APPLIED HYDRAULICS

CHPATER 9:

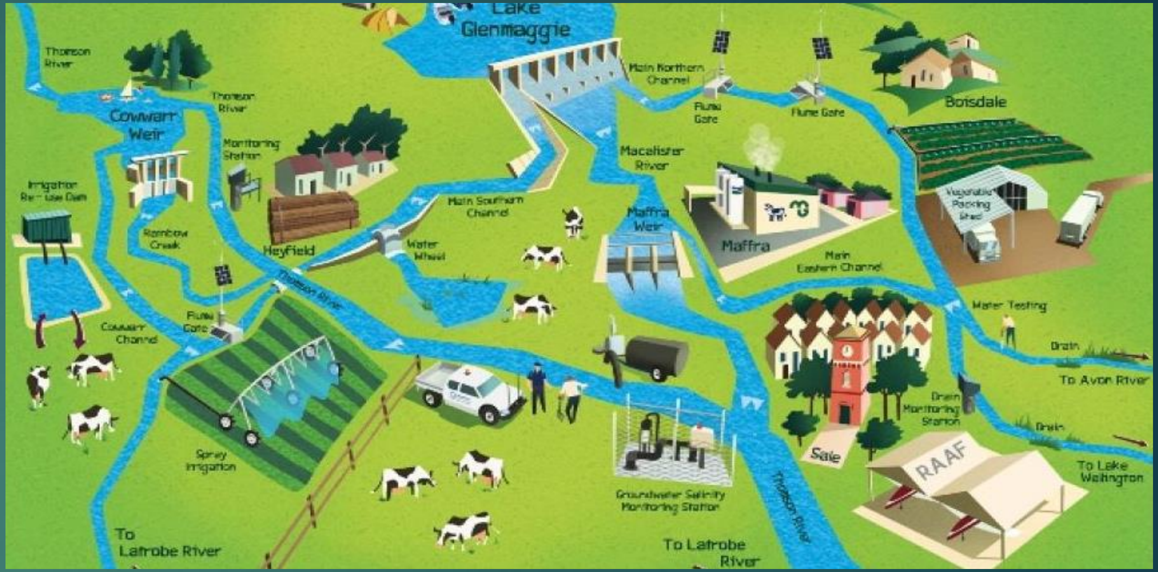
DAMS AND RESERVOIRS

Dams and Reservoirs

- Introduction
- Dams
- Dam failure
- Reservoir and Sedimentation

Dams and Reservoirs | Introduction

- Rivers are sources of water supply for drinking, industrial and agricultural uses and source of energy in the form of hydroelectric power.
- Rivers maybe serve as transportation arteries and sources of recreation.
- Rivers are also often used for sewage disposal.
- However, flooded rivers causing property damage and loss of life.



Dams and Reservoirs | Introduction

- As rivers have played an important and life-sustaining role in human societies, we need to control them to our advantages.

- Building structures such as dams is a way to control rivers.

- The most important items that must be considered in the planning and design of a *dam* and *reservoir* are:

