Department of Hydraulic and Water Resources Engineering

KOIT, Wollo University

**Lecture Notes**

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# Chapter 3: Small, Mini, and Micro Hydro Schemes

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## CHAPTER 3: Small, Mini, and Micro Hydro Schemes

**3.1** Identification of civil works for Small, mini, and micro hydro schemes for various head.

**3.2** Location of civil works for small, mini, micro hydro schemes for various head.

**3.3** Layout of civil works for small, mini, micro hydro schemes for various head.

**3.4** Design of civil works for small, mini, micro hydro schemes for various head.

**3.5** Construction of civil works for small, mini, micro hydro schemes for various head.

**3.6** Maintenance of civil works for small, mini, micro hydro schemes for various head

# Background

Hydroelectricity is one of the most mature forms of renewable energy, providing more than 19% of the world's electricity consumption from both large and small power plants.

Countries such as Brazil, the United States, Canada and Norway produce significant amounts of electricity from very large hydroelectric facilities.

There are also many regions of the world that have a significant number of small hydro power plants in operation, such as

**In China, more than 19,000 MW of electricity is produced from 43,000 small hydro facilities**

# Cont'd.

- There is no universally accepted definition of the term "small hydro"
- local definitions (Depends on the country you are in) can range in size from a few kilowatts to 50 megawatts or more.
- Projects in the 100 kW to 1 MW range sometimes referred to as "mini" hydro, projects under 100 kW referred to as "micro" hydro and projects under 5 kW are named as Pico hydro.

# Components of small hydro

The components can broadly be classified into two

- Civil work.
  - Intake
  - Canal
  - Silting basin
  - Forebay
  - Support and anchor blocks
  - Power house
- and Electro-Mechanical equipment.
  - Trash rack
  - Penstock and gates
  - Turbine
  - Generator
  - Load controller

# Civil works

The main civil works of a small hydro development are:

1. The diversion dam or weir,
2. The water passages and,
3. The powerhouse.

# Cont'd.

- The diversion dam or weir directs the water into a canal, tunnel, penstock or turbine inlet.

- The water then passes through the turbine, spinning it with enough force to create electricity in a generator.

- The water then flows back into the river via a tailrace

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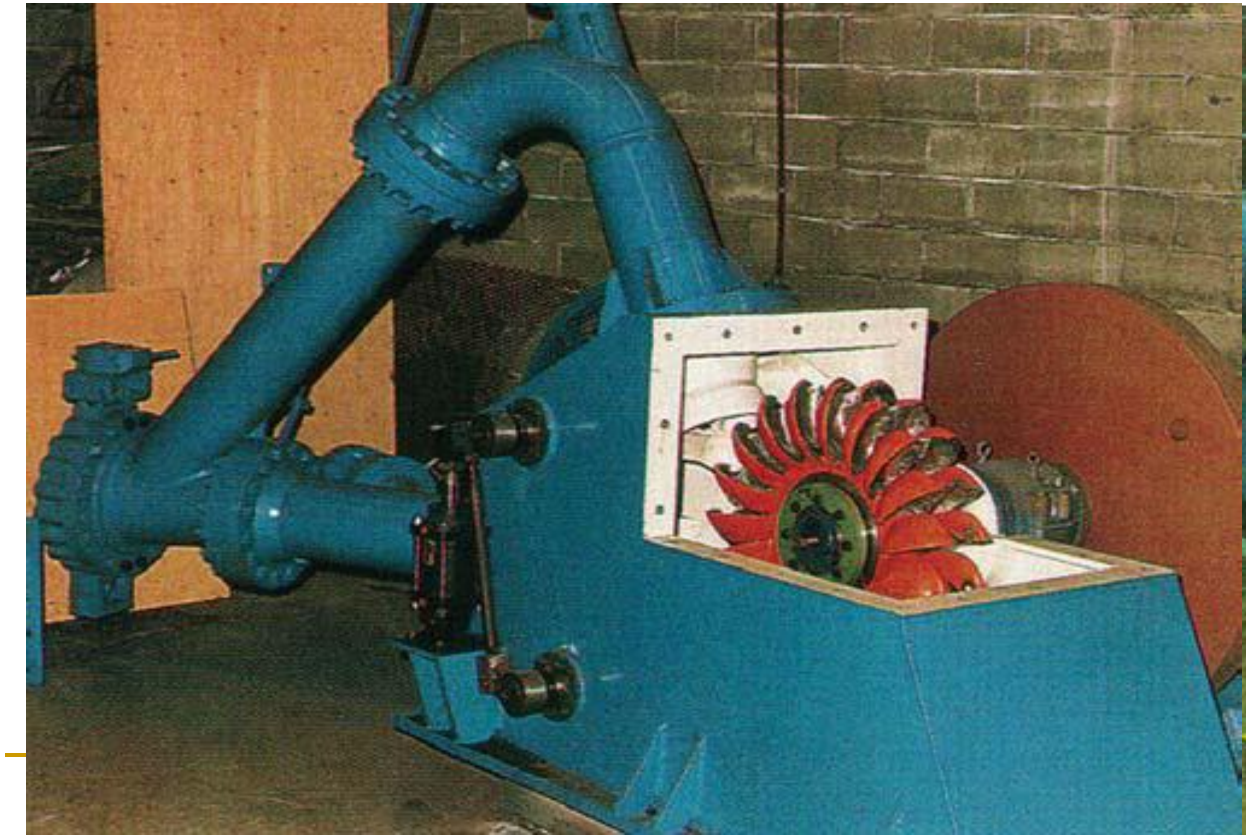
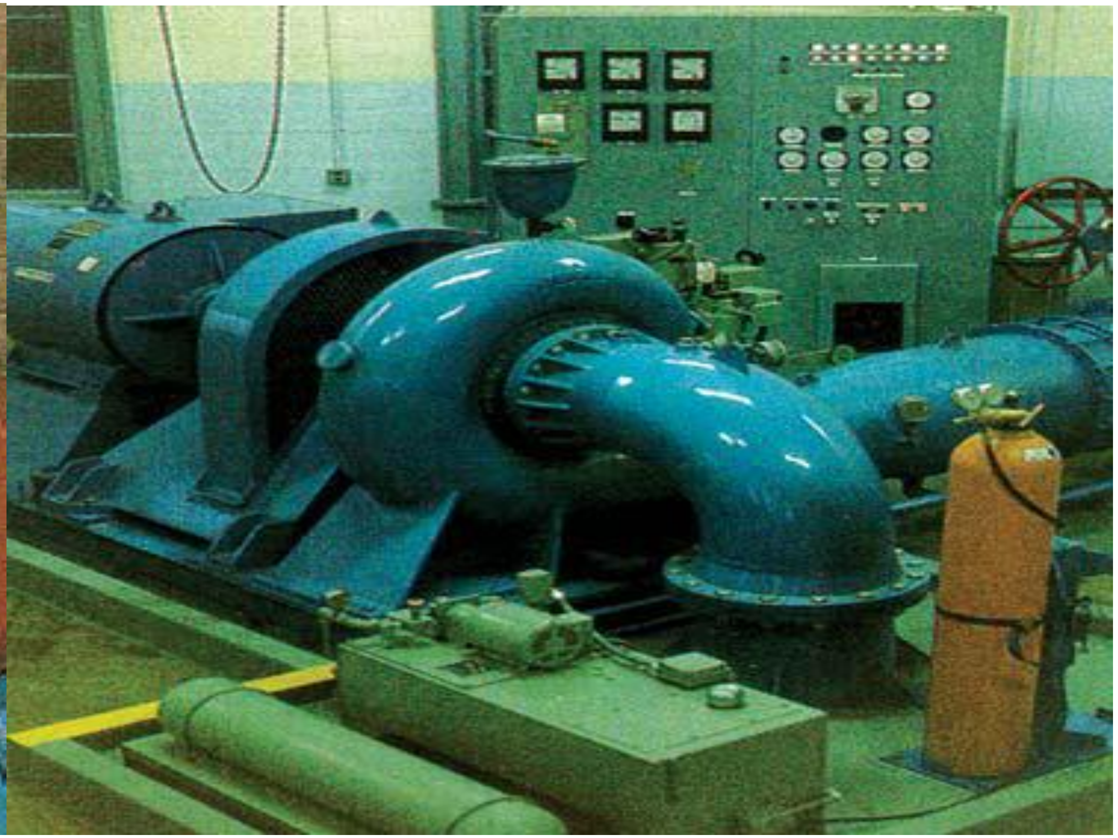
- The powerhouse contains the turbine or turbines and most of the mechanical and electrical equipment

# Cont'd.

The technical and financial viability of each potential small hydro project are very site specific.

Power output depends on the available water (flow) and head (drop in elevation).

The amount of energy that can be generated depends on the quantity of water available and the variability of flow throughout the year.

# Types of small hydro developments

1. Run-of-river developments
2. Water storage (reservoir) developments

1. Run-of-river developments

It refers to a mode of operation in which the hydro plant uses only the water that is available in the natural flow of the river

"Run-of-river" implies that there is no water storage and that power fluctuates with the stream flow.

# 2. Water storage (reservoir) developments

*For a hydroelectric plant to provide power on demand, either to meet a fluctuating load or to provide peak power*, water must be stored in one or more reservoirs.

Unless a natural lake (lake tana) can be tapped, providing storage usually requires the construction of a dam or dams and the creation of new lakes.

# Cont'd.

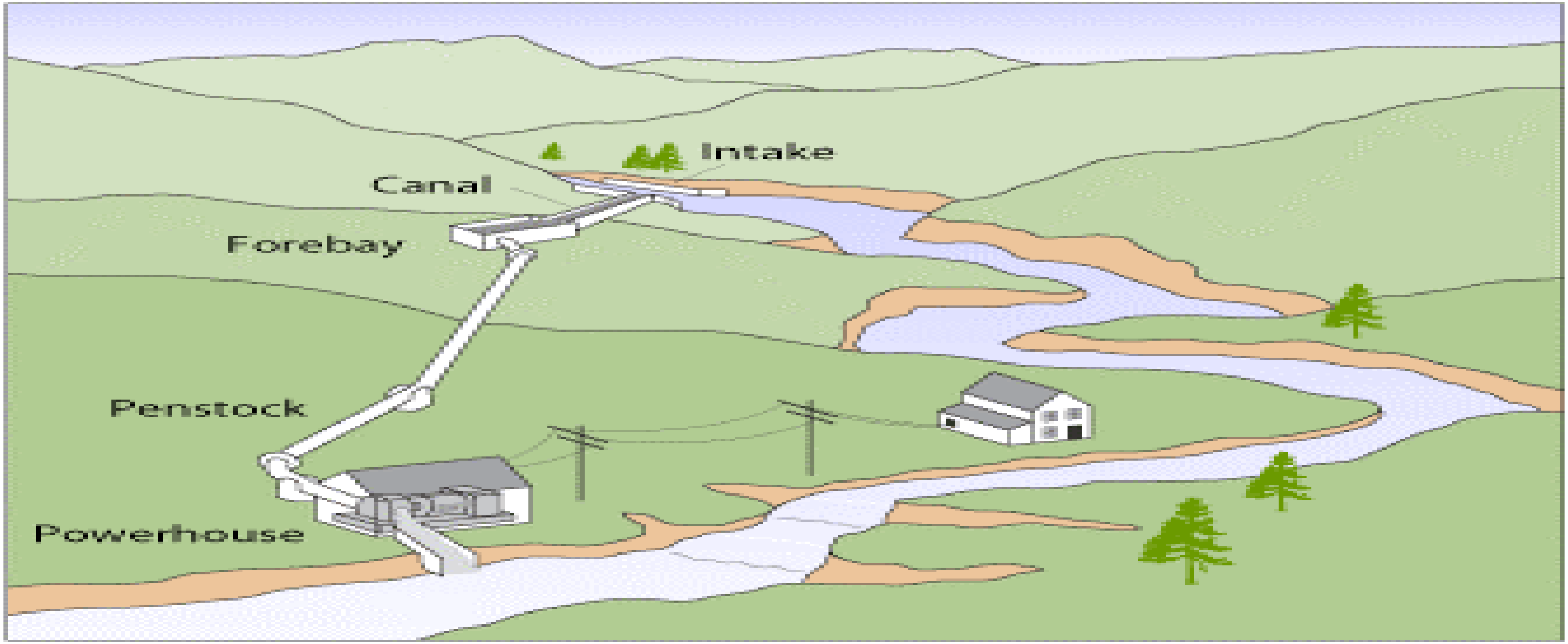
- Storage at a small hydro plant, if any, is generally limited to small volumes of water in a new head pond or existing lake upstream of an existing dam.
- Pondage is the term used to describe small volumes of water storage.
- Pondage can provide benefits to small hydro plants in the form of increased energy production and/or increased revenue.

# Cont'd.

Another type of water storage development is "pumped storage" where water is "recycled" between downstream and upstream storage reservoirs.

Water is passed through turbines to generate power during peak periods and pumped back to the upper reservoir during off-peak periods.

# Typical hydropower scheme



# Objective of a hydropower Scheme

- To convert the potential energy of a mass of water, flowing in a stream with a certain fall (termed the .head.), into electric energy at the lower end of the scheme, where the powerhouse is located.
- The power of the scheme is proportional to the flow and to the head.

Small hydropower energy is an excellent option to promote productive uses, economic growth and development for small remote communities in developing countries, because:

- Hydro is usually the cheapest of all electrification option to promote productive uses, economic growth and development for small remote communities, where hydro resources exist;
- Hydro energy is a mature technology, widely proven and now manufactured in a number of developing countries;
- Hydro energy resources are fully predictable, and generate energy 24 hours a day, so they can safely be used to provide a range of services to health and educations centers, for drinking water, for communication and other services;

## Cont'd….

- Hydro is an appropriate energy option for intensive energy consumption, because the costs for electricity generation are negligible,

- It can be adapted to the local skills and capabilities for implementation, operation and maintenance;

