45 PUMPED DRAINAGE

45.1 INTRODUCTION

Urban drainage and stormwater system design in low-lying and tidal areas involves a number of special considerations. Because of the difficulties of designing gravity systems in low-lying areas it may be necessary to use floodgates/ tidegates, and/or pumped systems. This chapter discusses pumped drainage systems.

45.2 PLANNING PROCESS OF PUMPING STATION

Because of its high cost and the potential problems associated with pump stations, stormwater pumping is generally used only when gravity drainage is not feasible. When operation and maintenance cost are capitalised, a considerable expenditure can be justified for a gravity system. Keeping the drainage area as small as possible and providing storage in storm drains can reduce the pumping capacity required to handle peak runoff rates.

Pump station design presents the designer with a challenge to provide a cost-effective drainage system that meets the needs of the project. There are myriad of considerations involved in their design. Below is a listing of some of them:

- wet-pit vs. dry pit
- type of pumps
- number and capacity of pumps
- motor vs. engine drive
- peak flow vs. storage
- force main vs. gravity
- above grade vs. below grade
- monitoring systems
- backup systems
- maintenance requirements

Many of the decisions regarding the above require engineering judgement and experience. To assure cost-effectiveness, the designer should assess each choice and develop economic comparisons of alternatives on the basis of annual cost. However, some general recommendations are made in the subsequent sections, which will help minimise the design effort and the cost of these expensive drainage facilities.

45.2.1 Planning of Site Location

Several important considerations affect planning and site selection for pump station. The access necessary for safe operation, maintenance, and emergency functions must be available at all times. Hydraulic conditions will have primary importance in site selection, but site appearance and sound attenuation should be also assessed. In normal circumstances, the location of the pump station is at the drainage system outlet, just immediately upstream from the receiving waterbody to minimise the conveyance's head-loss.

Foundation investigations are necessary and enough space must be provided in the area outside the station to accommodate parking as well as movements of large machinery.

A dependable energy source is essential. The primary source of electrical power for most stormwater pump stations is a public utility. Underground service is preferred for safety and aesthetic reasons, and overhead lines into the station should be avoided, as they present potential safety hazards during large equipment operation.

The essential components that require to be considered in the preparation of the layout for the pumping station are as follows:

- Overflow weir and control gate structures
- Storage reservoir
- Pump sump
- Outflow channel from the pumps to receiving waterbody
- Control panel and switchboard room
- Sub-station and/or generator room
- Excess road and ramp, parking space and service area

45.2.2 Station Types

Basically, there are two types of stations, wet-pit and dry-pit. Each of these types are discussed in the following:

Wet-Pit Stations: In the wet-pit station, the pumps are submerged in a wet well or sump with the motors and the controls located overhead. With this design, the storm water is pumped vertically through a riser pipe. The motor is commonly connected to the pump by a long drive shaft located in the centre of the riser pipe. See Figure 45.1 for a typical layout. Another type of wet-pit design involves the use of submersible pumps. The submersible pump commonly requires less maintenance and less horsepower because a long drive shaft is not required. Submersible pumps are now available in large sizes. A major advantage is that they are designed to allow removal of pumps without entering the wet well.

A small dewatering pump is necessary to drain empty the wet pit for inspection and maintenance purposes. It also functions to desilt the pit if necessary.

Dry-Pit Stations: Dry-pit stations consist of two separate elements: the storage box or wet well and the dry well. Stormwater stored in the wet well is connected to the dry well by horizontal suction piping. The stormwater pumps are located on the floor of the dry well. Centrifugal pumps are usually used. Power is provided by either close-coupled motors in the dry well or long drive shafts with the motors located overhead. Small submersible sump pumps or portable pumps are provided in the dry well of dry-pit stations to protect equipment from seepage water damage.

The main advantage of the dry-pit station for storm water is the availability of a dry area for personnel to perform routine and emergency pump and pipe maintenance. See Figure 45.2 for a typical layout.

Since dry-pit stations are as much as 60% more expensive than wet-pit stations, wet-pit stations are most often used. Dry-pit stations are more appropriate for handling sewage because of the potential health hazards to maintenance personnel. The hazards associated with pumping storm water usually do not warrant the added expense. Some advantages associated with dry-pit stations include ease of access for repair and maintenance and the protection of equipment from fire and explosion.

45.2.3 Pump Types and Selection

The two main categories of pumps commonly available are the turbo-type and displacement, and the former is most commonly used in stormwater pumping system. Basically, this category of pumps applies energy to liquid by means of an impeller rotating inside a casing. The turbo-type pumps are further divided into three types.

1. Centrifugal pumps - These pumps apply pressure and velocity energy to liquid by centrifugal force of an impeller. They will handle any range of head and discharge but are the best choice for high head applications. The centrifugal pumps generally handle debris quite well because the impellers can be designed with large openings to avoid clogging.

2. Axial pumps - These are pumps that use vane lifting force to apply pressure and speed energy to liquids and further to convert speed energy to pressure energy by diffuser vanes. They are commonly used for low head, high discharge applications. Axial flow pumps do not handle debris particularly well because large and hard objects or fibrous material may damage and jam the propellers.

3. Mixed-flow pumps - These are pumps that give pressure and velocity energy to liquids by the centrifugal force of impellers and the lifting force of vanes, which is the combination of the above two types. They are used for intermediate head and discharge applications and handle debris slightly better than propellers.

All the pumps can be driven by motors or engines housed overhead or by submersible motors. Submersible pumps frequently provide special advantages in simplifying the design, construction, maintenance and therefore the cost of the pumping station (See Figure 45.3). Noise generated from the motors will also be less.

