Presentation 2: HEP Design, Construction and Operation

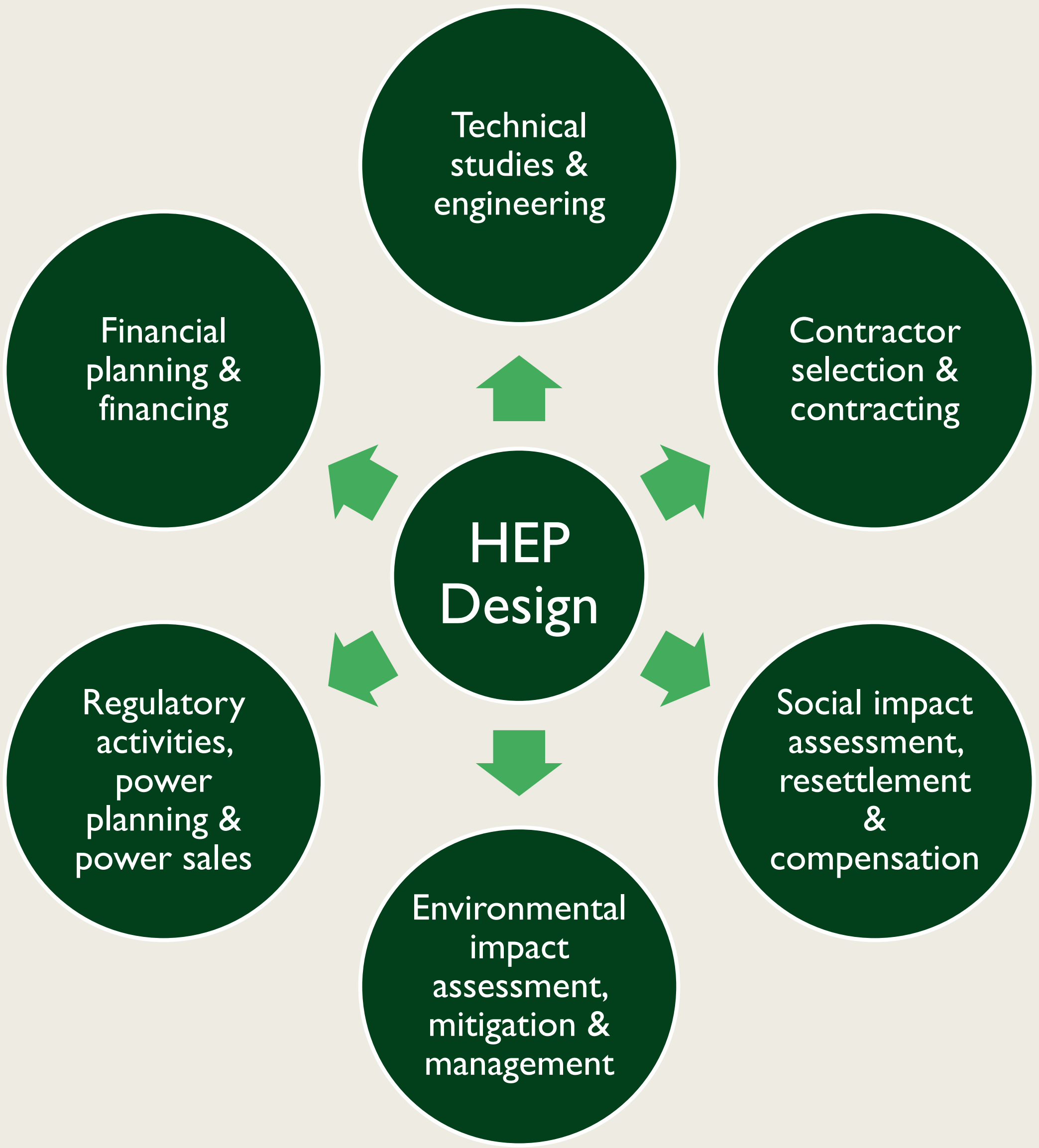
Dr Tahir Mahmood Hayat
Mr Muhammad Ayub Malik

24 April 2024

HEP development

- HEP design and construction is an **iterative process** that takes place over several years. Above all, it is **challenging**.
- The designer must confront and overcome **numerous hurdles** – environmental, technical, social, financial and regulatory – before the HEP can become operational.

The HEP development process



Development activities

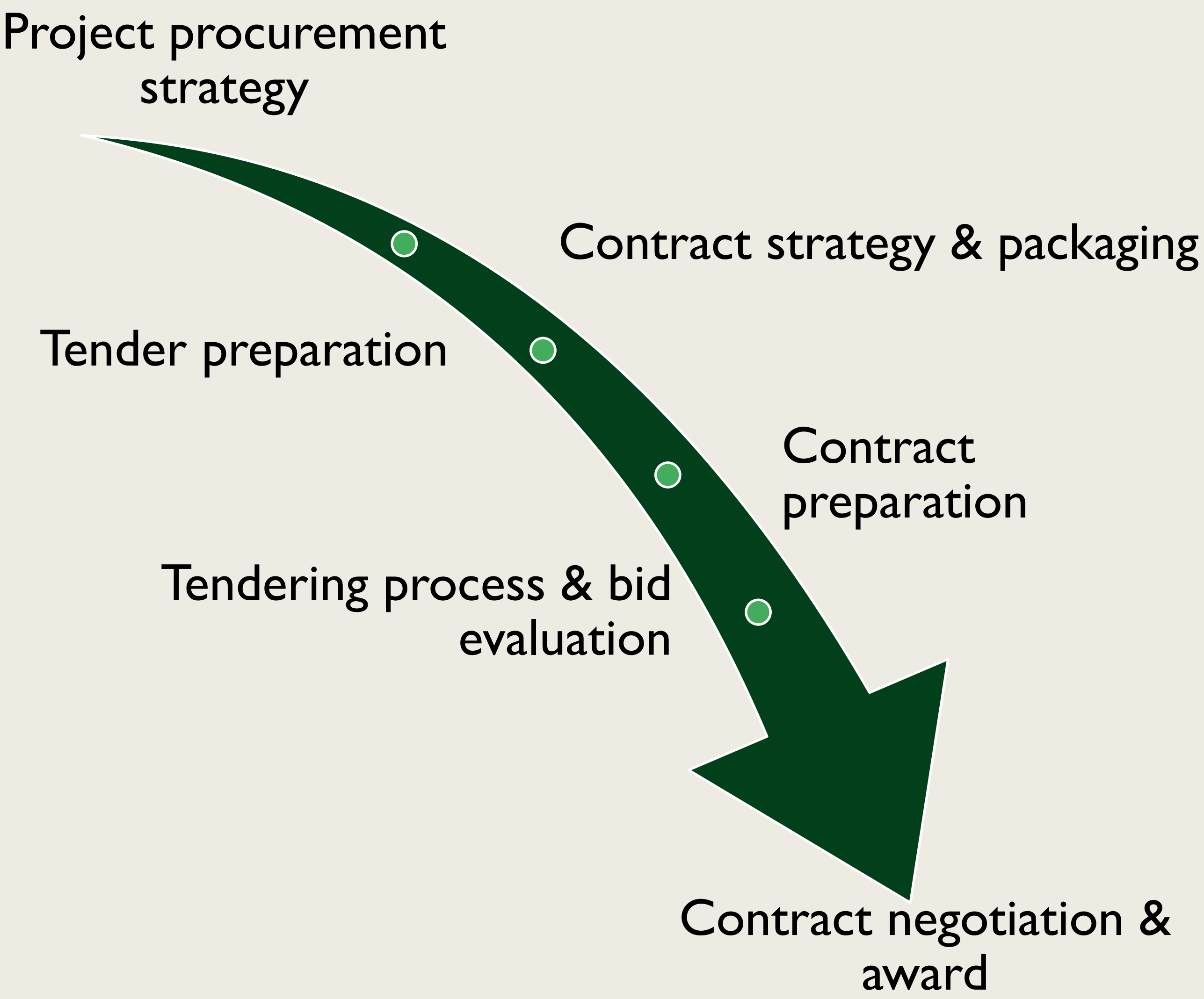
- HEP design ordinarily entails **six** processes intended to carry the project from **identification to operation**.
- All six must be carried out **in parallel**; the failure of one could entail the failure of the project.

