CHAPTER - 7

BASIC PLANNING AND DESIGN ASPECTS

7.1 INTRODUCTION

Planning and design aspects of a pumping station is of great importance because it is necessary to minimize initial capital costs and reduce the operation and maintenance costs. This means that the pumping station must be highly reliable, economical, energy saving and be easy to operate and maintain. The designers, construction and operations staff therefore must give consideration to these aspects when planning, designing, constructing and operating pumping stations.

The basic steps in planning and designing of a pumping station can be identified as:

* **Conceptual study of the project.**
* **Familiarisation with the local characteristics.**
* **Estimation of the water demand.**
* **Planning and designing of structures and equipment.**

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7.2 BASICS OF INVESTIGATION PROCEDURE

7.2.1 INTAKE OR LOW LIFT PUMPING STATION

If the source is a river or a tank, both the present and future users (such as farmers, domestic users etc.) of the source must be identified and minimum down stream flow requirement must be ensured. Return periods of the worst conditions must be considered in the design. The water quality, maximum and minimum water levels should also be taken into a consideration. The type and quantity of trash that are present in the river also must be studied as it can cause problems to operation of pumps. The possible inflow of sand to the pumps should not be forgotten as sand particles can cause serious problems to the moving parts of the pump and its bearings. This has been further discussed in Chapter - 9.

7.2.2 HIGH LIFT PUMPING STATION

Maximum and minimum operational water levels in the sump. influent flow variations to the reservoir. communication facilities and automatic controls must be studied. In the case of a booster pumping station, inlet and delivery line pressure monitoring systems must be planned.

7.2.3 AREA TO BE COVERED

The area to be covered by the project should be well defined. Once it is finalised. all future development plans, such as industrial. urban. employment. tourism etc. shall be considered for the prediction of the population and the expansion of the facility. Migration due to urbanisation and industrial development should be given enough thought rather than theoretical mathematical population predictions.

When calculating the population increase, it is advisable to get information from the Department of Census and Statistics rather than calculating based on past data as mentioned earlier. This is very important when predictions are made for periods more than 10 years ahead during which many things can change.

7.2.4 FUTURE DEMANDS

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This depends on:

* **Per-capita consumption.**
* **Level of service.**
* **Unaccounted for water.**

Per-capita consumption is not a unique figure. This depends on cultural habits. affordability, willingness to pay, climatic conditions, area under consideration and attitude towards water etc. Therefore enough thought should be given before determining this value. The level of service required will also depend on the above factors.

Assuming a figure for unaccounted for water alone is insufficient. The age of the system. attitude towards water. number of unmetered connections and illegal connections will play a vital role in determining this figure. It is always advisable to use a figure prevailing in a similar scheme.

7.2.5 CIVIL ENGINEERING ASPECTS OF PLANNING

Civil Engineering work can commence only after the pump designers decide on the pump types and numbers. Maximum and minimum water levels in the suction side and the delivery side has a direct impact on the total head, hence pumping efficiency. Therefore these levels must be very carefully determined. Flow rate and the total head, in other words, the duty point of the pumps should be determined as accurately as possible.

Intake structures should be designed to take water at different levels in order to get the best quality of water. Flood protection, access during floods, operation under minimum water level conditions, lighting and security should also be considered at the planning and design stage.

Economics and the advantages and disadvantages of having a negative or positive suction systems should be analysed.

Location of the pumping station in the case of river intake should be given careful consideration. The study of the behavior of the stream during low flood and high flood conditions should be studied in both the short term and the long term plan.

Operator facilities, possibility to allow for future expansion, stability of the structure, silt accumulation and equipment for removing silt should be considered at the planning and design stage.

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7.2.6 RELIABILITY, DURABILITY, SAFETY AND FLEXIBILITY

The reliability, durability, safety and the flexibility of a system is very vital from the operational point of view. For civil works this can be achieved by following acceptable guide lines given for the design and construction. In the case of electrical and mechanical equipment specifications, the evaluation of technical proposals and the selection of equipment play an important role. Hence highly durable and efficient energy saving equipment should be selected from among those that have already proven to have high performance.

A high degree of safety can be achieved by practicing proper designs, construction and installation procedures. Unprotected drops, walkways, ladders and temporary or exposed wiring, unguarded moving and rotating parts are the major causes of accidents at pumping stations.

