# 14 Pump Stations

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## 14.1 INTRODUCTION

Stormwater pump stations are used to remove stormwater from highway sections that cannot be drained by gravity. When operation and maintenance costs are evaluated, a considerable expenditure can be justified for a gravity system. But, due to high costs and the potential problems associated with pump stations, their use is recommended only where other systems are not feasible. Alternatives to pump stations include deep tunnels, siphons, and recharge basins, although recharge basins are often aesthetically unpleasing and can create maintenance problems. General guidance and information on all aspects of pump stations can be found in FHWA's Hydraulic Engineering Circular 24, "Highway Stormwater Pump Station Design" (HEC 24).

### 14.1.1 Policy

The following policies are specific to pump station design:

- A pump station must only be used where a gravity system is not practical or feasible.
- The design frequency for pump stations shall be the same as the frequency for the roadway system being drained.
- Pump stations must be designed to satisfy the spread-criteria limitations of the roadway section being drained.

## 14.2 DESIGN CONSIDERATIONS

Pump-station design presents the hydraulics engineer with a more challenging problem than merely providing a cost-effective drainage system that meets the needs of the project. The following are some of the considerations involved in pump station design:

- Wet-pit versus dry-pit;
- Type of pumps;
- Number and capacity of pumps;
- Motor versus engine drive;
- Peak flow versus storage;
- Force main versus gravity;
- Above grade versus below grade;
- Monitoring systems;
- Backup systems; and
- Maintenance requirements.

Many of the decisions regarding these considerations are based on engineering judgment and experience. To assure cost-effectiveness, the hydraulic engineer should assess each choice and develop economic comparisons of alternatives based on annual cost. However, some general recommendations are discussed in this chapter that will help minimize the design effort and the cost of these expensive drainage facilities.

The following sections provide an overview of the pump-station design process and options that are available to the hydraulic engineer in designing a pump station. For further information on the design and use of pump stations, see HEC 24, or Chapter 15 of the AASHTO *Drainage Manual*. The Hydraulic Institute (New Jersey) has developed standards for pumps, and pump-station design should be consistent with these standards.

### 14.2.1 Location

Economic and design considerations dictate that a pump station should be located relatively near the low point of the highway. Easy access to the station is desirable. The station and access road should be located on high ground so that access is possible even if the highway becomes flooded. It is necessary to first prepare a complete foundation report that provides soil-boring data, groundwater elevations, and soil makeup for the selected site. Architectural and landscaping decisions should be made in the location phase for above-ground stations so the station will be compatible with the surroundings and community. Location and design of pump stations should consider:

- Designing a pump station which is architecturally pleasing with a minimal increase in cost;
- Inclusion of clean, functional lines that will improve the station’s appearance;
- Masonry or a textured-concrete exterior treatments;
- Providing screening walls to hide exterior equipment and break up the lines of the building;
- Inlcuding a small amount of landscaping which can substantially improve the overall appearance of the site;
- Placing the pump station entirely underground, if necessary; and
- Including ample parking and working areas adjacent to the station for maintenance and repair vehicles.

### 14.2.2 Hydrology

Pump stations serving expressways and major arterials are usually designed to accommodate a 50-year storm. On interstate highways, no inundation of travel lanes is permitted for the 50-year storm. The drainage system must be checked for the 100-year storm to determine the extent of flooding and the associated risks. For safety reasons the maximum ponding depth for the 100-year storm must not exceed two feet.

Hydrologic design should be based on the ultimate development of the area that must drain to the station. Every attempt should be made to minimize the area draining to the station. This may include utilizing crest vertical curves on approach roadways, dikes, and inlets above the sump. The design should bypass as much drainage as possible to reduce pumping requirements. Avoid future increases in pumping by isolating the drainage area. For example, prevent off-site drainage from possibly being diverted to the pump station.

