

**CHAPTER 10**  
**PUMP STATIONS**

**NOTE: All questions and comments should be directed to the Drainage Specialist, Design Support Area.**

**Revised January 2006**

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## 10.1 INTRODUCTION

This chapter describes the major components and design considerations for stormwater pump stations and makes recommendations on some characteristics to achieve the most cost-effective design and installation. The Project Manager should coordinate project-related work with the Design Engineer-Municipal Utilities Unit, Design Engineer - Electrical Unit, and the Design Engineer - Hydraulics/Hydrology Unit. The information in this chapter is a guideline to the design, operation, construction, and maintenance of MDOT pump stations and their structural, mechanical, and electrical systems. The information in this chapter has been divided into five categories:

- General Design, Section 10.3
- Mechanical System, Section 10.4
- Electrical System, Section 10.5
- Retrofitting, Section 10.6
- Maintenance, Section 10.7

Stormwater pump stations are necessary to remove stormwater from highway sections that cannot be drained by gravity. Because of high costs and the potential problems associated with pump stations, their use is recommended only where other systems are not feasible. When operation and maintenance costs are capitalized, a considerable expenditure can be justified for a gravity system. Alternatives to pump stations include deep tunnels, siphons, and infiltration systems, although infiltration systems are often aesthetically displeasing and can create maintenance problems. This chapter complements information and general guidance found in FHWA's, HEC-24, *Manual for Highway Storm Water Pumping Stations*, although typical pump station design procedure presented in the current FHWA Manual differs from MDOT's trunkline stormwater pump station design, construction, and maintenance practices.

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 many considerations involved in their design. Below is a listing of some of them.

- Wet pit vs. dry pit (Section 10.3.2.2)
- Type of pumps (Section 10.4)
- Number and capacity of pumps (Section 10.4.2.1)
- Peak flow vs. storage (Section 10.3.1)
- Force main vs. gravity (Section 10.3.3)
- Above vs. below grade (Section 10.3.2.1)
- Monitoring systems (Section 10.3.2.7)
- Backup power systems (Section 10.5.4)
- Maintenance requirements (Section 10.7)

- Flow control using variable speed pumps or throttling valves (may not be practical due to high cost)
- Risk management and life cycle cost analysis (Section 10.3.2.1)
- Retrofitting existing pump stations (Section 10.6)

Many of the decisions regarding these factors are currently based on engineering judgment 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, as discussed in this chapter, can be made which will help minimize the design effort and the cost of these expensive drainage facilities.

For further information on the design and use of pump stations see, *Highway Storm Water Pumping Stations*, Volumes 1 and 2, FHWA-IP-82-17, NTIS Numbers PB 84-152727 and 152735, and the other references given at the end of this chapter. The Hydraulic Institute, 9 Sylvan Way, Parsippany, New Jersey 07054-3802, has developed standards for pumps. Pump station design should be consistent with these standards.

For mechanical, electrical, and miscellaneous metal work (including field coating) refer to MDOT's Standard Specifications for Construction.

## 10.2 DEFINITIONS

Following are discussions of concepts which will be important in the design of pump stations. These concepts will be used throughout this chapter.

Air/Vacuum Valve - An Air/Vacuum valve is used to allow air to escape the discharge piping when pumping begins, and to prevent vacuum damage to the discharge piping when pumping stops. If the pump discharge is open to the atmosphere, an air/vacuum release valve may not be necessary. Combination air release valves are frequently used at high points in force mains to evacuate trapped air.

Anti Ratchet Device - A device used to stop backflow from reversing the direction of pump and motor rotation in vertical shaft pumps. Installation of this type of device is mandatory in all vertical shaft pump equipped stations.

Check Valve - A watertight fitting used in pipes to prevent back flow to the pumps and subsequent re-circulation. MDOT prefers a check valve that is sealed with a rubber seated ball type fitting.

Collection System - Stormwater is conveyed from the drainage area of the highway to the pump station in a system of ditches, gutters, manhole inlets, and conduits that comprise a collection system.

Dry Pit Station - The dry pit station is comprised of two main chambers: a dry well and a wet well. The stormwater enters the station and is stored in the wet well. The wet well is usually separated from the dry well by a wall and is connected to the dry well by a suction line for each pump. See Section 10.3.2.2 for more details.

Flap Gate - 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 watertight so the invert elevation of the discharge pipe should be set above the high water levels in the outfall surge chamber. If flap gates are used, it may not be necessary to provide for check valves.

Gate Valve - A gate valve is a simple shut-off device that is used to isolate pumps and facilitate removal. These valves should not be used to throttle flow. They should be either totally open or totally closed.

Pump Control - A device that activates pumps successively in response to a rising water level in the sump. The control regulates the pump activity until the inflow into the wet well has ceased.

Pump - A device that increases the static pressure of fluids. In other words, a pump adds energy to a body of fluid in order to move it from one point to another.