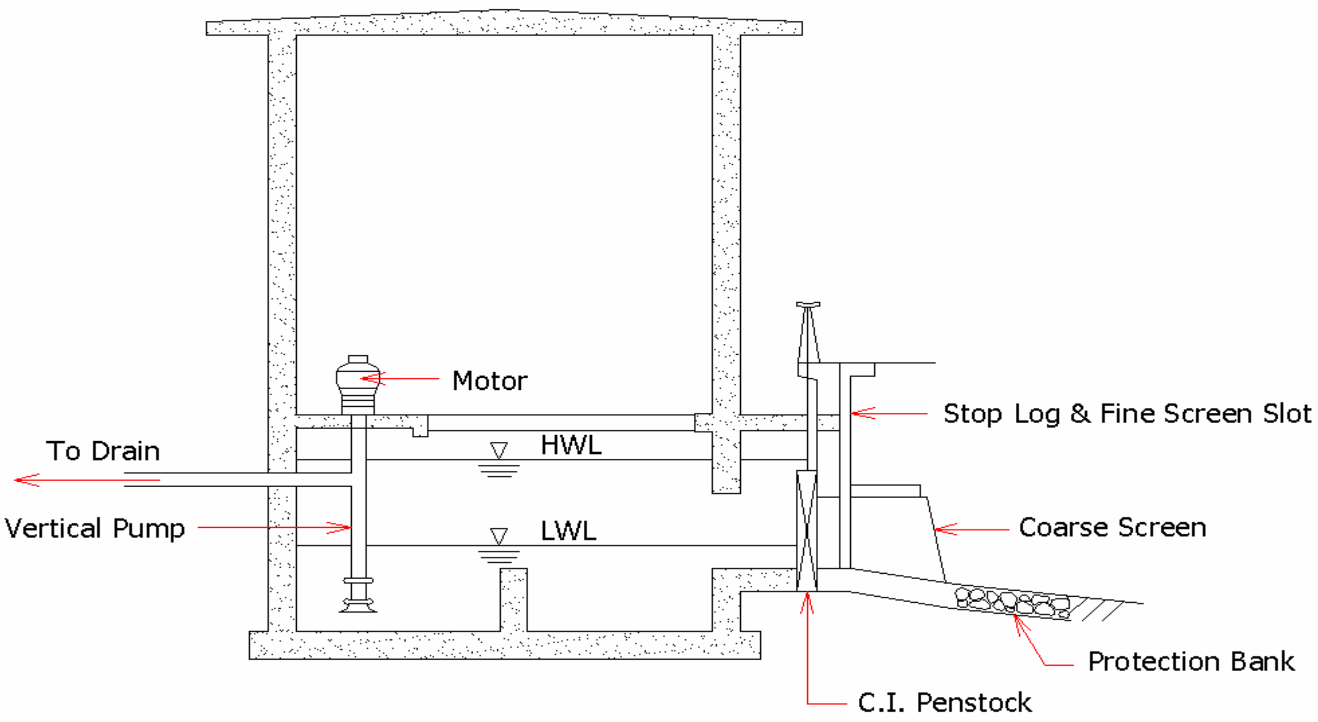

Figure 45.1 Typical Wet-pit Station

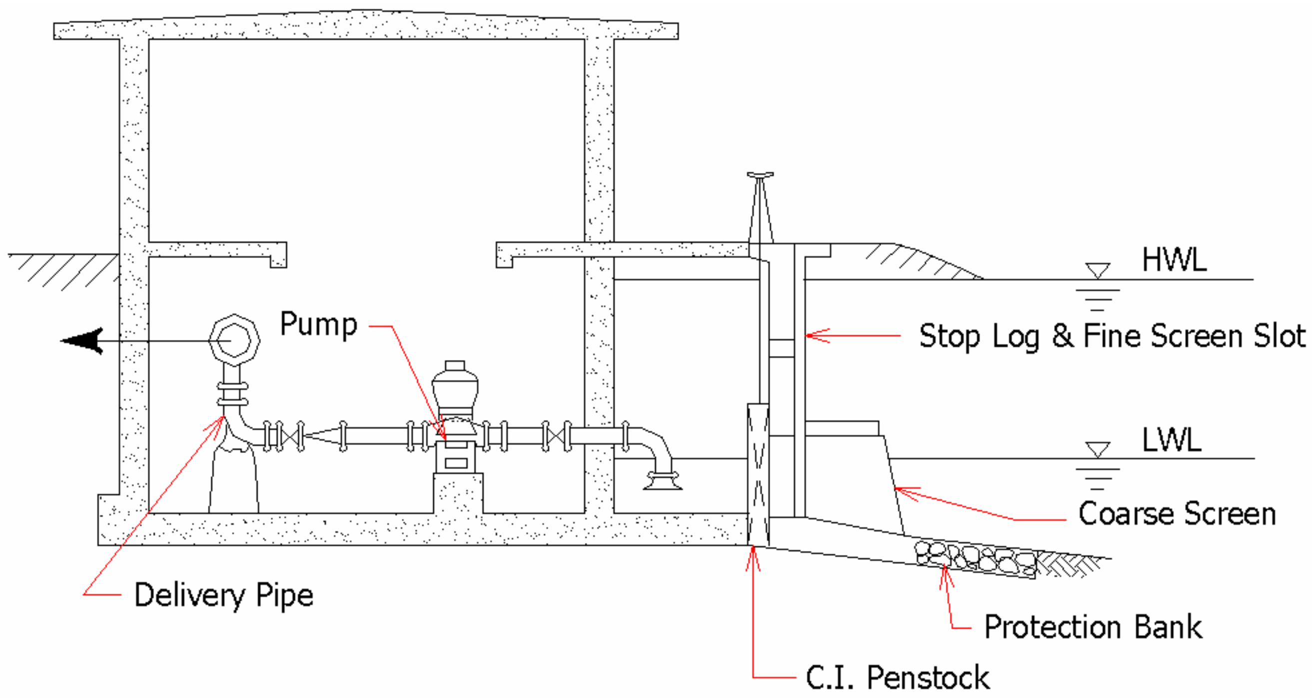

Figure 45.2 Typical Dry-pit Station

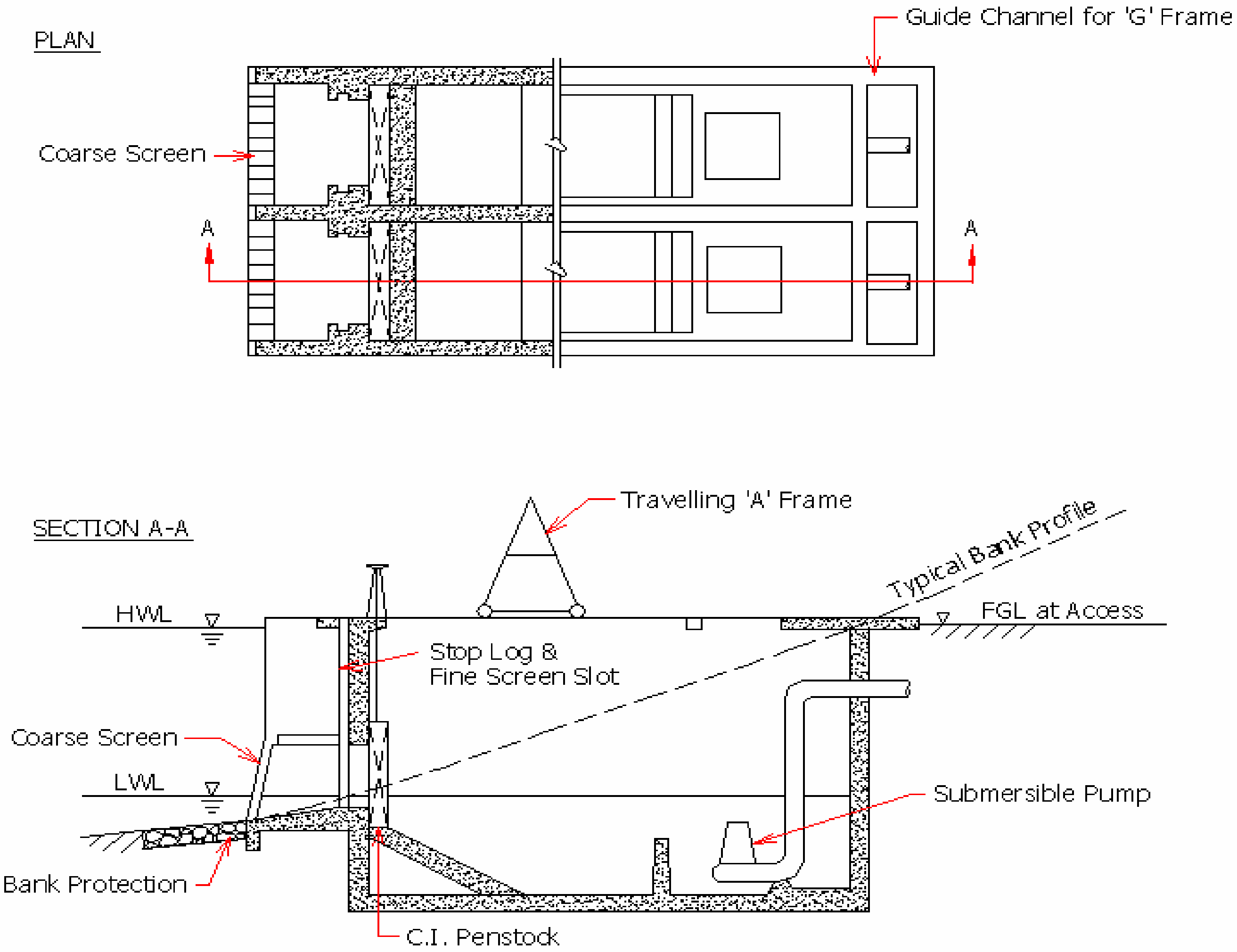

Figure 45.3 Typical Submersible Stormwater Pump

The pump selection procedure is to first establish the criteria and then to select a combination from the options available, which clearly meets the design criteria. Cost, reliability, operating and maintenance requirements are all important considerations when making the selection procedure. First costs are usefully of more concern than operating cost in storm water pump stations since the operating periods during the year are relatively short. Ordinarily, providing as much storage as possible minimises first costs.

The performance curve developed by the manufacturer should be obtained before selecting a particular pump. The advantage of using standard equipment, however, often outweighs the need to obtain a perfectly tailored design.

Either two to three pumps should be used, except in very large installations. If the total discharge to be pumped is small, a two-pump station is preferred. Consideration may be given to over sizing the pumps to compensate, in part, for a pump failure. The two-pump system could have pumps designed to pump from 66% to 100% of the required discharge and the three-pump system could be designed so that each pump would pump 50% of the design flow. The resulting damage caused by the loss of one pump could be used as a basis for deciding the size and numbers of the pumps.

Economic limitations on power unit size as well as practical limitations governing operation and maintenance should be used to determine the upper limit of pump size. The minimum number of pumps used may increase due to these limitations.

Except for low flow or dry weather pumps, which may be necessary to prevent too frequent starting and stopping of bigger pumps, all pumps in a station should be of the same size and type to enable all pumps to be freely alternated into service. It is recommended that an automatic alternation system be provided for each pump station to automatically redefine the lead pump after each pump cycle. The lead pump will always come on first, but this pump would be redefined after each start so that each pump in turn would become the lead pump. This equalises wear and reduces needed cycling storage. It also simplifies scheduling maintenance and allows pump parts to be interchangeable. Hour meters and start meters should be provided to aid in scheduling maintenance.

Considering the short duration of high inflows, the low frequency of the design storm, the odds of a malfunction, and the typical consequences of a malfunction, spare or standby pumps are typically not warranted in storm water applications. If the consequences of a malfunction are particularly critical, it is more appropriate to add another main pump and reduce all the sizes accordingly.

45.2.4 Pump Sump and Intake System

Pump to pump, pump to back wall and pump to sidewall clearances should be as recommended by the Hydraulic Institute (see Figure 45.7a and 45.7b for vertical pump dimensions). The clearance from the pump inlet to the floor plus the pump submergence requirement constitutes the distance from the lowest pump off elevation to the wet well floor. The final elevation may have to be adjusted if the type of pump to be installed is different than anticipated.

The primary function of the intake structure is to supply an even distribution of flow to the pumps. An uneven distribution may cause strong local currents resulting in reduced pump efficiency and undesirable operational characteristics. The ideal approach is a straight channel coming directly into the pump or suction pipe. Turns and obstructions are detrimental, since they may cause eddy currents and tend to initiate deep cored vortices. The inflow should be perpendicular to a line of pumps and water should not flow past one pump to get to another. Unusual circumstances will require a unique design of the intake structure to provide proper flow to the pumps.

For important and major pumping system where the configuration of the pump inlet and pump sump cannot comply with the recommended dimensions provided by the manufacturer due to site constraints or other reasons, physical modelling is recommended to be carried out to test the proposed configuration and layout.

45.2.5 Collection Systems

Stormwater drains leading to the pumping station are typically designed on mild grades to minimise depth, pumping head and associated construction cost. To avoid siltation problems in the collection system, a minimum grade that produces a velocity of 1.0 m/s in the conveyance system while flowing full is suggested. Minimum cover or local head requirements should govern the depth of the uppermost inlets. The inlet should enter the station perpendicular to the line of pumps. The inflow should be distributed equally to all pumps by means of flow channels or baffles.

In normal circumstances to reduce the operation cost, by-pass is constructed to enable the stormwater to be gravity drained when the waterlevel at receiving waterbody is low such as during normal flow or low tides at the river. Control valves such as flap gates or level control gates are used at the outlet of the by-pass so that if the gravity drainage is not possible, the stormwater flow will be diverted into the pump sump so that it will be discharged off through pumping system. This will also disallow the high waterlevel at the receiving waterbody from backflow into the drainage system.

It is recommended that screens be used to prevent large objects from entering the system and possibly damaging the pumps. Screens should be placed in a collecting chamber upstream of the pump station. This approach has the additional advantages of possibly eliminating costly trash racks and simplifying debris removal since debris can be more easily removed from the manhole than from the wet well. The screen inlet should be adequately sized by taking into consideration of the partial clogging of the inlet by debris that prevents the full flood flows from entering the pump sump.

45.2.6 Discharge System

The discharge piping should be kept as simple as possible. Pump systems that lift the storm water vertically and discharge it through individual lines to a gravity storm drain as quickly as possible are preferred. Individual pump discharge lines are the most cost-effective system for short outfall lengths. Damaging pump reversal could occur with very long force mains. The effect of storm water returning to the sump after pumping stops should be considered.

Check valves must be provided on the individual lines to keep storm water from running back into the wet well. Check valves should preferably be located in horizontal lines. Gate valves should be provided in each pump discharge line to provide for continued operation during periods of repair, etc. The number of valves required should be kept to a minimum to reduce cost, maintenance and head loss through the system.

45.3 DESIGN CONSIDERATIONS FOR PUMP AND STORAGE SIZING

45.3.1 Hydrology

The design standard and procedure to derive the design flood hydrographs for a stormwater pumping station should be the same as for the major drainage system. However, if storage is formed part of the system, not only the design peak discharges need to be considered but also the runoff volumes and hydrograph shapes for various rainstorm duration.

Every attempt should be made to keep the drainage area tributary to the station as small as possible. By-pass or pass-through all possible drainage to reduce pumping requirements. Avoid future increase in pumping by isolating the pump drainage area with the gravity drainage area through high level drains or bunding to prevent off-site drainage from possibly being diverted to the pump station. Hydrologic design should be based on the ultimate development of the area, which must drain to the station.

Designers should consider storage, in addition to that which exists in the wet well, at all pump station sites. Additional storage, skilfully designed, may greatly reduce the peak pumping rate required. An economic analysis can be used to determine the optimum combination of storage and pumping capacity.

If storage is used to reduce peak flow rates, a routing procedure must be used to design the system. The routing procedure integrates three independent elements to determine the required pump rate: an inflow hydrograph, a stage-storage relationship and a stage-pump discharge relationship. Computer methods are advantageous to simplify this calculation.

45.3.2 Discharge Head and System Curve

Most types of stormwater pumps are sensitive to changes in head, therefore the total head imposed on the pumps should be calculated as accurately as possible. All valve and bend losses should be considered in the computations. In selecting the size of discharge piping, consideration should be given to the manufactured pump outlet size vs. the head loss that results from a matching pipe size. The discharge pipe may be sized larger to reduce the loss in the line. This approach should identify a reasonable compromise in balancing cost.

The combination of static head, velocity head and various head losses in the discharge system due to friction is called total dynamic head (TDH). The TDH is computed as follows:

$$TDH = H_S + H_f + H_v + H_L \tag{45.1}$$

where: TDH = total dynamic head, (m)

H_s = static head, (m)

H_f = friction head, (m)

H_v = velocity head, (m) [= $V^2/(2g)$]

H_L = losses through fittings, valves, etc. (m)

These various head losses can be minimised by the selection of correctly sized discharge lines and other components.

The total dynamic head (TDH) must be determined for a sufficient number of points to draw the system head curve. Adjustments may need to be made to these curves to account for losses within the pumping unit provided by the manufacturer.

Once the head losses have been calculated for the range of discharges expected, the system curve (Q vs. TDH) can be plotted. This curve defines the energy required to pump any flow through the discharge system. It is especially critical for the analysis of a discharge system with a force main. When overlaid with pump performance curves (provided by manufacturer), it will yield the pump operating points (see Figure 45.4).

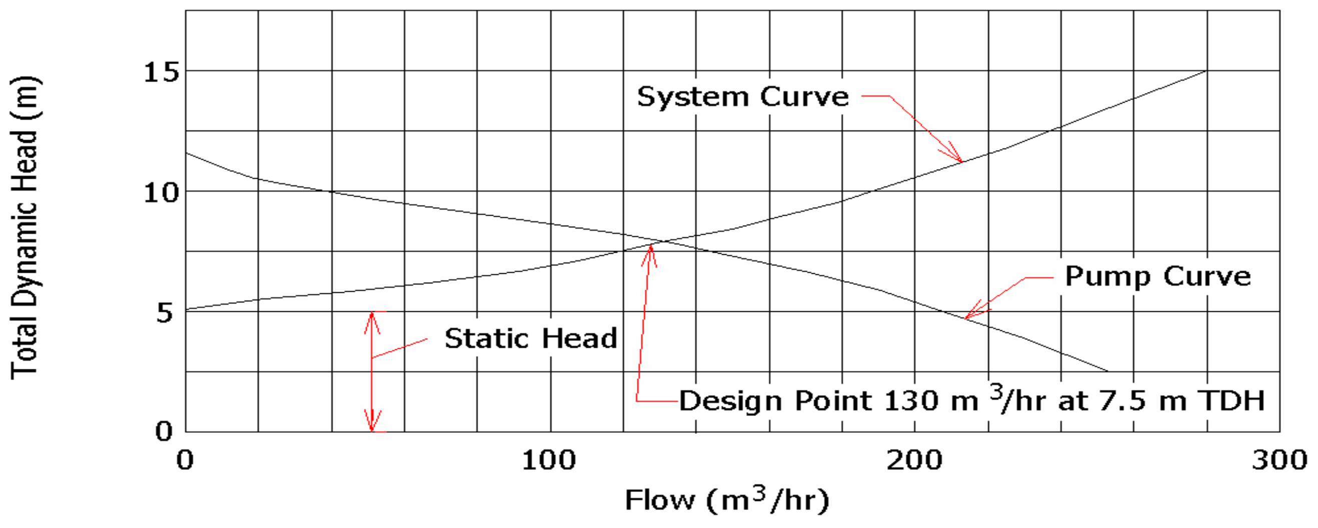

Figure 45.4 System Head Curve

When the pump is raising the water from lowest level, the static head will be greatest and the discharge will be the least. When operating at highest level, the static head will be the least and the discharge will be greatest. The capabilities of the pump must always be expressed in both quantity of discharge and the total dynamic head at a given level.

Pumps should be selected to operate with the best efficiency at the design operating point. The efficiency of a stormwater pump at its design point may be 75 or 80% or more, depending on the pump type. However if the pump will only operate infrequently, maximising efficiency is not so important.

When that static lift is greatest (low water in sump), the power required (kilowatts) might be the greatest even though the quantity of water raised is less. This is because the pump efficiency may also be many less. The pump selection should be made so that maximum efficiency is at the design point.

