Chapter 3: Planning of hydropower Projects

Introduction

- Hydro power is a mature technology –make use of the experience!
- Use proven design solutions, study operating projects with similar head and design flow.
- Hydropower plant design is unique and depends primarily on site specific features and also such as topography, geology, hydro-meteorology etc.
- Thus no practice can be generalized in case of hydropower civil design and presented as best practice.
- The planning is very important component for the optimum development of a hydro electric project in a river basin.
- A river valley can offer many sites potentially attractive to the planners of hydro electric development.
- Investigations at these sites can help identify the **optimum** dimensions of dam, reservoir and powerhouse that could give the most economical scheme.
- **Process of selecting the best option depends upon the judgment and experience of decision makers.**

- Hydropower project forms an integral part of overall development of water resources of the river basin.
- The hydro schemes also form part of the complex integrated power generation system with diverse power generation resources.
- In the planning of hydro development and deciding on installed capacity etc., these two inter-connections with the water resources developments of the river basin and with the power system are to be kept in view.
- In the overall basin context, the impact of operation of upstream projects, constraints imposed by the downstream projects, irrigation diversions downstream, flood moderation etc. are to be considered.

Hydropower Development Cycles

Resources studies

- Preparation/updating of resources inventories
- Preparation/updating of resources rankings

Site specific studies

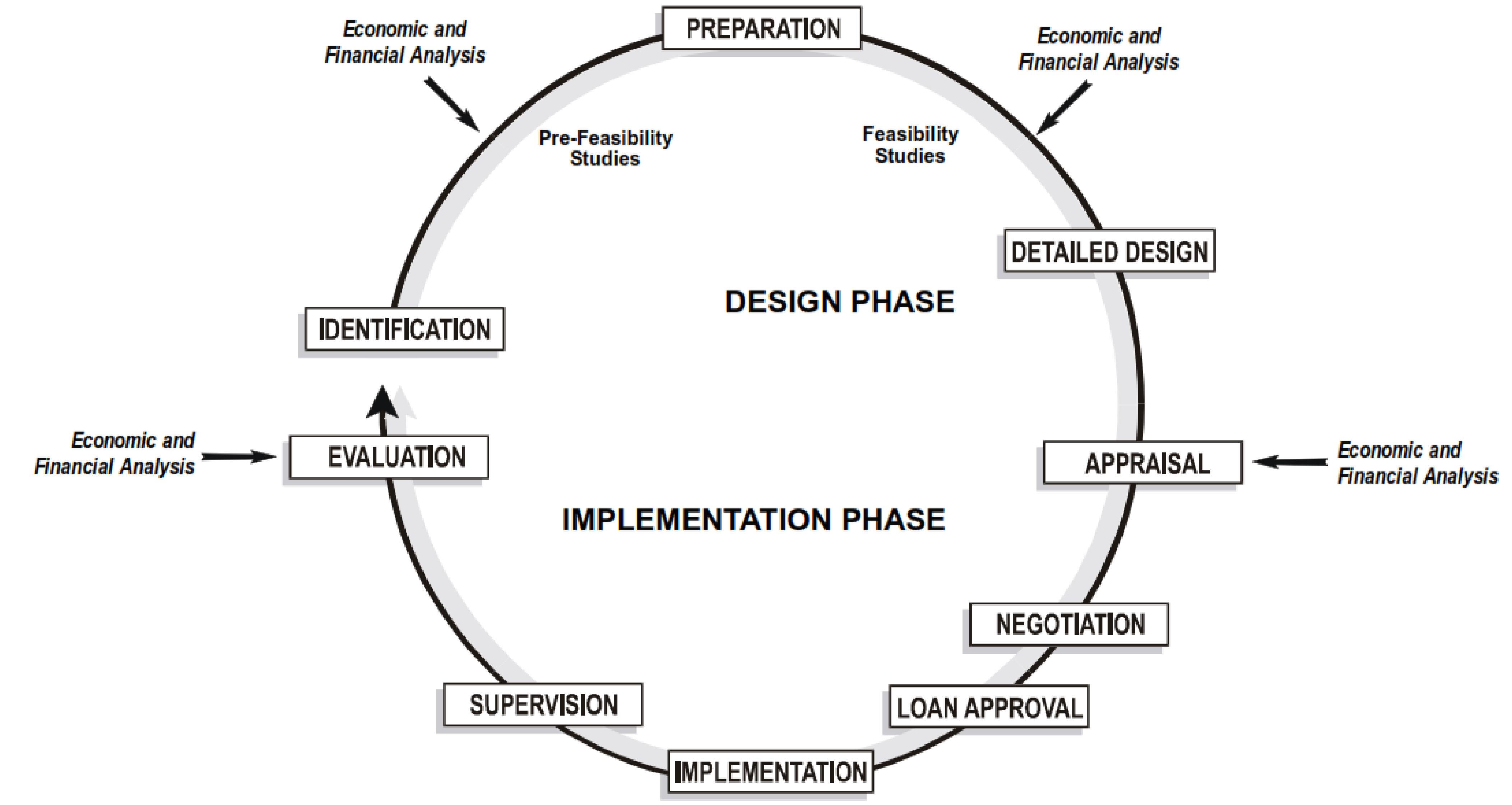
- Preliminary reconnaissance studies
- Pre-feasibility studies
- Feasibility studies

Resource inventory to identify, register and catalogue the hydropower resource existing in a river basins; areas; districts and provinces.

