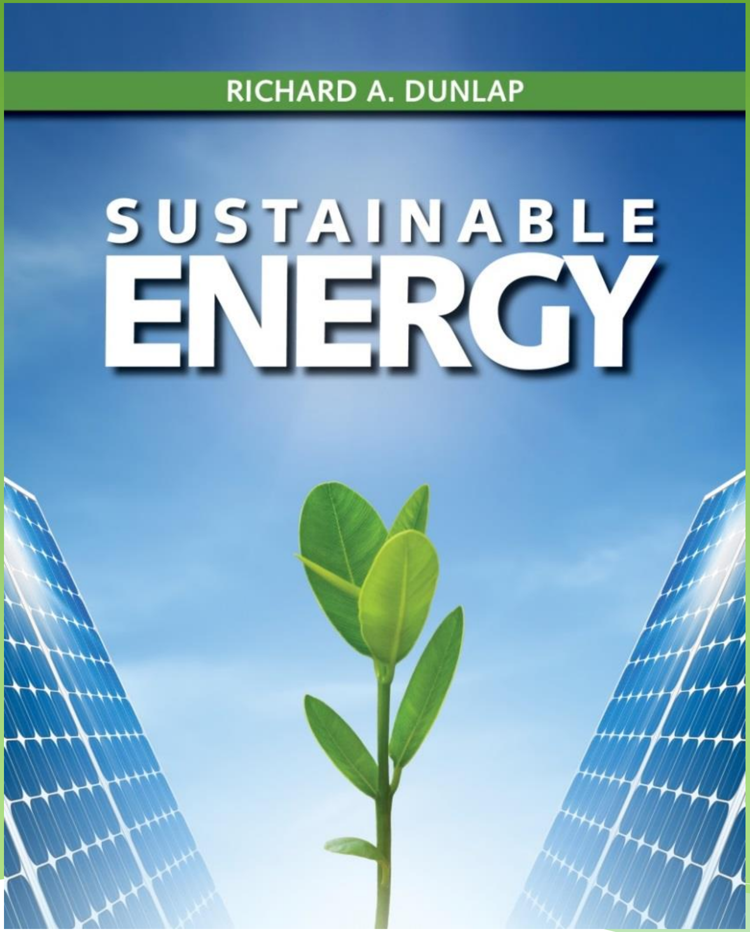
Sustainable Energy



Chapter 11

- Hydroelectric Energy

Learning Objectives

- The potential energy associated with water.
- The kinetic energy associated with water.
- The different types of water turbines and their applications.
- The design and properties of high head hydroelectric systems.
- The design and properties of low head and run of the hydroelectric systems.
- The availability and utilization of hydroelectric energy worldwide.
- The effects of hydroelectric energy on the environment and risks to society.

Energy from water

The energy associated with water running downhill can be harnessed by turbines in two ways:

(1) potential energy associated with water
confined behind a dam

(2) kinetic energy associated with flowing water

High head systems

High head systems utilize the first approach

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Figure 11.2: Three Gorges hydroelectric facility in China. This is the world's largest hydroelectric facility, currently rated at 22,500 MW_e. The environmental consequences of the Three Gorges Dam are discussed in Energy Extra 11.2.

head refers to the height of the water above the turbine

Low head and run-of-the-river systems

Run of the river systems use the second approach

Richard A. Dunlap

Figure 11.3: Small run-of-the-river hydroelectric facility on the Musquash River in New Brunswick, Canada, with output of about 7 MW_e. The cylindrical tank is a surge tank used for evening out fluctuations in water flow to the turbines.

