HYDRAULIC ENERGY

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INDEX

1. <u>Introduction</u>

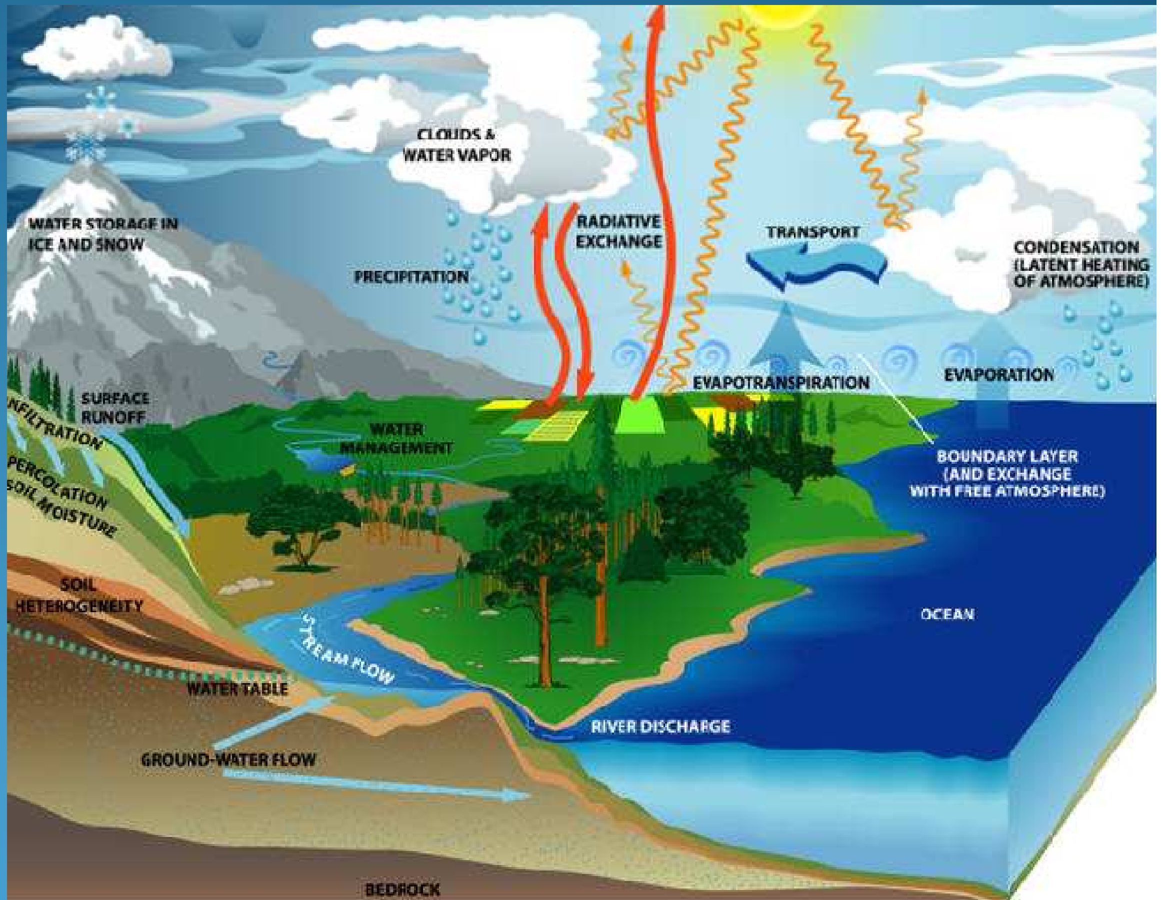
What do small hydro systems provide?

* Electricity for

Central-grids

Isolated-grids

Remote power supplies



...but also...

Reliability

Very low operating costs

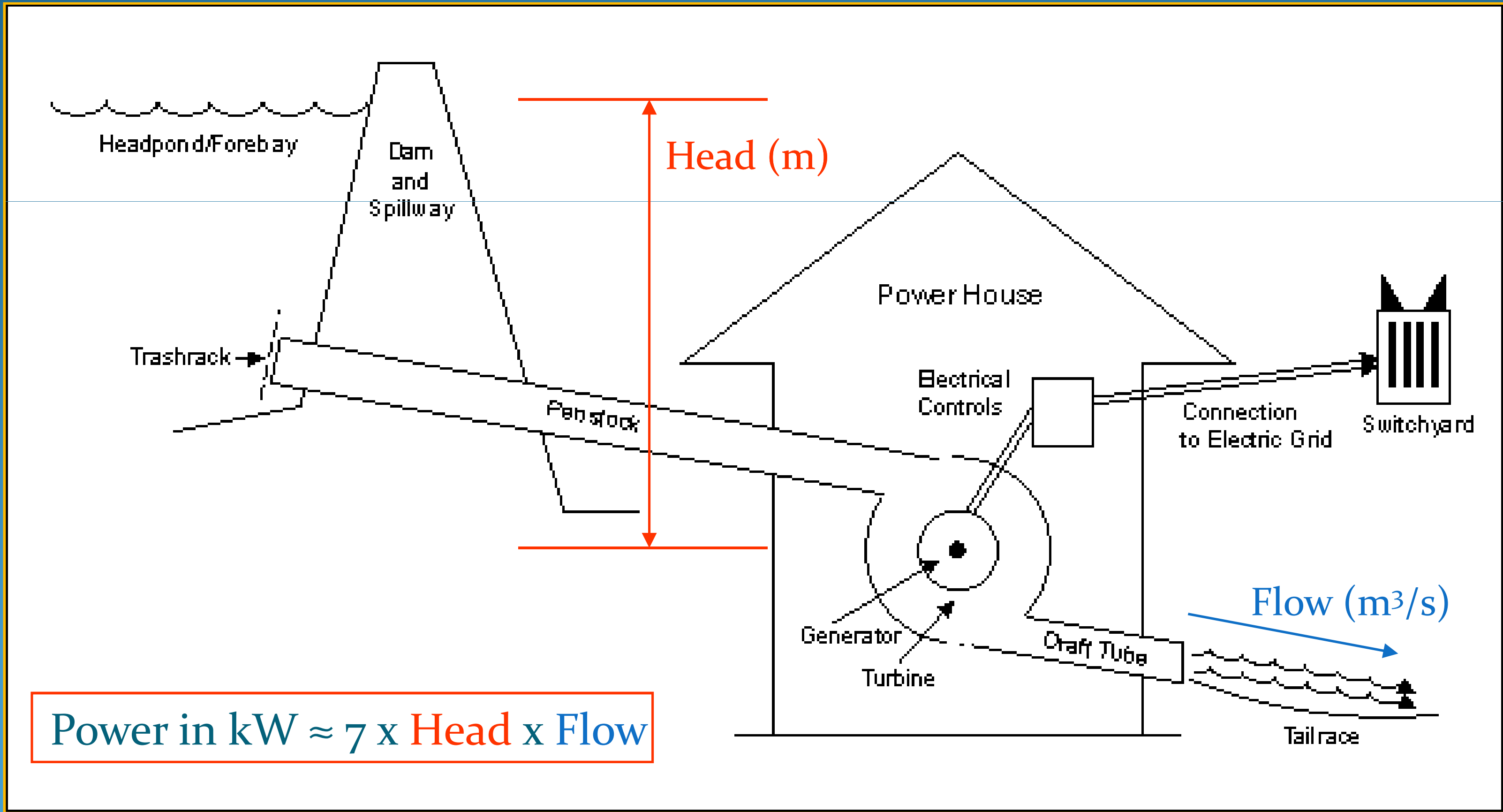
No volatility in prices

http://www.youtube.com/watch?v=iHBRf2bUNXU

http://www.youtube.com/watch?v=cEL7yc8R42k

Context of small scale hydropower:

- distributed power generation
- distribution network with low voltages (eventually sub-regional grid)
- not owned by utilities (individuals, communities)



“Small” is not universally defined

- Size of project related not just to electrical capacity but also to whether low or high head.

Different sizes hydropower installations

Hydropower installations can be classified as follows:

name	description
Large	all installations with an installed capacity of more than 1000 kW (according to some definitions more than 10,000 kW)
Small	general term for installations smaller than 1000 kW (or < 10,000 kW). Also used for installations in the range between 500 and 1000 kW.
Mini	capacity between 100 and 500 kW
Micro	hydropower installations with a power output less than 100 kW (or less then 1000 kW)

In USA:

- Small hydro: 1-30 MW
- Low power : between 500kW and 1MW
- Micro hydro: more than 5 and less than 500 kW
- Pico hydro: less than 5 kW

2. Site configurations

http://www.youtube.com/watch?v=dZZt8CpNbSU&feature=related

Types of hydropower schemes:

* Regarding to water pressure or "head" (fall to the turbine):

Low head: 2-30m

Medium head: 30-100m

High head: 100m and above

* Regarding to location:

Run-of-river scheme

Power house located at the base of a dam

Integrated on an irrigation canal or in a water supply pipe

* Run-of-river scheme:

- Constant head
- Low head losses
- Variable power dependent on the river flow

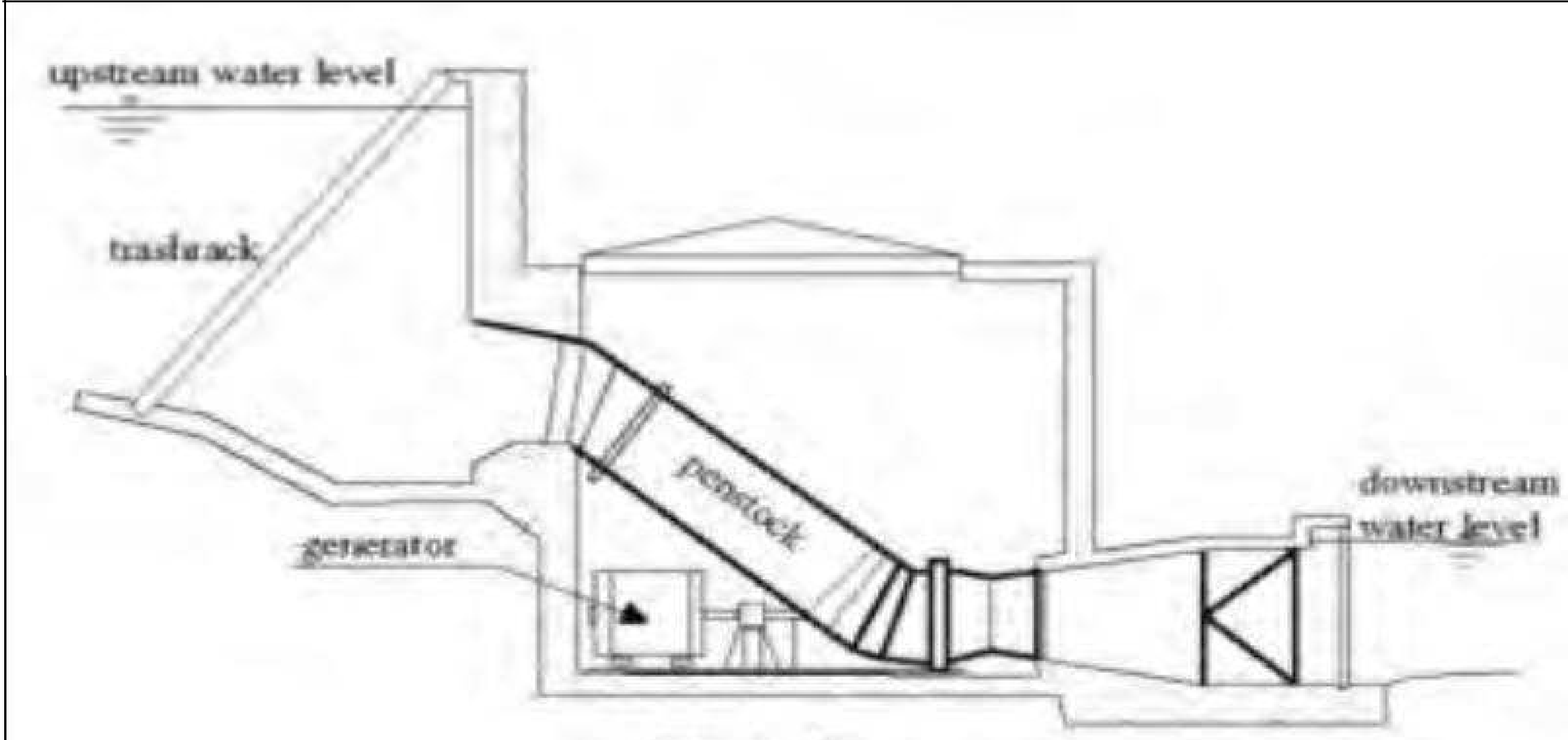
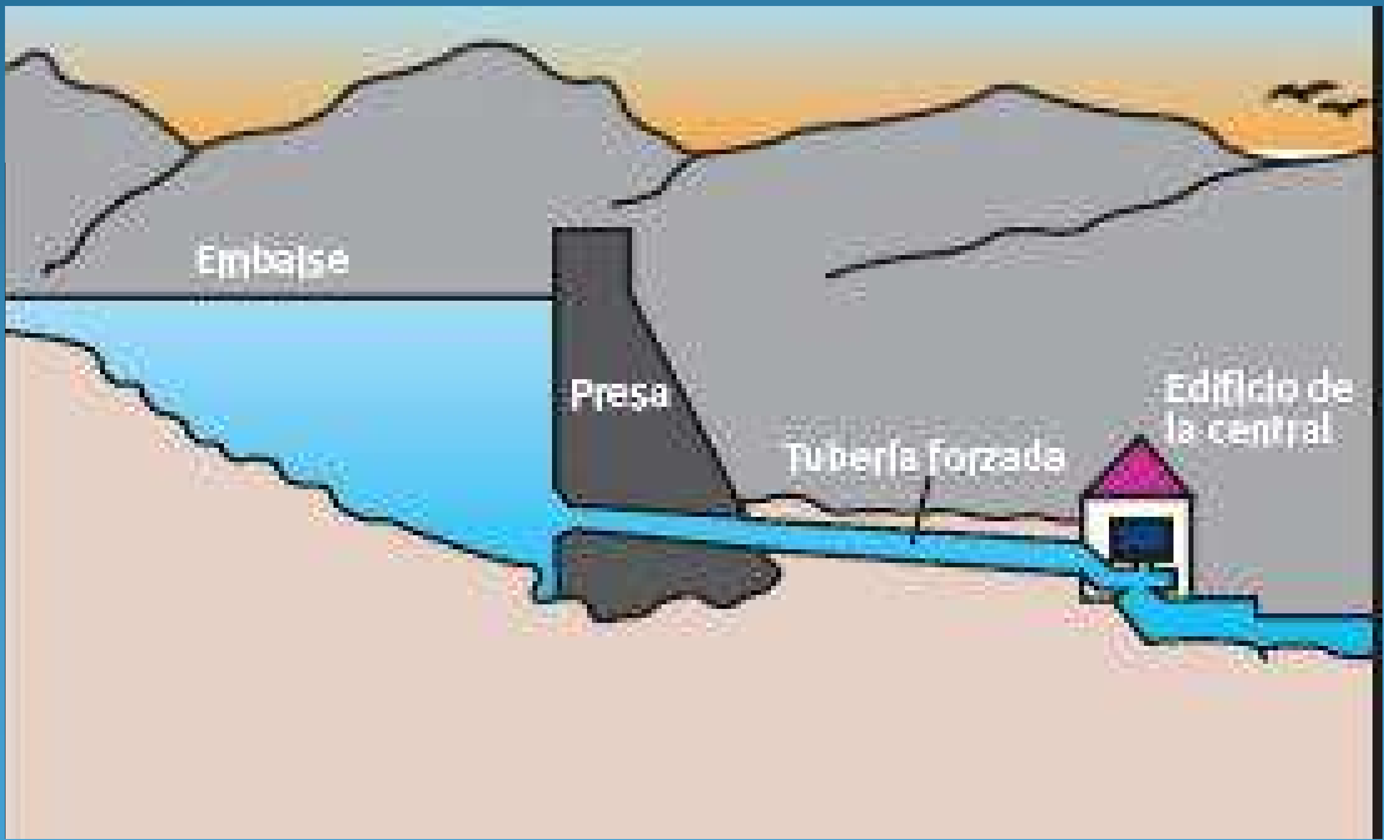

upstream water level
trashrack
penstock
generator
downstream water level

figure 1.2

* Powerhouse at the base of a dam:
  - Flow regulation capacity
  - Working frequency: daily, weekly,..
  - Need of a previously built dam (for water supply, irrigation,..)



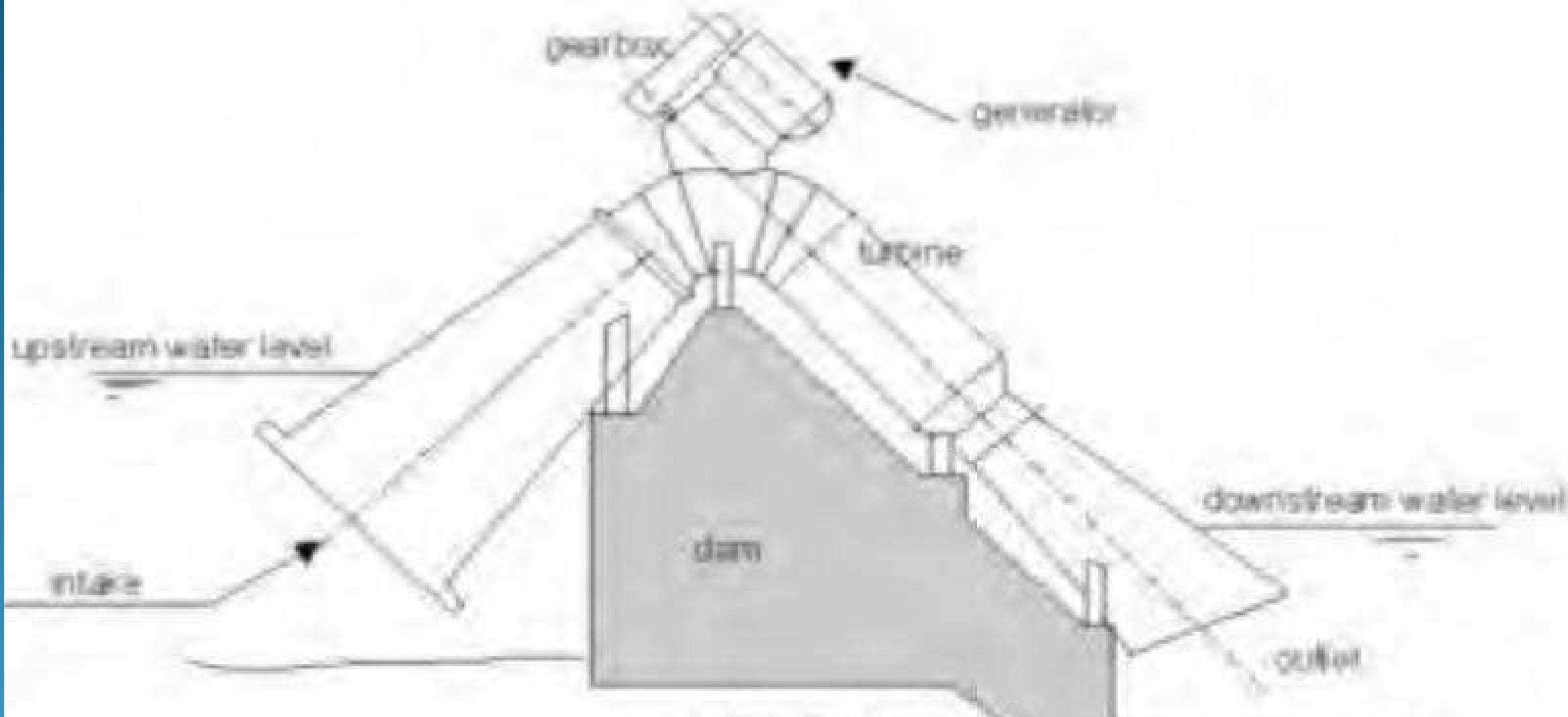
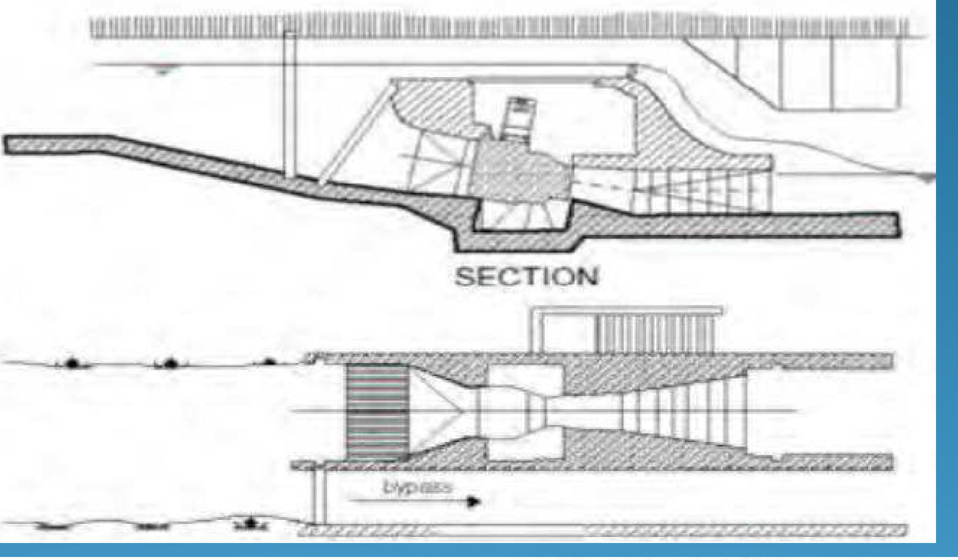
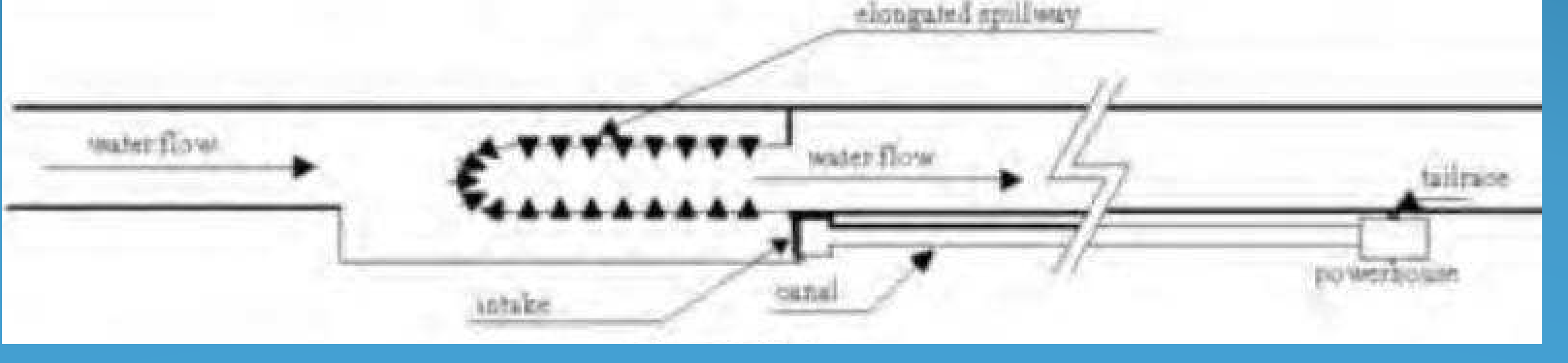