1. Concept
2. Pre-feasibility
3. Feasibility
4. Engineering design
5. Construction design

Design phases

- HEP design usually goes through **five** phases before construction can commence.
- These commence with **site identification** and end with **fine-tuning** the ultimate design.

Contractor selection



- All projects require the selection of a **contractor** to carry out construction of the HEP.
- Final contract likely to be in line with internationally-recognized **construction precedents**, e.g. FIDIC Red, Yellow or Silver Books.

Social impact

- All HEP projects have **social impacts**, assessed via a hierarchy of studies using the Equator Principles, IFC Performance Standards, or World Bank Standards.
- **High social impacts** make many projects infeasible because of the reputational risks to investors and lenders.

Social impacts	Potential mitigation
Involuntary displacement of communities	Appropriate site selection
Water quality reduction and water borne diseases	Resettlement and livelihood restoration
Loss of agricultural land	Payment of compensation
Loss of commercial opportunities (e.g. fishing, mining, tourism)	**NB:** *No mitigation possible for an unsuitable site*
Loss of spiritual or other indigenous sites	

Environmental impact

Impact on wildlife

- Flooding of natural habitats, possibly including endangered species
- Effects on fish and other aquatic life
- Floating aquatic vegetation
- Loss of terrestrial wildlife

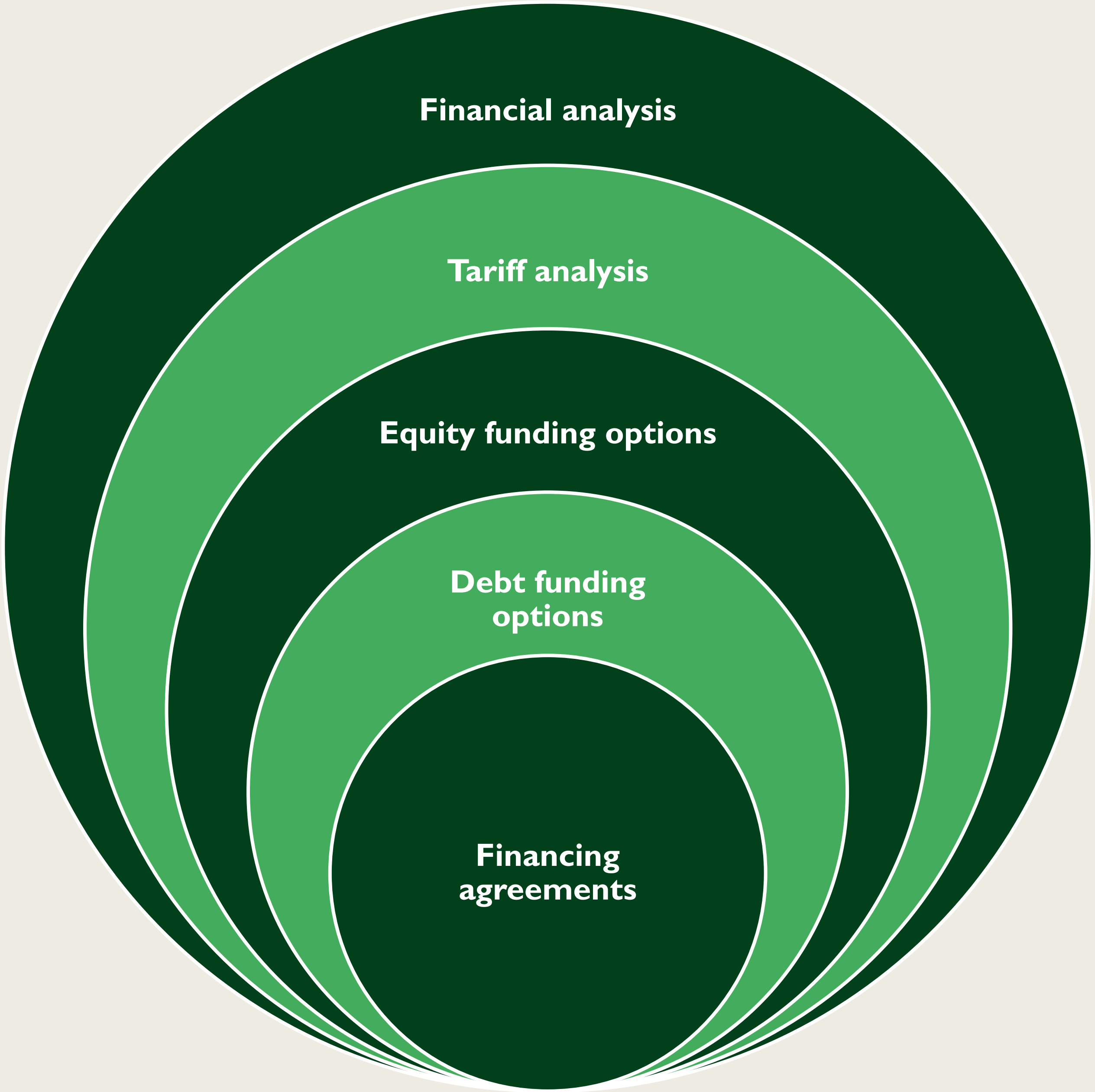
Wider impact

- Downstream hydrological changes due to streamflow, sediment transport, water quality, etc.
- Reservoir sedimentation
- Greenhouse gas production from reservoirs
- Water borne diseases

Potential mitigation

- Appropriate site selection
- Environmental offsets
- **NB:** *No mitigation possible for an unsuitable site*

- All HEP projects have **cumulative environmental impacts**, assessed using the using the Equator Principles, IFC Performance Standards, or World Bank Standards..
- Can cause projects to **fail** due to weak cost/benefit rationale and reputational risk to investors and lenders.



Financial planning

- Entails the raising of **funds for construction** via debt, equity and/or government funding.
- Unless funded **entirely by government**, the vast cost of HEP projects means that many projects fail at this stage.

Regulatory activities

- Power purchase agreements
- Land acquisition agreements
- Water rights agreements
- Project implementation/concession agreements
- Any other necessary permits