There may be cases where more than one combination of pumps should be operated to suit the system demands. Therefore depending on the situation, more than one combination should be available for the operator to have flexibility wherever possible. However low efficiency and system problems should be avoided. This could be achieved only if considered at the design stage. Example: solo and parallel operation of pumps.

7.2.7 ENVIRONMENTAL CONSIDERATION

There can be detrimental effects in the down stream side of the intake to fish, plant and cultivators and other river users. These should be avoided or mitigated by carrying out an environmental impact assessment.

Noise and vibration should be minimised. It is important to deal with these problems at the beginning of the project.

7.3 PUMPING EQUIPMENT

Planning and design of pumping equipment involves the following items which are not independent but correlated.

* **Selection of pump types.**
* **Determination of shaft type.**
* **Determination of floor type.**
* **Determination of number of pumps.**
* **Pump installation.**
* **Pump speed.**
* **Layout of equipment.**
* **Electrical Facilities.**

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7.3.1 **PUMP TYPE**

All centrifugal, Mixed flow and Axial flow pumps can be divided into two groups namely high head and low head. Low head pumps are generally used for drainage purposes and are mainly of the axial flow type.

For water supply purposes high head pumps as well as medium head pumps are used. centrifugal and mixed flow types fall into this group.

The figure appearing on top of the overleaf shows a typical example of applicable ranges for respective pump type.

The bottom figure of the overleaf is the applicable diagram for high head centrifugal pumps. Kilowatt ratings are the motor out puts for reference.

Annexes 7.1, 7.2 and 7.3 give the applicable diagrams for high head vertical shaft mixed flow pumps, low head mixed flow pumps and low head axial flow pumps respectively.

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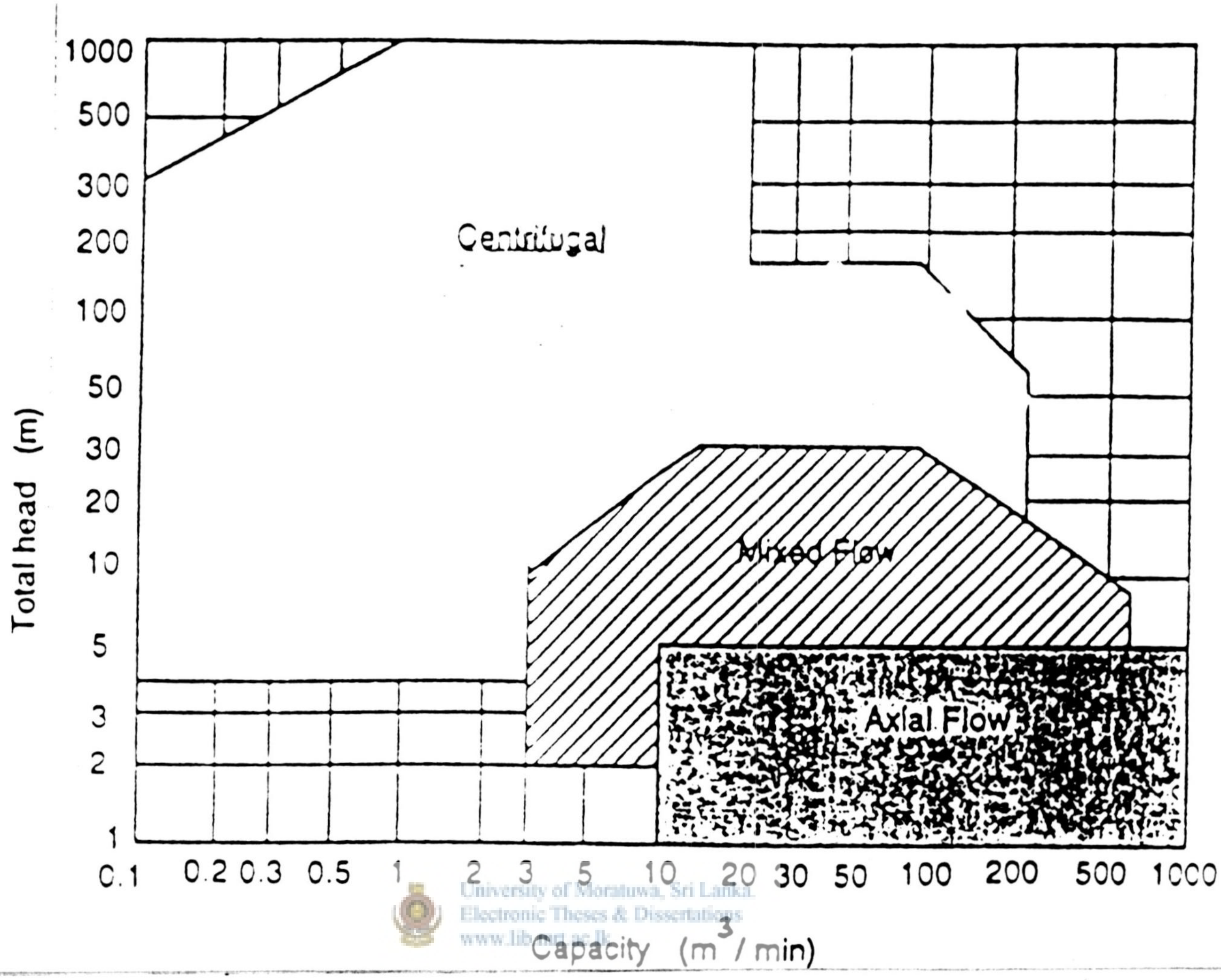