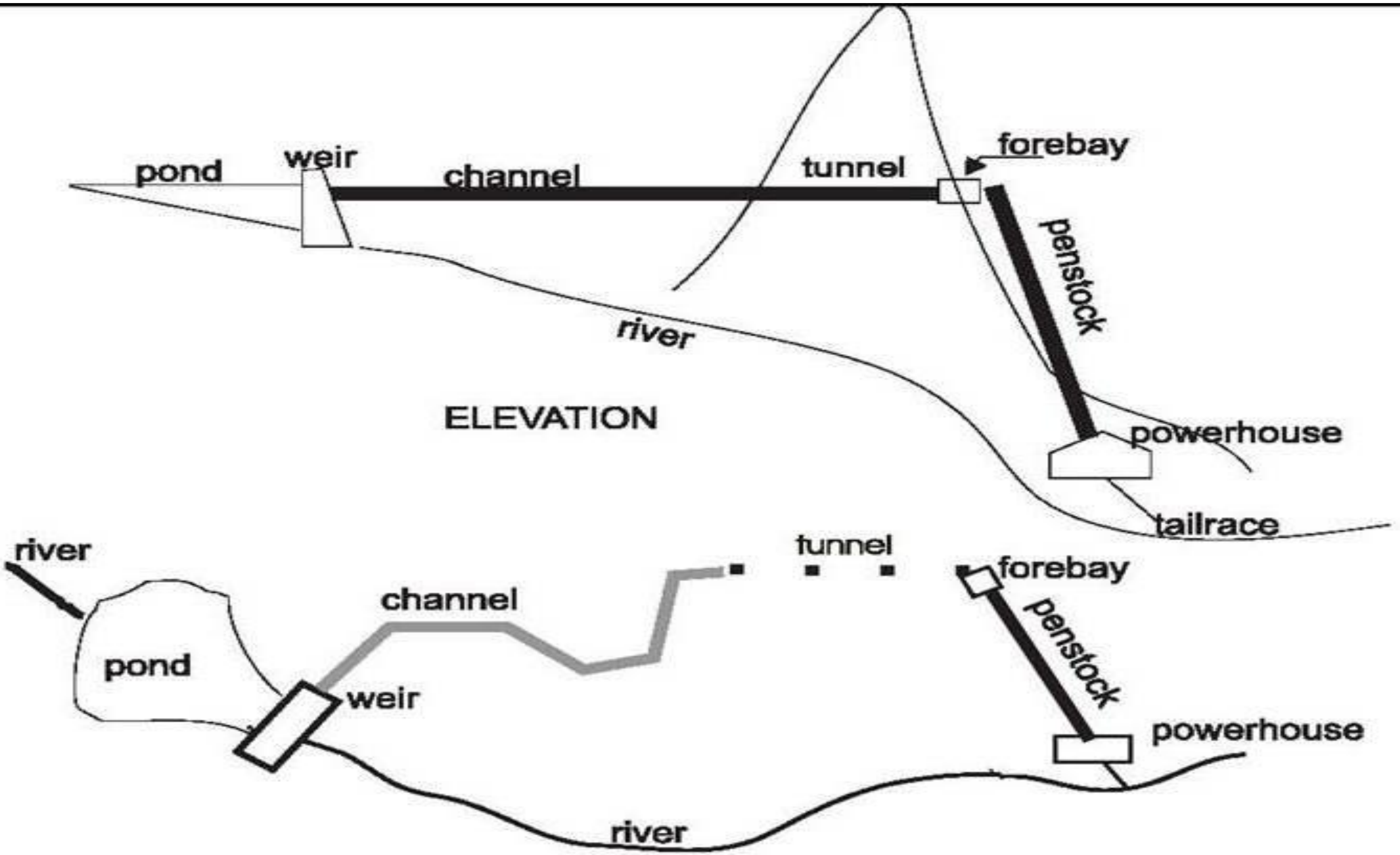
- Hydro is a clean energy option, which can be harnessed with minimum alteration of the environment and no green house gases emissions;

# Classification of small scale hydropower

- Scheme classification based on head

- High head: 100-m and above
- Medium head: 30 - 100 m
- Low head: 2 - 30 m

# A typical Site configuration



# Other classifications

- Run-of-river schemes.
- Schemes with the powerhouse located at the base of a dam.
- Schemes integrated on irrigation canal or in a water supply pipe.

# Run-of-river schemes

- In the “run-of-river” schemes the turbine generates electricity as and when the water is available and provided by the river.
- When the river dries up and the flow falls below some predetermined amount . the minimum technical flow of the turbine equipping the plant -, generation ceases.

# Cont'd.

- Medium and high head schemes use weirs to divert water to the intake, from where it is conveyed to the turbines, via a pressure pipe or penstock.

- Penstocks are expensive and consequently this design is usually uneconomic.
- An alternative is to convey the water by a low-slope canal, running alongside the river, to the pressure intake or forebay, and then in a short penstock to the turbines.

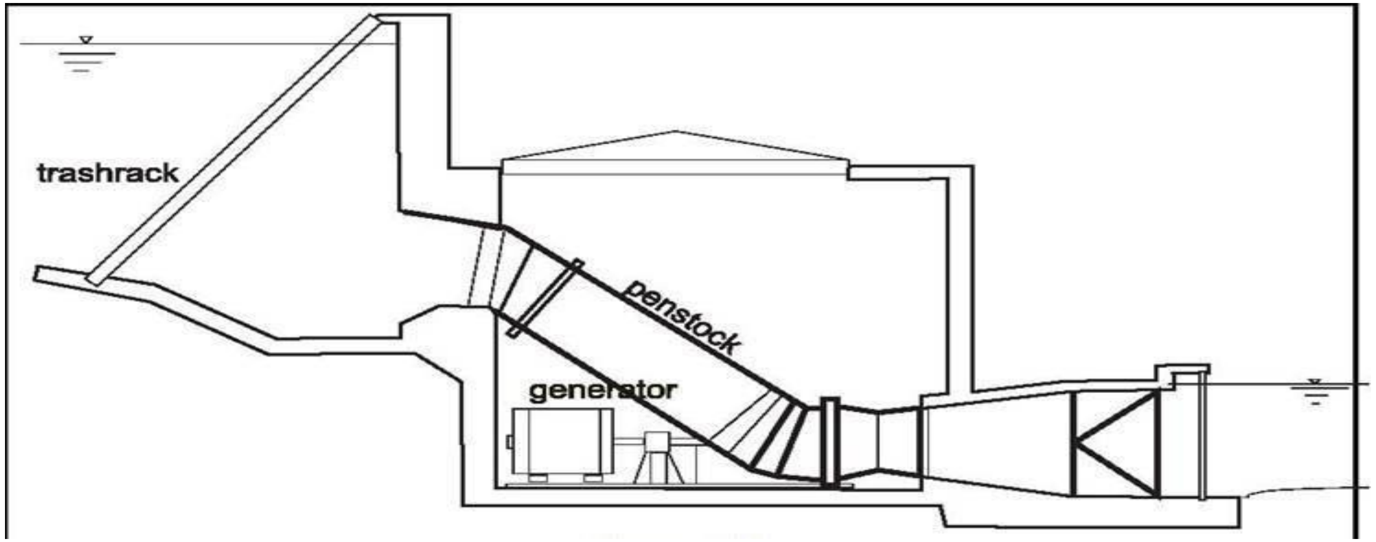
- If the topography and morphology of the terrain does not permit the easy layout of a canal, a low-pressure pipe, with larger latitude in slopes, can be an economical option.

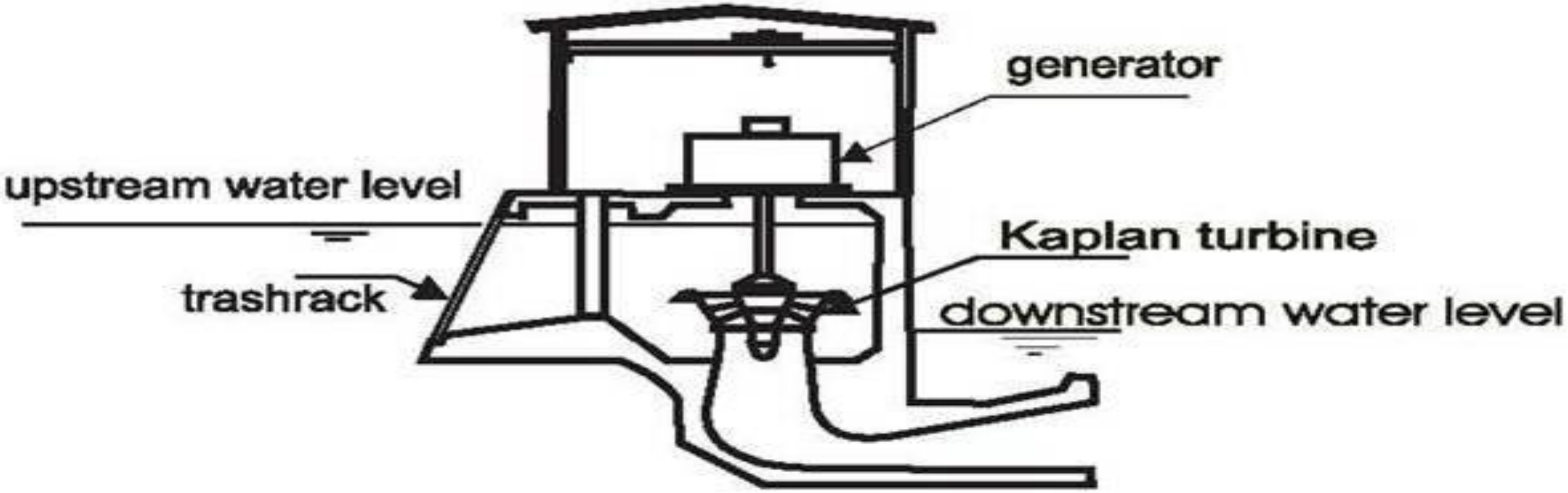
- At the outlet of the turbines, the water is discharged to the river, via the tailrace.

# Cont'd.

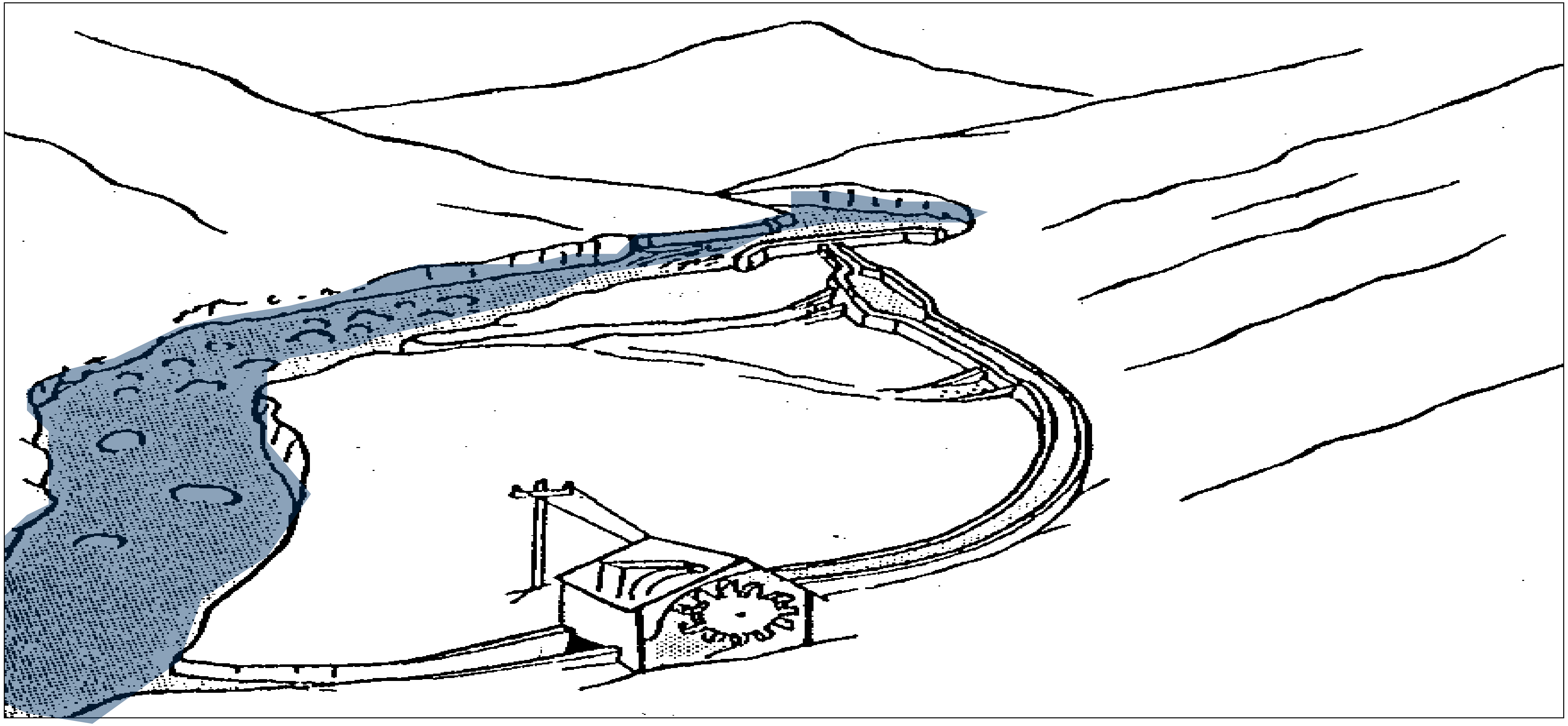
- Low head schemes are typically built in river valleys.
- Two options can be selected.
- Either the water is diverted to a power intake with a short penstock, as in the high head schemes,
- or the head is created by a small dam, provided with sector gates and an integrated intake, powerhouse and fish ladder.

# Run of the river Low Head Schemes

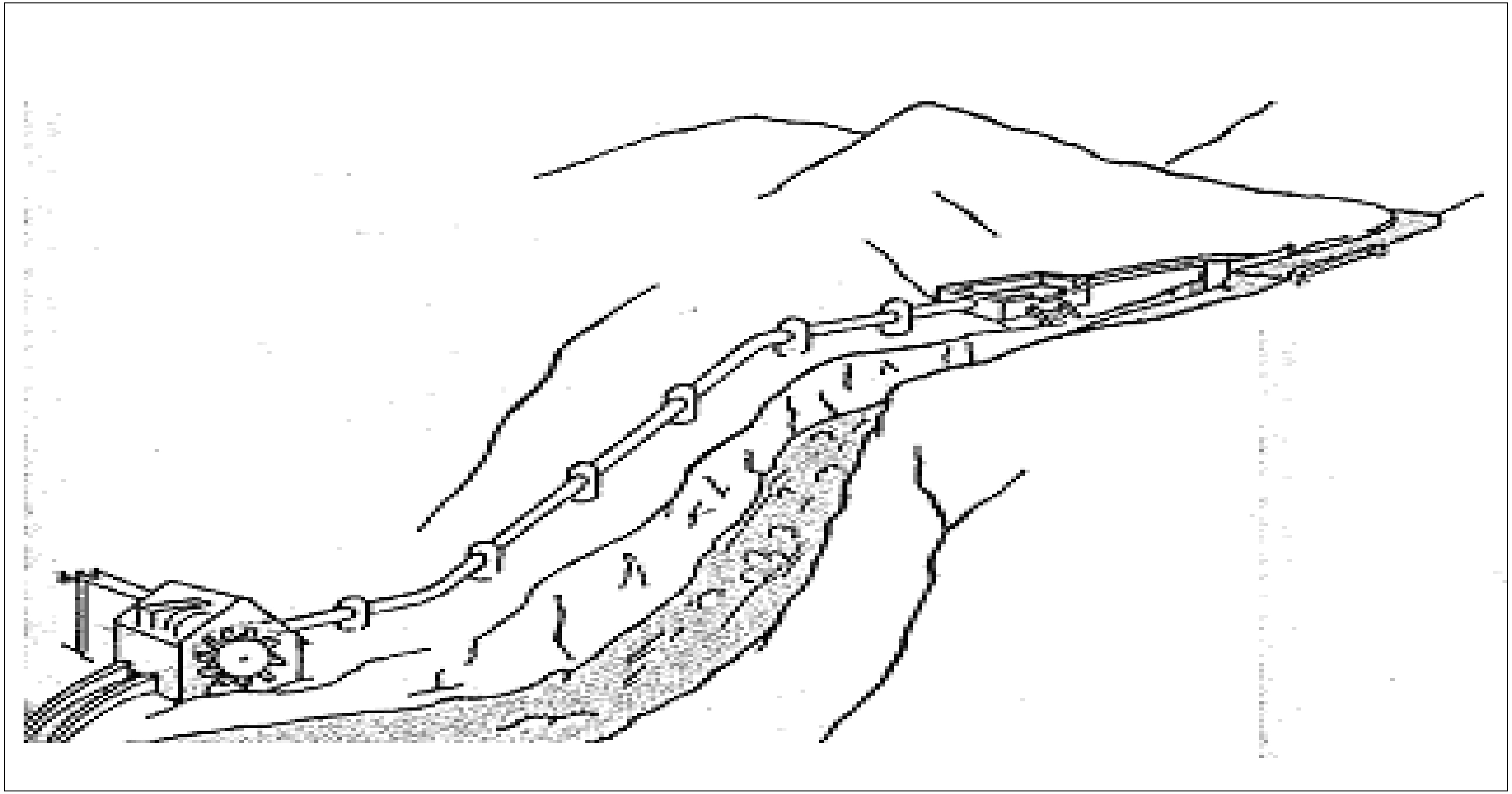


# Low head with channel

- 

# High head with no channel



# Schemes with the powerhouse at the base of a dam

- A small hydropower scheme cannot afford a large reservoir to operate the plant when it is most convenient; the cost of a relatively large dam and its hydraulic appurtenances would be too high to make it economically viable.