Low head systems are intermediate between these two

Analysis of high head systems

Gravitational potential energy is given as

$$E = mgh \tag{11.1}$$

Power is given as the energy per unit time

$$P = \frac{E}{t} = \frac{m}{t}gh \tag{11.2}$$

This may be written as

$$P = \rho\varphi gh \tag{11.3}$$

where φ is the flow rate in volume of water per unit time

Analysis of run-of-the-river systems

The kinetic energy associated with a moving mass of water is

$$E = \frac{1}{2}mv^2 \qquad (11.4)$$

The power generated is

$$P = \frac{1}{2}\left(\frac{m}{t}\right)v^2 \qquad (11.5)$$

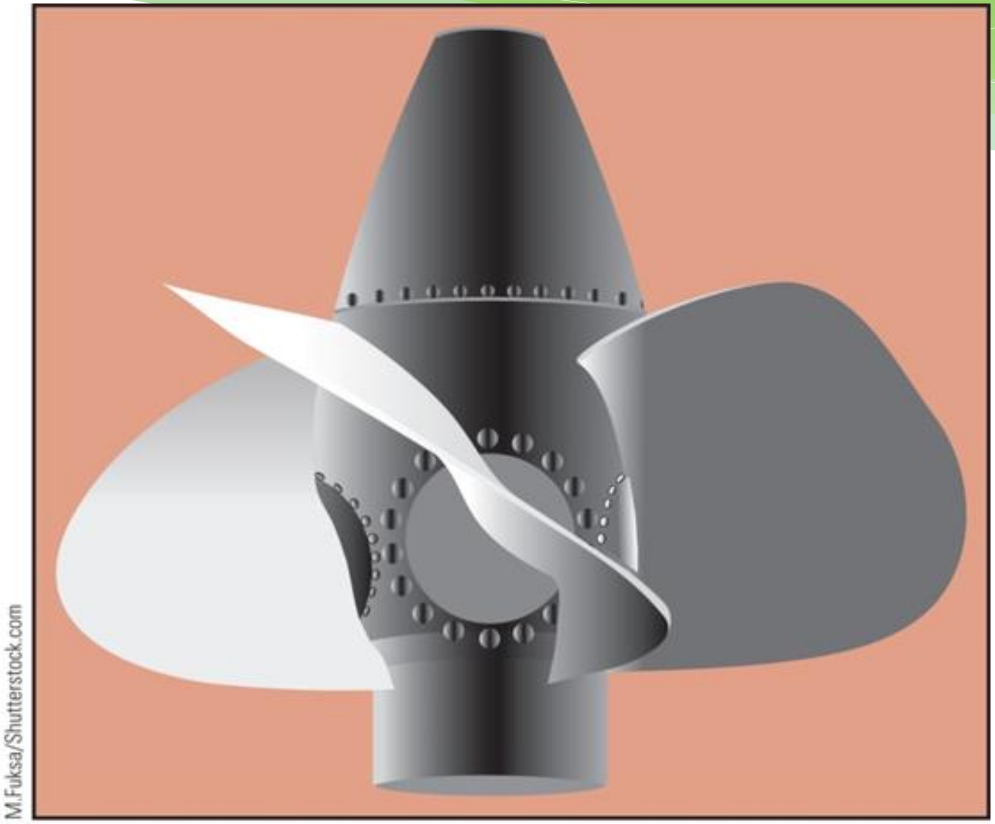
or

$$P = \frac{1}{2}\rho\varphi v^2 \qquad (11.6)$$

Turbine design

There are several different turbine designs in common use which are distinguished by the geometry of the runner (rotating hub and blades).

Kaplan turbine runner



M.Fuksa/Shutterstock.com

Figure 11.5: Kaplan turbine runner.

Francis turbine runner

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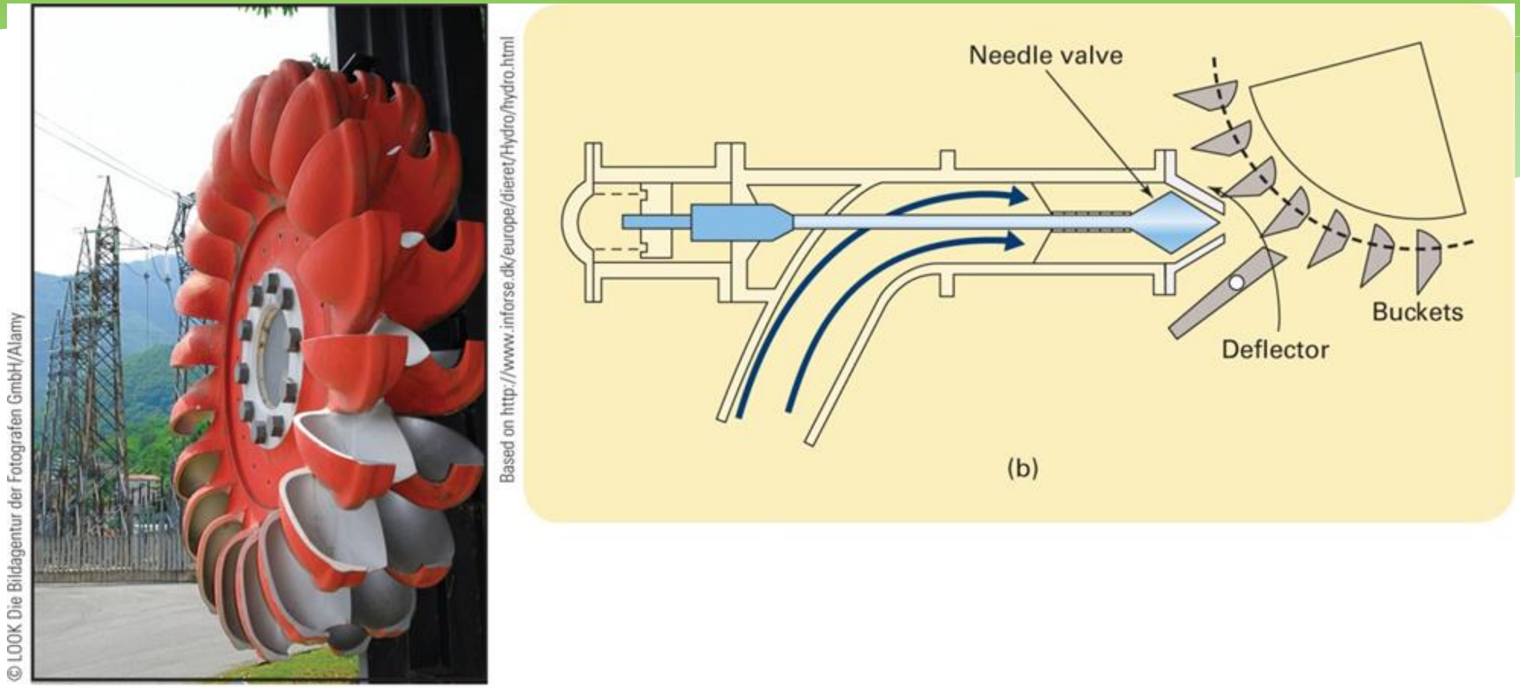
Figure 11.7: Francis turbine runner.