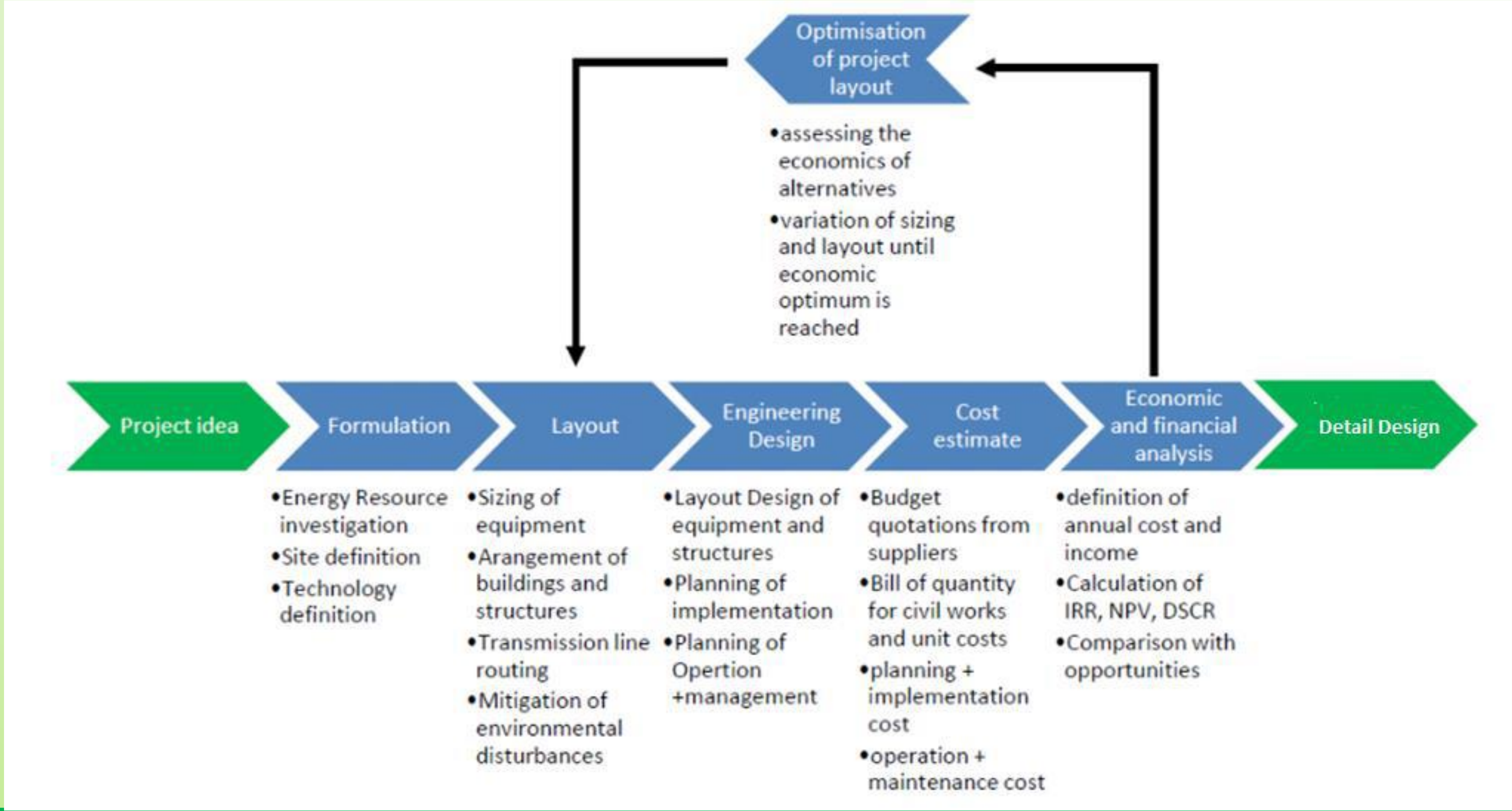
Flow data and data on topography is sufficient to establish the production and generating capability of a site.

The identified project sites are ranked according to size, cost, electric demand, etc.

Hydropower Development Cycles



The planning process and its optimization



Major steps involved in the planning of hydropower project

Project formulation and layout

- Site Identification
- Hydrological study (flow duration, flood conditions, dry/wet year conditions)
- Basic topographical overview (possible head, access conditions, existing roads)
- Preliminary assessment of slope stability and sediment loads
- Basic project layout with first approximation of electricity generation

Engineering design and layout optimization

- Pre-design of hydraulic structures with cost estimations
- Evaluation of layout alternatives
- Optimization of sizing
- Assessment of power and energy benefits

Definition of project layout

- Detailed field investigations
- Preparation of detailed project report

Major steps involved in the planning of hydropower project (cont.)

Project investigation, planning and design are normally organized in several consecutive studies which are listed here in increasing order of detail, importance and reliability:

- Reconnaissance studies
- Prefeasibility studies
- Feasibility studies

Reconnaissance study

- Are made to find potential energy sources and to estimate the energy available in streams, and may not be too site specific
- This study uses contour maps or digital elevation models to determine heads available in streams and water flow can be estimated using parametric curves of the flow duration in the streams
- Some site specific studies may use mean annual runoff or a characteristic such as the 95% of time flow available for energy development.