- But if the reservoir has already been built for other purposes, like: flood control, irrigation network, water abstraction for a big city, recreation area, etc, - it may be possible to generate electricity using the discharge compatible with its fundamental usage or the ecological flow of the reservoir.

# Cont'd.

- The main question is how to link headwater and tail water by a waterway and how to fit the turbine in this waterway.

- If the dam already has a bottom outlet, as in figure below the solution is clear.
- Otherwise, provided the dam is not too high, a siphon intake can be installed. Integral siphon intakes provide an elegant solution in schemes with heads up to 10 meters and for units of no more than 1.000 kW,
- although there are examples of siphon intakes with an installed power up to 11 MW (Sweden) and heads up to 30,5 meters (USA). The turbine can be located either on top of the dam or on the downstream side

# Cont'd

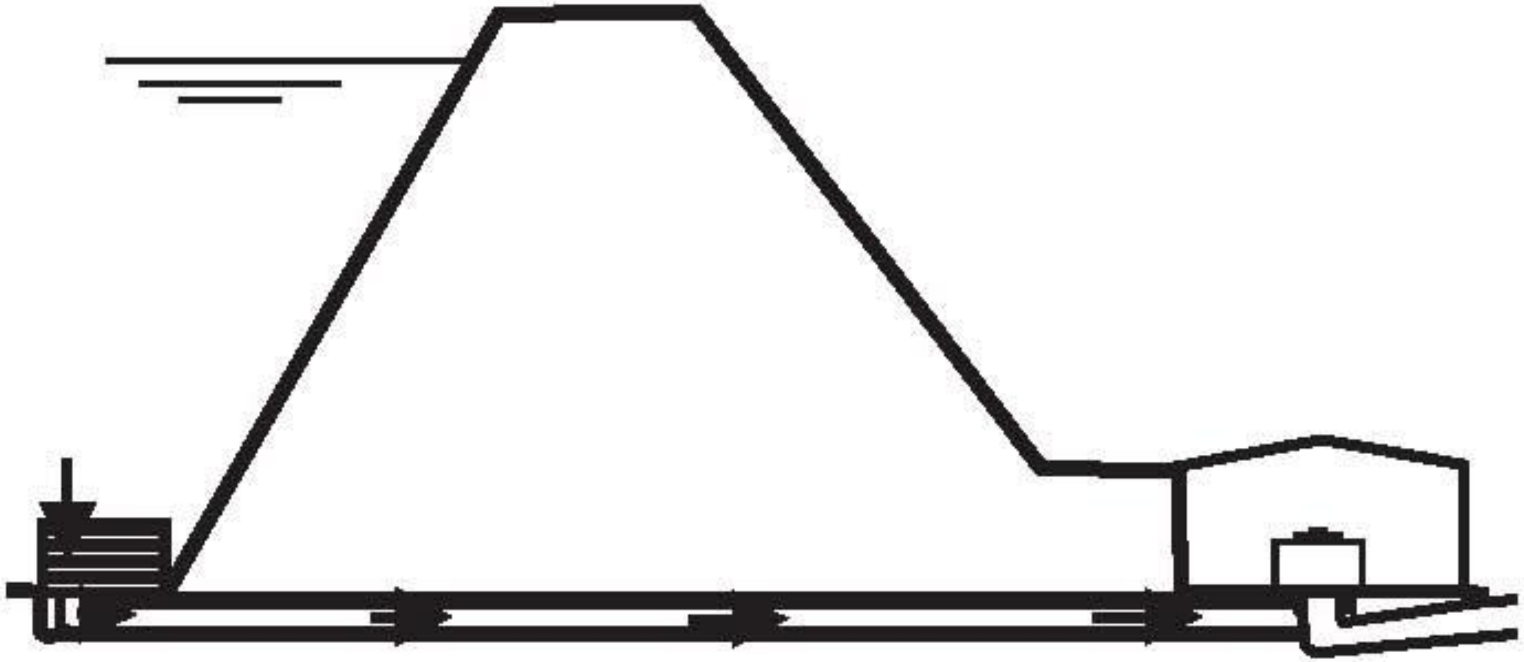


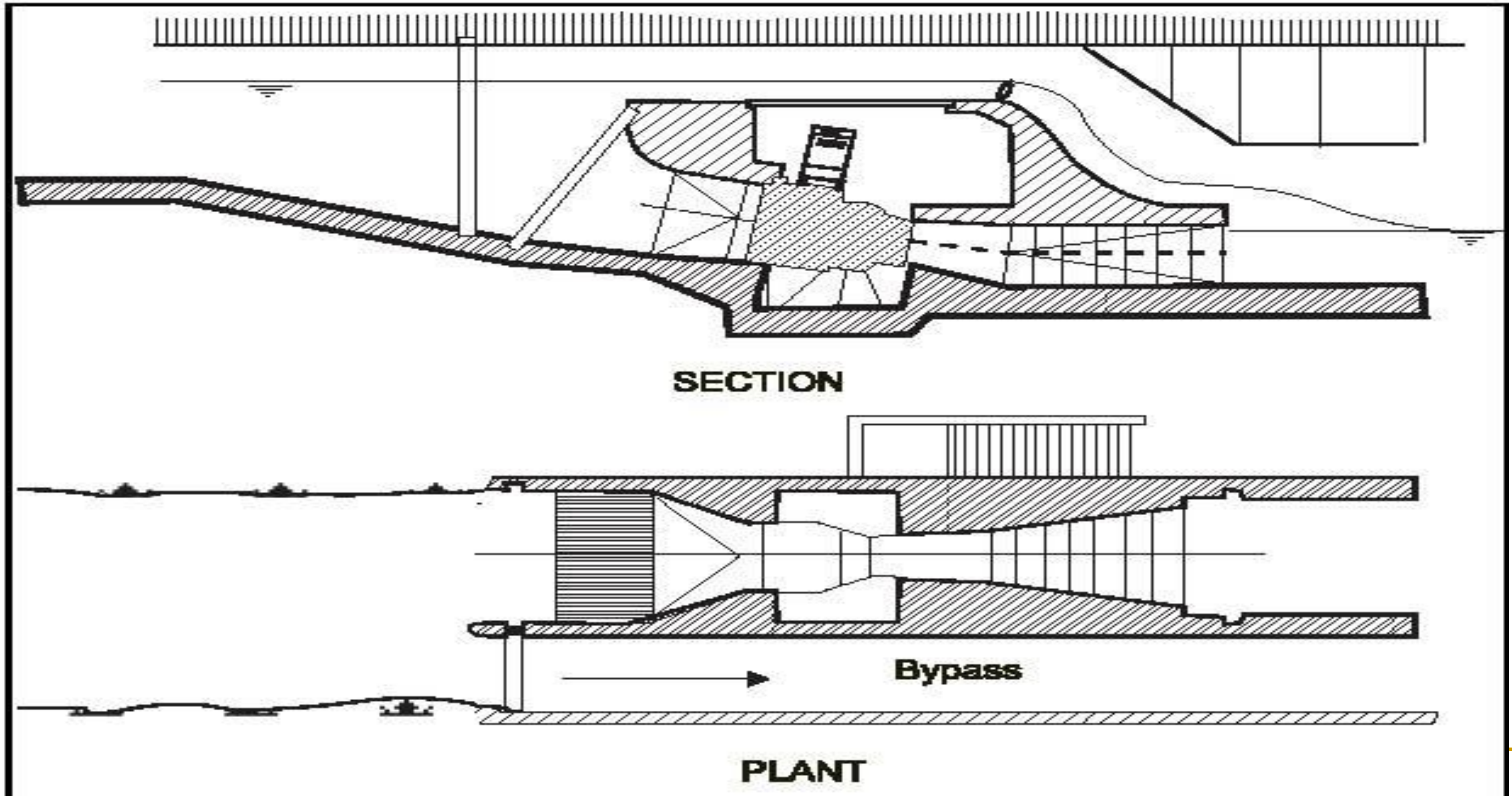
figure 1.4

powerhouse at the base of a dam

# Schemes integrated with an irrigation canal

- Two types of schemes can be designed to exploit irrigation canal falls:
  - The canal is enlarged to the required extent, to accommodate the intake, the power station, the tailrace and the lateral bypass.
  - The figure in next slide shows a scheme of this kind, with a submerged powerhouse equipped with a right angle drive Kaplan turbine. To ensure the water supply for irrigation, the scheme should include a lateral bypass, as in the figure, in case of shutdown of the turbine. This kind of scheme must be designed at the same time as the canal, because the widening of the canal in full operation is an expensive option.

# Cont’d.




Schemes integrated with an irrigation canal

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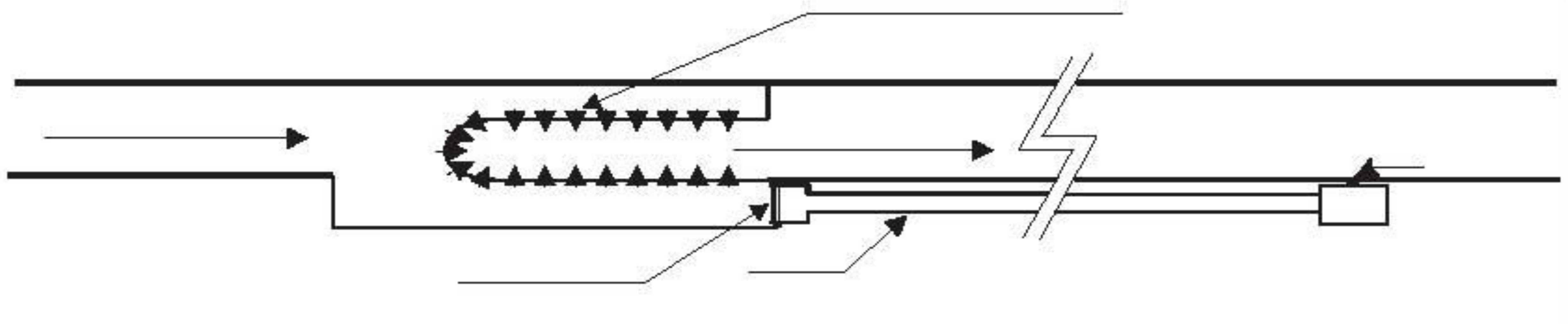
- If the canal already exists, a scheme like the one shown in figure below is a suitable option. The canal should be slightly enlarged to include the intake and the spillway.



Small hydro in irrigation canal

# Cont'd.

- To reduce the with of the intake to a minimum, an elongated spillway should be installed.
- From the intake, a penstock running along the canal brings the water under pressure to the turbine.
- The water, once through the turbine, is returned to the river via a short tailrace.
- As generally, fish are not present in canals, fish passes are unnecessary.

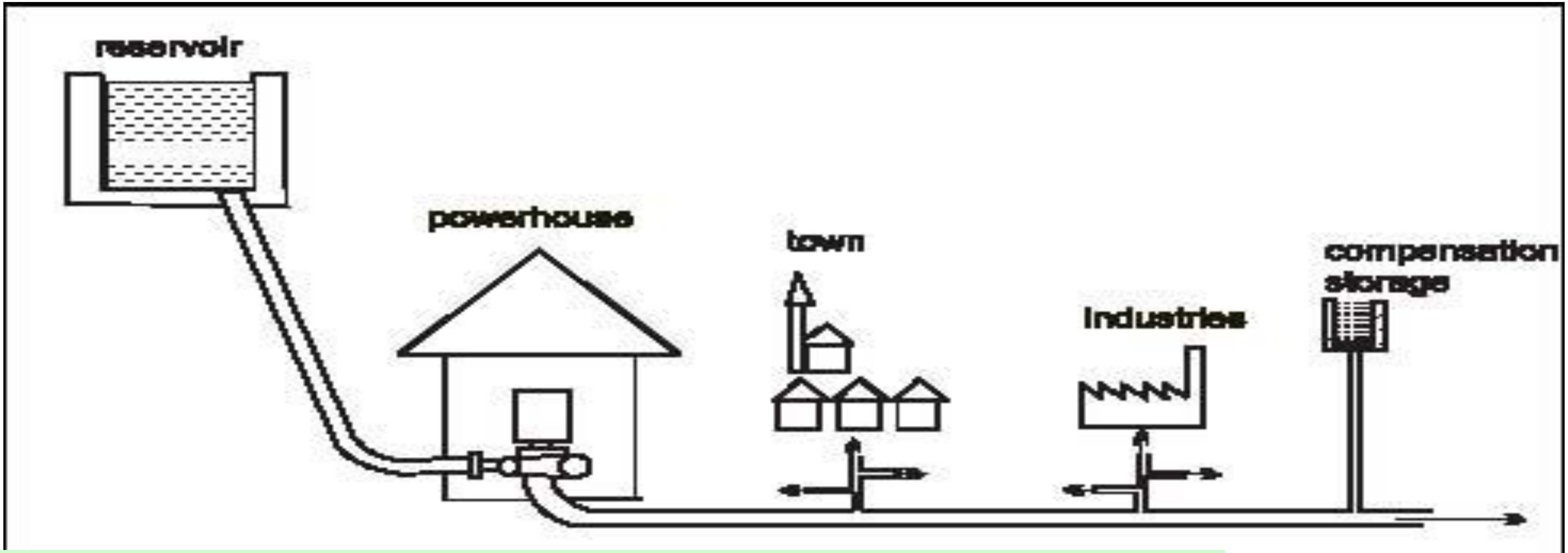
# Schemes integrated in a water abstraction system

- The drinking water is supplied to a city by conveying the water from a headwater reservoir via a pressure pipe.

- Usually in this type of installation, the dissipation of energy at the lower end of the pipe at the entrance to the Water Treatment Plant is achieved through the use of special valves.

- The fitting of a turbine at the end of the pipe, to convert this otherwise lost energy to electricity, is an attractive option, provided that water hammer, that would endanger the pipe, is avoided.

