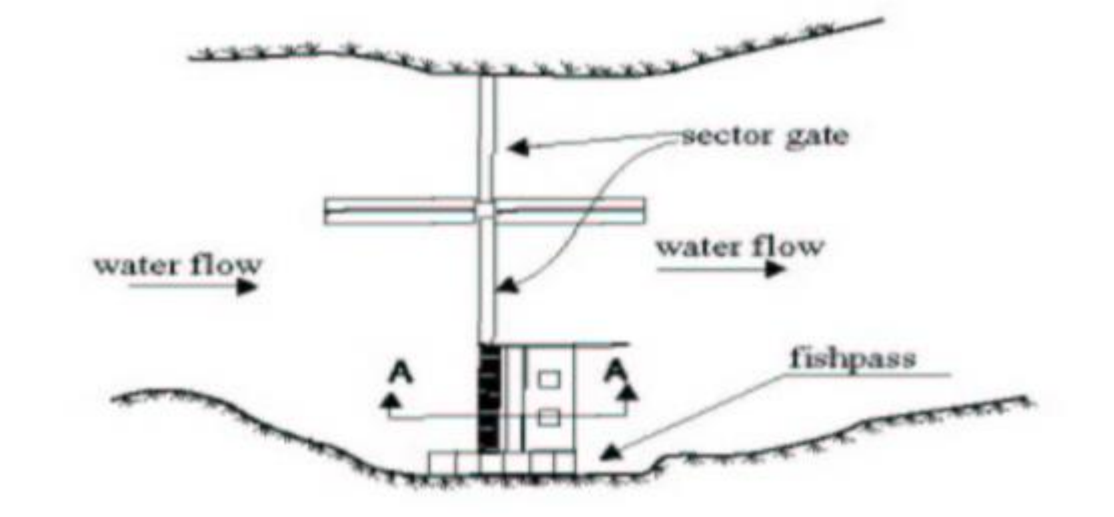


figure 1.2

Run-of-river Schemes
Low head scheme integrated in dam

2. The head is created by a small dam, provided with sector gates and an integrated intake, powerhouse and fish ladder/fishpass.



Additional Terms

Fish ladder: A transport structure for safe upstream fish passage around hydropower projects.

Fishpass: A series of artificial pools arranged like ascending steps, enabling migrating fish to swim upstream around a dam or other obstruction.

Upstream: Toward or closer to the source of a stream; in the direction opposite to that of the current.

Schemes with the powerhouse at the base of a dam (cont'd)

– If the reservoir has already been built for other purposes, such as flood control, irrigation, water abstraction for a big city, recreation area, etc., - it may be possible to generate electricity using the discharge compatible with its fundamental use or the ecological flow of the reservoir.

– The main issue is how to link headwater and tail water by a waterway and how to fit the turbine in this waterway.

Low head scheme using an existing dam

If the dam already has a bottom outlet, the following scheme can be a solution.

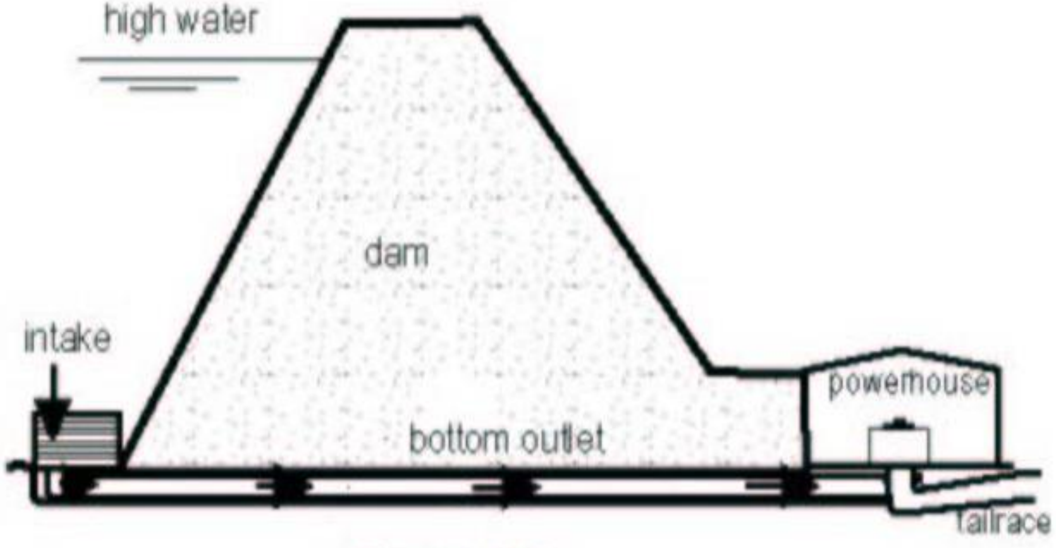


figure 1.4

Low head scheme – siphon intake

- If the dam is not too high, a siphon intake can be installed.
- The unit can be delivered pre-packaged from the works, and installed without major modifications to the dam.

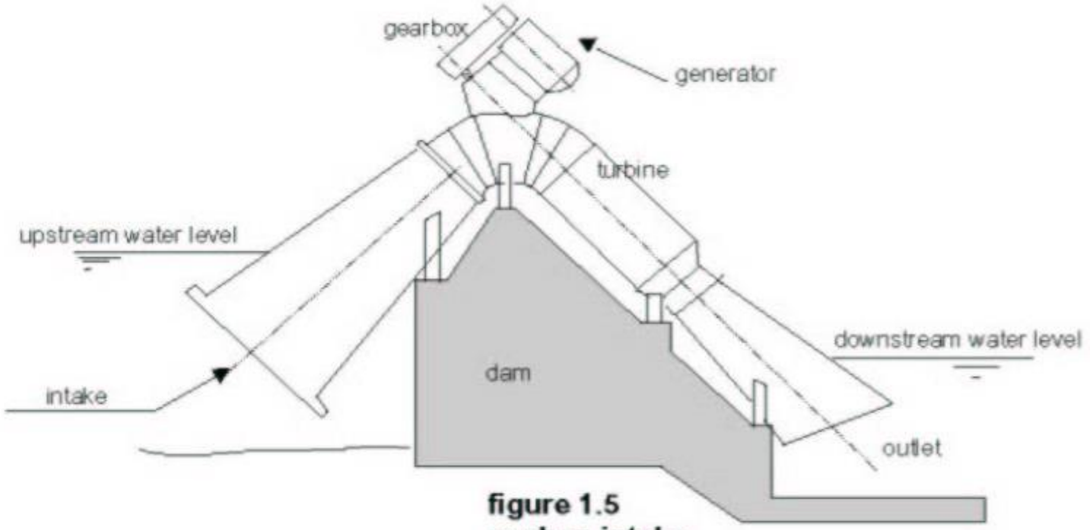


figure 1.5
syphon intake

Schemes integrated within an irrigation canal (cont'd)

- If a canal already exists, it should be slightly enlarged to include the intake and the spillway. To reduce the width of the intake to a minimum, an elongated spillway should be installed.
- From the intake, a penstock running along the canal brings the water under pressure to the turbine. The water passes through the turbine and is returned to the river via a short tailrace.
- **Spillway**: A structure used to provide the release of flows from a dam into a downstream area.

