0. GENERAL

0.1 PROJECT LAYOUT

The planning process of hydropower projects is a step-wise procedure. Studies with increasing level of detail are carried out at every step. The newly gained information should provide the basis to decide whether to continue or to abandon the project, keeping in view that every further step will be associated with higher investments, which will finish when the plant is commissioned.

The main steps in the development of a project are:

- Reconnaissance/identification
- Pre-feasibility
- Feasibility
- Detailed design
- Tendering
- Construction design

At each step, the activities aim at obtaining a more detailed knowledge of the overall project but concentrating especially on critical issues in order to reduce risks associated with the construction and later operation of the project. In this connection, layout and sizing play a fundamental role.

Layout and sizing are normally decided at the initial stages of development of the project, namely identification, prefeasibility and feasibility level. Only minor changes and adjustments are taken at later stages, which concentrate on detailed design and dimensioning of the project elements.

When systematically done, the layout of hydropower projects is initially considered at identification stage. Preferably, the layout of a project should be decided keeping in view the overall potential of the river basin where the project is located and whenever possible also the available resources in adjacent river basins. This should be done aiming at a rational exploitation of available resources.

An efficient layout should ensure that:

- The maximum amount of sediment free water is transferred from the intake to the powerhouse
- The maximum possible head is exploited
- The waterways have the shortest possible length
- The most suitable structures are selected for prevailing geologic conditions
- The project elements have the smallest possible dimensions with acceptable safety levels
- All present and future environmental constraints are considered

The decisions taken at identification stage are very important for the future development of the projects. This especially applies to technically feasible and economically attractive sites. An efficient layout at the early stages, reflected into maximum power and energy output at the lowest possible cost, provides the basis to encourage the further consideration of the project.

The general framework for the selection of the project layout is given by many factors, especially:

- Hydrological regime (streamflows, floods and sediments)
- Topography, especially with regard to available head and gradient
- Conditions of terrain to accommodate the project components
- Geologic and seismo-tectonic set-up
- Water rights, especially for multiple purpose projects
- Land use, especially population centres, cultivated areas, etc.

- Accessibility

The initial decisions to be taken are:
- Location and type of the diversion structure and intake (weir, dam or temporary structure)
- Type and alignment of waterways (canal or tunnel on left or right river bank)
- Type and location of the surge structure (surge bay or surge tank)
- Type and alignment of pressure conduit (penstock or pressure shaft)
- Type and location of powerhouse (external or underground)

Normally, at identification level the project layout is decided on basis of preliminary information. The design parameters adopted for dimensioning and costing are often established on basis of estimated physical data. After identification the most promising projects are selected for more detailed study and finally to their implementation. Obviously, during subsequent stages of study, the project layout may be subjected to modifications and adjustments, especially when more detailed information becomes available.

The procedures normally followed to decide about layout and sizing of hydropower projects are discussed below.

RECONNAISSANCE/ IDENTIFICATION
This is the initial and therefore fundamental step in the life of a hydropower project. It should provide information about following aspects:
- Power market
- Hydrologic parameters
- Environmental viability
- Power and energy potential
- Project layout and size
- Project cost
- Economic viability

Almost independently of the available information and site conditions, the identification proceeds according to following sequence:

Desk Works
Carry out power market and demand forecasting studies to establish local and regional power and energy requirements.

Collect and process all available hydrologic information in order to derive basic parameters for the selection of project layout and sizing.

Concerning the identification of projects, the very fist step is to try to assess the site conditions with help of maps, aerial photographs and other relevant information. In this regard, following aspects are considered:
- Appraisement of the river gradient. Evidently, the hydropower project should be placed where both discharge and gradient are largest. Therefore, it is always advisable to prepare longitudinal profiles of the river course under consideration, showing also the available discharge at relevant points.

- Possible location of intake, aiming at the diversion of the maximum possible discharge. The site selection requires the consideration of physical conditions, which may either favour or constraint the development. These include aspects such as:

  - Existing infrastructure (buildings, bridges, roads, railways, irrigation canals, etc.)

- River confluences (to ensure larger discharges intakes should preferably be placed downstream the confluence)
- Topographic conditions (narrow valleys normally lead to smaller less cost intensive structures)
- Natural conditions, especially adverse, such as poor geologic set-up (karst, landslides, etc.), extraordinary floods, volcanic activity, glaciers, etc.
- Political constraints, such as borders

- Possible powerhouse site. The site selection requires the consideration of physical and political constraints.

- Exploitation of the gross head available between intake and powerhouse, following the shortest possible path.

- Determination of hydrologic parameters at intake and powerhouse sites.