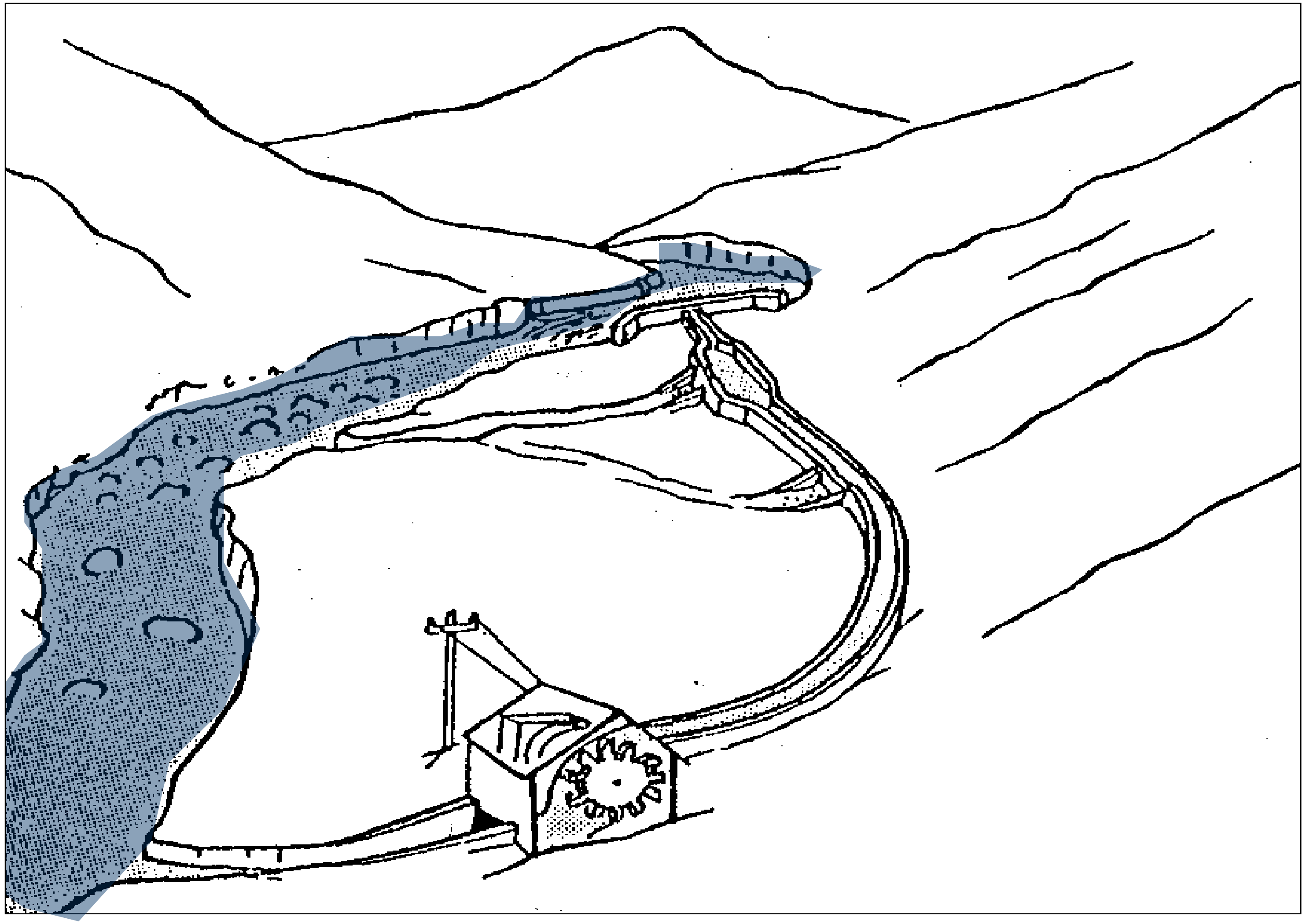
# Cont’d



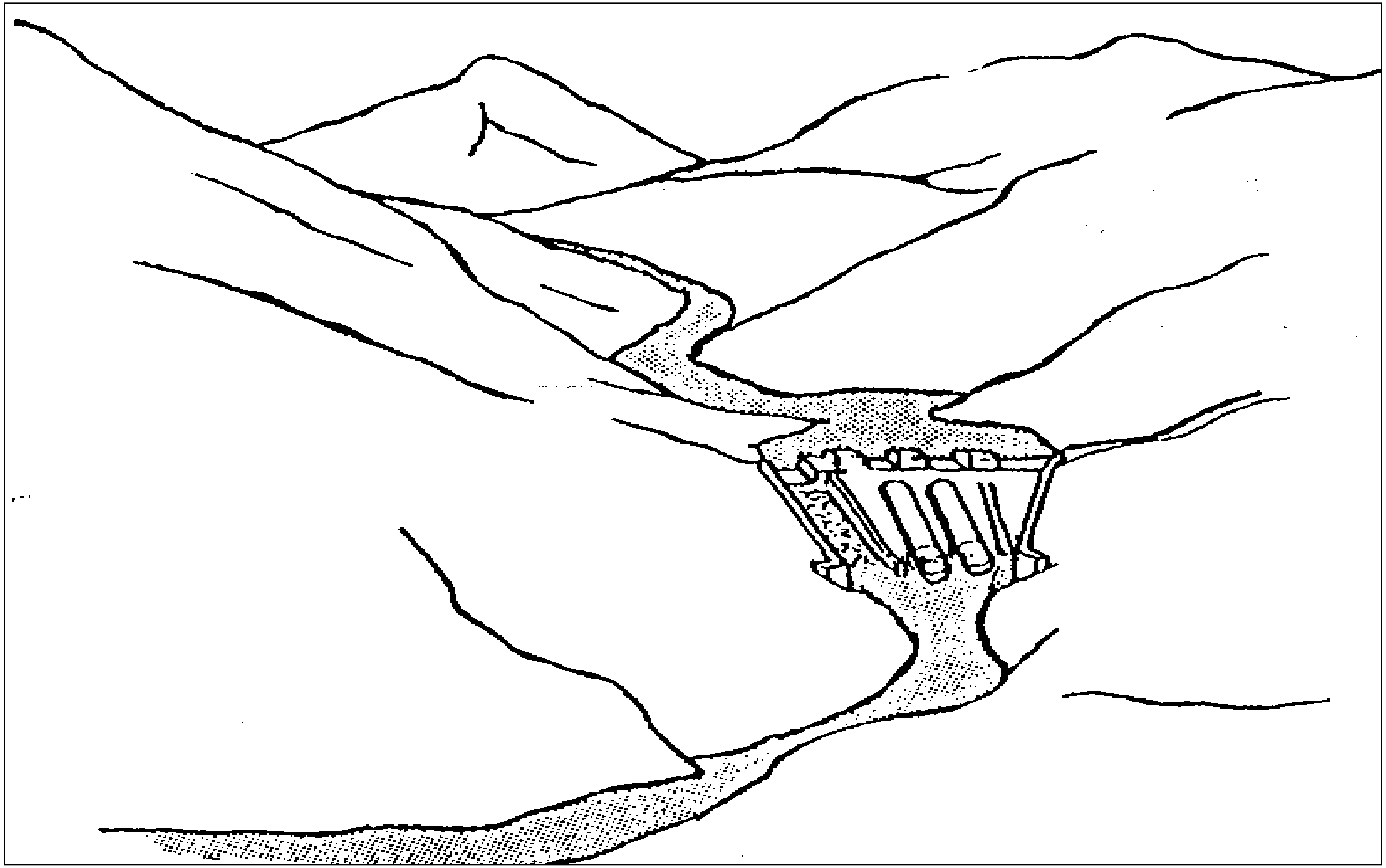

To ensure the water supply at all times, a system of bypass valves should be installed.

- ***Layout of hydropower developments***
  - Various possibilities exist for the general layout of hydro scheme. The layout of hydropower scheme should be done in order to have *optimum layout* and which also gives *minimum cost* for implementation, maintenance and operation.
  - A decision must be made with regards to the *relative lengths of the penstock and channel/tunnel, and how to route them*.

