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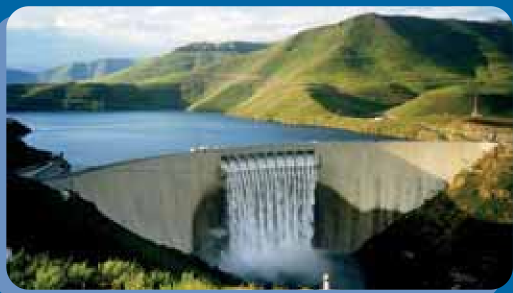
DAMS & The World's Water

An Educational Book that Explains how Dams Help to Manage the World's Water

International Commission On Large Dams
Commission Internationale des Grands Barrages

About ICOLD



The International Commission On Large Dams (ICOLD) was founded in Paris in 1928.

It is currently comprised of **88 countries and 10,000 individual members**: Engineering Companies, Consultants, Builders, Development companies, Scientists, Researchers, Engineers, University Professors, Governments, Financial Institutions, Associations..

ICOLD is the **world's leading professional organization in the field of dams**, advancing the technology of dam engineering and supporting the socially and environmentally responsible development and management of water resources to meet the worldwide demand.

ICOLD is a forum for the exchange of knowledge and experience in dam engineering. With an annual meeting in a different country each year and a Congress every three years, it has built up nearly **one century of knowledge**.

This permanent search for progress is organized through 24 Technical Committees and 500 experts on specific themes. ICOLD also promotes public awareness of the beneficial role of dams in the sustainable development and management of the world's water resources.

ICOLD **leads the profession** in setting standards and guidelines to ensure that dams are built **safely** and **economically, and in an environmentall and socially sustainable manner**.

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The information, analyses and conclusions in this document have no legal force and must not be considered as substituting for legally-enforceable official regulations. They are intended for the use of experienced professionals who are alone aquipped to judge their pertinence and applicability and to apply accurately the recommendations to any particular case.

This document has been drafted with the greatest care but, in view of the pace of change in science and technology, we cannot guarantee that it covers all aspects of the topics discussed.

We decline all responsibility whatsoever for how the information herein is interpreted and used and will accept no liability for any loss or damage arising therefrom.

Do not read on unless you accept this disclaimer without reservation.

DAMS
& The World's Water

An Educational Book that Explains how Dams Help to Manage the World's Water

CIGB
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International Commission On Large Dams
Commission Internationale des Grands Barrages

© 1 (see p.64)

Preface

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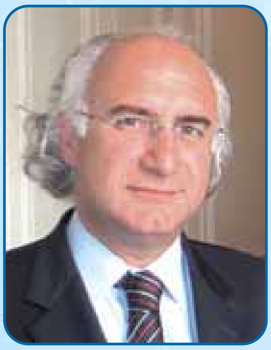

Mr Michel de VIVO
Secretary General, ICOLD

During the coming century, water will continue to be a vital resource for human civilization. An adequate and safe water supply is an essential component to our health, environment, communities and economy. But two major factors will increase the stakes: the incoming climate change, making the water resources more irregular, with drying trends necessitating more water storage; and the world population growth, increasing the demand for domestic, agricultural and industrial water with emphasis on irrigation for food production. Therefore, the crucial role dams played throughout human history will continue during the 21^{st} century.

ICOLD has played, since its inception in 1928, a key role in the spreading of knowledge about dams and water. For a long time now, ICOLD is not only open to engineers but also to the public. It is therefore natural for ICOLD to explain to the younger generation what kind of challenges they will face in the management of the world's water. This booklet gives, in a simplified but rigorous way, the basic facts on the beneficial role of dams: for water storage and management, food production, electricity generation and flood protection. It also delivers the essential facts about the world's water, its distribution and its cycle.

We are confident that this message will be useful to the generation that will have the responsibility to lead human civilization to the 22^{nd} century. And we hope that they will use it efficiently to build their own future.

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DAMS &The World's Water

Introduction

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Serre-Ponçon Dam - France a multiple purpose dam

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Water is the vital resource to support all forms of life on earth. It is essential for the well-being of our civilization and is the essential element for growth and development as well as the basic requirement for the health of the world's environment. To assist the readers in understanding some of the terms used in this book, a glossary of terms has been included as Appendix A.

In this book you will learn that there is a fixed amount of water on the earth. Of this fixed amount, only a small portion is fresh and available for human consumption, irrigation of crops and industrial use. You will also see that we receive a fixed amount of precipitation or rainfall and only a small portion falls on our landmass. A significant portion of this ends up as runoff to our streams and rivers and then into the oceans. This leaves a small amount of rainfall for human use and infiltration into the ground to replenish our groundwater, which highlights the need to collect, store and manage water in reservoirs.

You will also see that this rainfall is not evenly distributed by season or location, and since there is an imbalance between availability and demand, careful management is essential. You will see the summary of the world population and the anticipated growth rate. Note that most of this growth in population will occur in the less developed countries - where the need for water is the greatest and the current supply is limited. It is important to recognize that careless use and contamination of the water that is available is widespread. In some regions of the world, life is threatened by the imbalance between the demands and available supplies of water, food and energy.

You will see that throughout the history of the world, dams and reservoirs have been successfully constructed across rivers to collect and store vast amounts of water and then manage releases to make daily river flows to support civilization. For more than 4000 years, civilization has used dams to provide the necessary water to sustain life in all parts of the world. Many of these dams are still in operation today.

The demand for water as a result of the expanding world population and economic growth has increased the need to build dams for storing large amounts of water. Today, dams and reservoirs continue to serve the same purposes of meeting the social and economic needs throughout the world and at the same time are compatible with the natural environment of each region. You will see the full range of benefits that we receive from dam and reservoir projects - water supply, irrigation, flood control, hydropower, inland navigation and recreation.

The earth embankment of a dam in Santa Fe United States

Civilization needs water in adequate quantities and quality to sustain life and to support growth and development

© 3 (see p.64)

The world contains a large amount of water

2 The World's Water

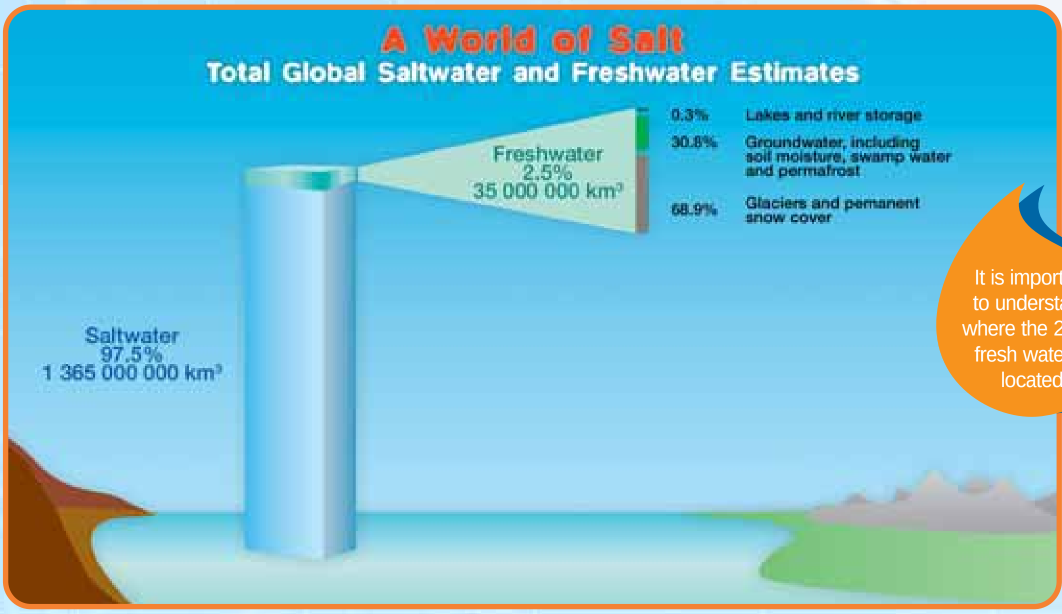
Oceans contain 97.5% of the water in the world

© 4 (see p.64)

This section explains where and in what form the world's water exists and then how we get water - "the water cycle". It may seem surprising to most people that only 2.5% of the water in the world is fresh water (located in glaciers, groundwater and our lakes and rivers) and is available for the people and nations of the world.

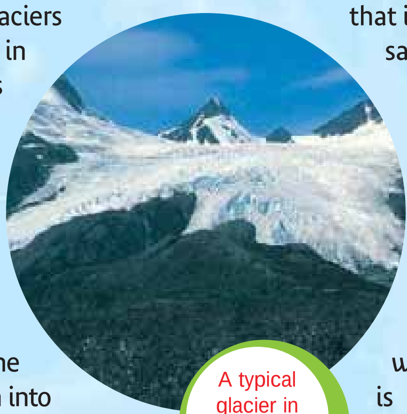
Most of the world's water is located in the oceans, the permanent snow and ice, glaciers of the Artic and Antarctic, rivers, lakes and groundwater. The actual distribution of the world's water is shown on the following diagram.

The World's Water



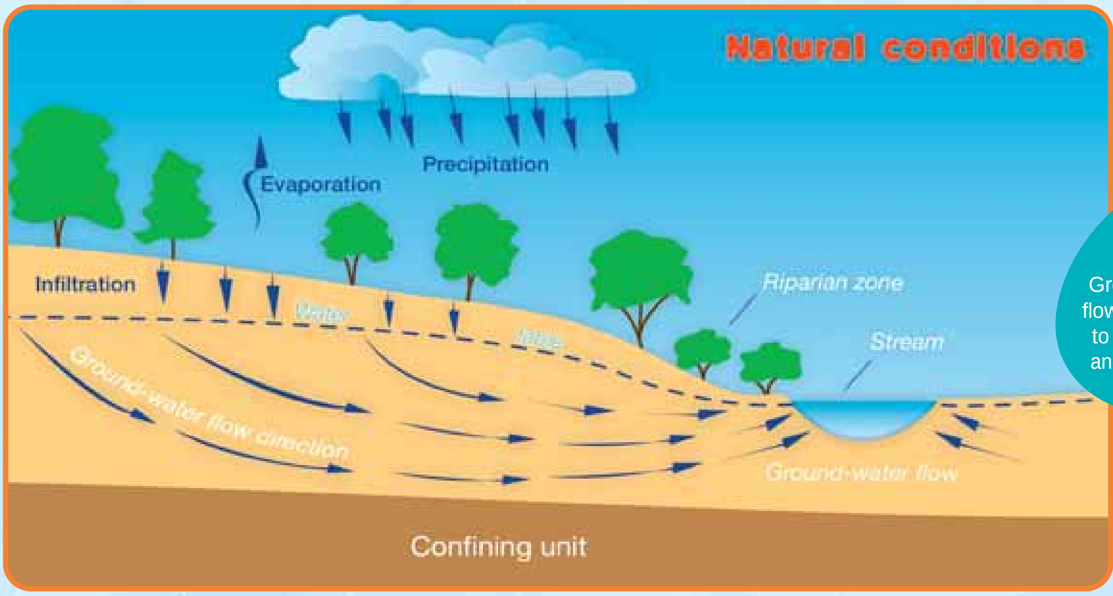
It is important to understand where the 2.5% fresh water is located

A major portion of the world's fresh water (68.9%) is in the form of glaciers and permanent snow cover in the Artic and Antarctic regions of the world. However, only small portions become available each year.



A typical glacier in North America

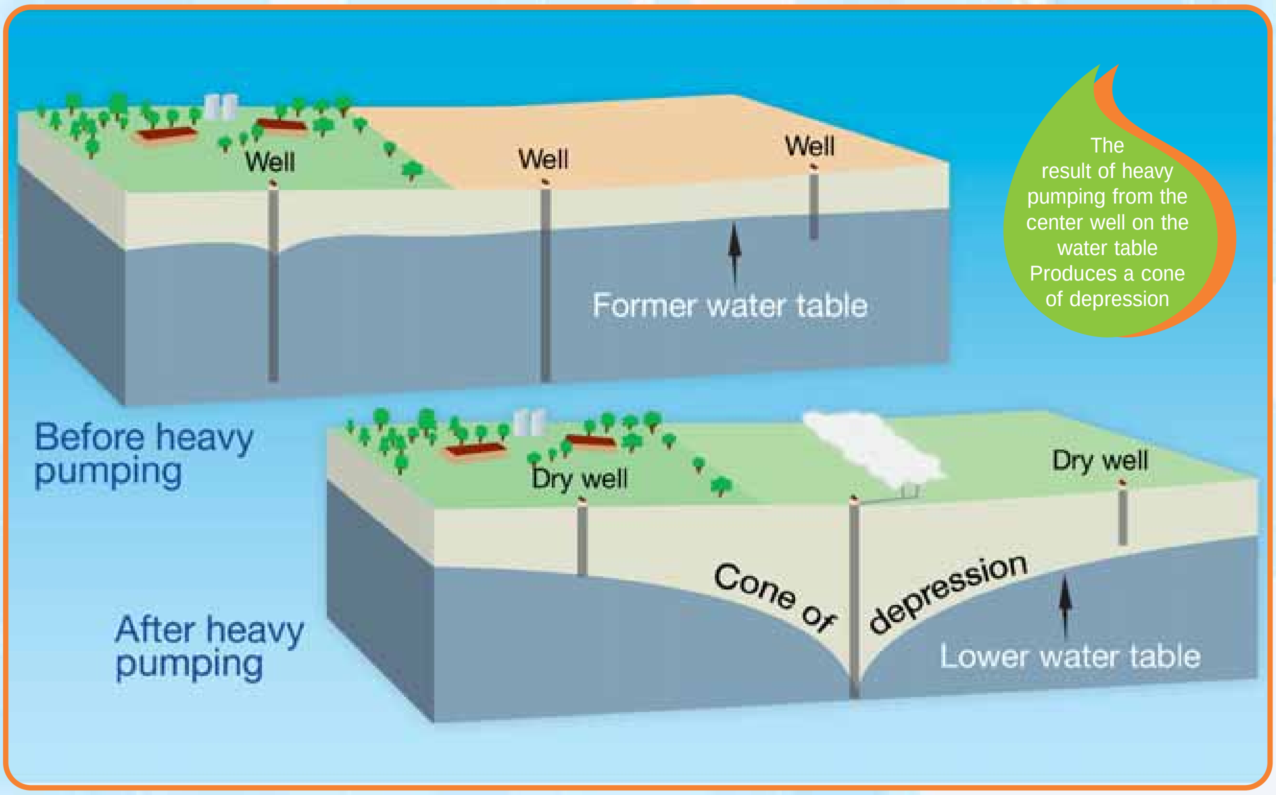
Groundwater is a source of usable fresh water. Its source is the rain, snow, sleet, and hail that infiltrate or soak into the ground. The water moves down into the ground because of gravity, passing between particles of soil, sand, gravel, or rock until it reaches a depth where the ground is filled, or saturated, with water. The area that is filled with water is called the saturated zone and the top of this zone is called the water table (see diagram below). The water table may be close to the ground's surface or it may be hundreds of meters below the surface. Groundwater is a reliable source in rural areas of the world. Most of the groundwater is clean, but groundwater can become polluted, or contaminated. It is important that we protect it from contamination.



Groundwater flows downhill to our rivers and streams

Today a large portion of the world's population obtains its water from groundwater. In comparison with surface water storage, such as lakes, groundwater has the advantage that it is often available locally and does not require transportation. In addition, investments in developing groundwater resources can be made on an "as needed" basis. Since groundwater exists naturally, the location and amount cannot be changed or expanded. In the arid regions of the world, groundwater is too scarce to provide adequate quantities. In and around Riyadh in Saudi Arabia, for example, the groundwater is mined from a depth of 1200-1800 meters. During the development of the city of Phoenix, Arizona in the USA, mined groundwater was relied on to the point of exhaustion. To meet today's needs; water from the Colorado River has been piped across the desert.

In section three, we will see that of all the rain on the world, 19% of this rain falls on our landmass. Once the rain is on the land it can either be absorbed into the ground, or it runs off into streams and rivers to our oceans. The amount of rainfall that is absorbed is the source to recharge or replenish our groundwater. For open vegetated land with no development, absorption is the greatest - up to 75% of the rainfall. In areas with paved parking lots and other development, runoff is the greatest - about 75% of the rain fall. In conclusion, it is important to realize that as development occurs, runoff is increased and absorption decreases.



To obtain groundwater, wells are installed to withdraw water for domestic, agricultural and industrial use. This withdrawal must be managed so we do not lower the water table and deplete it at some locations by heavy over pumping (from the center well).

It is essential to manage withdrawals of groundwater with respect to recharge or replenishment to ensure that the local groundwater is not depleted over time.

Over-pumping of groundwater will lower the water table. This often requires pumping water from ever greater depth. Over time, this could lead to depletion of the groundwater at that location. At present, over-pumping is known to be occurring in parts of Saudi Arabia, Israel, South Africa, India and the western parts of the United States. In these areas of the world it is necessary to manage withdrawal of the groundwater and augment it with reservoirs.

Our lakes and rivers contain the smallest portion of our fresh water. As it rains, some of the water in these lakes flow into our streams and rivers and then the ocean.

Less than 1 % of the world's water supply is in our lakes...

Because of the relatively small amount of freshwater available for consumption, it is essential that we manage it and do not pollute or contaminate our natural lakes and rivers. This requires waste water treatment plants and managed landfill sites for waste disposal.