Pelton runner



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Based on http://www.inforse.dk/europe/dieret/Hydro/hydro.html

(a)

(b)

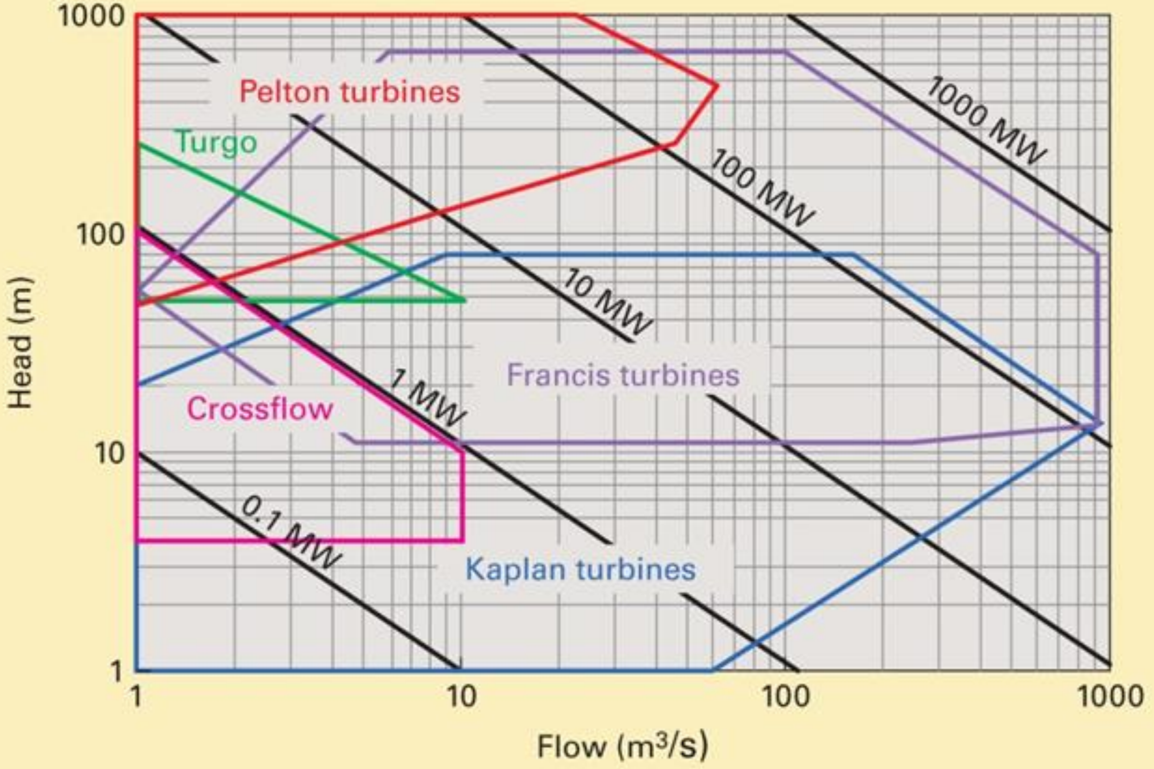
Figure 11.8: (a) Photograph of a Pelton runner; (b) diagram of a Pelton turbine.

Turgo runner

Joseph Hartvigsen

Figure 11.9: A micro-Turgo runner.

Different turbine designs are appropriate for different heads and flow rates



Based on www.hydroni.co.uk, Turbine Application Chart

Figure 11.10: Operating ranges for some common water turbine designs.

Typical turbine applications

Francis turbines are the most commonly used design for high head systems (general vertical axis geometry).

Kaplan turbines are the most commonly used design for low head systems (vertical or horizontal axis geometry).