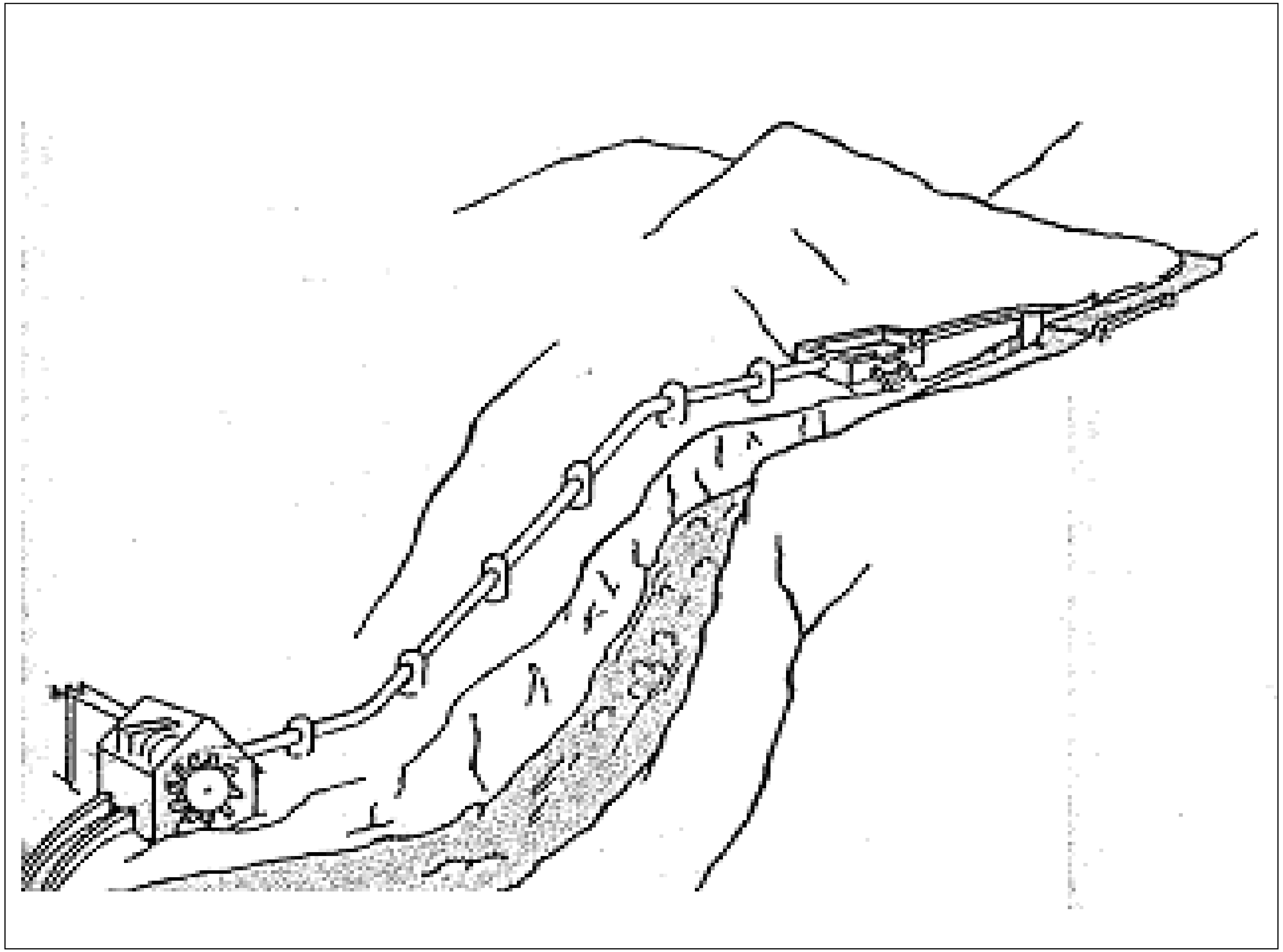
# Low head with channel



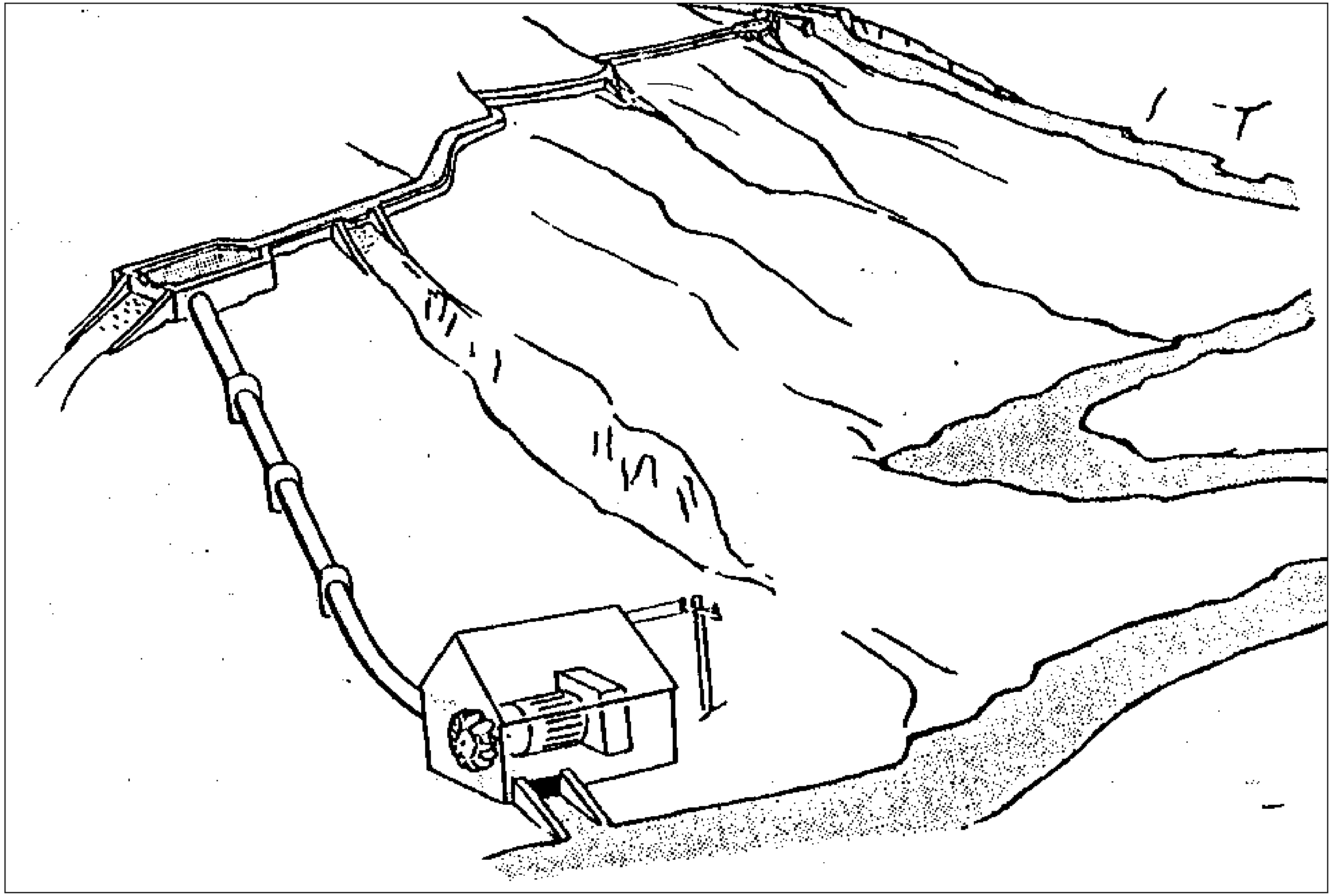
# Low head river barrage



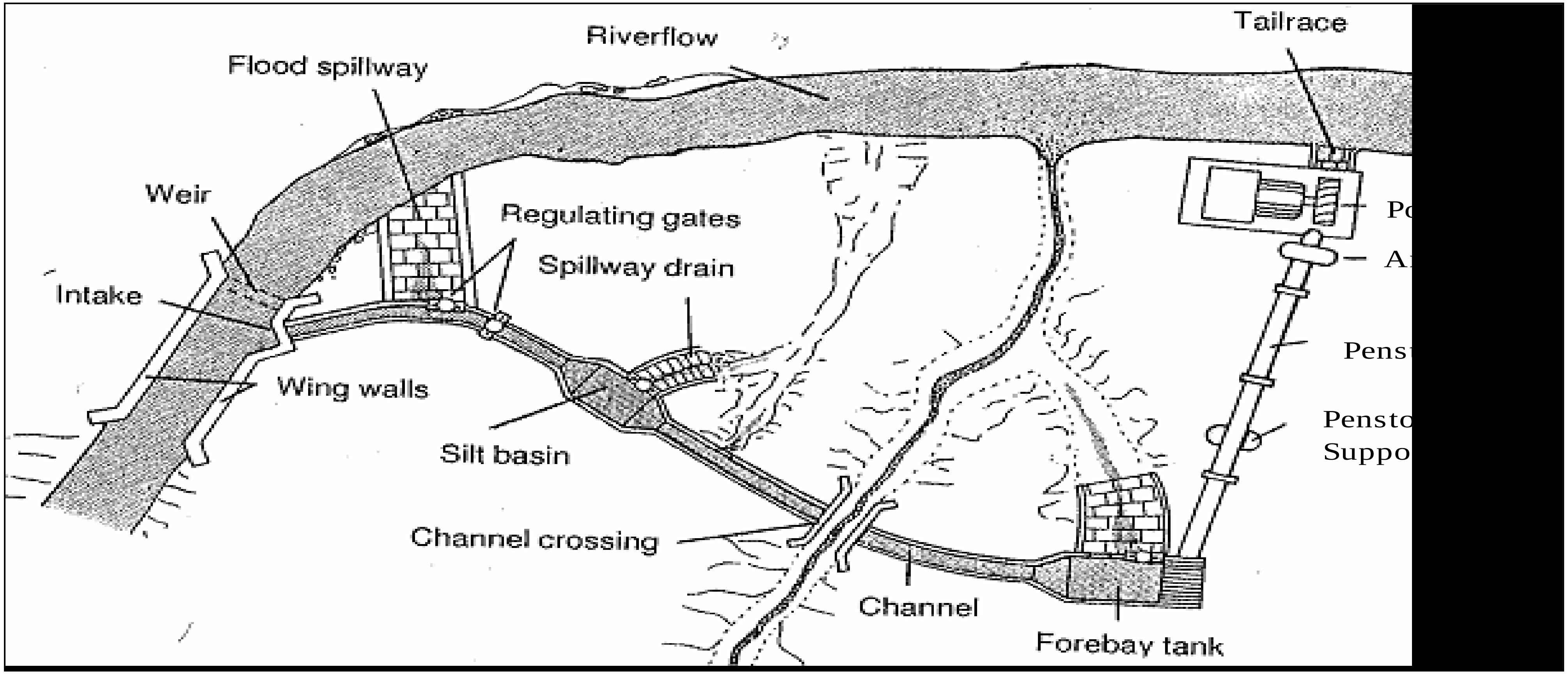
# High head with no channel



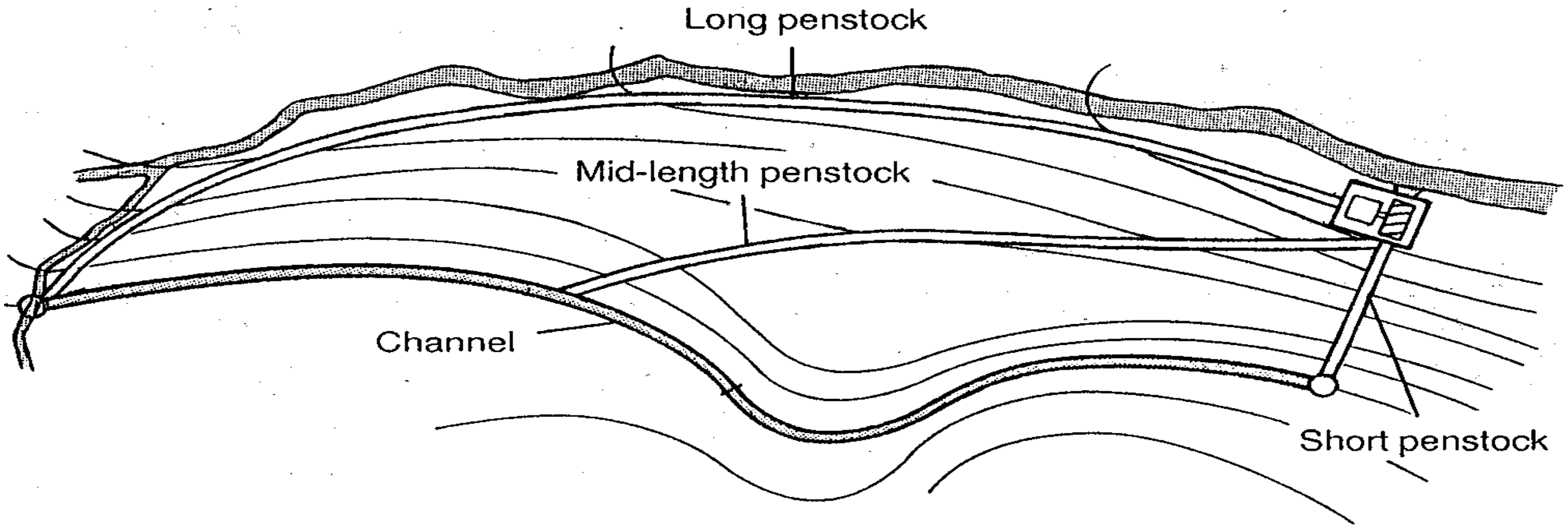
# High head with channel

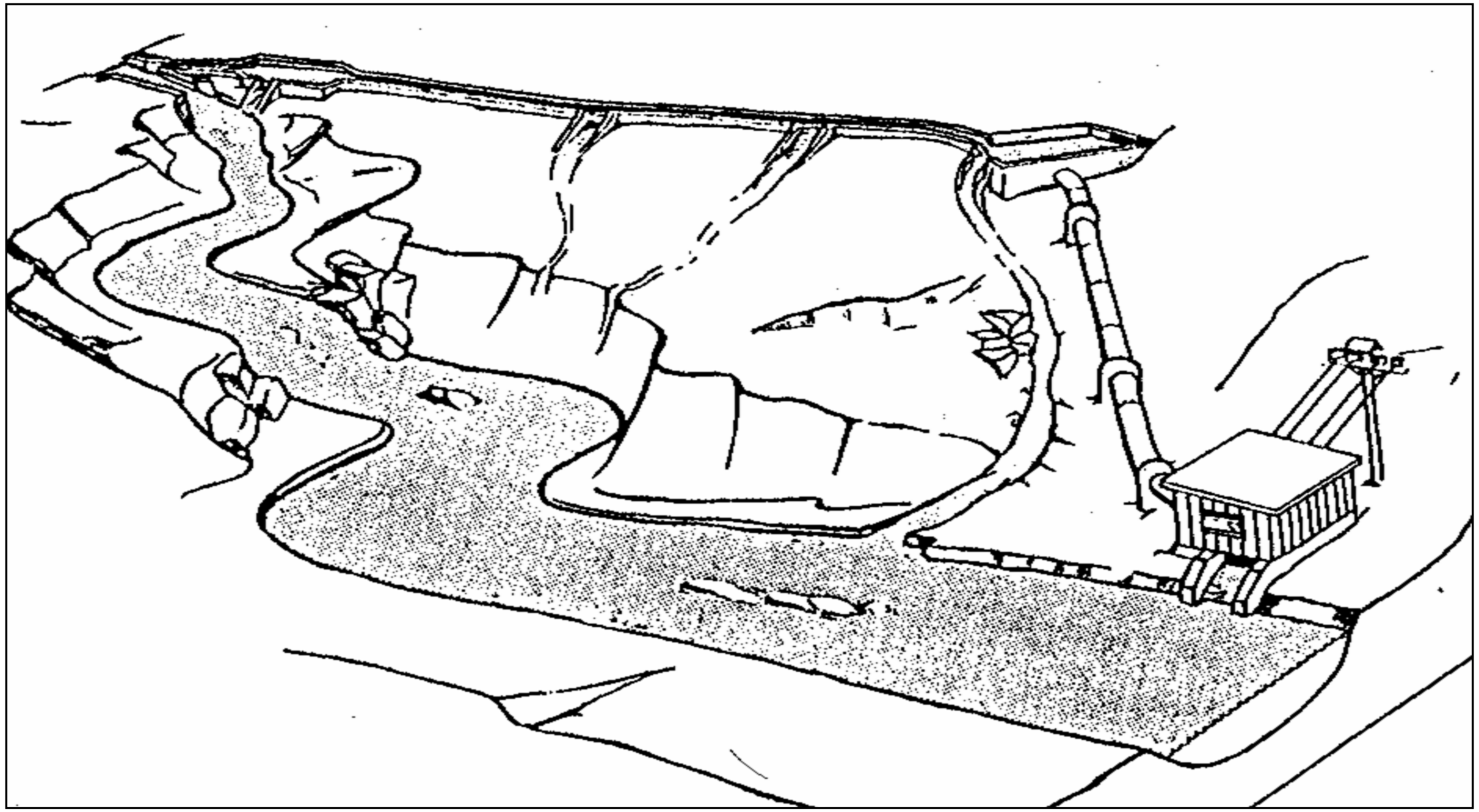


# The components of hydro scheme

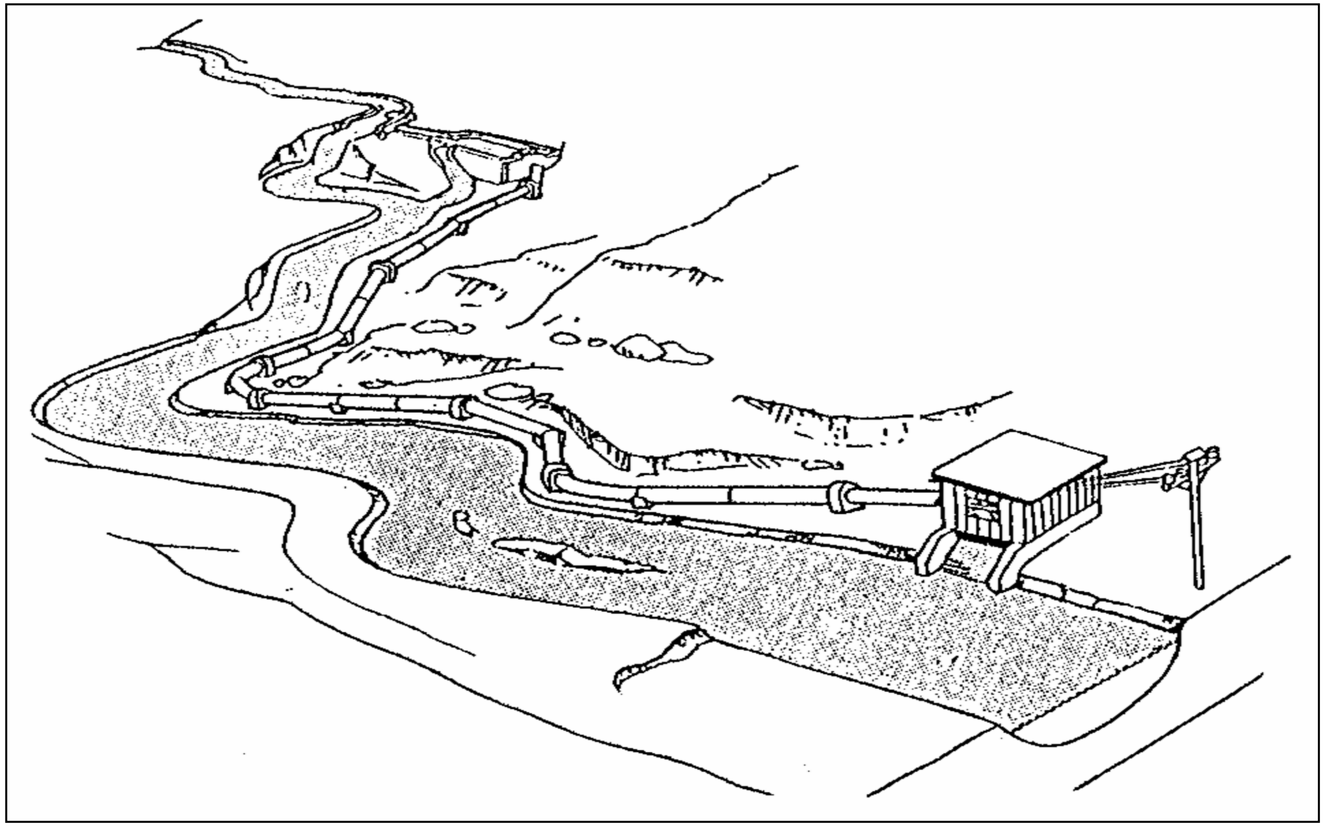


# System Layout

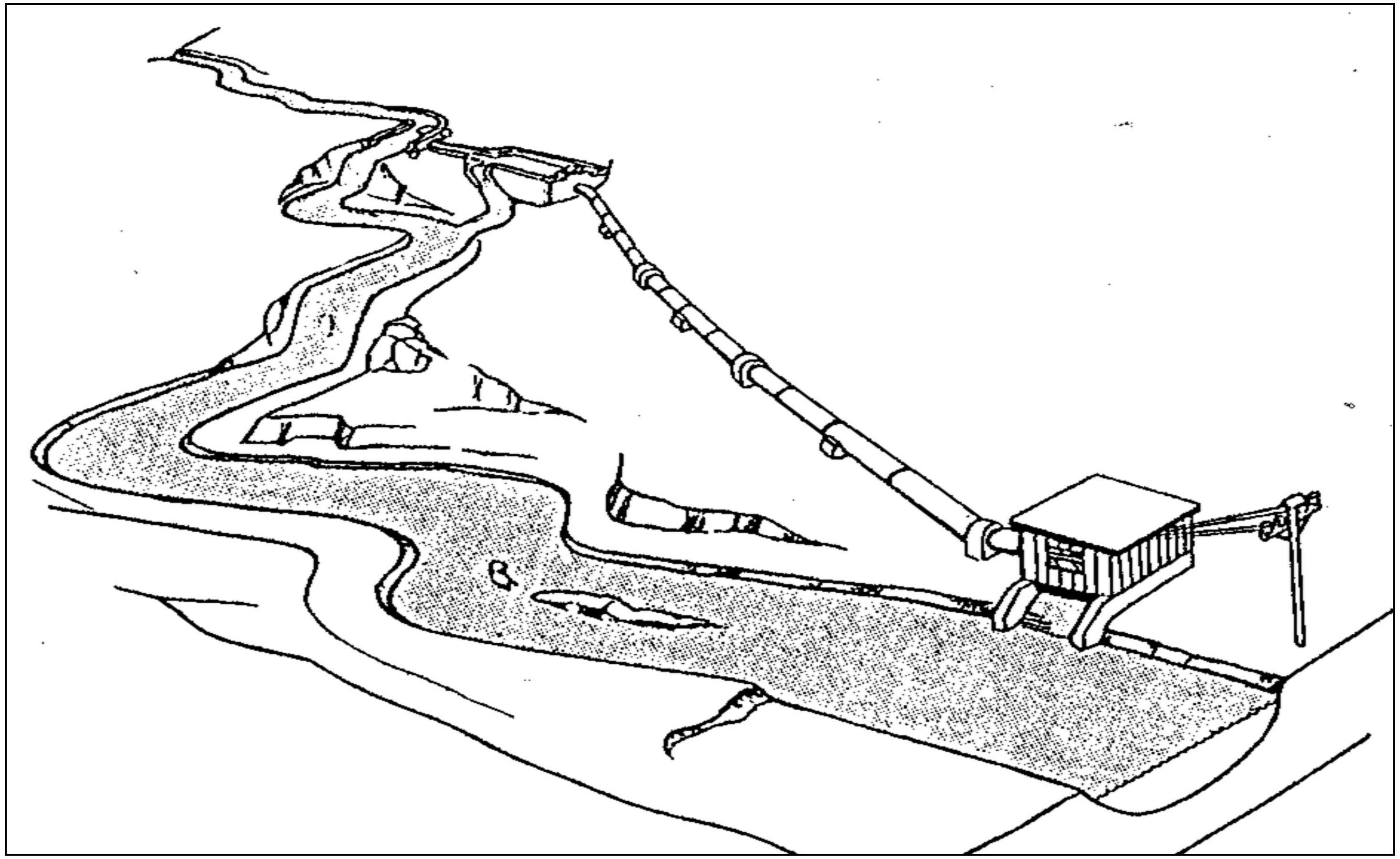




**Short penstock**



**Long Penstock following river**



**Mid-length penstock**

# Planning a small hydropower scheme

- The final scheme of the project comes as the result of a complex and iterative process, where, always having in view the environmental impact, the different technological options are compared from an economic point of view.
- It is not easy to provide a detailed guide on how to evaluate a scheme, but it is possible to describe the fundamental steps to be followed, before deciding if one should proceed to a detailed feasibility study or not.