All pumps for a given station are selected to operate together to deliver the design flow (Q) at a total dynamic head (TDH) computed to correspond with the design water level. Because pumps must operate over a range of water levels, the quantity delivered will vary significantly between the low level of the range and the high level. Typically, the designer will be required to specify at least three points on the performance curve. These will typically be the conditions for the TDH near the highest head, the design head versus pump capacity is always plotted for each pump by the manufacturer (see Figure 45.5 for a typical curve). When running, the pump will respond to the total dynamic head prevailing and the quantity of discharge will be in accordance with the curve. The designer must study the pump performance curves for various pumps in order to develop an understanding of the pumping conditions (head, discharge, efficiency, horsepower, etc.) through the full range of head that the pump will operate under.

45.3.3 Pump and Storage Sizing

There is a complex relationship between the variables of pumping rates, storage and pump on-off settings in pump station design. Additionally, the allowable pumping rate may be set by storm water management limitations, capacity of the receiving system, desirable pump size, or available storage. Multiple pumps are usually recommended for redundancy, and the number of pumps may be varied to achieve the required pump capacity. A trial and success approach is usually necessary for estimating pumping rates and required storage for a balanced design. The goal is to develop an economic balance between storage volume and allowable or desired pump capacity.

Storage capacity is usually required as a part of station design to permit the use of smaller, more economical pumps. When determining the volume of storage for a pump station, the designer should recognise that a balance must be obtained between storage and required pump size. The process of determining appropriate storage volumes and pump sizes requires a trial and success procedure in conjunction with an economic analysis. Pump stations are costly, and alternatives to minimise total costs need to be considered.

The principle of minimum run time and pump cycling should also be considered during the development of an optimum storage requirement. Typically, the concern for meeting minimum run times and cycling time will be reduced with increased storage volume because the volume of storage is sufficient to prevent these conditions from controlling the pump operation.

An important initial evaluation in pump station design is how much total storage capacity can or should be provided. Using the inflow hydrograph and pump-system curves, various levels of pump capacity can be tried and the corresponding required total storage can be determined. Comparing the inflow hydrograph to the controlling pump discharge rate as illustrated in Figure 45.6 gives an estimate of the required storage volume. The volume in the shaded area is the estimated volume available above the last pump turn-on point. The volume in the shaded are is the estimated volume available above the last pump turn-on point. The basic principle is that the volume of water as represented by the shaded area of the hydrograph in Figure 45.5 is beyond the capacity of the pumps and must be stored. If most of the design storm is allowed to collect in a storage facility, a much smaller pump station can be utilised, with anticipated cost benefits. If the discharge rate is to be limited, ample storage is essential.

A worked example of the pump rate and storage volume calculation is given in Appendix 45.A.

45.3.4 Cycling Sequence and Volumes

Cycling is the starting and stopping of pumps, the frequency of which must be limited to prevent damage and possible malfunction. The pumping system must be designed to provide sufficient volume for safe cycling. The volume required to satisfy the minimum cycle time is dependent upon the characteristics of the power unit, the number and capacity of pumps, the sequential order in which the pumps operate and whether or not the pumps are alternated during operation. The development of the mass curve routing diagram will aid in the definition of pump cycling and volume requirements.

45.3.5 Water-Level Sensors

Water-level sensors are used to activate the pumps and, therefore, are a vital component of the control system. There are a number of different types of sensors that can be used. Types include the float switch, electronic probes, ultrasonic devices, mercury switch, and air pressure switch.

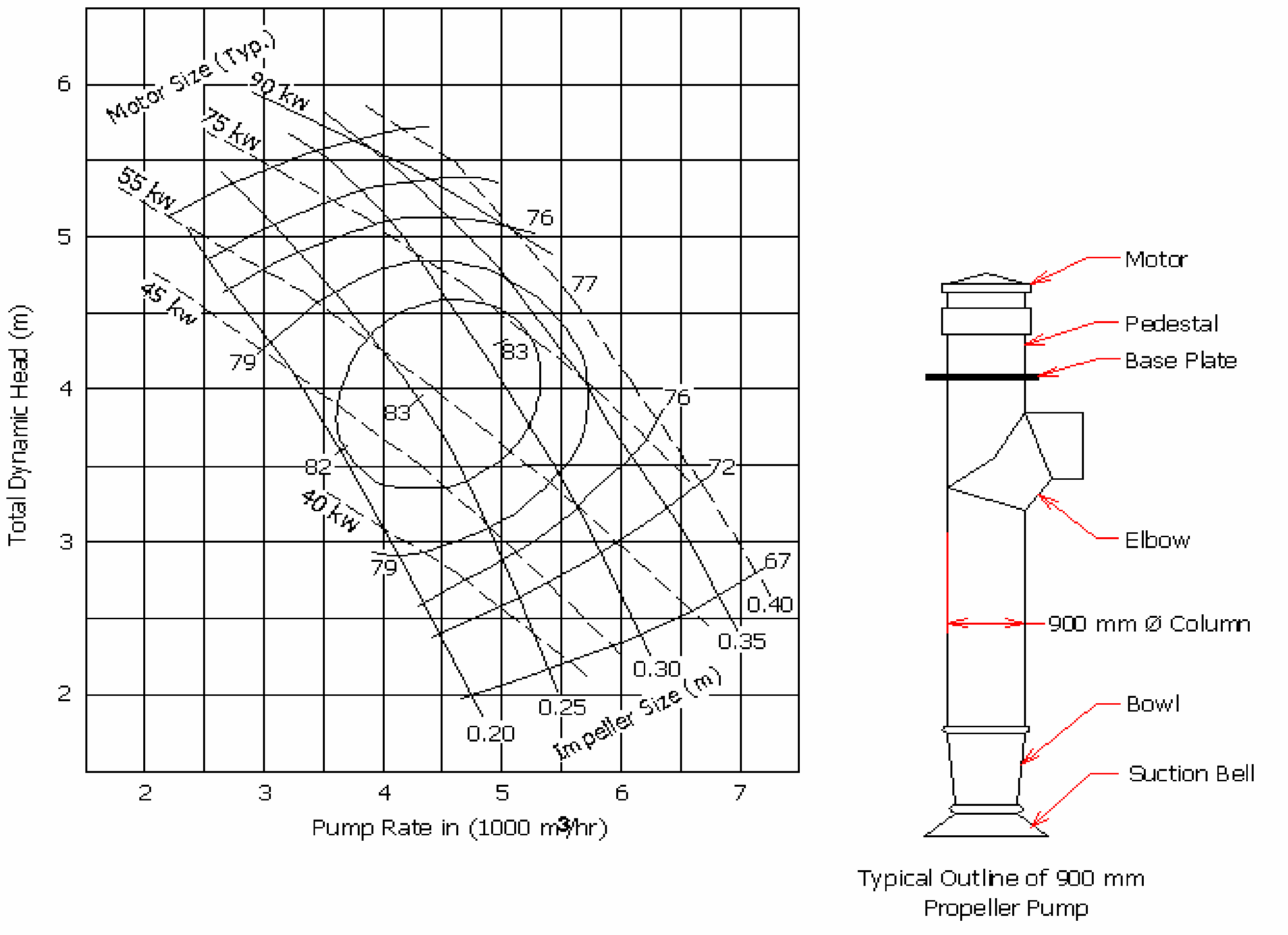

Figure 45.05 Performance Curve for 900 mm Pump Rotating at 590 r.p.m

Figure 45.5 Performance Curve for 900 mm Pump Rotating at 590 r.p.m

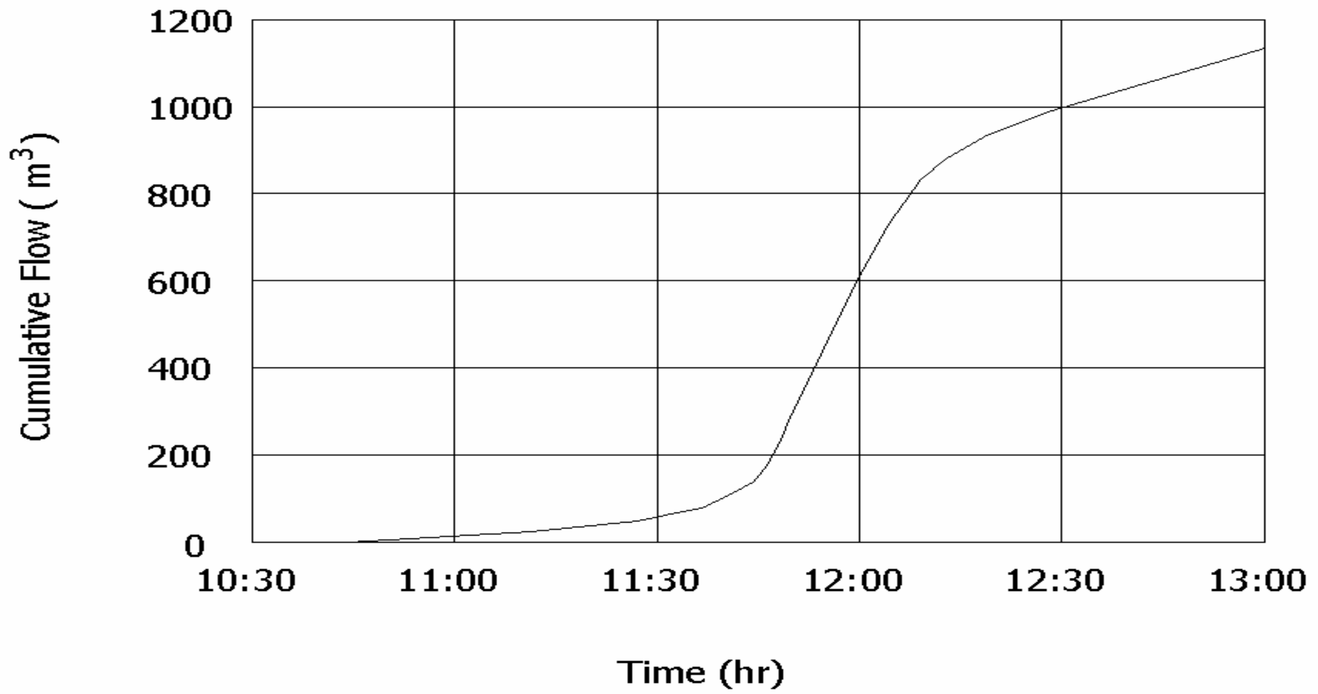

Figure 45.6 Estimated Required Storage from Inflow Hydrograph.

The location or setting of these sensors control the start and stop operations of pump motors. Their function is critical because pump motors or engines must not start more frequently than an allowable number of times per hour (i.e., the minimum cycle time) to avoid damage. To prolong the life of the motors, sufficient volume must be provided between the pump start and stop elevations to meet the minimum cycle time requirement. The on-off setting for the pump is particularly important because it defines the most frequently used cycle.

45.3.6 Allowable High Water Elevation

The allowable high water (AHW) elevation in the station should be set such that the water surface elevation at the lowest inlet in the collection system provides 0.3 to 0.6 m of freeboard below the roadway grate.

45.4 OTHER FACILITIES AND REQUIREMENTS

45.4.1 Power

Several types of power may be available for a pump station. Examples are electric motors and petrol, diesel or natural gas engines. The designer should select the type of power that best meets the needs of the project based on an estimate of future energy considerations and overall station reliability. A comparative cost analysis of alternative is helpful in making this decision. However, when readily available, electric power is usually the most economical and reliable choice. The maintenance engineer should provide input in the selection process.

There generally is a need for backup power. However, if the consequences of failure are not severe, backup power may not be required. The decision on whether to provide backup power should be based on economics and safety.

Motor voltages between 415 volts is recommended for pumping applications. Consequently, it is recommended that 225 kW be the maximum size motor used. This size is also a good upper limit for ease of maintenance.

45.4.2 Flap Gates and Valving

Flap Gates – The purpose of a flap gate is to restrict water from flowing back into the discharge pipe and to discourage entry into the outfall line. Flap gates are usually not water tight so the elevation of the discharge pipe should be set above the normal water levels in the receiving channel. If flap gates are used, it may not be necessary to provide for check valves.

Check Valves – Check valves are water tight and are required to prevent backflow on force mains which contain sufficient water to restart the pumps. They also effectively stop backflow from reversing the direction of pump and motor rotation. They must be used on manifolds to prevent return flow. Check valves should be 'non-slam' to prevent water hammer. Types include: swing, ball, dash pot and electric.