© 5 (see p.64)

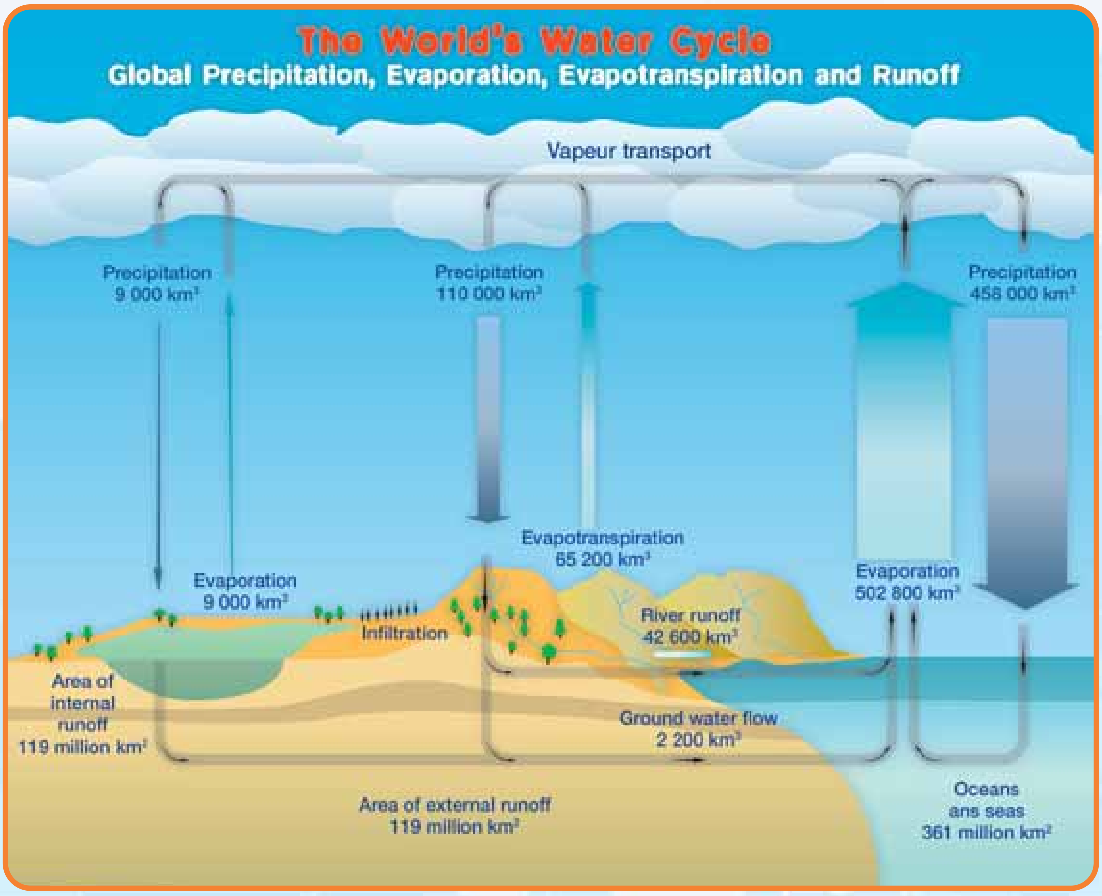
... and in our rivers

How we Get Water "The World's Water Cycle" 3

Water exists on earth as a solid (ice), liquid (water in the oceans, lakes and rivers) or as a gas (water vapor). The oceans, rivers, clouds and rain, all of which contain water, are in a frequent state of change (surface water evaporates, cloud water precipitates, rainfall infiltrates the ground, etc.). However, it is important to understand that the total amount of the earth's water does not change. The circulation and conservation of earth's water is called the "water cycle".

How we Get Water
"The World's Water Cycle"

3



This World Water Cycle or Hydrologic Cycle as it is sometimes known refers to cycles the earth's finite and valuable water supply. In other words, the water keeps getting used over and over again. The sun's energy in the form of light and heat causes water to evaporate from oceans, rivers, lakes and even puddles. Evaporation means the water turns from a liquid to a gas, or vapor. Warm air currents rising from the earth's surface lift this water vapor up into the atmosphere.

When the air currents reach the cooler layers of the atmosphere, the water vapor condenses around and clings on to fine particles in the air. This step is called condensation. When enough vapor attaches itself to tiny pieces of dust, pollen or pollutants, it forms a cloud. As the air absorbs more moisture, the droplets which form the clouds grow larger and larger. Eventually they will get so big that the swirling atmospheric winds can no longer hold them up. The droplets then fall from the sky as precipitation. This precipitation can be in the form of rain, snow, sleet or hail, depending on other atmospheric conditions such as temperature.

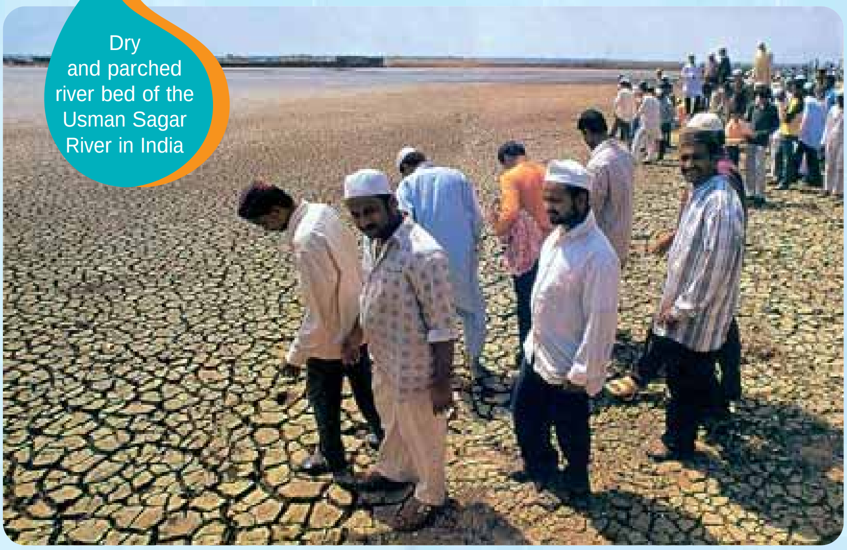
When precipitation reaches the ground, several things can happen to it. Much of the water will become run-off that goes into streams and rivers as it flows back to the ocean. Some of the precipitation will be absorbed into the ground. This is called infiltration. Once in the ground, the water can join the earth's ground water supply. Ground water is one of the world's largest sources of water. Unfortunately, it is not evenly located around the world. Thus some areas of the world have limited access or no access at all to groundwater.

From the water cycle diagram above, it is important to understand that of the total precipitation or rainfall (577,000 km^3) falling on the earth 79% falls on the ocean, 19% on land and 2% on our lakes. This means that only 110,000 km^3 or 19% of our rainfall goes to our landmass. It is essential to understand that of this 110,000 km^3 of rainfall, 59% evaporates and 38% runs off into our rivers and then to the ocean. Only 2,200 km^3 or 2% is infiltrated to our groundwater. This highlights the need to store water in reservoirs.

Distribution of the World's Water

4

Unfortunately, water is not always available exactly where and when we need it. Precipitation or rain is also not evenly distributed over the world by season and location. Development in the watershed increases runoff and loss to replenish groundwater. Landscape with natural groundcover has the smallest amount of runoff and the maximum absorption for groundwater. A highly developed area results in most of the rainfall ending up as runoff and then flooding. Some parts of the world such as Africa and Asia have severe droughts making water a scarce and precious commodity. In other parts of the world water appears in long periods of raging rainfall which cause loss of life and damage to crops, houses and buildings. Sometimes within one country there can be devastating floods in one area, while extreme droughts are occurring in other areas.



Dry and parched river bed of the Usman Sagar River in India

Floods represent 30% of all natural disasters. Between 1975 and 2000 there were 95 significant floods in the world.

Flooding in China

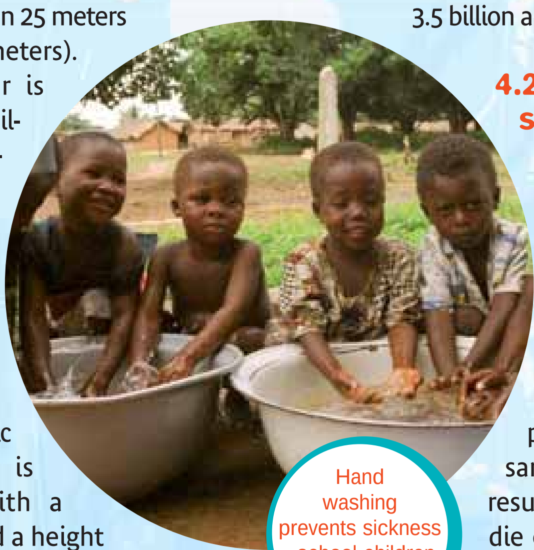
4 Distribution of the World's Water

4.1 Water-stressed and water-scarce countries

Landscape in a water-scarce region of Africa

© 6 (see p.64)

The United Nations characterizes countries with limited availability of water as water-stressed or water-scarce depending on the amount of renewable water available. Water-stressed countries have fewer than 1,700 cubic meters of water available per person per year (this volume is the same as a pyramid having a base on 25 meters and a height of 8.2 meters). This means that water is often temporarily unavailable at particular locations, which requires difficult choices be made for the use of water between personal consumption, agriculture, or industry. Water-scarce countries have fewer than 1,000 cubic meters per year (this is the same pyramid with a 25 meter base width and a height of only 4.8 meters). In such cases, there may not be enough water to provide adequate food, the economic development may be hampered and severe environmental difficulties may develop. This problem is discussed in detail in the section on water requirements.



Hand washing prevents sickness - school children in africa

A dry river bed in a water-stressed area

© 7 (see p.64)

For most purposes, river basins are a more appropriate unit than countries for analyzing water flows. However, many of the world's major river basins encompass more than one country, a situation which requires coordination between the governments. Currently 2.3 billion people live in river basins that are at least water-stressed; 1.7 billion live in basins where scarcity conditions prevail. By 2025 these numbers are projected to be 3.5 billion and 2.4 billion, respectively.

4.2 Water for sanitation

Lack of sanitation is a major public health problem causing disease, sickness and death. More than 2.6 billion people, or 40% of the world's population, lack basic sanitation facilities. As a result, thousands of children die every day from diarrhea and other water borne, sanitation and hygiene related diseases. Many more suffer and are weakened by illness. In the past, progress in sanitation has suffered from limited political commitment and demand.

Today, water from reservoirs provides reliable storage of water for treatment and to improve sanitary conditions. However, simply providing access to improved water and sanitation does not guarantee the use of the services or the much expected health benefits to the people in the region. The promotion of fundamental behavior changes is key to integrating the appropriate use of services into daily routine and needs to start in early childhood. Health and hygiene education programs provided by schools are an integral part of every water and sanitation program.

4.3 Integrated water management

There is a critical need for integrated water management in the river basin or watershed. Dams and reservoirs that are strategically located in a river basin allow for the storage of water during rainfall events and then manage the releases to ensure that our rivers have a minimum daily flow at all times. Integrated water management means storing water in all of the reservoirs in the watershed during periods of rainfall and then managing the releases of a coordinated and predetermined amount of water from each dam to maintain a consistent daily flows in the rivers downstream of the dams.

Integrated water management ensures an average daily flow in our rivers

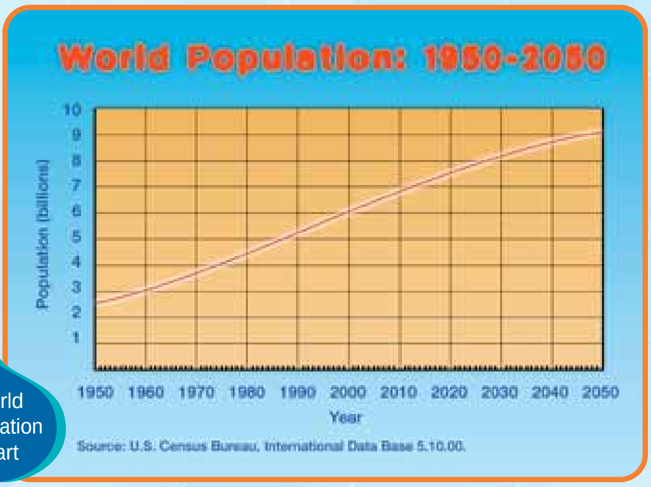
World Population Data

5

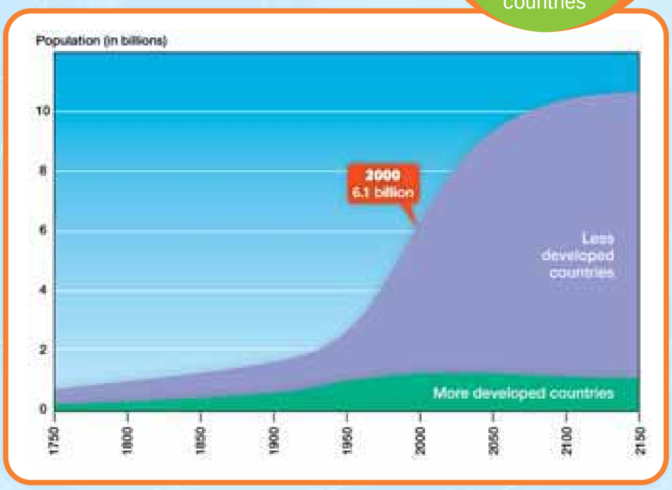
In 2005 the world population was estimated to be 6.45 billion and it continues to grow at an annual rate of 1.3% or 77.3 million per year. The projection for the world population through 2050 is as shown below. A large portion of this growth is in the arid portions of the world - Africa and Asia. This growth continues to place a significant demand on water, food, energy and other infrastructure and services.

With the current total growth, the world's population will double every 54 years. We can expect the world's population of approximately 6 billion to reach 12 billion by 2054 if the current rate of growth continues.

It is important to understand that the growth rate is much higher in developing countries as shown on the chart. In these countries the supply of fresh water and electricity is very limited.



World population chart



Population growth rate chart showing significant growth in developing countries

Water Requirements

6

6.1 Domestic water requirement

Water requirements are classified as domestic, agricultural and industrial. The recommended basic domestic water requirement in liters per person per day that has been adopted as the world-wide standard is as follows:

Purpose	liters/person/day
Drinking	5
Sanitation	20
Bathing	15
Cooking	10
Total	50

this equates to 18.25 cubic meters or 4,821 gallons per person per year *

* This amount does not include losses in the treatment process and distribution systems

For example, a city of 500,000 people requires 25 million liters per day for the basic domestic water requirement and about 27 million liters per day (this equates to an international soccer field with water 4.7 meters deep) including losses. A town of 1,000 people will need 50,000 liters per day or 55,000 liters per day (equates to a pyramid having a base of 8 meters and a height of 2.6 meters) including losses. Even a small village of 500 inhabitants will require 25,000 liters per day or 27,500 liters per day with losses.

Many parts of the world lack adequate quantities of water and distribution systems

In 2000, there were 61 countries with a total population of 2.1 billion who can not get access to the minimum requirement of 50 liters per person per day. With the anticipated population growth in less developed countries this number of people will double to 4.2 billion by 2025.

6.2 Combined domestic, agricultural and industrial water requirement

The combined water requirement includes domestic, agricultural and industrial needs. It is important to remember that the United Nations established three thresholds for combined water requirements. The first threshold is countries that have more than 1,700 cubic meters of water per person per year (equates to a pyramid having a base on 25 meters and a height of 8.2 meters) available and are considered to have an adequate supply to support the nation. Note that the domestic requirement is about 1% of this total. The second threshold is countries that have less than 1,700 cubic meters of water per person per year available and are considered to be water-stressed. The third threshold is countries that have less than 1,000 cubic meters of water per person per year (equates to a pyramid with the same base width and a height of only 4.8 meters) available and are considered water-scarce. At this last level, there may not be enough water to provide adequate food, economic development is hampered and environmental difficulties will develop.

In the year 2000, there were 31 countries with a combined population of 508 million who were considered water-stressed. By the year 2025, it is estimated that the number of water-stressed countries will increase to 48 countries with a combined population of about 3 billion. River basins are a more appropriate unit than countries for analyzing water flows. Many of the world's major river basins encompass more than one country. This requires coordination between countries.

7

What is a Dam?

A dam is defined as a barrier or structure across a stream, river or waterway to confine and then control the flow of water. Dams vary in size from small earth embankments often for farm use to high massive concrete structures generally used for water supply, hydropower and irrigation.

The construction of a dam usually requires the relocation of existing villages, individual houses, farms, highways, railroads and utilities from the river valley to a higher elevation above the reservoir. The principal types of dams in the world are embankment, gravity and arch. Typical cross sections of each type are shown in section 9.3. The appurtenant or additional structures of a dam include a spillway, outlet works, hydropower plants and a control facility.

Dams are constructed to store and control water for domestic water supply, irrigation, navigation, recreation, sedimentation control, flood control or hydropower. Some of our dams serve one purpose and are therefore known as a "single purpose dam". Today, dams are being built to serve several purposes and are therefore called "multipurpose dams". A multipurpose dam is a very important and cost effective project for developing countries because the population receives several domestic and economic benefits from a single investment. It is the cornerstone in the water resources development of a river basin.