Pump Driver - The device used to provide power to the pump. Alternating current electric motors are the most common type of driver. Squirrel cage (single speed), induction, or synchronous motors (large horsepower with low rpm) are preferred by MDOT. Although less frequent, engines may also be used as pump drivers.

Screw Pump - A positive displacement pump comes with two or three screws (a single screw version is called a "progressing cavity" pump). The pump forms cavities, which contain the fluid and move it along the screw. Screw pumps are normally not used in MDOT's stormwater applications.

Sump Pump - A pump installed in the sump of wet wells of wet pit and dry pit stations. The sump pump is used to pump out the water remaining in the well after the water level has dropped and all the primary pumps are no longer pumping. The sump pump may also remove the accumulation of solids, such as silt, sand, and debris, that accumulate at the bottom of the wet well. MDOT does not recommend the use of permanently installed sump pumps.

Ungula - A section or part of a cylinder cut off by a plane oblique to the base. Used to describe the volume of water (in-line) in the pipe upstream of a pump station. For further information on ungula volume and its use in pump station design, see *Highway Storm Water Pumping Stations*, FHWA-IP-82-17 (HEC-24).

Well - A chamber from which stormwater is pumped. Stations in which the pumps are placed in the wet well are known as wet pit stations. Some stations use a separate well (dry well) to house the pump and driver and are referred to as dry pit stations.

Wet Pit Station - A wet pit station typically comprises of a wet well or several wet wells and a pump house. Generally, one of two configurations is used: rectangular or caisson. Two types of pumps, vertical and submersible, may be installed in the wet well of the wet pit station. See Section 10.3 for more details.

To provide consistency within this chapter, as well as throughout this manual, symbols presented in Appendix 10-A will be used. These symbols were selected because of their wide use in hydrologic publications. A list of acronyms used in this chapter is also presented in Appendix 10-A.

### 10.3 GENERAL DESIGN CRITERIA

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

#### 10.3.1 Hydrology and Storage

##### Hydrology

Because of traffic safety and flood hazards, pump stations serving major expressways and arterials are usually designed to accommodate a 2 percent chance (50-year) storm event. It is desirable to check the drainage system for a 1 percent chance (100-year) storm event to determine the extent of flooding and the associated risk. Every attempt should be made to keep the drainage area tributary to the station as small as possible. Bypass or pass-through all possible drainage to reduce pumping requirements. Avoid future increases in pumping by isolating the drainage area, i.e., prevent off-site drainage from possibly being diverted to the pump station. Hydrologic design should be based on the ultimate development of the area that must drain to the station. Refer to Chapter 3, Hydrology, and consult with the Design Engineer - Hydraulics/Hydrology. Also, refer to Chapter 8, Stormwater Storage Facilities.

The release rate of the pump station is determined by the outlet capacity and conditions. For more information on proper outlets and outlet design, see Chapter 3, Hydrology, Chapter 4, Natural Channels and Roadside Ditches, and Chapter 8, Storage Facilities.

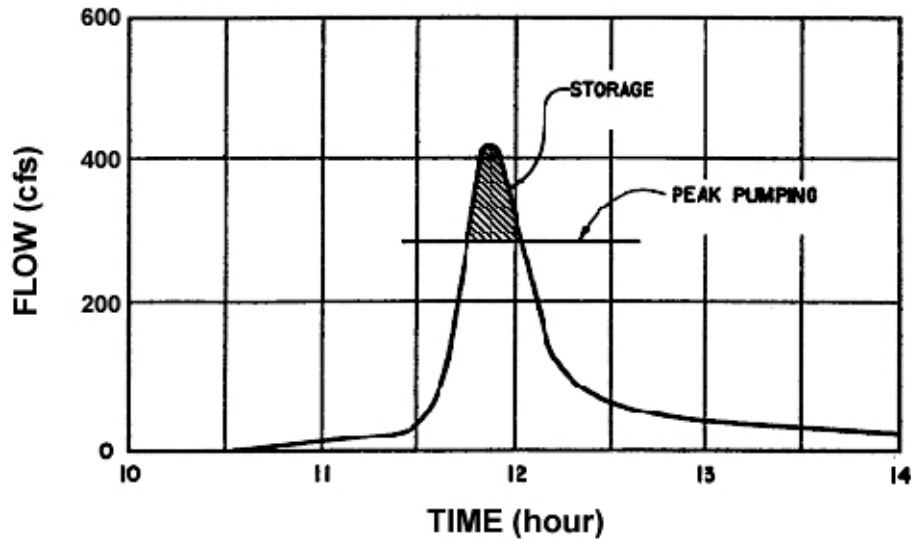
##### Storage

Designers should consider additional storage, other than storage provided in the wet well, at all pump station sites. For most highway pump stations, high flows of the inflow hydrograph occur over a relatively short time. Additional storage may greatly reduce the peak pumping rate required. The basic principle is that the volume of water, as represented by the shaded area of the hydrograph in Figure 10-1, Estimating Required Storage, is beyond the capacity of the pumps and must be stored. Economic factors can influence the combination of storage and pumping capacity. Because of the nature of the sites where highway-related pump stations are located, the high water elevation in the structure must be at least 2 feet below the lowest point of the gutter line.