Reconnaissance studies

- The details and data requirements of these studies are regional in nature.
- Accuracy of these data as a requirement is less.
- Carried out for specific purpose such as: to establish the available potential in a district.
- They are concerned with project selection from inventories of resources.
- The main objectives may be such as:
  - Assessment of demand or define electric power need
  - Selection of candidate projects from the resources inventories which will meet the electric power demand
  - Investigation of candidate projects and project alternatives to the best technical level
  - Technical ranking of candidate projects should be prepared and well recorded
  - Selection of a suitable project from the list of investigated candidate projects.
  - Estimation of preliminary cost and implementation schedule.

Prefeasibility study

In this phase one or more identified projects are brought one step further in the planning process.

The main purpose of pre feasibility investigations is to:

- establish the need and justification for the project
- formulate a plan for developing the project
- determine the technical, economical and environmental practicability
- define the limits of the project
- ascertain local interest in and the desire for the project
- make recommendations for further action

Feasibility Study and its objectives

- An expert analysis of the likelihood of success of the project in a technical and economical sense.
- Presents the project layout as a result of the evaluation of design alternatives
  - calculates the average annual electricity generation and the revenues
  - gives information how the budgetary investment cost was determined
  - evaluates the economic and financial profitability and its sensitivity against changes in the assumptions
  - assesses the environmental and social impacts

Field work during feasibility study

The following issues should be recorded properly

- Terrain features such as location and placement of structures
- Infrastructures such as access to the project, transmission lines, settlement and resettlement issue
- Availability of construction material
- Environmental issues such as diversion of flow from one catchment to the other, deforestation, etc.
- Multipurpose uses
- Diversion of flow during construction of Headwork and/or coffer dams
- In case of reservoir and tunnel projects special attention shall be given to the geological and geo technical properties.
- Appraisal of discharge available
- Study of existing and future water uses such as drinking, irrigation, etc.
- Verification of estimated head, Powerhouse type, location and equipment

Feasibility report stage

i) Detailed study of hydrology, which includes water availability studies, flood studies and collection of historical hydrological data and meteorological data.

ii) The installed capacity of the project along with design head and the design discharge for the project.

iii) Fixation of location of the dam and the powerhouse.

iv) Fixing of the height of the dam above riverbed.

v) Fixing the preliminary layout of the water conductor system.

vi) Fixing the type of the power house

vii) Working out the design energy for the project.

viii) Evaluation of infrastructure works likely to be involved.

ix) To work out the knowledge of civil design, electrical design, hydrology, geology, construction and cost engineering is very important to arrive at a good feasibility report.

Hydrological study -Outputs

- Average flow duration curve as basis for the average annual generation and determination of the optimal design discharge
- Flow duration curve of the driest year
- Residual flow as a requirement from the ecological point of view
- Estimated flood events and water levels to design the hydraulic structures safely

Estimation of flow to ungauged sites

- There are several methods to estimate flows from ungauged catchments:
  - ➢ Regional frequency analysis,
  - ➢ Use of Parametric Flow Duration Curve

Regional frequency analysis

- A regional frequency analysis involves regression analysis of gauged catchments within the general region.
- Through this technique, sufficiently reliable equations can often be derived for peak flow of varying frequency given quantifiable physical basin characteristics and rainfall intensity for a specific duration.
- Once these equations are developed, they can then be applied to ungauged basins within the same region and data of similar magnitude used in developing the equations.

Some of the equations may have the form:

$$Q_2 = 0.24A^{0.88}P^{1.58}H^{0.80}$$

$$Q_5 = 1.20A^{0.82}P^{1.37}H^{0.64}$$

$$Q_{10} = 2.63A^{0.80}P^{1.25}H^{0.58}$$

$$Q_{25} = 6.55A^{0.79}P^{1.12}H^{0.52}$$

$$Q_{50} = 10.4A^{0.78}P^{1.06}H^{0.48}$$

$$Q_{100} = 15.7A^{0.77}P^{1.02}H^{0.43}$$

Where:

Q = peak discharge

A = drainage area

P = mean annual precipitation

H = altitude index

A regional analysis usually consists of the following steps:

- Selecting components of interest, such as mean and peak discharge
- Selecting definable basin characteristics of gauged watershed: drainage are, slope, etc.
- Deriving prediction equations with single or multiple linear regression analysis
- Mapping and explaining the residuals (differences between computed and observed values) that constitute "**unexplained variances**" in the statistical analysis on a regional basis.

Parametric Flow Duration Curve

The first step in applying the method was to take the flow values for the key exceedance percentages of Q(95), Q(30), Q(50), and Q(30) from each of the duration curves developed for **gauged streams**. These particular exceedance values were chosen because these percentages are important in the sizing of hydropower plants. Next the average annual flow was computed for each site. The values of Q(exceedance %) vs. Average Annual Flow were plotted for each exceedance value at each site and a best fit curve was matched to the data sets. An example of the resulting parametric curves is shown in Figure .