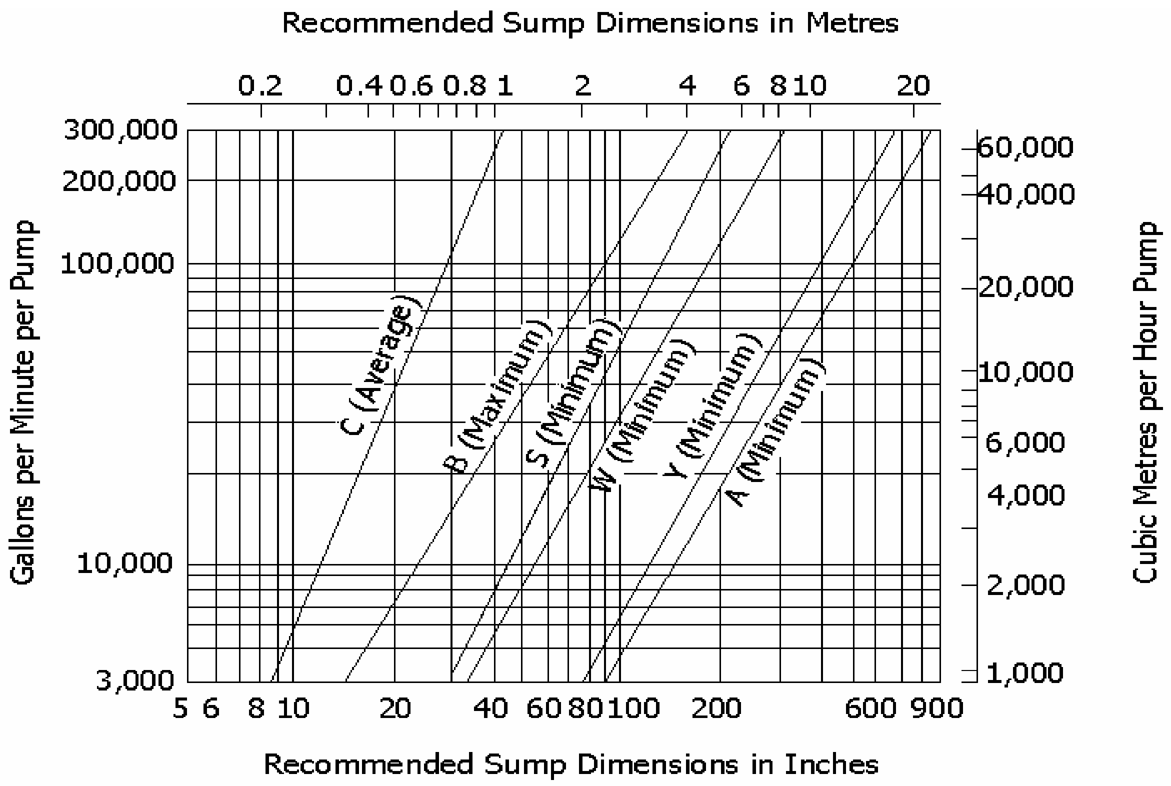

Figure 45.7a Sump Dimensions, Wet-pit Pumps (see Figure 45.7b for dimension location)

Figure 45.7a Sump Dimensions, Wet-pit Pumps (see Figure 45.7b for dimension location)

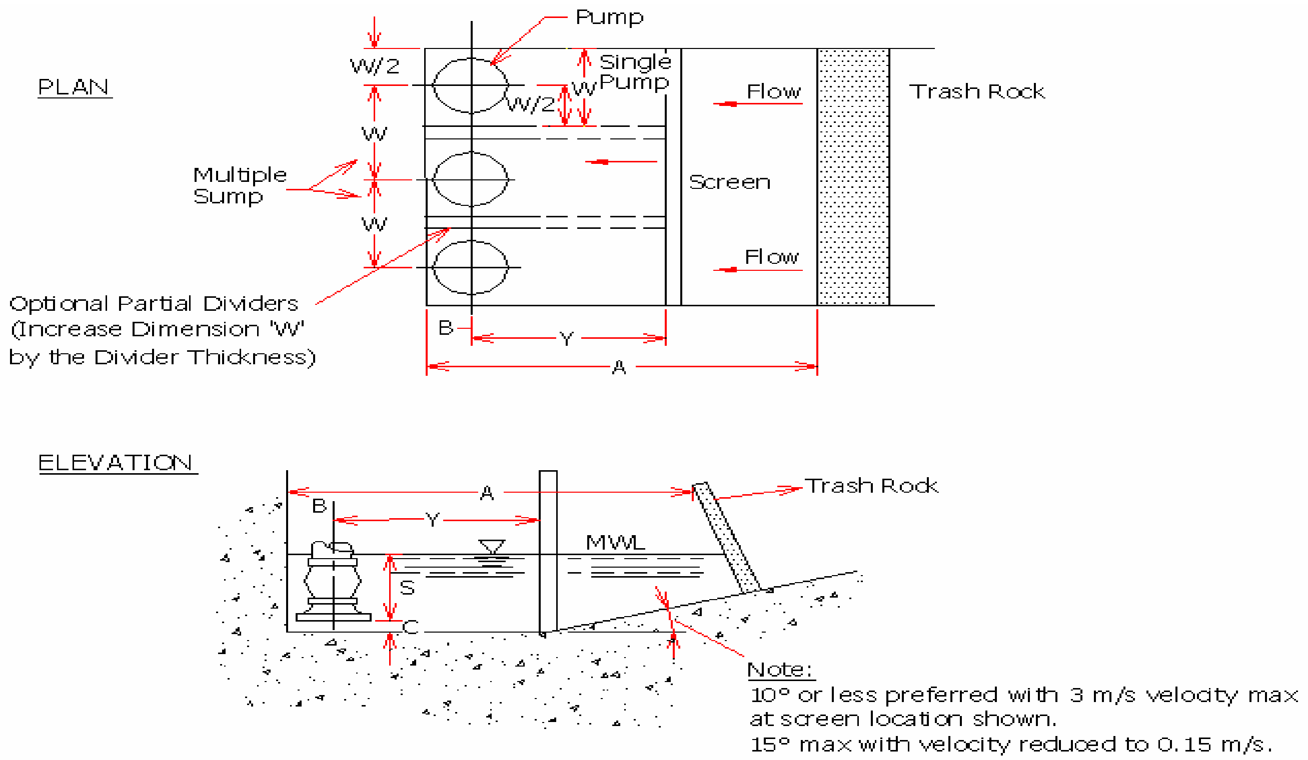

Figure 45.7b Wet Pit Type Pumps; Plan and Elevation (see Figure 45.7a for dimensions)

Figure 45. 7b Wet Pit Type Pumps; Plan and Elevation (see Figure 45.7a for dimensions)

Gate Valves – Gate valves are simply a shut-off device used on force mains to allow for pump or valve removal. These valves should not be used to throttle flow. In normal operation they should be fully open.

Air/Vacuum Valves – Air/Vacuum valves are used to allow air to escape the discharge piping when pumping begins and to prevent vacuum damage to the discharge piping when pumping stops. They are especially important with large diameter pipe. If the pump discharge is open to the atmosphere, an air-vacuum release valve is not necessary. Combination air release valves are used at high points in force mains to evacuate trapped air and to allow entry of air when the system is drained.

45.4.3 Trash Racks and Grit Chambers

Trash racks should be provided at the entrance to the wet well if large debris is anticipated. For storm water pumping stations, simple steel bar screens are adequate. Usually, the bar screens are inclined with bar spacing approximately 35 mm. Constructing the screens in modules facilitate removal for maintenance. If the screen is relatively small, an emergency overflow should be provided to protect against clogging and subsequent surcharging of the collection system. Screening large debris at surface inlets may be very effective in minimising the need for trash racks. Automatic trash racks of various designs may also be used in area where trash problem is serious.

If substantial amounts of sediment are anticipated, a chamber may be provided to catch solids that are expected to settle out. This will minimise wear on the pumps and limit deposits in the wet well. The grit chamber should be designed so that a convenient means of sediment removal is available.

45.4.4 Ventilation

Ventilation of dry and wet wells is necessary to ensure a safe working environment for maintenance personnel. Wet wells commonly have exhaust fan systems that draw air from the bottom of wet well. The ventilation system can be activated by a switch at the entrance to the station. Maintenance procedures should require personnel to wait ten minutes after ventilation has started before entering the well. Some owners require the air in the wet well be tested prior to allowing entry. Safety procedures for working in wet wells should be well established and carefully followed.

If mechanical ventilation is required to prevent buildup of potentially explosive gases, the pump motors any spark producing equipment should be rated explosion proof or the fans run continuously. Heating and dehumidifying requirements fare variable. Their use is primarily dependent upon equipment and station type, environmental conditions and station use.

45.4.5 Roof Hatches and Monorails

It will be necessary to remove motors and pumps from the station for periodic maintenance and repair. Removable roof hatches located over the equipment are a cost-effective way of providing this capability. Mobile cranes can simply lift the smaller equipment from the station onto maintenance trucks. Monorails are usually more cost-effective for larger stations.

45.4.6 Equipment Certification and Testing

Equipment certification and testing is a crucial element of pump station design. The purchaser has a right to witness equipment testing at the manufacturer's lab. However, this is not always practical. As an alternative, the manufacturer should provide certified test results to the owner. It is good practice to include in the contract specifications the requirement for acceptance testing by the owner, when possible, to ensure proper operation of the completed pump station. The testing should be done in the presence of the owner's representative. If the representative waves his right to observe the test, a written report should be provided to give assurance that the pump equipment meets all performance requirements. Any component which fails should be repaired and retest.

45.4.7 Monitoring and Maintenance

Pump stations are vulnerable to a wide range of operational problems from malfunction of equipment to loss of power. Monitoring systems such as on-site warning lights and remote alarms can help minimise such failures and their consequences.

Telemetry and SCADA system are options that should be considered for monitoring critical pump station. Operating functions may be telemetered from station to a central control unit. This allows the central control unit to initiate corrective actions immediately if a malfunction occurs. Such functions as power, pump operations, unauthorised entry, explosive fumes, and high water levels can be monitored effectively in this manner. Perhaps the best overall procedure to assure the proper functioning of a pump station is the implementation of a regular schedule of maintenance conducted by trained, experienced personnel.

Since major storm events are infrequent, a comprehensive, preventive maintenance program should be developed for maintaining and testing the equipment so that it will function properly when needed. Instruments such as hours-run meters and number-of starts meters should be used on each pump to help schedule maintenance. Regular inspections as well as disassembly inspections should be conducted in conjunction with regular inspections to prevent any accidents from occurring. The following list will explain the basic maintenance procedures as well as detailed explanations regarding inspections and troubleshooting :

- A maintenance reference guide with details regarding the appropriate frequency and time intervals between inspections and part replacements should be created to assist with maintenance activities and smooth accident free operation;

- Create daily and monthly logs, and enter information regarding maintenance inspection etc. Always make note of condition of the machinery;

- Classify each unit and create a log to record detailed information on inspections, maintenance activities, repairs and other problems for future reference; and

- Organise and store special tools used for repairs and maintenance, spare parts and consumables so they will be readily available if needed.

Most of the pump suppliers will provide together with the pump the checklist, maintenance and service manuals for reference during the operation period.

45.4.8 Safety

All elements of the pump station should be carefully reviewed for safety of operation and maintenance. Ladders, stairwells and other access points should facilitate use by maintenance personnel. Adequate space should be provided for the operation and maintenance of all equipment. Particular attention should be given to guarding moving components such as drive shafts and providing proper and reliable lighting. It may also be prudent to provide air-testing equipment in the station so maintenance personnel can be assured of clean air before entering.

Pump stations should be classified as a confined space. In this case, access requirements along with any safety equipment are all defined by code. Pump stations should be designed to be secure from entry by unauthorised personnel.

45.5 DESIGN PROCEDURE

This section presents a systematic design procedure for the design of stormwater pump stations. It incorporates the design criteria discussed in previous sections and yields the required number and capacity of pumps as well as the wet well and storage dimensions. The final dimensions can be adjusted as required to accommodate non-hydraulic considerations such as maintenance. Though the recommended station is a wet-pit, this procedure can be adapted for use in designing dry-pit stations as well. Theoretically an infinite number of designs are possible for a given site. Therefore, to initiate design, constraints must be evaluated and a trial design formulated to meet these constraints. Then by routing the inflow hydrograph through the trial pump station its adequacy can be evaluated.

The hydraulic analysis of a pump station involves the interrelationship of three components:

- the inflow hydrograph
- the storage capacity of the wet well and the outside storage, and
- the discharge rate of the pumping system

The inflow hydrograph is determined by the physical factors of the watershed and regional climatological factors. Therefore, the main objective in pump station design is to store enough inflow (volume of water under the inflow hydrograph) to allow station discharge to meet specified limits. Even if there are no physical limitations to pump station discharge, storage should always be considered since storage permits use of smaller and/or fewer pumps.

The procedure for pump station design is illustrated in Figure 45.8. It comprises the following 11 steps.

Step 1. Inflow to Pump Station

Develop an inflow hydrograph representing the design storm.