Schemes integrated within an irrigation canal

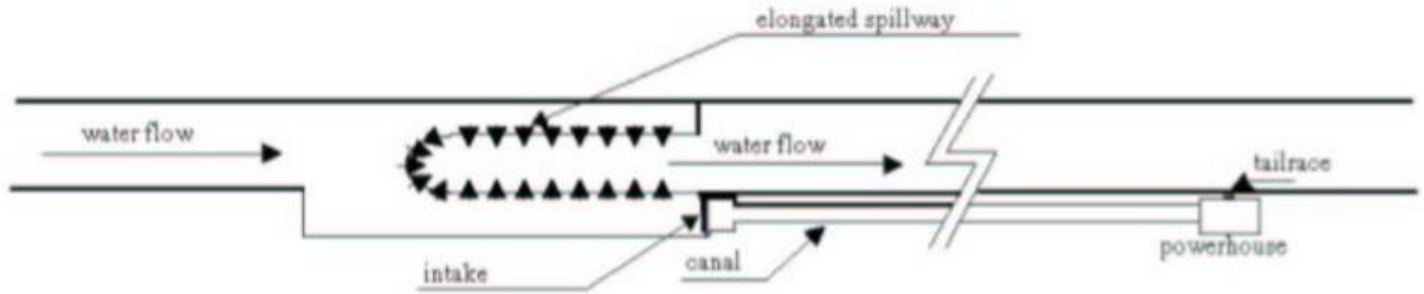


figure 1.7

Types of Hydropower Turbine (cont’d)

Two main types of hydro turbines:

1. **Impulse**

Impulse turbine generally uses the velocity of the water to move the runner and discharges to atmospheric pressure. The water stream hits each bucket on the runner, and the water flows out the bottom of the turbine housing after hitting the runner. Example: Pelton, Turgo & Cross-flow.

2. **Reaction**

Reaction turbine develops power from the combined action of pressure and moving water. The runner is placed directly in the water stream flowing over the blades rather than striking each individually. Example: Kaplan, Francis & Propeller.

Impulse Turbine

- The type of hydro-turbine, where the turbine is rotated by the impulse force of the water jet is known as impulse turbine. In the impulse turbine, the pressure of water is converted into kinetic energy in a nozzle and then the velocity of the water jet drives the turbine.

- The main components of an impulse are: set of runner blades and nozzle. The nozzle converts the pressure of water jet into kinetic energy, after discharging from the nozzle, the water jet strikes the runner blades and turns the runner through its axis. In this way, the impulse force of water jet drives the turbine.

https://www.tutorialspoint.com/difference-between-impulse-turbine-and-reaction-turbine

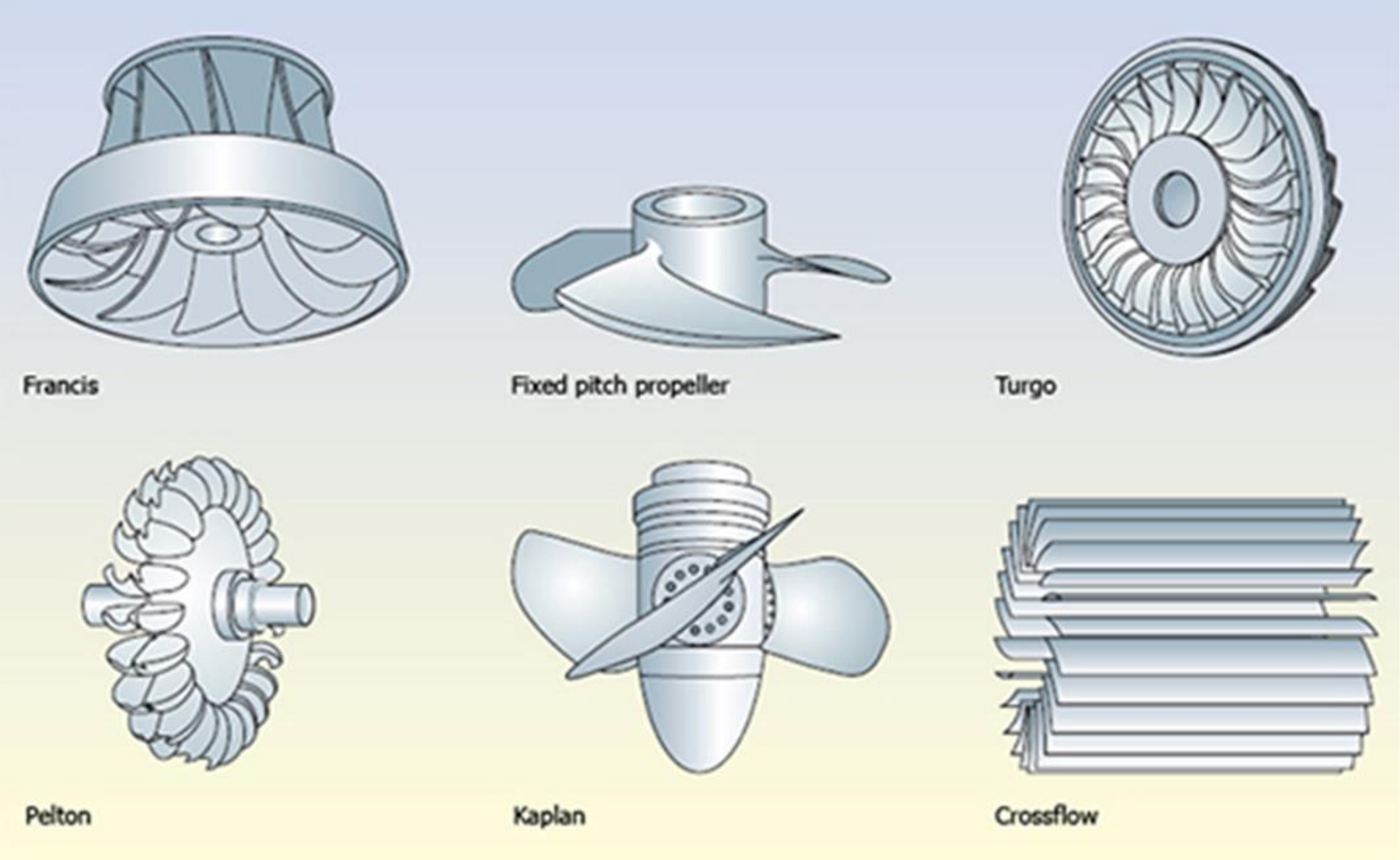
Reaction Turbine

- The type of hydro turbine, which uses the pressure as well as velocity of the moving water to spin the runner is called a reaction turbine. The reaction turbines are placed in the water stream where the water enters the turbine casing and after rotating the blades, the water leaves the turbine casing.

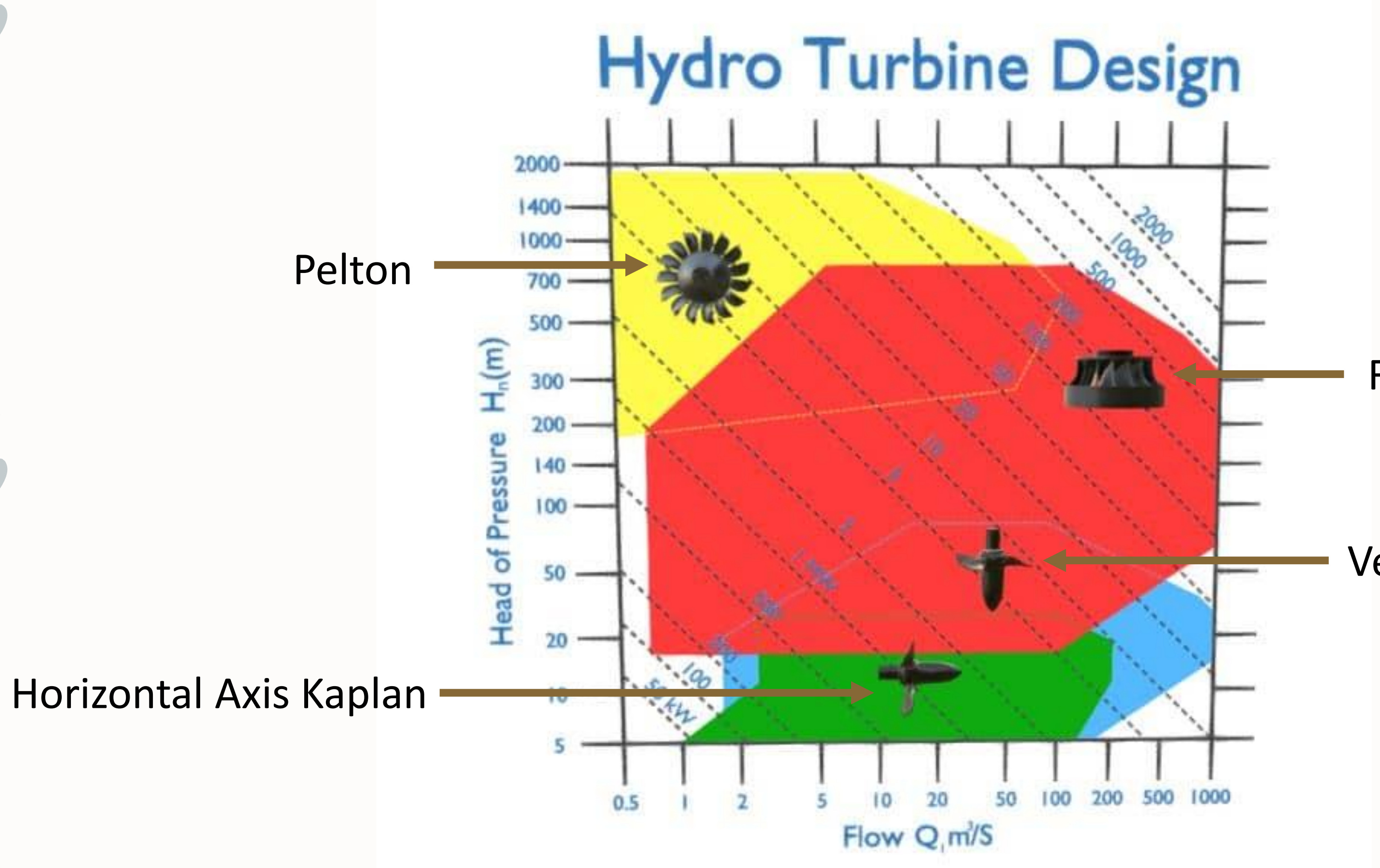
- A typical reaction turbine consists of rows of fixed blades and rows of moving blades. In the reaction turbine, the moving water can produce a reaction force on the runner blades, which can rotate the runner on its axis. After moving the runner blades, the water leaves the turbine cashing.