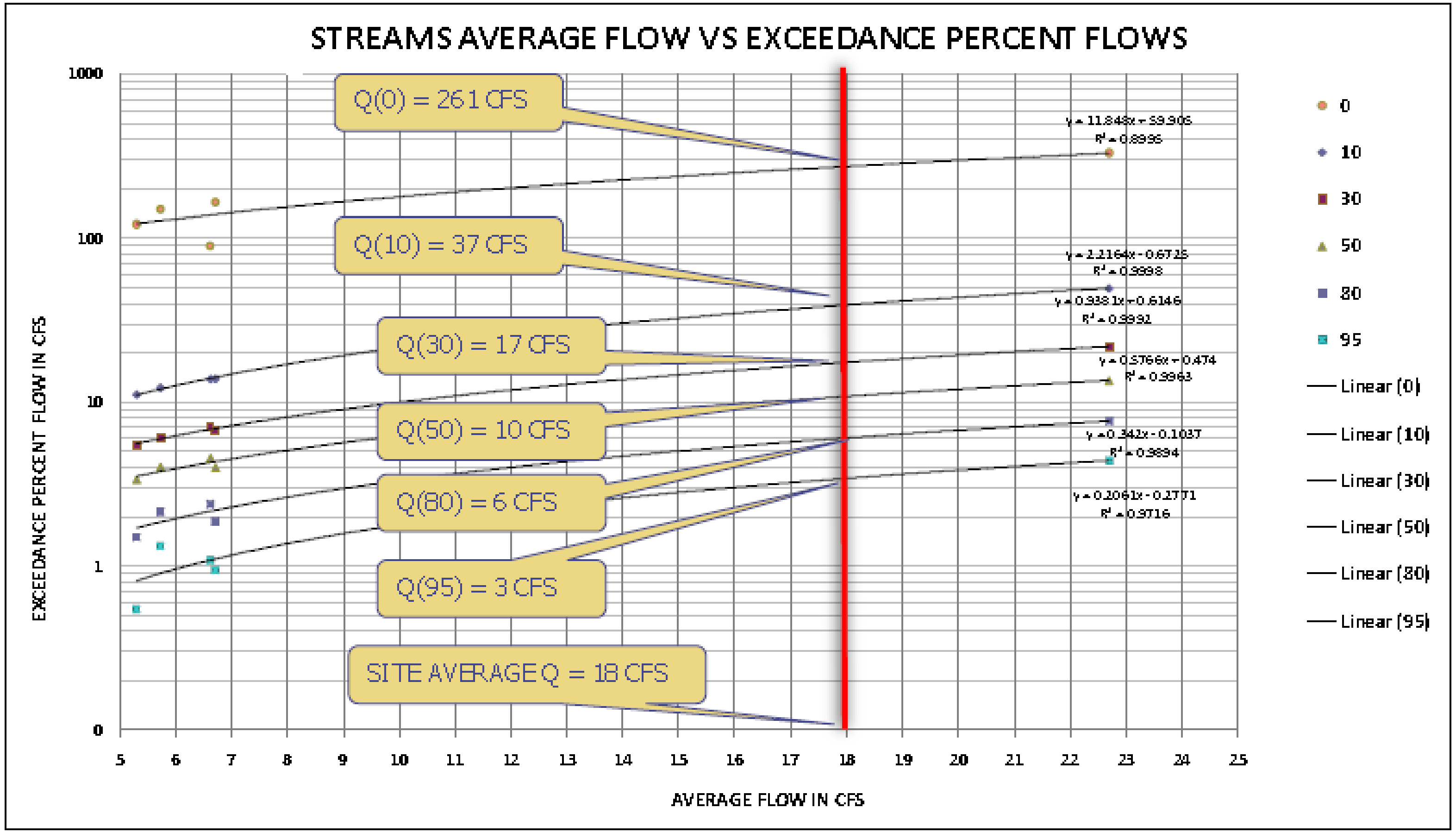


Figure Parametric Flow Duration Curves

Power Potential Studies

- Power Potential studies are carried out for assessment of available Power
- Potential of a river/basin based on a set of inflows and available head conditions under various operating policies.
- These studies play an important role in the optimization and design of new hydro facilities.
- They are used for examination of various configurations and their integration into existing networks.
- The studies are carried out for optimization of project parameters and for evaluation of Energy and Power benefits.

Determination of Installed Capacity

- For selection of installed capacity, benefits from the project with different possible installed capacities are evaluated.
- Optimum installed capacity is selected after carrying out incremental analysis for the most attractive alternative and also considering the system load factor (LF).
- In addition, cost of generation from alternate sources such as wind energy, geothermal turbines, and hydro are worked out.
- The least cost of energy from among these options is adopted for evaluating the benefits of the installation.

First approximation of the average annual electricity generation

Typical procedure

- Choose Design Discharge based on flow duration curve
- Choose penstock diameter (5% head loss for a start) and determine the net head.
- Chose the turbine type and number of units
- Determine the total efficiency of conversion equipment as a function of discharge (use suppliers data)
- With the above information calculate annual power generation as first approximation.