8

History of Dams in the World

Recent archaeological findings indicate that simple earth dams and networks of canals were constructed as far back as 2000 BC to provide people with the reliable source of the water they need to live. The building of the Marib dam in Yemen began around 750 BC and took 100 years to complete. It consisted of an earth embankment 4 meters in height and stone sluices to regulate discharges for irrigation and domestic use. In 1986, the existing dam was raised to a height of 38 meters that creates a reservoir of 398 million cubic meters of water.

Aerial view of Sayamaike dam built is the 7th century and still in use today

History of Dams in the World

Inscriptions in the sluice of the original Marib dam, built in 750 BC

Historically, dams have enabled people to collect and store water when it is plentiful and then use it during dry periods. Therefore, they have been essential in establishing and supporting towns and farms as well as providing food through irrigation of cropland.

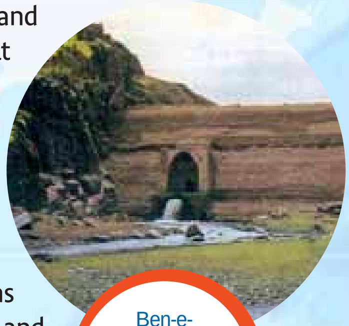
The new Marib dam, Yemen - built in 1968

One of the oldest dams that is still in use today is an earth and rockfill embankment dam built around 1300 BC in what is now Syria. In China, a system of dams and canals was constructed in 2280 BC. Several ancient dams from the 13th to the 16th century in Iran are still in use today.

In Sri Lanka, for example, ancient chronicles and stone inscriptions state that numerous dams and reservoirs were built as early as the 6th century BC. Inter-basin canals augmented many of these large reservoirs for irrigation. One of these large dams, the Minneriya dam, was constructed during the rein of King Mahasen (276-303 AD), and was in tact when it was discovered in 1900. It was restored in 1901 and is still in use today. More than 50 other ancient dams in Sri Lanka have been restored.

Ancient outlet tower of Minneriya dam that was built 276 -303 AD in Sri Lanka and was restored in 1901 for irrigation. It is still in use today

The main reason for the successful functioning of these reservoirs today is that the sluice structures, spillways and riprap that had been built during that early era are compatible with the modern design principles and criteria. Some of the masonry sluice towers and sluice gates constructed two to three millennium ago have been repaired and converted to working structures during the 1900's.



Ben-e-Golestan dam, Iran - constructed about 1350 AD

The Romans built an elaborate system of low dams for water supply. The most famous was the Cornalbo earth dam in southern Spain which had a height of 24 meters (78 feet) and a length of 185 meters (606 feet). After the Roman era, very little development in dam construction took place until the end of the 16th century when the Spanish began to build large dams for irrigation. European engineers refined the design and construction knowledge in the 19th century that gave rise to the capability to construct dams to a height of 45-60 meters or 150-200 feet.

Hand placed rip-rap of Giritale dam in Sri Lanka constructed in 608-618 AD

An early irrigation dam in Egypt

Historically, dams have been planned and constructed for the purpose of water supply, irrigation, and flood control. In the late 1800's, hydropower and navigation were added. Recreation has been a very beneficial additional purpose at many reservoir projects. In more recent times, dams have been built to serve several purposes and are therefore called multipurpose dams.

The Sayamaike dam, one of the oldest dams in Japan, was built in the early 7th century and after several modifications and a heightening is still in use today.

Requirements, Purpose, Types, Features and Construction of a Dam

9

9.1 Requirements of a dam

Because dams are a critical and essential part of our infrastructure, they must meet certain technical and administrative requirements to ensure safe, effective and economical operation. The design, construction and operation of all dams must comply with the following technical and administrative requirements:

Technical requirements of a dam:

- The dam, foundation and abutments must be stable under all loading conditions (reservoir levels and earth quakes).
- The dam and foundation must be sufficiently watertight and have adequate seepage control measures to ensure safe operation and to maintain storage capacity.
- The dam must have adequate freeboard to prevent overtopping by waves and in the case of an embankment dam must include an allowance for settlement of the foundation and embankment.
- The dam must have sufficient spillway and outlet capacity to prevent over-topping by the reservoir during an extreme flood.

Administrative requirements of a dam:

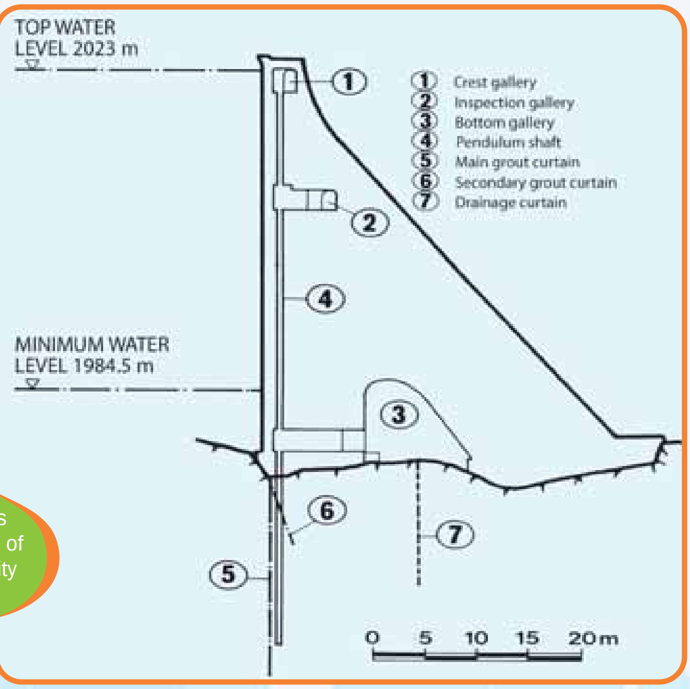
- An operation and maintenance manual.
- Adequate instrumentation to monitor performance.
- A plan for monitoring and surveillance of the dam and structures.
- An Emergency Action Plan.
- Should support the natural environment.
- A schedule for periodic inspections, comprehensive review, evaluation and modifications as appropriate.
- Formal documentation of the design, construction and operational records.

9.2 Purpose of a dam

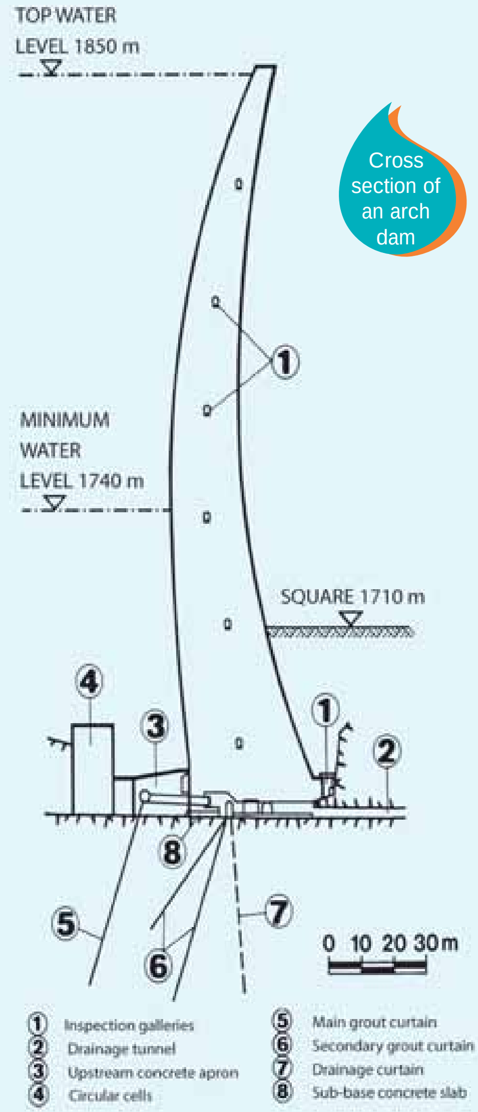
As is the case with all large public and private structures, dams are built for a specific purpose. In ancient times, dams were built for the single purpose of water supply or irrigation. As civilizations developed, there was a greater need for water supply, irrigation, flood control, navigation, water quality, sediment control and energy. Therefore, dams are constructed for a specific purpose such as water supply, flood control, irrigation, navigation, sedimentation control, and hydropower. Recreation is sometimes added to for the benefit of the population. A dam is the cornerstone in the development and management of water resources development of a river basin. The multipurpose dam is a very important project for developing countries, because the population receives domestic and economic benefits from a single investment.

9.3 Types of dams

Dams are classified by the material used to construct them. Dams built of concrete, stone, or other masonry are called gravity dams, arch dams or buttress dams. Dams built of earth or rocks are called embankment dams.

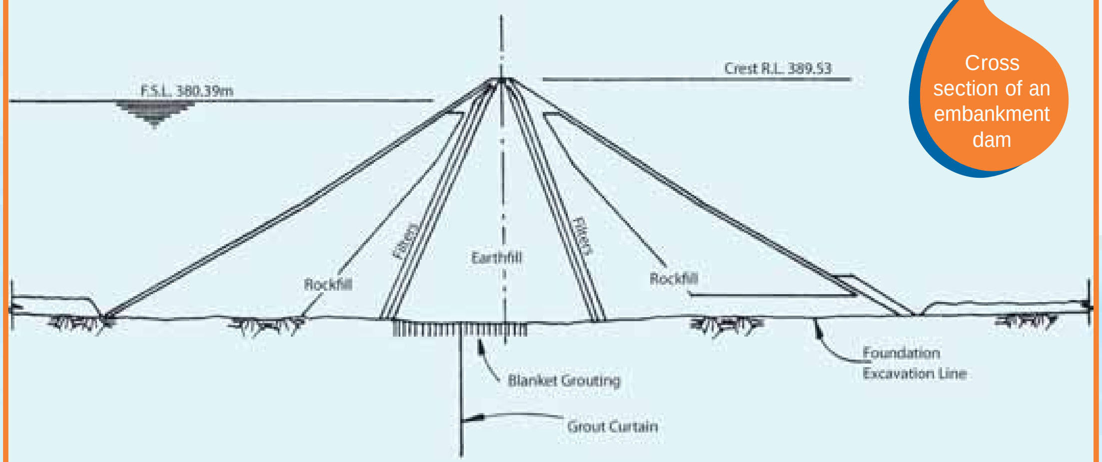


Cross section of a gravity dam



Cross section of an arch dam

Embankment dams are constructed of either earth fill or a combination of earth and rock fill. Engineers generally choose to build embankment dams in areas where large amounts of earth or rocks are available. Embankment dams represent about 75% of all of the dams in the world. Some earth dams are constructed completely by earth and are known as earthfill dams, while others are rockfill dams, are constructed with rock. Many embankment dams are constructed with a combination of earth and rock and are know as earth and rockfill dams.



Cross section of an embankment dam

Requirements, Purpose, Types, Features and Construction of a Dam

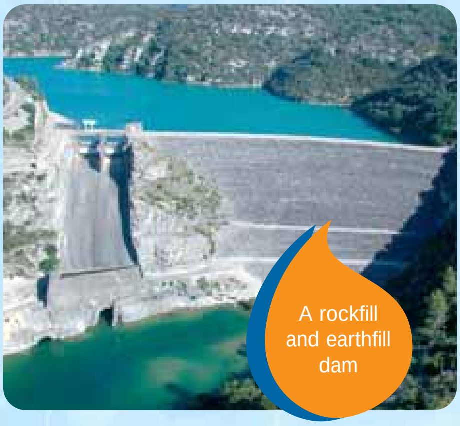
A large earthfill embankment dam

© 8 (see p.64)

Gravity dams depend entirely on their own weight to resist the tremendous force of the stored water. Some early gravity dams have been constructed with masonry blocks and concrete and are known as masonry dams. Today gravity dams are constructed by mass concrete or roller-compacted concrete (concrete placed in layers and compacted by a roller) and are referred to as concrete gravity dams.

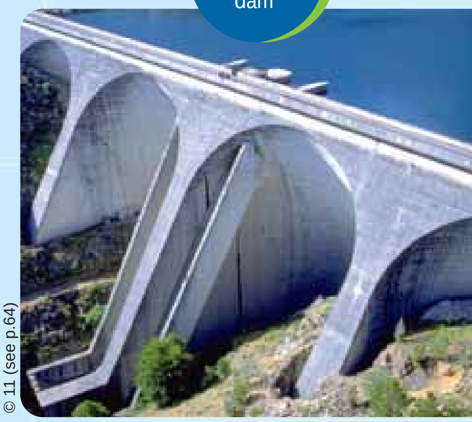
A concrete arch dam

© 9 (see p.64)



A rockfill and earthfill dam

© 10 (see p.64)



A buttress dam

© 11 (see p.64)

A concrete gravity dam

© 12 (see p.64)

Arch dams are concrete dams that curve upstream toward the flow of water. Most are built in narrow canyons. As the water pushes against the dam, the arch transfers the water's force to the canyon wall. Arch dams require much less concrete than gravity dams of the same length. They also require a solid rock foundation to support the weight of the dam.

Buttress dams depend for support on a series of vertical supports called buttresses. The buttresses run along the dam's downstream face: that is, the side facing away from the water's flow. The downstream face of a buttress dam usually slopes outward at about a 45-degree angle. The sloping face and the buttresses serve to transfer the force of the water downward to the dam's foundation.

A rockfill and earthfill dam

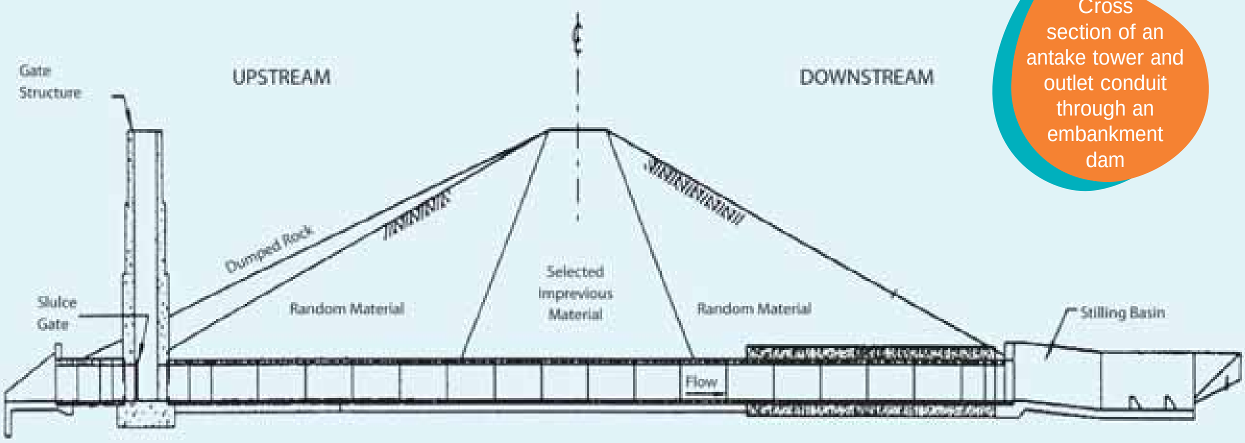
© 13 (see p.64)

9.4 Features of a dam

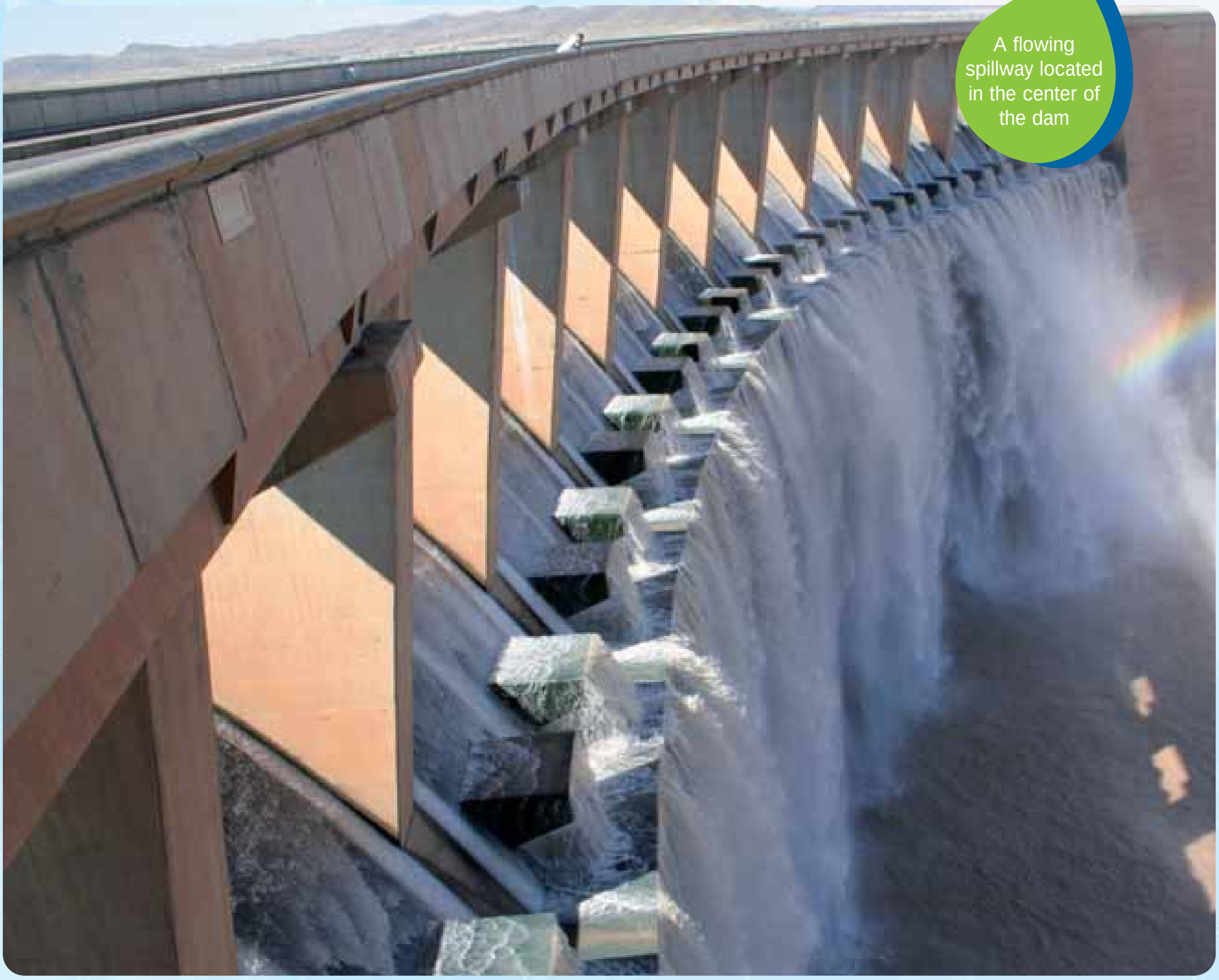
To operate properly, a dam must have several features. They are the reservoir, spillway, outlet works and a control facility. In the case of a dam with hydropower, penstocks, generators and a switchyard are included. The reservoir is the feature that stores water. The inflow must be continuously monitored and the outflow controlled to obtain maximum benefits. Under normal operating conditions the reservoir level is managed by the control facility which controls discharges in the outlet works, which consists of a large tunnel or conduit at stream level with control gates. Under flood conditions the reservoir level is maintained by both the spillway and outlet works.