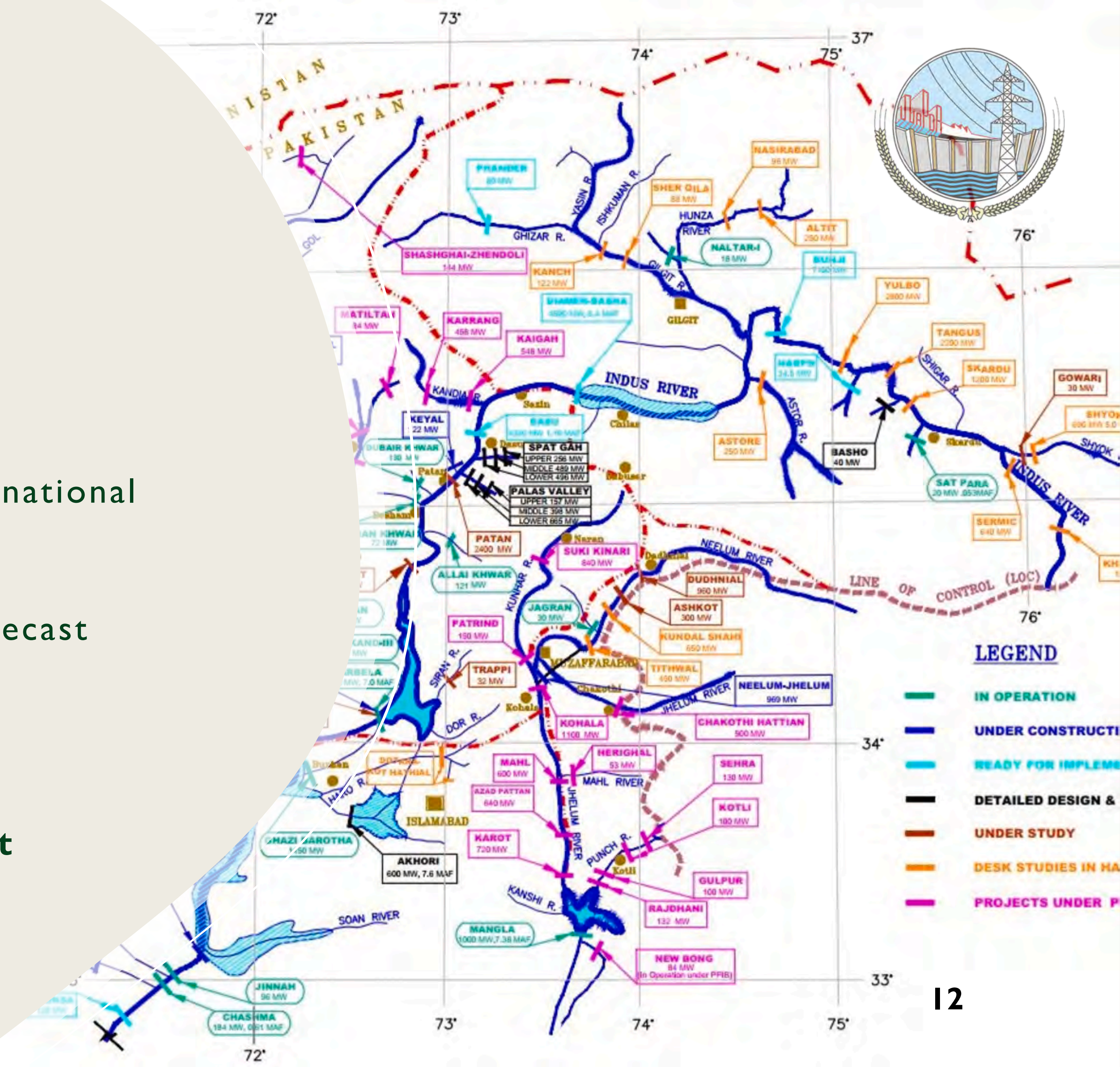
- Entails the establishment of the **legal and regulatory framework** for the implementation of the project.
- Requires liaising with **multiple agencies** at the local, regional and national governmental levels.

HEP design

Step 1:

Project concept

- **Identify project site** based on national inventory and master plans.
- **Screen candidates** to meet forecast demand.
- Desk study to create **concept**.
- Budget for **future development activities**.



STEP 2:

Pre-feasibility study

- Assess **financial viability** of process and select **technical concept**.
- Conduct **data collection** and preliminary **site investigation**.
- Evaluate **technical options** (run-of-river, storage work, pumped hydro).
- Undertake **cost/benefit analysis**.
- Assess **market** and run economic and financial analyses.

Step 3:

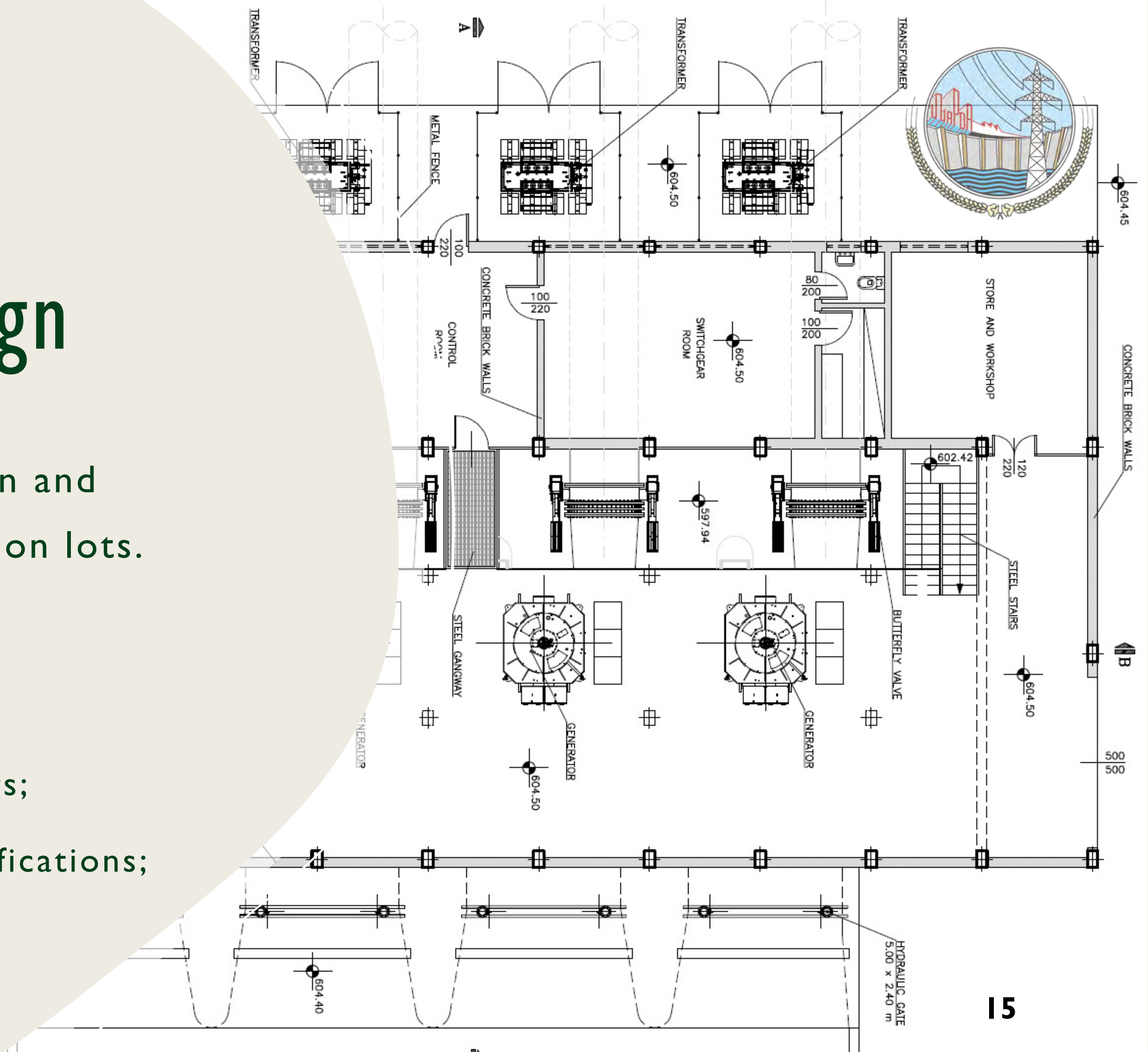
Feasibility study

- **Confirm** the technical, economic, financial and commercial viability of the project.
- Entails a detailed **site investigation** (hydrology, sediment, geology, etc.); **optimization and design** of the preferred option.
- Further requires a detailed **cost/benefit** analysis; **construction planning**; and further **financial and tariff assessment**.

