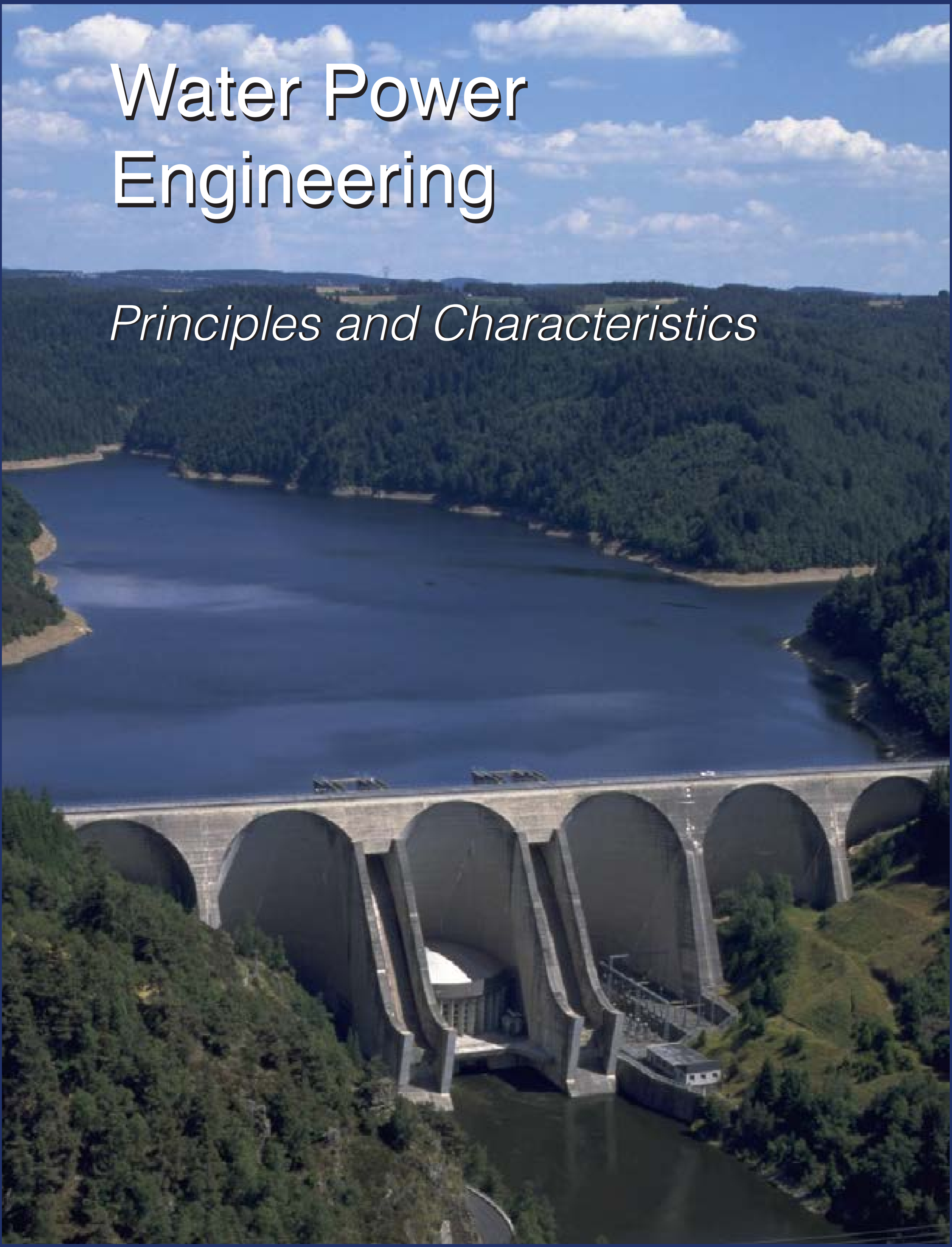
J. van Duivendijk

Water Power Engineering

Principles and Characteristics



Lecture notes CT5304
Edition april 2014 with appendix by
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Module name: Water Power Engineering
Principles and Characterstics

Module code: CT 5304

Date: 03 – 2007

TU Delft
Faculty CiTG

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On behalf of the Section of Hydraulic Engineering published by:
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internet: http://www.vssd.nl/hlf

Preface

These lectures on water power engineering concern the design and construction of hydraulic engineering works required for the generation and transport of (hydro-electric) energy.

The energy in water resources is present as potential or kinetic energy. Accordingly, one may generate hydro-electric energy from water in rivers and streams, from waves, marine currents and tides, while energy can also be generated by making use of temperature and density differences.