### 14.2.3 Collection Systems

Storm drains of the pumping station are usually designed with minimum grades to minimize depth and cost. A minimum grade that produces a velocity of 3 ft/s in the last section of pipe when flowing one-fourth full is suggested to avoid siltation problems in the collection system. The last section of pipe is defined as the end portion of the pipe, where the pipe invert is at or below the elevation of the first pump. Minimum cover or local-head requirements should govern the depth of the uppermost inlets. The inlet pipe should enter the station perpendicular to the line of pumps. The inflow should distribute itself equally to all pumps. Baffles may be required to ensure that this is achieved. It is recommended to use grate inlets as screens to prevent large objects from entering the system and possibly damaging the pumps.

### 14.2.4 Station Types

There are two basic types of stations: wet-pit and dry-pit.

#### Wet-Pit Stations

In a wet-pit station, pumps are submerged in a wet well. This requires use of submersible pumps. These pumps handle stormwater effectively and allow for convenient maintenance in wet-pit stations because they are easily removed. Submersible pumps are available in large sizes and should be considered for use in all station designs. CDOT typically uses wet-pit stations. See Figure 14.1 for a typical wet-pit station layout.

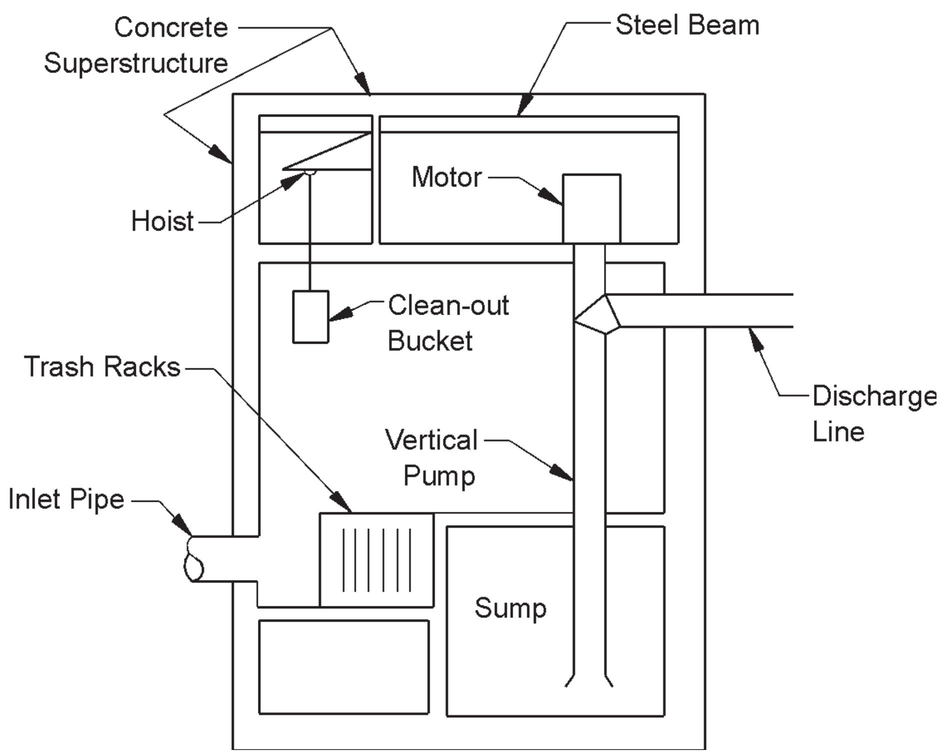


**Figure 14.1** Typical Wet-Pit Station, Source: HEC-24

### Dry-Pit Stations

Dry-pit stations consist of two separate elements: the storage box or wet well, and the dry well. Storm water is stored in the wet well, which is connected to the dry well by horizontal suction piping. Dry-pit stations are more expensive than wet-pit stations. Centrifugal pumps are normally used in dry-pit stations. The main advantage of a dry-pit station is the availability of a dry area for personnel to perform routine and emergency pump and pipe maintenance. See Figure 14.2 for a typical dry-pit station layout.