figure 1.5
syphon intake

* Integrated within an irrigation canal:

- Submerged powerhouse
- High slope canal (with penstock)

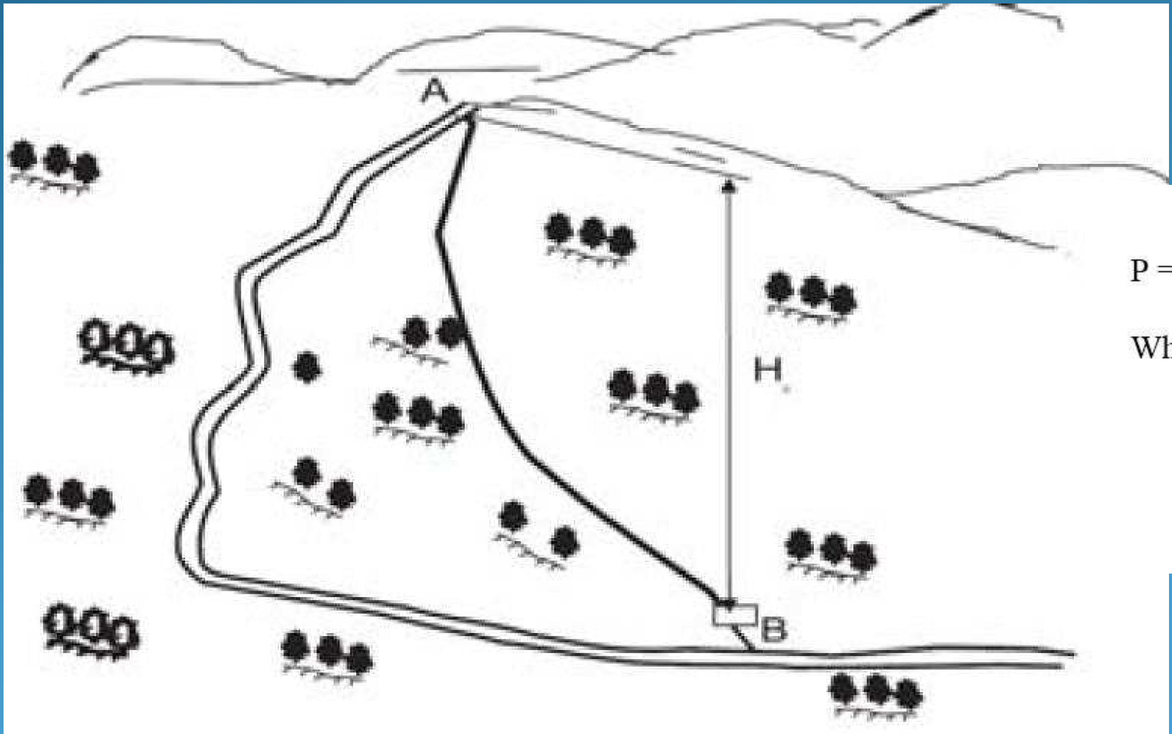




2. Design principles

Generated power dependent on

- net head of the scheme (water pressure created by difference in elevation)
- discharge flow



$P = Q \cdot H_g \cdot \gamma$

Where:

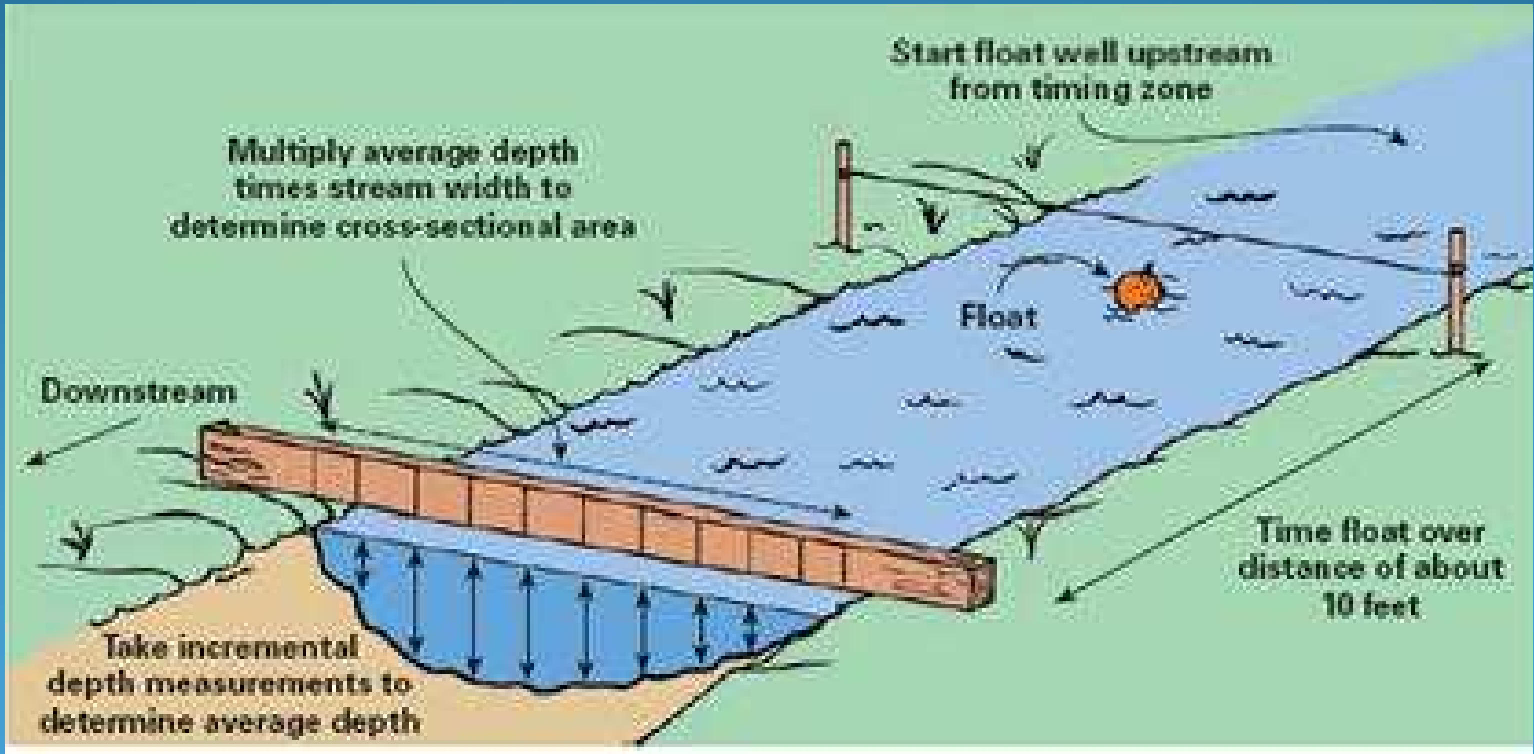
P is the power in kW lost by the water
Q is the flow in m3/s
H_g is the gross head in m, $= Z_A - Z_B$, and
γ is the specific weight of water, (9.81 kN/m3).