# Cont'd

- A list of the studies that should be undertaken:
  - Topography and geomorphology of the site.
  - Evaluation of the water resource and its generating potential.
  - Site selection and basic layout.
  - Hydraulic turbines and generators and their control.
  - Environmental impact assessment and mitigation measures.
  - Economic evaluation of the project and financing potential.
  - Institutional framework and administrative procedures to attain the authorizations.

# Cont'd

- The water flowing along natural and man-made canals, conducted by low and high-pressure pipes, spilling over weir crests, and moving the turbines, involves the application of fundamental engineering principles of fluid mechanics.

# Investigation of Water Resources and Hydropower Projects

- WR & HP project investigation is the process of exploring or searching for sites suitable for WRD & HP generation.

CATEGORIES OF RESOURCES INVESTIGATIONS

**1. Basic Investigations**:

- The main purpose of such investigation is to register, catalog & rank (according to size, costs, priority, etc.) the available resources
- To determine size and other qualities.
- No established development

# Investigation of Water Resources and Hydropower Projects

CATEGORIES OF RESOURCES INVESTIGATIONS

## 2. **Purpose Oriented Investigations**:

- Carried out for specific purposes, i.e. in order to meet identified needs for electric power through finding suitable supply.

- Used to identify and select the best projects from available hydropower resources for the stated purposes.
  - Have specific terms of reference to meet.

# Investigation of Water Resources and Hydropower Projects

## Investigation of Hydropower Projects

- Several planning parameters and comprehensive data and information are needed for investigation of HP resources and planning of hydropower projects.

- The main data are derived from:

1. Forecast of demand for electricity, and from studies of:
    - Hydrology
    - Topography
    - Geology, soils and materials

# Investigation of Water Resources and Hydropower Projects

## Investigation of Hydropower Projects

2. Important issues, indirectly part of the planning process, are:
    - Environmental constraints
    - Socio-economic considerations
    - Electricity tariffs, and tariff policy

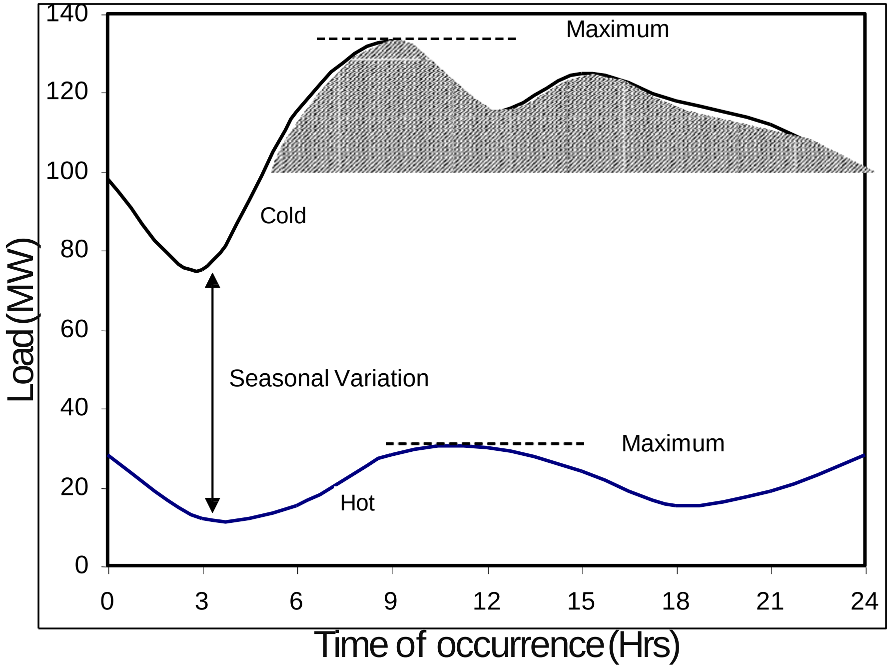
- In order to make predictions about the future need for electricity and to establish a demand (or load) forecast, precise and reliable knowledge about the market situation, socio-economic trends and development plans are needed.

# Investigation of Water Resources and Hydropower Projects

## Investigation of Hydropower Projects

### POWER MARKET

- Demand: Size & Shape




✓ Indicate need for regulation of water course

✓ Provide data needed to determine the size of generation, installations, unit size and transmission facilities.

✓ The minimum installation in the development should at least satisfy the energy and power demand required by the load curve often termed as firm power or energy and the maximum size can also be fixed by referring the peak demand.

# Investigation of Water Resources and Hydropower Projects

## Investigation of Hydropower Projects

### POWER MARKET

- Power market surveys are means of evaluating the present and potential markets for electric energy in a defined area

- The market survey will consider the effects on the use of electric energy within the survey are of such factors as:
    - Geographical location
    - Natural resources
    - Industrial development
    - New power uses, the economic status and prospective growth of the population

# MINI HYDROPOWEWR DEVELOPMENT

Small Hydropower may be classified according to different criteria such as

- head,
- powerhouse layout, and
- installed capacity.

The definition may vary at different times and in different countries implying that it has no strict definition.

According to UNDO an installed capacity between 101KW and 1000KW is defined as Mini Hydropower (MHP) development.

- The main prerequisite for socio-economic development in an area is the acquisition of economic and reliable energy.
- According to statistics from the United Nations, a total installed capacity of 85 GW should be newly added in the world's rural areas so that the un electrified rural areas inhabited by 1.7 billion people will have electricity for basic needs (exclusive of industrial and agricultural loads).
- However due to the limitation of conventional energy resources and a shortage of funds and expertise etc, only a few millions of rural people in the world can be energized in a year.
- Therefore, the lack of electricity becomes a great constraint to the rural and the national economic development of a country.

- Most energy consumption in rural areas is still from biomass and electricity occupies only a small portion of the energy consumed
- In our country more than 80% of the population is scattered in the country side consuming 88.4% of the Biomass energy out of 94.5% of Biomass energy consumption in the country (1996- statistics).
- On the other hand 751.128 metric tone of fuel oil was consumed out of which only about 8% of the fuel oil was consumed by rural energy consumption.
- This shows that the imposition on the financial balance of the country is high but urban and industrial centers are using large proportion of imported energy sources.
- Such disproportionate energy allocation leads to an increase in fire wood consumption in rural areas resulting in soil erosion and loss as well as a decrease in soil fertility and damage to the environment.

Therefore, the promotion of rural commercial energy is a critical decision for our nation.

Those who are in favor of using conventional energy think that

- if all the total fire wood consumption in rural areas of the world is replaced by oil,
  - ✓ **about 0.2 billion tons of oil will be needed annually**
  - ✓ **occupying only 7% of the total oil production in the world.**
- So shortage of energy in rural areas is actually is an issue of poverty rather than an energy issue.

- However, past energy crises and escalation in oil prices clearly show that this strategy is neither realistic nor cost effective
- Moreover; the large scale burning of Hydrocarbons would exacerbate the green house effect, making a serious ecological impact on the environment.

Thus it is necessary to set up a clean rural energy structure.

**Those who are in favor of a centralized energy supply think that**

- **MHP plants are neither economically feasible nor technically viable and**
- **the energy demand in rural could be better solved by the extension of large grids.**
- **Again this approach is not the case in reality.**
- **More over many rural areas are rich in MHP resources and many remote areas can not be economically energized by the extension of large grids.**
- **In reality a flexible or diversified strategy of rural electrification should be considered based on local conditions.**
- **In china diversity and decentralization of energy supply has brought effective rural economic development**

# *The Mini Hydropower development*

In new and renewable energy sources, SHP is mature in technology.

Long ago human beings learnt how to make use of water for power.

In the country it is still possible to find primitive Hydraulic Devices (Water Mills).

Nowadays, SHP is well developed,

- ✓ with the application of new technology
- ✓ design to shorten its construction period
- ✓ the initial cost being reduced by full use of local labour and
- ✓ materials as well as a series of preferential policies from government.

# The main advantages of MHP are

- its suitably for decentralized development, fully using local materials and appropriate technology with the participation of local people,
- its mature technology and small investment risk,
- its low operating costs easy maintenance and reliable power supply
- little environmental impact during construction with some positive impact on the environment
- the obvious social benefit to a developing local economy and improvements in the material and spiritual life of local residents

# *Factors of MHP development*

On the basis of the experience of some countries, the following factors are required for the development of MHP:

1. Rich MHP resources and certain loads
2. Sufficient funds for the construction of MHP stations
3. Expertise in its economic exposition
4. Preferential policies from central and local governments

# PREFERENTIAL POLICY FOR MHP DEVELOPMENT

**For instance in china, the government has stipulated a series of preferential policies to promote SHP development as follows:**

1. **The “three self policy“, namely**
   - self construction,
   - self management and self consumption;

**which means that the people who invested in and constructed SHP stations have the right to manage the plant to use, to use the output of SHP plant and to obtain benefits from the station**

2. **“Further developing SHP with benefits from existing stations which means that the benefits of SHP should be reinvested to further develop SHP or local grids**
3. **Local grids can have their own supply area and unified management system of generation, distribution and power supply and be connected to and mutually aided by large (or national) grids**
4. **The government gives preferential loans and exemption to SHP developers**

# FUNDING

**Generally speaking the unit cost of SHP or MHP is greater than that of medium and large hydropower plants and**

**its initial investment is a great burden for local developers.**

**The funding of SHP or MHP should mainly be self generated and be based on the particular conditions of a country.**

**In any case a feasibility study of the project is first required for the developer or owner so as to make the right decision.**

**The funds for SHP or MHP can be gathered from:**

- some subsidies or preferential loans from central and local governments
- loans from banks
- investment from industrial consumers and local people

# *Appropriate technology for MHP*

typical designs are available gates, pre-stressed concrete penstocks and pre-cast concrete poles

many micro hydropower plants have been packaged and commercialized

electro mechanical equipment in SHP and MHP plants have been standardized and serialized thus reducing thus SHP or MHP unit cost

some practical devices, such as ELC (Electric Load Control), a simplified govern or (operator), auto-valves with counterweight and automatic controllers have been invented which reduces the operating cost and improved operation

# BENEFITS OF MHP

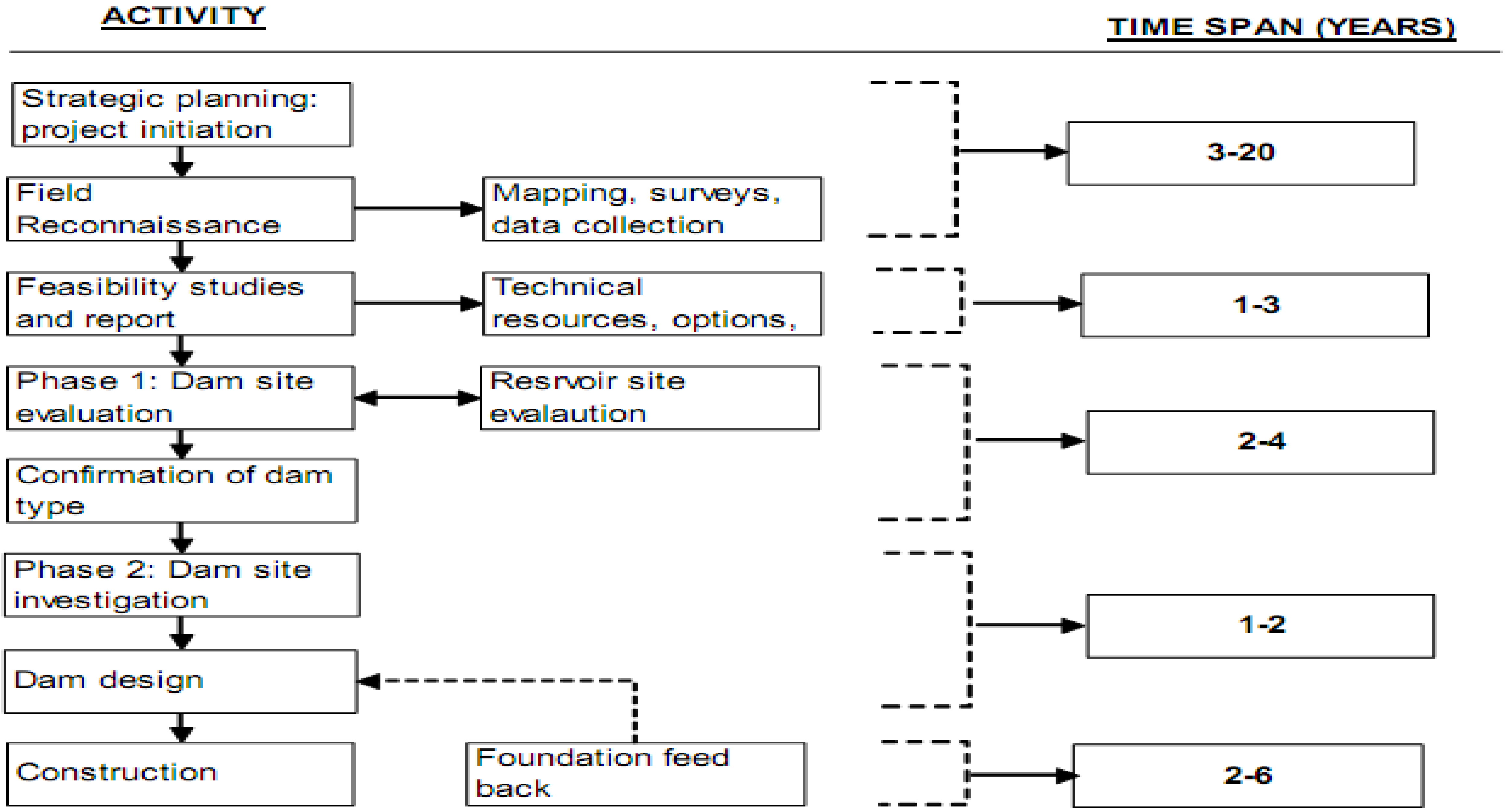
MHP has economic, social and environmental benefits such as:

- Providing cheap power for local industry and agro-by-product processing
- MHP development can be combined with irrigation, water log control and flood prevention, thus promoting crop yields and agricultural modernization
- Increasing revenue for local government and income for local people
- Creating  more jobs and reducing the migration of rural people in to cities
- Invigorating rural cultural life and improving the living standards of the local people
- MHP can be used in hilly areas for cooking, instead of firewood, hence conserving the environment
- Developing tourism in rural areas
- Benefiting social developments and stability

# DAM CONSTRUCTION ( Novak Page153-168)

- ✓ ***Procedures of dam construction***
- ✓ ***Concrete dam construction***
- ✓ ***Embankment dam construction***
- ✓ ***Dam safety ,Instrumentation and surveillance***

## *Stages in dam site appraisal and project development Activities:*



## Phases of Project Excution

Provision of site infrastructures: Access roads, offices, workshops, accomodation, etc.