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Fig 7.1 (A) Applicable Ranges

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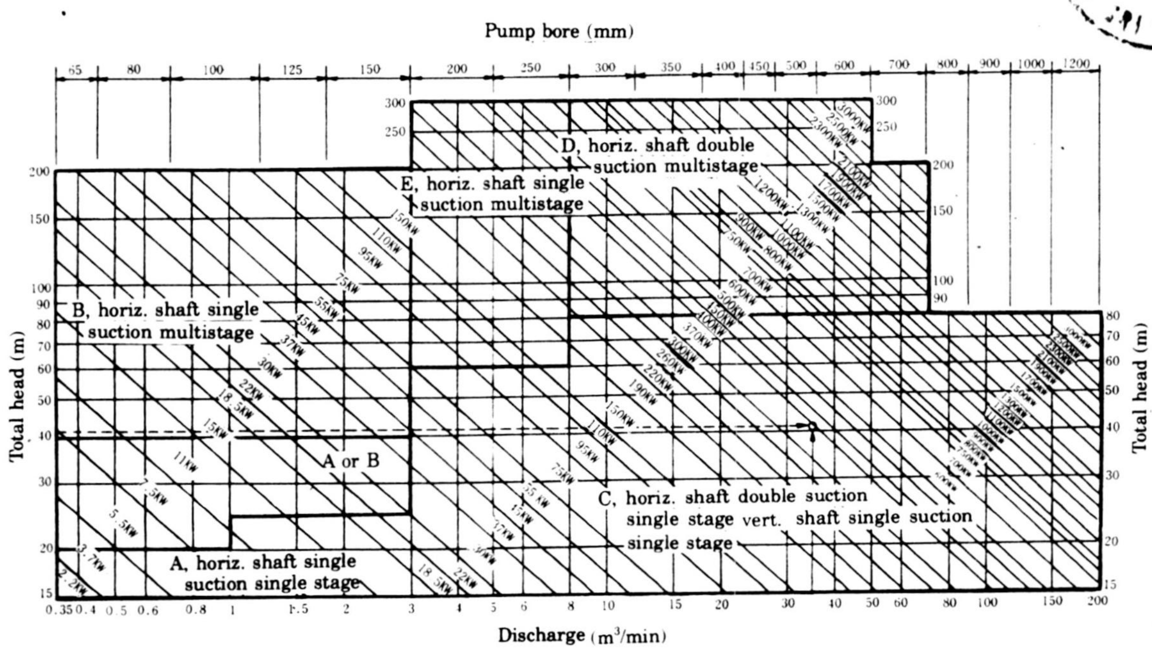

Fig 7.1 (B) Applicable diagram for high-head centrifugal pumps (50Hz)

7.3.2 SHAFT TYPE

Selection of shaft type (horizontal or vertical) depends on various factors such as site and installation conditions etc. Please refer Chapter 9 for a detailed assessment.