* Evaluation of the streamflow:

- Records: flow time series (Gauging station)
- Experimental methods:
    - Container fill method
    - Float method
    - Weir method

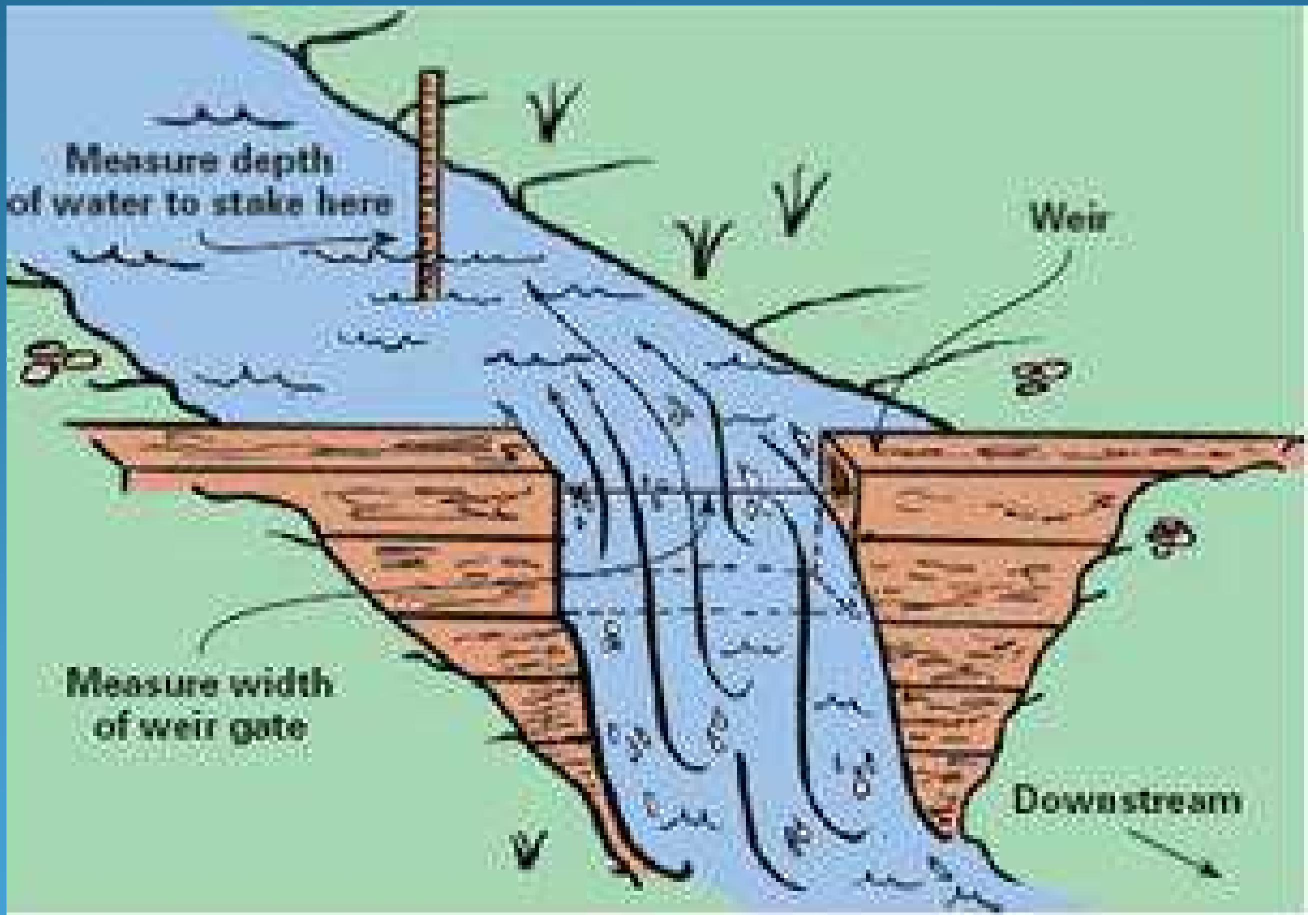
* Float method:

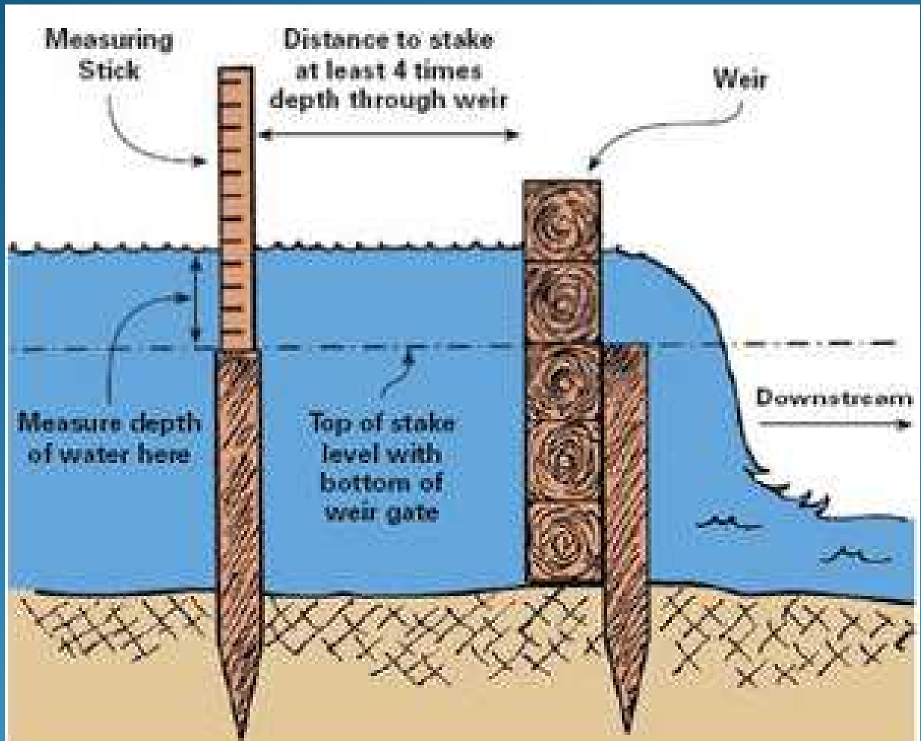
  - Useful for large streams
  - Steps:
    - Measure average depth of stream
    - Compute area of cross-section
    - Measure the speed



* Weir method:

- Most accurate method in small and medium sized streams
- Temporary dam with rectangular slot
- Depth measurement and table used





Weir Flow Table*

Depth (in.)	Additional Fraction of an Inch							
	None	+1/8	+1/4	+3/8	+1/2	+5/8	+3/4	+7/8
0	0.00	0.01	0.05	0.09	0.14	0.19	0.26	0.32
1	0.40	0.47	0.55	0.64	0.73	0.82	0.92	1.02
2	1.13	1.23	1.35	1.46	1.58	1.70	1.82	1.95
3	2.07	2.21	2.34	2.48	2.61	2.76	2.90	3.05
4	3.20	3.35	3.50	3.66	3.81	3.97	4.14	4.30
5	4.47	4.64	4.81	4.98	5.15	5.33	5.51	5.69
6	5.87	6.06	6.25	6.44	6.62	6.82	7.01	7.21
7	7.40	7.60	7.80	8.01	8.21	8.42	8.63	8.83
8	9.05	9.26	9.47	9.69	9.91	10.13	10.35	10.57
9	10.80	11.02	11.25	11.48	11.71	11.94	12.17	12.41
10	12.64	12.88	13.12	13.36	13.60	13.85	14.09	14.34
11	14.59	14.84	15.09	15.34	15.59	15.85	16.11	16.36
12	16.62	16.88	17.15	17.41	17.67	17.94	18.21	18.47
13	18.74	19.01	19.29	19.56	19.84	20.11	20.39	20.67
14	20.95	21.23	21.51	21.80	22.08	22.37	22.65	22.94
15	23.23	23.52	23.82	24.11	24.40	24.70	25.00	25.30
16	25.60	25.90	26.20	26.50	26.80	27.11	27.42	27.72
17	28.03	28.34	28.65	28.97	29.28	29.59	29.91	30.22
18	30.54	30.86	31.18	31.50	31.82	32.15	32.47	32.80
19	33.12	33.45	33.78	34.11	34.44	34.77	35.10	35.44
20	35.77	36.11	36.45	36.78	37.12	37.46	37.80	38.15

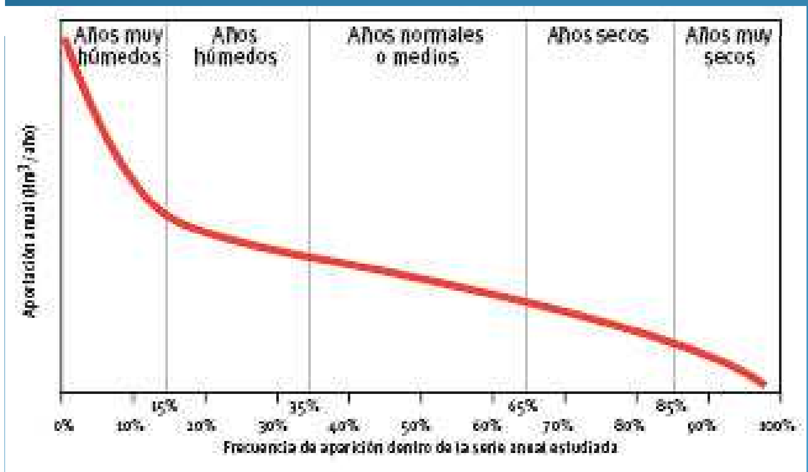
*In cfm per 1-inch gate width

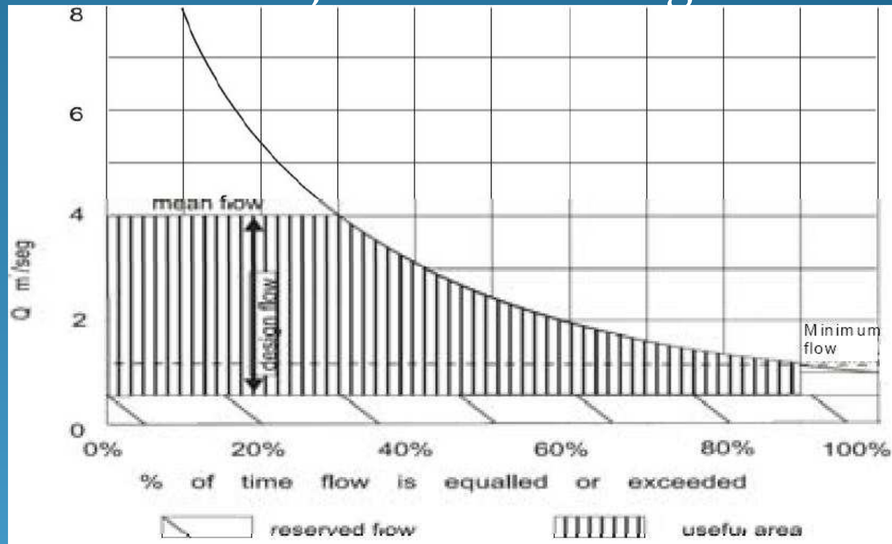
* Stream flow characteristics:

- Flow Duration Curve (FDC)

Proportion of time during which the discharge there equals or exceeds certain values.

- FDC presents more information than just mean average flow.