- Accessibility to the sites where the most important project components are proposed.

At this stage, various alternatives may be considered for the location of intake and powerhouse and the alignment of the waterways.

The information should be critically used. The availability of maps is no guarantee for reliable parameters, especially in large-scale maps covering remote area where the geodetic networks have limited density. For example, elevation contours in maps of densely vegetated areas developed with help of aerial photographs do not always match the terrain. Errors up to 30 meters (depending on the height of the trees) are very often, which would provide an incorrect basis to determine the dam height, significantly affecting the quantification of the regulating capacity of a proposed reservoir.

On the other hand, the date of elaboration of the maps has to be taken into consideration. In many cases, the basis for these maps was aerial photographs taken various years before the maps were prepared. Therefore, when old photographs were used the maps are outdated, not necessarily reflecting the present conditions in a reliable manner. This is especially important with respect to available infrastructure, population settlements, land use, water rights, etc.

Another important aspect to consider is the scale of the available maps and the density of the contour lines. For example, when maps on scale 1:50,000 are used the elevation contours are normally drawn with 20 to 40 meter intervals. This level of detail may be insufficient for power projects having gross heads of 100 meters or less. On the other hand, the contours may not provide adequate information in very steep terrain, which may be the case of dam sites in narrow valleys.

FIELD WORKS
Independently of the reliability and level of detail of the information used to carry out the desk works, any proposed layout has to be critically checked in the field. This is especially important to assess:

- Reliability of available maps
- Basic dimensions of the structures
- Geologic conditions for all proposed project elements
- Land use and vegetation cover
- Water rights

The proposed layouts resulting from the desk studies may be adjusted, modified or even rejected during the field visit.

Dimensioning
With exception of hydrologic parameters, which may be obtained from published data or as result of the application of mathematical models, the dimensioning of the main project components should be based on data collected during filed work. This especially applies to topographic, geologic and environmental information.

Dimensioning implies the design of project components. The level of detail and reliability of the results obviously depends on the quality and quantity of basic data.

In the past, dimensioning of project components was done with the help of tables and charts. With the development of computer hardware and software the use of computer programs has become more common. On such program is HPC (Hydropower Dimensioning and Costing).

Quantities
Quantities of works are determined on basis of the layout and dimensions of the project components. These include all civil works (excavation, dewatering, concrete works, etc), hydro-mechanical equipment (gates, valves, turbines, etc) and electromechanical equipment (generators, transformers, switch gear, etc.)

Unit rates
Unit rates or unit prices are determined on basis of market surveys. For small projects normally the information from the local market may be sufficient. However, the international market may have to be consulted in case of large projects, especially when technologies are being considered, which are not locally available.

The unit rates are determined on basis of required labour, equipment and materials (see for example Construction Planning, Equipment and Methods by Peurifoy and Ledbetter). The detail depends on the level of the project under consideration. However, the information should be reliable to avoid incorrect and misleading cost estimates.

At identification level, especially when a large number of projects has to be considered, unit rates may be lumped together to reduce the amount of work.

Base Cost
Project costs are calculated on basis of estimated quantities and the unit rates for civil works, hydro-mechanical and electrical equipment. These cost estimates may include a component for contingencies, the assumed amount depending strongly on the reliability of the data.

Indirect Costs
These are the costs not included in the base costs, but are incurred during the construction of the project. They comprise mainly following items:

For civil works:
- Mobilisation, site installation and demobilisation
- Engineering and supervision
- Administration, audit and account
- Overheads

For hydro-mechanical and electrical equipment:
- Transportation
- Erection
- Engineering and supervision
- Import charges
- Overheads

Total Cost
The total project cost is estimated by adding the base cost and the indirect cost.

Project Size
Whether at preliminary level or at a more advanced stage, the determination of the size of a project has technical, economic and financial implications. Therefore, decisions on the future mode of operation of the project, isolated or interconnected, should be known as early as possible. The reason is that the economic and financial feasibility of the project strongly depends on the overall project cost and expected revenues.

An isolated operation is normally associated with a small power market, which will likely have a slow development and consequently small returns during the initial years of operation. The consumers will mostly be domestic, which in rural isolated areas have very low-income levels. Under these circumstances, the economic and financial feasibility may not be granted and the project can only be implemented with subsidies. The project size may have to be restricted, leading in some cases to inefficient exploitation of the available potential. Additionally, this type of development may not awake much interest from private investors.

An unconstrained interconnected operation can secure that the total project output is delivered to a larger market. These conditions normally ensure a better return on investment, allowing also a better exploitation of the available natural potential.

