

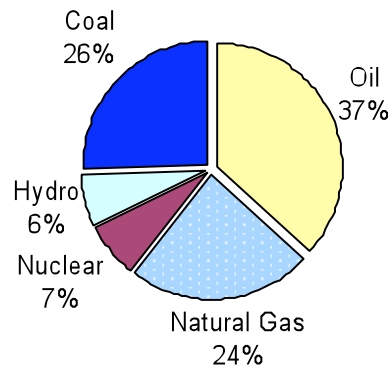


Overview

- Hydroelectric penetration
 - Hydro plants worldwide
- Hydropower plant types
 - Turbine types
- Determining power output
 - Equations for characterizing the energy capture
- Pumped storage

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Power Generation Worldwide



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World's Largest Hydroelectric Plants

Name of dam	Location	capacity (GW)	Year of Operation
Three-Gorges	China	18	-
Itaipu	Brazil/Paraguay	14	1983
Guri	Venezuela	10	1986
Grand Coulee	Washington	6.5	1942
Krasnoyarsk	Russia	6	1968
Churchill Falls	Canada	5.4	1971
Bratsk	Russia	4.5	1961

- Comparison to typical coal and nuclear plant capacities?

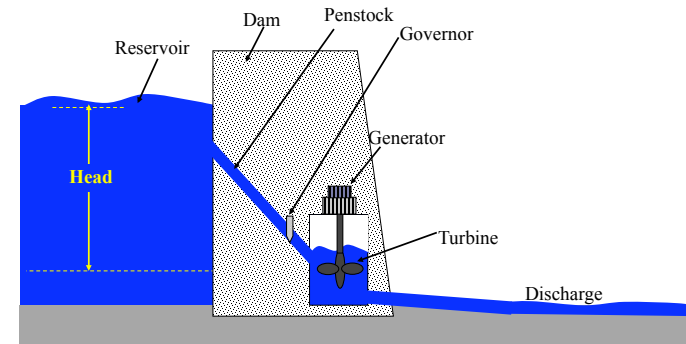
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Types of Hydro Power Plants

- **Impoundment Hydropower:**
 - Most common type
 - Used with high heads.
- **Diversion Hydropower:**
 - Used with low heads and strong current
 - Divert part of river with strong current (no reservoir)
 - Lower capacity than impoundment
- **Pumped Storage Hydropower:**
 - Dual action water flow system.
- **Small-scale hydroelectric plants:**
 - Mini- and micro- hydro
 - Run of the river

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Impoundment Hydropower



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Main Components of Hydropower

- **Dam:**
 - The barrier to create a reservoir
 - Potential energy available for conversion
 - Proportional to the volume and height of the lake
- **Grand Coulee dam** in Washington State
 - 170 m in height, and 1.5 km in length.
 - The volume of the concrete in the dam is almost enough to build 10,000 km of 2-lane highway

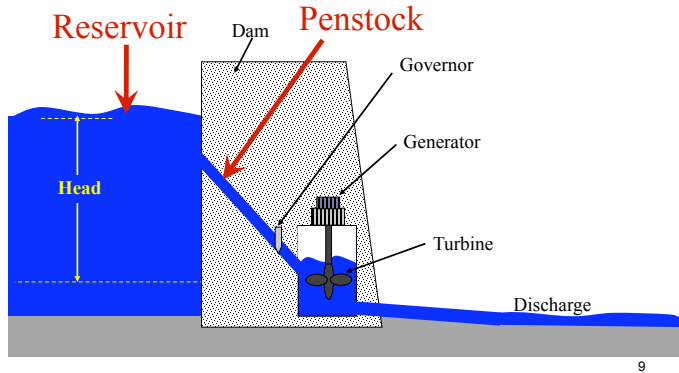
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Main Components of Hydropower

- **Reservoir:**
 - Lake behind the dam.
 - Grand Coulee dam created an artificial lake 250 km long, with over 800 km of shore line.
- **Penstock:**
 - Large pipe that channels water from the reservoir to the turbine
 - The water flow in the penstock is controlled by a valve called **governor**.

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Impoundment Hydropower

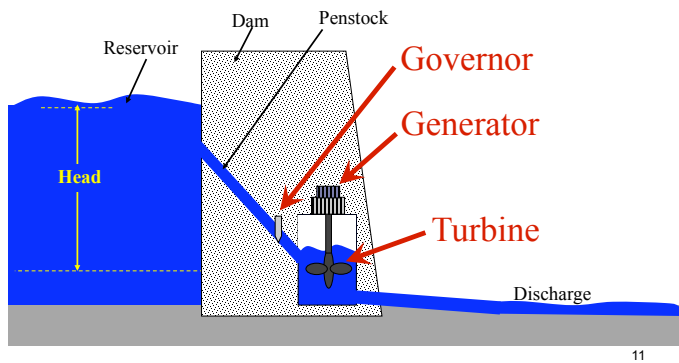


Main Components of Hydropower

- **Governor:**
 - The valve that *regulates* the flow of water in the penstock.
- **Turbine:**
 - An advanced water wheel.
 - The electrical generator is mounted on the same turbine shaft
- **Generator:**
 - Converts mechanical to electrical energy.