Step 2. Estimate Pumping Rate, Volume of Storage, and Number of Pumps

Because of the complex relationship between the variables of pumping rates, storage, and pump on-off settings, a trial and success approach is usually necessary for estimating the pumping rates and storage required for a balanced design. A wide range of combinations will produce an adequate design. The goal is to develop an economic balance between storage volume and pumping capacity. Some approximation of all three parameters is necessary to produce the first trial design. One approach to estimating storage volume was illustrated in Figure 45.6. In this approach, the peak pumping rate is assigned and a horizontal line representing the peak rate is drawn across the top of the hydrograph. The shaded area above the peak pumping rate represents an estimated volume of storage required. This area is measured to give an estimated starting size for the storage facility. Once an estimated storage volume is determined, a storage facility can be estimated. The shape, size, depth, etc. can be established to match the site, and a stage-storage relationship can be developed.

The total pumping rate may be set by stormwater management limitations, capacity of the receiving system, the desirable pump size, or available storage. Two pumps would be the minimum number of pumps required.

However, as many as five pumps may be appropriate. Size, and the number of pumps, may be controlled by physical constraints such as portable standby power.

Step 3. Design High Water Level

The highest permissible water level should not be set higher than 0.3 m to 0.6 m below the finished pavement surface at the lowest pavement inlet. The lower the elevation the more conservatism in the design.

At the design inflow to the pumps, some head loss will occur through the pipes and appurtenances leading to the pumps station. Therefore a hydraulic gradient will be established and the maximum permissible water elevation at the station will be the elevation of the hydraulic gradient. This gradient will be very flat for most wet well designs with exterior storage because of the unrestricted flow into the wet well.

Step 4. Determine Pump Pit Dimensions

Determine the minimum required plan dimensions for the pump station from manufacturer literature. The dimensions are usually determined by locating the selected number of pumps on a floor plan keeping in mind the need for clearances around pumps, valves, electrical panels and associated equipment that will be housed in the pump station building.

Actual dimensions of pump sump are normally recommended by the pump manufacturer to ensure conducive pumping condition and avoid damaging hydraulic problems such as vortices and swirl. As discussed, physical modelling maybe required in special conditions.

Step 5. Stage – Storage Relationship

Routing procedures require that a stage-storage relationship be developed. This is accomplished by calculated the available volume of water of storage at uniform vertical intervals.

Having roughly estimated the volume of storage required and a trial pumping rate by the approximate methods described in the preceding steps, the configuration and elevations of the storage chamber can be initially set. Knowing this geometry, the volume of water stored can be calculated for its respective depth. In addition to the wet-pit, storage will also be provided by the inflow pipes and exterior storage if the elevation of water in the wet-pit is above the inflow invert.

Step 6. Pump Cycling and Usable Storage

One of the basic parameters addressed initially was that the proper number of pumps must be selected to deliver the design flow (Q). Also, the correct elevations must be chosen to turn each pump on and off. Otherwise, rapid cycling may occur causing undue wear and possible damage to the pumps.

Before discussing pump cycling calculations, operation of a pump station will be described. Initially, the water level in the storage basin will rise at a rate dependent on the rate of the inflow and physical geometry of the storage basin. When the water level reaches the stage designated as the first pump start elevation, the pump will be activated and discharge water from storage at its designated pumping rate. If this rate exceeds the rate of inflow, the water level will drop until it reaches the first pump stop elevation. When the pump stops, the basin begins to refill and the cycle is repeated. This scenario illustrates that the cycling time will be lengthened by increasing the amount of storage between pump on and off elevations. This volume of storage between first pump on and off elevations is termed usable volume. In theory, the minimum cycle time allowable to reduce wear on the pumps will occur when inflow to the usable storage volume is one-half pump capacity. Assuming this condition, cycling time can be related to usable volume as follows:

t = time between starts
= time to empty + time to fill usable storage volume V_t

when the inflow (I) is set to equal one half of the pump capacity (Q_P), then:

$$t = \frac{V_t}{(Q_p - I)} + \frac{V_t}{I} = \frac{V_t}{(Q_p - 0.5Q_p)} + \frac{V_t}{(0.5Q_p)} = \frac{4V_t}{Q_P} \tag{45.2}$$

$$t_{\min} = \frac{4V_t}{Q_P}\left[\frac{1\,\text{min}}{60\,\text{sec}}\right] = \frac{V_t}{15Q_P} \tag{45.3}$$

where;

t = time between starts, s

V_t = usable storage volume, m^3

Q_p = pump capacity, m^3/s

I = inflow, m^3/s ($I = ½\,Q_P$)

Generally, the minimum allowable cycling time, t, is designated by the pump manufacturer based on electric motor size. In general, the larger the motor, the larger is the starting current required, the larger the damaging heating effect, and the greater the cycling time required. The pump manufacturer should always be consulted for allowable cycling time during the final design phase of project development. However, Table 45.1 displays limits that may be used for estimating allowable cycle time during preliminary design.

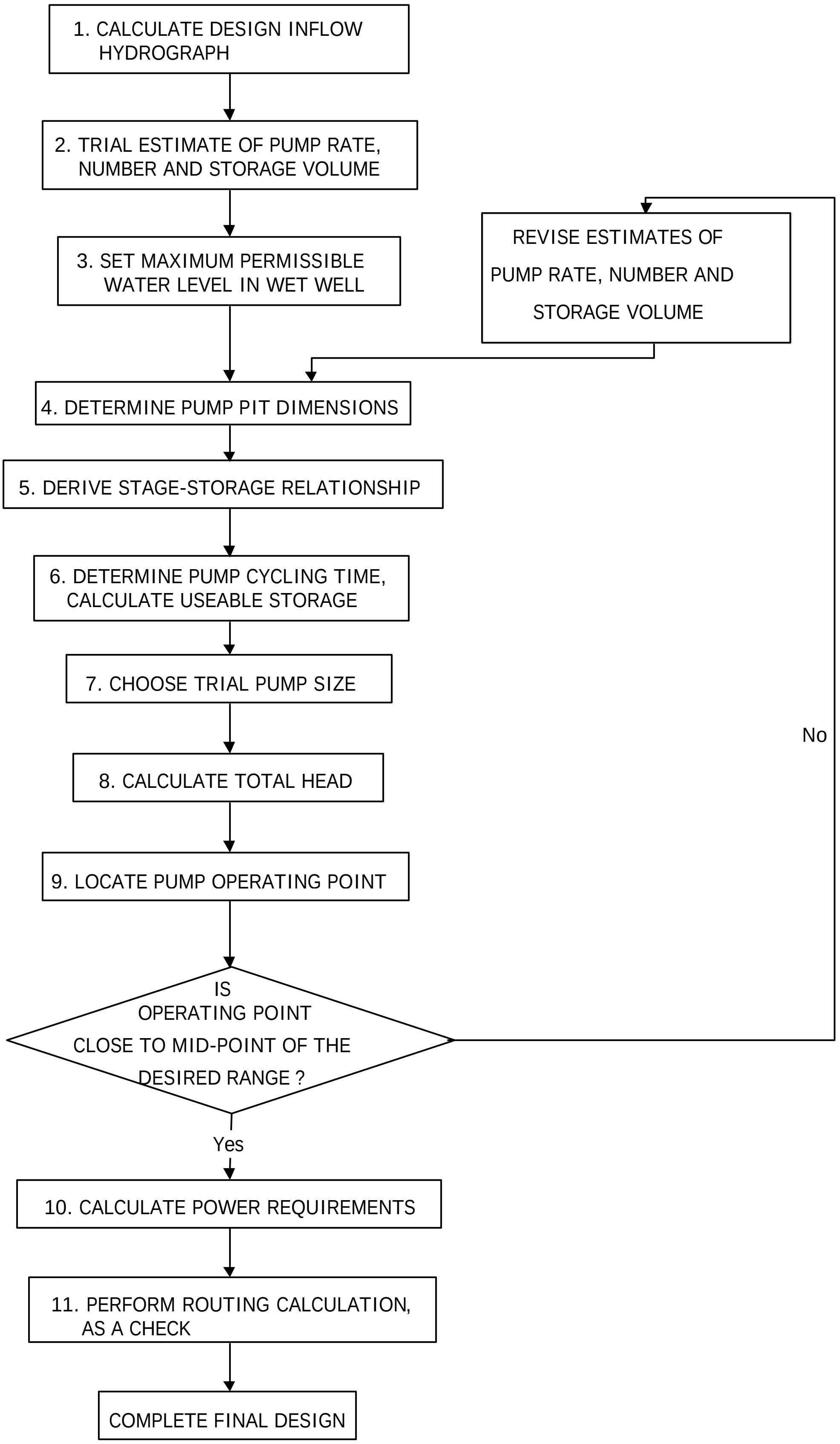

Figure 45.8 Flowchart for Pump Station Design

Table 45.1 Pump Cycle Time Limits

Motor Power (KW)	Cycling Time, t (Minutes)
0 – 11	5
15 – 22	6.5
26 – 45	8
49 – 75	10
112 - 149	13

Knowing the pumping rate and minimum cycling time (in minutes), the minimum necessary allowable storage, *V*, to achieve this time can be calculated from Equation 45.4.

$$V = 15 Q_P t \tag{45.4}$$

Having selected the trial wet-pit and storage dimensions, the pumping range, Δh, can then be determined. The pumping range represents the vertical height between pump start and pump stop elevations. Usually, the first pump stop elevation is controlled by the minimum recommended bell submergence criteria specified by the pump manufacturer. The first pump start elevation will be a distance, Δh, above H.

When larger volumes of storage are available, the initial pump turn on should typically have the ability to empty the storage facility, its turn off elevation would be the level of the bottom of the storage basin. The minimum allowable storage would be calculated by Equation 45.4. The elevation associated with this volume in the stage-storage curve would be the lowest turn-on elevation that should be allowed for the starting point of the first pump. The second and subsequent pump start elevations will be determined by plotting the pump performance on the mass inflow curve.

This distance between pump starts may be in the range of 0.3 to 1.0 metres for stations with a small amount of storage and 75 mm to 150 mm for larger storage configurations.

Step 7. Trial Pumps and Pump Station Piping

The designer must select a specific pump in order to establish the size of the discharge piping that will be needed. This is done by using information either previously developed or established. The designer should study various manufacturers' literature in order to establish a reasonable balance between total dynamic head, discharge, efficiency, and energy requirements. This study will also give the designer a good indication of discharge piping needed since pumps will have a specific discharge pipe size.

Each pump considered will have a unique performance curve that has been developed by the manufacturer. More precisely, a family of curves is shown for each pump, because any pump can be fitted with various size impellers. These performance curves are the basis for the pump curve plotted in the system head curves discussed above. The designer must have specific information on the pumps available in order to be able to specify pumps needed for the pump station. Figure 45.5 demonstrates a typical pump performance curve. All designers should make a study of a pump performance curve.

Any point on an individual performance curve identifies the performance of a pump for specific Total Dynamic Head (TDH) that exists in the system. It also identifies the horsepower required and the efficiency of operation of pump (see Figure 45.5). It can be see that for either an increase or decrease in TDH, the efficiency is reduced as the performance moves away from the eye of the performance curve. It should also be noted that as the TDH increases, the horsepower requirement also increases. The designer must make certain that the design point be as close the eye as possible, or else to the left of the eye rather than to the right of or above it. The range of the pump performance should not extend into the areas of reduced efficiency.

Step 8. Total Dynamic Head

Total Dynamic Head is the sum of the static head, velocity head and various head losses in the pump discharge system due to friction. Knowing the range of water levels in the storage pit and having a trial pump pit design with discharge pipe lengths and diameters and appurtenances such as elbows and valves designated, total dynamic head for the discharge system can be calculated using Equation 45.1.

Step 9. Pump Design Operating Point

Using methods described in the previous step, the Total Dynamic Head of the outlet system can be calculated for a specific static head and various discharges. These TDH'S are then plotted vs. discharge. The plot is called a system head curve. A system head curve (see Figure 45.4) is a graphical representation of total dynamic head plotted against discharge Q for the entire pumping and discharge system. The required operating point of the pump is given by the intersection of the system curve and the pump curve.

The design operating point determined above should correlate with an elevation at about the mid-point of the pumping range. By doing this, the pump will work both above and below the TDH for the design point and will thus operate in the best efficiency range.

Step 10. Power Requirements

To select the proper size pump motor, compute the power required to raise the water from its lowest level in the pump pit to its point of discharge. This is best described by analysing pump efficiency. Pump efficiency is defined as the ratio of pump power output to the power input applied to the pump. The efficiency of the pump is then expressed as:

$$\text{Efficiency, } \varepsilon = \frac{\text{pump output power}}{\text{pump motor rating}} \tag{45.5}$$

The pump power output can be determined as:

$$P = \frac{gQH}{1000} \tag{45.6}$$

where;

P = power output from the pump, kW

g = specific weight of water, 9800 N/m^3

Q = pump flow rate, m^3/s

H = pump head, m

Efficiency can be broken down into partial efficiencies – hydraulic, mechanical, etc. The efficiency as described above, however, is a gross efficiency used for the comparison of centrifugal pumps. The designer should study pump performance curves from several manufacturers to determine appropriate efficiency ranges. The designer should specify a minimum acceptable efficiency for each performance point specified.