A temporary condition may also occur. A project may operate in isolation during the initial years and later on interconnected to a regional or even larger network. A strategy for the development of the project may have to be devised for a technically sound as well as acceptable economic and financial feasibility.

FEASIBILITY STUDIES
Feasibility studies address all relevant project issues in more detail. The produced document gives sufficient information to developers (public or private), banks, etc. about the technical, economic and financial feasibility of the project.

The layout and size is normally decided at this stage. Therefore, the feasibility study typically comprises following aspects:

1. Executive summary
2. Description of project area
3. Socio-economic set-up
4. Power market and demand forecast
5. Access
6. Topography
7. Hydrology
8. Geology
9. Seismic risk
10. Environment
11. Power potential
12. Layout and sizing
13. Physical and mathematical modelling
14. Civil works
15. Hydro-mechanical equipment
16. Electrical equipment
17. Project quantities and cost
18. Construction planning and budgeting
19. Economic analysis

20. Financial analysis

Executive summary
Should contain the salient features of the project aiming at providing a clear and objective picture of the project. It should help developers, public or private, gain a thorough understanding about the project and its feasibility. The supporting data and criteria for the selected project layout and size should be clearly presented.

Description of project area
Contains information about the project site and surroundings. Has normally little influence on the layout and size of the project.

Socio-economic set-up
Addresses issues related to population, income distribution, etc. Should provide detailed information about the degree of development of the area of influence of the proposed project. Depending on the relative size of the project under consideration, the population centres located in the vicinity of the project will be given more attention.

Power market and demand forecast
Provides an assessment of present energy consumption in general and particularly electricity. The information should provide the basis to forecast future requirements. This information is very important, as it is considered to decide whether the project will operate in isolation or as part of an interconnected system.

Access
This information is relevant to establish the presently available road infrastructure, especially the accessibility to the project area. Besides an indication of additional roads to be constructed for the project implementation, this chapter should also contain information about characteristics and capacity of roads, railways and waterways that may be used to transport machinery, construction material and heavy equipment parts such as turbines and transformers.

Road conditions and alignment play an important role in the selection of turbo-generating equipment. Therefore, it may have an influence on the selection of project layout and size, but mainly affects the selection of the type and number of turbo-generating units.

Topography
Topographic data is the basis for the project layout and design. It provides also basis for other relevant disciplines involved, such as geological mapping, environmental impact assessment, etc. Therefore, this chapter should contain information about the topographic works carried out and their degree of accuracy.

The scope of the topographic works will depend on the works carried out for proposed layout at reconnaissance/identification level. However, additional requirements may be established in accordance to the number of alternatives to consider, additional information not available at identification level, etc.

Hydrology and Sediment Transport
Should contain details about the available hydrologic data and the parameters derived for project design. Important is the assessment of available discharges for power generation and the maximum expected floods during construction and operation of the project.

Sediment transport affects the project according to the selected layout and structures. Both bed load and suspended sediment load should be dully quantified.

Geology
Plays a fundamental role in the selection of the project layout in general and each project component in particular. It has been statistically established that about 85% of project failures and cost overruns are due to adequate assessment of the geologic site conditions.

Seismic risk
Depending on the project size and tectonic set up, it should provide information about the main seismic sources within a radius of 100 to 200 km. It must also give information on the design parameters for different project components.

Environment
Contains information about the impact of the project on the surrounding environment, mitigation measures and associated costs.

Layout and sizing
Constitutes a critical stage in the overall project conception. Normally, it may be based on works previously carried out at reconnaissance/identification level. However, it is expected that the layout and design will be fixed at feasibility level. Further stages of project preparation concentrate on detailed design of the components.

Power potential
The power and energy potential is established according to the hydrologic regime, available head and selected layout. The estimation should take into account the existing and future water rights, in-stream water requirements, flushing of reservoirs and sand traps, etc. It also requires the assumption of expected head losses along waterways and efficiency of turbo-generating equipment, which strongly depend on the selected layout and type of turbo-generating units adopted.

The expected power and energy potential have a direct incidence on project sizing and at this level have to be estimated with the maximum possible detail.

Physical and mathematical modelling
May be used as complementary means to critically check different project alternatives. Physical modelling is normally expensive and time consuming. Therefore, whenever possible mathematical modelling is now being applied.

Civil works
For the selected layout and alternative, comprises the civil design of the project components at feasibility level. The detail with which each component is treated should be explicitly described.

Hydro-mechanical equipment
For the selected layout and alternative, comprises the design of the hydro-mechanical components at feasibility level.