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Impoundment Hydropower



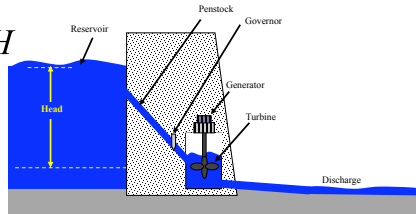
Hydroturbine-generator units at Grand Coulee Dam, each unit \approx 50MW



Calculations: Reservoir Potential Energy

$$PE_r = M * g * H$$

$$M = Vol * \rho$$



- M: the water mass behind the dam in kg
 - g: the acceleration of gravity in m/s²
 - H: the water head in m.
 - PE_r: Potential Energy of reservoir in Joules (Watt s)
 - Vol: the volume of water in m³
 - ρ: the water density in kg/m³. (At 20°C, ρ=1000 kg/m³)
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Reservoir Potential Energy

How much energy is in the reservoir?

- The volume of the reservoir behind a dam is 15 km³
- The water head is 75 m

Solution:

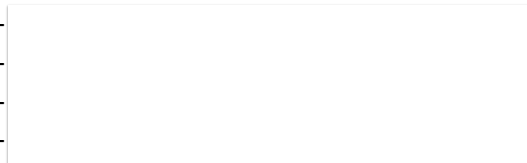
$$PE_r = Vol * \rho * g * H = 15 * 10^9 * 1000 * 9.8 * 75$$

$$= 1.1 * 10^7 \text{ GJ}$$

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Factors in 'Dispatching' Hydro?

- 1*10⁷ GJ appears almost infinite
- What are reasons for careful scheduling of hydroelectric use?



- Issues in California and Canada

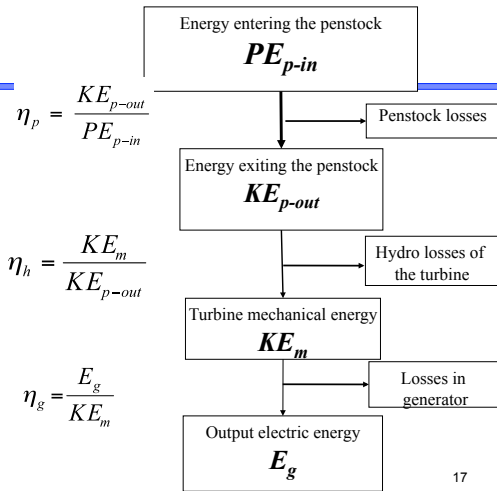
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The Elements for Determining Electrical Output Are...?

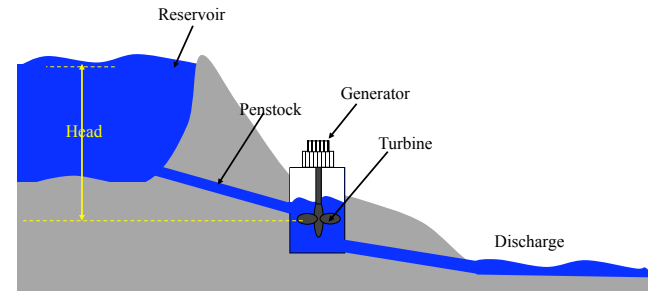
- Potential energy in the reservoir
- Penstock
 - Potential energy of water entering the penstock
 - Kinetic energy of water leaving the penstock ($\eta_p = KE/PE$)
 - Mechanical power of water leaving the penstock, P_w
- Turbine
 - Kinetic energy captured by the turbine
 - Mechanical power of the water striking the turbine, P_t
 - Hydroelectric conversion efficiency, C_p → losses
 - Mechanical output of the turbine P_m = C_pP_t
- Generator efficiency η_g

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Losses
figure
6.22



Reservoir-Type Small Hydro System



Potential energy in reservoir

$$PE_r = W * H$$

Weight of water in reservoir Water head

$$W = m * g$$

$$PE_r = m * g * H$$

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Potential energy of water entering penstock

$$PE_{p-in} = m * g * H$$

mass of water entering penstock Water head

Water flow in penstock $f = \frac{m}{t}$

$$PE_{p-in} = f * t * g * H$$

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Kinetic energy of water exiting penstock

$$KE_{p-out} = \frac{1}{2} m v^2 = \frac{1}{2} vol * \rho * v^2$$

Water velocity
Water density, 1000kg/m³

$$KE_{p-out} = 500 vol * v^2 \quad \quad \quad vol = A v t$$

Cross section of penstock

$$KE_{p-out} = 500 A * v^3 * t$$

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Solution

- What do we know?
- What expressions do we have to solve for the height of the dam?