Step 4:

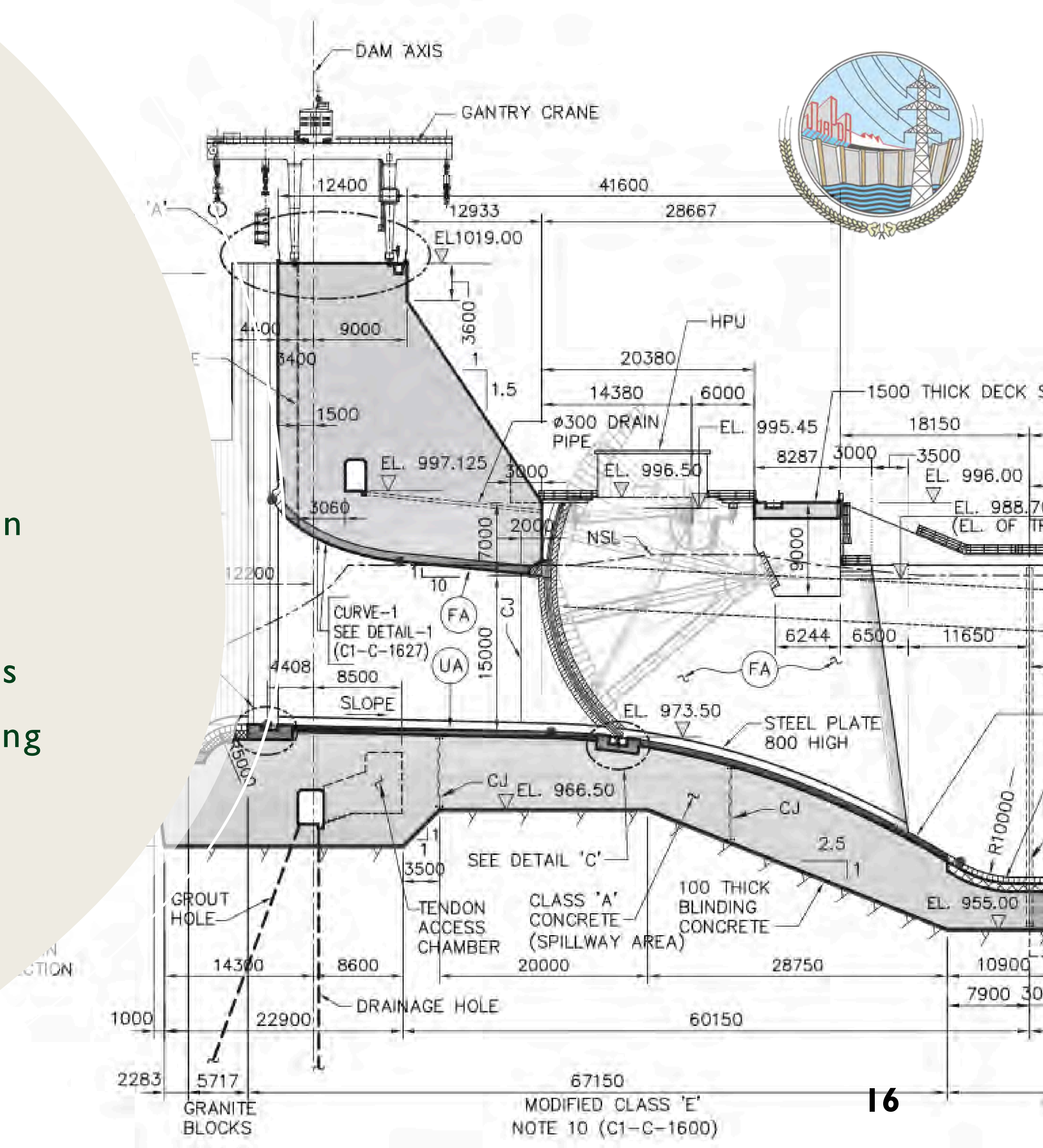
Engineering design

- **Prepare** the detailed design and specification for all construction lots.
- **Entails**:
- Engineering analysis;
- Preparation of tender drawings;
- Preparation of technical specifications;
- Construction planning.



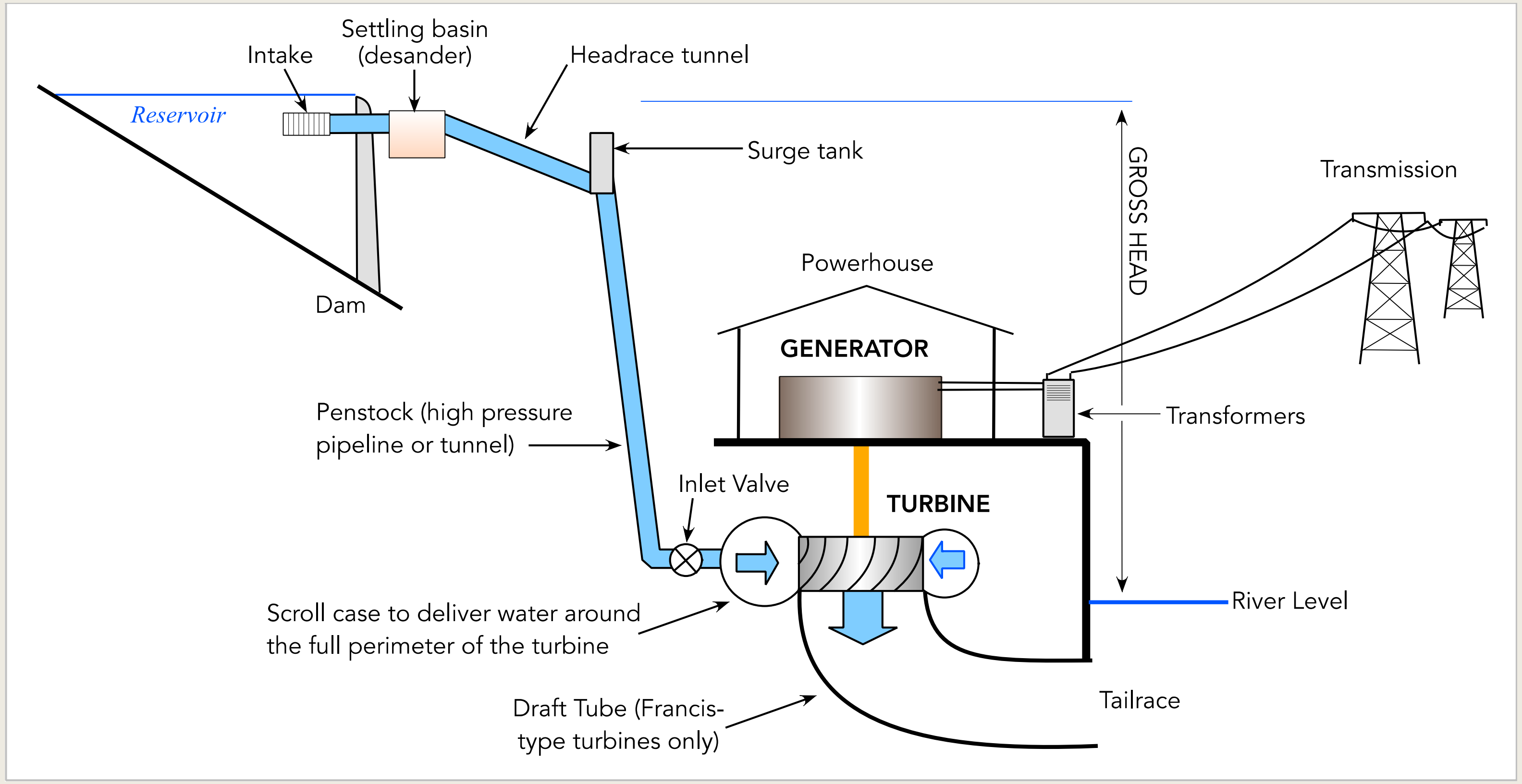
Step 5: Construction design

- **Finalize** the project design in conjunction with the contractor.
- **Entails** the fine-tuning of detailed designs for each component of the final HEP, including headworks, tunnelling, turbines and transmission lines.