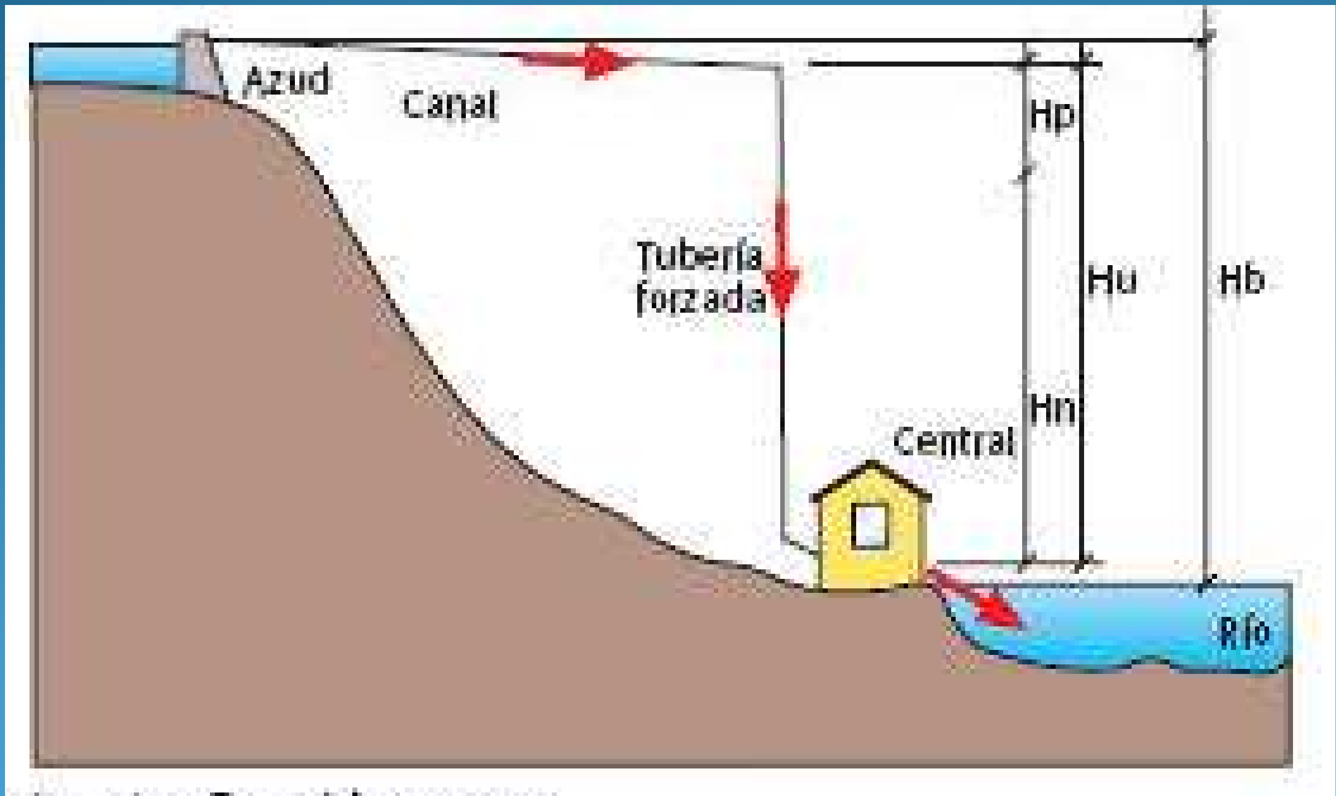




	No of days	% of the year
Flows of 8.0 m3/s and greater	41	11.23
Flows of 7.0 m3/s and greater	54	14.9
Flows of 6.5 m3/s and greater	61	16.8
Flows of 5.5 m3/s and greater	80	21.8
Flows of 5.0 m3/s and greater	90	24.66
Flows of 4.5 m3/s and greater	100	27.5
Flows of 3.0 m3/s and greater	142	39
Flows of 2.0 m3/s and greater	183	50
Flows of 1.5 m3/s and greater	215	58.9
Flows of 1.0 m3/s and greater	256	70
Flows of 0.35 m3/s and greater	365	100

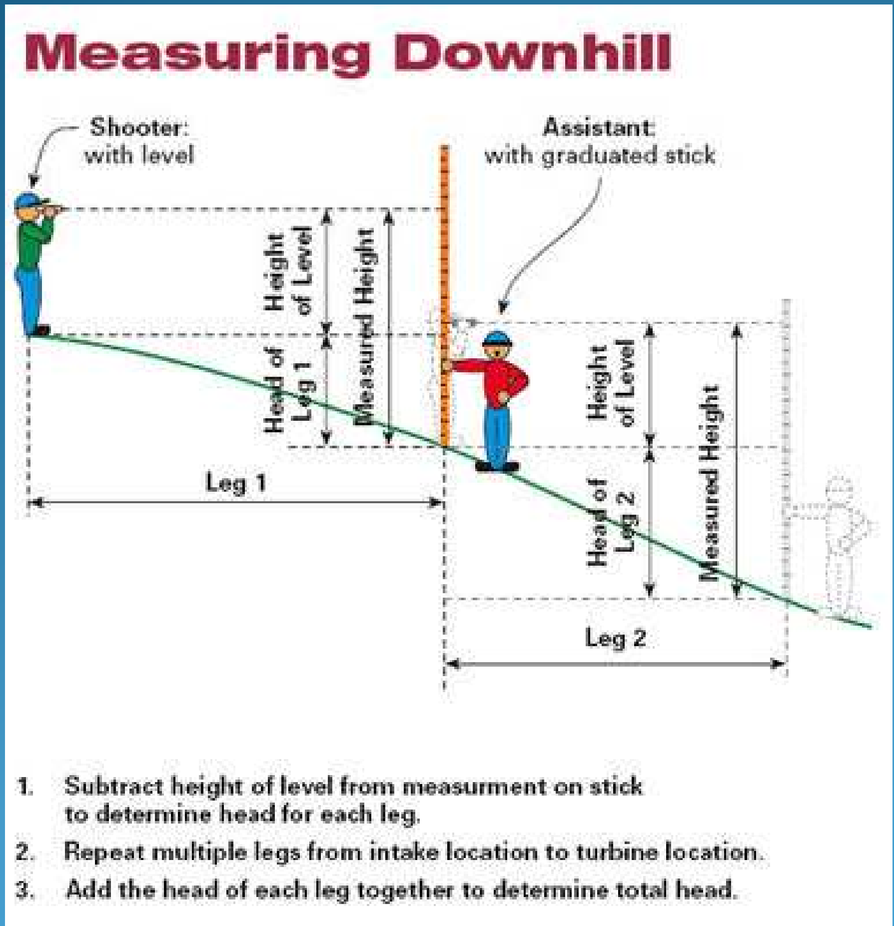
* Evaluation of Water pressure or “head”:

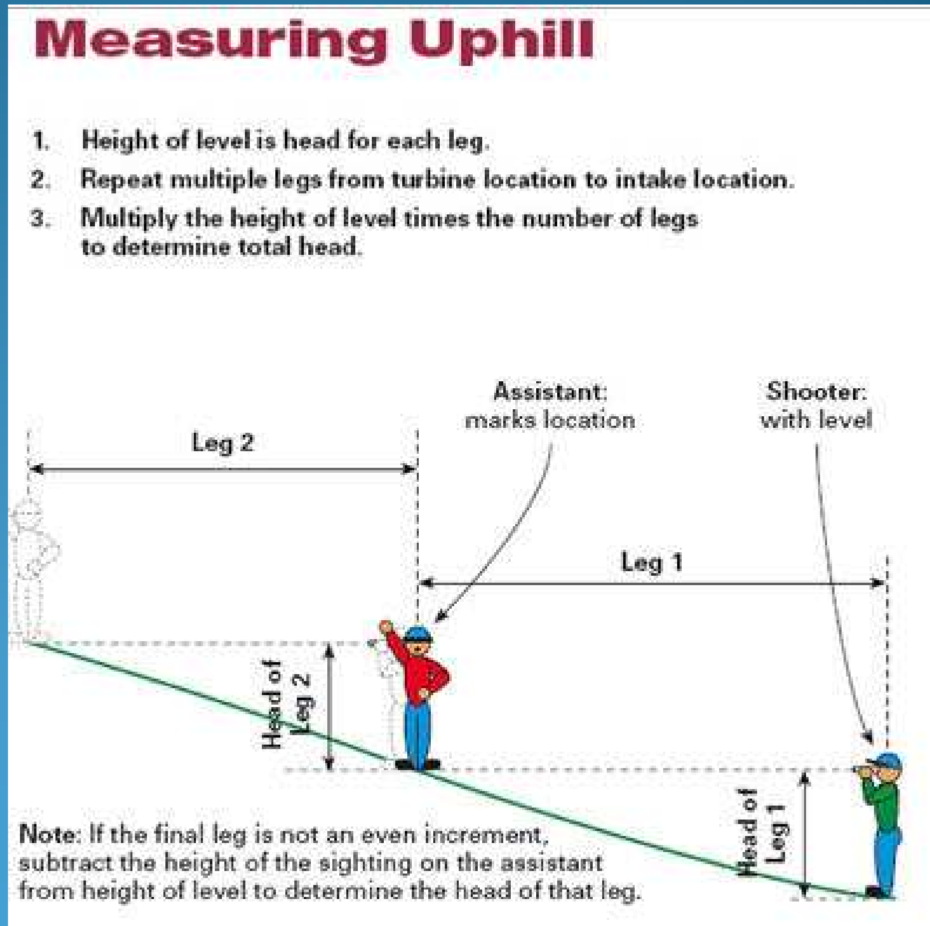
- Gross head
- Net head – losses (trash racks, valves, bends, pipe friction)
- Residual flow
- Minimum technical flow of turbines



$E\ (kWh) = 9{,}81 * Q * H_n * T * e * \eta$

* Direct Height measurement
  - Laser level, sight level, etc.
  - Need of an assistant





* Water pressure measurement:

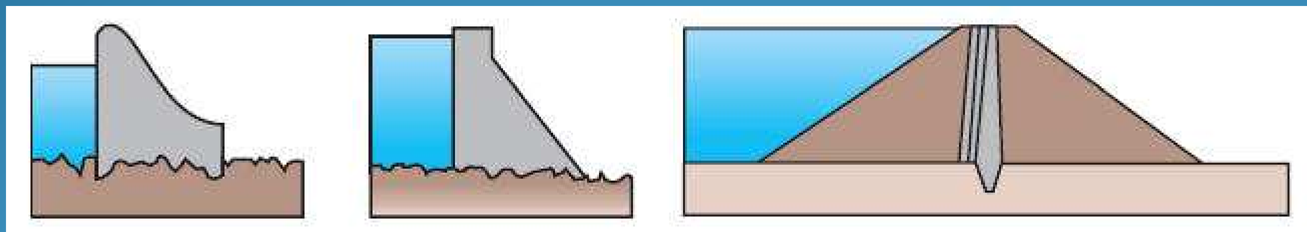
- Measure the pressure at the bottom of a hose
- Run the hose from proposed intake site to proposed turbine location
- An accurate pressure gauge needed

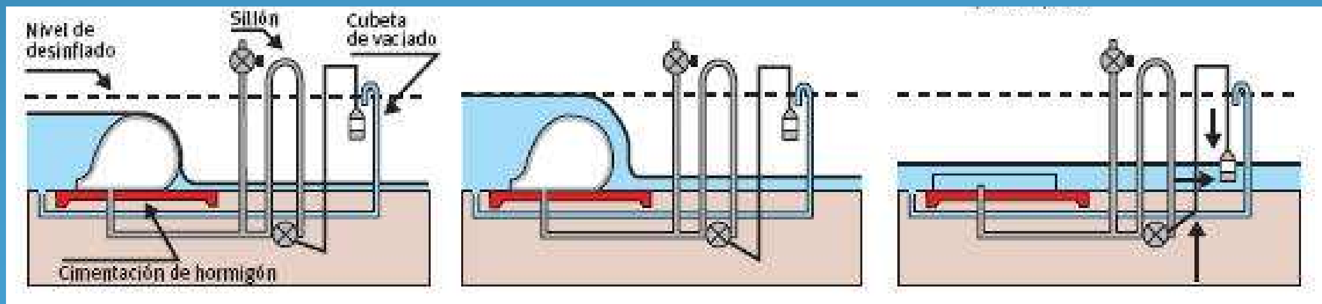
2. Hydraulic structures

- Dams and weirs

Objective: divert the river flow into the water conveyance system leading to the powerhouse.