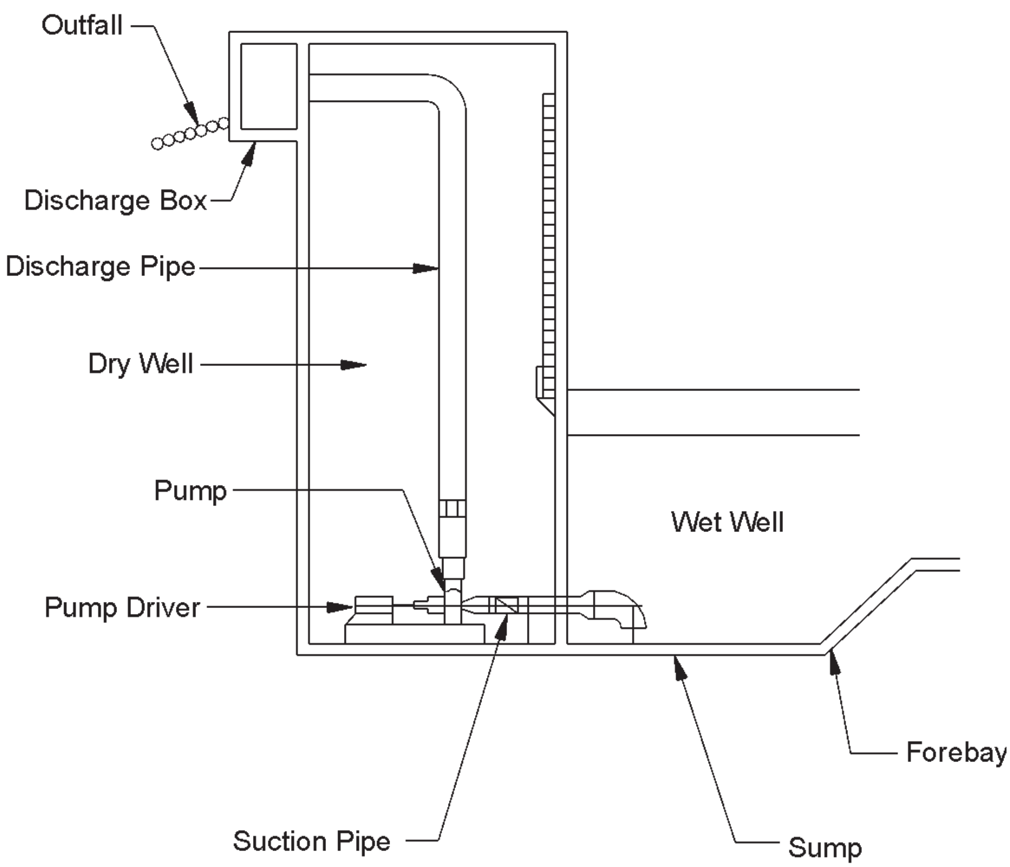


**Figure 14.2** Typical Dry-Pit Station, Source: HEC-24

### 14.2.5 Pump Types

The most common types of stormwater pumps are axial flow (propeller), radial flow (impeller), and mixed flow (combination of the two).

**Axial-Flow Pumps:** Axial-flow pumps lift the water up a vertical riser pipe. The flow is parallel to the pump axis and drive shaft. They are commonly used in low-head, high-discharge applications. Axial-flow pumps do not handle debris well because the propellers will bend or possibly break if they strike a relatively large, hard object. Also, fibrous material will wrap itself around the propellers.

**Radial-Flow Pumps:** Radial-flow pumps utilize centrifugal force to move water up the riser pipe. They are typically used in dry-pit stations and/or for high-head applications. Radial-flow pumps generally handle debris quite well. A single-vane, non-clog impeller handles debris best because it provides the largest impeller opening. The debris-handling capability decreases with an increase in the number of vanes because the size of the openings decreases.

**Mixed-Flow Pumps:** The flow in mixed-flow pumps is very similar to axial-flow pumps except they create head by a combination of lift and centrifugal action. An obvious physical difference is the presence of the impeller bowl just above the pump inlet. Mixed-flow pumps are used for intermediate head and discharge applications, and handle debris slightly better than propellers.

All of these pumps can be driven by motors or engines housed in a dry well, or by submersible motors located in a wet well. Submersible pumps provide additional advantages by simplifying the design, construction, and maintenance, therefore reducing the cost of the pump station.