HEP components

Main HEP components

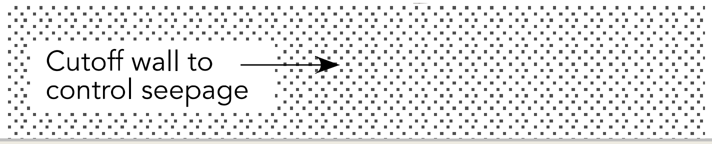


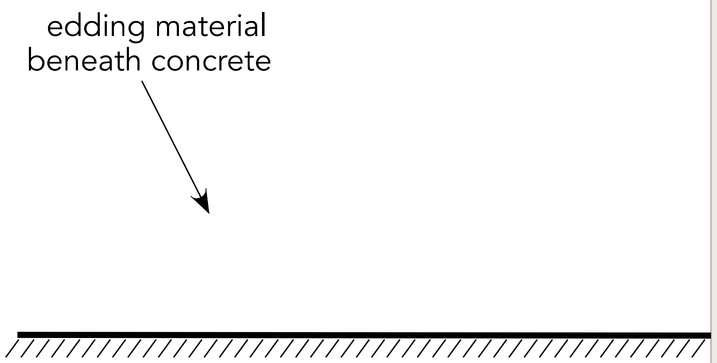
Dam

- The **dam** serves to impound water, and it may also serve as a structure upon which gates and spillways are located.
- Based on construction materials they can be generally classed as **concrete**, **earthen**, or a combination of the two represented by the **concrete face rockfill dam** type.
- The selection of dam type depends on the type of foundation and locally available materials.

Types of dam

CONCRETE	EARTHEN	CONCRETE FACE ROCKFILL

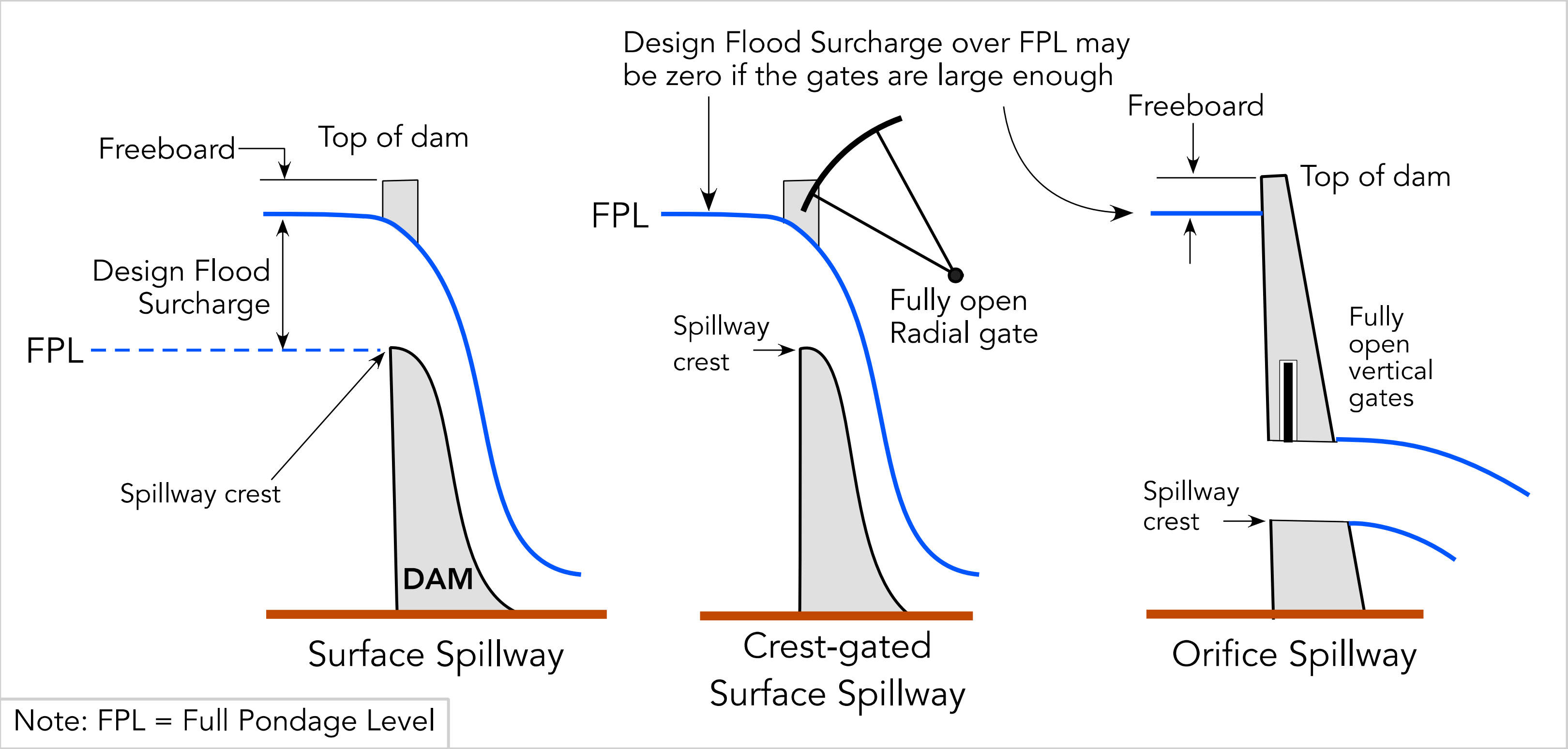




Spillways

- Spillways are used to release floods to the river below the dam in a controlled manner (no damage), but may have other applications (e.g. sediment management).
- At some sites, flood surcharge can exceed 20m. Gates allow the flood surcharge to be controlled and used beneficially.

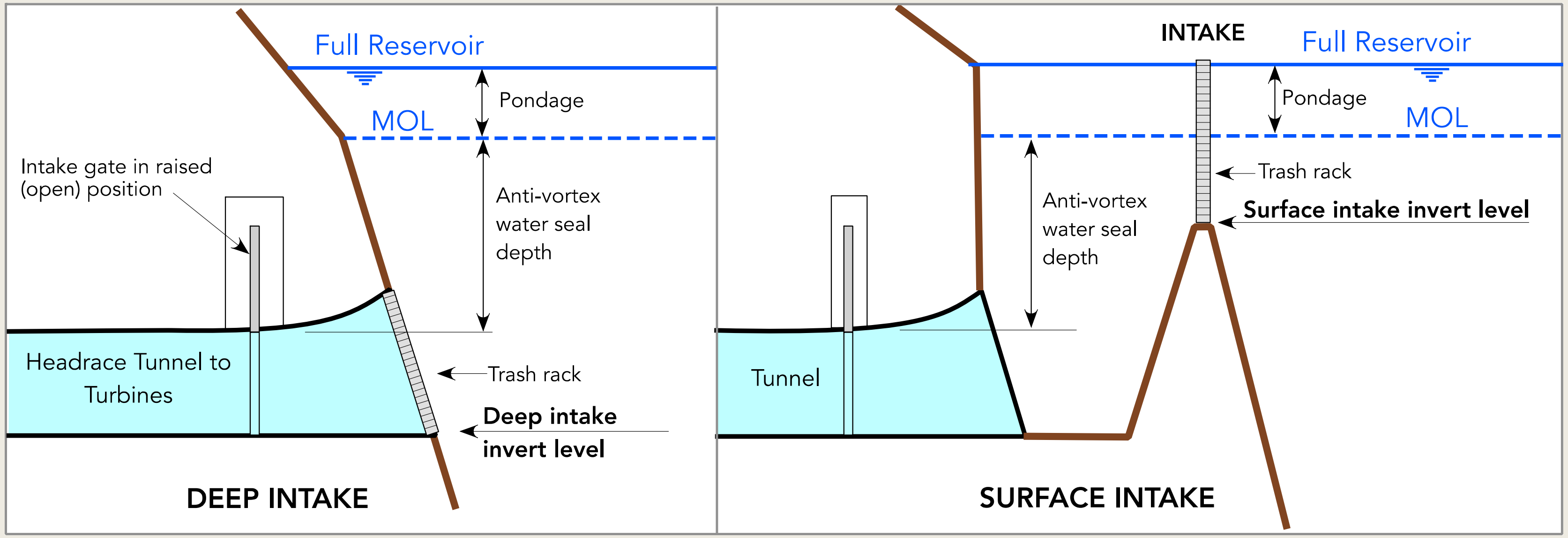
Types of spillway



Intakes

- Run-of-River HEPs are susceptible to sedimentation.
- Intakes should be designed with the idea of minimizing entrainment of sand with the diverted water.
- A basic principle of RoR intake design is to withdraw water from as high in the water column as possible using a **surface intake**.
- A **deep intake**, on the other hand, is more applicable to storage reservoirs in which sediment has not yet reached the dam.