Example of an intake tower in the reservoir connected to the outlet conduit

The reservoir of a flood control dam is kept as low as possible during several months of the year to create the maximum amount of storage for use in the flood season. For an irrigation project, the reservoir is filled as high as possible in the winter and early spring and is maintained at that level for maximum release during the dry season. The reservoir of a hydropower dam will be maintained at a constant level to create a uniform head for use by the generators. Water quality is a very important aspect for sustaining a balance in nature and measures to maintain good water quality are incorporated into modern dams. Intake ports at various depths allow selective withdrawal and mixing to produce the desired temperature and oxygen content to enhance the downstream environmental conditions. Fish ladders, a series of elevated pools, are provided at many dams to allow free passage of fish upstream and downstream of the dam. Screens are used to prevent fish from entering the turbines of the generators. Since most modern dams are multipurpose, the discharge must be managed carefully and continuously to optimize economic and environmental benefits.



Cross section of an antake tower and outlet conduit through an embankment dam



A flowing spillway located in the center of the dam

© 14 (see p.64)

Example of a spillway for an embankment dam in Idaho, United States

All of the features of a dam are monitored and operated from a control room. This room contains the necessary monitors, controls, computers, emergency equipment and communications systems to allow project personnel to operate the dam safely under all conditions. Weather conditions, inflow, reservoir level, discharge and downstream river levels are also monitored. In addition, the control room monitors instrumentation located in the dam and appurtenant features that measure the structural behavior and physical condition of the dam.

9.5 Section of the site and type of dam

The selection of the type of dam for a site is dependent on technical and economic data, along with environmental considerations. In the early stages of design, several sites as well as several types of dams are carefully considered. After a hydrologic survey is made, an exploration program, in the form of drill holes and test pits is made at each site to obtain soil and rock samples to test the physical properties of these materials. In some cases field pumping tests are performed to evaluate seepage potential. Preliminary designs and cost estimates are prepared and reviewed by hydrologic, hydraulic, geotechnical and structural engineers and geologists. Environmental quality of the water, ecological systems and cultural data are also used in the site selection process.

Factors which affect the selection of the type of dam are topography, geology, foundation conditions, hydrology, earthquakes and availability of construction materials. The foundation of the dam should be solid. Narrow valleys with shallow sound rock favor a concrete dam, while wide valleys with varying rock depth and condition favor embankment dams. Earth embankment dams are the most common type since they accommodate all the material from required excavation.

9.6 Construction of a dam

The construction of a dam is a major activity requiring large amounts of materials, equipment and personnel. The construction period or time to build the dam usually takes from 4 to 5 years and sometimes as long as 7 to 10 years for very large multi purpose dam projects.

After the highways, railroads and the gas and electric utility lines have been relocated from the valley floor to above the top of dam or to another location; construction of the dam can begin. The first step consists of the site preparation or the clearing of trees, vegetation and buildings. This is followed by diversion of the river so that the foundation can be excavated and the concrete, earth, or rock placed. To divert the flow of the river from the area, frequently half of the riverbed is excavated at one time. The other half of the riverbed is used for the flow of the river. In some cases, it is more economical to bore a tunnel through an adjacent canyon wall. This tunnel may be temporary or may become part of the outlet works of the project and it permits the entire flow of the river to pass around the dam site during the construction period. To accomplish this diversion, cofferdams (small dams placed temporarily across a stream) are built upstream to divert the river into the tunnel. After the dam has been built high enough, the operating gates for the tunnel are installed. After the outlet works and main dam are completed to an appropriate level, the stream is diverted into the outlet works by another cofferdam of sufficient height to prevent overtopping during construction in the other half of the river bed. A downstream cofferdam may also be required to keep the dam site dry. In the final part of the construction period the entire dam is brought to full height.


© 15 (see p.64)

Nakai Dam (Nam Theun 2) - Laos - a roller compacted concrete dam


© 16 (see p.64)

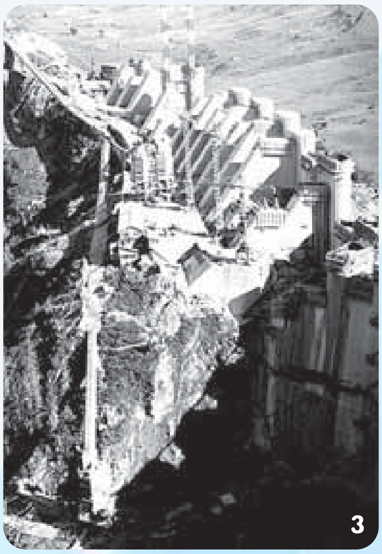
Nakai Dam - Laos - concreting going on

Ganguise Dam - France - heightening an existing earth dam


© 17 (see p.64)

Requirements, Purpose, Types, Features and Construction of a Dam

© 18 (see p.64)



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1 & 2 Chambon Dam - France - building a gravity dam in the 1930-35 years

3 Roselend Dam - France - the construction period

4 Construction of the Nam Them Dam - Laos

5 Potrerillos Dam

6 & 7 Potrerillos Dam - Argentine - upstream face

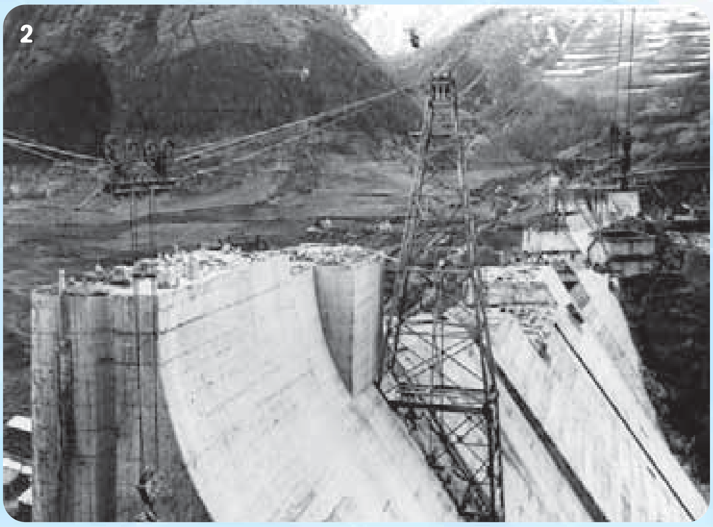
8 & 9 Katse Dam - Lesotho - concreting an arch dam

10 Ceyrac Dam - France - concreting a gravity dam

11 Construction of a roller-compacted concrete dam - Penn Forest dam, USA (Delivery, placement, spreading and compaction by a roller)

12 Villerest Dam - France - building a gravity curved dam

13 Construction of the spillway of a mass concrete gravity dam



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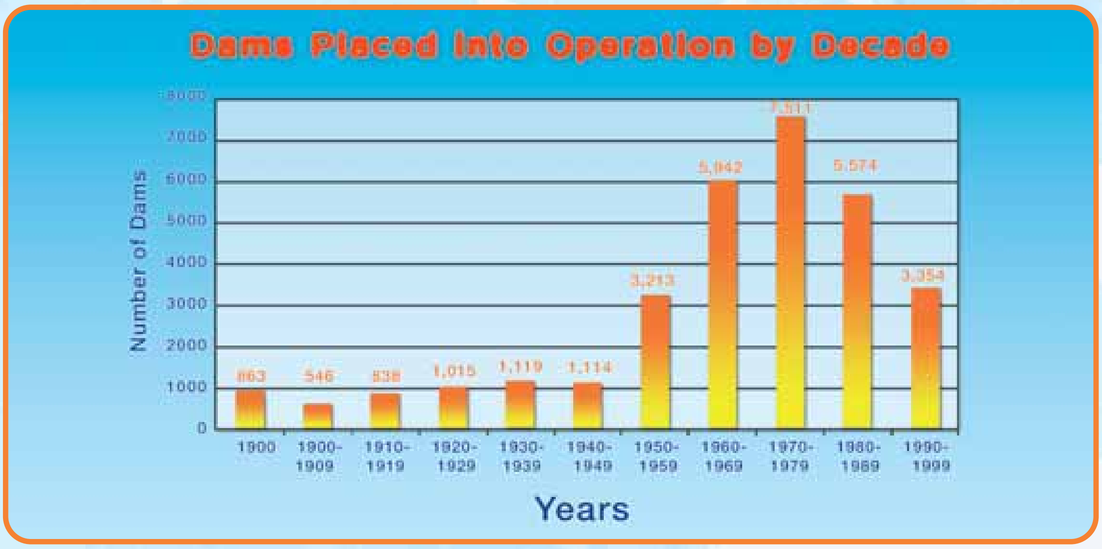
13

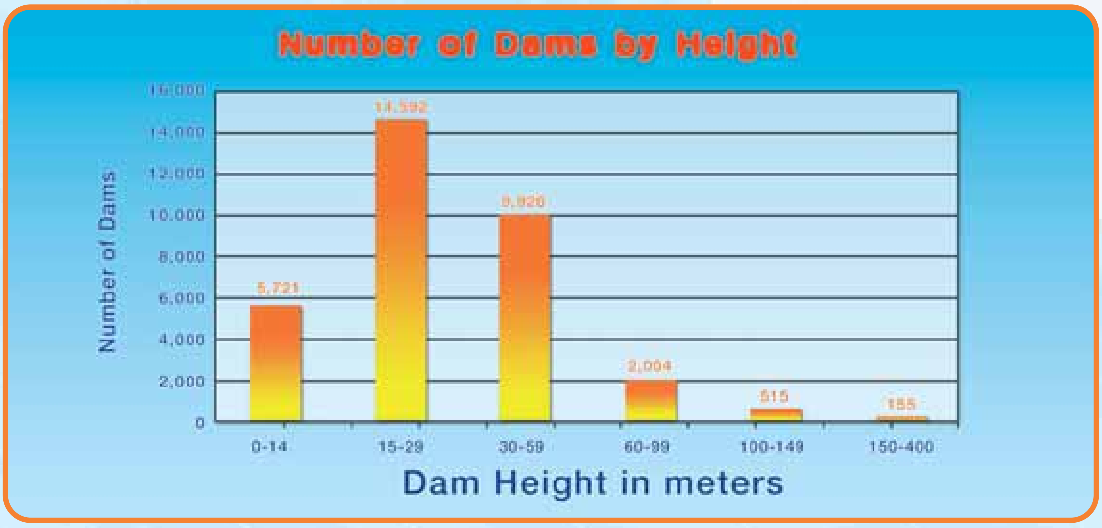
Dams of Today

10

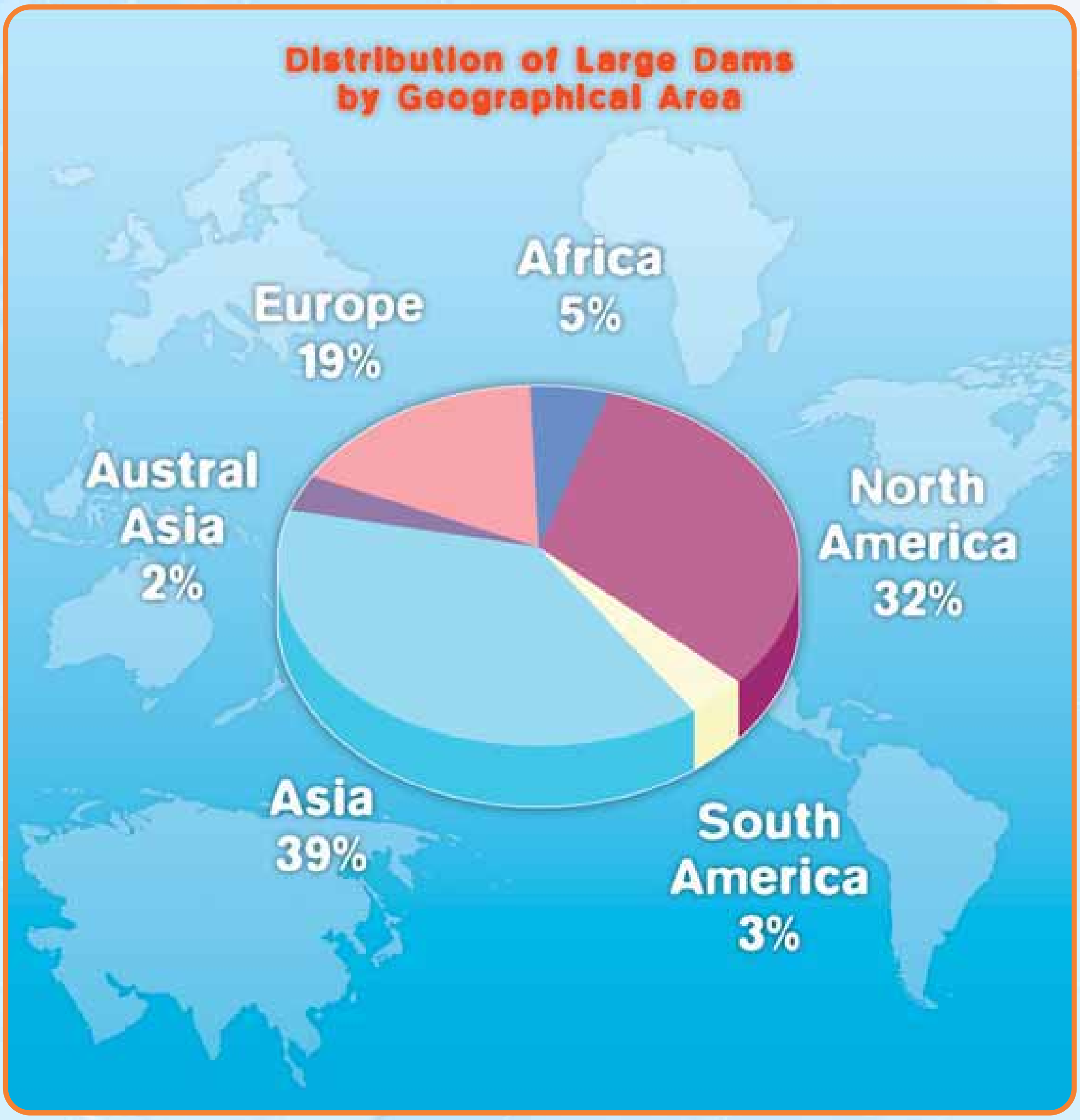
The International Commission on Large Dams (ICOLD) maintains a Register of Dams in the World. For a dam to be considered large and be included in the register it must have a height of 15 meters or 10 to 15 meters and store more than 3 million cubic meters of water in the reservoir. The dams are listed by country and include data such as the dam name, year of completion, dam height, reservoir capacity, area of catchment (drainage area), the purpose, installed electric generating capacity, mean annual electricity energy produced, irrigated area, volume of water stored for flood protection and number of people affected by resettlement. The world data as of 2000 indicates that there are about 50,000 large dams in operation. Embankment dams are the predominant type followed by gravity and arch dams. The planning process for a dam project and public involvement along with the local socio-economic issues are discussed in section 13.

Graphs showing when the world's large dams were placed into operation, their distribution by height and distribution by geographic areas are shown below:





The primary type of dam is the earthfill embankment dam which represents 43.7% of the total. This is followed by gravity dams (10.6% of the total) and rockfill embankment dams (5.3% of the total).