Design of a high head system

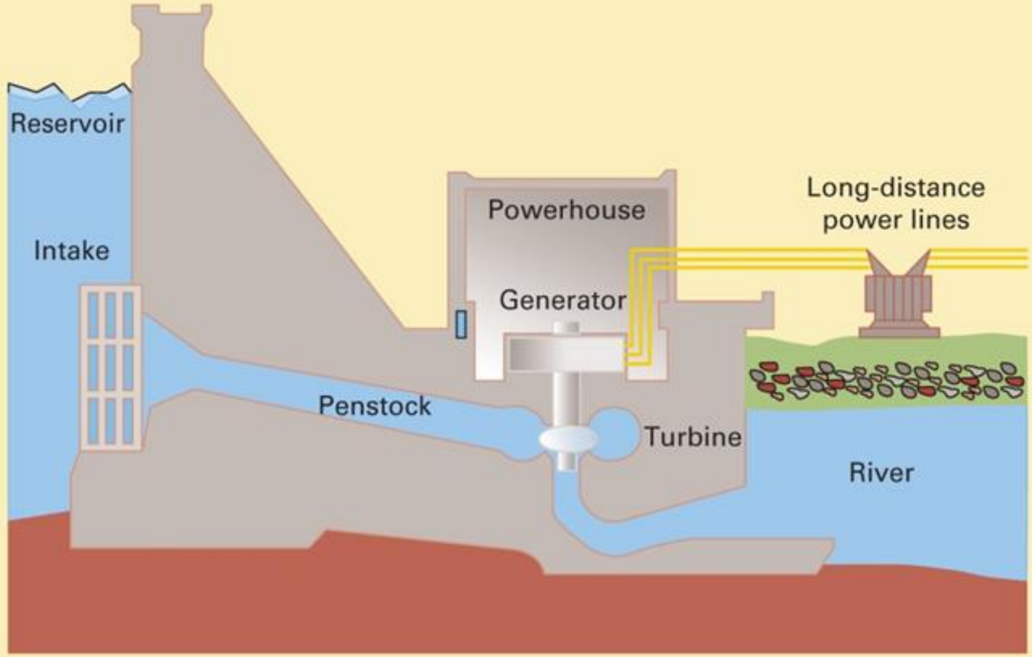
Water impounded behind a dam to create a head

U.S. Bureau of Reclamation photo archives

Figure 11.11: Grand Coulee Dam in Washington State, United States.

generator facility to the left and spillway to the right in the photograph

Cross sectional view of high head facility using vertical axis Francis turbine



Based on http://www.window.state.tx.us/specialrpt/energy/renewable/hydro.php

Figure 11.12: Schematic of a typical high head hydroelectric system showing dam, penstock, and turbine.

penstock used to carry water from source (reservoir) to turbine

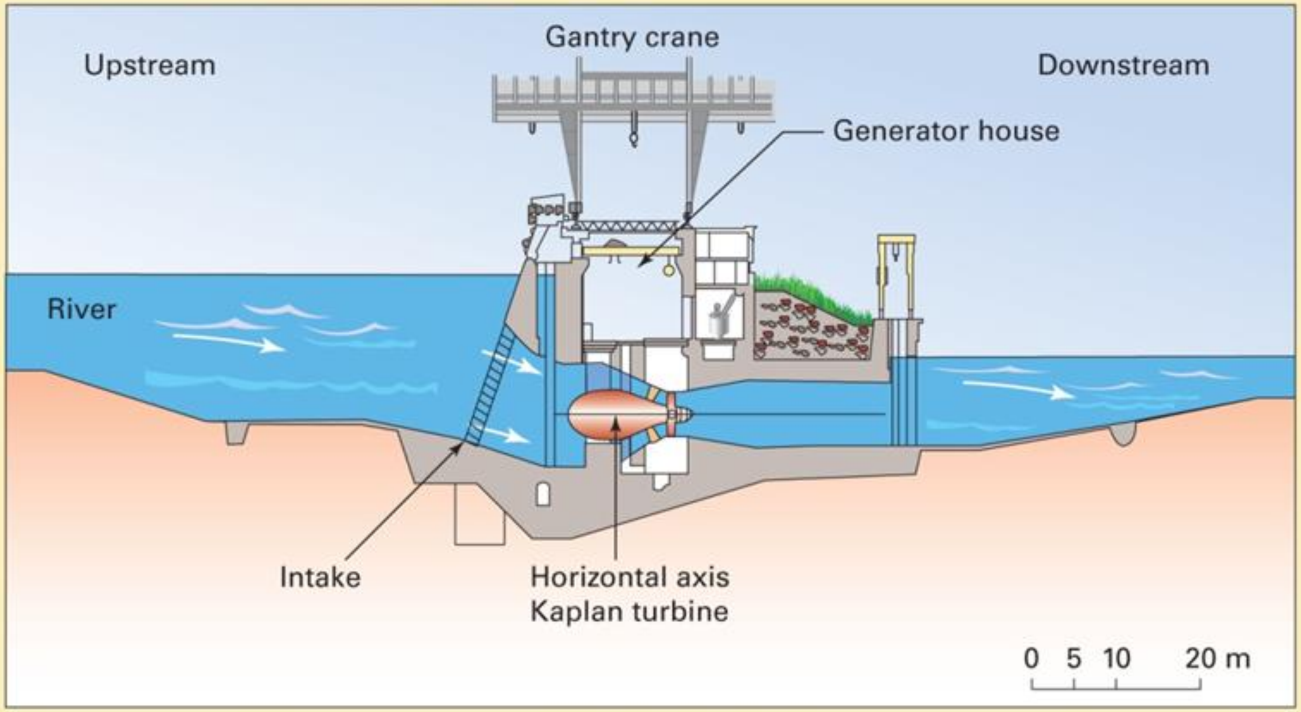
Design of low head and run of the river systems