Optimizing the size of the Hydropower Plant

After the first approximation, an optimization of the sizing of the plant needs to be done to obtain the most economic installed capacity. This requires the following steps:

- The investment cost of the entire plant is determined as a function of design discharge
- This requires that a formula is developed for the cost of each component in relation to the design discharge
- Varying the design discharge and the penstock diameter will vary the investment cost and at the same time the generation with revenue.
- The discharge which yields the highest NPV will be the most economic size the plant should be designed for.

Important issues as part of the planning process

- Environmental constraints
- Socio-economic considerations
- Electricity tariffs, and tariff policy

These issues influence project planning and project formulation and also contribute to project costs

Environmental and social impact assessment (ESIA)

- ESIA is obligatory covering the expected positive and potential negative environmental and social impacts of the proposed project and the related mitigation activities.

Emphasis will have to be put on the following parameters:

  - ➢ Residual flow of the river safeguarding functioning of flora and fauna (particular fish population)
  - ➢ Residual flow of the river safeguarding functioning of flora and fauna (particular fish
  - ➢ Proper construction and operation procedures assuring work safety

- Proper awareness of the potential impact of the SHPP project on potentially endangered species and the development and implementation of adequate mitigation activities
- Development and implementation of an adequate Environmental and Social Action and Monitoring plan

Implementation Phase

Project implementation is a multidisciplinary job which include:

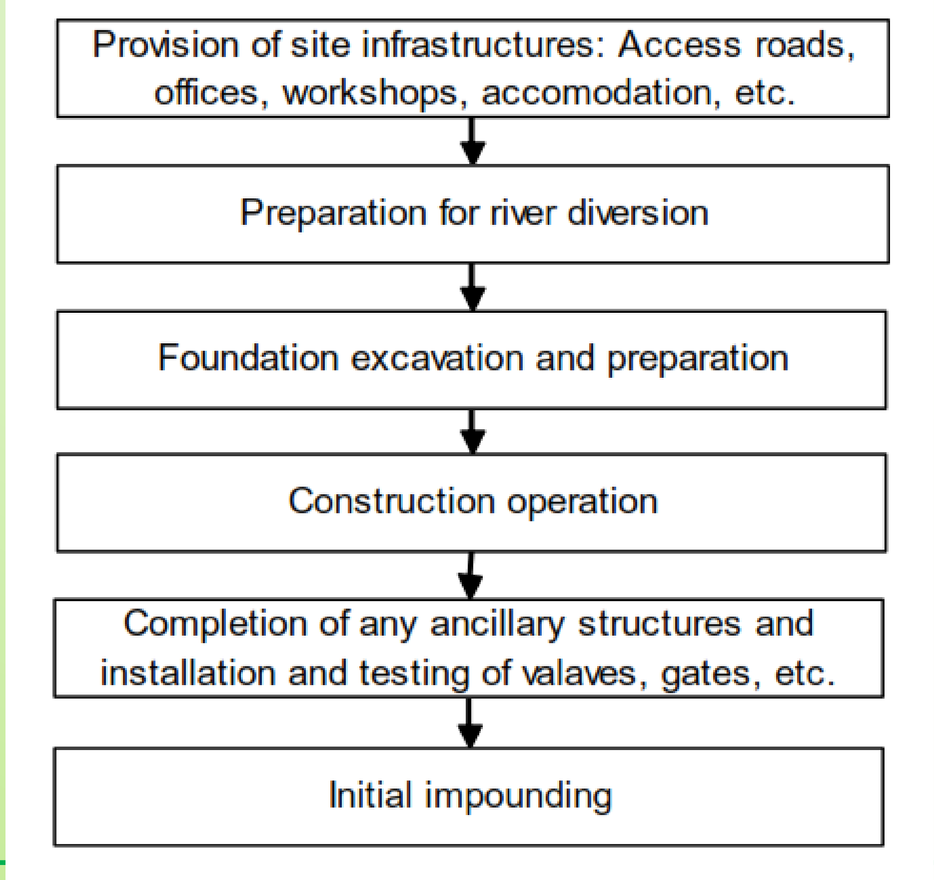
- Approval and appropriation of funds
- Pre-qualification and hiring of consultants
- Detailed design
- Preparation of tender/contract documents
- Pre-qualification of contractors
- Preparation of construction design and engineering design
- Preparation of operation manual
- Construction supervision
- Construction of civil works
- Supply and erection of equipment
- Testing, commissioning and commercial operation
- Preparation of completion report