The selection procedure is to first establish the criteria, then to select a combination from the options available that clearly meets the criteria. Cost, reliability, operating, and maintenance requirements are all important considerations when making the selection. It is difficult and beyond the scope of this manual to develop a totally-objective selection procedure. First costs are usually of more concern than operating costs in stormwater pump stations because the operating periods during the year are relatively short. Ordinarily, first costs are minimized by providing as much storage as possible with two or three small pumps that are electrically driven.

### 14.2.6 Submergence

Submergence is the depth of water above the pump inlet necessary to prevent cavitation and vortexing. It varies significantly with pump type, speed, and atmospheric pressure. The value for submergence is provided by the pump manufacturer, and determined by laboratory testing. A very important part of submergence is the required net positive-suction head (NPSH), because it governs cavitation. The available NPSH should be calculated and compared to the manufacturer's requirement. Additional submergence may be required at higher elevations. As a general rule, radial-flow pumps require the least submergence, while axial flow pumps require the most.

### 14.2.7 Water-Level Sensors

Water-level sensors activate the pumps. There are a number of different types of sensors that can be used, including: float switches, electronic probes, ultrasonic devices, and air-pressure switches. Only air-pressure sensors are used in CDOT pump stations.

### 14.2.8 Power

Several types of power may be available for a pump station. Examples are electric motors and gasoline, diesel, or natural gas engines. The hydraulic engineer 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 alternatives is helpful in making this decision. However, when readily available, electric power is usually the most economical and reliable choice. Maintenance personnel should provide input in the selection process.

The need for backup power is dependent upon the consequences of failure. The decision to provide it should be based on economics and safety.

### 14.2.9 Discharge System

Discharge piping should be kept as simple as possible. Pumping systems that lift stormwater 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 forced mains. Check valves should be installed. The effect of stormwater returning to the sump after pumping stops should be considered. Individual lines may exit the pumping station either above or below grade. Frost depth must be considered when deciding the depth of discharge piping. A frozen discharge pipe could exert additional back pressure on pumps.

### 14.2.10 Flap Gates and Valves

#### Flap Gates

The purpose of a flap gate is to restrict water from flowing back into a discharge pipe and to limit entry into the outfall line. Flap gates are usually not watertight, so the elevation of the discharge pipe should be set above normal water levels in the receiving channel. Experience has shown that debris can clog the opening of flap gates, preventing the closure of the gates. If flap gates are used, it may not be necessary to provide check valves.

#### Check Valves

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

Care must be taken to ensure that check valves do not obstruct the outflow in the discharge piping. Roadway drainage inherently includes debris, which can catch on a check valve, hamper valve operation, and restrict pump performance.

#### Gate Valves

A gate valve is 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. They should be either totally open or totally closed.

#### Air/Vacuum Valves

Air/vacuum valves are used to allow air to escape discharge piping when pumping begins, and to prevent vacuum damage to 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.

### 14.2.11 Trash Racks and Grit Chambers

Trash racks should be provided at the entrance to a wet well. For stormwater pump stations, simple steel-bar racks are adequate. Bar racks should be inclined on a 3:1 slope. Optimal bar spacing varies with pump size, and typically is 1.5 inches (3.5 centimeters). Constructing racks in modules facilitates removal for maintenance. If the rack is relatively small, an emergency overflow should be provided to protect against clogging and subsequent surcharging of the collection system.

If substantial amounts of sediment are anticipated, a chamber may be provided to catch solids that are expected to settle out. This will minimize wear on the pumps, and limit deposits in the wet well.

Access to the trash rack and the grit chamber should be designed so that a convenient means of debris and sediment removal is available.

### 14.2.12 Ventilation

Ventilation of dry and wet wells is necessary to ensure a safe working environment for maintenance personnel. Maintenance procedures should require personnel to wait several minutes after ventilation has started before entering the well.