U.S. Army Corps of Engineers

Figure 11.13: The Libby Dam in Montana.

generator facility to right, spillway to left

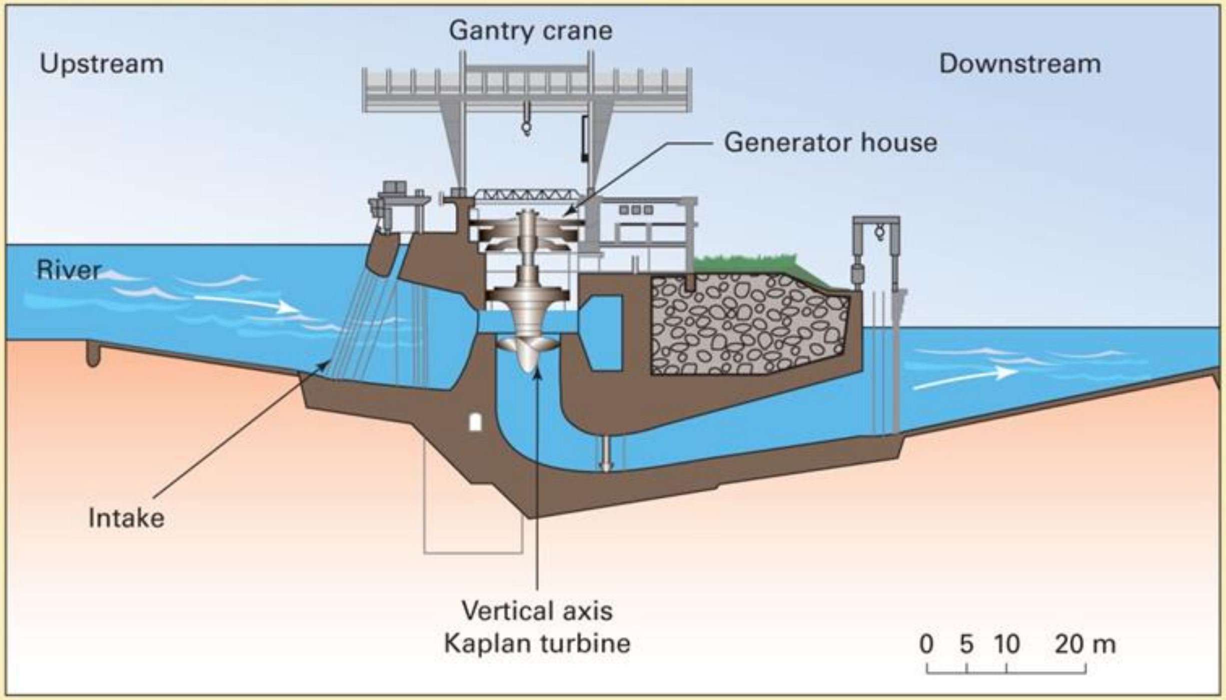
Cross sectional view of low head system using horizontal axis Kaplan turbine



Based on http://de.wikipedia.org/w/index.php?title=Datei:Kraftwerk_Ottensheim-Wilhering_Querschnitt_Krafthaus.jpg&filetimestamp=20051130202844

Figure 11.17: Low head or run-of-the-river hydroelectric generating facility utilizing a horizontal axis bulb (Kaplan-type) turbine.

Cross sectional view of low head system using vertical axis Kaplan turbine



Based on http://en.wikipedia.org/wiki/File:Kraftwerk_Wallsee-Mitterkirchen_Querschnitt_Krafthaus.jpg

Figure 11.18: Low head or run-of-the-river hydroelectric generating facility utilizing a vertical-axis Kaplan turbine.

Penstock can be used to carry water to generator facility

Erick Margarita Images/Shutterstock.com

Figure 11.15: Penstocks used to divert part of a river's flow through a generating station.