In these lectures the emphasis will be on the generation of hydro-electric energy from rivers, because a great number of hydraulic works are needed to pursue this aim. In this context the following works are mentioned: reservoir dams (built from non-cohesive materials or concrete), spillways and intake structures in reservoirs, water conveyance systems and hydropower plants.

Finally, the works required to extract energy from the water in seas and oceans will be discussed. Most of these works are, however, still at an early stage of their development.

Many hydraulic engineering works built for the purpose of energy generation are situated outside the Netherlands in surroundings that are completely different, in all aspects, from the Dutch surroundings. Special attention will therefore be paid to the typically non-Dutch features in these works, such as:

- multipurpose aspects of works;
- founding of structures on rock;
- economics of multipurpose reservoir systems;
- lack of data.

Internationally, the range of knowledge and experience in fields such as large dams and hydropower is very large. Accordingly, the material presented in these lecture notes can be viewed as nothing more than an introduction to the subject.
When compiling these lecture notes an attempt has, however, been made:

- to explain to students the principles and systems that are at the base of the design and construction of hydraulic engineering works required for the generation of energy from water in rivers and in the sea;
- to show students the way to existing handbooks, congress proceedings and magazine articles.

These lecture notes, CT5304, form an updated and translated version of the lecture notes F20 (later re-coded as CT wa5304, subsequently CT5304) ”Energiewaterbouwkunde”

(Water Power Engineering) (1989). The latter, in turn, were based on a complete revision of the tentative lecture notes for Water Power Engineering f20b (1983) and the (much older) outdated lecture notes for "Waterkracht" (Hydropower), f.20 and f.21.

Delft, March 2004

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ACKNOWLEDGEMENTS

The author is indebted to a great number of organizations, institutes, etc. for making available items of interest for these Lecture Notes like photographs and other records of dambuilding (tables, graphs,drawings, etc.).
In listing them below he wishes to express his sincere gratitude to each for information and photographs furnished.

Austrian Committee on Large Dams, Vienna, Austria
Brazilian Committee on Dams
Électricité d' Émosson SA, Martigny, Suisse
Hydro-Québec, Headquarters, Montreal, Canada
Institution of Civil Engineers, London, United Kingdom
International Commission on Large Dams (ICOLD), Paris, France
International Energy Agency (IEA)
International Journal 'Hydropower & Dams', Sutton, United Kingdom
International Magazine 'Water Power and Dam Construction', Sidcup, United Kingdom
John Wiley & Sons Inc, Permissions Department, Hoboken U.S.A
Médiathèque d'Electricité de France, Paris, France
Rendel Parkman, Consulting Engineers, United Kingdom
Royal Haskoning, Consulting Engineers, Nijmegen, Netherlands
Shell Planning, London, United Kingdom
United States Bureau of Reclamation, Denver, Colorado, U.S.A
Verlag Glückauf GmbH, Essen, Germany
World Commission on Dams (WCD), Cape Town, South Africa
World Resources Institute.

GLOSSARY OF SOME ABBREVIATIONS, DEFINITIONS, UNITS AND SYMBOLS USED IN THE TEXT

a. Abbreviations

m.a.s.l.	meters above sea level
ICOLD	International Commission on Large Dams
WCD	World Commission on Dams
IHA	International Hydropower Association
PATO or PAO	Stichting Postdoctoraal Onderwijs in de Civiele Techniek
WPDC	Water Power and Dam Construction (magazine)
HPD	Hydropower & Dams (technical journal)

(Note: abbreviations which are only used in a specific chapter are explained in that particular chapter).

b. Definitions

- Q_x is the discharge which is exeeded during x % of the time (in hours or days) available in a year (i.e Q_{25}, Q_{50}, Q_{100} etc.).
- Q_A is the plant discharge of a run-of-river plant, i.e. the total discharge through all the turbines at their rated discharge.

c. Units

- Volume of a reservoir in hm^3 (= million m^3) or km^3 (= billion m^3 = 10^9 m^3), sometimes in acrefeet (= 1233.52 m^3).
- Power or Capacity in watt (W), kilowatt (kW) or megawatt (MW). 1 MW is one million watt, 1 watt = 1 J/s = 1 N.m/s
  sometimes in "PK" (1 PK = 0.7355 kW) or in UK Horsepower "HP" (1 HP = 0.7457 kW).
- Energy in joules (J), kWh, MWh of GWh,
- 1 GWh = 1 million kWh = one thousand MWh.
  1 joule (J) = 1 N.m.
  1 kWh = 3,6 x 10^6 J = 3,6 MJ
- Force in newton N, kN
- Stress in pascal (Pa), kPa or MPa (tensile stress, compressive stress, shear stress)
  1 Pa = 1 N/m^2
- Time in seconds (s), hours (h). For technical purposes it is usually sufficiently accurate to reckon with: 1 year = 365 days = 8760 hours = 31.536 x 10^6 seconds.

d. Symbols

[22.2] is a reference to a document listed under nr. [22.2] in Chapter 22, last section
(22.4) is a reference to Chapter 22, Section 22.4.
(25) is a reference to formula numbered (25)

Symbols and parameters used in formulae and graphs are normally explained in the text or in the relevant captions.