  1. Hydrological Data

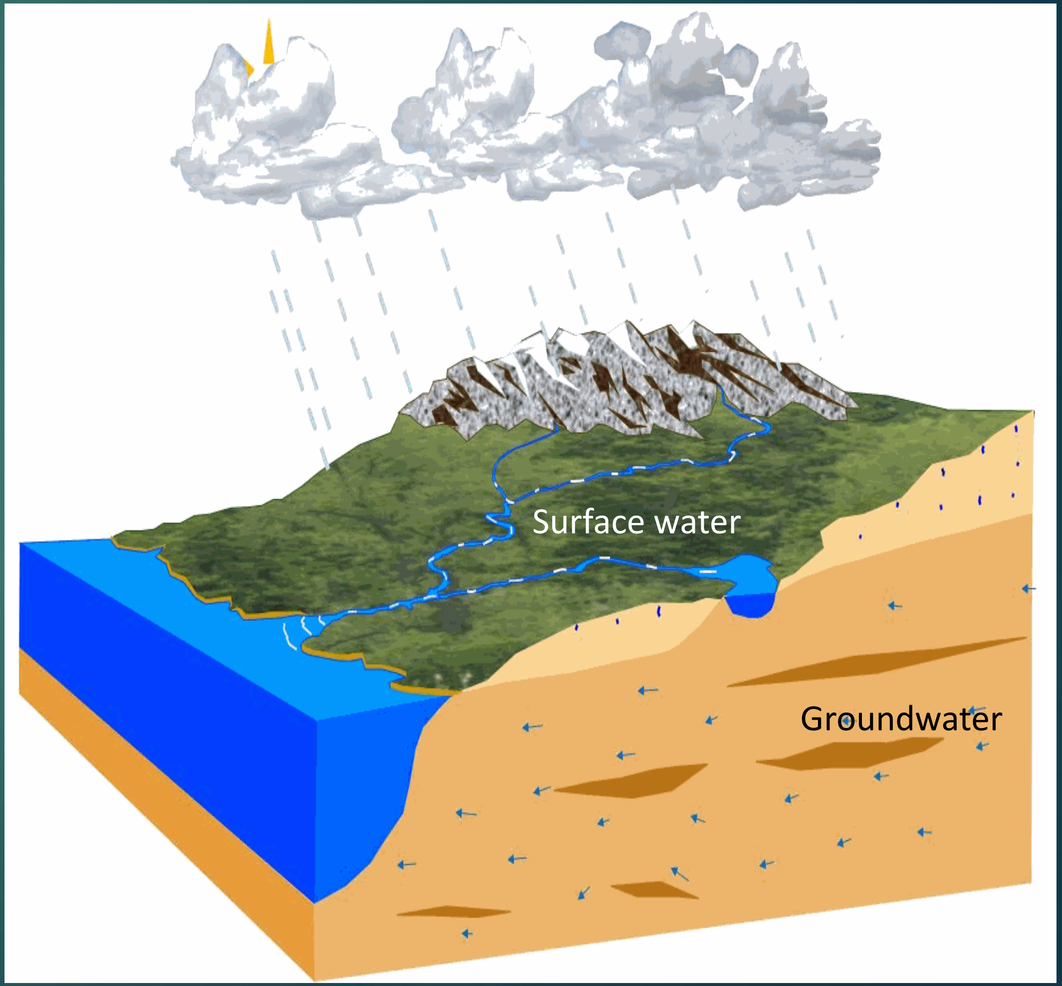
  2. Geologic Data

  3. Reservoir Data

  4. Environmental Data

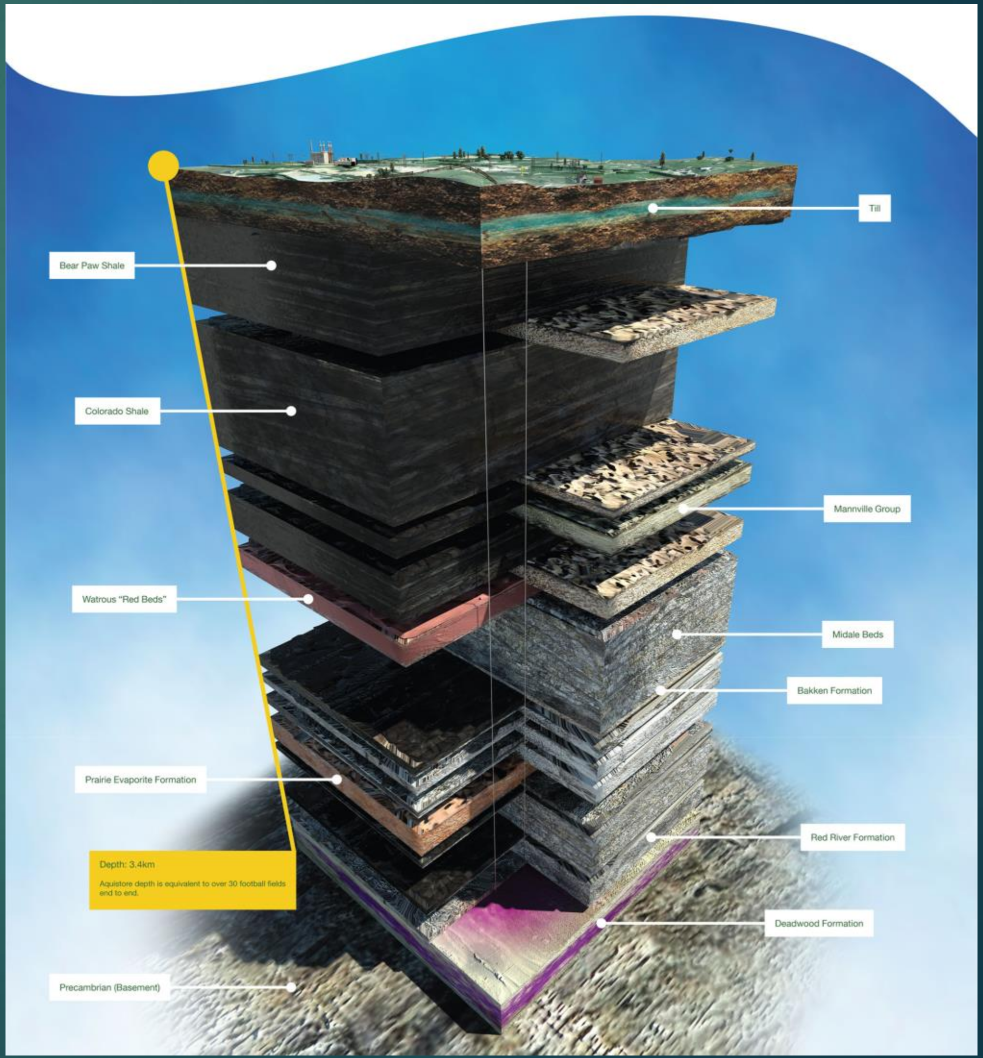
Hydrological Data

- **Hydrology** is the scientific study of the movement, distribution, and quality of water on Earth and other planets.
- Main Hydrological data are Surface water data, Water quality data, and Groundwater data.
- Data are used to determine the flood and drought conditions as well as obtaining the required capacity of the reservoir.



Geologic Data

- **Geology** is the study of the Earth, the materials of which it is made, the structure of those materials, and the processes acting upon them.
- Geology data of the area that dam is to be built are used to find the structural ability of the foundation materials.
- Geology data also help engineers to indicate the leakage and erosion problems.



Dams and Reservoirs | Introduction

Reservoir Data

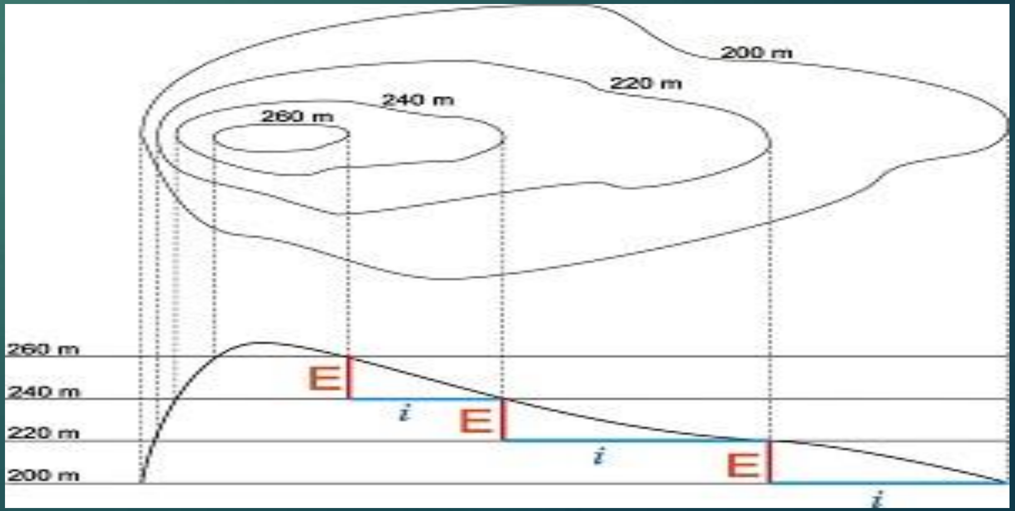
- Topographic maps, land ownerships, land classification, location of roads and public utilities.

Environment Data

- We need Environmental Impact Statement (EIS) or Environmental Impact Report (EIR) to assess the impact that maybe created by the project.

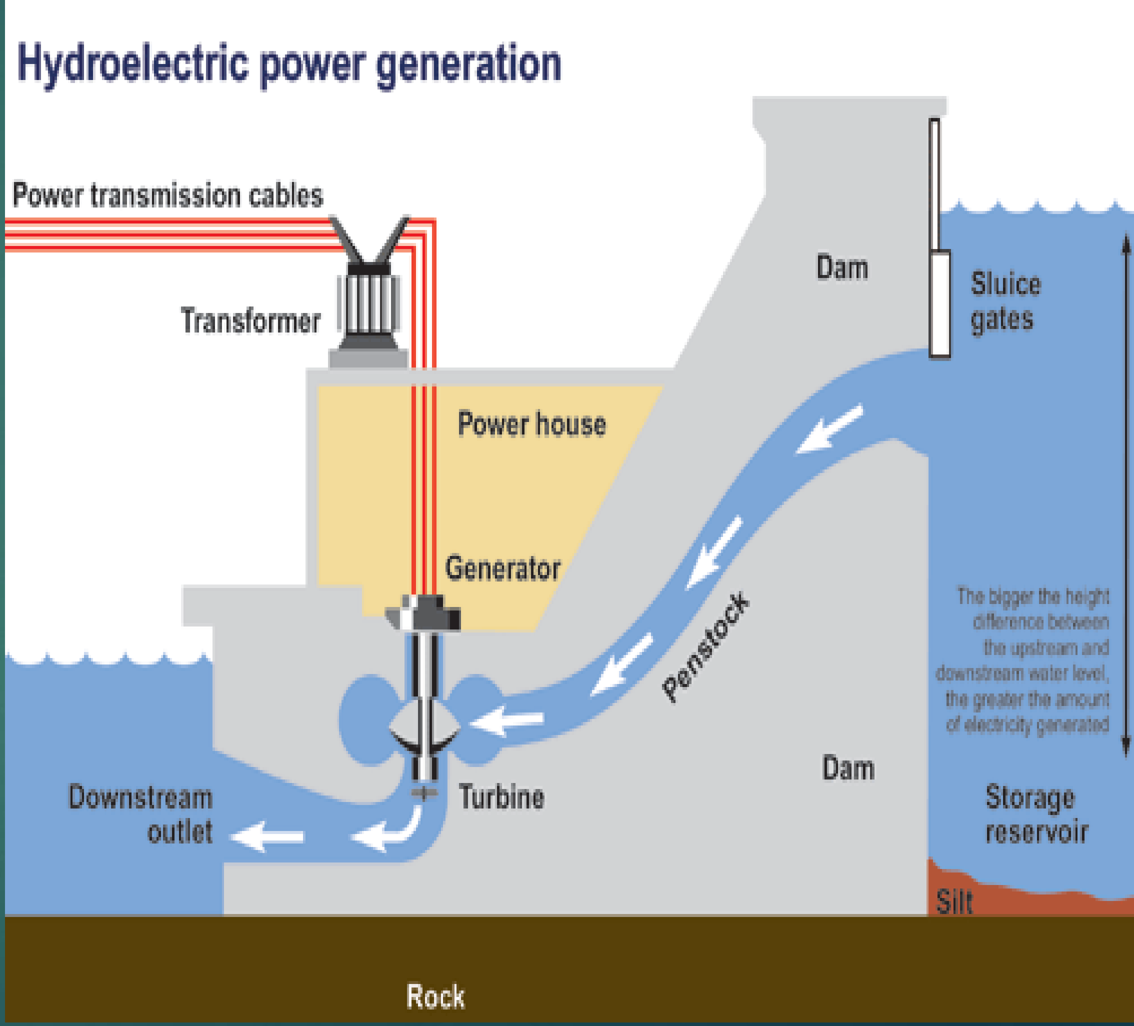
- A topographic map uses lines to show change in elevation and to determine the heights of features such as mountains and valleys.