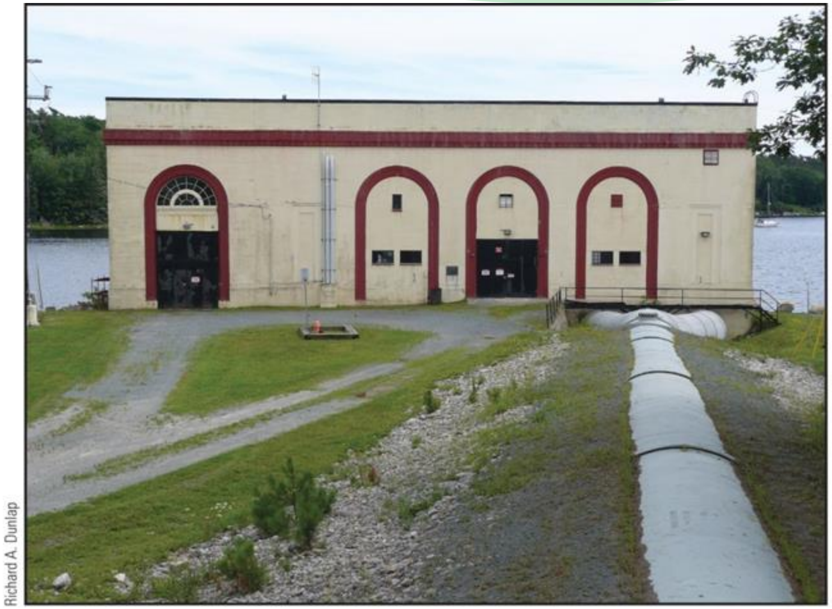


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Figure 11.16: Small hydroelectric facility in Head of St. Margaret's Bay, Nova Scotia, Canada, showing the penstock that supplies the water to the turbines.

World use of hydroelectric power

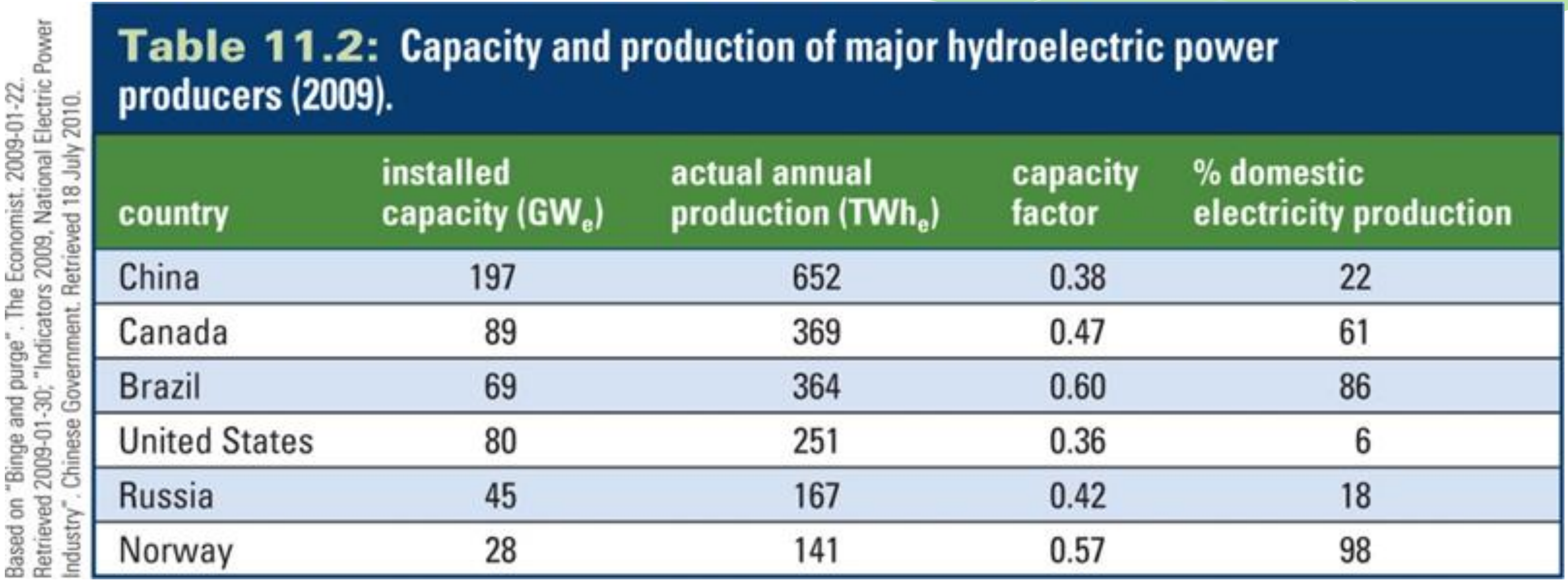


Table 11.2: Capacity and production of major hydroelectric power producers (2009).

country	installed capacity (GW_e)	actual annual production (TWh_e)	capacity factor	% domestic electricity production
China	197	652	0.38	22
Canada	89	369	0.47	61
Brazil	69	364	0.60	86
United States	80	251	0.36	6
Russia	45	167	0.42	18
Norway	28	141	0.57	98

Based on "Binge and purge". The Economist. 2009-01-22. Retrieved 2009-01-30; "Indicators 2009, National Electric Power Industry". Chinese Government. Retrieved 18 July 2010.