PART A GENERAL

1. INTRODUCTION

At present, the sources from which energy can be generated are:

- fossil fuels: coal, oil, natural gas and peat
- uranium
- river water
- sun radiation
- fire wood
- wind
- sea water (tides, waves, currents, temperature differences and variations in density)
- geothermal heat

For some energy sources hydraulic engineering works are needed to facilitate the generation of electricity as a form of energy, or for the transportation of electricity.

In this respect the following energy sources are mentioned:

i. water from rivers and streams (hydropower)
ii. coal, oil, natural gas
iii. wind
iv. water in the seas and oceans (tidal and wave power).

In these lectures the emphasis will be on the generation of hydroelectric power from rivers, because a great number of hydraulic works are needed to pursue this aim. In this context the following works are mentioned: reservoir dams (built from non-cohesive materials or concrete), spillways and intake structures in reservoirs, water conveyance systems and hydropower plants.

The hydraulic engineering works that are needed for the generation of energy from coal, oil and natural gas can also be substantial. In this connection one should think of entry shafts for the mining industry; cooling water systems at thermal plants, coal harbours near coal-fired plants and oil and gas extraction at sea (offshore). These last subjects, however, are to a greater extent already treated elsewhere.

For the third mentioned energy source (wind), the hydraulic engineering aspect comprises the foundation and construction of the substructures of wind turbines located in water or at the coast. But also this aspect is already treated by other sections of the Faculty of Civil Engineering and Geosciences of this University.

Finally, the source of energy: water from the seas and oceans, will be discussed. The generation of energy can be based on a) the tides, (b) the waves, (c) marine currents,(d) the difference in temperature and (e) the density of sea water at different depths.

Besides discussing the theory and the applied principles of hydraulic engineering works with regard to energy generation, attention will be given to a more thorough discussion of a few projects designed in the Netherlands and abroad. Some of these have actually been built (marked by C). Amongst these projects are:

- Kainji hydropower plant in Northern Nigeria (C);
- planned pumped storage plants in the Netherlands (known as PAC and OPAC);
- run-of-river plants in the Netherlands: Hagestein, Maurik (C);
- small scale hydropower in the Netherlands;
- the tidal power plant La Rance in France (C).

Many hydraulic engineering works built for the purpose of energy generation are situated abroad in surroundings that are completely different, in all aspects, from the Dutch surroundings. Special attention will therefor be paid to the typically non-Dutch features in these works such as:

- multipurpose aspects of works;
- founding of structures on rock;
- economics of multipurpose reservoir systems;
- lack of data.

The hydraulic engineering aspects of energy generation that are discussed in other lectures, be it in a different context, will not be discussed.

2. DEMAND AND SUPPLY OF ELECTRICTY[1]

2.1. Introduction

The aim of this introductory chapter is to give an impression of the use of electricity in general, the sources from which we can extract energy and the share that electricity (and particularly that share generated from hydropower) makes up at this moment.

Electricity is a product that cannot be missed in the world economy. The fact that the use of electricity (or quantity produced) per capita is used as a measure for the development of a country marks its importance.

One requires the availability of electricity in any given quantity at any given moment. Too little or too much electricity influences the economy.

However, electricity is only one of many forms of energy. Others are heating, lighting, and motion.
In fact, electricity is an intermediate form of energy that can be used directly as a source of energy for the three others. The advantage of this form of energy is that it is easily transported, simple to convert into another form of energy and, finally, it is environmentally friendly in itself.

As stated, electricity is an intermediate form of energy. Sources of energy were mentioned before in Chapter 1[2]. Each of these sources makes a contribution to the World's energy requirements. In Fig. 2.1 a possible 'Dematerialisation Scenario' is shown outlining future contributions of these sources to energy production.

2.2. Global and Regional Electricity Demand

The distribution of energy resources and rate of consumption of energy resources is uneven throughout the world and within countries. Measured in per capita consumption terms there is a large difference in consumption patterns. Figure 2.2 highlights the large variation in per capita electricity consumption for the developed and developing countries. While demand in OECD countries is beginning to level, due to zero population growth and for other reasons, there is a strong commercial energy demand in transitional and developing countries.
The vast majority of the world's population live in poverty, in developing countries that are characterised by low levels of social and economic development, as well as inadequate infrastructure and institutions for the provision of energy services. During the last century, the most important way, by which countries have increased energy availability for their economies, has been to invest in electricity supply.
Global and regional statistics indicate that the average per capita consumption of electricity is 7 500 kWh/year in OECD countries as compared to 482 kWh/year in Asia (excluding China, where it is 822 kWh/year), 490 kWh/year in Africa, and 1 402 kWh/year in Latin

1 This chapter is mainly based on [2.1]

2 The difference between sources and forms of energy is not very distinct. One could even state that sun radiation and gravity are the only true sources of energy.