Combining Equation 45.6 with the definition of efficiency and changing some of the units, the power put into the pump shaft can be expressed as:

$$P_m = \frac{Q.H}{6122e} \tag{45.7}$$

where;

P_m = pump motor rating (kW)

Q = flow (m^3/hour)

H = head (m)

e = efficiency

The designer must recognise that each pump motor has a service factor, which defines the range of energy capable of being produced by a given motor. Typical service factors are 1.15 and 1.25. This indicates that a motor can produce 1.15 or 1.25 times the rated kW for short periods of time, but should not be continuously operated at this level. Operating above these limits will burn out the electric motor almost immediately.

Step 11. Mass Curve Routing

The procedures described thus far will provide all the necessary dimensions, cycle times, appurtenances, etc. to complete a preliminary design for the pump station. A flood event can be simulated by routing the design inflow hydrograph through the pump station by methods described in Section 45.2. In this way, the performance of the pump station can be observed at each hydrograph time increment and pump station design evaluated. Then, if necessary, the design can be "fine-tuned".

APPENDIX 45.A WORKED EXAMPLE

45.A.1 Storage

Stormwater storage can reduce the require peak capacity of a pump station. Selection of a peak pumping capacity is a trial and error process that considers the inflow hydrograph, available storage, and possible pump discharge rates.

The approximate method includes adjusting the inflow hydrograph to an equivalent triangular hydrograph, as shown in Figure 45.A1. An estimate of the storage required to reduce the peak pumping rate to a desired value can be found by assigning a peak pumping rate and plotting it as horizontal, as shown in Figure 45.A2.

The area of the triangular hydrograph above the peak pumping rate represents an estimate of the storage volume required. This assumes that storage below the last pump-on elevation will not affect the design. The effect of this storage on final design can be considered using the computer program, or a mass curve routing procedure as presented in next section. The required storage can be estimated by the equation :

$$\frac{V_s}{V_t} = \left(\frac{\Delta Q}{Q_p}\right)^2 \qquad (45.8)$$

where :

V_s = Required storage volume, m^3

V_t = Volume of triangular inflow hydrograph, m^3

ΔQ = Peak flow reduction, cumec

Q_P = Peak flow of triangular inflow hydrograph, cumec

A graphical presentation of the relationship in Equation 45.8 is shown in Figure 45.A3. By selecting a peak reduction ratio ($\Delta Q/Q_p$), the storage ratio (V_s/V_t) can be obtained directly. When the inflow hydrograph volume (V_t) is known, the storage required is estimated as the product of the storage ratio and the inflow hydrograph volume.

(A) Inflow Mass Curve

The inflow mass curve is developed by dividing the inflow hydrograph into uniform time increments, computing the inflow volume over each time step, summing the inflow volumes to obtain a cumulative inflow volume, and plotted against time to produce the inflow mass curve. Figure 45.A4 illustrates the resulting inflow mass curve (plot of time vs. flow values).

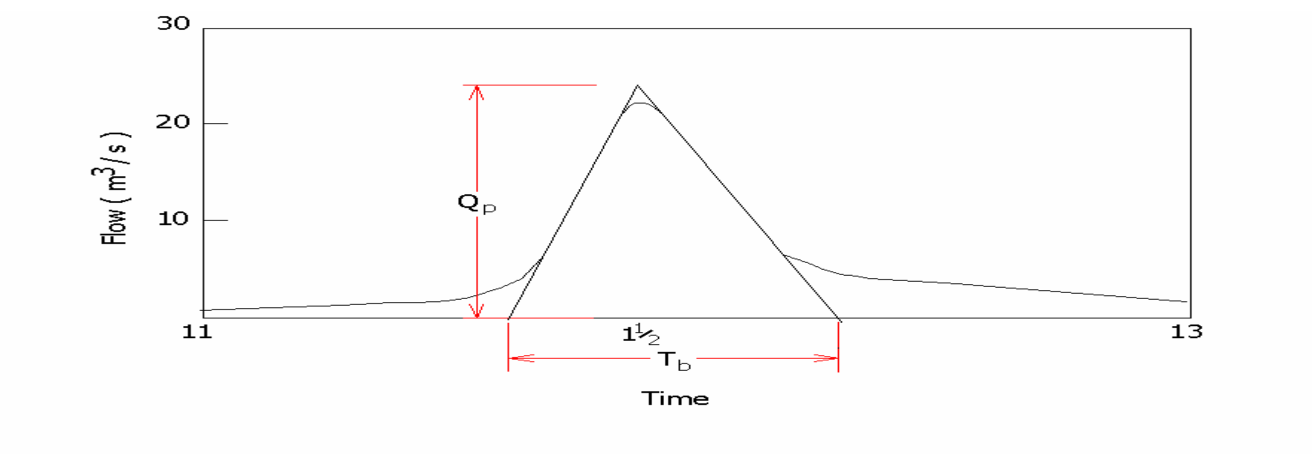

Figure 45.A1 Triangular Approximation of an Inflow Hydrograph (Fed. Highways Adm., 1982)

Figure 45.A1 Triangular Approximation of an Inflow Hydrograph (Fed. Highways Adm., 1982)

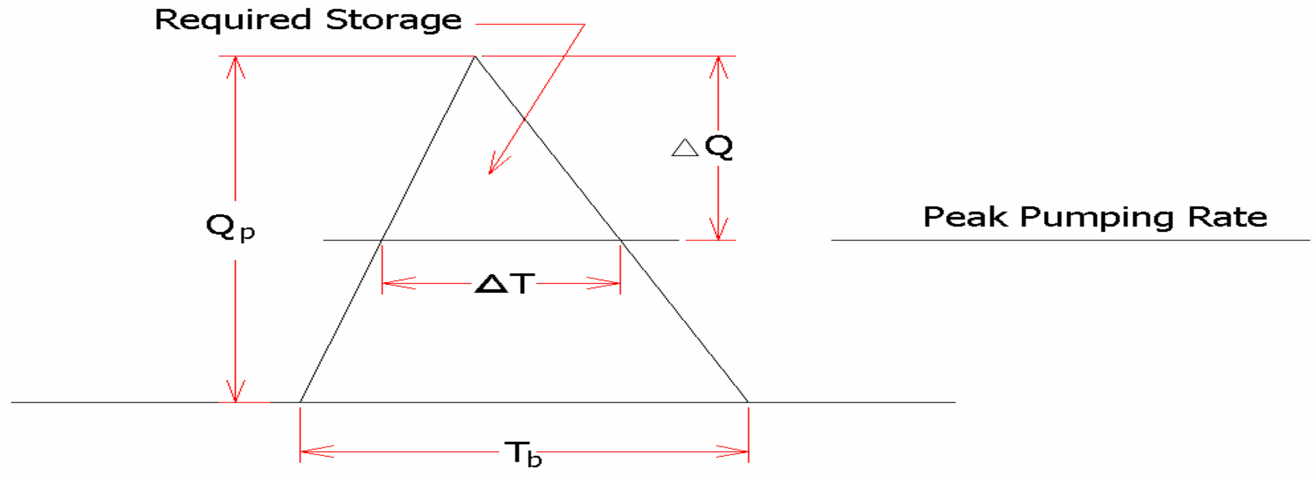

Figure 45.A2 Estimation of Required Storage Based on a Selected Peak Pumping Rate (Fed. Highway Adm., 1982)

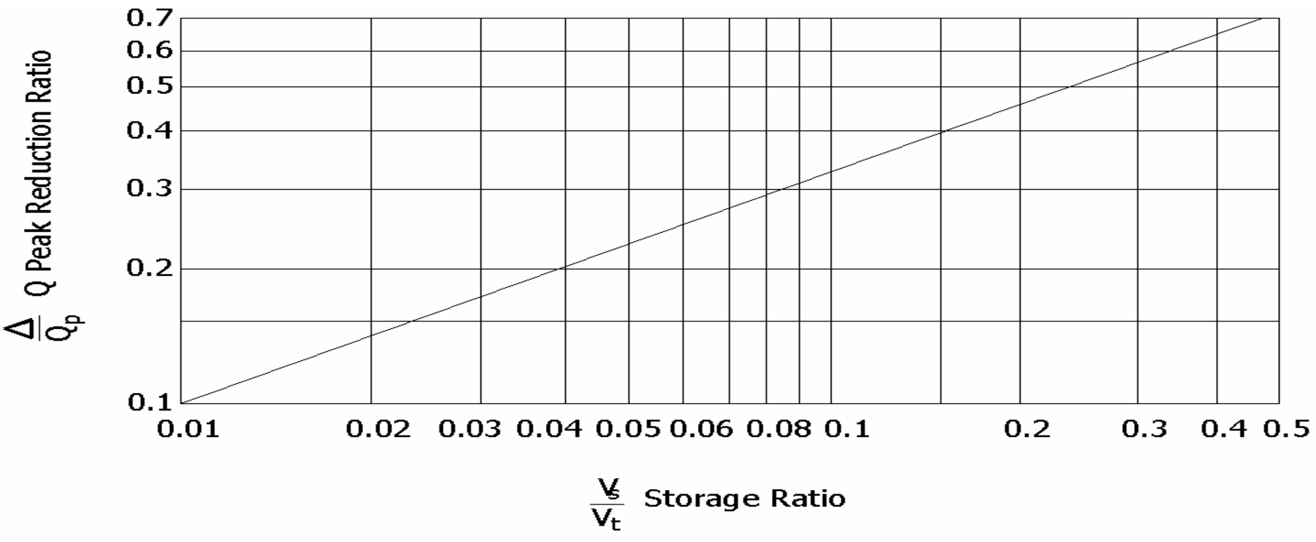

Figure 45.A3 Relationship between Peak Reduction Ratio and Storage Ratio : $Vs/V_T = (\Delta Q/Q_p)^2$ (Baumgardner, 1981)

(B) Mass Curve Routing

The approach used to evaluate the relationship between pump station storage and pumping rates involves using the mass inflow curve in a graphical mass curve routing procedure. The designer assigns an initial pump discharge rate based on downstream capacity considerations, limits imposed by local jurisdictions, or other criteria. With the inflow mass curve and an assigned pumping rate, the required storage can be determined by various trials of the routing procedure.

It is important that the designer have an understanding of how a typical pump station operates prior to starting the mass curve routing. As storm water flows to the pump station, the water will be stored and the water level will rise to an elevation, which activates the first pump to start. If the inflow rate is greater than the pump rate, the water will continue to rise and cause the second pump to start. This process will be continued until the inflow rate subsides. As the inflow rate drops below the pumps rate, the stage in the station will recede until the pump-stop elevations are reached. This process is illustrated graphically on the mass curve diagram during the mass flow routing procedure.

A wide range of storage and pumping rate combinations should be evaluated when considering pumping cycles for frequent small volume storms and the potential for flooding from less frequent, large-volume storms. Usually, computer programs are best suited to this type of trial and error evaluation. A mass curve routing procedure developed by Baumgardner (1982) follows.

Developed an inflow hydrograph, a stage-storage curve, and a stage-discharge curve for the range of pumping facilities being considered. If the pumping rate is constrained by downstream or environmental considerations, the required storage must be determined by various trials of the mass curve routing procedures.

Establish the point at which the cumulative flow curve has reached the storage volume associated with the first pump-on elevation.

Draw the pump discharge line from the intersection point, upward to the right at a slope equal to the discharge rate of the pump. The vertical distance between the mass inflow curve and the pump discharge curve represents the amount of stormwater, which must be held in storage.

To determine the maximum storage volume required, a line is drawn parallel to the pump discharge curve, and tangent to the mass inflow curve. The vertical distance between this tangent and the pump discharge line represents the maximum storage volume required.

The storage pipe and wet well should be designed to handle sediment, while the pumping system should be designed to safely carry sediment, which is flushed from the wet well.

The mass flow routing procedure is demonstrated by Example 45.A.2.

45.A.2 Mass Curve Routing

Given: The inflow mass curve in Table 45.A1 and Figure 45.A4, and the storage pipe and pump stations wet well shown in Figure 45.A5. The stage-storage relationship for the pipe and pump station wet well are provided in Table 45.A2 and Figure 45.A6.