Wet wells commonly have dual-fan systems, although they can be designed to rely on natural ventilation. An intake fan forces fresh air down ducts to the lower areas of the well. An exhaust fan pulls stale air or any potentially-explosive gases from the opposite side of the sump. If mechanical ventilation is required to prevent buildup of potentially-explosive gasses, pump motors or any spark-producing equipment must be rated explosion proof, or the fans must be run continuously. Enough ventilation should be provided to prevent condensation from damaging electrical components.

### 14.2.13 Roof Hatches and Monorails

Motors and pumps have to be removed 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 lift the equipment directly from the station onto maintenance trucks. Monorails are usually more cost-effective for larger stations.

### 14.2.14 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. The contract specifications should contain 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 that fails should be repaired and retested.

### 14.2.15 Monitoring

Pump stations are vulnerable to a wide range of operational problems, from malfunction of the equipment to loss of power. Monitoring systems, such as on-site warning lights and remote alarms, alert maintenance personnel and limit negative consequences of these problems.

### 14.2.16 Hazardous Spills

The possibility of hazardous spills under highway conditions is always present. Of particular concern are gasoline spills, and the vulnerability of pump stations and pumping equipment to fire damage. There is a history of such incidents having occurred, and also of spills of oils, corrosive chemicals, pesticides, and similar materials having been flushed into stations with undesirable results. The usual design practice is to provide a closed conduit system without any open forebay, which leads directly from the highway to the pump station, and intercepts hazardous fluids or vents off volatile gases. With a closed system, there must be a gas-tight seal between the pump pit and the motor room in the pump station. Preferably, the pump station should be isolated from the main collection system and the effects of hazardous spills mitigated by a properly-designed storage facility upstream of the station. This may be an open forebay, or a closed box below the highway pavement or adjacent to it. The closed box must be ventilated by sufficient grating area at each end.

## 14.3 Construction and Operation Considerations

### 14.3.1 Construction

The method of construction has a major impact on the cost of a pump station. Operating costs for stormwater-pump stations are often insignificant compared to construction costs. Therefore, the type of construction should be chosen carefully. A decision must be made between selecting caisson construction, in which the station is usually circular, or open-pit construction. Soil conditions are the primary factor in selecting the most cost-effective alternative.

### 14.3.2 Maintenance

Maintenance personnel should provide input in the design and selection of each element in the station. A comprehensive system should be developed for maintaining and testing the equipment so that it will function properly. Input from maintenance forces should be a continuous process so that each new generation of stations will benefit by what has been learned. Annual inspection by mechanical and electrical engineers can provide valuable information to maintenance personnel regarding items that need attention. The engineers will often identify deficiencies not noted by regular maintenance personnel. Detailed records of maintenance activities must be kept for every pump station so that present and future personnel will know the status of the station. These records also allow determination of operating costs for the station.

## 14.4 RECOMMENDED DESIGN CRITERIA

The following recommendations are being made with the objective of minimizing the construction, operation, and maintenance costs of highway stormwater pump stations while remaining consistent with the practical limitations of all aspects.

### 14.4.1 Station Type and Depth

CDOT typically uses wet wells with separate sediment pits in its pump stations. Station depth should be minimized, and should be no greater than that required for pump submergence and clearance below the inlet invert, unless foundation conditions dictate otherwise.

### 14.4.2 Power

CDOT Region personnel decide what type of power source to use. The need for backup power is dependent upon the consequences of failure, and secondary power sources should be considered.

### 14.4.3 Discharge Head

Since stormwater pumps are extremely sensitive to changes in head, the head demand 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 versus the head loss produced by smaller piping. This approach should identify a reasonable compromise in balancing cost and design.

The total dynamic head (*TDH*) should be based on the maximum static head (the lowest pump-off elevation). This allows rising water levels in the wet well to compensate for a portion of lost capacity due to pump wear, oxidation, and mineral deposits in the discharge system.

The *TDH* is computed as follows:

$$TDH = H_s + H_f + H_v + H_l \tag{14.1}$$

where: *TDH* = total dynamic head, ft; $H_s$ = maximum static head (at lowest pump-off elevation), ft; $H_f$ = friction head, ft; $H_v$ = velocity head, ft; and, $H_l$ = losses through fittings, valves, etc., ft.