Electrical equipment
For the selected layout and alternative, comprises the design of the electrical components at feasibility level.

Project quantities and costs
Includes the quantities of civil works hydro-mechanical and electrical equipment, estimated according to the selected layout and design. The costs are determined on basis of unit rates for civil works (local and international), quotations submitted by equipment manufacturers (local and international), etc.

The costs should also include contingencies, whose magnitude will depend on the detail and reliability of the data used. Additionally indirect costs should also be accounted.

For civil works:
- Mobilisation, site installation and demobilisation
- Engineering and supervision
- Administration, audit and account
- Overheads

For hydro-mechanical and electrical equipment:
- Transportation
- Erection
- Engineering and supervision
- Import charges
- Overheads

Construction planning and budgeting
Contains details about the foreseen stages for the construction of civil works and erection of hydro-mechanical and electrical equipment. It provides the basis to establish the required cash flow, which is required to quantify interests during construction (IDC) and to establish the economic and financial viability of the project.

The construction schedule strongly depends on the characteristics, size and layout of the project. However, it also needs to consider all relevant constraints, which may have an effect on the project implementation. In this regard, following may need to be considered:

- Accessibility
- Weather conditions, especially the severity of winter
- Frequency, magnitude and duration of floods
- Migratory patterns of population and availability of labor

Economic analysis
Reflects the economic viability of the selected alternative. Requires a clear definition of the parameters used in the analysis, basically because these may have a significant effect on the adopted size of the project.

Financial analysis
Reflects the financial viability of the selected alternative. The project may be developed in the public or private sector. Keeping in view that the analysis at this stage is based on certain assumptions, the adopted parameters need to be clearly spelled out.

Generally, projects connected to a large network may prove to be financially feasible. The reason is that a market constituted by different types of consumers in cities and industrial, areas having higher income levels than in rural areas, may ensure a return in investment.

However, projects planned to operate in isolation, supplying mainly rural areas with low-income population, may not be financially feasible and their implementation and even operation will require subsidies from government and other sources.

DETAILED DESIGN

This part concentrates on the detailed design of project components, for which complementary field data may be required. Normally, the work is carried out for a given project layout and size, which was decided at feasibility level.

1. INTERDEPENDENCE OF PROJECT LAYOUT, SIZE, COST AND ECONOMICS

Planning of hydropower projects is a multidisciplinary effort, which requires the contribution of professionals in different fields. During the planning process there is a strong interdependence between layout, size, cost and economics.

Normally the approach starts by assessing the power and energy requirements. Therefore, depending on the project size, an initial decision to be taken is whether the project will operate in isolation or as part of an interconnected system.

The study proceeds then with a critical assessment of site conditions, namely:

- Topography, especially the gradient of the river
- Regional and local geology
- Seismicity
- Hydrology and sedimentation
- Present and future water rights
- Environment

Normally, whenever the site conditions allow, the basic aim is to exploit the steepest reaches of the river where sufficient discharge is available. This will lead to a maximum gain of head with the shortest possible waterways and very likely the lowest costs.

Once a basic layout is selected, the next step is to decide about the design discharge of the plant. This decision will be affected by following aspects:

- Hydrologic regime, i.e. availability of water throughout the year
- Mode of operation (isolated vs. interconnected)
- Possibility of seasonal or daily regulation, which depend on topographic, geologic and environmental conditions
- Accessibility
- Availability of construction materials

The design discharge affects the dimension of the waterways, expected project output and project cost.

In general, smaller discharges lead smaller installed capacities and thereby also smaller construction costs. However smaller design discharges yield smaller generated power and thereby smaller benefits. The opposite occurs when lager discharges are considered.

However, site conditions in nature are complex and characterised by variability. Therefore different alternatives of layout may be proposed at the beginning of this procedure. As a matter of fact, it is always advisable to consider all thinkable possibilities of development. Some may be mutually exclusive while others may be only variations of basic cases. The alternatives are then analysed one by one with the same level of detail. The less favourable ones are screened out and the most promising ones are kept for further analyses and investigations.

The aim of this works is to reduce alternatives at each stage of elaboration and to develop an optimised hydropower station. Otherwise layout studies can be proceeded for years without any chance for implementation.

The work may be more time effective with the application of computerised procedures for dimensioning and costing of the project elements. The costs for different design discharges can be calculated easily and compared with the benefits obtained from the generated power. The criteria adopted to assess the project benefits should consider the expected ownership of the project (public or private), mode of operation (isolated or interconnected) as well as the structure of the tariffs (flat rate, differentiated rate, etc.)