In the case of the dam, produce additional head and provide storage capacity.



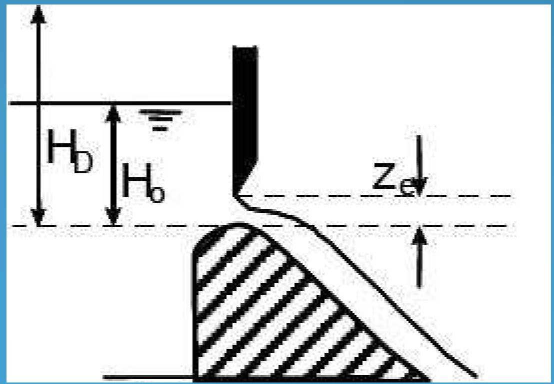


- Spillways

Objective: safely accommodate high floods that can exceed normal flow conditions in the river by orders of magnitude.

- Fixed: cannot regulate water level. (weirs, ungated spillways)

- Mobile: regulate water level such that it stays constant for most incoming flow conditions. (gated spillways, inflatable weirs).

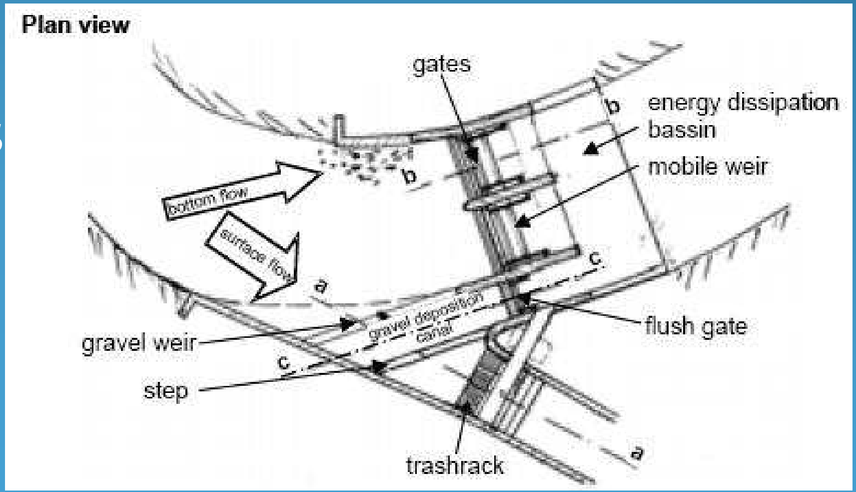


- Intake structures

Objective: divert water into a power canal or into a penstock

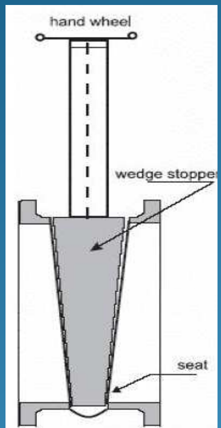
- Power intake: water directly to the turbine via a penstock
- Conveyance intake: water to other waterways that end in a power intake.

Need for the use of trashracks

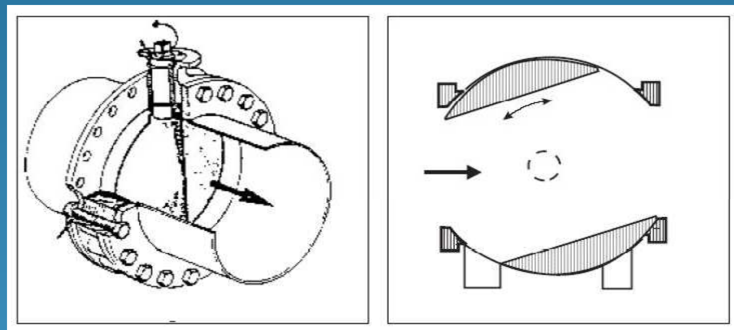


- Gates and valves

Objective: need to temporalily isolate certain components.



Different types: wedge-shaped, butterfly, globe



- Penstocks

Objective: convey water from the intake to the powerhouse.

Installation dependent on site conditions

(over or under the ground)

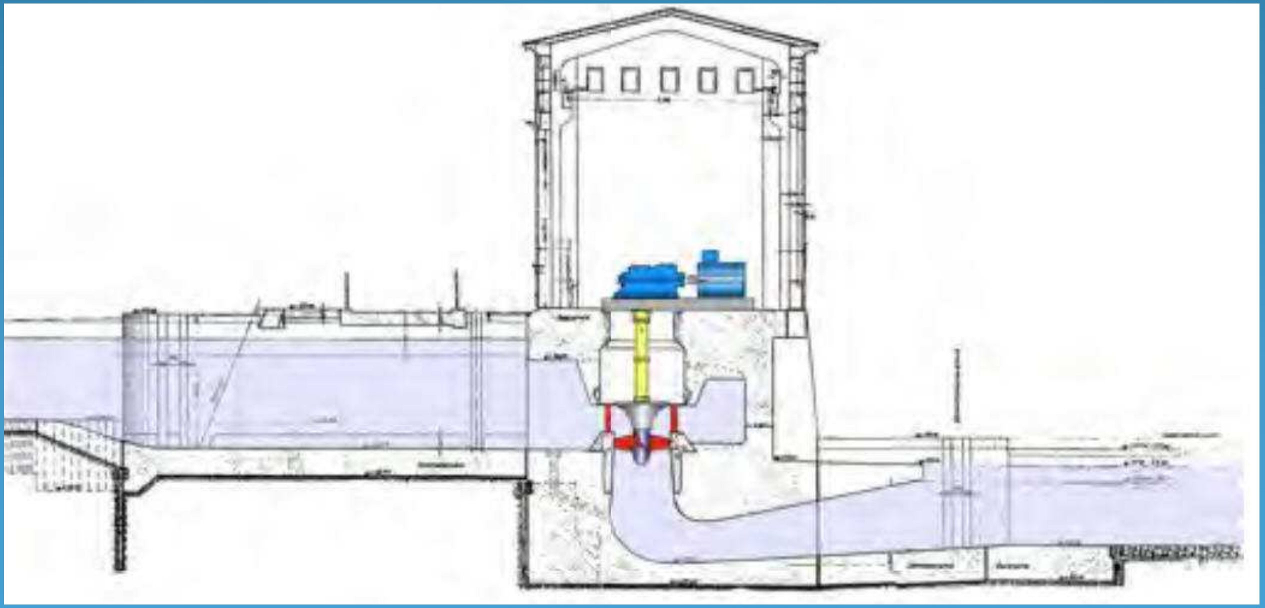
Different materials (iron cast, steel, etc)

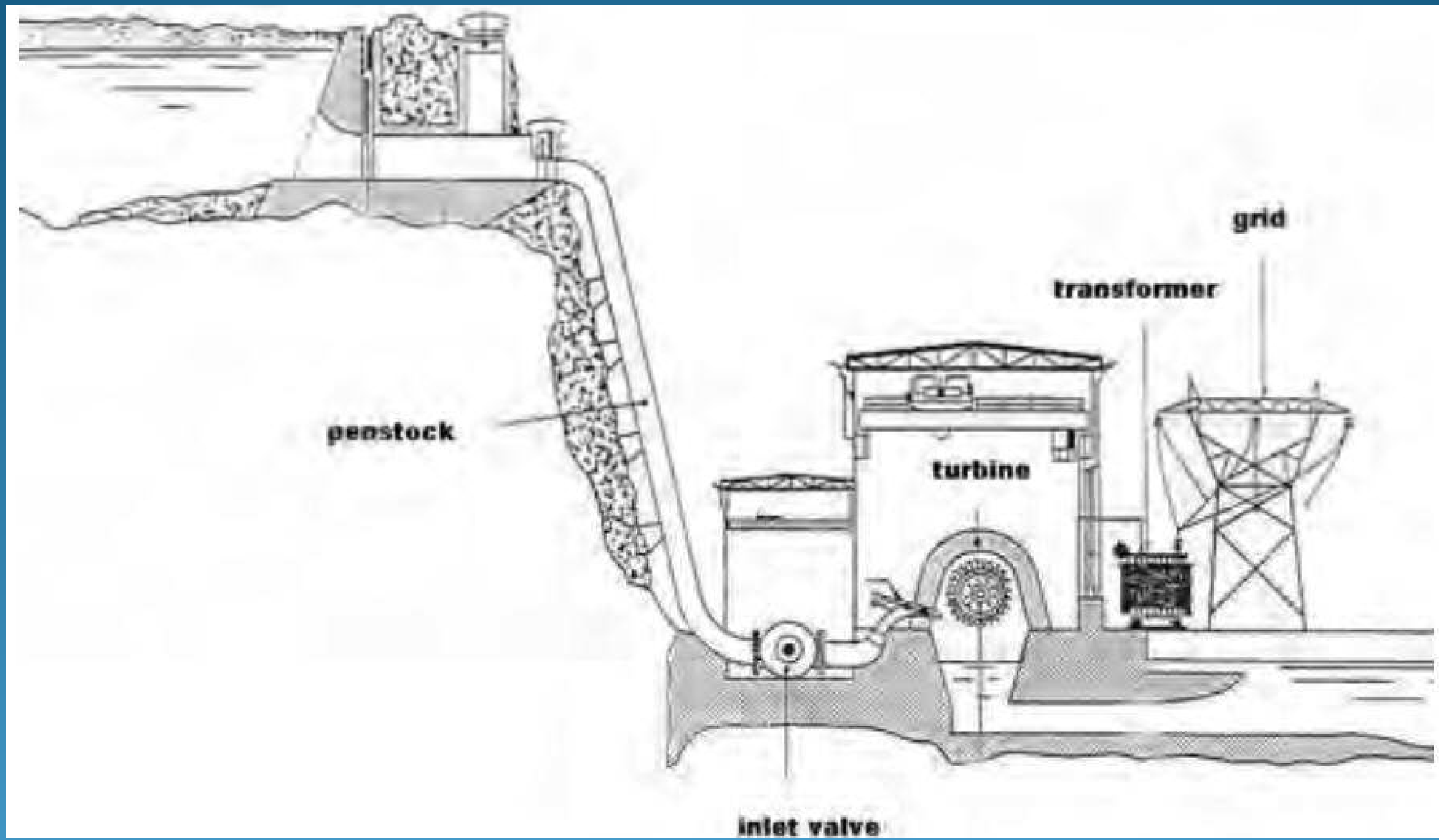
2. Electro-mechanical equipment

- Powerhouse

Objective: protect electro-mechanical equipment from weather hardships.