### 14.4.4 Main Pumps

#### Number and Capacity

A minimum of three pumps is recommended. If the total discharge to be pumped is very small and there is little chance of the area draining to the station increasing substantially, the use of a two-pump station may be considered. The two-pump system could have pumps designed to pump 66%- 100% percent of the required discharge, and the three-pump system could be designed so that each pump will pump 50% of the design flow. The damage resulting from the loss of one pump could be used as a basis for deciding the size and number of pumps.

If there is constant water entering the pump station, one of the pumps could be smaller in order to minimize the use of the larger and more-expensive pumps. However, it is recommended that equal size pumps be used. Identical size and type enables all pumps to be freely alternated in service. This equalizes wear and reduces the need for cycling storage. It also simplifies scheduling maintenance and allows pump parts to be interchanged. Hour meters should be provided to aid in scheduling required maintenance.

#### Final Selection

For the typical highway application, any of the three pump types described in Section 14.2.5 will usually suffice. If not, manufacturers' information will likely aid in determining the type required. However, knowing the operating RPM, a calculation for specific speed can be made to check the appropriateness of the suggested-pump type (see Figure 14.3). Type of existing pumps, inventory of spare parts, and local availability of parts for any specific pump should be considered before ordering a particular brand.

### 14.4.5 Spare Pumps

Spare pumps are not warranted in stormwater applications. If the consequences of a malfunction are particularly critical, it is more appropriate to add another main pump and reduce the sizes accordingly. In CDOT pump stations, spare pumps are the same model and size as the main pumps.

### 14.4.6 Pump ON/OFF Settings

Pump ON/OFF settings, which control the starting and stopping of pump motors, correspond to rising and receding water levels in the sump. These settings must be carefully established so that the pumps can handle the design peak flow and all lesser flow rates and durations, and so that the motors will not experience rapid starting cycles. The first pump ON/OFF setting is extremely important as it establishes the most-frequent cycle time. To prolong the life of the motors, sufficient volume must be provided in this cycle to meet the minimum-cycle time required by the pump motors. Other pump settings are then established so that there is sufficient volume of storage to provide an acceptable cycle time for all remaining pumps. Rotating pumps in the starting cycle will prolong pump life. The combination of pump settings and pump capabilities establishes the stage-discharge relationship for the pump station.

### 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 one to two feet of freeboard below the roadway grate.

### Clearances

Pump-to-pump, pump-to-backwall, and pump-to-sidewall clearances should be the minimum possible to minimize potential sedimentation problems. For these clearances, consult the manufacturer or a dimensioning guide. The pump-inlet-to-floor clearance plus the pump-submergence requirement constitute the distance from the lowest pump-off elevation to the floor of the wet well. The final elevation may have to be adjusted if the type of pump installed changes.

### Design Examples

For specific design information, procedures, and design examples, refer to Chapter 15 of the AASHTO *Drainage Manual.*