Importance of hydroelectric power

about 16% or world's electricity
6% of total world energy

major component of electricity for some countries

e.g. Canada 61%
Norway 98%

less important in the United States

Growth of hydroelectric power in recent years

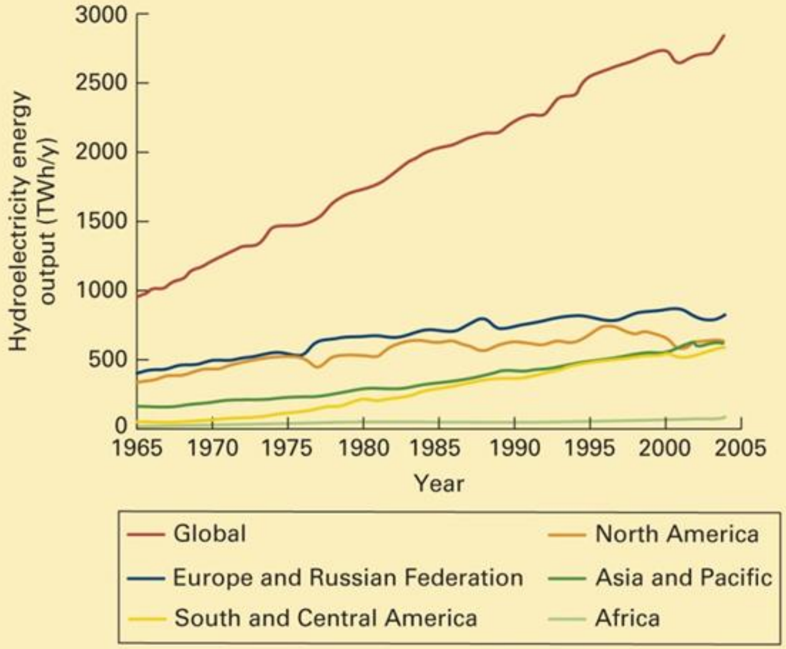


Figure 11.19: Annual production of hydroelectric power worldwide.

Based on http://openlearn.open.ac.uk/file.php/4184/!via/oucontent/course/479/s278_8_f024hi.jpg

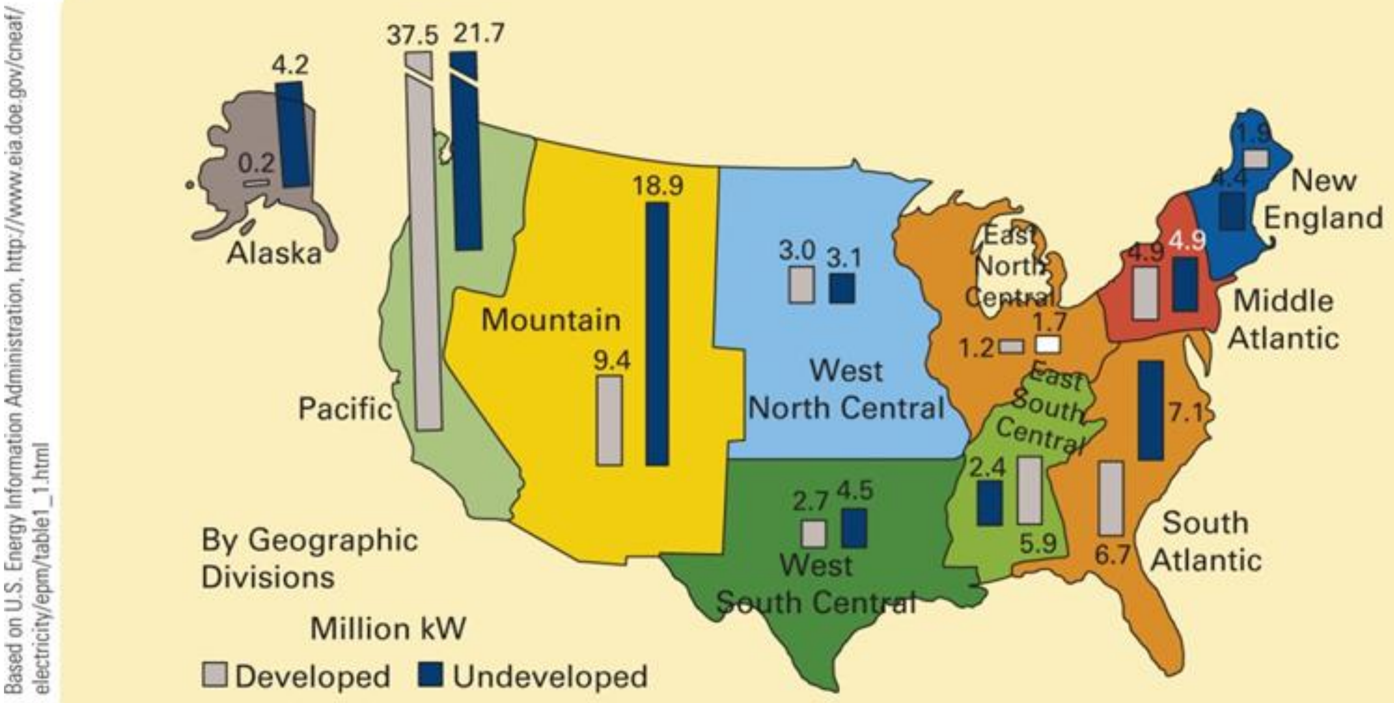
Relatively little growth in Europe and North America
Substantial growth in South America and Asia (particularly China)