Table 45.A1 Inflow Mass Curve Tabulation for Example 45.A.1

(1)Time (hr)	(2) Inflow (m^3/s)	(3) Average Flow (m^3/s)	(4) Time Incr. (s)	(5) Incr. Flow (m^3)	(6)Cum. Flow (m^3)
10:30	0.000	---	---	---	0
10:35	0.003	0.002	300	0.45	0.45
10:40	0.006	0.005	300	1.35	1.80
10:45	0.009	0.008	300	2.25	4.05
10:50	0.011	0.010	300	3.00	7.05
10:55	0.014	0.013	300	3.75	10.80
11:00	0.017	0.016	300	4.65	15.45
11:05	0.020	0.019	300	5.55	21.00
11:10	0.023	0.022	300	6.45	27.45
11:15	0.025	0.024	300	7.20	34.65
11:20	0.028	0.027	300	7.95	42.60
11:25	0.031	0.030	300	8.85	51.45
11:30	0.034	0.033	300	9.75	61.20
11:35	0.071	0.053	300	15.8	76.95
11:40	0.127	0.099	300	29.7	107
11:45	0.326	0.227	300	67.9	175
11:50	0.538	0.432	300	130	304
11:55	0.609	0.574	300	172	476
12:00	0.481	0.545	300	164	640
12:05	0.340	0.411	300	123	763
12:10	0.184	0.262	300	78.6	842
12:15	0.142	0.163	300	48.9	890
12:20	0.113	0.128	300	38.3	929
12:25	0.099	0.106	300	31.8	960
12:30	0.093	0.096	300	28.8	989
12:35	0.076	0.085	300	25.4	1015
12:40	0.071	0.074	300	22.1	1037
12:45	0.065	0.068	300	20.4	1057
12:50	0.059	0.062	300	18.6	1076
12:55	0.057	0.058	300	17.4	1093
13:00	0.054	0.056	300	16.7	1110

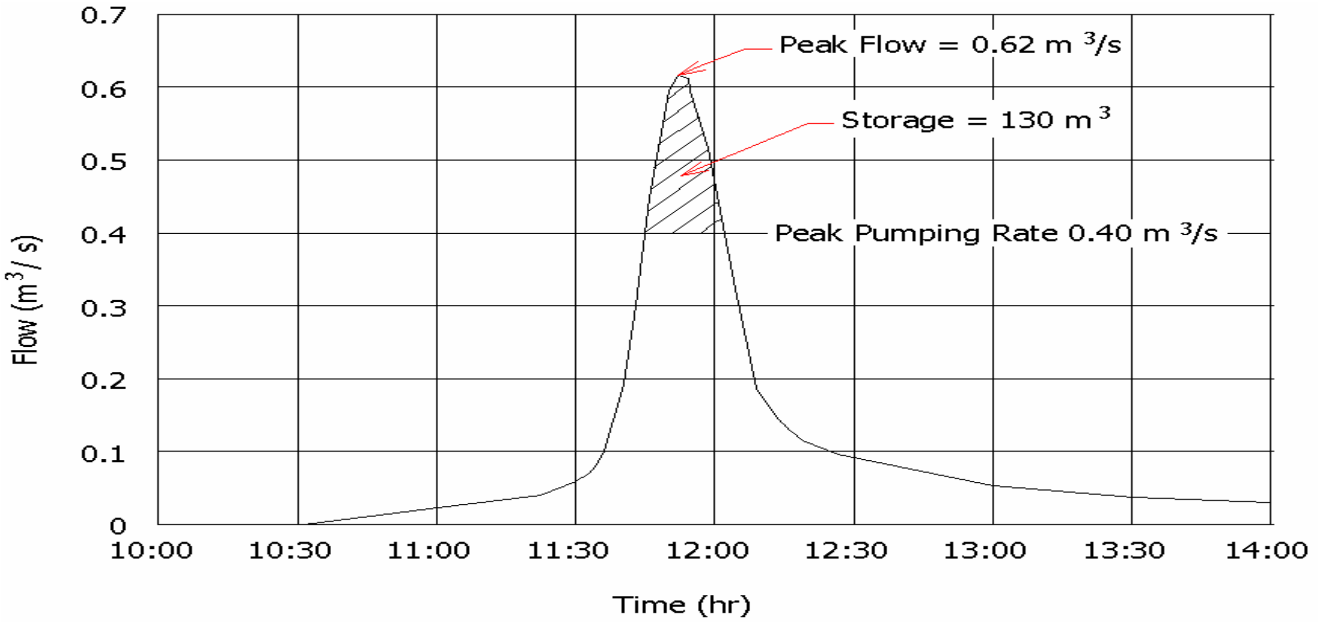

Figure 45.A4 Mass Inflow Curve for Example 45.A.1

Problem: Determine the maximum required pump station storage to reduce the peak flow of 0.62 m^3/s to 0.40 m^3/s.

Solution:

For this design, two equal size pumps are initially selected each having a peak capacity of 0.20 m^3/s. It will be assumed that, with both pumps operating, the necessary peak flow of 0.40 m^3/s will be produced.

Storage for the pump station will occur in the storm drain and the wet well shown in Figure 45.A5. The storm drain is a 160 m long, 1200 mm diameter pipe placed on a slope of 0.40%. Using geometric relationships, the volume of storage was determined for various water level elevations. Table 45.A2 lists the stage-storage data and the stage-storage curve is illustrated in Figure 45.A6. Note that the volume in the wet well below elevation 0.0 m is not included in the available storage volume. This volume is assumed to be initially filled with water since it is below the initial pump on setting described in the following paragraph.

Table 45.A3 provides the initial pump control parameters selected. The numbers in parenthesis in Table 45.A3 are the storage volumes (m^3) associated with the respective elevations. These volumes are illustrated on the stage-storage curve in Figure 45.A6. The stage-discharge curve for this pumping plan is shown in Figure 45.A7.

The mass flow routing is performed by plotting the pump discharge on the mass inflow curve in a graphical procedure as illustrated in Figure 45.A8. The procedure progress as follows:

As indicated in Table 45.A3, the pump no. 1 start elevation corresponds to a storage value of 55 m^3. This point is identified on Figure 45.A8 by drawing a vertical line from the horizontal axis to the inflow mass curve so that the vertical line intersects the mass curve at a cumulative flow value of 55 m^3. This occurs near the time of 11:30. At this time, the pump will start to discharge at a rate of 0.20 m^3/s.

Next, a pump discharge line is constructed. The slope of this line is equal to the pump rate of 0.20 m^3/s (720 m^3/hr). The pump discharge curve starts at the intersection of the vertical line and the baseline (abscissa), and is shown as line AB. During the time the pump is discharging at a rate of approximately 0.03 m^3/s. Therefore, the basin will quickly empty and pump no 1 will shut off. This is shown by the fact that the pump discharge line intersects the inflow mass curve at point B.

With pump no. 1 shut off, the discharge curve continues as a horizontal line (segment BC) until the water level builds up again to the pump start elevation. This occurs at point C where an additional incremental inflow mass of 55 m^3 is reached following shut-off of pump no. 1, and the pump restarts.

At point C, a line with a slope of 0.20 m^3/s is again constructed to represent discharges from pump no. 1. The pump discharge line continues as line CD, at slope of 0.20 m^3/s (720 m^3/hr) since only pump number 1 has restarted. From point C to D, the inflow and pump discharge lines are diverging. This indicates that inflows are exceeding the capacity of the single pump, and the storage is continuing to fill. At point D, the vertical distance between the inflow and pump curves equals 118 m^3, which represents the point where the second pump starts.

At point D a new pump curve is constructed having a slope equal to 0.40 m^3/s. This represents the combined discharge from pump no. 1 and pump no. 2. This new pump discharge curve continues until the point where the inflow mass curve and pump curve converge, and the vertical separation between these lines is 17 m^3, representing the point where pump no. 2 shuts off. This occurs at point E in Figure 45.A8.

At point E, the slope of the pump curve is reduced to 0.20 m^3/s representing discharges from pumps no. 1 only. Pump no. 1 then shuts off when the pump curve intersects the mass inflow curve at point F.

Beyond point F, the pump no. 1 continues to cycle on and off at the appropriate control elevations until all inflow stops.

Figure 45.A8 can also be used to determine the maximum required storage by drawing a line parallel to the combined pump discharge curve and tangent to the inflow mass curve. This line is shown as line GH. This line intersects the inflow mass curve at point I. The vertical distance from point I to the pump discharge line represents the maximum storage required. The maximum required storage is 245 m^3.

The designer now has a complete design that allows the problem to be studied in-depth. The peak rate of runoff has been reduced from 0.62 m^3/s , the inflow hydrograph peak, to 0.40 m^3/s, the maximum pump discharge rate. A reduction of 46.5 percent is accomplished by providing 245 m^3 of storage. The available storage at the high water alarm is 250 m^3 as shown in Figure 45.A6.

To aid the reader in visualising what is happening during the routing process, the pump discharge curve developed in Figure 45.A8 is superimposed on the design inflow hydrograph in Figure 45.A9. In Figure 45.A9, the shaded area represents storm water that has gone into storage, pump cycling at the end of the hydrograph is omitted for simplicity.

Table 45.A2 Stage – Storage Tabulation for Example 45.A.2

Elevation (m)	Drain storage (m^3)	Wet Well Storage (m^3)	Total Storage (m^3)
0.00	0	0	0
0.20	7	6	13
0.40	13	13	26
0.60	35	19	54
0.80	69	26	95
1.00	105	32	137
1.20	140	39	179
1.40	166	45	211
1.60	180	51	321
1.80	185	58	243
2.00	185	54	249
2.20	185	71	256

Table 45.A3 Pump Controls and Operational Parameters for Example 45.A.2

Pump No.	Pump Flow m^3/s	Pump-Start Elevation m (m^3)	Pump-Stop Elevation m (m^3)
1	0.20	0.6 (55)	0.0 (0)
2	0.20	0.9 (118)	0.3(17)