- Topographic maps can show the heights of features a variety of ways, including contour lines, relief, and color.



Dams and Reservoirs | Dams

- A dam is a hydraulic structure built across a river to create a reservoir on its upstream side.
- Purposes: Water-supply (drinking, irrigation, industry), Hydropower, Flood Control, Navigation, Fishing and Recreation.
- Dam construction is an efficient way to manage water resources by creating reservoir to storage water and distributes it at the right time into downstream districts.



Dams and Reservoirs | Dams

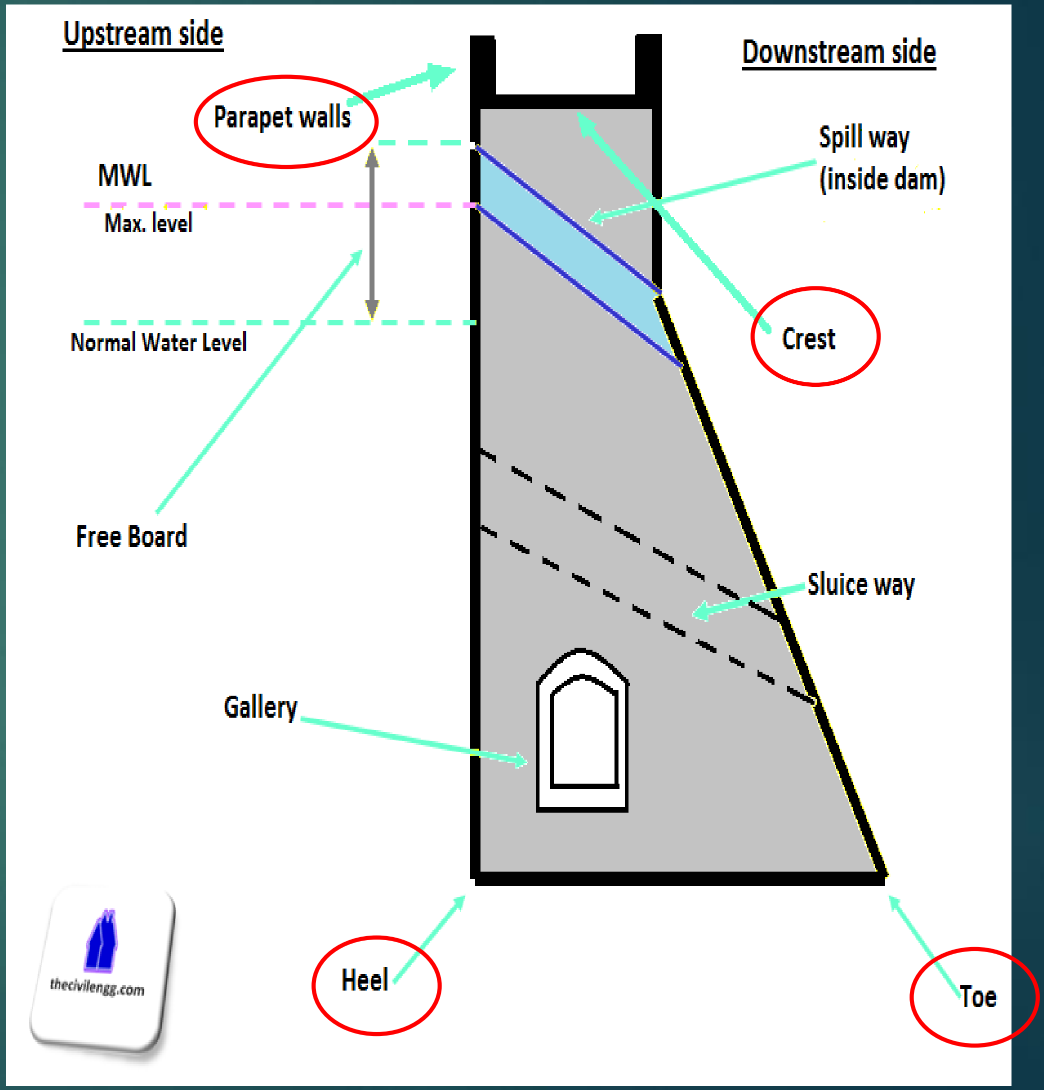
Different parts and terminologies of Dams:

- Crest: The top of the Dam. These may in some cases be used for providing a roadway or walkway over the dam.

- Parapet walls: Low Protective walls on either side of the roadway or walkway on the crest.

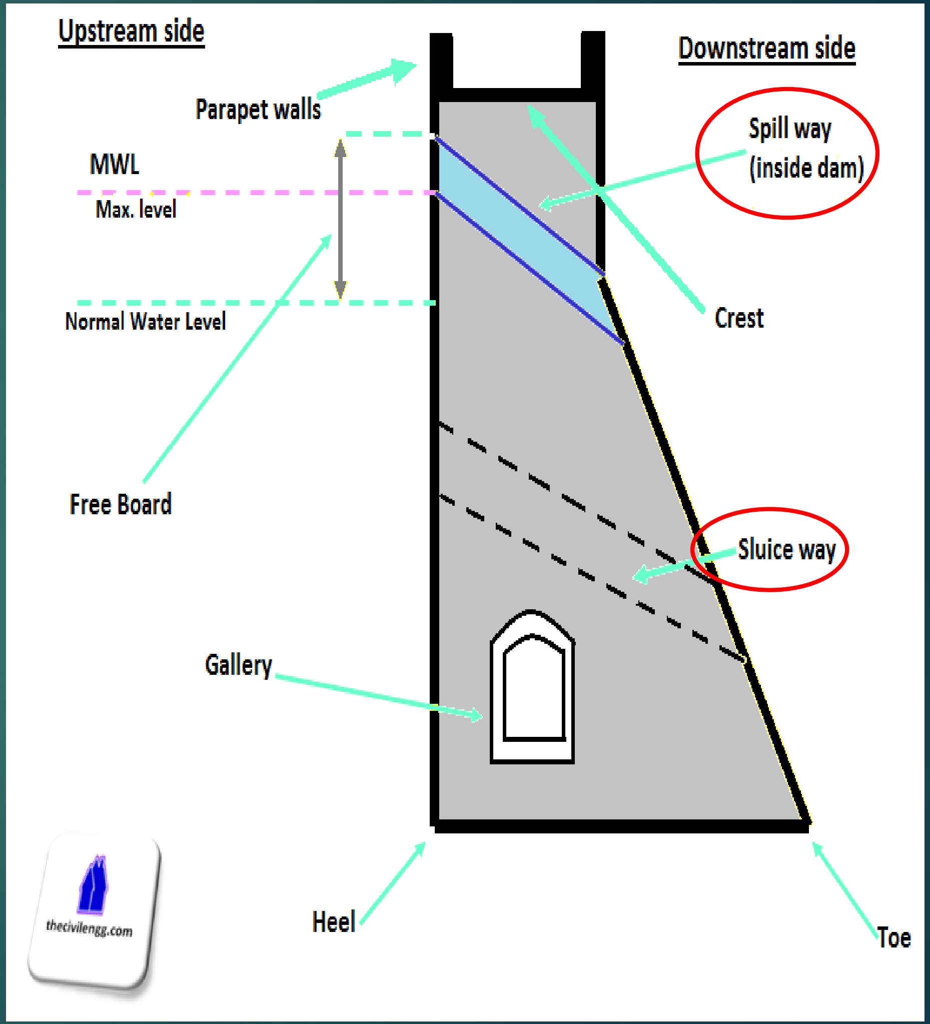
- Heel: Portion of Dam in contact with ground or river-bed at upstream side.

- Toe: Portion of dam in contact with ground or river-bed at downstream side.