In the case of the dam, produce additional head and provide storage capacity.




grid
transformer
penstock
turbine
inlet valve

- Hydraulic turbines

Objective: transform the water potential energy to mechanical rotational energy.

Types:

- Reaction turbines (water pressure applies force on the face of runner blades)
- Impulse turbines (water pressure is converted into kinetic energy before entering the runner)

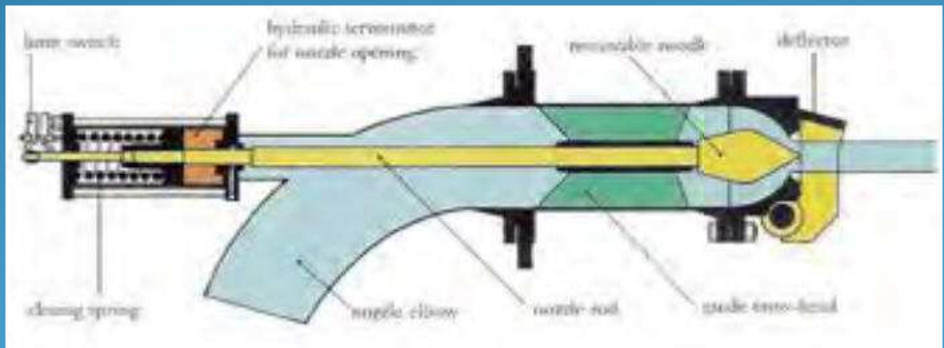
- PELTON turbines

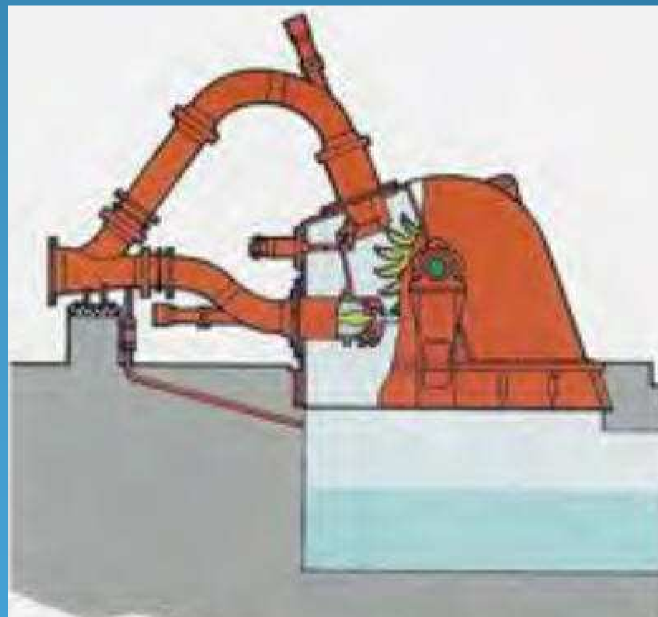
*Wheel with a large number of buckets

* Used for high heads (more than 60m)

* Jet of water through a nozzle with a needle valve (flow control)

* Good efficiency from 30% to 100% of the maximum discharge



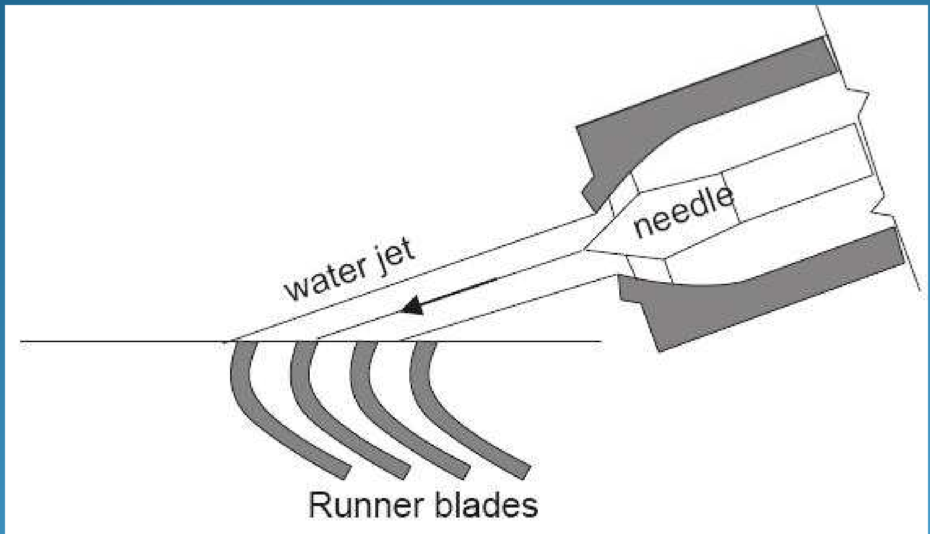


http://www.youtube.com/watch?v=Jd5BN7SPkqI

- TURGO turbines

***High rotational speed**

* Lower efficiency than Pelton turbines

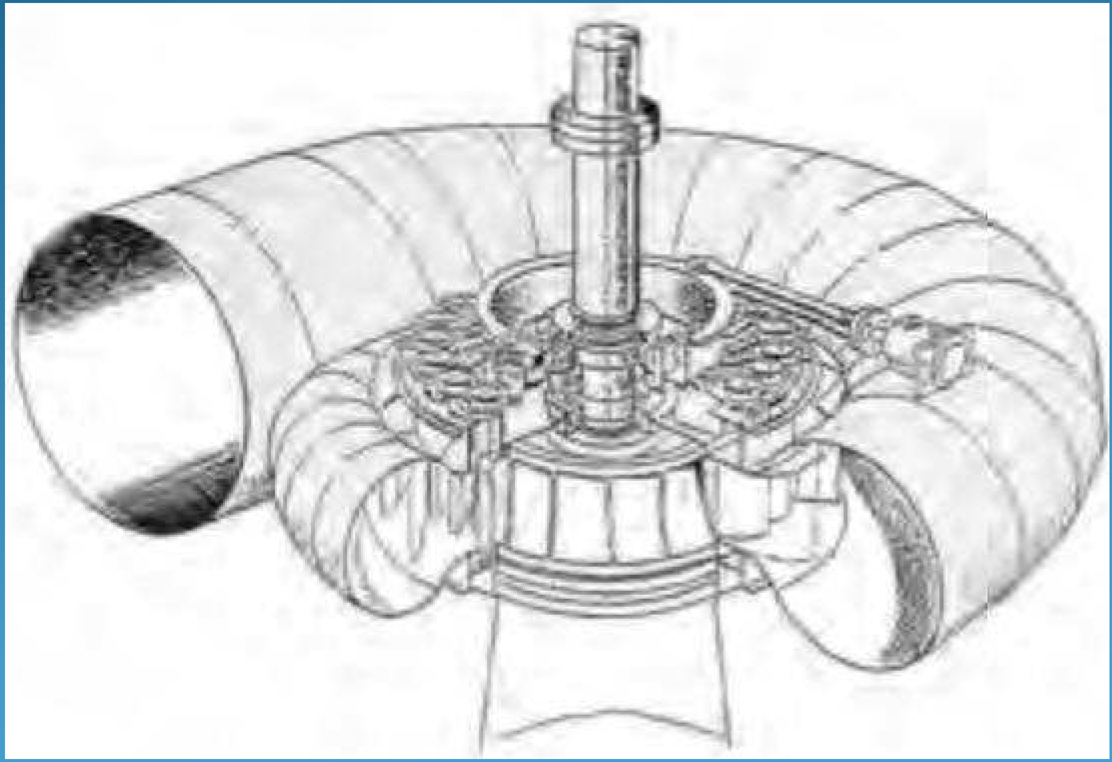


- FRANCIS turbines

*Fixed runner blades and adjustable guide vanes

* Used for medium heads (25-350m)

*Discharge and inlet angle control



http://www.youtube.com/watch?v=IZdiWBEzISM

- KAPLAN turbines

*Axial-flow reaction turbines

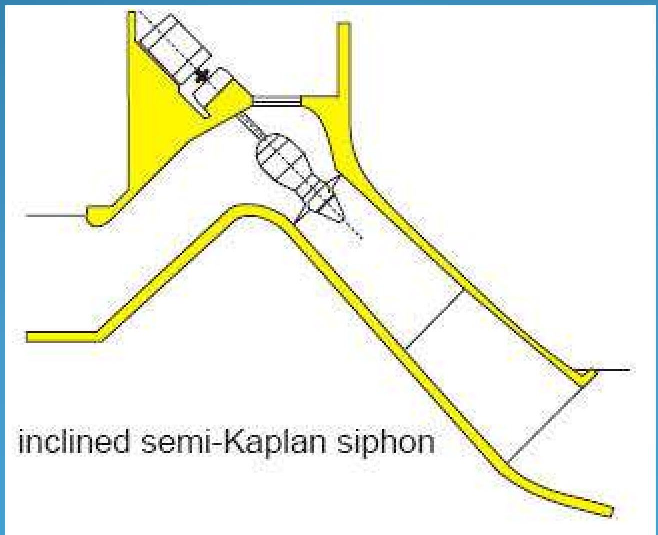
* Used for low heads (2-40m)