Types of intake

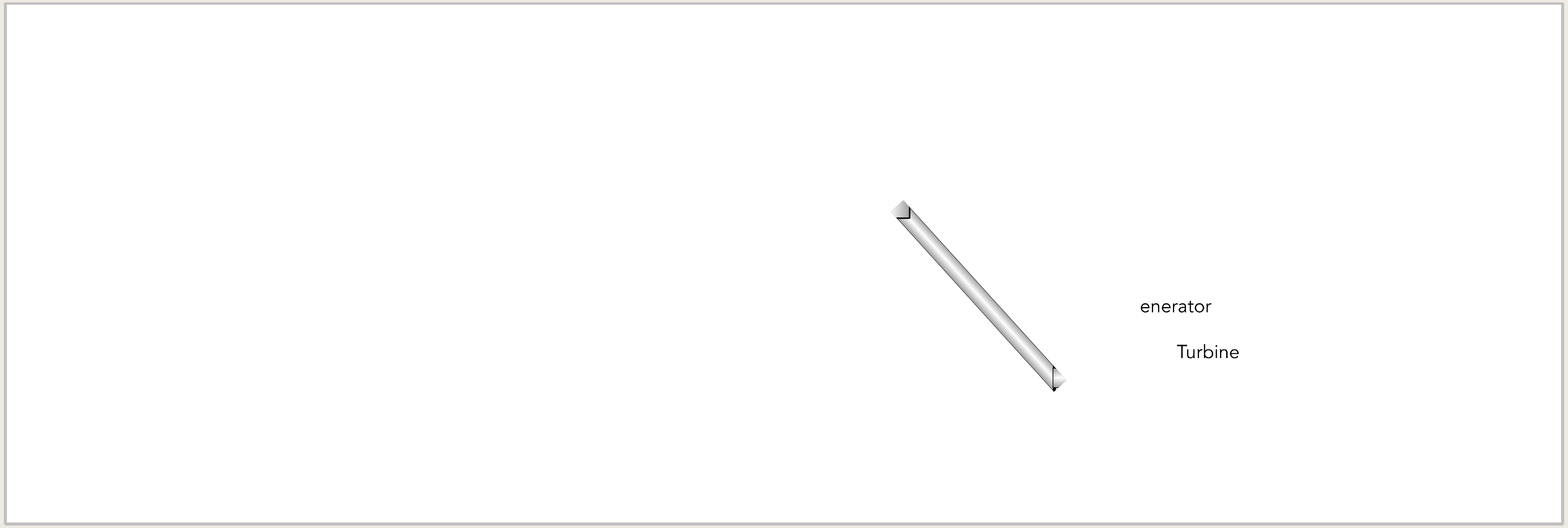


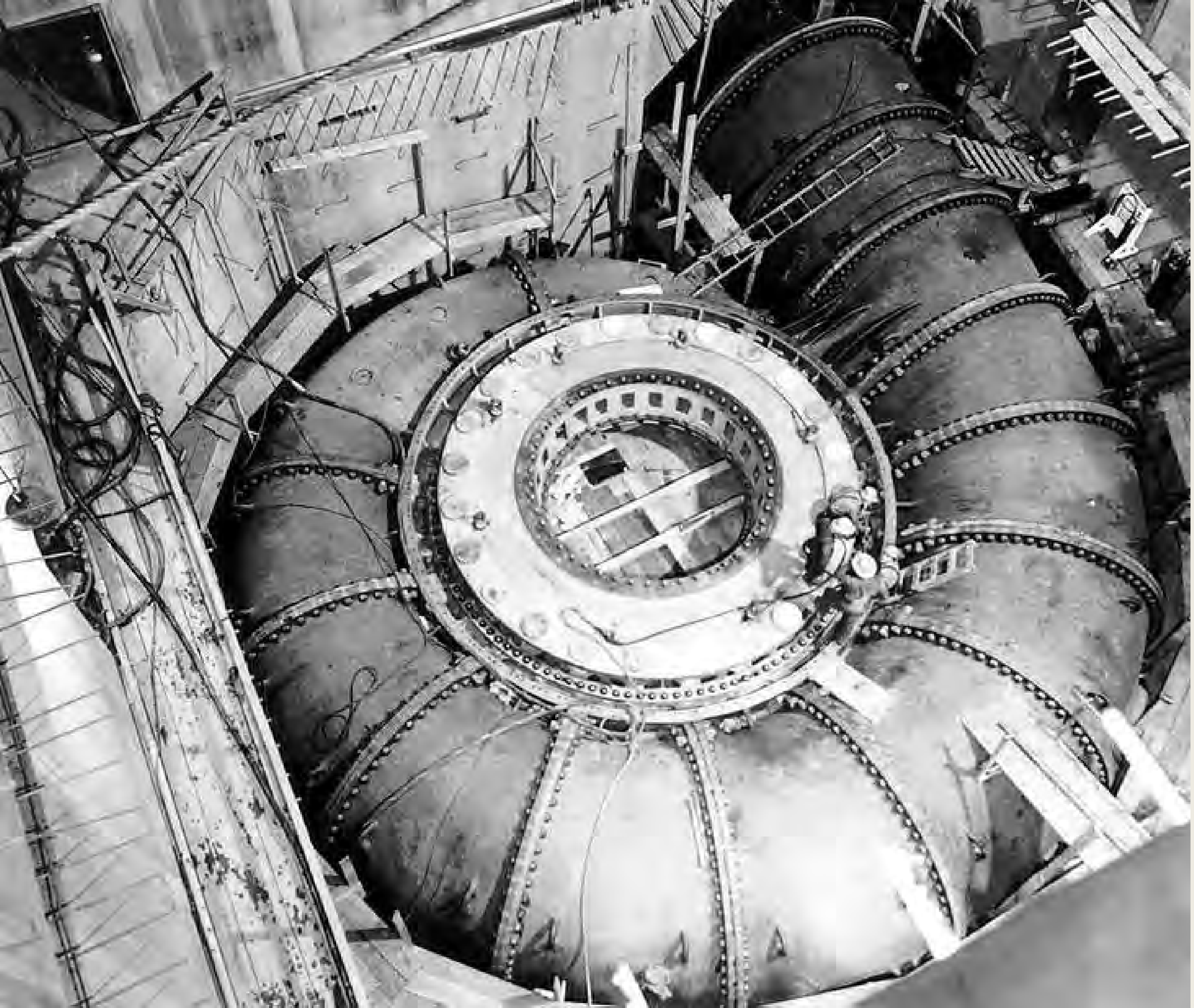
- Intakes may be defined by their depth relative to the reservoir's **minimum operating level** (MOL).
- A **surface** intake commences at the surface and then terminates just below the MOL; a **deep** intake is situated entirely below the MOL.
- Both intakes may incorporate a water seal to prevent **vortexing**.