Dams and Reservoirs | Dams

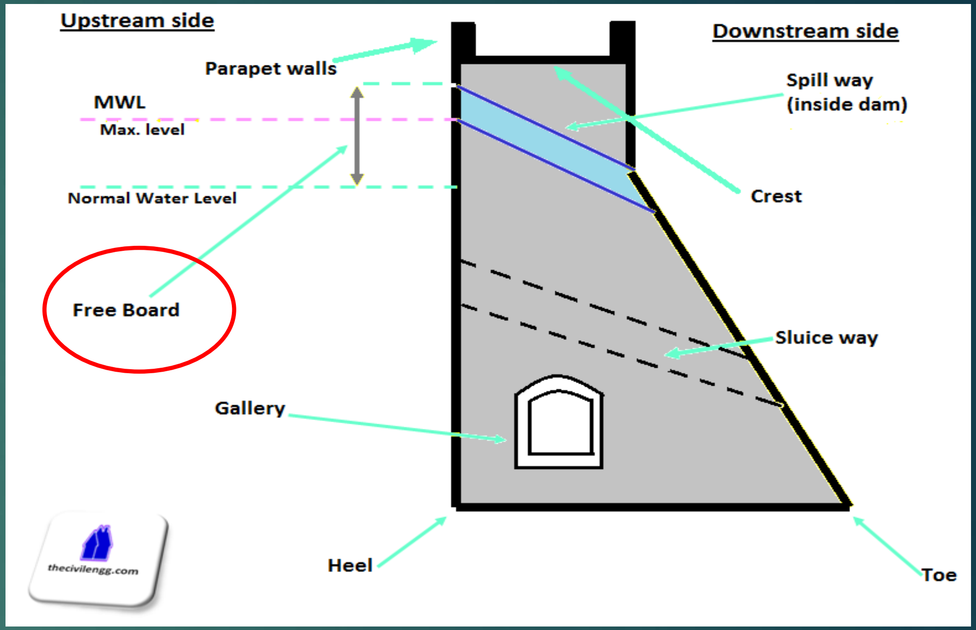
- Spillway: It is a waterway near the top of dam for the passage of excessive water from the reservoir.

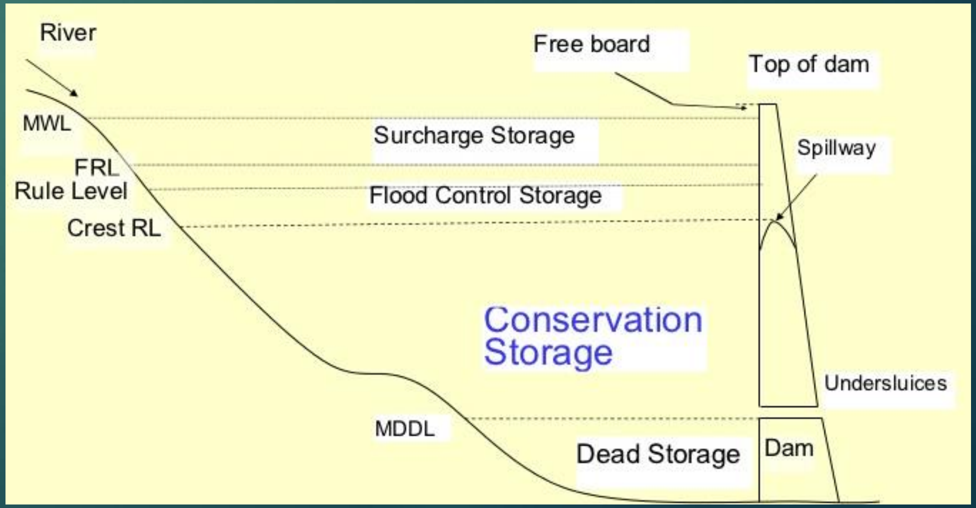


- Sluice way: Opening in the dam near the base, provided to clear the silt accumulation in the reservoir.

Dams and Reservoirs | Dams

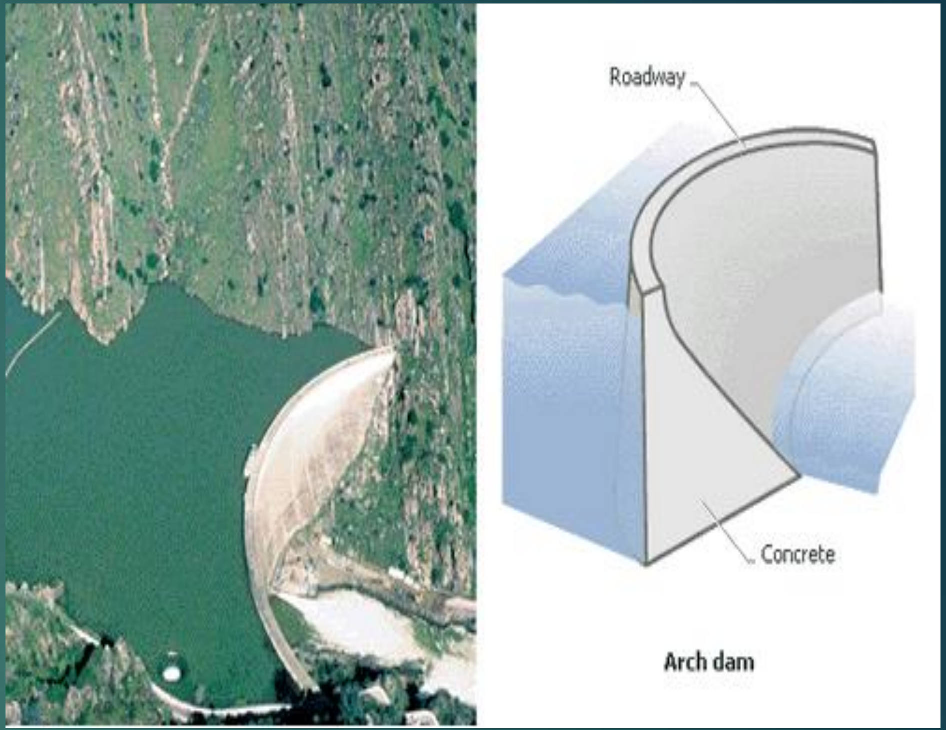
- **Free board**: The **space** between the highest level of water in the reservoir and the top of the dam.
- **Dead Storage level**: The portion of total storage capacity that is equal to the volume of water below the level of the lowest outlet (the minimum supply level).
- **Diversion Tunnel**: Tunnel constructed to divert or change the direction of water to bypass the dam construction site.
- The dam is built while the river flows through the diversion tunnel.





Types of Dams

- **Arch Dams**: An arch dam is curved in plan, with its convexity towards the upstream side.
- They transfers the water pressure and other forces mainly to the abutments by arch action.
- An arch dam is quite suitable for narrow canyons with strong flanks.



Based Examples of Arch dam: Hoover Dam (USA) and Idukki Dam (India)

Dams and Reservoirs | Dams

- **Diversion dams**: A diversion dam is constructed for the purpose of diverting water of the river into an off-taking canal (or a conduit).

- Such shorter dams are used for irrigation, and for diversion from a stream to a distant storage reservoir.

- It is usually of low height and has a small storage reservoir on its upstream.

Dams and Reservoirs | Dams

- **Coffer Dam:** It is built around the construction site to exclude water.
- It creates a dry work environment for the major work to proceed.
- A coffer dam is thus a temporary dam constructed for facilitating construction.

Dams and Reservoirs | Dams

- **Steel Dam**: A steel dam consists of a steel framework, with a steel skin plate on its upstream face.

Dams and Reservoirs | Dams

- **Timber Dam**: Main load-carrying structural elements of timber dam are made of wood.

- Timber dams are made for small heads (2-4 m or, rarely, 4-8 m) .

Dams and Reservoirs | Dams

- **Gravity Dam**: A gravity dam is a massive sized dam fabricated from concrete or stone masonry.

- By using concrete, the weight of the dam is actually able to resist the horizontal thrust of water pushing against it. This is why it is called a gravity dam.

- Gravity essentially holds the dam down to the ground, stopping water from toppling it over.