America. However, these figures mask variations in the number of people in a particular society with electricity access, and actual use per person, household or industry[3].

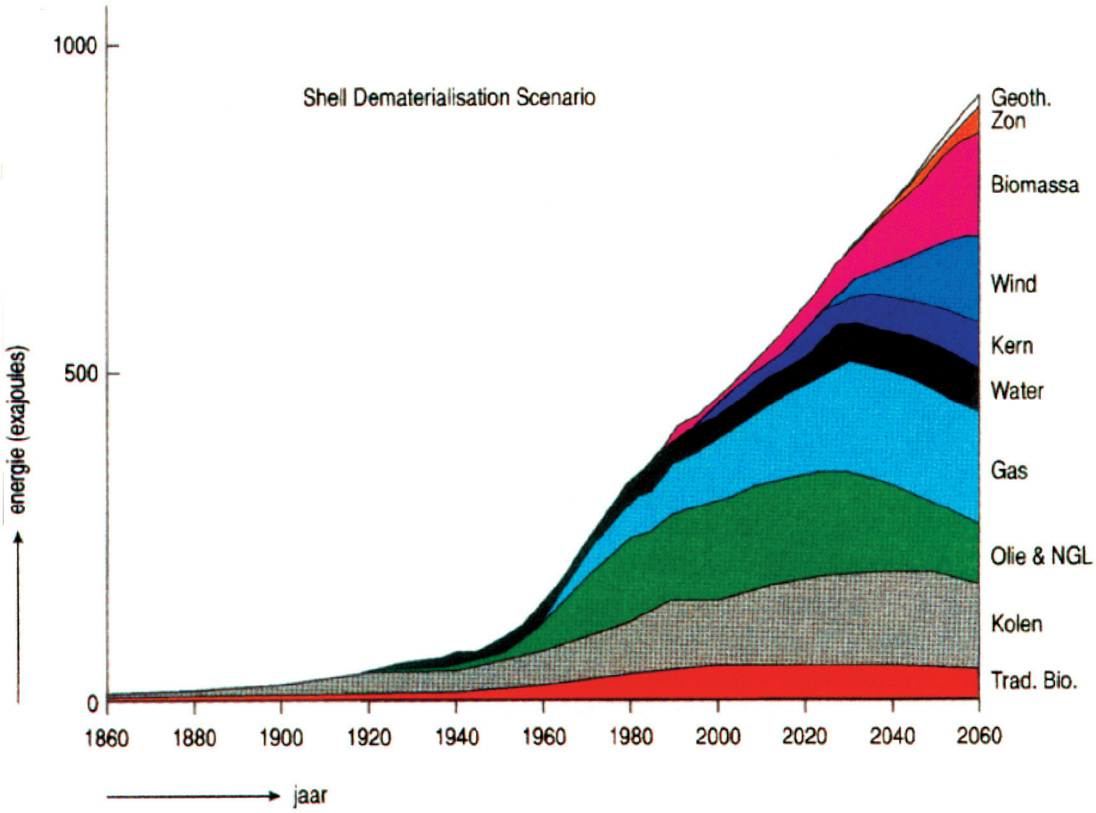

Figure 2.1: *'Dematerialisation Scenario' as developed by Shell outlining the distribution of energy production over potential sources* (Source: Shell Planning, London, 1955)

The increase in fuel consumption as well as the relative contribution of electricity as an energy source since the early 1970s is depicted in Table 2.1. Electricity consumption has increased from 9.4 to 14.3% of total energy consumption, during the period 1973-1996 (Table 2.1).

2.3. Sources of Energy for Electricity Supply

An example of the shift in electricity energy supply resources over the last few decades is displayed in Table 2.2. This study of non-OECD countries demonstrates the shift from oil to gas, nuclear and hydro between 1973 and 1996. Coal has remained steady, accounting for around 38% of the world's electricity generation, with hydro reducing slightly during the period[4].

[3] In The Netherlands the average family in 1979 consumed 3290 kWh annually. This is more or less 10 kWh a day or 1 to 2 kWh during peak hours.

[4] Statistics on the contribution of hydropower in electricity supply vary, depending whether installed capacity or energy generation is considered.