Construction features of hydropower projects

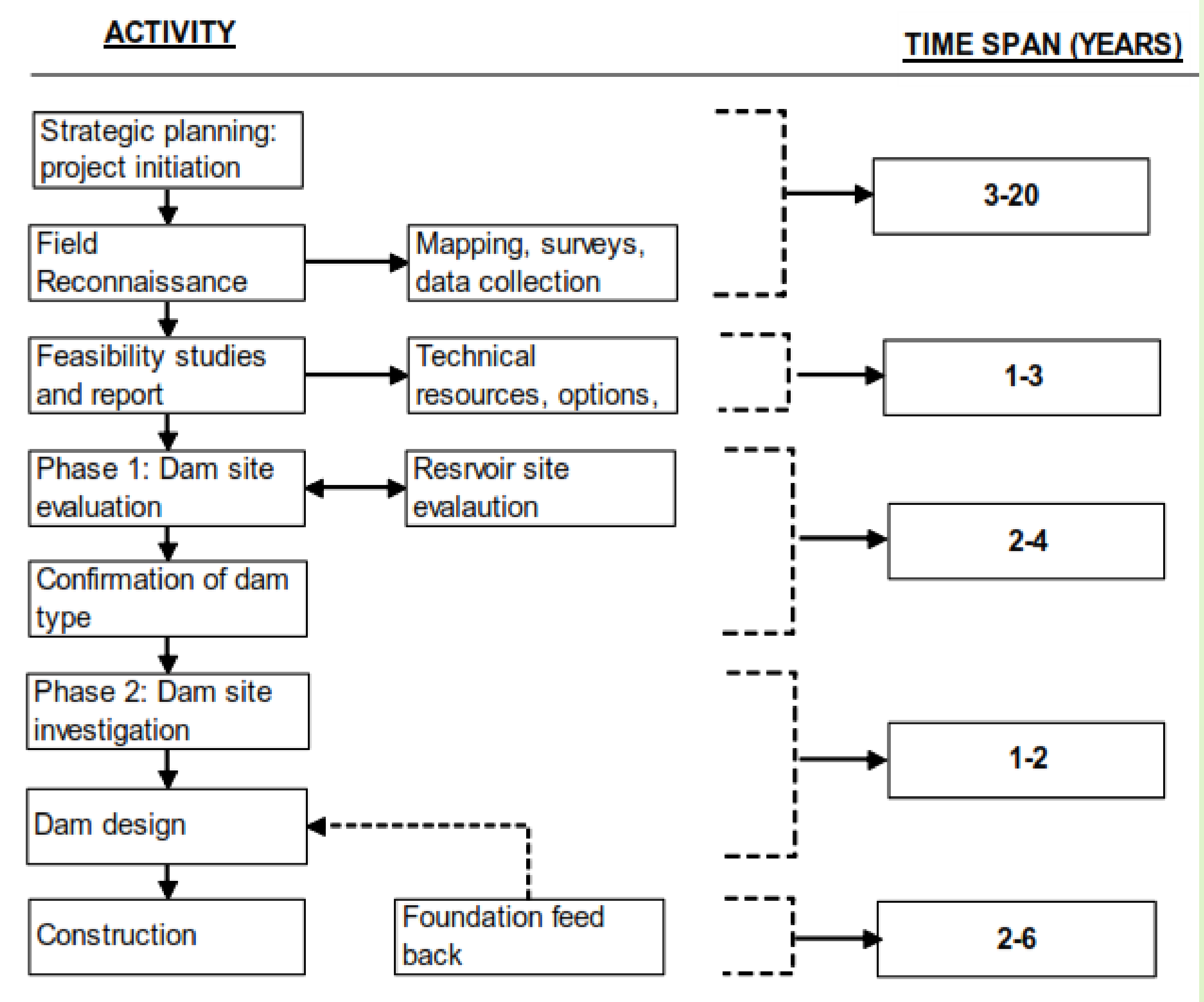
Main feature of hydropower project:

- Storage
- Conveyance
- Power house

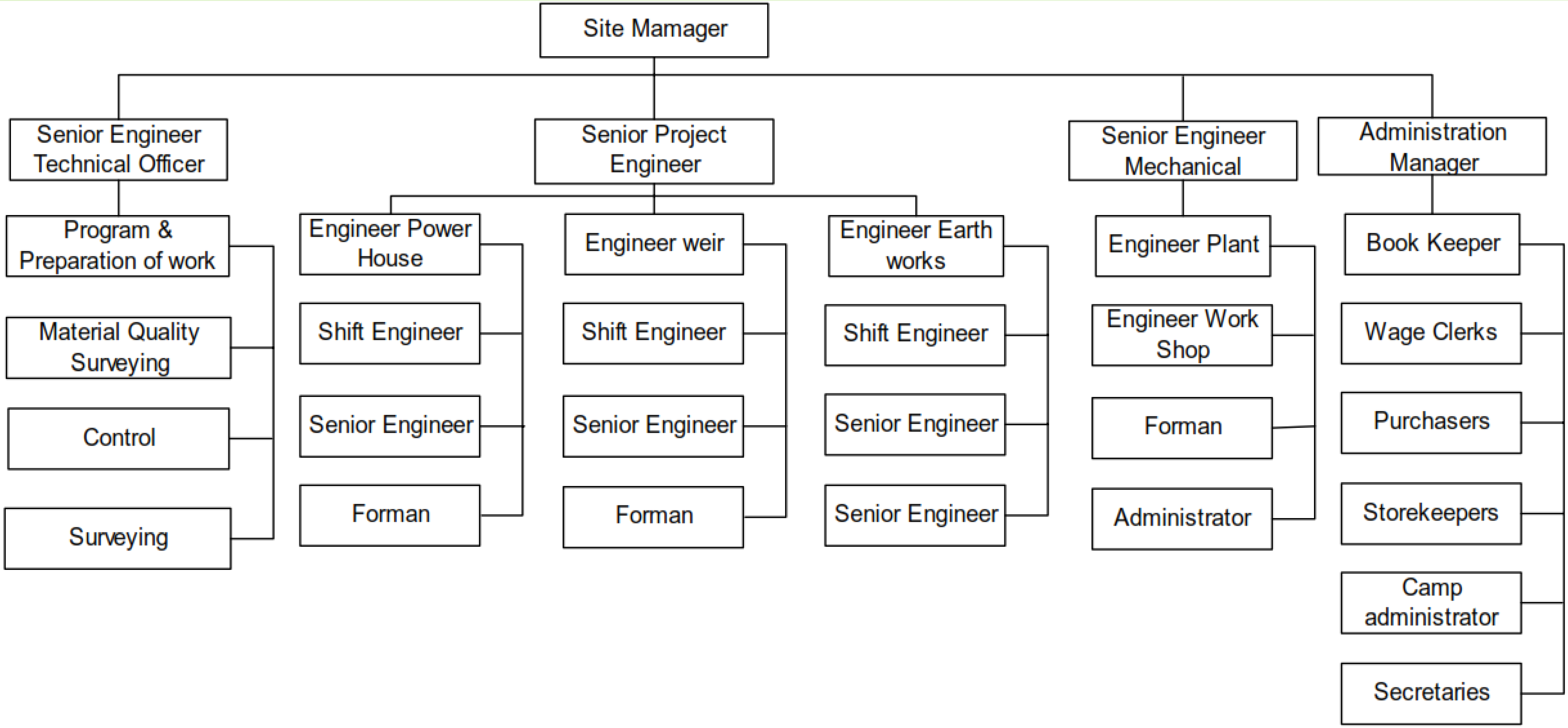
Phases of Project Execution



Stages in dam site appraisal and project development activities:



Organization chart of project construction operation



Monitoring system for hydro-electric projects

- Monitoring is a general term implying continuous tracking of progress in comparison to a predetermined plan, i. e. the schedule, and to avoid and remedy any drifting from the schedule.

The monitoring of a project comprises:

- Defining and setting targets
- Reporting achievements against the targets.
- Deviations from the targets and reasons thereof.
- Corrective action to undo and to contain the damage and avoid further delay.
- Rigorous follow-up for enforcement of the decisions of the management for augmenting the progress, directly as well as indirectly.

Monitoring system for hydro-electric projects *contd.*

- Hydropower projects has large number of interlinked activities, some of which are more important than the rest.
- It is therefore, necessary to have a plan that gives a bird's eye view of how the whole project work will proceed and which activities are more important than others, requiring special attention.
- Such a schedule is termed "Master Control Network" or Level-I schedule, which is basically a schedule based on Critical Path Method (CPM), and shows only the major activities with their interdependence, start/end dates, allowable delays (floats) and criticalities.

Contract Management:

- Since most of the works are done through large contracts, the management of contracts is very vital for the progress. After award the contracts are operated by the site officials.
- Slippage of even one package from its program may lead to disturbance in other works and delay in commissioning of the project, besides other legal problems that follow the delays.
- Due care is therefore taken to keep the pace of work as per the plan. Whenever there is any apprehension of delay or problem in execution of work, necessary assistance is provided to the project.

Financial Control

- The project is required to be completed within the approved cost that was envisaged at the detailed estimate stage of the project.
- During the execution stage, attempts are made to maintain the expenditure incurred on each work within the provision kept for that work.
- All financial controls are enforced both at the project level and at the Corporate Office level to ensure this vital aspect by constant monitoring.
- However, sometimes due to unforeseen or unavoidable reasons, the cost overshoots the prescribed limit in spite of best efforts to contain it.
- In such circumstances the estimate has to be revised and a fresh approval needs to be obtained.

Start-up and Commissioning

Project start-up and commissioning including:

- Inspection and testing
- Operations and maintenance support
- Staff training and knowledge transfer

Operation

The essential procedures include:

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

Reservoir Operation

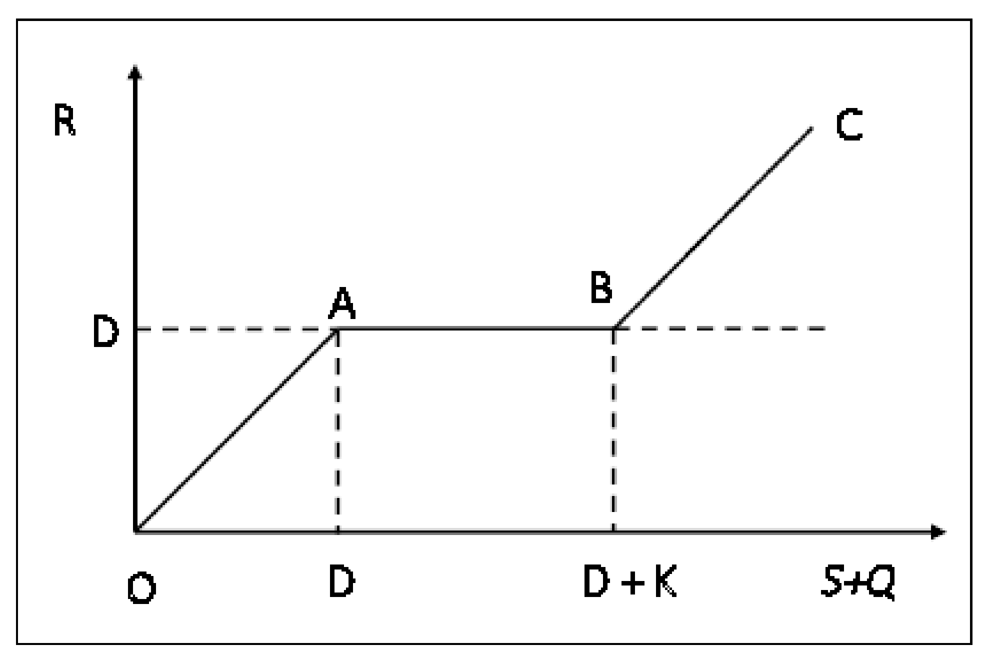
- Reservoir operation policy indicates the amount of water to be released based on the *state of the reservoir, demands and the likely inflow to the reservoir.*
- The release from a single purpose reservoir can be done with the objective of maximizing the benefits.
- For multi-purpose reservoirs, there is a need to optimally allocate the releases among purposes.
- The simplest of the operation policies is the Standard Operation Policy (SOP).