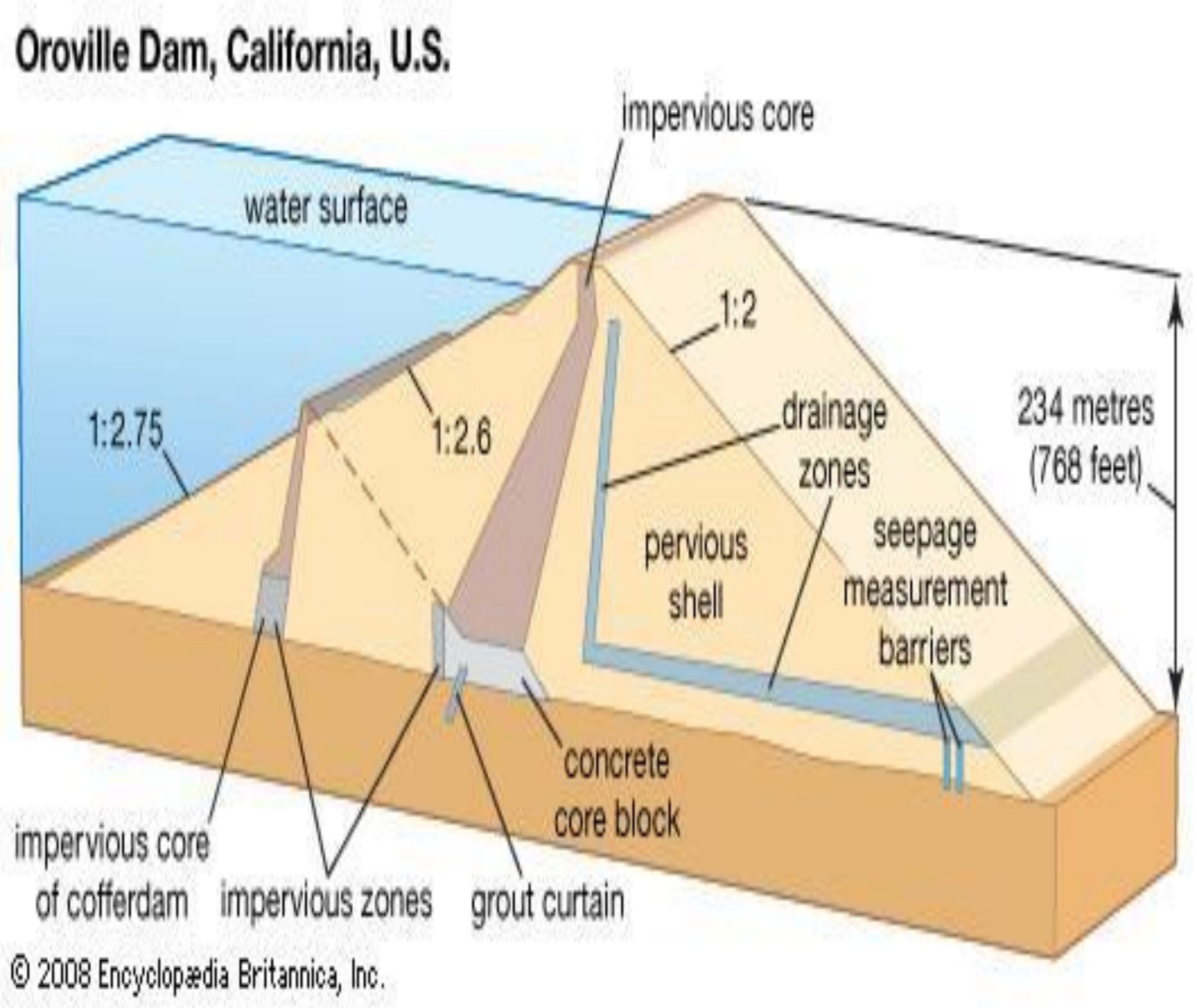
- Since gravity dams must rely on their own weight to hold back water, it is necessary that they are built on a solid foundation of bedrock.

Dams and Reservoirs | Dams

Examples: Grand Coulee Dam (USA), and Itaipu Dam (Between Brazil and Paraguay).

Dams and Reservoirs | Dams

- **Earth-fill Dams**: An earth dam is made of earth (or soil) built up by compacting successive layers of earth, using the most impervious materials to form a core.
- Earth dam resists the forces exerted upon it mainly due to shear strength of the soil.
- Although the <u>weight of the earth dam also helps in resisting the forces</u>, the structural behavior of an earth dam is entirely different from that of a gravity dam.



Dams and Reservoirs | Dams

Examples: Rongunsky dam (Russia)

Dams and Reservoirs | Dams

Hydropower Dams

Dams and Reservoirs | Dam Failure

Dams can fail for one or a combination of the following reasons:

- Overtopping caused by floods that exceed the capacity of the dam
- Structural failure of materials used in dam construction
- Movement and/or failure of the foundation supporting the dam
- Settlement and cracking of concrete or embankment dams
- Piping and internal erosion of soil in embankment dams
- Inadequate maintenance and upkeep

Dams and Reservoirs | Dam Failure

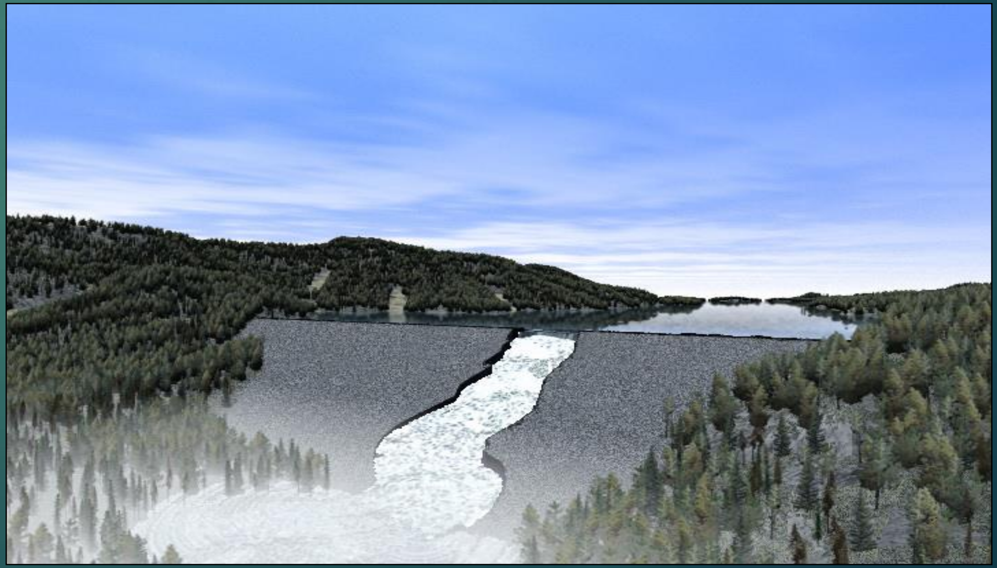
- The proper design of a dam's spillway prevents any undesirable problems such as overtopping.

- A spillway is a structure used to provide the controlled release of flows from a dam into a downstream area.

Dams and Reservoirs | Dam Failure

Overtopping

- If the spillway capacity is not enough to pass the flow, Overtopping or overflow of an embankment dam happens and will cause dam failure.
- Failure of dams due to overtopping is a common failure mode, accounting for 30 percent of the failures in the U.S. over the last 75 years.



Dams and Reservoirs | Dam Failure

Overtopping

Dams and Reservoirs | Dam Failure

Oroville Dam Overtopping

- It is an earthfill embankment dam.
- Purpose Water supply, flood control, power
- Construction 1961-1968
- Crest elevation: 1328.6 ft
- Height above foundation: 770 ft
- Crest Length: 6920 ft
- Crest Width: 80 ft
- Crest length: 1700 ft
- Discharge Capacity: 250,000 cfs

Dams and Reservoirs | Dam Failure

Oroville Dam normal operations

1. The lake level is controlled using the main spillway gate, which releases water down the concrete spillway to get to the river below.
2. The emergency spillway, which has a 30 ft (9 m) high concrete wall at the top of a hill, is unused.