↓

Preparation for river diversion

↓

Foundation excavation and preparation

↓

Construction operation

↓

Completion of any ancillary structures and installation and testing of valaves, gates, etc.

↓

Initial impounding

## Sequences of Concret dam Construction

Formwork Erection

↓

Surface preparation and placing concrete

↓

Compaction by vibrators

↓

Interval for initial shrinkage

↓

Curing of the completed pour

# *CONSTRUCTION CONCRETE DAM*

- **Construction of a concrete dam requires *large volume of concrete.***
- **A mass concrete for use in dam must be:**
  - ✓Have satisfactory density and strength
  - ✓Be durability
  - ✓Have low thermal volume change
  - ✓Have resistance to cracking
  - ✓Be economical
- **Due to the small *surface area-to-volume ratio*, concrete dams are often subjected to high potential of *thermal cracking*, *caused by the heat generation from cement hydration.***
- **A decrease in temperature of concrete *causes volumetric changes* resulting in the development of tensile stresses and consequent cracking in the concrete mass occur .**

# *WHAT SHALL WE DO?*

- ***"Low heat" Portland cement*** **would always be preferred for massive structures such as dams.**
- **Both economy and low rise in temperature would be achieved by *limiting the cement content* of mass concrete to as low a value as possible**

## *Concrete placing*

- **For laying concrete over the rock foundations, it has to be ensured that the surface is clean to develop tight bond between rock and concrete.**
- **Then the *surface has to be moistened* to a depth of about 15 cm to prevent the subgrade from absorbing water from the fresh concrete.**
- **A layer of concrete that is laid is generally kept as 1.5 m-2m, in a view to ease construction and *limit excessive temperature rise*.**
- **Before the concrete placing of the next lift begins, a 12.5 mm thick layer of mortar should be applied to permit proper bond between the concrete of the lower lift**

# CONCRETE JOINTS

***What happened the absence of this joints ?***

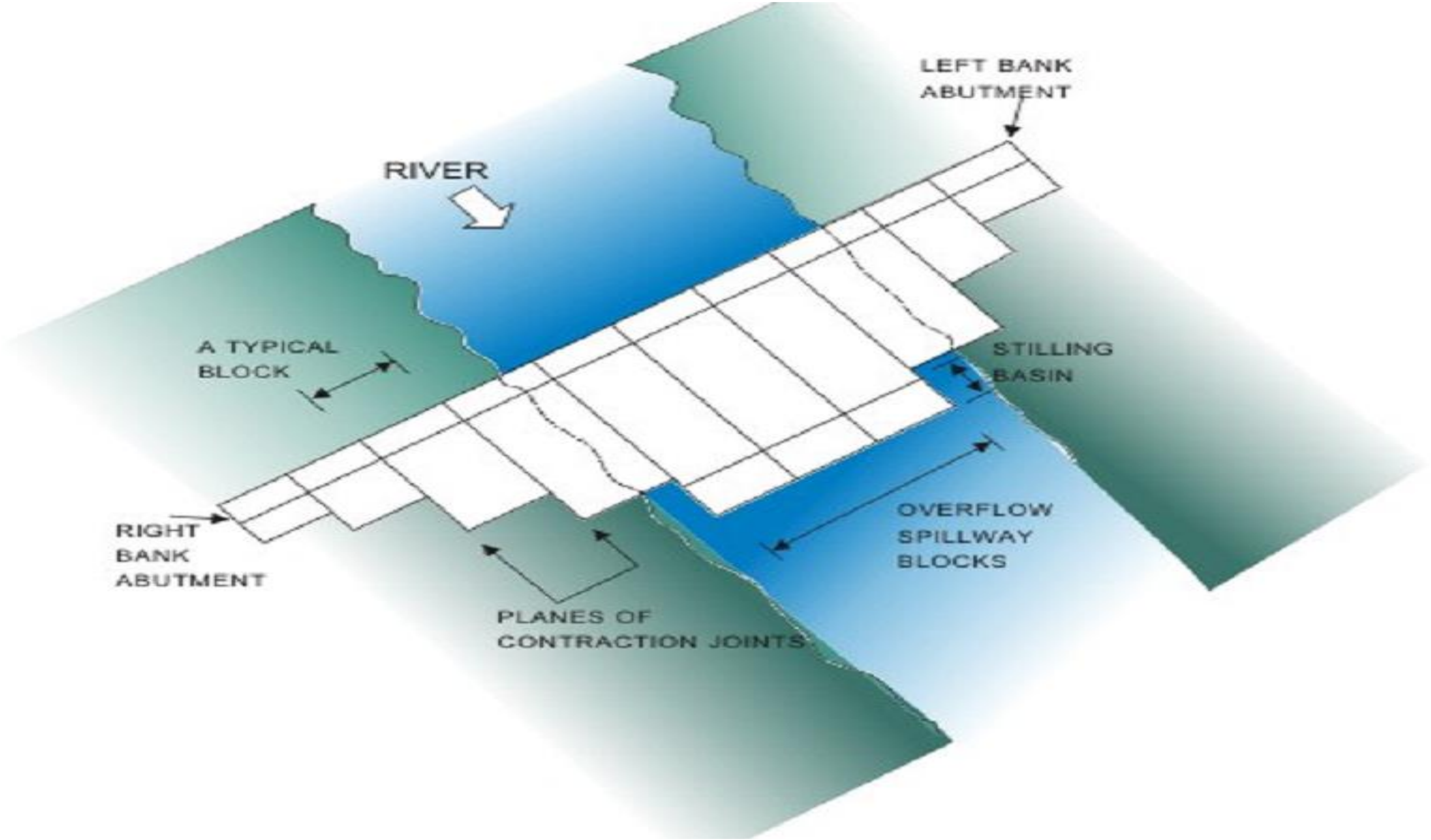
**Transverse joints (Inter block joints):**

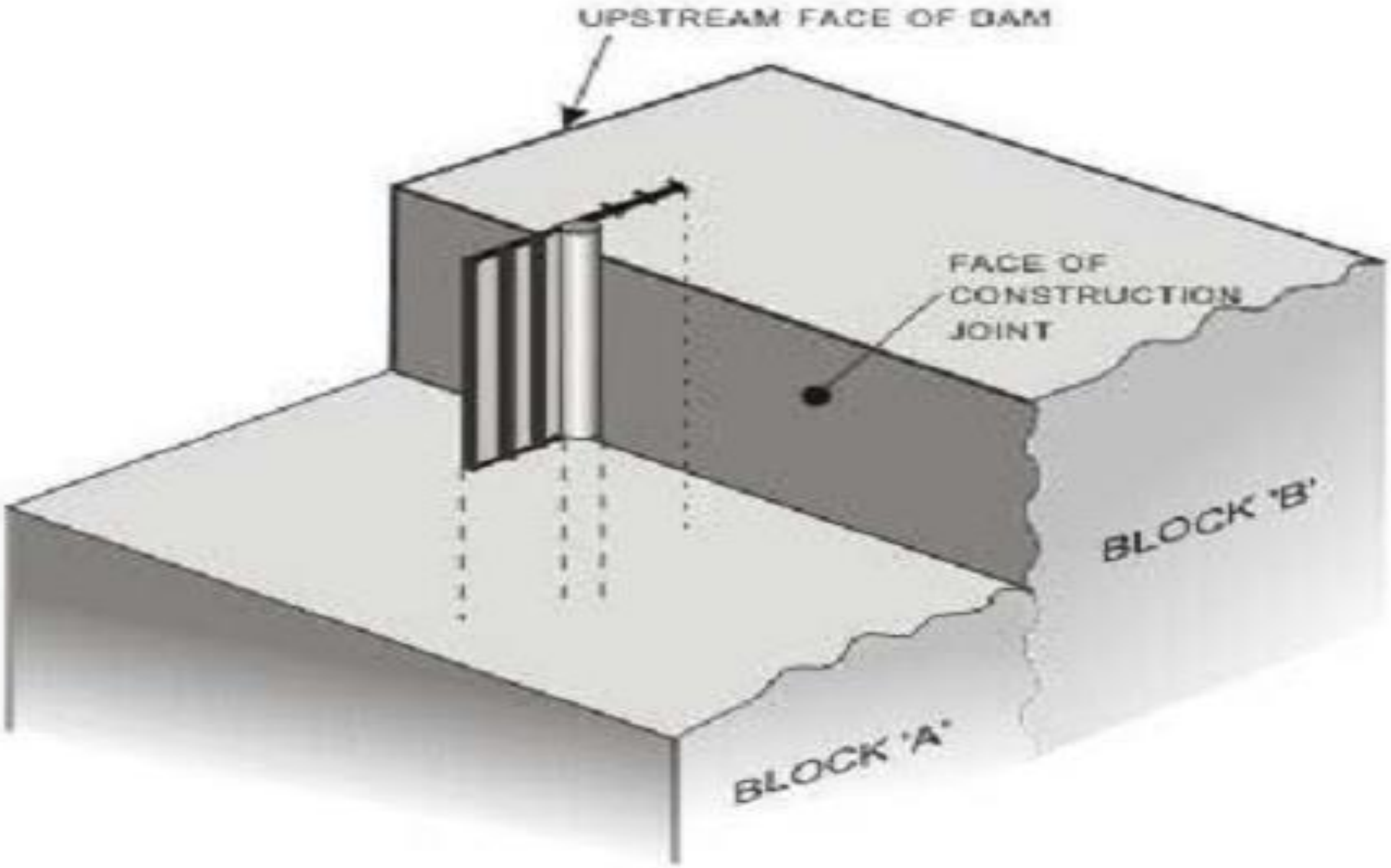
- ❖ If a concrete gravity dam is more than 20 m in length , it is necessary to divide the structure into blocks by providing ***transverse contraction joints.***
- ❖ These joints are in vertical planes that are at the right angle to the dam axis and
- ❖ These vertical contraction joints are formed at regular intervals of ***12-15m along the dam axis***.
- ❖ The joints are made necessary be the shrinkage and thermal characteristics of mass concrete.
- ❖ They permit minor differential movements between adjacent blocks, and ***in their absence major transverse cracks will develop***.
- ❖ To control seepage along the plane of the joints a ***water barrier (300mmPVC water stops)*** is formed close behind the upstream face.

- `

## ***Construction joints (inter lift joint):***

- Individual concrete pours within each monolith must be limited ***in volume*** and ***in height*** to reduce post construction **shrinkage and cracking.**
- Concrete pours are therefore restricted by the regular formation of near horizontal construction or “lift” joints.
- Lift height is generally limited to ***1.5 -2.0m.***
- The lift surface is generally constructed with a stepped or uniform fall of ***5-10%*** towards the upstream face to improve the notional resistance to sliding on that potentially weaker plane.


LEFT BANK
ABUTMENT
RIVER
A TYPICAL
BLOCK
STILLING
BASIN
OVERFLOW
SPILLWAY
BLOCKS
RIGHT
BANK
ABUTMENT
PLANES OF
CONTRACTION JOINTS


UPSTREAM FACE OF DAM
FACE OF
CONSTRUCTION
JOINT
BLOCK 'B'
BLOCK 'A'

1. **Block construction adjacent pours phased to accommodate shrinkage- lag time approximately 30-60 days.**
2. **Construction with contraction gaps or shrinkage slots: gaps concreted approximately 30-60 days after adjacent lifts completed.**

# CONSTITUENT MATERIALS OF CONCRETE

## *Cement:*

- ***Low heat Portland*** cement is recommended
- Thermal problems can be alleviated by the use of *pozzuolana blended* Portland cements.
- In the absence of special cements, partial replacement with and /or cooling are also effective in containing ***pulverized fuel ash (PFA)*** heat build up.

## *Aggregate*

- A maximum size of coarse aggregate of ***75-100mm*** is considered the optimum with rounded or irregular natural gravels
- In fine aggregate range, i.e. <4.67mm size natural sands are similarly preferable to crushed fines.
- Aggregates should be ***clean*** and free from surface weathering or impurities.

## *Water*

- **Water for use in concrete should be free of undesirable chemical contamination, including organic contaminates.**
- **A general standard is that the water should fit for *human consumption.***

## *Admixtures*

- **Air entraining agent (*AEA*) is added to the concrete which helps in *reducing the water contents,* and increases workability.**
- **Water reducing admixture (*WRAs*) is sometimes employed to cut the water requirement, typically by 7-9%.**
- **They are also effective in delaying setting time under conditions of high ambient temperatures.**

# CONCRETE MIX PARAMETER

- The parameters which are principally responsible for controlling the properties of concrete manufactured with specific cement and aggregates are:

- ✓ cement content, C (kg/m3);
- ✓ water content, w (kg/m3) and
- ✓ Water: cement ratio (by weight).

- Some further influence can be exerted through the addition of PFA and and/or the use of other admixtures such as AEA and WRA.

## Characteristics of Mass concrete for dams

| Characteristics | Unit | Concrete mix | |
|---|---|---|---|
| | | Hearting | Facing |
| Cement(C) +PFA(F) | ($kg/m^3$) | 150-230 | 250-320 |
| F/(C+F) | % | 20-35 | 0-25 |
| Water : (C+F) ratio | - | 0.5-0.70 | 0.45-0.65 |
| 90-days compressive strength, $\sigma_c$ | $MN/m^2$ | 18-30 | 25-40 |
| Tensile strength, $\sigma_t$ / Compressive strength, $\sigma_c$ | - | 0.10-0.15 | 0.07-0.10 |
| Unit weight, $\gamma_c$ | $KN/m^3$ | 23-25 | |
| Modulus of elasticity E, | $GN/m^2$ | 30-45 | |
| Poisson ratio | - | 0.15-0.22 | |
| Shrinkage (at 1 year) | % | 0.02-0.05 | |
| Coefficient of thermal expansion | $X10^{-6}/C$ | 9-12 | |

# HANDLING AND PLACING OF CONCRETE

- For lower lifts it may be possible to carry the concrete by trucks but for higher lifts, the concrete is to be carried by crane arrangement, traveling overhead cable ways and conveyor systems.
- Concrete lifts are normally formed in at least two layers, and compacted by poker vibrators.
- Uniformity and consistency has to be ensured during concrete production and placing over the period of the construction

# CONTROLLING CONCRETE TEMPERATURE

- During placing, the concrete temperature has to be maintained low (12-150C).
- The temperature can be brought down either by pre-cooling of coarse aggregate and use of spraying cool water during concrete production.
- Pre-cooling of the coarse aggregate is done by spraying cool water

*Post Cooling*

- Depending on the ambient temperature, post cooling may be needed.
- High density polyethylene pipes are laid between 1.0 to 1.5m interval in the lifts and ice cooled water (3-40C) is circulated through the pipes.
- The period of post cooling could be as high as *6 months*

# ROLLER COMPACTED CONCRETE (RCC) DAM CONSTRUCTION

- The construction of concrete gravity dam needs long time due to the ***slow curing process*** of mass concrete to ***avoid thermal shrinkages.***
- RCC dam construction was introduced in ***1970s .***
- For large projects, RCC dams can be finished ***1 to 2 years*** earlier compared to regular mass concrete dams

## ❖ *Types of RCC dams:*

- ✓ RDLC- Rolled Dry Lean Concrete
- ✓ RCD- Rolled –Concrete Dam (Japan) – lean hearting
- ✓ RCC- Roller – Compacted Concrete – high paste content material and known to have ***high PFA*** content
- ❖ In the construction of RCC dam the concrete is handled ***as an earth fill,*** and compacted at or near its optimum moisture content in thin layers.
- ❖ The RCC approach is best suited to ***wide valley*** and particularly suited to more ***remote sites*** where ***importation*** of cement and/or PFA is difficult or expensive
- ❖ The construction saving realized are at a maximum for high-volume dams and arise from a ***25-35%*** reduction in construction time.
- ❖ Depending on the complexity of the structure, RCC costs ***25 to 50%*** less than conventional concrete.
- ✓ ***Eg. Renaissance Dam***