https://www.tutorialspoint.com/difference-between-impulse-turbine-and-reaction-turbine

Types of Hydropower Turbine



Hydro Turbine Design



https://savree.com/en/encyclopedia/hydro-turbine-comparison-model

Fundamentals of Hydraulic Eng. Water Flow in Pipes

– A body of water will have a potential energy by virtue of its velocity and the vertical height through which it drops, which is known as its "head".

– This energy is its "Gravitational Potential Energy" which is product of mass, acceleration due to the effects of gravity and head $m \times g \times h$ and is generally expressed in Joules (J).

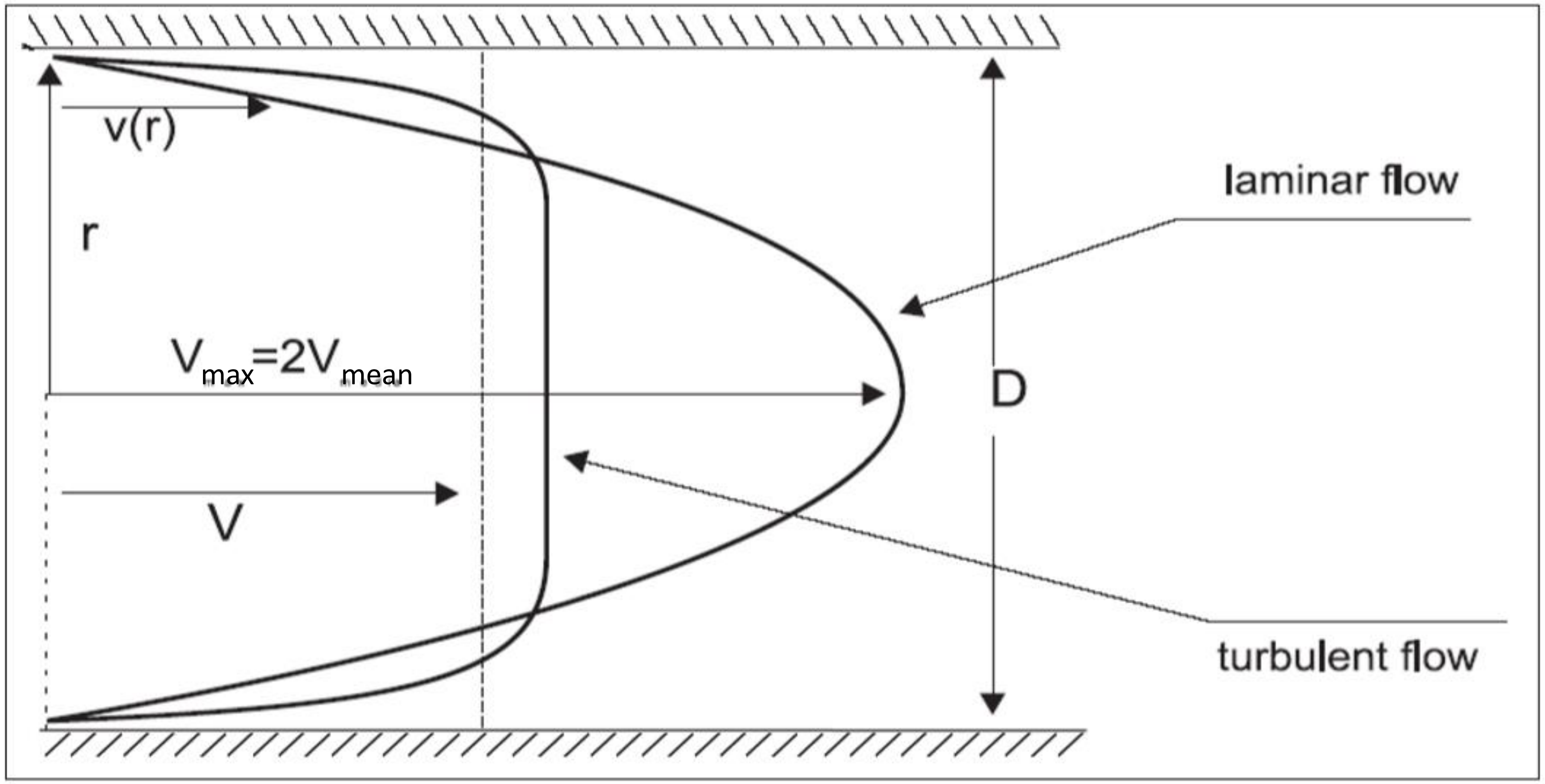
Water Flow in Pipes

The energy head in the water flowing in a closed conduit of circular cross section, is given by Bernoulli's equation:

$$H_1 = h_1 + \frac{P_1}{\gamma} + \frac{V_1^2}{2g}$$

H_1	is the total energy head
h_1	is the elevation above some specified datum plane,
P_1	the pressure
γ	the specific weight of water $= \rho . g$
V_1	the velocity of the water, and
g	the gravitational acceleration.

Laminar and Turbulent Flows (cont’d)



Laminar and Turbulent Flows

- The water flows in lamina (layers), like a series of thin walled concentric pipes. The outer virtual pipe adheres to the wall of the real pipe, while each of the inner ones moves at a slightly higher speed, which reaches a maximum value near the center of the pipe.
- If the flow rate is gradually increased, a point is reached when the lamina flow suddenly breaks up and mixes with the surrounding water. The particles close to the wall mix up with the ones in the midstream, moving at a higher speed, and slow them. At that moment the flow becomes turbulent, and the velocity distribution curve is much flatter.

Reynolds number

The transition from laminar flow to turbulent flow depends, not only on the velocity, but also on the pipe diameter and on the viscosity of the fluid, and is a ratio of the inertia force to the viscous force (Reynolds number).

$$R_e = \frac{D \cdot V}{\nu} = \frac{\rho \cdot D \cdot V}{\mu}$$

dynamic viscosity

(2.2)

where:

D (m) is the pipe diameter

V is the average water velocity (m/s), and

ν is the kinematics viscosity of the fluid (m^2/s).