10.1 The purposes of the current dams in the world

Most of these dams in the ICOLD register (71.7%) are single-purpose dams, but there is a growing number (28.3%) of multipurpose dams. Today, irrigation is the most common purpose of the dams in the ICOLD register. The distribution for each purpose among the single-purpose dams leads to the following results:

- 48.6% for irrigation
- 17.4 % for hydropower
- 12.7% for water supply
- 10.0% for food control
- 5.3% for recreation
- 0.6% for navigation and fish farming
- 5.4% others

Chaudanne Dam - France - is an arch dam providing water to a naturally dry region for domestic, irrigation, industrial and hydropower use

© 26 (see p.64)

11

The Benefits we Receive from Dams

One of the fundamental requirements for socio-economic development throughout the world is the availability of adequate quantities of water with the appropriate quality and an adequate supply of energy. Properly planned, designed and constructed and maintained dams contribute significantly toward fulfilling our water supply and energy requirements. To accommodate the variations in the hydrologic cycle, dams and reservoirs are needed to store water and then provide a consistent discharge to maintain the required daily flow in our rivers throughout the year.

11.1 Water supply for domestic and industrial use

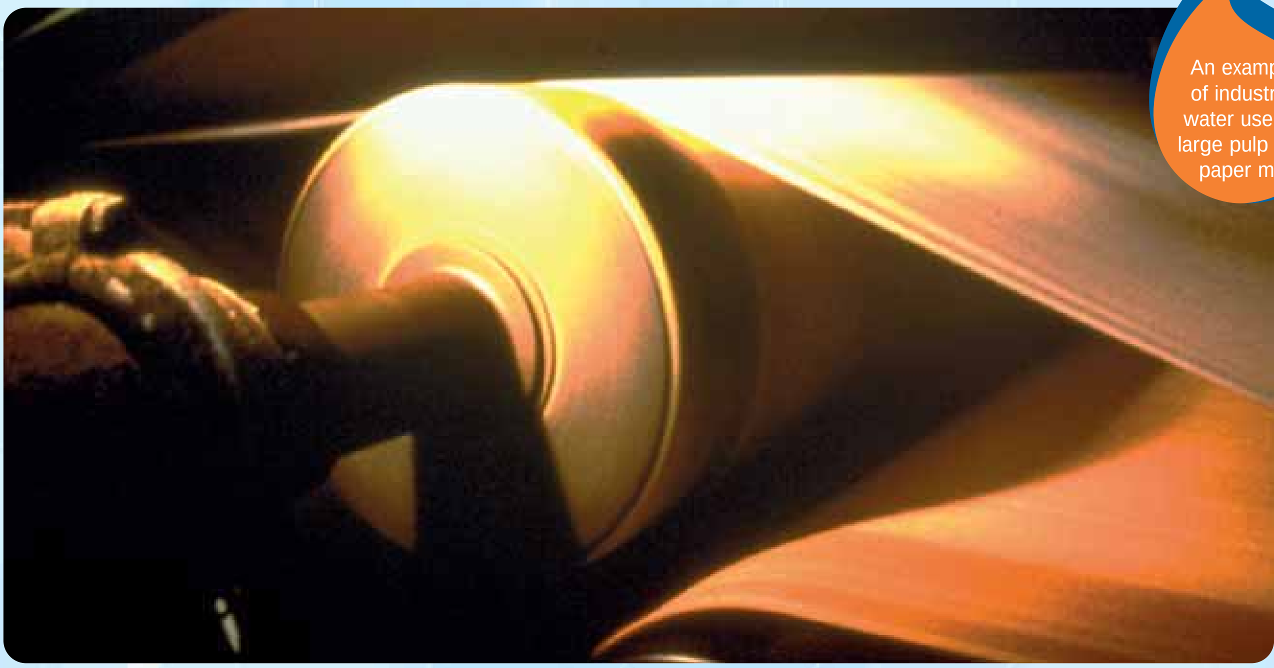
An adequate and dependable source of water is needed both to sustain existing civilization and to support future growth. In the past and in many regions of the world today, the main sources of domestic and industrial water are groundwater or aquifers (layers of sandy gravels or rock beneath the ground surface which contain and are capable of storing water). Today, the withdrawal from many of these aquifers exceeds the natural recharge, which results in lowering of the water table. This situation can lead to depletion of the groundwater both in times of drought and permanently. It is important to remember from section 3 that of the total rainfall falling on the earth, only 19% falls on our land mass and a large portion ends up as runoff leaving only 2% is infiltrated to replenish our groundwater. Properly planned, designed and constructed and maintained dams to store water contribute significantly toward fulfilling our water supply requirements. To accommodate the variations in the hydrologic cycle, dams and reservoirs are needed to store water and then provide more consistent supplies during shortages.

The Benefits we Receive from Dams

© 27 (see p.64)

An example of ench dam

It is becoming essential that our water supply obtained from groundwater be augmented with additional water from reservoirs. Large urban areas depend heavily on water stored in reservoirs during periods of high rainfall which is then used during dry periods. This is especially critical in arid regions of the world.



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An example of industrial water use - a large pulp and paper mill

Water stored in reservoirs is also used for industrial needs. These needs ranges from the direct use in manufacturing to chemical and refining processes and for cooling at conventional and nuclear power plants. Managed flows from reservoirs can be used to dilute discharged substances by augmenting low river flow to maintain water quality at safe limits.

Industry needs millions of liters per day

© 29 (see p.64)

11.2 Meeting the agricultural demand for food supply

One of the biggest uses of water on a world-wide scale is irrigated agriculture. Since the early 1990s, less than 1/5 of the land suitable for agriculture in the world has been irrigated, and it has contributed about 1/3 of world food production. A popular saying among the people in arid regions of the world is "Food grows where water flows".

It is estimated that 80% of additional food production by the year 2025 will need to come from irrigated land. This will put an additional demand on our fresh water supply. Most of the areas in need of irrigation are in arid zones, which represent a major portion of the developing countries. Even with the widespread measures to conserve water by improvements in irrigation technology, the construction of more reservoir projects will be required.

Providing water for food in developing countries

© 30 (see p.64)

“Food Grows where Water Flows”

11.3 Flood control

Dams and reservoirs can be effectively used to regulate river levels and flooding downstream of the dam by temporarily storing the flood volume and releasing it later. The most effective method of flood control is accomplished by an integrated water management plan for regulating the storage and discharges of each of the main dams located in a river basin. Each dam is operated by a specific water control plan for routing floods through the basin without damage. This means lowering of the reservoir level to create more storage before the rainy season. This strategy eliminates flooding. The number of dams and their water control management plans are established by comprehensive planning for economic development and with public involvement. Additional information on integrated water management plans is in paragraph 11.7. Flood control is a significant purpose for many of the existing dams and continues as a main purpose for some of the major dams of the world currently under construction.

Flood in a village

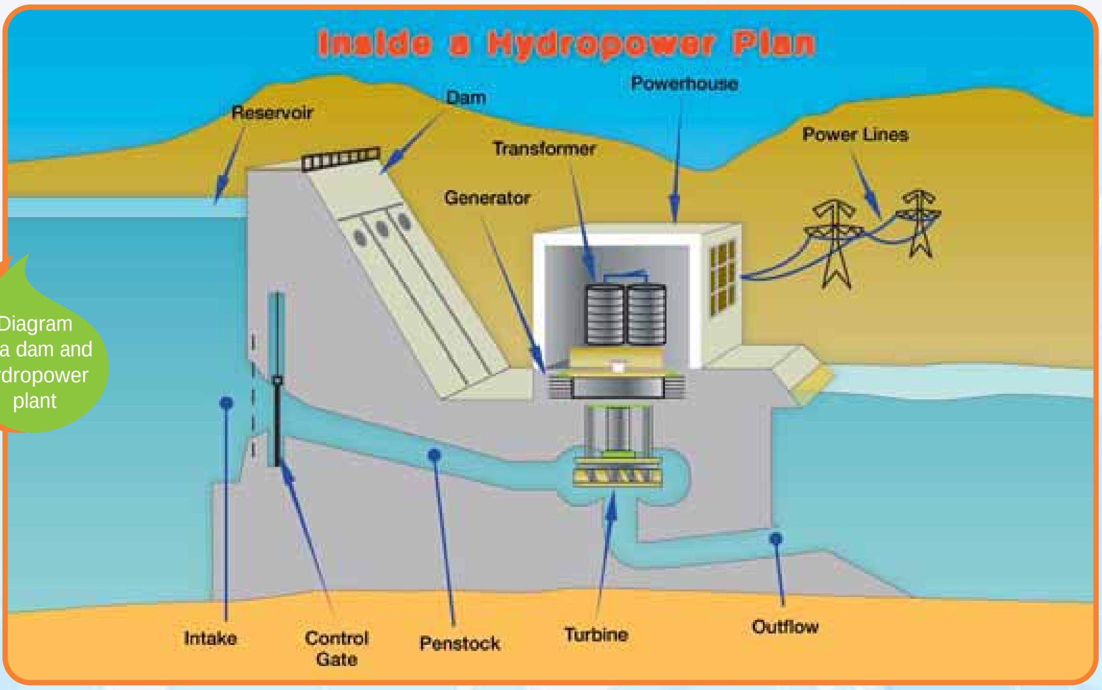

Diagram of a dam and hydropower plant

11.4 Hydropower

Water has been used as a form of power since Roman times. It was first used to drive water wheels for various mechanical processes, such as grinding corn, sawing timber or driving textile mills. In the early 19th century, the water turbine was developed as a much more efficient machine than the waterwheel, and by the mid-19th century, water power was used to produce electricity for the first time. The concept of using moving water to turn a turbine connected by a shaft to a generator to create electricity is known as hydropower. Since water is the source, hydropower is a renewable and widely used source of electricity.

A turbine used for hydropower

© 31 (see p.64)

Generators in the power plant

© 32 (see p.64)

The Benefits we Receive from Dams

© 33 (see p.64)

Castillon Dam - France - showing the plant at dam-foot, switch-yard and line on the top right

The greater the available force of water to turn the turbine, the more power can be produced. The amount of electricity which can be produced thus depends on the height though which the water has to fall to reach the turbine and the volume of water flowing through the turbine. A major advantage of hydroelectric power, compared with other sources of electricity (for example burning coal, oil or gas), is that the source is renewable. In other words, it is not consumed by the process of creating electricity and is still available for other uses when it is discharged from the power station. Also it is a clean source of power, as it does not involve burning fuel which can pollute the environment.

Some of the first countries to develop hydroelectricity on a large scale were Norway, Sweden and Switzerland in Europe, Canada, the USA, Australia and New Zealand. On a smaller scale, projects were built many years ago in some of the Asian countries with appropriate conditions; India's first small hydropower plant, for example, is more than 100 years old.

Almost 200 countries in the world have some kind of capability to develop hydroelectric power, whether on a large or small scale. The best natural conditions are in countries which are mountainous or hilly, with plenty of lakes or rivers, or with big river systems. The largest hydro station in operation is Itaipu, built on the Rio Parana River between Brazil and Paraguay. Although this is an exceptionally large hydropower project (with power capacities of more than 14,000 MW (Mega Watt or 1 million watts), there are hundreds of thousands of medium-scale stations worldwide. Brazil produces more than 90% of its electricity from hydropower projects.

Vaugris step on the Rhône River: dam, plant and lock - a multiple purpose equipment

© 34 (see p.64)

11.5 Inland navigation

Natural river conditions, such as changes in the flow rate and river level, ice and changing river channels due to erosion and sedimentation, create major problems and obstacles for inland navigation. The advantages of inland navigation, however, when compared with highway and rail are the large load carrying capacity of each barge, the ability to handle cargo with large-dimensions and fuel savings. Enhanced inland navigation is a result of comprehensive basin planning and development utilizing dams, locks and reservoirs which are regulated to provide a vital role in realizing regional and national economic benefits.

In addition to the economic benefits, a river that has been developed with dams and reservoirs for navigation may also provide additional benefits of flood control, reduced erosion, stabilized groundwater levels throughout the system and recreation.

11.6 Recreation

The attractiveness of reservoirs for recreation is often a significant benefit, in addition to the other purposes of a dam. This is very significant in areas where natural surface water is scarce or non-existent. Recreational benefits associated with lakes, such as boating, swimming, fishing, bird-watching and nature walks, are taken into account early at the planning stage and along with other objectives achieve a balanced project. The operation of the dam and reservoir can enhance recreational opportunities.

11.7 Integrated water management in the river basin

The availability of water in sufficient quantities and of adequate quality where it is needed remains the basic challenge. Thus, the water obtained from groundwater, natural lakes, free flowing rivers and reservoir projects is used to meet the domestic, agricultural and industrial demands. Of these four sources, reservoir projects are the only source that can effectively be managed to meet both the water and energy needs in a state, region and country. The inflow and outflow from a reservoir must be managed. Integrated water management in the river basin is the process by which the water stored in reservoirs and the daily amount released is managed in the basin to ensure that an adequate and dependable quantity is available. An example is storing the storm flows for flood control. During a period of drought gradual releases from each dam are coordinated to ensure an adequate quantity is available over the entire basin. Each dam and reservoir in the basin has a water control plan that outlines discharges from that reservoir based on inflow to the reservoir and downstream needs. Each water control plan is coordinated with other dam and reservoir projects within the river basin. The overall coordination and control is accomplished by a basin-wide organization such as a River Basin Commission. This organization has a critical role in controlling droughts and floods within the river basin.

Intakes located at different elevations on the control tower of the dam allow the operators to make selective withdrawal of water at different temperatures that, when combined as discharge to provide the desired temperature in the downstream river to enhance downstream water quality. A properly managed reservoir project also maintains a predetermined reservoir level during the various seasons of the year to maintain environmental requirements.

The objective of integrated water management in the river basin is to satisfy demands for water without sacrificing existing uses. The major issues to accomplish this in a river basin are:

- Formulating a strategy to provide adequate stream flow and at the same time maintain appropriate reservoir levels (flood and drought management).
- Satisfying municipal, agricultural and industrial demands without injury to the environment.
- Evaluating and improving water quality.

Integrated water management from dams in the watershed provides a reliable average daily flow over the year in our rivers

© 35 (see p.64)

Gambsheim Dam, power-house and locks on the Rhine river. A large multipurpose dam manages river flow to provide water supply, electrical energy, navigation, flood control and recreational use. A big fish passage is being constructed in the center part of the plant.

© 37 (see p.64)

Industrial plant

© 36 (see p.64)

11.8 Summary of benefits

The benefits of dams and reservoirs must be viewed and weighed from all perspectives: local, regional, national and global. The entire range of benefits from a dam project are not always realized in the immediate vicinity of the reservoir or by the population that lives there. Generally the people of a region and the whole nation receive the full benefits of a dam and reservoir. An example is the Aswan High Dam on the headwaters of the Nile River in Egypt. This dam stores and then discharges water to maintain an average daily flow in the Nile. This benefits the entire nation.

The value of integrated water management in a river basin can best be seen in developing and developed countries. For centuries several countries of Southeast Asia, for instance India and Indonesia, were periodically plagued by hunger. When the monsoon rains were delayed or insufficient, the country

© 37 (see p.64)

Maintaining fertile valleys by providing reliable river flow

Aerial view of Hungry Horse Dam, Texas, United States

was affected by starvation, frequently with a large number of deaths. When major reservoirs were built during the last five decades, the problem was solved by storing of large quantities of water from the surplus during rainy seasons, for regulated release during periods of drought.

An outstanding example of the water supply benefit in a water-stressed area is the Lesotho Highlands Water Project. Situated in southern Africa, it is a joint venture of the Kingdom of Lesotho and the surrounding Republic of South Africa. The project provides for storing water in several large reservoirs in the mountainous region of Lesotho where rainfall is relatively heavy. The water is then released through a nearly 80 kilometer long tunnel system and supplied to the arid central region of South Africa. Prior to this project, the Lesotho highlands were under developed and almost inaccessible. As part of this project new paved access roads with bridges for heavy traffic were built. The electricity and telecommunications networks in the whole country were substantially upgraded to modern standards or built from scratch, schools were established at the construction sites and in their surroundings and public health services and health care plans were introduced with hospital and medical emergency posts. This basic infrastructure remains in the area and continues to be a permanent benefit.

Obtaining water for irrigation

© 38 (see p.64)

Throughout the world, agriculture requires significant and reliable amounts water. Irrigation systems make this possible. In the United States, agriculture accounts for 49% of the fresh water consumption. In Africa and Asia, the United Nations estimates that 85% of the fresh water is used for agriculture. By 2025, the agricultural requirement for water will increase by 1.5 times the current use. Dams and reservoirs are the tool to provide the large quantities of water to meet this need.

Industrial plants and operations require a significant amount of water to operate efficiently. When fresh water is used, it must be treated before being discharged from the facility, since the industrial processes usually pollute the water.

Hydropower is the cheapest source of electric energy, because water, the driving force is free. So, hydropower can be a valuable means to tackle the problem of poverty in many parts of the world. Implementing a new hydropower plant can mean that some of the local population must be relocated from the reservoir area. Sao Paulo, Brazil is an example is a city of 18 million and the largest place of industrial concentration in South America. Of the total population, 5 million are classified as low income. São Paulo's electricity supply is almost entirely based on inexpensive hydropower. This has facilitated the creation of new jobs and improved the standard of living.

Inland navigation has the lowest fuel consumption and least amount of pollution of the bulk transportation modes. To move a given load over a long distance, the transport by road requires ten times, and by rail five times the quantity of fuel, consumed when shipping the load by barge. Since only few rivers are readily navigable, natural obstacles such as rapids, shallow stretches of the river bed or too a high velocity of the flowing water have to be overcome or eliminated by the construction of locks, dams and control structures. Inland navigation contributes to reducing the emission of greenhouse gases and thus to mitigating the worldwide effects of global warming.