- Aggregates greater than ***76 mm in*** diameter are rarely used in RCC because they can cause problems in spreading and compacting the layer.
- The use of material ***finer than 75 mm*** produces a more cohesive mixture by reducing the volume of voids.
- Compaction of the lift is achieved by using a ***vibrating steel-wheel roller.***
- Compaction of the lift should be performed as soon as possible, typically within ***10 minutes*** after spreading and no more than ***40 minutes*** after mixing.
- ***Good curing*** conditions for the finished surface are essential and the ***surface*** should be kept in a ***moistened*** condition until the next lift is placed

## Characteristics of RCCs for dams

| Characteristics | Unit | RCC type | | | |
|---|---|---|---|---|---|
| | | Lean RCC (RDLC) | RCD | High pasted RCC | Convention Lean Nearing concrete |
| Cement (C) + PFA(F) | $Kg/m^3$ | 100-125 | 120-130 | >150 | 150-230 |
| F/(L+F) | % | 0-30 | 20-35 | 70-80 | 20-35 |
| Water : (C+F)ratio | - | 1.0-1.1 | 0.8-0.9 | 0.5-0.6 | 0.5-0.7 |
| 90-days compressive Strength, $\sigma_c$ | $MN/m^2$ | 8-12 | 12-16 | 20-40 | 18-40 |
| Unit weight, $\gamma_c$ | $KN/m^3$ | 23-25 | 23-25 | 23-25 | 22-25 |
| Layer thickness | m | 0.3 | Lifts = 0.7-1.0 | 0.3 | Lifts = 1.5-2.5 |
| Contraction joint | | Sawn | Sawn | Sawn or formed | Formed |

# CONSTRUCTION OF EMBANKMENT DAMS:

**The construction operations of embankment dams fall in to four principal groups relating to:**

1. **Material source development:**
   - opening out of borrow areas or quarries,
   - installation of fixed plants,
   - e.g. crushers, and conveyors,
   - construction of access and haulage roads, etc.
2. **Foundation preparation and construction:**
   - river diversion,
   - removal of top soil and weathered surface.
3. **Fill construction:**
   - placing to materials and
   - compaction.
4. **Ancillary works construction:**
   - construction of spillways,
   - stilling basins,
   - culverts, tunnels and
   - outlet works.

# *GEOSYNTHETICS IN EMBANKMENT DAMS:*

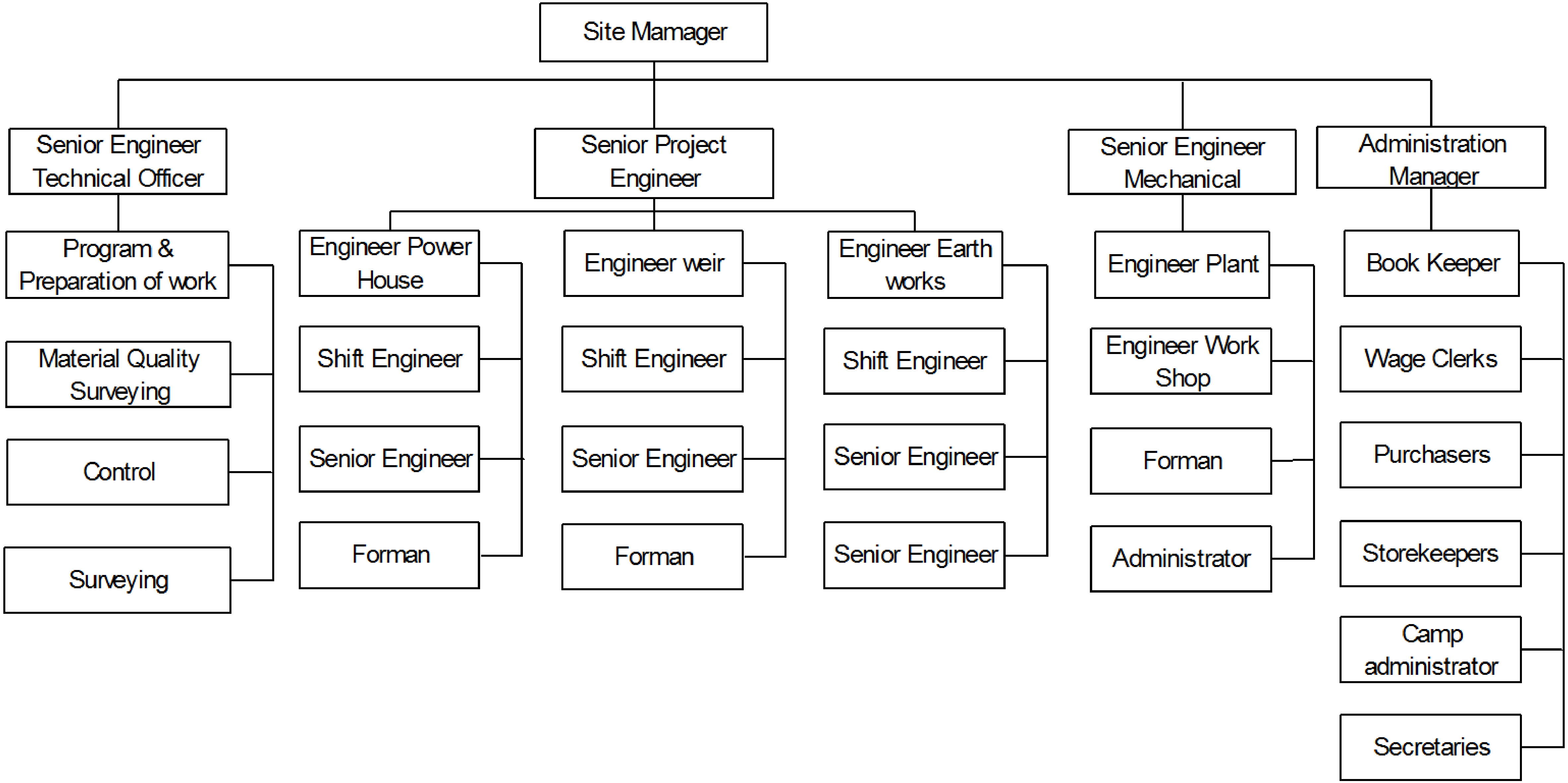
**Geosynthetics (geotextile and geomembranes) have considerable potential in dam engineering given that issues of durability in specific applications can be resolved.**

**A range of geosynthetics have been employed in a number of different applications both in new construction and *in rehabilitation projects.***

## *DIFFERENT APPLICATIONS OF GEOSYNTHETICS*

1. **Impermeable membranes (upstream or internal):**
   - Polyvinyl Chloride (PVC) and High Density Polyethylene (HDPE) upstream membranes have been successfully employed in dams up to 40m height.
   - The membranes, typically 3-4mm thick, are laid in 4-6m wide strips on a prepared sand bed and drainage layer, and anchored at crest and toe.
2. **Fitter and drainage layers (seepage control):**
   - Relatively thick geosynthetics with high internal transmissivity are suitable for filters or drainage layers.
3. **Earth reinforcement (Stability of slopes, etc.):**
   - Geosynthetics reinforcement materials,
   - e.g. geogrids, can be used to permit construction of steeper face slopes or
   - to help to contain lateral deformation and spread within the embankment or on a soft foundation.
4. **Control of surface erosion (precipitation or limited overtopping flows)**
   - The use of geogrids and mats in conjunction with natural vegetation has proved for erosion resistance.
5. **Separation interlayer:**
   - geosynthetics can be used to act as an interlayer
   - to ensure positive separation of fill materials, at an interface.

# ORGANIZATION CHART OF PROJECT CONSTRUCTION OPERATION



# INSTRUMENTATION OBJECTIVES AND DAM SAFETY

**The principal objectives of a geo-technical instrumentation plan may be generally grouped into four categories:**

1. **Analytical assessment**
2. **Prediction of future performance**
3. **Legal evaluation and**
4. **Development and verification of future research and designs**

## INSTRUMENTATION ACHIEVES THESE OBJECTIVES BY PROVIDING QUANTITATIVE DATA TO ASSESS

- groundwater pressure,
- deformation,
- total stress,
- temperature,
- seismic events,
- leakage, and
- water levels.

**Total movements as well as relative movements between zones of an embankment and its foundation may also need to be monitored.**

**A wide variety of instruments may be utilized in a comprehensive monitoring program to ensure that all critical conditions for a given project are covered sufficiently**

# ANALYTICAL ASSESSMENT:

**Analysis of data obtained from geo-technical instrumentation may be utilized to**

- ✓ Verify design parameters,
- ✓ Verify design assumptions and
- ✓ Construction techniques,
- ✓ Analyze adverse events, and
- ✓ Verify apparent satisfactory performance.

# PREDICTION OF FUTURE PERFORMANCE:

Instrumentation data should be used in such a manner that informed valid predictions of future behavior of an embankment can be made.

Such predictions may vary from indicating continued satisfactory performance under normal operating conditions to an indication of potential future distress which may become threatening to life or safety, and necessitate remedial action.

# LEGAL EVALUATION:

**Valid instrumentation data can be valuable for potential litigation relative to construction claims.**

**It can also be valuable for evaluation of later claims relative to changed groundwater conditions downstream of a dam or landward of a levee project.**

**In many cases, damage claims arising from adverse events can be of such great monetary value that the cost of providing instrumentation can be justified on this basis alone.**

**Instrumentation data can be utilized as an aid in determining causes or extent of adverse events so that various legal claims can be evaluated.**

# DEVELOPMENT AND VERIFICATION OF FUTURE RESEARCH AND DESIGNS:

**Analysis of the performance of existing dams and levees, and instrumentation data generated during operation, can be used to advance the state-of-the-art of design and construction.**

**Instrumentation data from existing projects can promote safer and more economical design and construction of future earth and rock fill embankments.**

# OPERATION AND MAINTENANCE PROGRAM:

**The people responsible for dam operation and maintenance should become involved with the dam during the design and construction stages**

**This will give O&M (operation and maintenance) personnel an opportunity to become familiar with design and construction considerations and**

**to become aware of problems that may require special attention during the operation and maintenance of the dam.**

# CONTD..

**An inspection should be made at construction completion by design, construction, and operations personnel to ensure that all items are complete or deficiencies are identified for later completion.**

**During this inspection, problems, unique operations, general maintenance requirements, etc. should be discussed and procedures established for their proper handling.**

**Requirements for initial filling should be available and should be agreed upon.**

**During this time extra precautions and procedures for operation should be established because unpredictable situations may occur.**

# CONTD..

**Routine maintenance and inspection of dams and appurtenant facilities should be an ongoing process.**

**All unusual conditions that may adversely affect the operation, maintenance, or safety of the dam should be reported promptly using predetermined written procedures.**

**In addition to ongoing routine maintenance and inspection, periodic in-depth inspections should be made on every dam at least every 5 years.**

**The depth and frequency of these inspections should depend on**

- dam size,
- hazard, complexity, and
- the previous problems encountered.

# CONTD..

**A qualified team, usually headed by an engineer not directly involved in the operation and maintenance of the facility, should perform these inspections.**

**The engineer should be accompanied by operations personnel familiar with all feature of the operation and maintenance of the dam.**

**Inspections should be scheduled, if possible, during alternate periods of high and low water to observe conditions unique to these situations.**

**Special inspections should be scheduled when there is reason to believe that significant damage has occurred or has potential to develop.**

**Deficiencies noted during the inspection should be identified and documented in the report, and procedures should be established for correction in a timely manner.**

**The responsibility for correcting problems should be clearly documented.**

# DAM SAFETY PRINCIPLE AND CONCEPTS NEW DAMS:

**Planning and Design**

**A new dam should be developed in accordance with state-of-the-art design techniques and construction practices**

**Careful attention must be given to the following planning and design considerations.**

- Selection of the dam site
- Estimation of the PMF and selection of the IDF
- Identification of earthquake source are and structure, estimation of MCE's (Maximum Credible Earthquake) and identification of earthquake related safety concerns
- Development of a site-specific geotechnical exploration program
- Design of the foundation, dam, and appurtenant structures
- Design of a system of instrumentation to monitor the performance of the dam, foundation, and appurtenant structures
- Development of an initial reservoir-filling and surveillance plan and of reservoir drawdown criteria
- Preparation of designer's operating criteria and identification of special considerations to be observed during construction and operation
- Provisions for the automatic, independent review by competent individuals of all design decisions, methods, procedures, and results related to dam safety
- Provisions to revise the design to make it compatible with conditions encountered during construction

# CONSTRUCTION

**Quality construction is critical to dam safety.**

**Construction personnel must be constantly alert to recognize and recommend the possible need for adjustments in**

- the design,
- construction materials, and
- construction practices to properly provide for actual conditions encountered.

**The essential aspects of the construction program include:**

1. **Keeping construction engineers and inspectors informed of**
   - the design philosophies,
   - assumptions, and intent of the designer with regard to foundation excavation and treatment,
   - to the usage and processing of construction materials, and
   - to the design concepts associated with the construction of embankments and
   - concrete structures and with the installation of mechanical and electrical equipment
2. **Keeping construction engineers and inspectors informed of the field control measures and tests required to ensure quality construction**

# CONTD..

3. Maintaining an adequately staffed and equipped materials laboratory at the dam site to meet the field testing requirements

4. Providing a formal plan for construction inspection to ensure that each facet of essential work is accomplished in multi shift operations

5. Giving the Project Construction Engineer the authority to suspend work until all site conditions different from those anticipated are evaluated and the necessary design or construction changes are implemented

6. Inspection and accepting of critical work stages, by the appropriate engineers or geologist (design and/or technical review personnel)

7. Keeping a job diary and documentation that provides a complete history of the work

8. Providing mapping and photographic documentation of the construction progress and of significant events; e.g., geologic maps and photographs of final treated foundations.

# EXISTING DAMS:

## Operation and Maintenance

**The operation and maintenance procedure implemented should ensure the safe operation of the dam and provide for timely repair of facilities.**

**The essential procedures include:**

1. Preparing SOP’s (Standing Operating Procedures);
2. Training personnel in both normal and emergency operation and maintenance responsibilities and in problem detection
3. Maintaining a written record of reservoir, waterway, and mechanical equipment operations and of maintenance activities
4. Testing full operation of spillway and outlet works gates on a regular basis, using both primary and auxiliary power systems
5. Providing for public safety and for security against vandalism of essential operating equipment
6. Establishing and maintaining communication links with local governmental agencies and authorities
7. Preparing and maintaining current EPP’s (Emergency Preparedness Plan)

# CONTD..

- **Periodic Examinations and Evaluations**

**The periodic examination and evaluation of dams and reservoirs is of considerable importance for public safety.**

**The intent of conducting periodic examinations and evaluations is to disclose conditions that can disrupt operations or threaten dam safety early enough for these conditions to be corrected.**

- ***Documentation on Dams:***

**All significant design data,**

**computations, and**

**engineering and management decisions should be documented and retained throughout the life of a dam.**

**The documentation should cover investigations and design, construction plans and specifications, construction history, operation and maintenance instructions and history, instrumentation monitoring instructions, structural behavior history, damage, repairs and improvements, and periodic examinations and evaluations. Memoranda, reports, criteria, computations, drawings and records of all major decisions regarding the design, construction, operation and maintenance, and safety of the dam should be permanently retained and accessible in central file**

*Thank you!!*