Lost of head

– It can be verified that for water flowing between two sections, a certain amount of the head of energy h_f is lost:

asumsi diameter sama

$$\frac{V_1^2}{2_g} + \frac{P_1}{\gamma} + h_1 = \frac{V_2^2}{2_g} + \frac{P_2}{\gamma} + h_2 + h_f$$

major (friction)

minor (dst)

ekspansi
kontraksi
bending
trash rack

$$h_f = f \cdot \left(\frac{L}{D}\right) \cdot \frac{V^2}{2g}$$

f = friction factor, a dimensionless number
L = the length of the pipe in m
D = the pipe diameter in m
V = the average velocity in m/s, and
g = the gravitational acceleration (9.81 m/s2).

Friction Factor
Laminar Flow

- For laminar flow:

$$f = \frac{64 \cdot \nu}{V \cdot D} = \frac{64}{R_e}$$

- When the flow is practically turbulent (Re>2000), the friction factor become less dependent on the Reynolds number and more dependent on the relative roughness height e/D, where "e" represents the average roughness height of irregularities on the pipe wall and *D* is the pipe diameter.

Relative roughness

for Moody diagram

Pipe material	e (mm)
Polyethylene	0.003
Fiberglass with epoxy	0.003
Seamless commercial steel (new)	0.025
Seamless commercial steel (light rust)	0.250
Seamless commercial steel (galvanised)	0.150
Welded steel	0.600
Cast iron (enamel coated)	0.120
Asbestos cement	0.025
Wood stave	0.600
Concrete (steel forms, with smooth joints)	0.180

Friction Factor Turbulent Flow (cont'd)

– It is well known that, even in turbulent flows, immediately next to the wall pipe there exists, a very thin layer of flow referred to as the laminar sub layer. When Re increases, the sub layer's thickness diminishes. Whenever the roughness height "e" is resolutely lower than the sub layer thickness the pipe is considered hydraulically smooth.

– In a hydraulically smooth pipe flow, the friction factor f is not affected by the surface roughness of the pipe:

$$\frac{1}{\sqrt{f}} = 2 \cdot \log_{10}\left(\frac{R_e\sqrt{f}}{2.51}\right)$$

Friction Factor Turbulent Flow (cont'd)

- For a hydraulically rough pipe:

$$\frac{1}{\sqrt{f}} = 2 \cdot \log_{10}\left(3.7\frac{D}{e}\right)$$

- If the pipe is neither completely smooth nor completely rough, Colebrook and White devised the following equation:

$$\frac{1}{\sqrt{f}} = -2 \cdot \log_{10}\left(\frac{e/D}{3.7} + \frac{2.51}{R_e\sqrt{f}}\right)$$

Friction Factor Turbulent Flow

- Manning's equation can be used to calculate cross-sectional average velocity flow in open channels, but also applicable to closed pipes.

$$Q = AV = A\left(\frac{k_n}{n}\right)(R_h)^{2/3}(S)^{1/2}$$

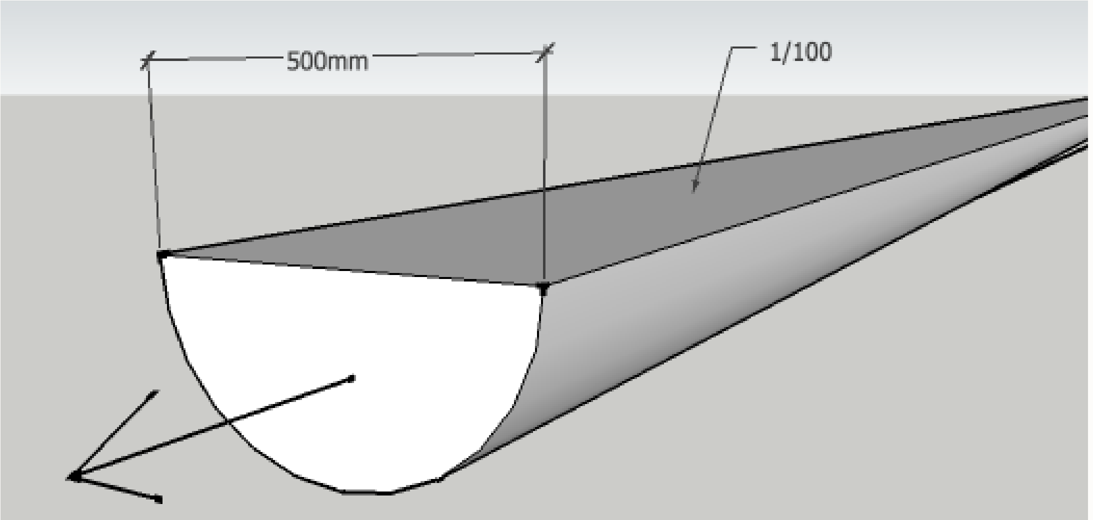
$$R_h = \frac{A}{P_W}$$

Where

- *Q = volume flow (m^3/s)*
- *A = cross-sectional area of flow (m^2)*
- *k_n = 1.0 for SI units*
- *n* = Manning coefficient of roughness - ranging from 0.01 (a clean and smooth channel) to 0.06 (a channel with stones and debris, 1/3 of vegetation)
- *R_h* = hydraulic radius (m)
- *S* = slope or gradient of pipe (m/m)
- *P_w = wetted perimeter (m)*

Exercise – Manning Equation

A channel with the shape of an half circle is 100% filled. The diameter of the half circle is 500 mm (0.5 m) and the channel is made of concrete with Manning coefficient of 0.012. The slope of the channel is 1/100 m/m. Calculate the discharge/debit of the flow in the channel!



https://www.engineeringtoolbox.com/mannings-formula-gravity-flow-d_800.html

Answer (cont'd)

The cross section area of the half circle flow can be calculated as

$$A = (0.5\ \pi\ ((0.5\ m) / 2)^2)$$

$$= 0.098\ m^2$$

The wetted perimeter of the half circle flow can be calculated as

$$P = 0.5\ 2\ \pi\ (0.5\ m) / 2)$$

$$= 0.785\ m$$

The hydraulic radius of the channel can be calculated

$$R_h = A / P$$

$$= (0.098\ m^2) / (0.785\ m)$$

$$= \underline{0.125}\ m$$

Answer (cont'd)