Towboats push barges tied together to form a "tow". A tow may consist of four or six barges on smaller waterways up to more than 40 barges on larger rivers. The barges of a tow moving through a lock can be seen in the following picture.

Large shipments of goods move the locks and dams on inland waterways such as this tow

© 39 (see p.64)

12

Dams and the Environment

The economic recovery throughout the world following World War II was accompanied by phenomenal growth in infrastructure systems that included the world's largest dam construction period. Dam construction reached a peak in the 1970s. As this economic development and construction continued, the world population became aware of the environmental price that was being paid for this development. Today the people are looking for a balance between the economic benefits and environment benefits for water resources projects. They are also looking for an equal distribution of the benefits for the entire population in the region. People prefer that water resources development and management be accomplished on the entire watershed rather then in isolated areas.

In 1997, the International Commission On Large Dams (ICOLD) published a document that presents guidance for environmental consideration, assessment and mitigation: "Position Paper on Dams and the Environment". It states:

> **"Increased awareness of the natural environment and its endangered situation is one of the most important developments of the late 20th century."**

Today we are mitigating the environmental impacts of dams. In many countries, governments have mandatory requirements to take into account and plan to mitigate the possible impact which dams may have on nature and the environment when selecting where a dam should be built, as well as how it will be constructed and operated. By taking these predictions seriously, many possible consequences can be addressed in a positive way.

The goal for a nation is to achieve clean and healthy watersheds which support aquatic life as well as their economic development and human needs. This goal is best met by encouraging and supporting comprehensive water resource management that is tailored to the regional and local needs. Water management is essential to achieve both water quality and water quantity requirements. Environmental conservation includes mitigation and enhancement for new projects, maintaining the existing conditions and restoration where appropriate.

12.1 Environmental conservation and enhancement

Managing water resources in a river basin has an impact on its natural water cycle. The scale of the impact depends on the actual size and natural condition of the area to be developed and the extent of development. Concerns about environmental issues and implementation of mitigation measures are essential elements in the planning of a project. This includes: clearing of vegetation in the area to be flooded, multi-level outlet structures to optimize downstream water temperature and quality, provisions for the migration of fish and other aquatic organisms, and operational rules for regulating downstream flows at critical times to protect habitat for reproduction or migratory routes. Appropriate site selection, together with the implementation of these techniques,

© 40 (see p.64)

Conservation of the natural habitat is part of the design of a dam project

will result in both new and rehabilitated projects that minimize unacceptable environmental impacts.

Encouraging and supporting a comprehensive water resource management plan can accomplish environmental conservation and enhancement for both existing and new projects. According to the regional and local needs, the plan should include conservation, mitigation and enhancement of the existing conditions. An example of optimizing the environmental conservation and enhancement is treatment of the area where the reservoir meets the land (reservoir rim), limiting access in the reservoir area, and providing small dams with outlets in the headwaters. This is very effective for multi-purpose projects where the reservoir level may fluctuate during operation. Parts of the reservoir area are restricted for wetland development, aquatic habitat and animals. Islands and small dams are constructed to protect the wetlands from reservoir fluctuations. The dam in the headwaters also serves to control sedimentation. Uneven shorelines can be created for wetland development. Many existing projects throughout Europe and Asia have been modified and changed to incorporate these measures.

An example of the implementation of this technology can be seen at the Rottach reservoir in Bavaria, Germany. This same environmental mitigation and enhancement can be incorporated in projects world-wide.

View looking downstream - showing shallow water and wetland development

© 55 (see p.64)

Creating a separate pond and wetlands at the upstream end of the Rottach reservoir in Germany

© 56 (see p.64)

Aerial view showing a completed pond and wetlands for ecosystem conser-vation

© 57 (see p.64)

Sedimentation aspects

Rivers naturally transport sediments. Sediment deposition occurs as the river enters a reservoir and its sediment transport capacity decreases in the backwater created by the dam. Coarse sediment is typically deposited first while finer clay and silt fractions are transported much deeper into a reservoir. Most reservoirs trap nearly 100 % of the river sediment loads that enter them, but sedimentation typically only becomes a significant problem 50 or more years after construction of a dam, since dams are designed with extra storage to allow for sediment deposition.

Due to the rapid growth in dam development during the 1960s to 1970s, about 45 percent of the current storage capacity in reservoirs would be seriously affected by reservoir sedimentation in 20 years time. Most existing dams would be seriously affected by lost storage due to sedimentation by the year 2065.

Sedimentation rates vary greatly with some of the highest yields being found in geologically active regions where earth-quakes occur. Sedimentation impacts on reservoirs are gener-ally however most severe in semi-arid regions where sediment yields are relatively high and dam catchments large.
Agriculture and afforestation, deforestation of natural forests, overgrazing and other human activities with help of stormwater, are the main contributors to catchment erosion.

To limit soil erosion and reservoir sedimentation, human organisations have to deal with technical tools and regulatory ones, such as catchment management policies.
The ideal solution is indeed to minimise the accumulation of sediment within reservoirs.

- Build small (relative to the river flow) dams on rivers that carry substantial sediment loads. These dams must be provided with large low level gates to flush deposits out during floods when necessary.

- Storage dams should be built in valleys with low sediment yields and/or with small catchments, and should be sized with additional dead storage for future sedimentation of say 50 to 100 years.

Once sediments have become deposited and consolidated, it becomes very difficult to remove and store them cost-effectively by mechanical means. Alternative solutions such as dam heightening may be better than recovering lost storage capacity by dredging.

The riverbed directly downstream of a dam typically experiences degradation (lowering of the riverbed) due to the sediment being trapped in the reservoir, depending on the existence of large tributaries downstream the dam location.

Looking to the Future - Dams for the 21st Century

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Today, the world is undergoing major changes in social and business practices as well as vast economic development associated with the world globalization and the rapid advances in technology and expanded communications associated with the continued unprecedented increase in population. At the same time, in many areas careless use of our water have accelerated pollution of the environment.

At the 2005 World Summit of the United Nations General Assembly eight Millennium Development Goals (MDG's) were presented for achievement by 2015 to eradicate poverty, improve education, improve health, combat disease and ensure environmental sustainability. These Millennium Development Goals can be viewed at www.un.org/millenniumgoals. The United Nations also states that management of the world's water resources is an essential ingredient to achieving all of the MDG's. They recognize that dams and reservoirs will continue to play a major role in the management of the world's water resources.

As the world needs significant quantities of water for domestic, agricultural, energy and flood control to sustain development, multipurpose dams are the most realistic option. Solar, wind and groundwater schemes must be pursued for the purpose of augmentation, but again they do not offer the quantities for viable alternatives. Conservation measures are a must - but they are not stand-alone measures.

Effective management of the world's water resources in watersheds by dams and reservoirs in conjunction with other measures is essential to sustaining both the existing and future population of the world. This is critical for the developing nations and in the vast arid regions of the world. Basin-wide planning for water management is the key element to providing optimum water supply and other benefits. While dams provide significant benefits to our society, their impacts on the surroundings may include:

- Resettlement and relocation of the affected population.
- Socio-economic impacts.
- Environmental concerns.
- Sedimentation issues.
- Safety aspects.

The challenge for the future will be the wise planning and utilization of dams and reservoirs in the watershed in conjunction with the groundwater, climate, environment and land use for the wise management of the world's water resources as part of each nation's social and economic development goals.

13.1 Planning process for a dam and reservoir project

The watershed or river basin is defined by hydrology and transcends national, political, social and economic boundaries making it the basic element for the planning and management of water resources and the ecosystems. The planning for water resource development should be accomplished on a watershed basis rather than a "project-by-project" basis. The planning process is a systematic and comprehensive activity that considers all resources in the watershed. Therefore the size and location of reservoir projects is best determined on this basis.

Once a dam and reservoir project is located detailed planning in the region can begin. With regard to a specific dam project, every effort is made to assure that an economic, social and environmental value is added to the watershed. Ecosystem restoration is one of the primary environmental objectives of a dam project. For the specified project goals and objectives of a new dam project, this process contains six individual steps and is a structured approach to identifying and then solving issues and problems. It provides a rational framework for sound decision making. This process is also applicable for many other types of major projects. The six steps are :

- **Step 1**
  Identifying issues,
  problems and opportunities.
- **Step 2**
  Inventorying and forecasting conditions.
- **Step 3**
  Formulating alternative plans.
- **Step 4**
  Evaluating alternative plans.
- **Step 5**
  Comparing alternative plans.
- **Step 6**
  Selecting a plan that best meets the needs.

A successful project is generally based on the accomplishment and documentation of all of these steps. It is essential that planners, economists and engineers conduct each step as a team. It is important that this be a repetitive process that includes public and partner involvement. As more information is acquired and developed, it may be necessary to reiterate some of the previous steps.

These six steps are presented in a sequential manner for ease of understanding, but one step usually occurs several times and sometimes concurrently. Iterations of steps may be conducted as necessary to formulate efficient, effective, complete and acceptable alternatives for selecting the best. Wise planning with input from all stakeholders is essential for successful dam projects.

13.1.1 Public involvement and coordination

The purpose and goal of public involvement and coordination is to open and maintain channels of communication with the public and local businesses in order to give full consideration of public views and information in the planning process. The objective of public involvement is to ensure that the dam projects and programs are responsive to the needs and concerns of the public. Elements critical to a good public involvement and coordination process are disseminating information about proposed activities, understanding the public's desires, needs and concerns, providing for consultation with the public before decisions are reached, and taking into account the public's views.

All planning studies incorporate public involvement, collaboration and coordination with the public. This is initiated during the initial planning process, where issues, opportunities and problems are identified, and continue throughout the planning process. Involvement at the initial stage of the planning process not only helps to identify the problems and opportunities, but also extends an invitation to the public to have continued involvement and an opportunity to voice their concerns, ideas and suggestions in the planning and decision making process.

Based on an initial public meeting, in the early phases of the planning process, the project team will determine, the extent of public involvement required and will establish an appropriate strategy for integrating public involvement into the planning process. It is important to develop a strategy that creates relevant, quality public involvement opportunities for those who have, or may have, an interest in the study. The strategy shall reflect the scope and complexity of each particular study. Major public involvement activities conducted during the planning process are announcing the initiation of the study, identifying the public, and the scoping process. It is important for the public to see and have input to the alternatives being studies. At the end of the planning process, the public should be briefed on the selected alternative and the schedule for design and construction.

13.2 Socio-economic issues associated with a dam and reservoir project

In a national economic development plan, significant benefits are needed. This results in the planning, design and construction of large dams that create significant reservoirs. The project can create local economic and social issues that if not addressed early in the planning can result in impacts. Resettlement programs for the local population and businesses must involve the identification of the affected population as well as the affected activities such as agriculture, irrigation, forestry, commerce and industry. Appropriate compensation, movement and actual rebuilding of communities for the population and business activities above the reservoir level are an essential budget item in the project cost.

In tropical areas of the world, sanitation must be addressed. Reservoirs can create an environment which is favorable for the transmission of water-related diseases. The primary preventive measures are sanitation and health-care programs for the population around the reservoir, in conjunction with appropriate operating rules such as fluctuating lake's water level to discourage growth of disease-carrying insects.

In summary, one of the most important objectives of a dam is to ensure that an appropriate share of the benefits go to the population directly affected.

13.3 Increased need of integrated water management in the watershed or river basin

Water in adequate quantities and of adequate quality at the right locations will be the essential ingredient to support expansion of the world's population and assist developing countries in making progress to meet their social and economic development goals. Dams which are properly planned, designed, constructed and maintained contribute significantly toward fulfilling our water and energy requirements. The primary source of fresh water supply is from rainfall. We must always

Maintaining constant water levels to ensure reliable wetlands for habitat

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© 42 (p.64)

A dry river an example of the need for water management

© 43 (p.64)

Example of a river that has integrated water management to provide a minimum and dependable flow throughout the year

An example of industrial development: a large pulp and paper plant

© 44 (see p.64)

be mindful that throughout the world the hydrologic cycle varies and is not predictable. To accommodate these variations in the hydrologic cycle, we need to manage the fresh water that is available to us effectively.

Wise management of the water in our reservoirs is essential to support the growing demands. Dams and reservoirs are a useful tool for the management process, since they can store water and then provide more consistent supplies during shortages. In short terms Dams will continue to enable us to manage water so that we do not have dry streams for most of the year. The goals of regional integrated water management in the watershed are:

- Improved management of the water supply.
- Improved water quality in our rivers.
- Improved environmental conditions in the watershed.

Therefore, the traditional approach of water resources development of water supply, irrigation, navigation, hydropower and recreation must be expanded to include:

- Water quality.
- Management of water quantity - (flood and drought).
- Sedimentation control.
- Climate assessment.
- Land use and zoning.
- Groundwater management.
- Maintaining the habitat.
- Maintaining and enhancing the environment.

13.3.1 Need for real time water management in the watershed or river basin

Water management in a river basin includes the collection and evaluation of the critical information so that decisions can be made to achieve the optimum releases from reservoir projects to meet domestic, industrial and agricultural demands in the river basin. For example, it takes 38 liters or 110 gallons to refine 3.8 liters or 1 gallon of gasoline. To satisfy the increasing demand for water, a swift, accurate and reliable data management system is required. These real time decisions are driven by observed and real time date collection, modeling and forecasting of the current weather and river flow conditions. The information and data used in these decisions relate to:

- Water quality in the river.
- Managing river flows for both droughts and floods.
- Emergency planning and response for floods.
- Planning, zoning, and land use by communities.
- Improving the efficiency and benefits of existing dam projects.
- Planning in the river basin (modifying the operation (storage and releases) of existing dams and new dam projects where and when needed).

The requirements for this type of system are :

- River basin wide network for real-time data collection.
- Development of a dependable database.
- Mathematical modeling within the river basin.
- Detailed mapping.
- A fast and reliable computer system .

Watershed modeling is an important aspect of this system. It includes the hydrologic data, reservoir storage data and the system hydraulics. The output is in the form of forecasts for various scenarios and appropriate reservoir operations to optimize benefits and minimize damage

13.4 Irrigation in the future

Irrigation will be necessary throughout much of the world to ensure that agriculture production is possible to support the expanding population. While people in the developed countries enjoy prosperity and plentiful food, it is estimated that half of the people in the world, some three billion people, have insufficient food to sustain life. These same people do not have access to safe drinking water.

Management of water and efficiency of irrigation will play a key role in the future. Successful irrigation requires a reliable water supply throughout the growing season. Reduced losses in canals, improved measurement, monitoring and control systems will help optimize the amount of water used for irrigation. The use of water

Managed water and soluble fertilizers will improve food production

soluble fertilizers will improve the food production from a given field. Storage of water during periods of excess flow for use during periods of storage by using dams and reservoirs is the most important factor for assuring that a reliable water supply will be available.

13.5 Hydropower in the future

Hydropower supplies about 20 % of the world's electricity today and there are hydro stations being built in virtually all parts of the world because it is a renewable source of electricity.

A country's basic hydroelectric potential can be worked out based on its annual rainfall, its river systems, and its topography (hilly or mountainous terrain). But not all of this potential can ever be used, as there may be areas where it is not technically possible to build a dam or power station, because geological or other conditions may not be right, and may also be economic and political constraints. There may be other priorities for a country's budget, or reasons to avoid some areas because of other uses for the land, or a large population living there.

The Three Gorges Project on the Yangtze River in China

Most remaining technically feasible sites remain today in Africa, Asia and Latin America, and in these regions there are often economic constraints. But there are hydroelectric schemes being either built or planned in about 180 countries. Currently, the leading countries at present for developing their hydroelectric potential are: China, India, Iran, Brazil and Turkey.

The largest hydro station in full operation is at the Itaipú dam, built on a river between Brazil and Paraguay producing 14,000 MW. The biggest one under construction is Three Gorges Project on the Yangtze River in China. When complete in 2009, it will produce 18,200 MW plus provide flood control and navigation. These are exceptionally large projects. There are hundreds of medium-scale hydropower facilities worldwide.

Many countries have connections to a grid system at the national or regional level. Hydro stations very often feed power into these systems. Often several neighboring countries have interconnected grid systems, so water resources in one country might be helping to supply electricity to others. Sometimes agreements are made between two countries whereby one will agree to buy power from another, and will help to finance and develop hydroelectric resources for its neighbor. Examples include Thailand buying power from Laos, and India buying power from Bhutan, in each case this is based on distribution of power in a region.

"Small-scale hydro schemes" can also play an important role worldwide. They generally only involve the construction of very small dams, so they are cheaper to build, and they may supply isolated areas of the countryside, or small communities, sometimes not reached by a national grid system. Small hydro stations can sometimes be added at dams which have been built mainly for other purposes. The relatively flat Mur River in Austria near the border with Slovenia has several low head small hydropower projects.