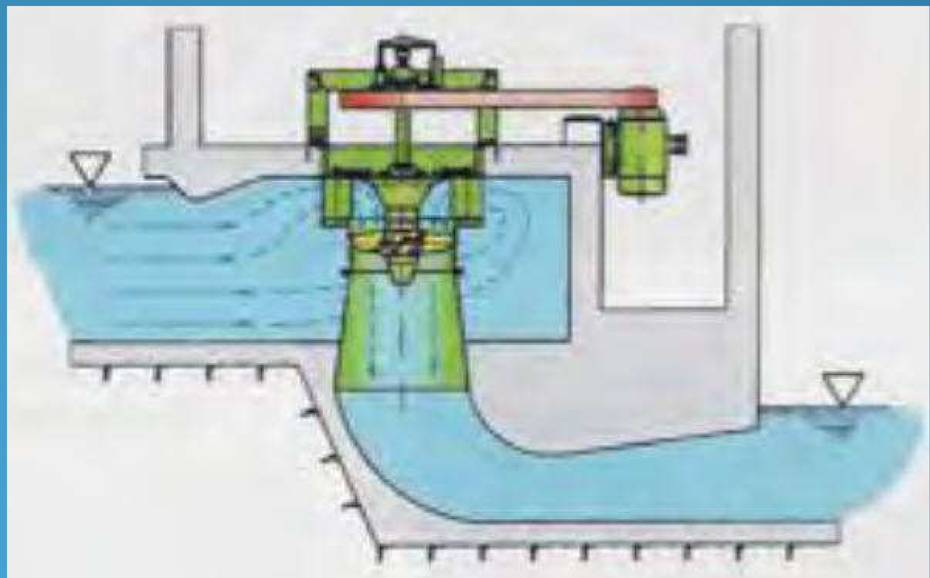
*Adjustable runner blades

*May or may not have adjustable guide-vanes

(single or double regulated)

* Single regulated--- adaptation to varying flow





- **PROPELLER turbines**
  * Fixed runner blade Kaplan
  * Used when both head and flow constant

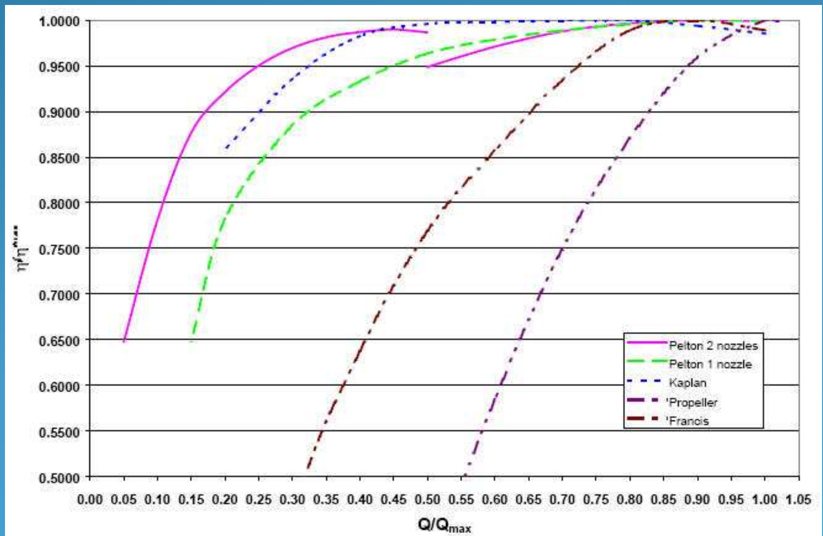
- Turbine selection criteria

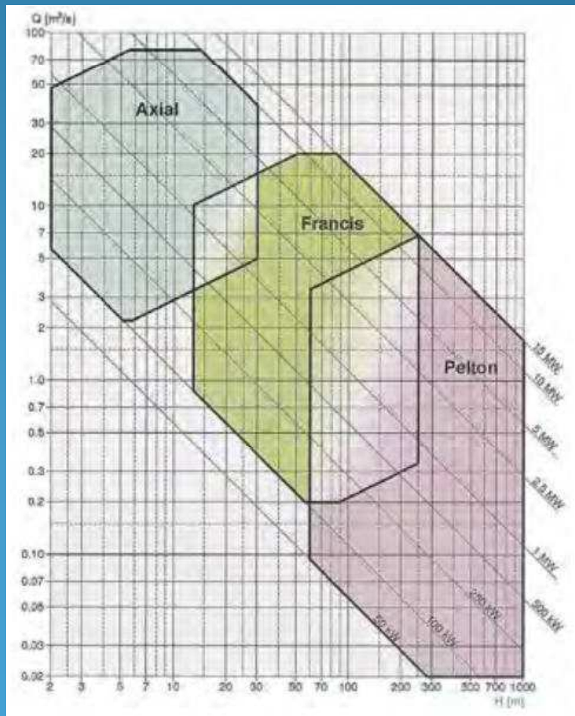
* Dependent on

head (low or high)

flow (constant or varying, low or hig)

* Important also the efficiency curve of each type of turbine





USURBILGO LANBIDE ESKOLA

- Turbine selection criteria

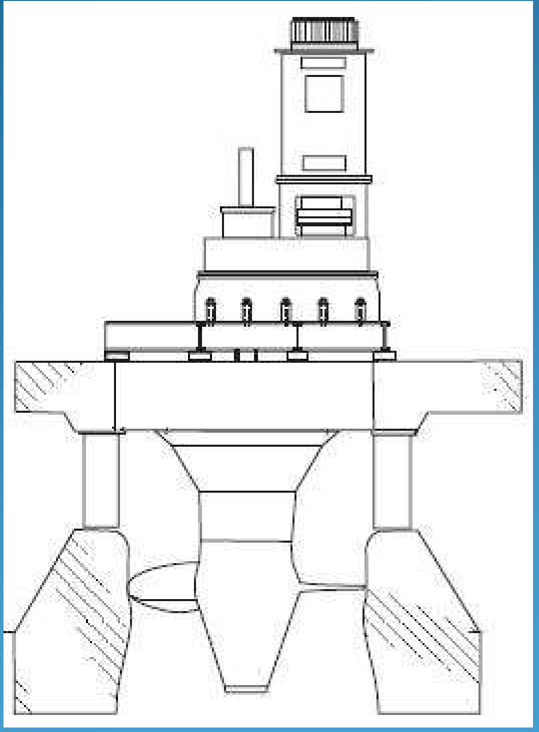
* Generally, the type of turbine to use
  - -Kaplan: low head/variable discharge
  - -Francis: medium head/constant discharge
  - -Pelton: high head/variable discharge

Turbine type	Acceptance of flow variation	Acceptance of head variation
Pelton	High	Low
Francis	Medium	Low
Kaplan double regulated	High	High
Kaplan single regulated	High	Medium
Propeller	Low	Low

- Speed increasers

* Direct coupling recommended

* Required in low head schemes to meet standard alternators speed



Number of poles	Frequency 50 Hz	Frequency 60Hz	Number of poles	Frequency 50 Hz	Frequency 60 Hz
2	3000	3600	16	375	450
4	1500	1800	18	333	400
6	1000	1200	20	300	360
8	750	900	22	272	327
10	600	720	24	250	300
12	500	600	26	231	377
14	428	540	28	214	257

- Generators

Objective: transform mechanical energy into electrical energy

* Types:

- Synchronous:

  DC electric exciter (rotating, brushless or static) associated to a voltage regulator

  Can run isolated from the grid

- Asynchronous:

  Excitation current from the grid

  Cheaper / No need of voltage regulation

- Variable speed-Constant frequency systems

  Frequency converter permits variable speed

- Voltage regulation and synchronisation

* Asynchronous generator:
    - Mains supply define frequency
    - Control of runaway speed

* Synchronous generator:
    - Previous synchronisation of voltage, frequency, phase angle with the mains speed

- Turbine control (off-grid systems)

Objective: keep turbine speed

Control of:

- Load from the generator
- Flow

Actuate on:

- Number of load connected to the system
- Opening of valves, nozzles, etc.

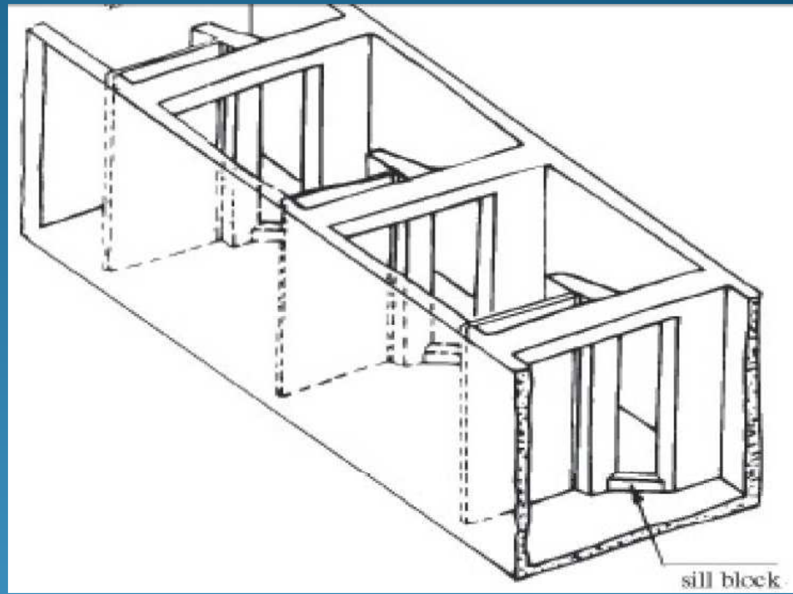
6. Environmental impacts

- Sonic: turbine and speed increasers
- Landscape: specially in high mountain hydro schemes
- Biological: fish passing conditions (flow variability)

  Need for maintainance of a **reserved flow**

- Fish passes

* Weir and pool
* Fish ladder
* Vertical slotted fish pass



7. Economic analysis

- Economic evaluation:
  * Static methods: Pay-back method
  * Dynamic methods: Net Present Value, IRR

- Tariffs and incentives
  * Feed-in tariffs
  * Tax discounts
  * Green certificates

8. Administrative procedures

- Energy regulation: water rights (authorization)
- Environmental Impact Assessment
  - * Reserved flow
- Electricity generation license

Grupo turbogenerador	30%
Equipos Eléctricos, Regulación, Control y Línea	22%
Ingeniería y Dirección de Obra	8%
Obra Civil	40%

	Central fluyente	Central pie de presa
Potencia instalada	5.000 kW	20.000 kW
Ratio medio inversión	1.500 €/kW	700 €/kW
Horas equivalentes	3.100	2.000
Energía producida	15.000 MWh/año	40.000 MWh/año
Vida útil	25 años	25 años
Precio venta energía	6,89 c€/kWh (1ºˢ 25 años) 6,12 c€/kWh (resto)	6,89 c€/kWh (1ºˢ 15 años) 6,12 c€/kWh (resto)
Coste mantenimiento	225.000 €/año 0,014516 €/kW	280.000 €/año 0,007 €/kW
Canon hidráulico		0,014 €/kW Grupo