The cross sectional mean velocity can be calculated

$$v = (k_n / n) R_h^{2/3} S^{1/2}$$

$$= (1.0 / 0.012) (0.125 m)^{2/3} (1/100 m/m)^{1/2}$$

$$= \underline{2.1} m/s$$

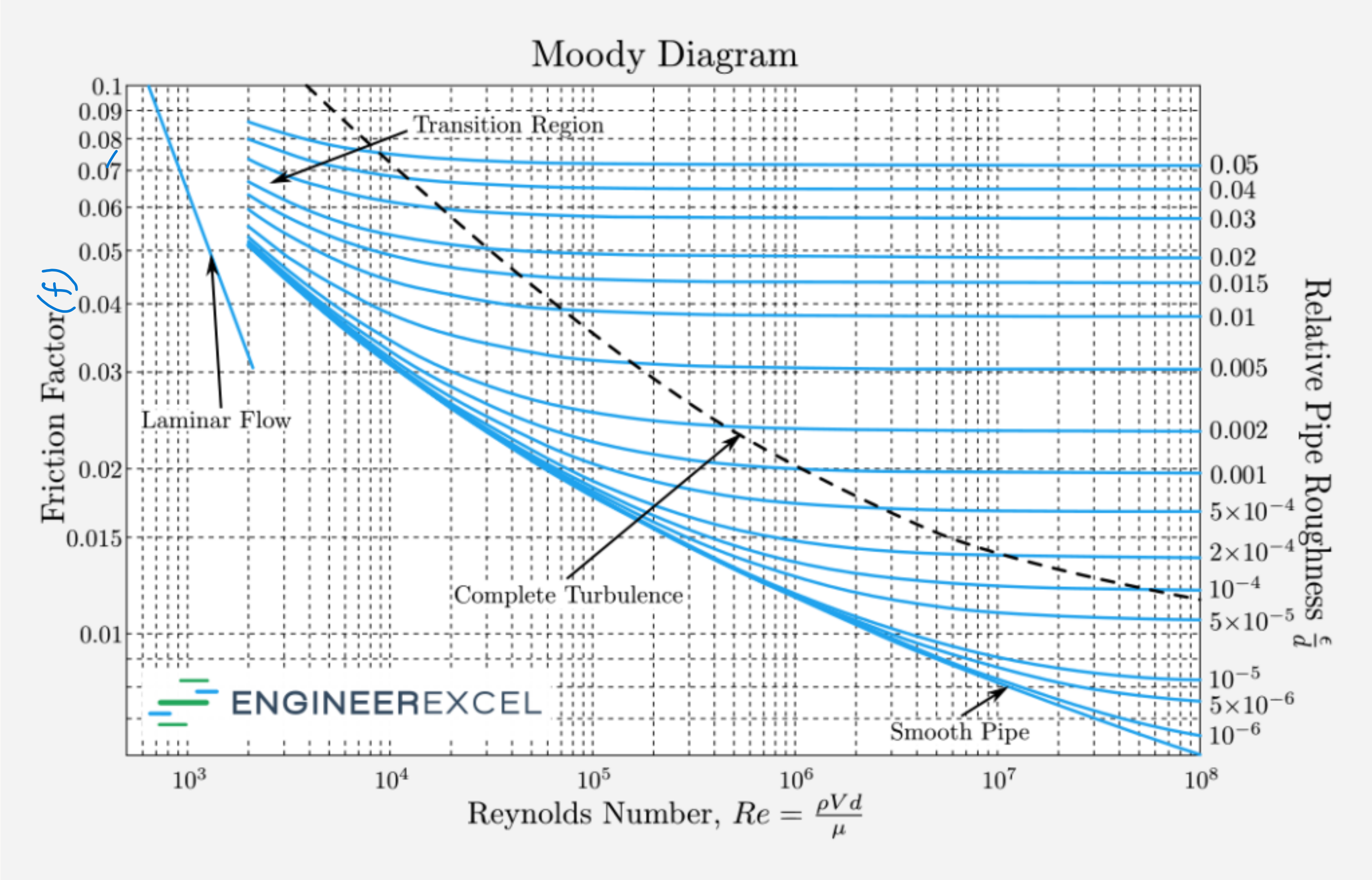
The volume flow can be calculated

$$q = A v$$

$$= (0.098 m^2) (2.1 m/s)$$

$$= \underline{0.20} m^3/s$$

Moody's Diagram



https://engineerexcel.com/moody-chart-calculator/

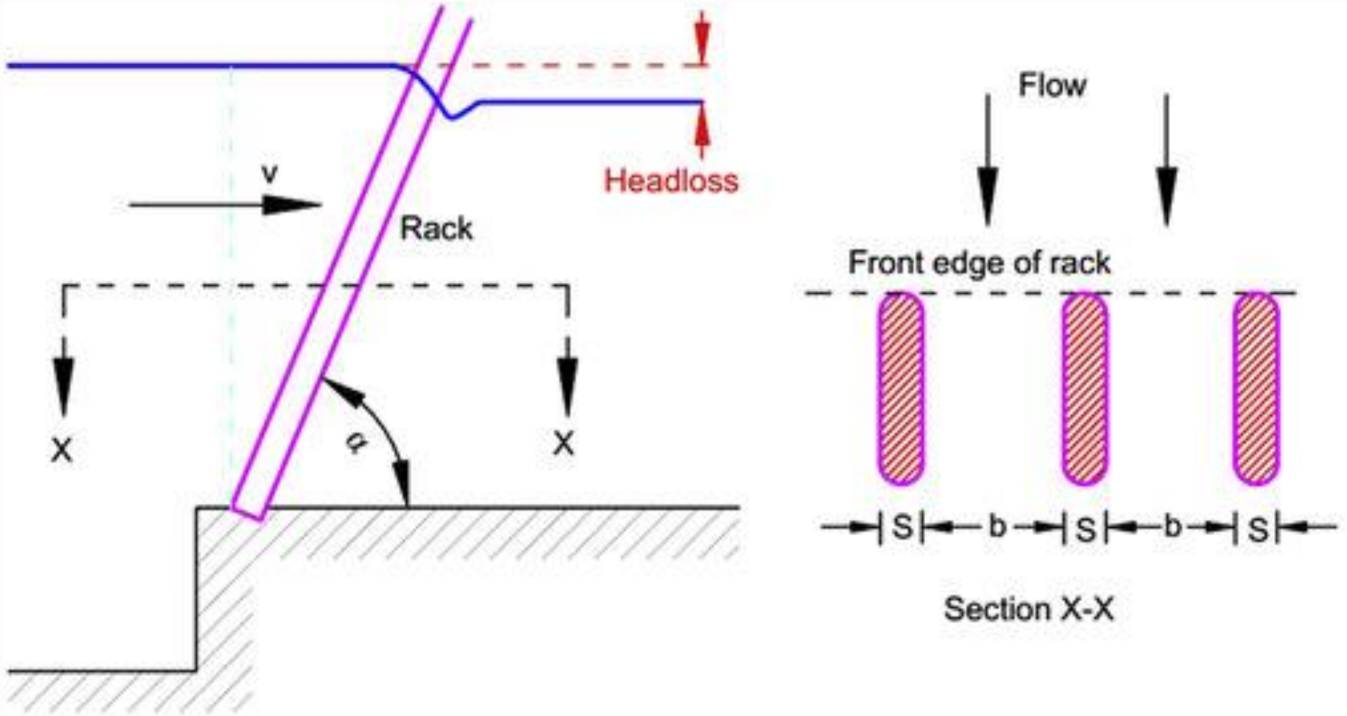
Minor Head Loss
Trash rack (or screen) losses

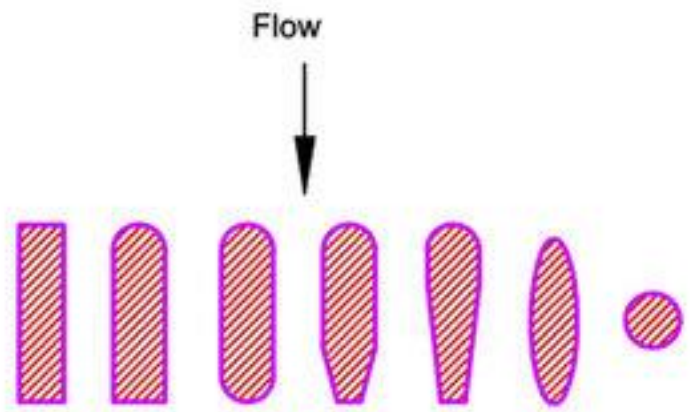
- A screen is nearly always required at the entrance of both pressure pipes and intakes to avoid the entrance of floating debris.
- The flow of water through the rack also gives rise to a head loss.

$$h_t = K_t \left(\frac{S}{b}\right)^{4/3} \left(\frac{{V_o}^2}{2g}\right) \sin \alpha$$

kemiringan trash rack thd horizontal

Trash rack (or screen) losses





Type	a	b	c	d	e	f	g
K_t	2.42	1.83	1.67	1.03	0.92	0.76	1.79

Loss of head by sudden contraction or expansion (cont'd)