2005: Upgrade proposal rejected

Despite concerns that the emergency spillway is vulnerable to erosion, a $100 million request by community groups to upgrade it to a concrete-lined auxiliary spillway is rejected by the federal regulators.

7 Feb 2017: Main spillway fails

Craters appear in the main spillway. To avoid increasing the damage to the spillway, water releases are slowed allowing the lake to rise.

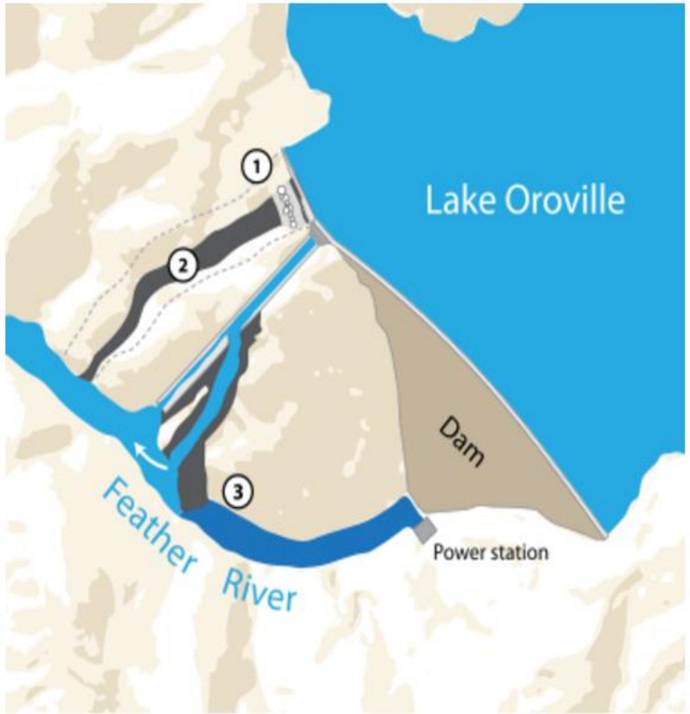
Dams and Reservoirs | Dam Failure

11 Feb 2017: Emergency spillway used

Water flows over the emergency spillway causing erosion and damage. This is by design and prevents water going over the top of the main dam. However the ground erodes faster than expected.

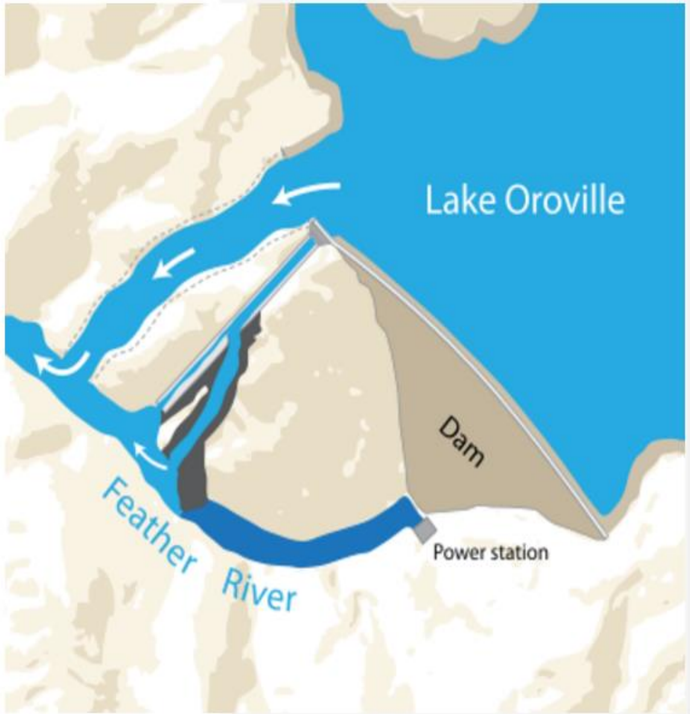
13 Feb 2017: Repairs made

Rocks and concrete (1) are placed under the emergency spillway weir to repair erosion damage (2). The release of water into the main spillway is increased, to lower the lake in preparation for more rain. This erodes the adjacent hillside considerably, generating a debris dam (3) that blocks the river and forces the closure of the hydroelectric plant.



Potential risks

While the main 770 ft (230 m) dam is not threatened, if the erosion on *either* spillway reaches the top, it would cause the weir or gate (respectively) to collapse, causing a large uncontrolled water release and life-threatening floods.



Dams and Reservoirs | Dam Failure

March 2011 February 7, 2017 February 27, 2017

Dams and Reservoirs | Dam Failure

Dams and Reservoirs | Dam Failure

- Oroville Dam repair cost estimated at $4.7 million per day.

Here's a snapshot of the resources involved in the repair effort:

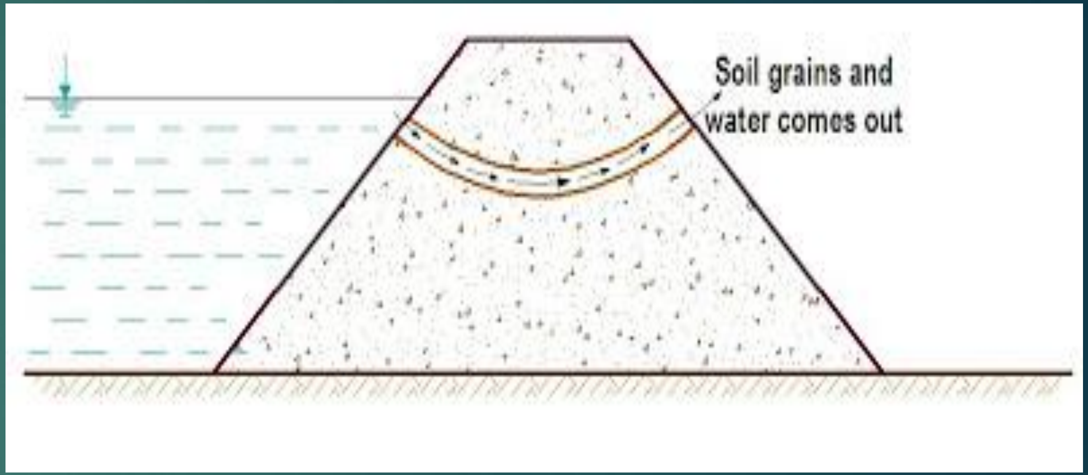
- More than 125 construction crews
- 40 truckloads of aggregate rock
- 1,200 tons of rock deposited in eroded/damaged areas per hour
- Two helicopter drops of rocks, concrete and/or other materials every minute and a half
- A California National Guard Black Hawk helicopter is assisting with drops

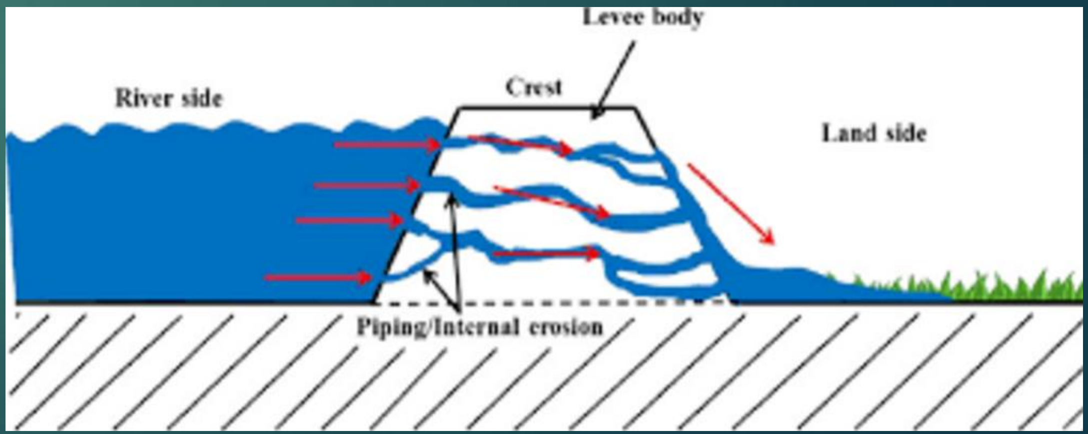
Internal Erosion

- The process of <u>moving soil particles</u> throughout the foundation or core of the dam is called internal erosion

- Internal erosion is one of the main causes of dam breaking.