No actual growth in U.S. in 40 years

Based on U.S. Energy Information Administration, Electric Power Monthly, http://www.eia.gov/electricity/monthly/

Figure 11.21: Fraction of electricity from hydroelectric generation in the United States as a function of year (yellow line), along with the total hydroelectric generation (blue line).

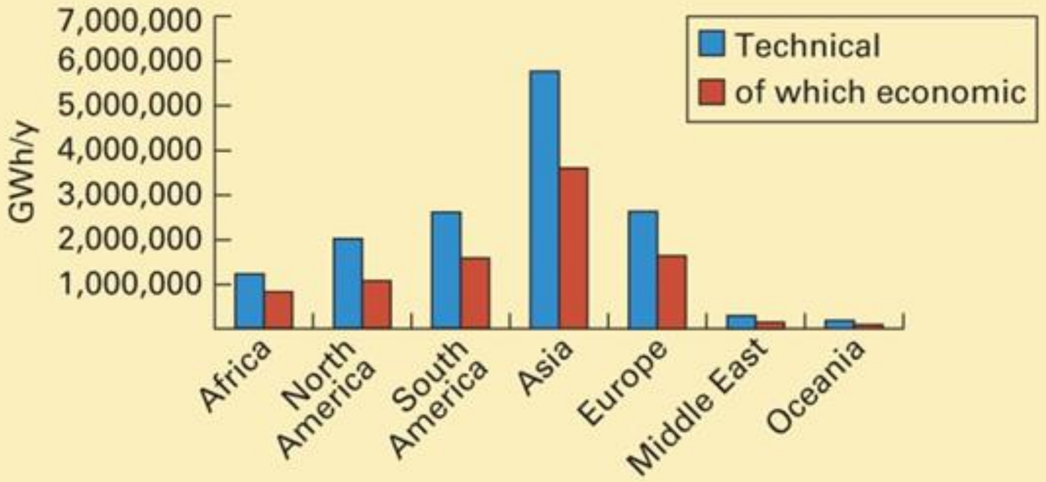
Potential for growth in the U.S.



Based on U.S. Energy Information Administration, http://www.eia.doe.gov/cneaf/electricity/epm/table1_1.html

Figure 11.22: Developed and undeveloped hydroelectric capacity in different regions of the United States.

Potential for growth worldwide



Based on 2010 World Energy Council, Survey of Energy Resources, http://www.worldenergy.org/documents/ser_2010_report_1.pdf

Figure 11.23: Technically viable and economically viable hydroelectric capacity in different parts of the world.

Growth potential greatest in Asia

Environmental consequences of hydroelectric power (high head)

- deforestation (loss of carbon sequestering trees)
- methane production from dead trees
- loss of wildlife habitat
- adverse effects on fish migrations
- loss of agricultural land
- adverse effects on transport of fertile material downstream for agriculture
- social impact
- potential for dam failure

consequences less significant for low head and run-of-the-river facilities

Teton Dam failure 1976

U.S. Bureau of Reclamation

Figure 11.25: Failure of the Teton Dam in Idaho in 1976.

Summary

- Potential energy of water in a reservoir can be used to generate electricity (high head systems)
- Kinetic energy of water flowing in a river can be used (run-of-the-river systems)
- Different designs of turbines are suitable for different applications depending on head and flow rate
- Francis turbines are most suitable for high head applications
- Kaplan turbines are most suitable for low head and run-of-the-river applications
- Hydroelectric power accounts for about 16% of the world's electricity production
- Some increase in capacity (particularly in Asia) is possible
- Environmental consequences of hydroelectric power (particularly high head facilities) need to be considered carefully