Kontraksi → pipa besar ke kecil

$$h_c = K_c \cdot \left(\frac{V_2^2}{2g}\right)$$

For a ratio up to *d/D* = 0.76, K_c approximately follows the formula:

$$k_c = 0,42\left(1 - \frac{d^2}{D^2}\right)$$

smaller

bigger

Pipe diameter

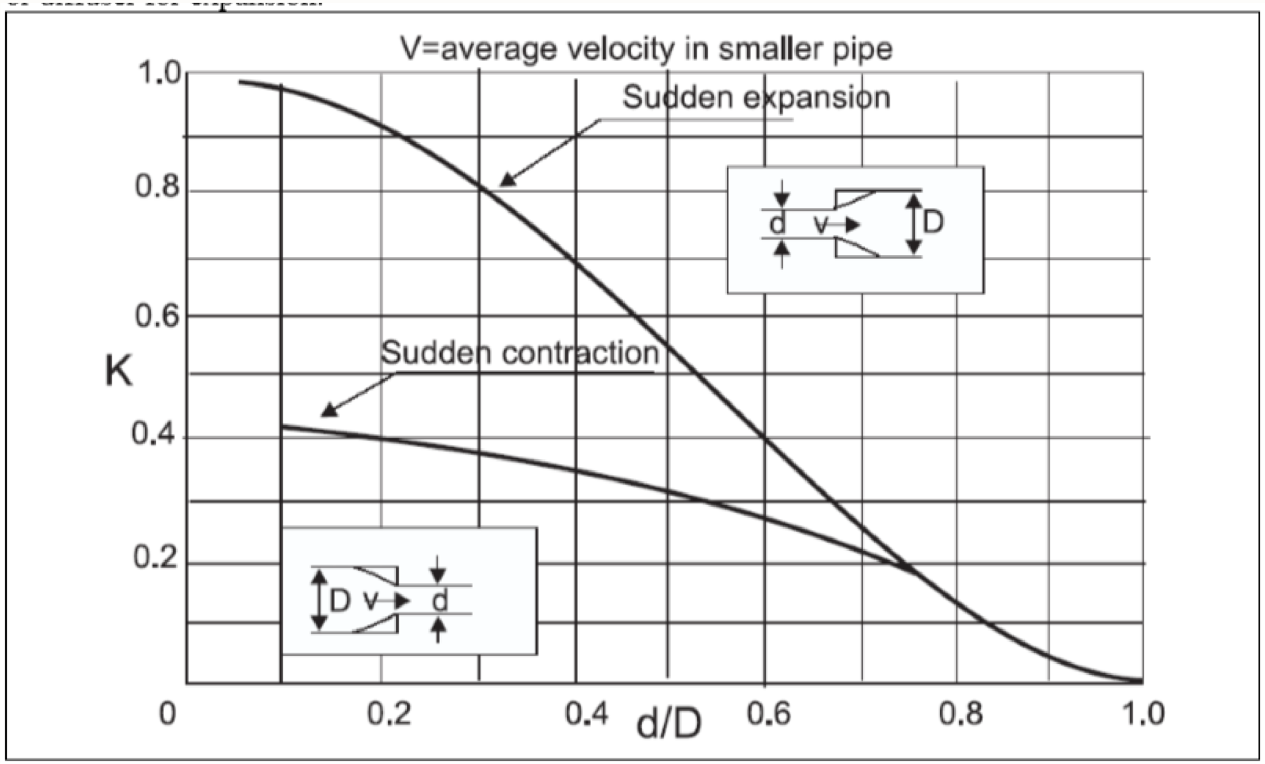
In sudden expansions, the loss of head is given by:

→ bigger pipe

$$h_{ex} = \frac{(V_1 - V_2)^2}{2g} = \left(1 - \frac{V_2}{V_1}\right)^2 \frac{V_1^2}{2g} = \left(1 - \frac{A_1}{A_2}\right)^2 \frac{V_1^2}{2g} = \left(1 - \frac{d^2}{D^2}\right)\frac{V_1^2}{2g}$$

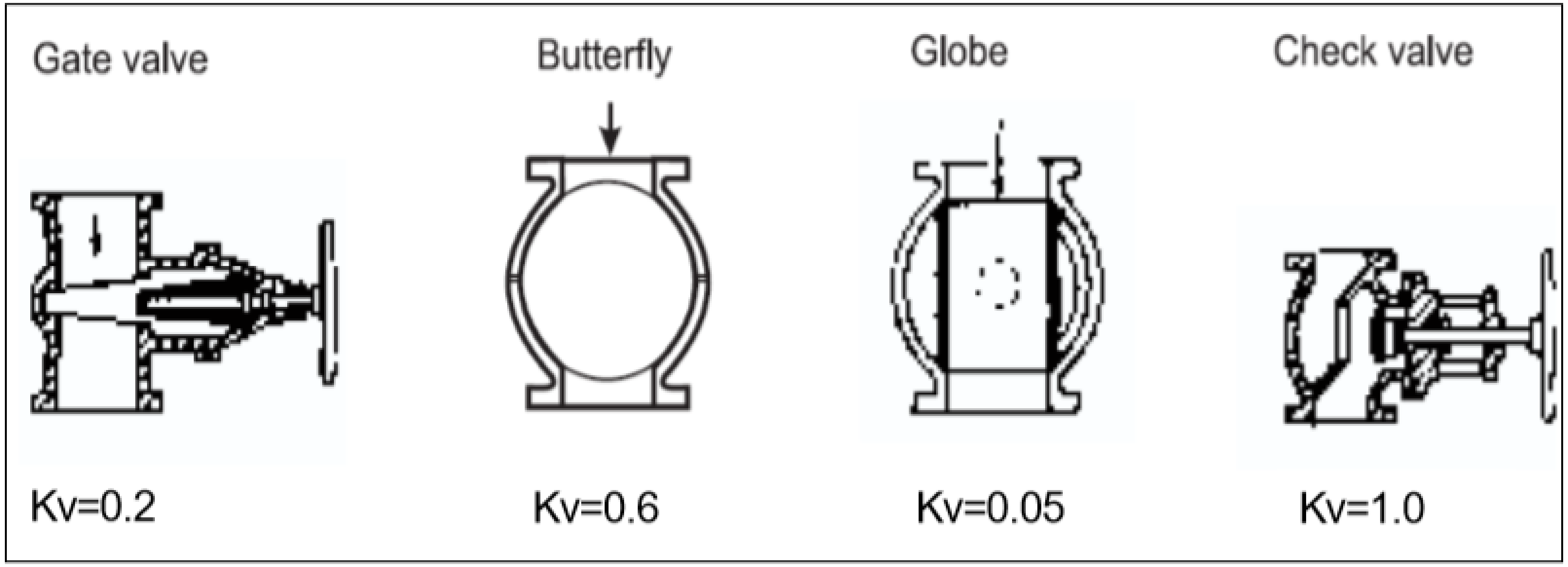
V_1 is the water velocity in the smaller pipe.

Loss of head by sudden contraction or expansion



Loss of head through valve

– The loss of head produced by water flowing through an open valve depends of the type and manufacture of the valve.



Bending

$$h_V = \frac{K_V \times V^2}{2g}$$

Evaluating Stream Flow

- All hydroelectric generation depends on falling water. This makes hydropower extremely site dependent.
- A sufficient and dependable stream flow is required.
- Planning for the exploitation of a river stretch or a specific site is one of the more challenging tasks that face a hydropower engineer, since there are an unlimited number of practical ways in which a river or site can be exploited.
- The hydropower engineer has to find the optimum solution for plant configuration, including dam type, water conveyance system, installed generating capacity, location of various structures, etc.