Conveyance elements

- The powerhouse may be located in or immediately adjacent to the dam.
- Where the powerhouse is located downstream of the dam, water is conveyed from the headworks to the powerhouse by the headrace and other elements.
- The headrace terminates with the penstocks, which then feed into a spherical valve (inlet) that connects to the turbine.

Types of conveyance elements

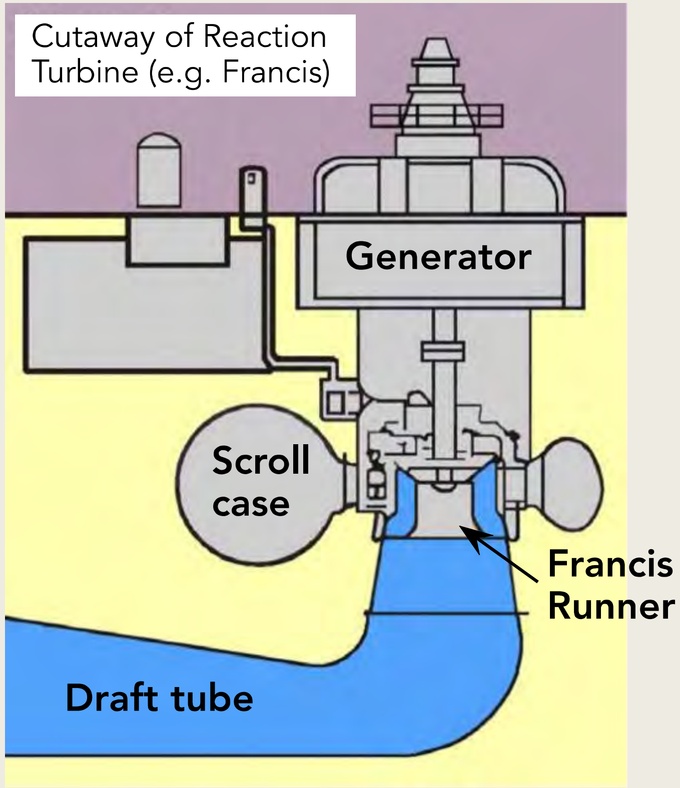


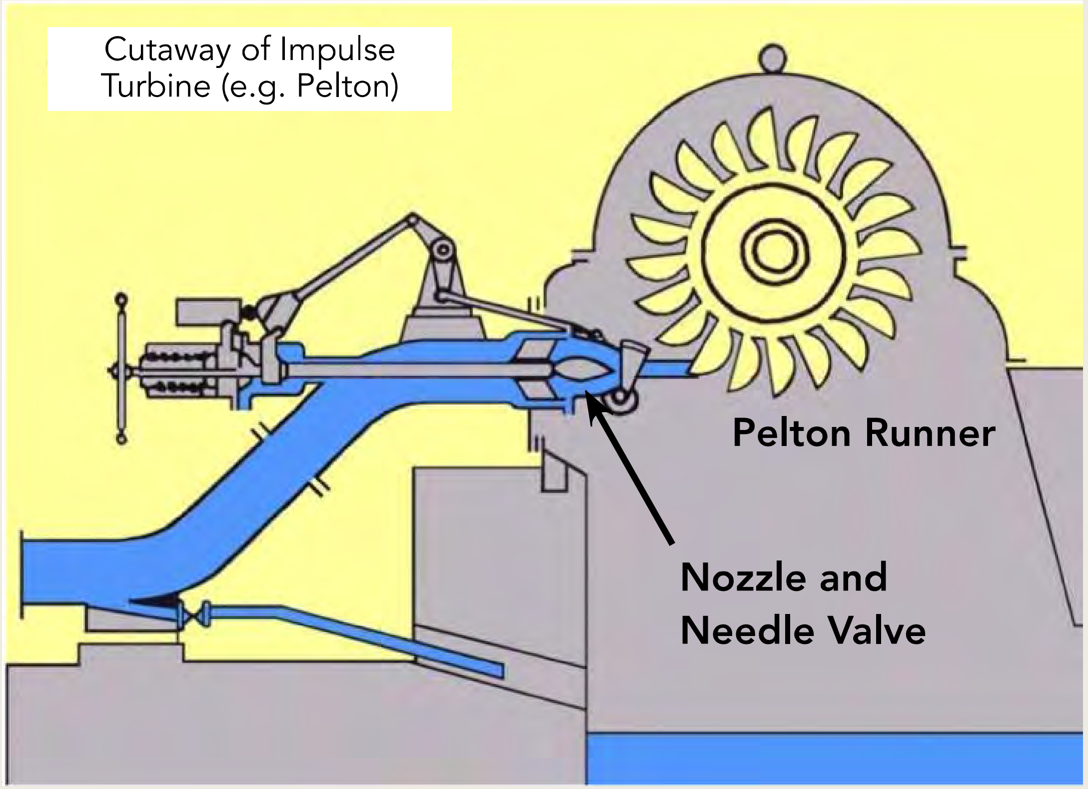


Turbines

- Turbines harness water delivered from the reservoir to create mechanical energy.
- Turbine design may vary. The two main types are **Francis** and **Pelton** turbines.

Types of turbine





Tailrace

- The tailrace delivers the water that exits the turbine back to the river.
- In many plants the draft tube discharges very close to the river and the tailrace is very short, but in some plants (NJHEP) it can consist of a long tunnel.

HEP construction

Challenges

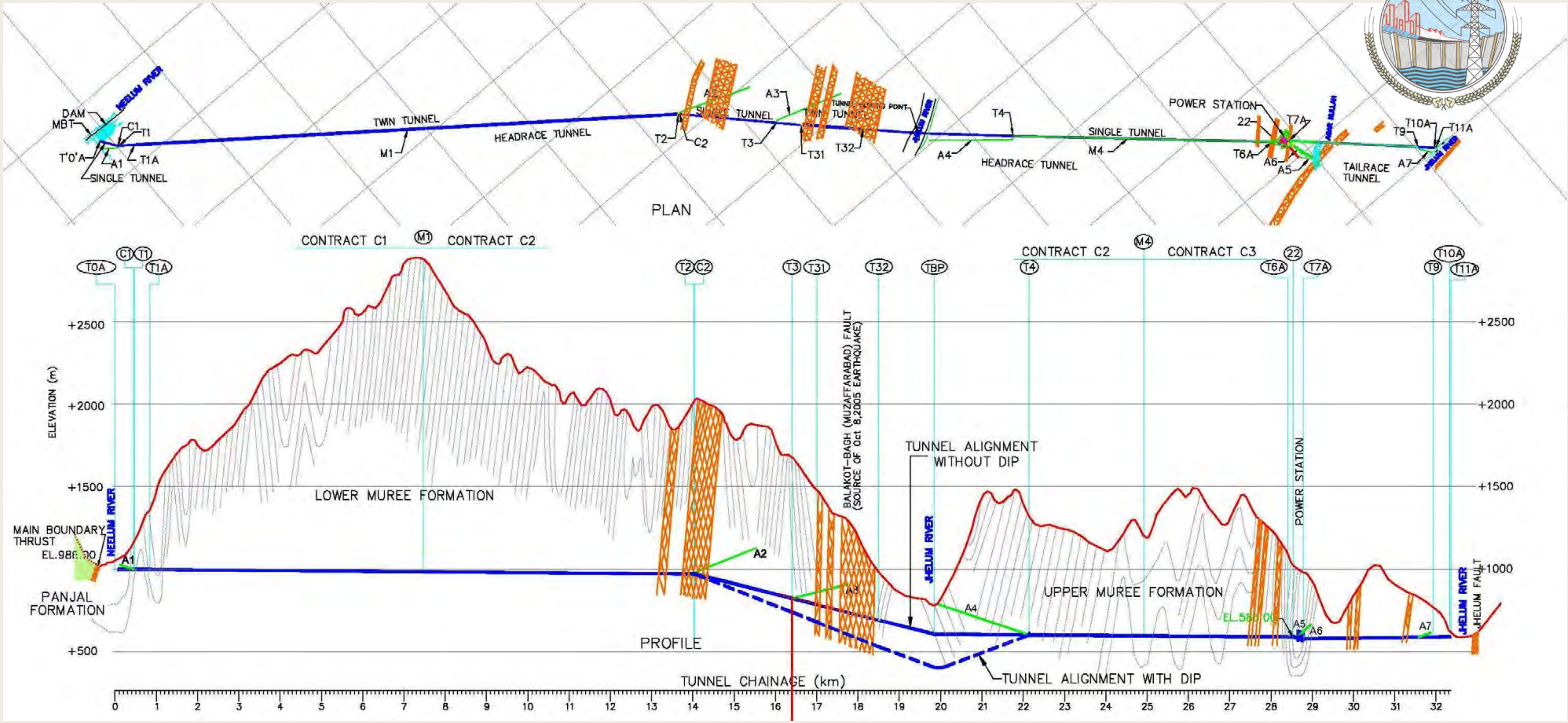
- NJHEP, all told, took over **10 years** to design and construct (January 2008 to December 2018).
- Multiple significant challenges, **typical of the Himalaya**:
  - Diversion and excavation;
  - Tunnelling;
  - Surge shaft;
  - Powerhouse.