7.3.3 FLOOR TYPE

The common types of pumping station floors in the water industry are,

* **Single floor.**
* **Two floor.**

Each of these types has its own merits and demerits. Generally the floor type is mainly governed by the type of installation and type of the pump to suit site conditions.

7.3.4 NUMBER OF PUMPS

The number of pumps to be installed should not be determined arbitrarily. The following points should be considered critically before determining the number of pumps.

* **Area available for installation.**
* **Current water demand.**
* **Variations in water demand, flexibilities and reliability in operations.**
* **Capital cost of civil works, plant and equipment.**
* **Operational cost of different options.**
* **Future demand for water.**

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The frequently used combinations are;

a). Two pumps of same capacity - One duty one standby.

b). Three pumps of same capacity - Solo or two in parallel.

c). Four pumps of same capacity - Solo or two or three in parallel.

d). Two pumps of two capacities - One duty one stand by or two in parallel.

e). Three pumps of two capacities - Two large, one small, solo or parallel.

f). Four pumps of two capacities - Three large one small, solo or parallel.

g). Variable speed pumps.

According to the different pump combinations, the size of the pump house, the size of the pumps, the size of the driver, sizes of ancillary equipment, pump efficiencies will vary.

Hence an economic analysis should be carried out to select the most appropriate combination.

The author suggests the following;

a). Design period of civil structures 40 years.

b). Design period of Mechanical & Electrical equipment 10 - 20 years .(depending on size).

c). Rate of return on capital 12%

d). Inflation 5%

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e). Therefore effective discounting rate ≅ 7%

Using the above factors in the equation

Annual expenses = Total Expenses x $i(1+r)^n/(1+i)^n - 1$

Where,

i = effective interest rate (7%) assumed

n = economical life in years.

annual expenses for civil engineering costs and Electro-Mechanical cost can be calculated.

Based on the pump efficiencies, pump operational costs per annum can also be calculated.

Hence by adding total capital and operational costs per annum can be calculated. Therefore the best combination can be selected accordingly.

A rough guidance for selecting number of pumps for Raw Water and Treated Water Pumps is given below: (Source : Seminar Papers Ebara Pumps).

Capacity	**Number of Pumps**
Upto 2,500 m3/day	One duty One standby
2,500 - 9,000 m3/day	Two duty One standby
Over 9,00 m3/day	Three or more duty One standby

Table 7.1

Variable speed pumps are more advantages from the energy saving point of view. However the equipment costs are rather high and high degree of professional maintenance standards are also required. Variable speed drives are suitable for rising system head curves and where there are considerable demand fluctuations. For parallel operation of identical units, respective pump speeds are synchronized.

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7.3.5 PUMP INSTALLATIONS

In addition to vertical turbine pumps and submersible pumps, centrifugal pumps can be installed to have positive suction conditions. This method of installations has several advantages namely;

* **Elimination of priming systems.**
* **Achievement of higher speeds.**
* **Smaller pumps and other handling equipment.**
* **Economical.**
* **Sufficient $NPSH_A$.**

However the selection of the method of installation will depend mainly on site conditions.

7.3.6 PUMP SPEED

As discussed in Chapter 1, to avoid cavitation pump speed is given by the basic equation

$$N = S\,(H_v + H_{sl})^{3/4} / Q^{1/2}$$

Where S = 1000 and

at Sea level and at 30 °C with an allowance of 0.5 m the equation boils down to

$$N = 1000(9.4 \pm H_{sl})^{3/4} / Q^{1/2}$$

Where H_{sl} is +ve or -ve Suction head and Q is in m^3/min. (Q/2 for double suction)
Figure given in page 25 is a diagram for determining the maximum pump speed for different suction conditions and capacities for volute pumps (Assuming S = 1000).

(Source : Pumping Station Engineering Hand Book 1991).

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7.3.7 LAYOUT OF EQUIPMENT

In laying out of the equipment in pumping stations, consideration should be given to the following;

* **Avoidance of bends on the suction side.**

* **Provision of sufficient space around pumps for easy installation inspection and maintenance.**

(Say = L_s 1/3 L) Where L = Length of Pumping Set

L_s = Space between pumping sets and also between walls and pumping sets.