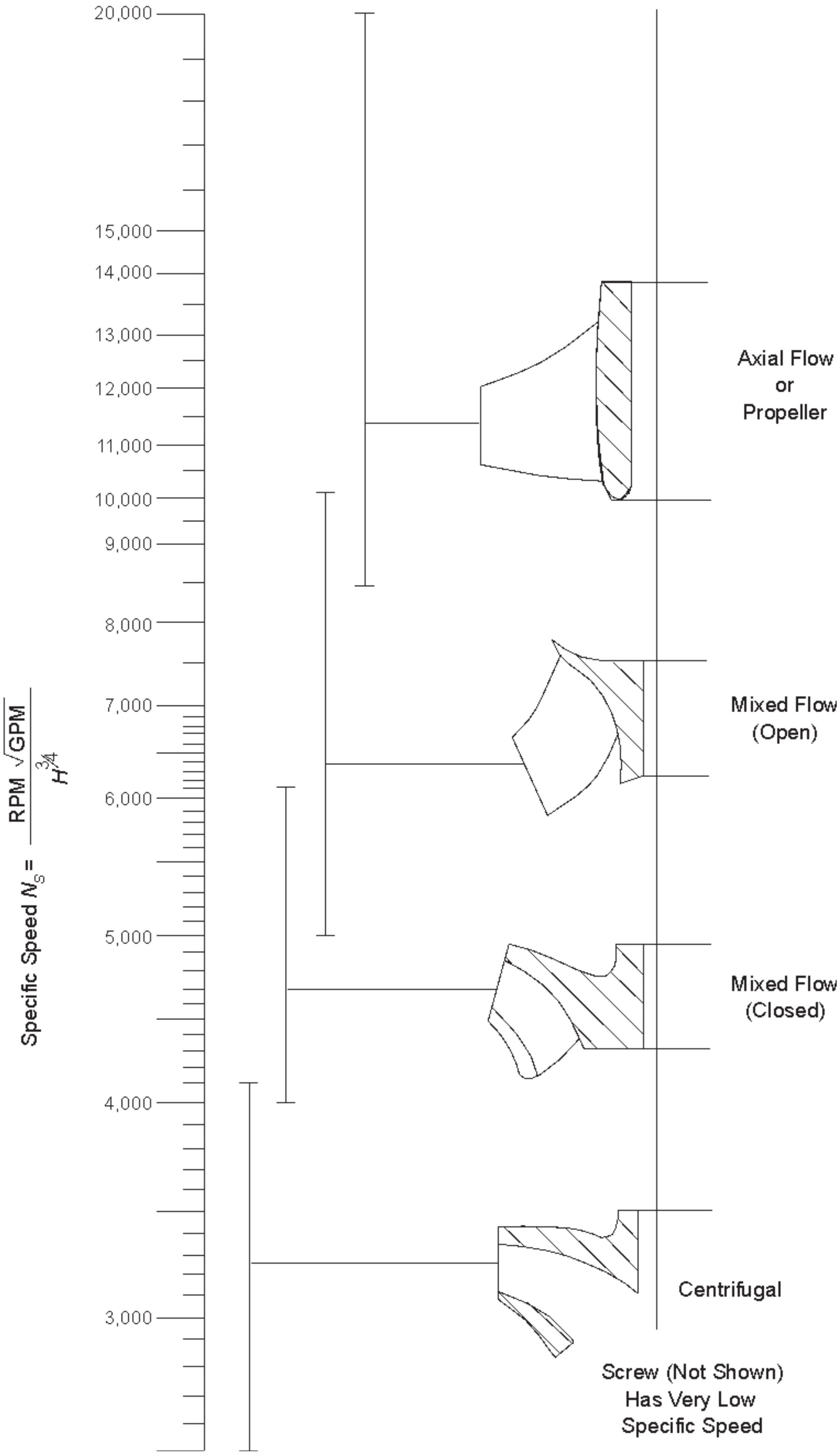


**Figure 14.3** Specific Pump Speed versus Impeller Types, Source: Los Angeles County Flood Control District

## REFERENCES

1. American Association of State Highway Transportation Officials, *Drainage Manual,* 2014.

2. U.S. Department of Transportation, FHWA, "Highway Stormwater Pump Station Design," Hydraulic Engineering Circular No. 24, February 2001.

3. FHWA, "Highway Stormwater Pump Station Design," Hydraulic Engineering Circular No. 24, FHWA-NHI-01-007, U.S. Department of Transportation, Washington DC, 2001.

4. Hydraulic Institute, American National Standard for Pump Intake Design, *Engineering Data Book*, ANSI/HI 9.8, Parsippany, New Jersey, 1998. Available from http://estore.pumps.org/directory.aspx.

5. Hydraulic Institute, *American National Standard for Vertical Pumps*, ANSI/HI 2.1-2.4, Parsippany, New Jersey, 2008.

6. Hydraulic Institute, *Centrifugal Pump Design and Application,* ANSI/HI 1.1-1.2 (2008), ANSI/HI 1.3 (2009), and ANSI/HI 1.4 (2010), Parsippany, New Jersey.