When applicable, physical and numerical modelling may be used as a complementary tool to evaluate performance of proposed alternatives.

The interaction of the different fields and disciplines is schematically illustrated in the following figure.

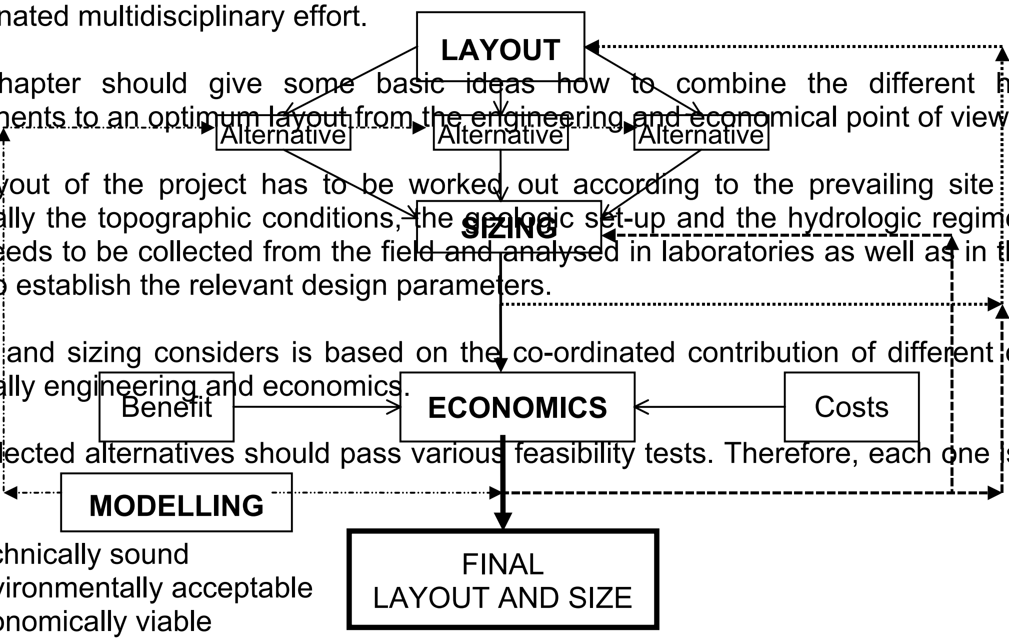

Fig. 1.1: Hydropower Planning – A Multidisciplinary Effort

In the following paragraphs different aspects are described and explained separately to be able to focus on specific aspects of each topic. However, in practice the work is complex requiring a co-ordinated multidisciplinary effort.

This chapter should give some basic ideas how to combine the different hydropower components to an optimum layout from the engineering and economical point of view.

The layout of the project has to be worked out according to the prevailing site conditions, especially the topographic conditions, the geologic set-up and the hydrologic regime. For this, data needs to be collected from the field and analysed in laboratories as well as in the office in order to establish the relevant design parameters.

Layout and sizing considers is based on the co-ordinated contribution of different disciplines, especially engineering and economics.

The selected alternatives should pass various feasibility tests. Therefore, each one is expected to be:

- Technically sound
- Environmentally acceptable
- Economically viable
- Financially workable
- Socially beneficial

- Politically agreeable

The project may become too expensive for implementation when the layout is developed only taken into account engineering aspects. Similarly, when the layout is conceived in view of economics only, the project might fail due to engineering limitations.

Additionally, physical and numerical hydraulic modelling may provide some insight when comparing different project layouts. Keeping in view the complex flow conditions and the sediment transport rates in many mountainous areas, hydraulic modelling is often used to achieve a better layout, dimensioning and design of the project components.

Hydraulic engineering tools are mostly based on one-dimensional approaches, which is reasonable at identification and feasibility stage. Therefore at design stage hydraulic modelling may be used to assess the impact of three-dimensional flows and to confirm/change the assumptions of hydraulic calculations. This can have an impact on the layout of the project and may help to achieve a more efficient design.

The layout and sizing of hydropower projects is the core of the engineering practice and therefore experienced professionals should do the work. Many alternatives are possible by combining different components presented in the chapter of “Developments and Components”, but only a few are reasonable with respect to engineering and economics. On basis of the initial consideration of different alternatives, the aim of this work is to recommend, at the end, one single layout and plant size.

The layout discussion follows with help of case studies from different sites in Pakistan. This is to avoid a discussion based on theoretically possible conditions to ensure a practice-oriented process. The table below gives an overview of several medium and high head hydropower sites, which are discussed with regard to site conditions, headworks, sediment handling structures, hydraulic conduits, selection of turbines and powerhouse layout.