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Example

- A man owns a property with a small river. He wants to build a dam to create a reservoir for a small hydro system. In order for him to generate 4 MW of electricity, compute the height of the dam.
 - The site can accommodate a penstock of 2.5m in diameter.
 - Assume that the penstock efficiency is 97%, the hydro turbine efficiency is 50%, and the generator efficiency is 95%.

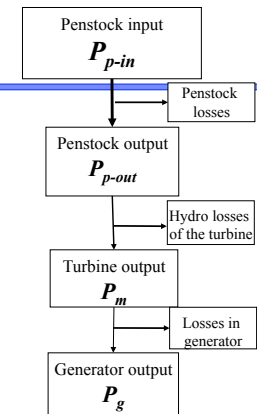
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Solution

First solve for the output power of the penstock

$$P_m = \frac{P_g}{\eta_g} = \frac{4}{0.95} = 4.2 \text{ MW}$$

$$P_{p-out} = \frac{P_m}{\eta_h} = \frac{4.2}{0.5} = 8.4 \text{ MW}$$



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Solution

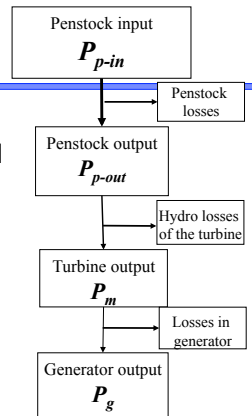
Next solve for the velocity of the water in the penstock, as this will allow us to write an expression for “H”

$$KE_{p-out} = 500 A * v^3 * t$$

$$P_{p-out} = \frac{KE_p}{t} = 500 A * v^3$$

$$v = \sqrt[3]{\frac{P_{p-out}}{500 A}} = \sqrt[3]{\frac{8.4 * 10^6}{500(\pi * 1.25^2)}} = 15.1 \text{ m/s}$$

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Solution

Finally, use the expression and value for the efficiency of the penstock to solve for the necessary height of the dam.

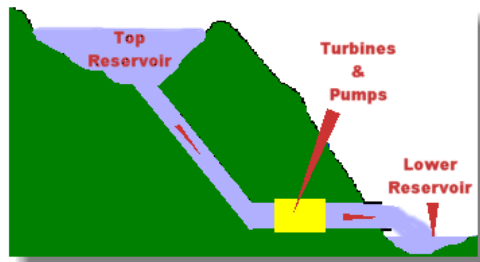
$$\eta_p = \frac{KE_{p-out}}{PE_{p-in}} = \frac{v^2}{2gH}$$

$$H = \frac{v^2}{2g\eta_p} = \frac{15.1^2}{2 * 9.8 * 0.97} = 12 \text{ m}$$

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* Pumped Storage *

- What are the economics behind using pumped storage?



<http://www.darvill.clara.net/altenerg/pumped.htm>

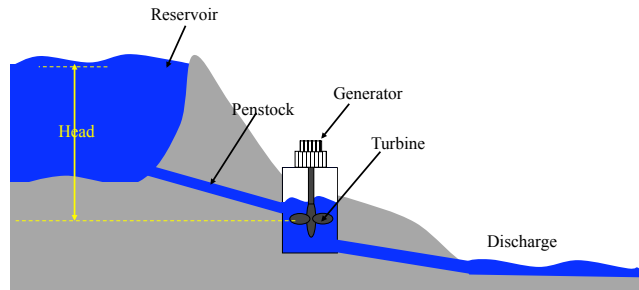
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Small Scale Hydro

- Small-scale, up to a few MW capacity
 - Mini- and micro-hydro
- Reservoir-Type
- Diversion-Type
 - Run of the river = diversion type

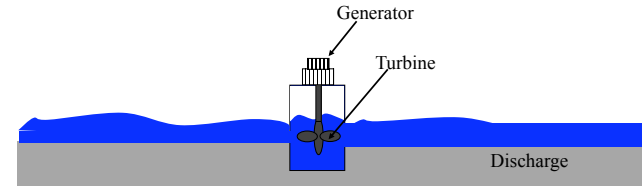
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Reservoir-Type Small Hydro System



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Diversion-Type Small Hydro System



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Small Scale Hydro

Country	micro (kilowatts)	mini (kilowatts)	small (megawatts)
United States	< 100	100 - 1000	1 - 30
United States	< 100	100 - 1000	-
China	-	< 500	0.5 - 25
USSR	< 100	-	0.1 - 30
France	5 - 5000	-	-
India	< 100	101 - 1000	1 - 15
Brazil	< 100	100 - 1000	1 - 30
Norway *	< 100	100 - 1000	1 - 10
various	< 100	< 1000	< 10

From: <http://microhydropower.net/size.php>

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Summary

- Categories of hydroelectric plants
- Components of a hydro facility
- Steps in calculating the power output of a hydroelectric facility
- Pumped storage

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