- It is dangerous because there is no external evidence during the episode and a dam may fail only some hours after evidence of internal erosion.





Dams and Reservoirs | Dam Failure

- Fines and soil particles when a water leak (seeps) through the dam body tends to make a pipe in the body of dam.

- Internal erosion of the foundation or embankment caused by seepage is known as piping.

- The piping failure is defined as breaking dam due to water penetrating throughout the embankment (or foundation) of dam and continuously widening the pipe.

- The process of internal erosion divided into four main parts:
  - Beginning of erosion
  - Continuance of erosion
  - Development to form a pipe, and
  - Configuration of a breach

Dams and Reservoirs | Dam Failure

Seepage

Seepage

Dams and Reservoirs | Dam Failure

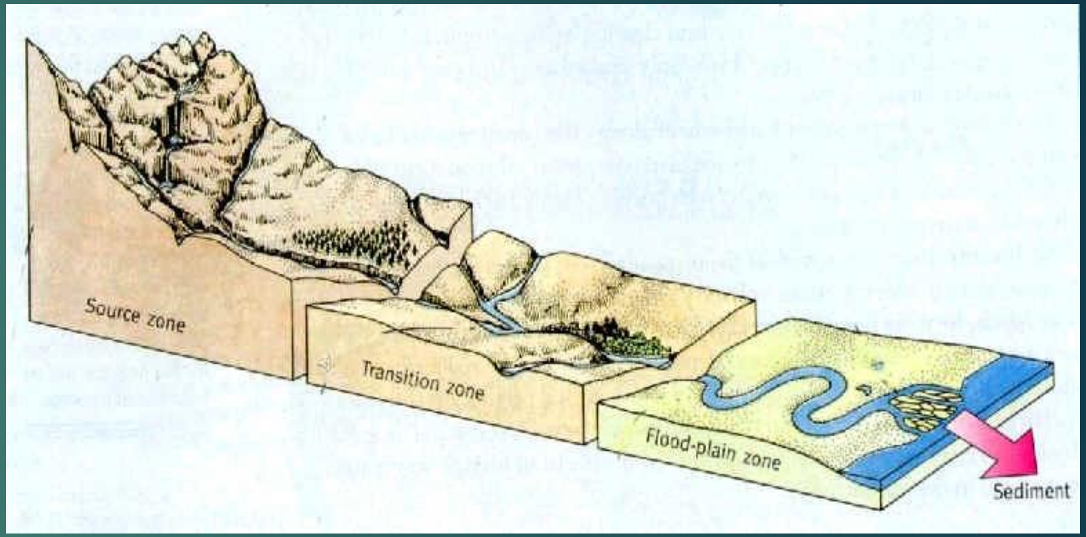
- Failed with small amount of water stored in the reservoir

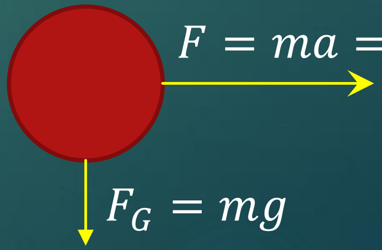
- Started as seepage through cracks in the rock of the right abutment.
- Dam had no filter-drainage zone.

Dams and Reservoirs | Sedimentation

Sedimentation

- The flow of water from the catchment upstream of a reservoir is capable of eroding the catchment area and of depositing material upstream of the reservoir.
- Sedimentation is the process of depositing sediment.
- The nature of the material in the catchment area and the slope of the catchment area are important factors.





$$F = ma = m\frac{V}{t}$$ Newton's second law

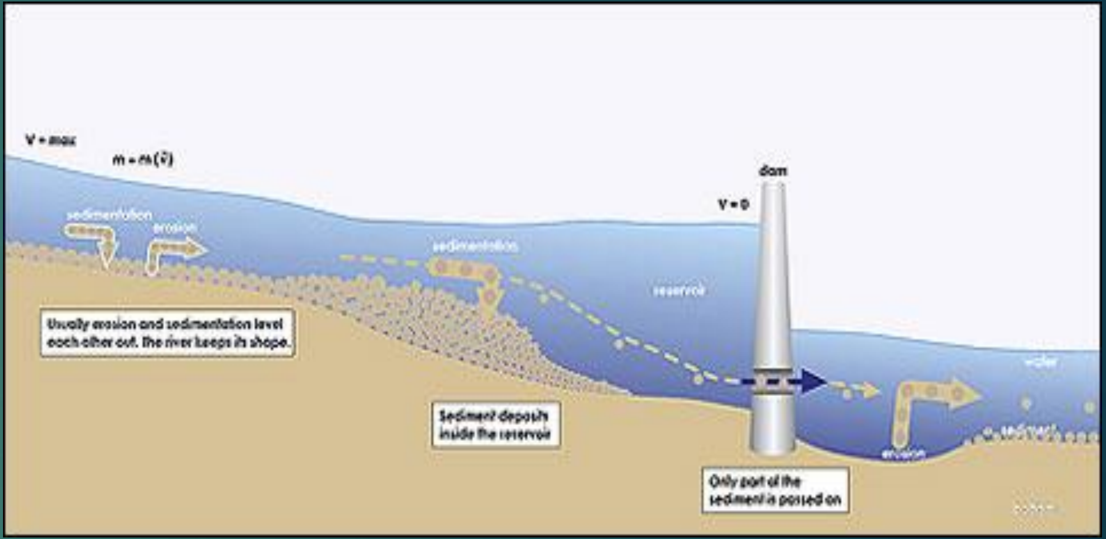
$$F_G = mg$$

Dams and Reservoirs | Sedimentation

- Sediments make the water appear brownish-grey
- Erosion due to intensive industrialized land use, and poor soil management.

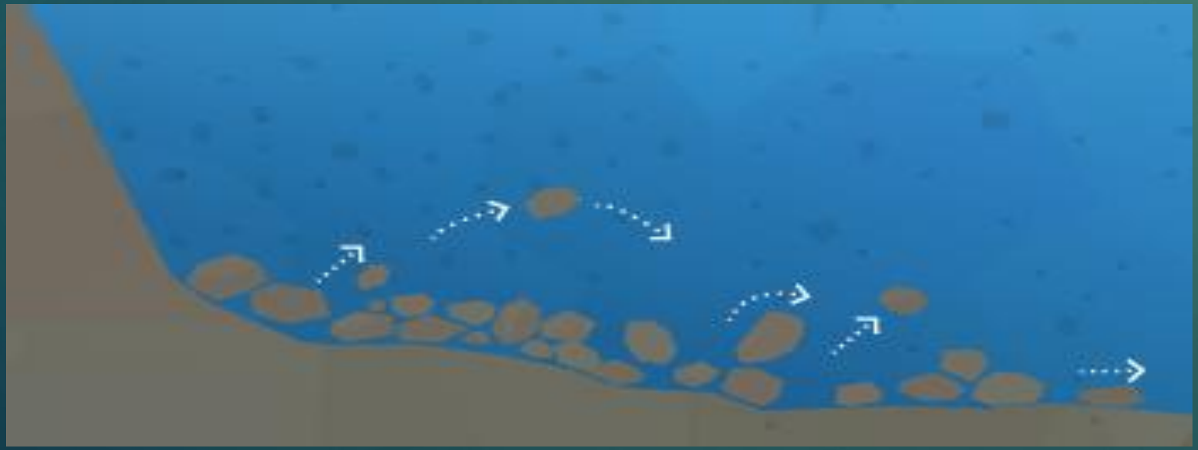
Dams and Reservoirs | Sedimentation

- If a high dam is constructed across the stream, a reservoir is produced.
- The flow velocity in the reservoir will be much smaller than the stream velocity.
- So, all sediment coming into reservoir will settle out and will be trapped.
- Reservoir sedimentation is filling of the reservoir behind a dam with sediment carried into the reservoir by streams.
- Therefore, the reservoir should be designed with enough volume to hold the sediment and still operate as water storage reservoir.