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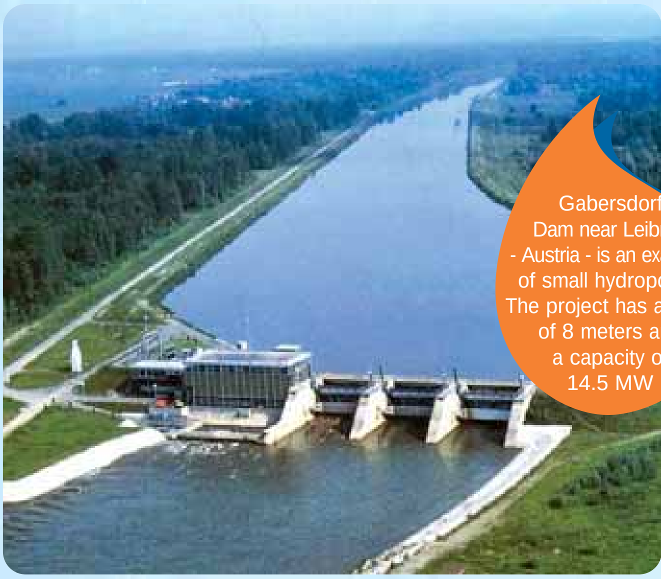
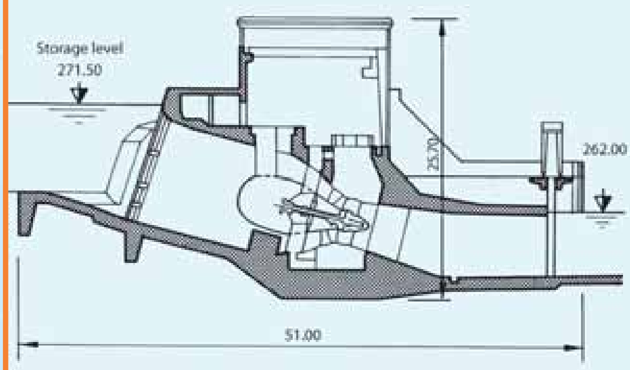
Itaipu Dam, Brazil and Paraguay. In 2006 the world's largest hydropower project

Generators in a hydropower plant

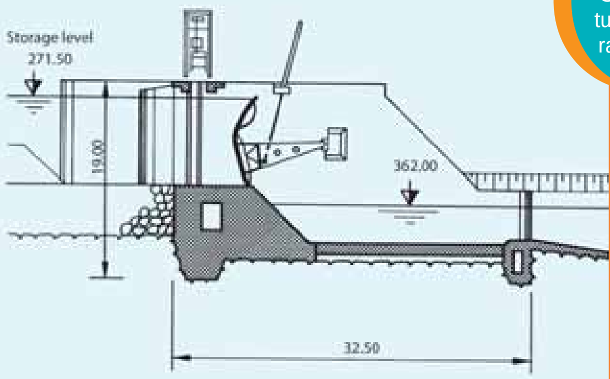


Gabersdorf Dam near Leibnitz - Austria - is an example of small hydropower The project has a head of 8 meters and a capacity of 14.5 MW

Powerhouse section



Weir section



Details of Gabersdorf turbines and radial gates

13.6 Flood control in the future

As in the past, a significant portion of the world's population will continue to settle near our rivers and streams. This situation will require optimization of existing flood control dams and projects as well as the planning, design and construction of new projects. It will be essential that the planning for these flood control projects be accomplished on a watershed basis to account for the anticipated amount of rainfall and locations of population growth.

Rochemaure Dam - France - dams and flood protection systems will continue to control flood waters in our rivers to prevent overtopping of the levee systems

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As part of the process to improve flood control systems, governments will need to review the climate changes and the standard level of protection to be provided. In many parts of the world this level will need to be raised. In addition, stricter zoning of land in and adjacent to the floodplain will have to be implemented.

Significant difficulties in weather prediction arise from rapidly developing climate changes in almost all parts of the world. Therefore, greater use of weather radar monitoring rainfall, hydrologic models and computer forecasting will allow real time forecasts for operational discharges from the dams and forecasts of all river stages in the basin. Here is an example of the components of a real time water management in a river basin.

Weather radar for prediction of the amount and locations of rainfall

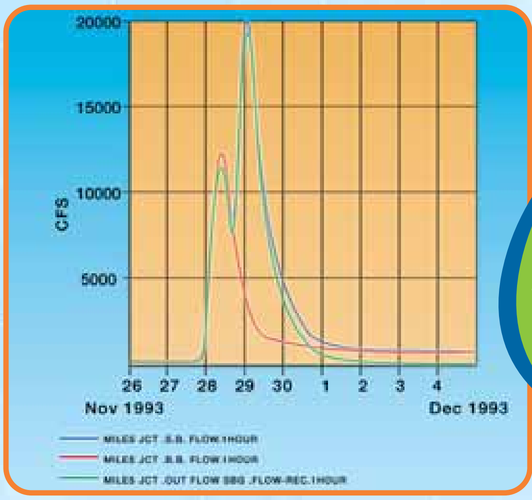
Automated stream gages to obtain real time stream flow and stage

13.7 Inland navigation in the future

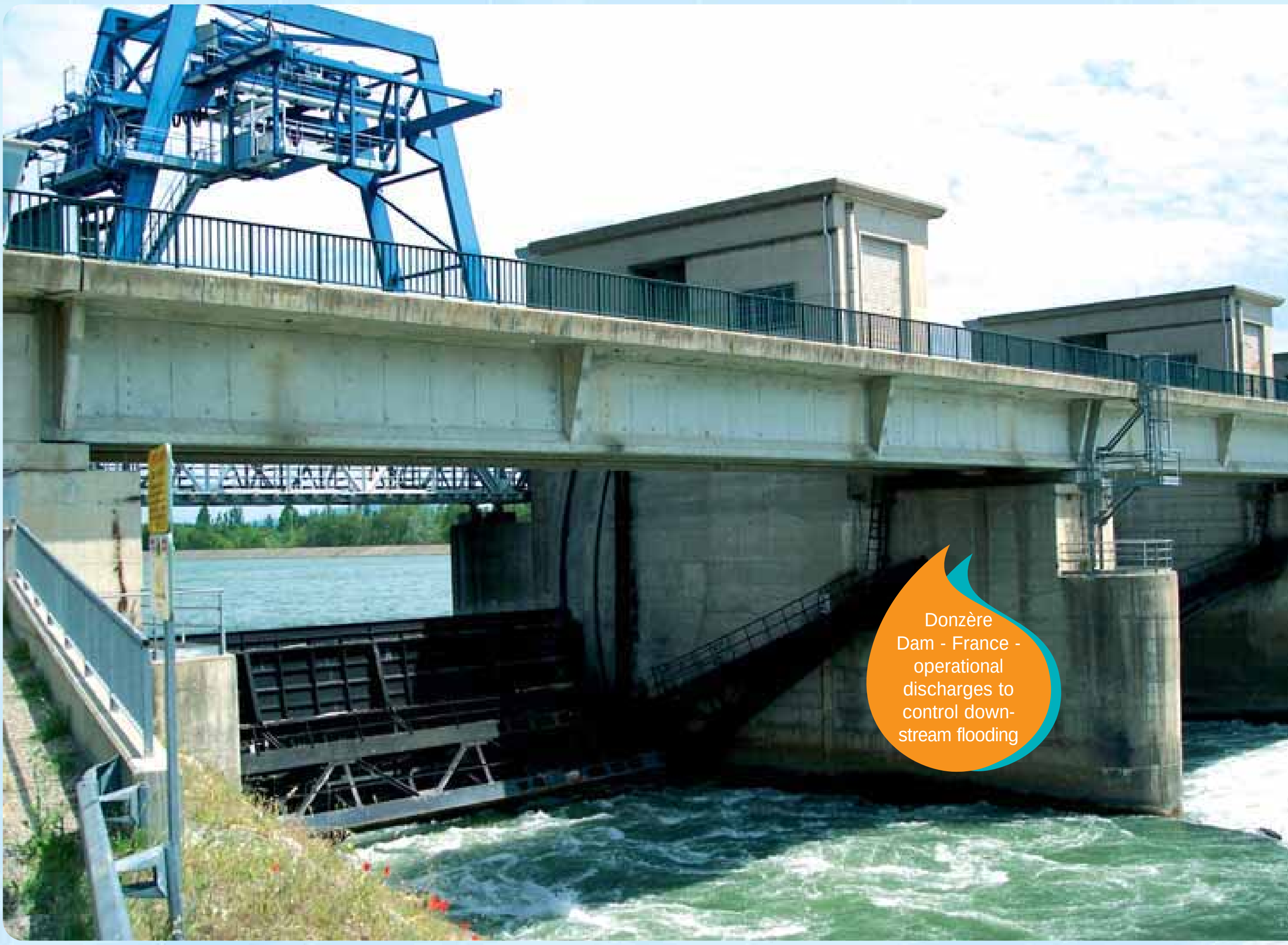
As economic development continues in the world, there will be a significant increase in the transport of raw materials and goods as well as an increased demand for products. Rising fuel costs will have an impact on the means of transportation used. Inland navigation is the most cost effective and least polluting means of transportation. A principal value of the inland waterways is their ability to efficiently convey large volumes of bulk commodities moving long distances. A 15-barge tow is common on larger rivers with locks. Such tows are an extremely efficient mode of transportation and can move about 22,500 tons of cargo as a single unit. Two examples of the cost effectiveness on inland navigation are as follows:

The capacity of 1 barge
= 15 jumbo rail cars
= 55 normal trucks

The capacity of 1 tow (15 barges)
= 21 four unit trains
= 870 trucks



Computerized hydrologic models to use real time input from weather radar and stream gages to make accurate forecasts for operational changes in reservoirs



Donzère Dam - France - operational discharges to control down-stream flooding

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Looking to the future, if the cargo transported on the inland waterways each year had to be moved by another mode, it would take about 6.3 million rail cars or 25.2 million trucks to carry the load. Imagine adding this traffic with the associated air pollution to the already congested rail lines and highways that pass through our communities.

The ability to move more cargo per shipment makes barge transport both fuel efficient and environmentally advantageous. On average, a gallon of fuel allows one ton of cargo to be shipped 59 miles by truck, 202 miles by rail, and 514 miles by barge. Developing countries with rivers will need to use inland navigation as part of their national economic development plan.

Central lock and dam structures

13.8 The balance between project benefits and the environment

The social and environmental impacts of dams and reservoirs built today must be avoided, or mitigated. The operation of existing dams must be reviewed and if necessary modified to accommodate project impacts on the environment. Every effort must be made to have the dam and reservoir project enhance or support the environment. Today's water resources professionals are guided by environmental policy as well as by engineering and safety concerns. Planners and engineers, many of whom are members of the International Commission on Large Dams, include the environment among their responsibilities. The teams of engineers and specialists from many disciplines - planning, engineering, environmental and social science - are involved in the planning, design and construction of dams. The following issues are considered when developing modern water resources projects:

- Dam and reservoir projects require system planning which recognizes the impact on an entire river basin and its ecosystems.
- Public consultation and input from all the people involved to obtain a consensus is necessary for the most effective project planning, implementation and operation.
- Include the environment, both natural conditions and social aspects, along with economic benefits in the initial planning for the project.
- Many countries now require the formal identification of environmental impacts during the conceptual phase of a project.
- Environmental protection and enhancement are generally included in all phases of the project.

Looking to the Future

Dams for the 21st Century

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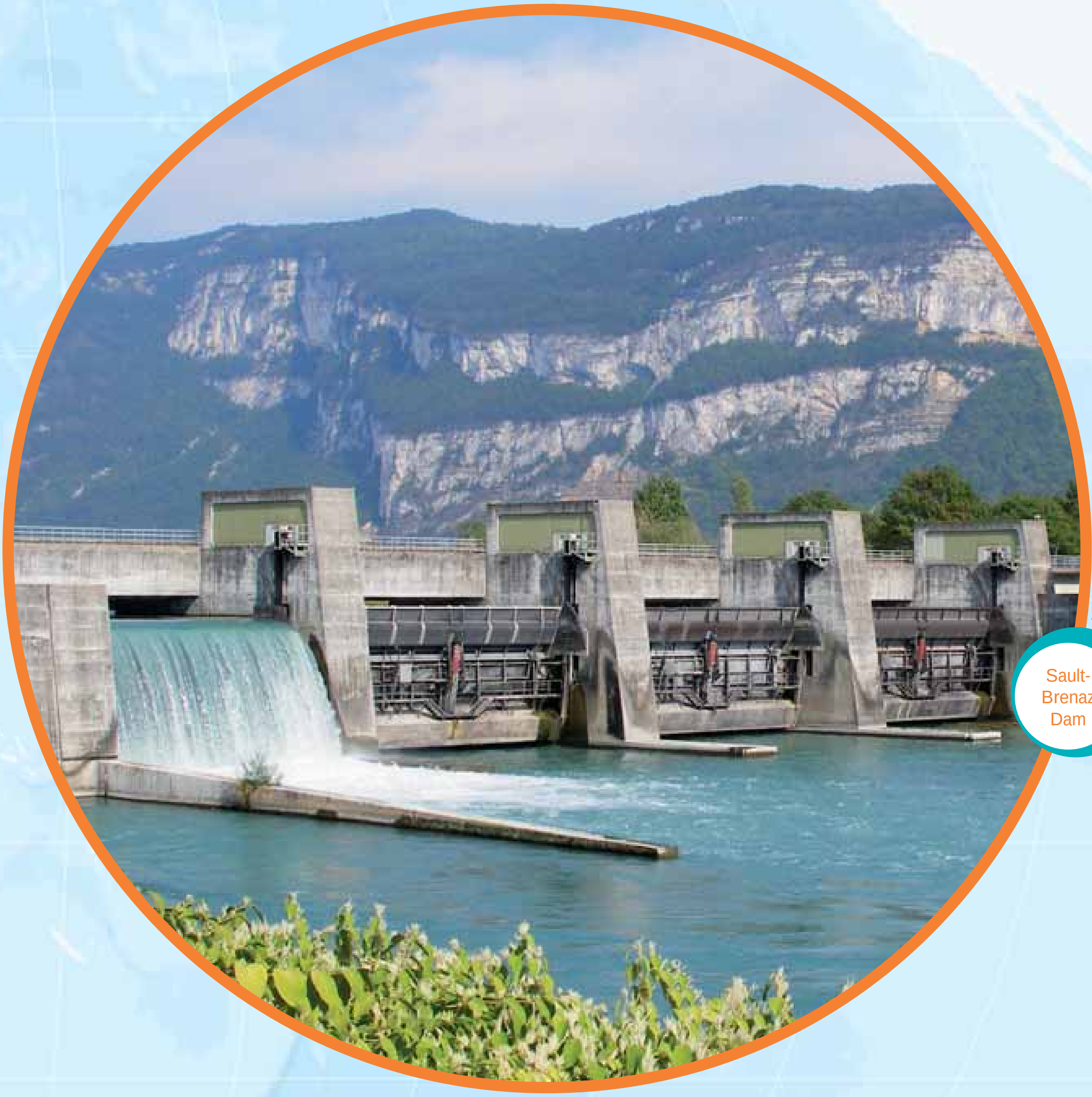

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- Rigorous economic analyses of the benefits and costs for environmental mitigation for large projects provide critical information to decision-makers.
- With careful planning and implementation, the people required to be resettled because of the reservoir project can and must benefit first.
- Monitoring of the environmental impacts of existing projects provides a better understanding of the true impacts rather than projected impacts.
- Research on the ecological aspects of the many existing dams and reservoirs can provide important lessons for future projects.

Looking to the Future
Dams for the 21st Century

13.9 The need for public awareness and education on water resources

The world is in an era where vast amounts of information are available through the all versions of the media. The Internet, publications and other forms of media have a significant impact on the knowledge and perceptions of society. The issue of the expansion and rehabilitation of the world's infrastructure and the debate about the need for and use of dams is an excellent example of this worldwide phenomenon.

It is important for the public be reminded about the realistic facts about water as the world's vital natural resource. Most of the water on the earth is located in the oceans. There is only a small of all of the water on the earth that is fresh and available on the earth for human consumption - 2.5% of the total. While groundwater is a widely used source, withdrawals must be managed to guard against depletion. The public must be made aware of the fact that the amount of water from precipitation or rainfall on the world remains constant and only 19% or 110,000 km^3 falls on land. Of this amount, 65,200 km^3 or 59% evaporates and 42,600 km^3 or 39% becomes runoff to the ocean. There is only 2,200 km^3 or 2% infiltration for groundwater. As the world develops it becomes more important that we capture some of the 42,600 km^3 of runoff in reservoirs to manage throughout the year. This has been a successful strategy for more that 5,000 years.

It is important to become aware of the challenges and opportunities that exist relative to the world's water and the benefits from the storage and management of water in river basins. The public must become aware of the beneficial role of dams in the management of water in watersheds or river basins to meet the increasing demand for water and to prevent floods as well as the relationship of dams and the environment.

ICOLD is a source reliable facts and information to the political decision-making bodies, financing agencies, environmental lobby groups and organizations, and to the general public, on the benefits of prudent utilization of water, especially by storage in reservoirs and the proper operation of dams.

Environmental mitigation and enhancement can be effective a river ecosystem in the USA

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The Role of ICOLD and the World's Water

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In summary, this book demonstrates that water remains the vital resource to sustain civilization around the world, and that fresh water for human consumption and irrigation is only available in limited quantities. Sustainability of life in some regions of the world is threatened by the imbalance between the demand for and available supplies of water, food and energy. We have seen how the world gets its water from the water cycle and the limited quantity of rain that falls on the world's landmass. We must remember that this limited quantity is not evenly distributed in the world by season or region. There is an imbalance between the demand for water and its availability.