Diversion and excavation

- Neelum River first had to be **diverted** (through an upstream coffer dam and then diversion tunnel).
- Hillside on left bank needed to be **cut away** to allow for construction of desander structure.

Tunnelling

- Greatest construction challenge for NJHEP:
- 58km of tunnels through difficult geology, including Muzaffarabad Fault.
- Lowest point 178m under Jhelum River.
- Specialised tunnel boring machine (TBM) required.



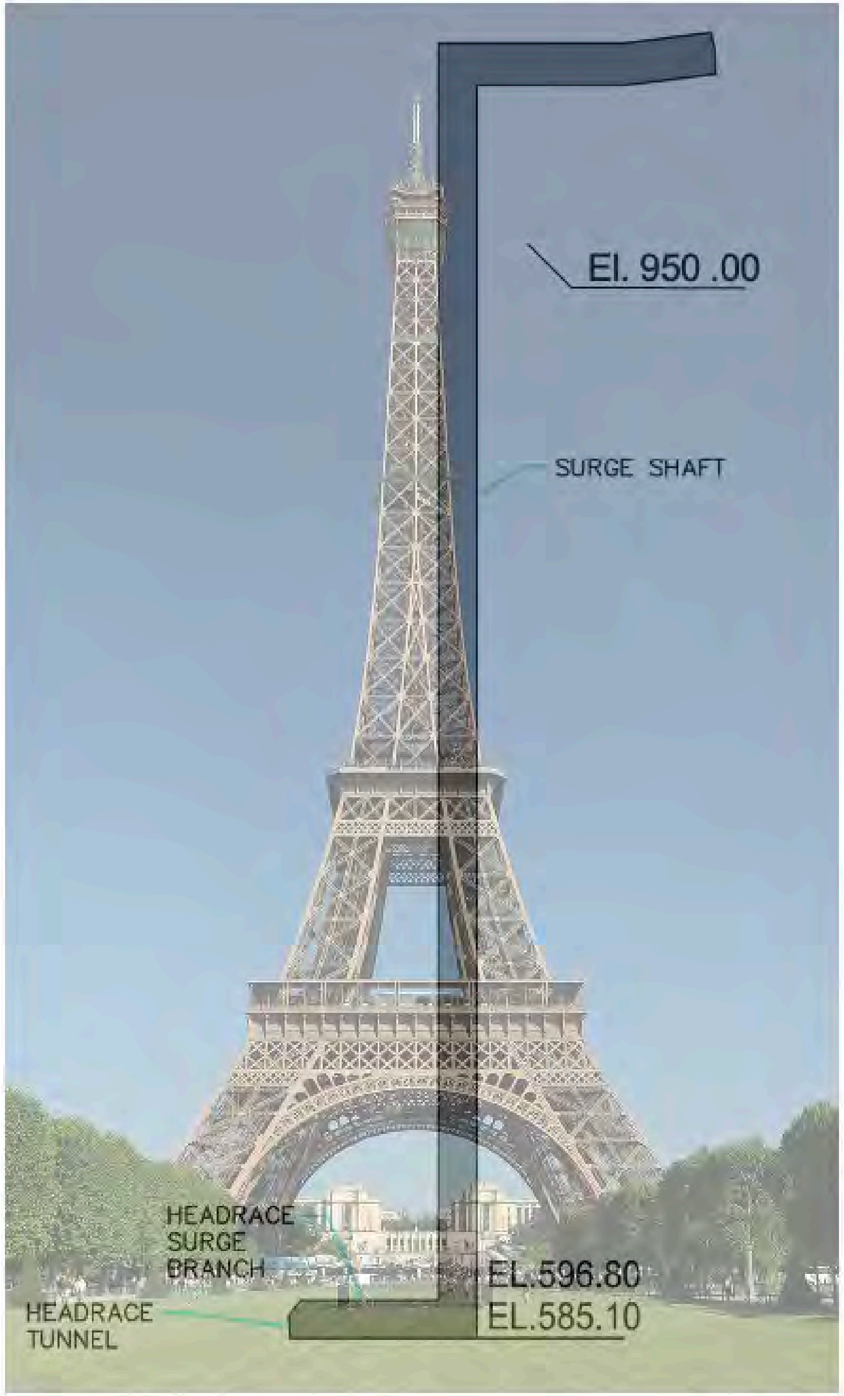
NEELUM RIVER
DAM
MBT
C1
T1
T'0'A
A1
T1A
SINGLE TUNNEL
TWIN TUNNEL
M1
HEADRACE TUNNEL
T2
C2
SINGLE TUNNEL
A3
T3
TWIN TUNNEL
T31
T32
JHELUM RIVER
T4
A4
HEADRACE TUNNEL
SINGLE TUNNEL
M4
POWER STATION
22
T7A
T6A
A6
A5
TAILRACE TUNNEL
T10A
T9
T11A
A7
PLAN
CONTRACT C1
M1
CONTRACT C2
T0A
C1
T1
T1A
T2
C2
T3
T31
T32
TBP
CONTRACT C2
M4
CONTRACT C3
T4
22
T6A
T7A
T10A
T9
T11A
ELEVATION (m)
+2500
+2000
+1500
+1000
+500
LOWER MUREE FORMATION
MAIN BOUNDARY THRUST
NEELUM RIVER
PANJAL FORMATION
A1
A2
A3
BALAKOT-BAGH (MUZAFFARABAD) FAULT (SOURCE OF Oct 8,2005 EARTHQUAKE)
TUNNEL ALIGNMENT WITHOUT DIP
JHELUM RIVER
A4
UPPER MUREE FORMATION
POWER STATION
A5
A6
A7
JHELUM RIVER
JHELUM FAULT
PROFILE
TUNNEL CHAINAGE (km)
TUNNEL ALIGNMENT WITH DIP
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32

Headrace bifurcation

- Need to minimize tunnel diameter due to poor geology means that the headrace must be split into two tunnels.
- Adds significantly to the amount of tunnelling required.

Headrace lining

- Headrace tunnels under the Jhelum River need to be lined with **steel cans**, necessitating the construction of a factory near the project site.
- Each can is 12m long and weighs 72 tons.



Surge shaft

- As part of the tunnel design, a surge shaft must be constructed from the point at which the headrace enters the penstocks to the surface.
- The resulting shaft is 353m high; for comparison, the Eiffel Tower is 330m high.

Powerhouse cavern

- In the process of excavating the powerhouse, **rock support issues** developed.
- Owing to high-stress zones causing brittle failure in the sandstone bed, **15m rock anchors** had to be sunk into the walls.