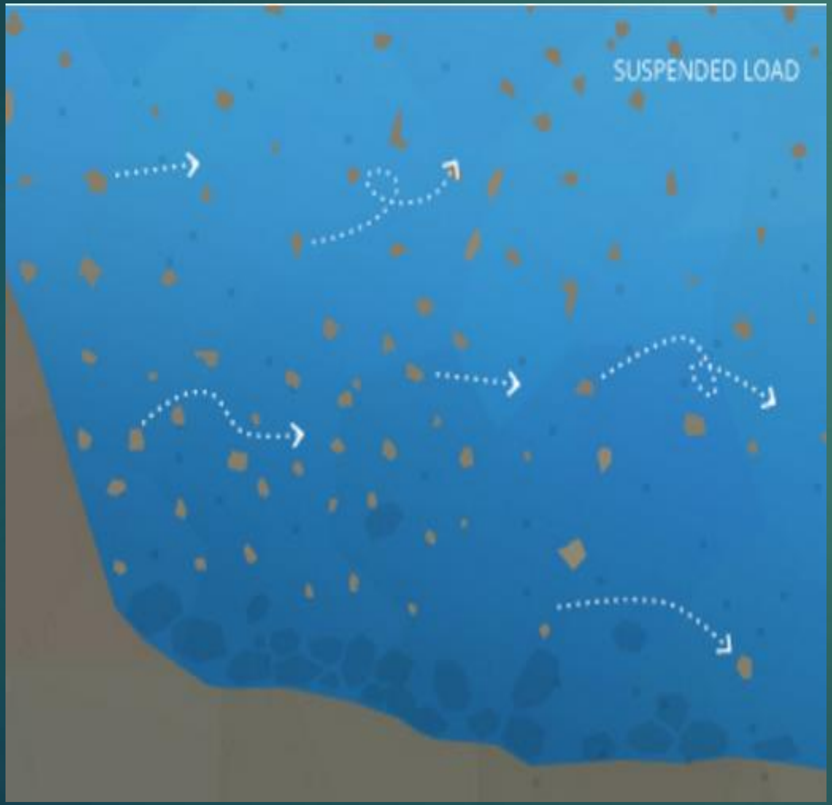
Dams and Reservoirs | Sedimentation

- Sediment transport, is also known as sediment load.
- The total load includes all particles moving as bedload, suspended load, and wash load.
- **Bedload** is the portion of sediment transport that rolls, slides or bounces along the bottom of a waterway.



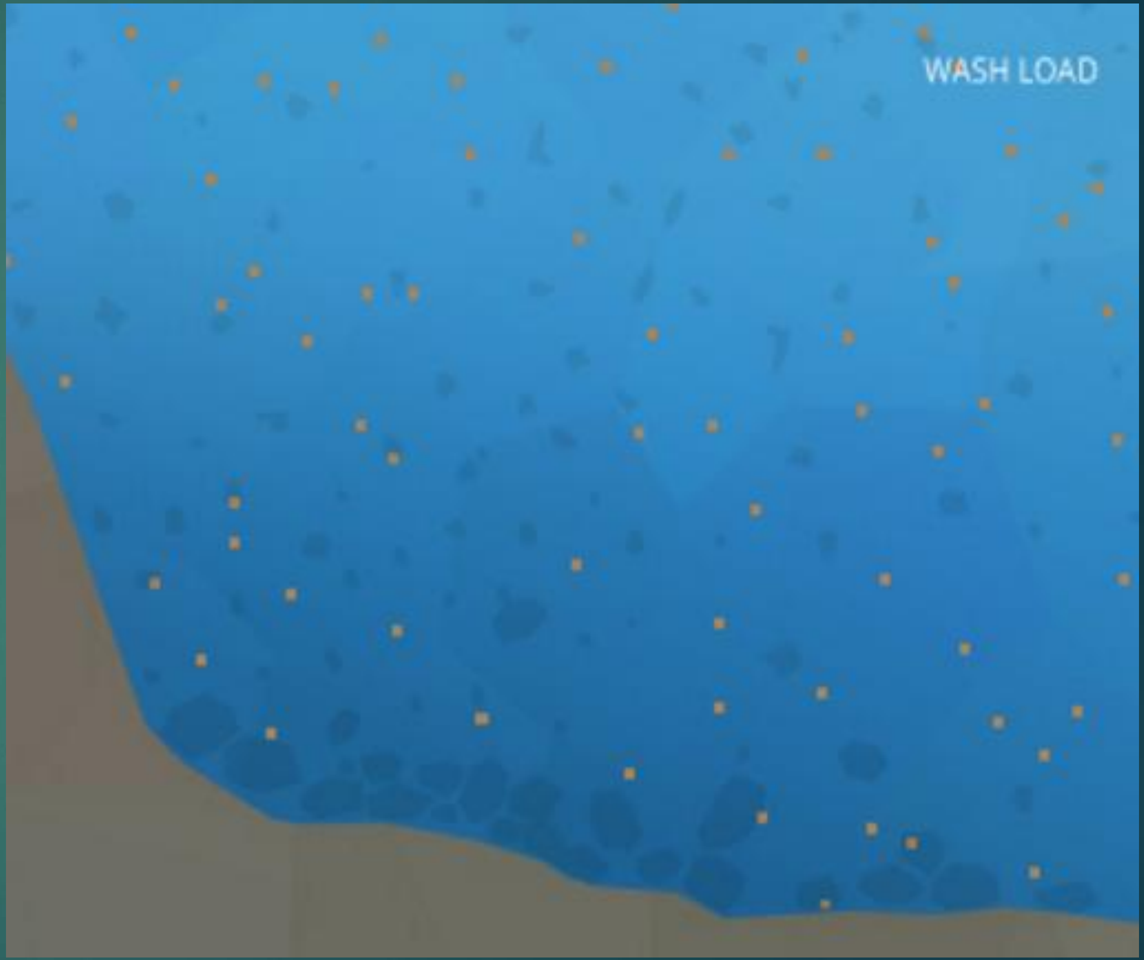
Dams and Reservoirs | Sedimentation

- The suspended load is the amount of sediment carried downstream by the water flow.



Dams and Reservoirs | Sedimentation

- The wash load is differentiated from the suspended load because it will not settle to the bottom of a waterway during a low or no flow period.
- Instead, these particles remain in permanent suspension as they are small enough to bounce off water molecules and stay a float.
- However, during flow periods, the wash load and suspended load are indistinguishable.



Stokes law

- If the particle is spherical, the settling velocity can be described by Stokes's law under laminar flow condition.

- Settling velocity also known as fall velocity, is the velocity reached by a particle as it falls through a fluid. It is dependent on factors like size and shape of particle.

$$V = \frac{g}{18\vartheta}(\rho_s - \rho)d^2 = \frac{g}{18\vartheta}(SG - 1)d^2$$

V is settling velocity

$SG = \frac{\rho_s}{\rho}$ is specific gravity

ρ_s is density of particles

ρ is density of water

d is particle dimeter

Example 1

Determine the settling velocity of the particle if

Water temp, T = 9.5°C

Particle diameter, $d = 6.56 \times 10^{-4}\ ft\ (0.2\ x10^{-3} m)$

S.G. of the particle = 2.65

Acceleration of gravity, $g = 32.2\ ft/s^2 s2\ (9.81\ m/s^2)$

Example 2

How long will take for soil particles with diameters of the following sizes to settle to a depth of 1 m.

Fine sand $d = 5.2 \times 10^{-2}\ mm$

Silt $d = 5.0 \times 10^{-3}\ mm$

Clay $d = 5.0 \times 10^{-4}\ mm$

$$\rho_s = 2650\ \frac{kg}{m^3}$$

$$\vartheta = 1 \times 10^{-3}\frac{kg}{ms}$$