* **Direction of intake and suction flange.**

* **Number of Pumps required in the installation.**

Pumps can be arranged as follows;

* **In a straight line.**

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* **Opposite to each other.**

* **In parallel.**

* **Staggered.**

* **In slanting position.**

These arrangements are shown in Annex 7.4. The most suitable arrangement should be selected according to the situation as there is no laid down rule.

7.3.8 ELECTRICAL FACILITIES

The planning and design aspects of the main electrical facilities consists of the study of;

* **Availability and reliability of the power supply in the project area.**

  This includes the quality of the power supply as well.

* **Estimation of present and future power requirements.**

  This depends on present and future water demands.

* **Calculation of transformer capacity.**

  This depends on equipment efficiency and power factor.

* **Decision on standby generators.**

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That is to decide whether standby generators should be provided for or not depending on the importance of the scheme and the reliability of the available power supply.

* **Determination of standby generator capacity.**

This depends on Voltage/Phase, Maximum voltage drop (Instantaneous), Type of fuel. Service duty (Standby/Prime Power), Altitude, Location Temperature, Input load sequence. Type of Load (loaded/unloaded) and method of starting. Computer software programmes can be made use of to determine the standby generator capacity.

* **Decision in the operating voltage for the motors.**

  Specially for the larger pumping stations.

* **Operational modes of pumps, valves and other auxiliaries.**

  That is manual or automatic.

* **Degree of motor enclosure protections.**

  Drip proof totally enclosed fan cooled or totally enclosed internally cooled motors are generally used.

* **Method of starting of Motors.**

  This depends on the rated capacity of the motor and the quality of electricity supply available. It can be DOL, Star-Delta, Auto-Transformer or Soft starters. (Solid state Starters).

* **Calculation of condenser capacity for power factor improvements.**

  In case of installations exceeding 50 KVA capacities.

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* **Design of distribution boards, motor, other equipment control systems and telemetry systems.**

  For flow measurement and operational control.

* **Provision of single line wiring diagrams, indicating electrical distribution, panel layouts and control sequences in case of automatic operations.**

Finally strict clear specifications must be drawn out giving all related standards and dimensions in order to obtain reliable equipment.

7.3.9 ENERGY CONSERVATION

In most of the pumping stations the energy required to carry out pumping is nearly 90% of the total power consumption at the pumping station and in smaller pumping stations this figure is almost 100%. Every year the cost of power is rising and therefore action should be taken to reduce the operational costs by reducing the cost of pumping. Energy required to pump a unit volume of water is a good measure of the pumping efficiency, the unit being kWh/m^3.

Power absorbed by the pump is given by

$$P = Q \times H/367 \times \eta_p \times \eta_m \quad kW$$

Where P = Power

Q = Total capacity (m^3/Hr)

H = Total head (m)

η_p = Pump efficiency (%)

η_m = Motor efficiency (%)

367 = Conservation factor

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∴ Unit energy consumption is (Po) becomes

$$P_o = H/367 \times \eta_p \times \eta_m \quad kWh/m^3$$

Hence, unit energy consumption is directly proportional to the total head and inversely proportional to pump and motor efficiencies.

Therefore to minimise the unit energy consumption pump should operate at its best efficiency point and also the motor efficiency must be at its maximum.

Therefore the calculation of head and capacity accurately is very important. Over design of the total head may lead to operate the pump with the discharge valve throttled, this will result in power losses.

Higher the output of the motor higher the efficiency however, the efficiency of a particular motor is maximum at its full load output. Since operation of a motor at part loads results in reduced efficiencies, overrated motors are not recommended.

Higher the output of the motor higher the efficiency however, the efficiency of a particular motor is maximum at its full load output. Since operation of a motor at part loads results in reduced efficiencies, overrated motors are not recommended.

Over a wide range, energy efficient motors are available. These motors are specially designed in standardised frames and outputs with optimum efficiencies and will produce significant energy savings making them a cost effective investment for the majority of applications. Use of these motors can reduce pumping costs.

Other methods available for energy saving are;

* **Modification of impeller to suit the system head**
* **Solo and parallel operation to meet the demand.**
* **Variable speed drives for varying demands.**
* **Selection of most economical diameter for long pumping mains.**
* **Separate booster pumping for different elevations in distribution systems.**
* **Selection of pump capacities to suit the system head** (Please see chapter 9).

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Except method 1, above all other possible methods should be looked into at the planning and design stage if pumping costs are to be reduced.