SOP

- Along *OA:* Release = water available;
- Along AB: Release = demand;
- Up to *A*: Reservoir is empty after release.
- Up to *B:*Reservoir is full after release.
- Along *BC:* Release = demand + excess water over the capacity (spill)

The releases according to the SOP need not be optimum

K= capacity of reservoir



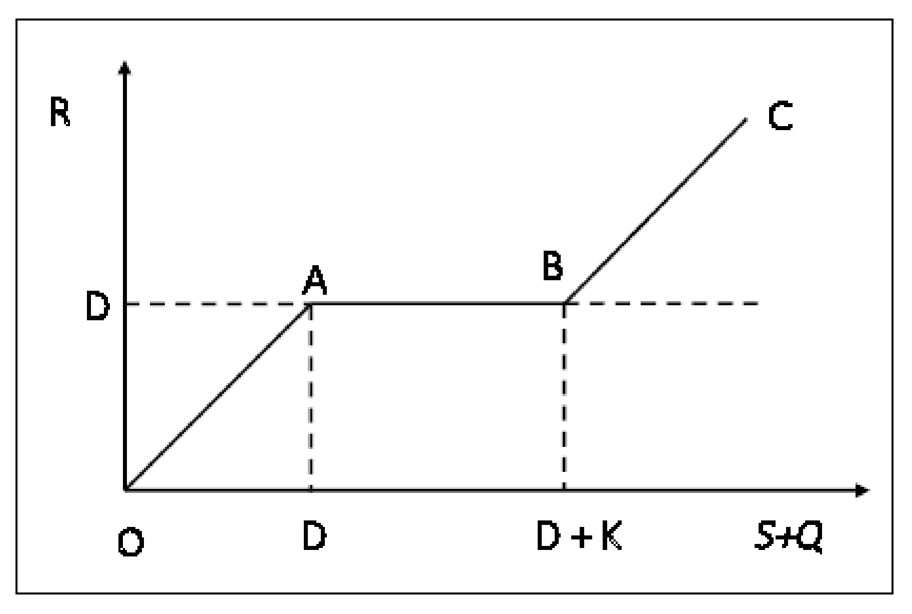
SOP

•The release in any time period $=S+Q$ or D; whichever is less as long as availability does not exceed $D+K$.

•Once the availability exceeds $D+K$,

release= demand + excess availability over capacity.

•For highly stressed systems, SOP performs poor in terms of distributing deficits across the performance in a year.



•The SOP is expressed as

$Rt=Dt$ if $St+Qt-Et\geq Dt$

$=St+Qt-Et$ otherwise

$Ot=St+Qt-Et-Dt-K$

if positive

= 0 otherwise

$St+1=St+Qt-Et-Rt-Ot$

$St+1=K$ if $Ot>0$

St is the storage at the beginning of the period t

Qt is the inflow during the period t

Dt the demand during the period t

Et is the evaporation loss during the period t

Rt is the release during the period t

Ot is the spill (overflow)

The monthly inflows (Q_t) and demands (D_t) and evaporation (E_t) in Mm^3 for a reservoir with a capacity of 350 Mm^3 are given below

	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Q_t	70.61	412.75	348.40	142.29	103.78	45.00	19.06
D_t	51.68	127.85	127.85	65.27	27.18	203.99	203.99
E_t	10	8	8	8	6	6	5

	Jan.	Feb.	Mar.	Apr.	May
Q_t	14.27	10.77	8.69	9.48	18.19
D_t	179.47	89.76	0	0	0
E_t	5	6	8	8	10

Initial storage, S_1 = 200 Mm^3

Simulate the reservoir operation with the standard operating policy

Solution

	Q_t	D_t	E_t	S_t	$S_t+Q_t-E_t$	R_t	O_t	S_{t+1}
June	70.61	51.68	10	200	260.61	51.68	0	208.93
July	412.75	127.85	8	208.93	613.68	127.85	135.83	350
Aug.	348.4	127.85	8	350	690.4	127.85	212.55	350
Sept.	142.29	65.27	8	350	484.29	65.27	69.02	350
Dec.	103.78	27.18	6	350	447.78	27.18	70.6	350
Jan.	45	203.99	6	350	389	203.99	0	185.01

Please complete the rest of the simulation