Evaluating stream flows by discharge measurements

Velocity-area Method

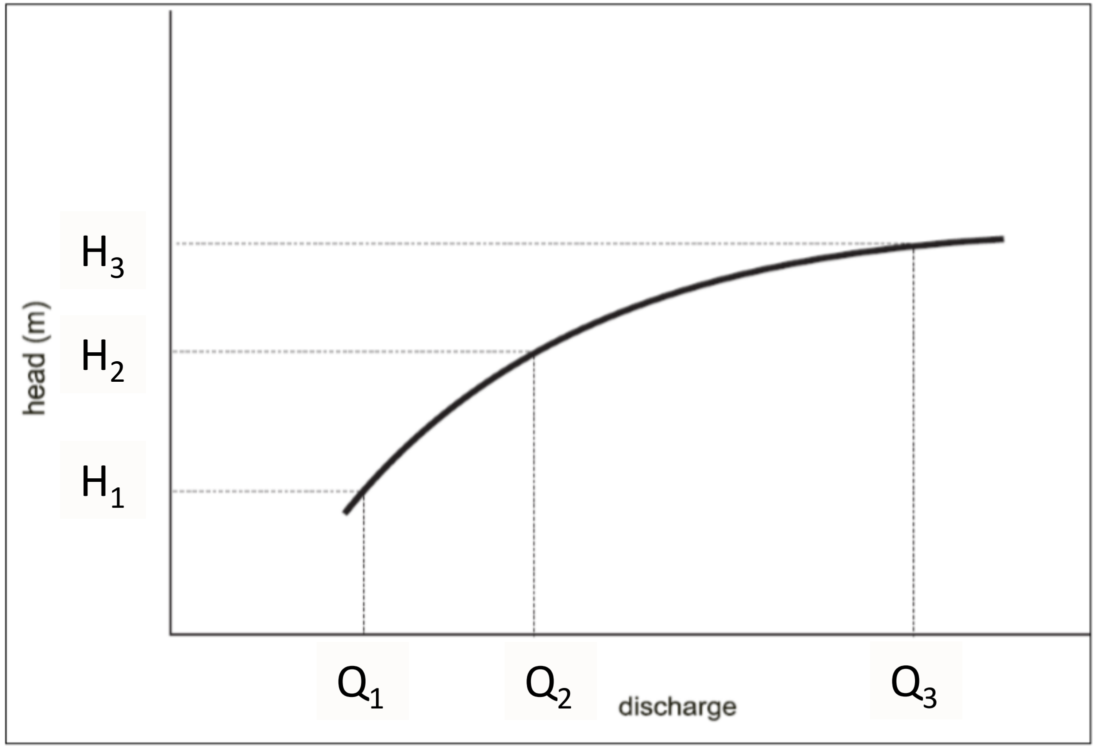
- This is a conventional method for medium to large rivers, involving the measurement of the cross sectional area of the river and the mean velocity of the water through it.
- An appropriate point must be selected on a relatively straight, smoothly flowing portion of the river to be measured.
- The river at this point should have a uniform width, with the area well defined and clean.
- As discharge varies, the top water level (=the stage of the river) rises and falls. The stage is observed daily at the same time each day on a board.

Velocity-area Method (cont'd)

- In modern gauging stations, instead of a board, that requires regular observations, any one of several water-level measurement sensors is available which automatically register the stage.
- To calibrate the stage observations or recordings, periodic discharge measurements from the lowest to the highest are made over a time period of several months.

Velocity-area Method

The correlation stage-discharge is called a rating curve and permits the estimation of the river discharge by reading the river stage.

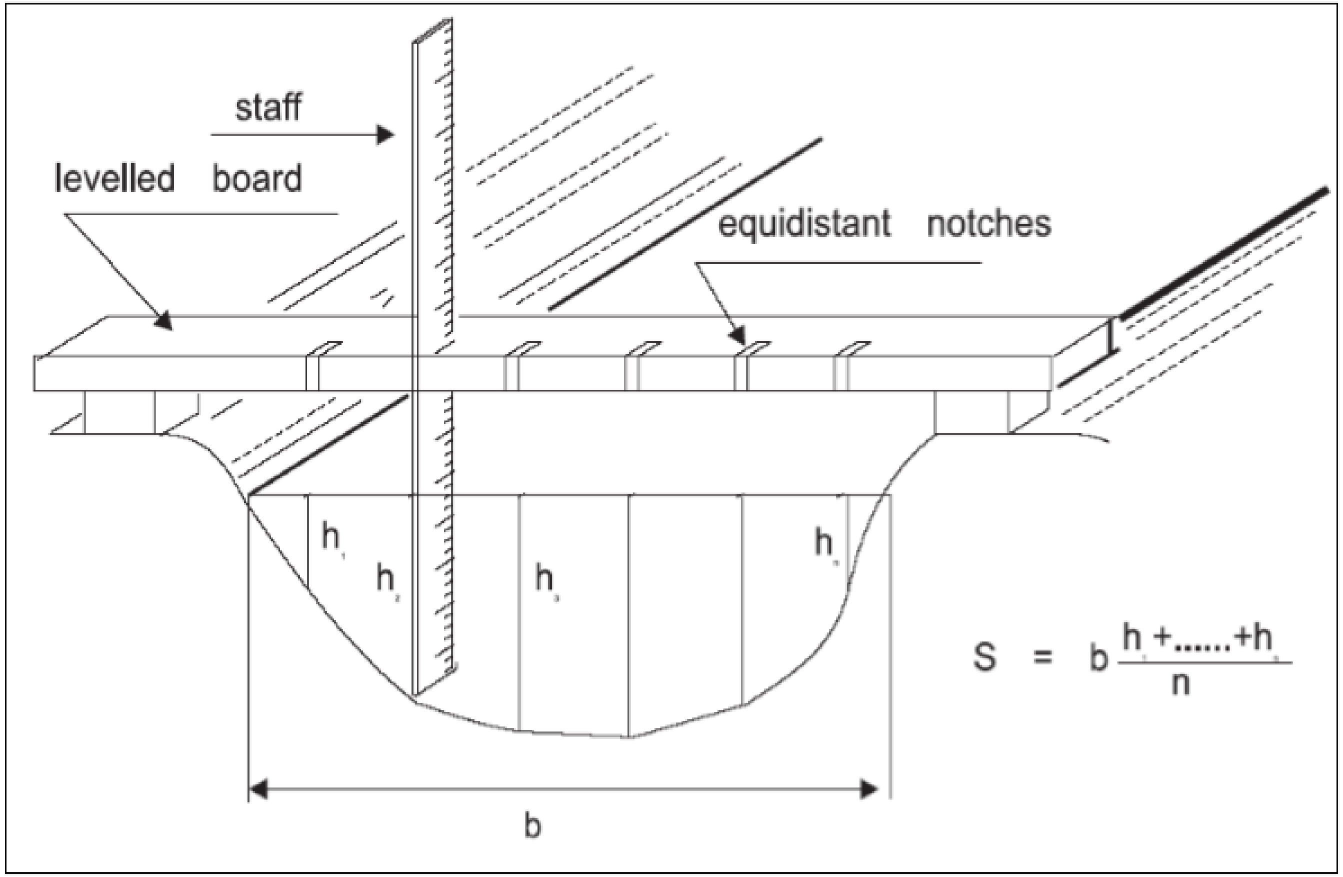


harapan: landai.
biar discharge naik
banyyak pun,
head ga perlu
tambah banyak

Measuring the cross-sectional area

- To compute the cross-sectional area of a natural watercourse it should be divided into a series of trapezoids.
- Measuring the trapezoid sides, the cross-section would be given by:

$$S = b\frac{h_a + h_2 + \ldots\ldots + h_n}{n}$$



Measuring velocity
Float Method

- A floating object, which is largely submerged (for instance a wood plug or a partially filled bottle) is located in the center of the stream flow.
- The time t (seconds) elapsed to traverse a certain length L (m) is recorded.
- The surface speed (m/s) would be the quotient of the length L and the time t.
- To estimate the mean velocity, the above value must be multiplied by a correction factor that may vary between 0.60 and 0.85 depending on the watercourse depth and their bottom and riverbank roughness (0.65 is a well accepted value).

0.65

Measuring velocity Current Meter

- Each revolution of the propeller is recorded electrically through a cable to the observer and the number of revolutions is counted by the observer, or automatically by the instrument itself, over a short period (say 1 or 2 minutes).
- These observations are converted into water velocities from a calibration curve for the instrument (modern instruments, with microprocessor technology will compute this and display it almost immediately).
- By moving the meter vertically and horizontally to a series of positions (whose coordinates in the cross-section are determined), a complete velocity map of the cross-section can be drawn and the discharge through it calculated.

$\frac{\text{Perimeter}}{\text{durasi}}$

Current Meter

Power Calculation

- The following equation can be used to calculate Power Output:

(seluruh sistem)

turbo generator efficiency

$$P = 1000 \times \eta \times Q \times g \times H$$

effective head

- For a typical small hydro system the turbine efficiency would be 85%, drive efficiency 95% and generator efficiency 93%, so the overall system efficiency would be:

$$\mathbf{0.85 \times 0.95 \times 0.93 = 0.751 \text{ i.e. } 75.1\%}$$

Sample Question

Calculate the hydropower contained in a water with a flow of 20 liters per second with a head of 12 meters.

Answer

Calculate the hydropower contained in a water with a flow of 20 liters per second with a head of 12 meters. w/o efficiency.