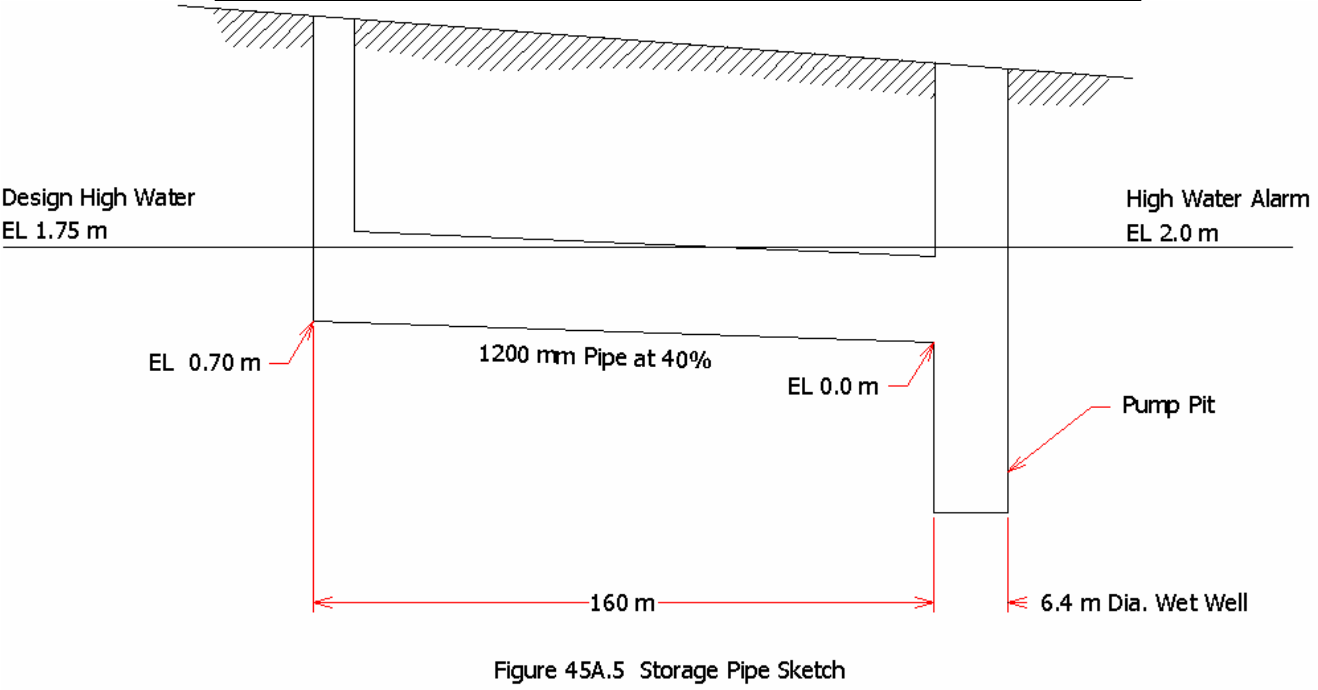

Figure 45.A5 Storage Pipe Sketch

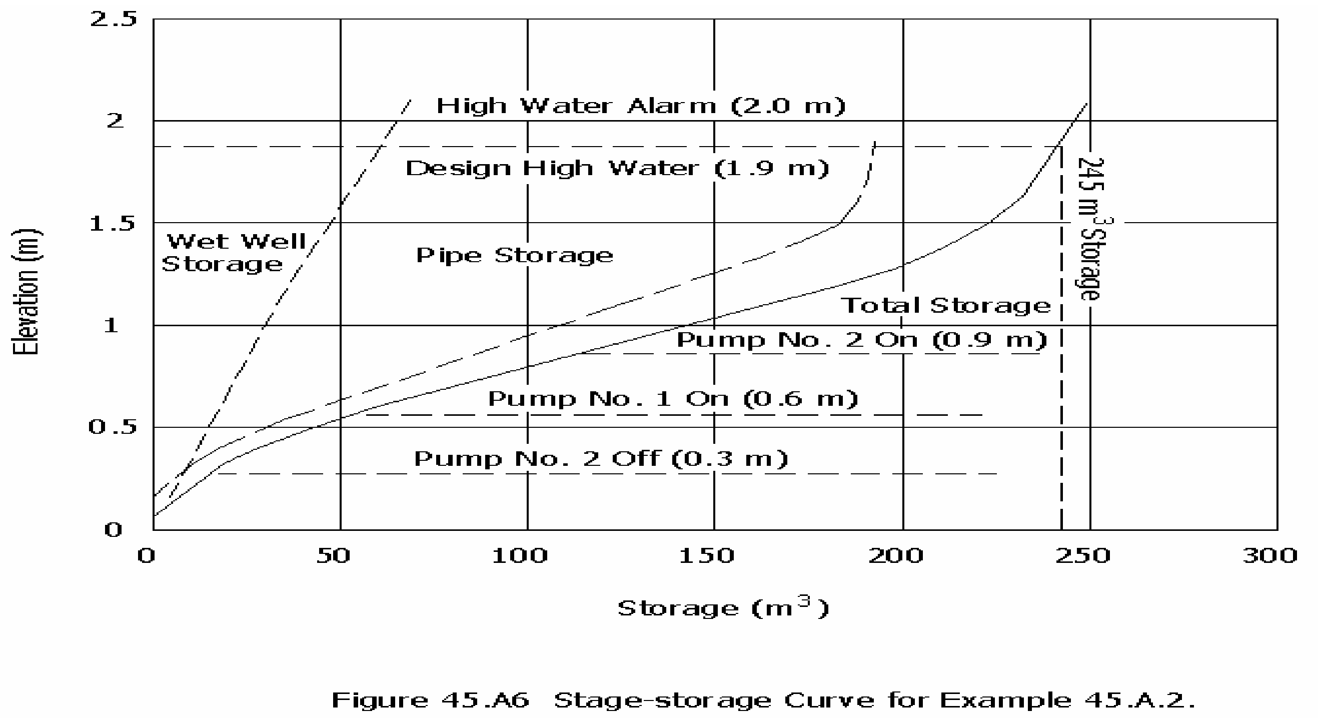

Figure 45.A6 Stage-storage Curve for Example 45.A.2

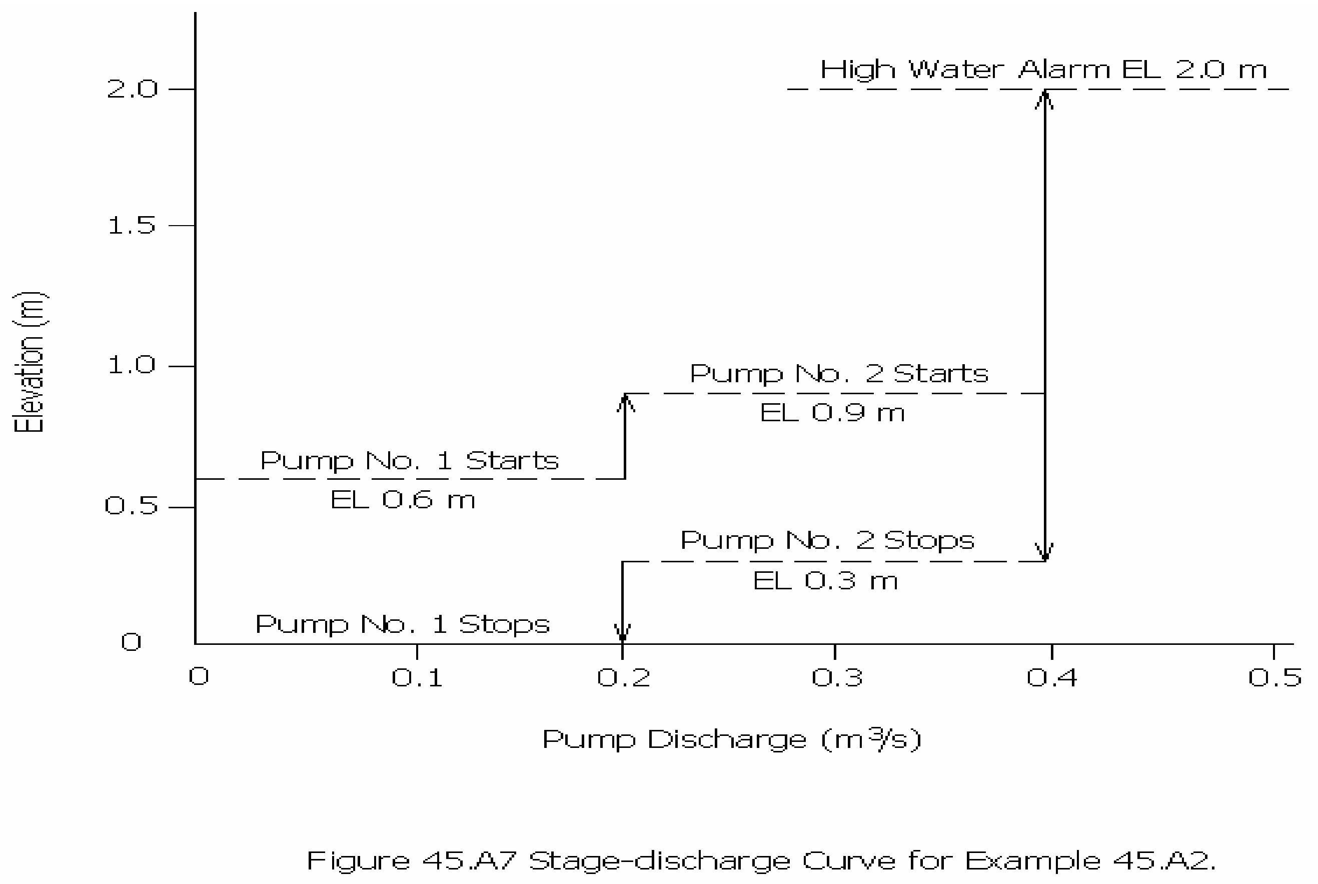

Figure 45.A7 Stage-discharge Curve for Example 45.A.2

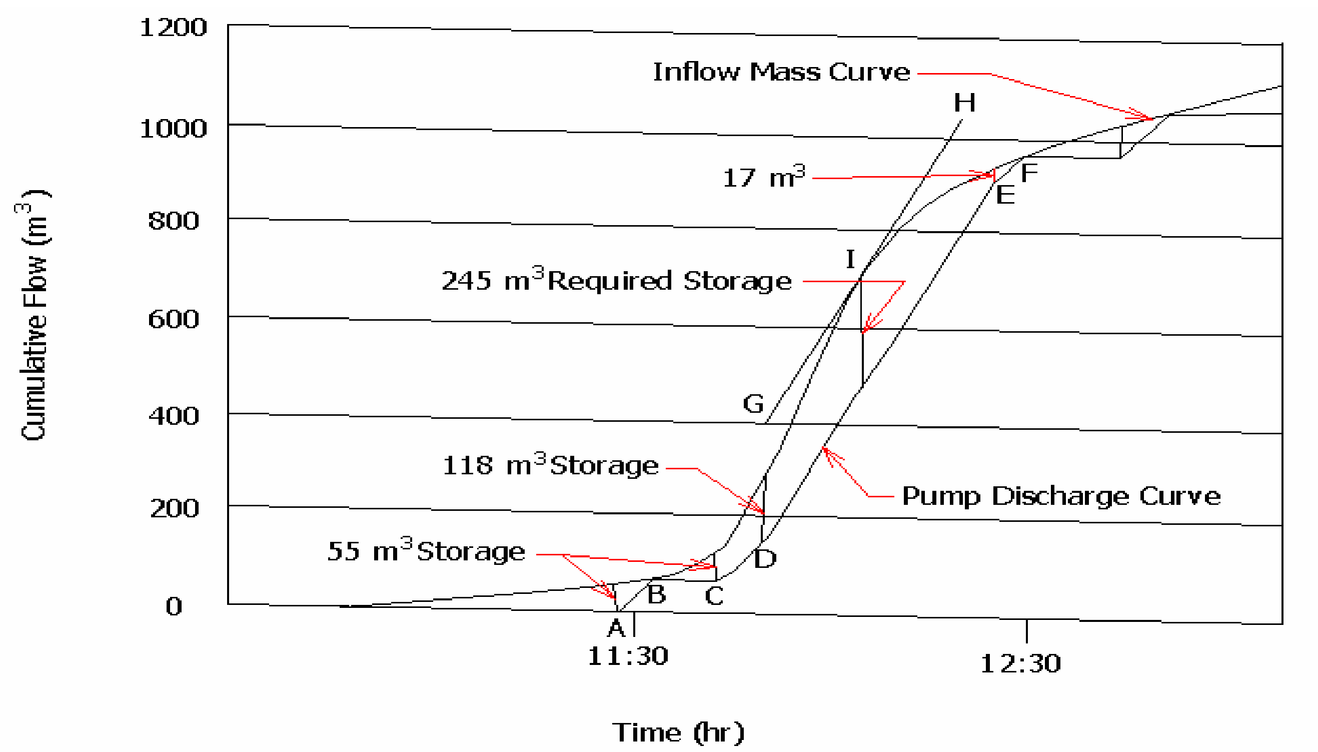

Figure 45.A8 Mass Curve Routing Diagram

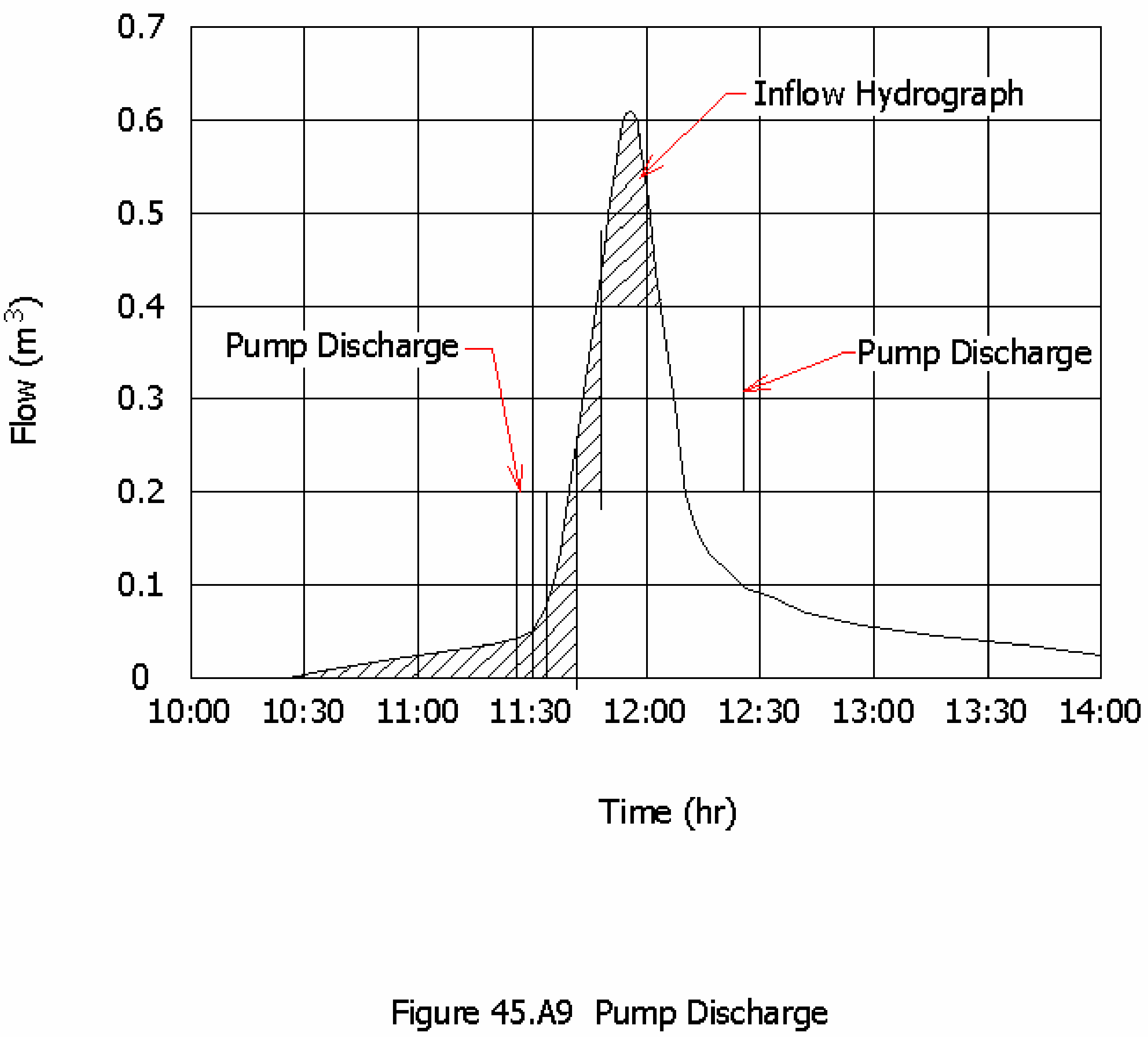

Figure 45.A9 Pump Discharge