History shows us that dams and reservoirs have been used successfully in collecting, storing and managing water needed to sustain civilization for five centuries. As we look to the future, we must learn from the past and project this knowledge to the future. ICOLD was established in 1928 and currently has 88 member countries with about 10,000 individual technical experts and has a long history of providing technical guidance and standards for the use of dams around the world. Today, ICOLD plays a major worldwide role in advancing the art and science of building dams to produce the most efficient, effective and responsible water resource projects for the benefit of society. This is accomplished by developing and promoting technically sound engineering concepts and guidelines that are compatible with the social, environmental, financial and operational requirements of a water resources development project. Looking to the future ICOLD is

"Preparing to meet tomorrow's challenges in the development and management of the world's water resources"

This goal is being accomplished by the international exchange and transfer of knowledge and experience about dams and their associated technology and functions. This process is very useful in passing information from those with long-term experience to those who have major construction programs ahead in their future. It is also important to ensure that existing dams remain safe, and are operated in the most efficient and economic way. This is where big international associations such as the International Commission On Large Dams (ICOLD) are important. The Commission was established at a time when major dam building programs were beginning in places like Europe and North America.

As we look to the future, the planning process must carefully document the proposed benefits as well as the concerns and impacts that must be mitigated. The concerns and adverse impacts of dams can be minimized or eliminated by careful planning and design that incorporate public involvement and input in the early stages of this process. When the appropriate mitigation measures are identified early in the planning and design process for a dam and reservoir, they can be efficiently and effectively incorporated into the design, construction and operation of the project.

ICOLD's intent is to ensure that the dams and associated structures required for water resource development and management around the world are safe, economical, environmentally responsible, socially acceptable and are operated and maintained for sustained reliability. Dams and reservoirs can and should be compatible with the social and natural environment of the region. The challenge for the future will be the utilization of dams and reservoirs for the wise management of the world's water resources as part of each nation's social and economic development goals.

15 Summary

In the beginning of this book, we have seen that there is a fixed amount of water in the water cycle and that only a small quantity of fresh water is available for human consumption. We now understand that most of the rain falls on the oceans and we understand that a significant portion of the rain that falls on land evaporates or ends up as runoff that goes into our streams and then the ocean. This means that only a small amount of water is available to replenish our groundwater. This emphasizes the need to collect, store and use integrated water management to insure adequate river flows throughout the year. History shows us that generations before us were quick to see the need for dams and reservoirs to store water for reliable distribution of water throughout the year.

As in the past, the well-being of people of the world in the future will continue to be closely linked to reliable and sustainable water supplies. The water shortages in many regions of the world will increase significantly. Reliable supplies of water will be needed to improve the state of health in the world and to increase the agricultural and industrial productivity.

Throughout the history of the world, dams have played a major role in storing and managing water needed to support civilization. Today, the world is undergoing major changes in ethical values, business practices, and living conditions as a result of rapid advances in technology and expanded communications associated with the continued unprecedented increase in population.

At the same time there has been careless use of our natural resources and accelerated pollution of the environment. As the population of the world continues to grow with the associated economic and agricultural development, so does the need for water supply and more dams.

The watershed is the basic element for managing water resources and the environment. Therefore, in looking to the future, planning and development must be made on a watershed basis. As the magnitude of the demand for water continues to increase, people will need to use wise planning and engineering in the successful six step planning process to best meet these needs and the goals and objectives of individual dam projects. With proper public involvement and coordination, the socio-economic issues such as resettlement and equal distribution of project benefits can be adequately solved. Then, dams of a proper size and location can be designed and constructed in the watershed. This is particularly important in the developing nations. The United Nations recognizes that water is the resource that is an essential ingredient to achieving their goals to eliminating poverty and hunger, improving health, and combating disease by 2015. The mitigation of flood damage to society will require increased flood control storage in both existing and new dams. More dams will be needed and we must be mindful that these dams and reservoirs, when properly managed, are the only viable option to provide the quantities of water needed. We must also recognize that they can be operated in an environmentally responsible manner.

Since the environment is an important aspect of our existence and is related to our streams and rivers, reservoir projects need to be managed on a watershed basis to optimize environmental mitigation and benefits. The objective of water management in the watershed remains unchanged: satisfy demands without sacrificing existing uses. The major issues with respect to water management in the watershed basins are:

- Formulating strategies to provide adequate stream flow.
- Satisfying the municipal and agricultural demands without injury to the environment.
- Evaluating and improving water quality.

Watershed planning and water management that includes environmental mitigation and conservation are the key elements to providing optimum water supply, flood control, hydropower and other benefits without harming the ecosystems. Successful integrated water management must incorporate real-time data collection, state-of-the-art spatially distributed rainfall-runoff flow forecasting capabilities and reliable models to ensure that adequate water quality and quantity is available to meet the regional and local needs.

Advanced technology is needed for the planning, design, construction, operation and maintenance of large dams and their related facilities so that they are economical, safe and environmentally responsible. As in the past, ICOLD continues to advance the state of the practice for the planning, engineering, construction, operation and maintenance for dams. The increasingly important role of ICOLD is to make sure that dams will be planned, designed, constructed and operated with maximum mitigation of environmental impacts while maximizing social and economic benefits. This is the best way to achieve sustainable development and management of the world's water resources. The goal is plan, design, construct and operate cost effective, efficient dams that are socially, environmentally responsible projects of our infrastructure. The best strategy is to use a wise planning process with public involvement that considers all water resources in a watershed. The concerns and potential adverse impacts of dams can be eliminated by this careful planning process.

Looking to the future, we must benefit and build on the successful experiences from previous generations for the management of the world's water. Wise planning for both groundwater and reservoirs in a watershed will best suit the growing need for water. Dams and reservoirs will continue to be needed to supply water in large quantities and adequate quality to meet the needs of a region.


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Glossary of Terms

The purpose of this glossary is to define the common terms used for dams and in water resources development and management. The terms are generic and applicable to all dams, regardless of size, owner, or location. The terms are listed in alphabetical order.

Abutment That part of the valley side against which the dam is constructed. An artificial abutment is sometimes constructed, as a concrete gravity section, to take the thrust of an arch dam where there is no suitable natural abutment. The left and right abutments of dams are defined with the observer viewing the dam looking in the downstream direction, unless otherwise indicated.

Acre-foot A unit of volumetric measure that would cover one acre to a depth of one foot. It is equal to 43,560 cubic feet or 1,233.6 cubic meters.

Appurtenant structure The other features of a dam project such as the control rooms, outlet conduit, outlet tunnel, spillways, penstocks, power plants, etc.

Aqueduct Bridges built to carry water across a valley

Bedrock Any sedimentary, igneous, or metamorphic material represented as a unit in geology; being a sound and solid mass, layer, or ledge of mineral matter; and with shear wave threshold velocities greater than 2500 feet/second.

Borrow area The area from which natural materials, such as rock, gravel or soil, used for construction purposes is excavated.

Channel A general term for any natural or artificial facility for conveying water.

Cofferdam A temporary structure enclosing all or part of the construction area that construction can proceed in the dry. A diversion cofferdam diverts a stream into a pipe, channel, tunnel, or other watercourse.

Compaction The mechanical action that increases the density by reducing the voids in a material.

Concrete lift The vertical distance measured in feet or meters between successive placements of concrete delineated by horizontal construction joints.

Conduit A closed channel to convey water through, around, or under a dam.

Core A zone of low permeability material in an embankment dam. The core is sometimes referred to as central core, inclined core, puddle clay core, rolled clay core, or impervious zone.

Crest length The measured length of the dam along the crest or top of dam.

Crest of dam See top of dam.

Cross section The elevation view of a dam formed by passing a plane through the dam perpendicular to the axis.

Dam An artificial barrier that has the ability to impound water, wastewater, or any liquid-borne material, for the purpose of storage or control of water.

- **Arch dam** A concrete, masonry, or timber dam with the alignment curved upstream so as to transmit the major part of the water load to the abutments.
- **Buttress dam** A dam consisting of a watertight part supported at intervals on the downstream side by a series of buttresses. Buttress dam can take many forms, such as a flat slab or massive head buttress.
- **Diversion dam** A dam built to divert water from a waterway or stream into a different watercourse.
- **Earthfill dam** An embankment dam in which more than 50% of the total volume is formed of compacted earth.
- **Embankment dam** Any dam constructed of excavated natural materials, such as both earthfill and rockfill dams.
- **Gravity dam** A dam constructed of concrete and/or masonry, which relies on its weight and internal strength for stability.
- **Masonry dam** Any dam constructed mainly of stone, brick, or concrete blocks pointed with mortar. A dam having only a masonry facing should not be referred to as a masonry dam.

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- **Multiple arch dam** A buttress dam comprised of a series of arches for the upstream face.
- **Rock-fill dam** An embankment dam in which more than 50% of the total volume is comprised of compacted or dumped cobbles, boulders, rock fragments, or quarried rock generally larger than 3-inch size.
- **Roller compacted concrete dam** A concrete gravity dam constructed by the use of a dry mix concrete transported by conventional construction equipment and compacted by rolling, usually with vibratory rollers.

Divert To make go another way.

Drainage area or catchment area The area that drains to a particular point on a river or stream (expressed in square miles or square kilometers).

Earthquake A sudden motion or trembling in the earth caused by the abrupt release of accumulated stress along a fault.

Erosion The wearing away of a surface such as the bank, streambed, embankment, or other surface by river flows, reservoir waves, wind, or any other natural process.

Evaporate The process of changing liquid into a gas or vapor which is incorporated into the air

Fertile The very rich soil which is best for producing crops

Flood A temporary rise in water surface elevation of a stream or river as a result of significant rainfall in the drainage area. It results in inundation of areas not normally covered by water.

Flood, Inflow Design (IDF) The flood flow above which the incremental increase in downstream water surface elevation due to failure of a dam or other water impounding structure is no longer considered to present an unacceptable threat to downstream life or property. The flood hydrograph used in the design of a dam and its appurtenant works particularly for sizing the spillway and outlet works and for determining maximum storage, height of dam, and freeboard requirements.

Flood, Probable Maximum (PMF) The flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in the drainage basin under study.

Flood plain The area adjoining a body of water or natural stream that may be covered by floodwater. It is also used to describe the downstream area that would be inundated or otherwise affected by the failure of a dam or by large flood flows.

Flood storage The retention of water or delay of runoff either by planned operation, as in a reservoir, or by temporary filling of overflow areas, as in the progression of a flood wave through a natural stream channel.

Foundation The portion of the valley floor that underlies and supports the dam structure.

Freeboard Vertical distance between a specified reservoir surface elevation and the top of the dam.

Gate A movable water barrier for the control of water.

- **Radial gate** A gate with a curved upstream plate and radial arms hinged to piers or other supporting structure.
- **Slide gate** A gate that can be opened or closed by sliding in supporting guides.

Generator The machine that produces electricity

Head The vertical distance between two elevations of water (expressed in feet or meters).

Headwater The water immediately upstream from a dam. The water surface elevation varies due to fluctuations in inflow and the amount of water passed through the dam.

Hydrology One of the earth sciences that deals with the natural occurrence, distribution, movement, and properties of the waters of the earth and their environmental relationships.

Hydrometeorology The study of the atmospheric and land-surface phases of the hydrologic cycle with emphasis on the interrelationships involved.

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Glossary of Terms

Instrumentation An arrangement of devices installed into or near dams that provide for measurements that can be used to evaluate the structural behavior and performance parameters of the structure.

Intake Placed at the beginning of an outlet-works waterway (power conduit, water supply conduit), the intake establishes the ultimate drawdown level of the reservoir by the position and size of its opening(s) to the outlet works. The intake may be vertical or inclined towers, drop inlets, or submerged, box-shaped structures. Intake elevations are determined by the head needed for discharge capacity, storage reservation to allow for siltation, the required amount and rate of withdrawal, and the desired extreme drawdown level.

Integrated water management in the river basin The process by which the water stored in reservoirs and the daily amount released is managed in the basin to ensure an adequate and dependable quantity is available. Each dam and reservoir in the basin has a water control plan that outlines discharges from that reservoir based on inflow to the reservoir and downstream needs. Each water control plan is coordinated with other dam and reservoir project within the river basin.

Length of dam The length along the top of the dam.

Low level outlet An opening at a low level from a reservoir generally used for emptying or for scouring sediment and sometimes for irrigation releases.

MW or Mega Watt A unit for measuring power. One MW equals 1 million watts.

Meteorology The science that deals with the atmosphere and atmospheric phenomena, the study of weather, particularly storms and the rainfall they produce.

Minimum operating level The lowest level to which the reservoir is drawn down under normal operating conditions. The lower limit of active storage.

Multipurpose project A project designed for irrigation, power, flood control, municipal and industrial, recreation, and fish and wildlife benefits, in any combinations of two or more. Contrasted to single-purpose projects that serves only one purpose.

Outlet An opening through which water can be discharged from a reservoir to the river.

Outlet works A facility of a dam that provides for the controlled release of water from a reservoir.

Peak flow The maximum instantaneous discharge that occurs during a flood. It is coincident with the peak of a flood hydrograph (expressed in cubic feet per second - cfs or cubic meters per second - cms or m^3sec).

Penstock A pressurized pipeline or shaft between the reservoir and hydraulic machinery.

Probable Maximum Flood (PMF) See Flood.

Probable Maximum Precipitation (PMP) Theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location during a certain time of the year.

Reservoir The body of water impounded by a dam and in which water can be stored.

Reservoir regulation The process of the compilation of operating criteria, guidelines, and specifications that govern the storage and release function of a reservoir. It may also be referred to as the flood control diagram, or water control schedule. These are usually expressed in the form of graphs and tabulations, supplemented by concise specifications and are often incorporated in computer programs. In general, they indicate limiting rates of reservoir releases required or allowed during various seasons of the year to meet all functional objectives of the project.

Reservoir rim The boundary of the reservoir including all areas along the valley sides at the water surface.

Reservoir surface area The area covered by a reservoir when filled to a specified level (expressed in square miles - $miles^2$ or square kilometers - km^2).

Reservoir Storage The retention of water or delay of runoff either by planned operation, as in a reservoir, or by temporary filling of overflow areas, as in the progression of a flood wave through a natural stream channel (expressed in acre-feet - ac-ft or cubic meters - m^3). Definitions of specific types of storage in reservoirs are:

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Active storage The volume of the reservoir that is available for some use such as power generation, irrigation, flood control, water supply, etc. The bottom elevation is the minimum operating level.

Dead storage The storage that lies below the invert of the lowest outlet and that, therefore, cannot readily be withdrawn from the reservoir.

Flood surcharge The storage volume between the top of the active storage and the design water level.

Inactive storage The storage volume of a reservoir between the crest of the invert of the lowest outlet and the minimum operating level.

Live storage The sum of the active-and the inactive storage.

Reservoir capacity The sum of the dead and live storage of the reservoir.

River basin or watershed The area drained by a river or river system or portion thereof. The watershed for a dam is the drainage area upstream of the dam (expressed in square miles or square kilometers).

Single purpose project A project that provides a single purpose, such as navigation only

Slope Inclination from the horizontal. Sometimes referred to as batter when measured from vertical.

Spillway A structure over or through which flow is discharged from a reservoir. If the rate of flow is controlled by mechanical means, such as gates, it is considered a controlled spillway. If the geometry of the spillway is the only control, it is considered an uncontrolled spillway.

Spillway capacity The maximum spillway outflow that a dam can safely pass with the reservoir at its maximum level (expressed in cubic feet per second - cfs or cubic meters per second - cms or m^3sec).

Spillway channel An open channel or closed conduit conveying water from the spillway inlet downstream.

Spillway crest The lowest level at which water can flow over or through the spillway.

Stability The condition of a structure or a mass of material when it is able to support the applied stress for a long time without suffering any significant deformation or movement that is not reversed by the release of the stress.

Stilling basin A basin constructed to dissipate the energy of rapidly flowing water, e.g., from a spillway or outlet, and to protect the riverbed from erosion.

Tailwater The water immediately downstream from a dam. The water surface elevation varies due to fluctuations in the outflow from the structures of a dam and due to downstream influences of other dams or structures. Tailwater monitoring is an important consideration because a failure of a dam will cause a rapid rise in the level of the tailwater.

Toe of the dam The junction of the downstream slope or face of a dam with the ground surface; also referred to as the downstream toe. The junction of the upstream slope with ground surface is called the heel or the upstream toe.

Topographic map A map with detailed graphic delineation (representation) of natural and man-made features of a region with particular emphasis on relative position and elevation.

Tributary A stream that flows into a larger stream or body of water

Tunnel A long underground excavation with two or more openings to the surface, usually having a uniform cross section used for access, conveying flows, etc.

Volume of dam The total space occupied by the materials forming the dam structure computed between abutments and from top to bottom of dam.

Watershed or river basin The area drained by a river or river system or portion thereof. The watershed for a dam is the drainage area upstream of the dam (expressed in square miles or square kilometers).

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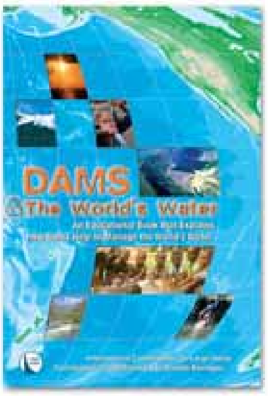

DAMS &The World's Water

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