Q = 20 l/s = 20 dm^3/s = 0.02 m^3/s

ρ = 1000 kg/m^3

g = 9.81 m/s^2

h = 12 m

$$P = Q \times \rho \times g \times h$$

$$P = 0.02\ \frac{m^3}{s} \times 1000\,\frac{kg}{m^3} \times 9.81\,\frac{m}{s^2} \times 12\ m$$

$$P = 2354.4\ W$$

Sample Question

Niagara Falls is 167 feet high and has an average discharge of 2400 m^3/s. What is the total power of the falls if the efficiency of the power plant is 75%?

Answer

Niagara Falls is 167 feet high and has an average discharge of 2400 m^3/s. What is the total power of the falls if the efficiency of the power plant is 75%?

w/ efficiency

h = 167 ft = 50.9 m

Q = 2400 m^3/s

η = 0.75

ρ = 1000 kg/m^3

g = 9.81 m/s^2

$$P = \eta \times Q \times \rho \times g \times h$$

$$P = 0.75 \times 2400 \frac{m^3}{s} \times 1000 \frac{kg}{m^3} \times 9.81 \frac{m}{s^2} \times 50.9\ m$$

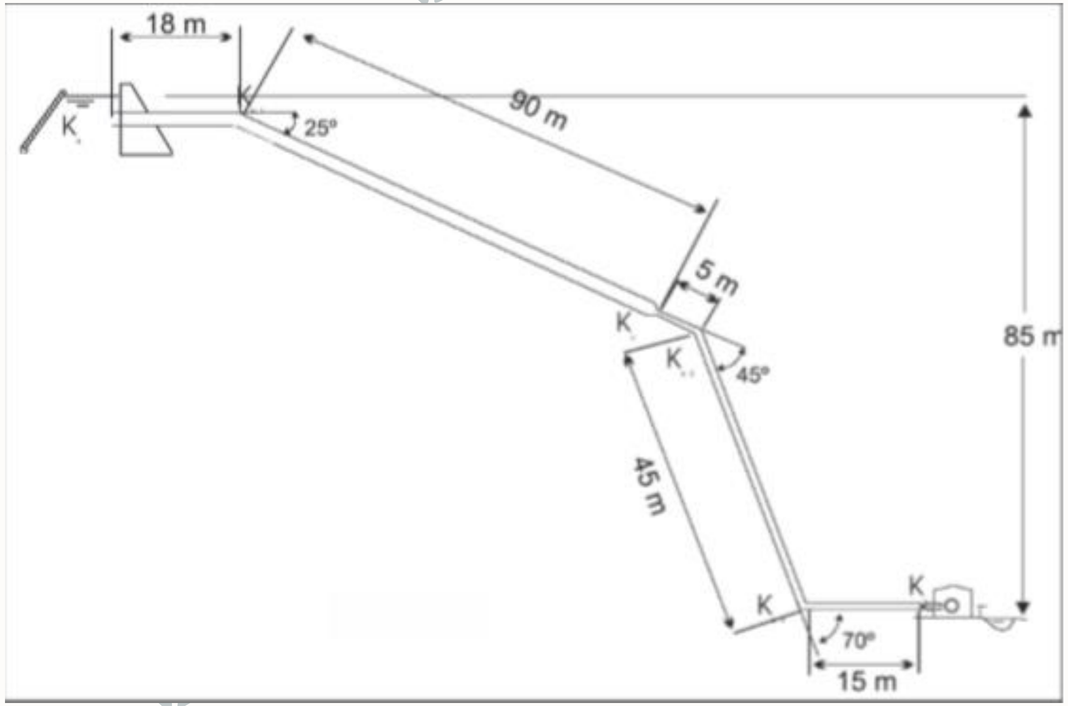
$$P = 0.8987\ GW$$

Calculation of Effective Head

- The equation to calculate effective head is:
- H is effective head
- h_f is head loss due to friction
- h_m is minor head loss

$$H = h - h_f - h_m$$

Example
Head Loss Calculation



The nominal discharge is 3 m^3/s and the gross head 85 m. The penstock is 1.5 m diameter in the first length and 1.2 m in the second one. All the pipes are made of welded steel with average roughness (e) of 0.6 mm. At the entrance of the intake there is a trash rack inclined 60° with the horizontal. The rack is made of stainless steel flat bars, 12 mm thick and the width between bars is 70 mm. Estimate the total head loss! Low head → lower loss

Answer (cont'd)

– The required trash rack area is estimated by the formula:

$$S = \frac{1}{K_1}\left(\frac{t}{t+b}\right)\frac{Q}{V_0}\frac{1}{\sin\alpha}$$

With V_0 should be between 0.25 m/s and 1.0 m/s based on experience.

Answer

where S is the area in m2, t the bar thickness (mm), b the distance between bars (mm), Q the discharge (m3/s), V_0 the water velocity at the entrance and K_1 a coefficient which, if the trash rack has an automatic cleaner, is equal to 0.80. Assuming $V_0 = 1$ m/s, S=5.07 m^2. For practical reasons a 6 m^2 trash rack may be specified, corresponding to a $V_0 = 0.85$ m/s, which is acceptable. The headloss traversing the trash rack, as computed from the Kirschner equation

$$h_r = 2{,}4\left(\frac{12}{70}\right)^{4/3} \frac{0{,}8^2}{2 \cdot 9{,}81} = 0{,}007\ m$$

Answer

The friction losses in the first penstock length are a function of the water velocity, 1.7 m/s. The entrance to the pipe has a good design and coefficient $K_e = 0.04$

The major head loss for the first length of pipe is:

$$\text{Re} = \frac{\rho VD}{\mu} = \frac{1000\ {}^{kg}/_{m^3} \times 1.7\ {}^{m}/_{s} \times 1{,}5m}{8.9\times10^{-4}Pa\ s} = 2.865\times 10^6$$

$$\frac{e}{D} = \frac{6\times10^{-4}m}{1.5\ m} = 4\times10^{-4}$$

f from Moody's Diagram ≈ 0.016

The headloss coefficient in the first bend is $K_b = 0.085$ (one half of the corresponding loss of a 901 bend); in the second $K_b = 0.12$ and in the third $K_b = 0.14$ The taper pipe, with an angle of 30^0, gives a loss in the contraction $K_c =$ 0.02 m (for a ratio of diameters 0.8 and a water velocity in the smaller pipe =2,65 m/s)

$$\text{Re} = \frac{\rho VD}{\mu} = \frac{1000\ {}^{kg}/_{m^3} \times 2.65\ {}^{m}/_{s} \times 1{,}2m}{8.9\times10^{-4}Pa\ s} = 3.573\times 10^6$$

f from Moody's Diagram ≈ 0.016

Answer

The coefficient of headloss in the gate valve is $K_v = 0.15$. Therefore the headloss due to friction is estimated to be

$$h_f = f\frac{L}{D}\frac{V^2}{2g}$$

$$h_{f1} = 0.016\frac{108\ m}{1.5\ m}\frac{(1.7\ {}^{m}/_{s})^2}{2(9.81\ {}^{m}/_{s^2})} = 0.17\ m$$

$$h_{f2} = 0.016\frac{65\ m}{1.2\ m}\frac{(2.65\ {}^{m}/_{s})^2}{2(9.81\ {}^{m}/_{s^2})} = 0.31\ m$$

The additional headlosses will be as follows:-

• In the trash rack		0.007 m
• In the pipe entrance	0.04 x 0,147	0.0059 m
• In the first bend	0.085 x 0.147	0.013 m

Answer

• In the second bend	0.12 x 0,359	0.043 m
• In the third bend	0.14 x 0,359	0.050 m
• In the confusor	0.02 x 0,359	0.007 m
• In the gate valve	0.15 x 0,359	0.054 m
	Headlosses	0.1799 m

The total head loss is equal to 0.48 m friction loss plus 0.18 m in local losses, giving a net head of 84.34 m. This represents a loss of power of 0.77% which is reasonable.

Note

Small high-head, low-flow hydro systems typically experience pipe head losses of between 10% and 20%. With low-head systems, pipe head losses are typically only a few percent.

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