If flow attenuation is required for purposes other than reducing the size of the pump facility and cannot be obtained upstream of the station, consideration may be given to providing the storage downstream of the pump station. This will require large flows to be pumped and, thus, construction and operation costs will be higher.



If storage is used to reduce peak flow rates, a routing procedure must be used to design the system. To determine the discharge rate, the routing procedure integrates three independent elements: the inflow hydrograph, the stage-storage relationship, and the stage-discharge relationship.



**Figure 10-1 Estimating Required Storage**

Since most highway-related pump stations are associated with either short underpasses or long depressed sections, it is generally not feasible to consider aboveground storage. However, if upstream, aboveground detention storage is available, it should be used to reduce the rate of flow to the pump station. Water that originates outside of the depressed areas should not be allowed to enter the depressed areas because of the need to pump all of this water. The simplest form of storage for these depressed situations is either the enlargement of the collection system or the construction of an underground storage facility. These can typically be constructed under the roadway area and will not require additional right-of-way. An equation for calculating the ungula volume is given in Appendix 10-B.

The designer shall develop a stage-storage curve to analyze the systems storage. This curve represents the total storage that is available within the system at any stage between the inlet invert elevation of the pump station and the maximum allowable elevation in the wet well.

The development of the wet well design, as discussed in Section 10.3.2.3, has general application when it is anticipated that most of the peak flow will be pumped. In that case, pump run time and cycling sequences are of great importance. In the case of many highway storm drain situations, it has been the practice to store substantial parts of the flow in order to minimize pumping requirements as well as the size of outflow piping. The demands on the pumping system are different and, thus, additional considerations should be made.

The designer should attempt to reach a balance between peak pumping rate and storage volume. This will require a trial and error procedure used in conjunction with an economic analysis. Pump stations are very costly and alternatives to minimize total costs need to be considered. Collection system storage, including "in-line" storage collection systems upstream from pump stations, optimize the size of wet wells for overall storage. Enlargement of wet wells for the purpose of storage is discouraged because it increases sedimentation around the pumps and likely will not be cost-effective.

The principles discussed for minimum run time, pump cycling, etc., in the design of wet wells should also be considered in the case of larger storage volume development. However, note that pumping differences exist as the volume of storage becomes larger. Typically, as the wet well becomes larger, the concern for meeting minimum run times and cycling time will be reduced because the volume of storage is sufficient to prevent these conditions from controlling the pump operation.

The mass inflow curve procedure discussed in HEC-24 is commonly used when significant storage is provided outside the wet well. The plotting of the performance curve on the mass inflow diagram gives the designer a good graphical tool for determining storage requirements. The procedure also makes it easy to visualize pump start/stop and run times. In the event that a pump failure should occur, the designer can also evaluate the storage requirement and, thus, the flooding or inundation that could occur. Appendix 10-B gives an example calculation for a mass inflow curve and pump discharge curves.

### **10.3.2 Station Design**

#### **10.3.2.1 Design Considerations**

##### Risk Management and Life Cycle Cost Analysis

Risk management must be considered while evaluating life cycle cost analysis with respect to new pump station construction and upgrade replacement projects. Designers should follow MDOT policy regarding public safety, health, and welfare.

##### Location

Economic and design considerations dictate that the pump station be located relatively near the low point of the highway. If possible, locate so that a frontage road or overpass is available for easy access to the station. The station and access road should be located on high ground so that access can be obtained if the highway becomes flooded. During the selection of the site, soil borings should be made to determine the allowable bearing capacity of the soil and to identify groundwater conditions or other potential geotechnical problems.

Architectural and landscaping decisions should be made in the location phase for aboveground stations so the station will blend in with the surrounding community. Following are some considerations that should be used in the location and design of pump stations:

- Modern pump stations can be architecturally pleasing with a minimum increase in cost. Use of masonry or textured concrete can improve appearance.
- Clean, functional lines will improve the station's appearance.
- Screening walls may be provided to hide exterior equipment and break up the lines of the building.
- Small amounts of landscaping can substantially improve the overall appearance of the site.
- Placement of the station entirely underground may be necessary or desirable.
- Ample parking and working areas should be provided adjacent to the station for maintenance and repair vehicles.
- Pump stations should be located away from vehicular traffic.

### Pump Station Orientation

Many pumping system problems are caused by inadequate pump suction conditions. For best results, refer to the Hydraulic Institute Standards for guidance on wet well configuration, orientation of pump suction piping and station inlet piping (suction piping clearances from floors, walls, and adjacent pumps), and related issues.

Recommended clearances should be followed or sedimentation problems could occur. Consult manufacturers' recommended requirements as well as Hydraulic Institute Standards.

### **10.3.2.2 Station Type and Depth**

There are two types of pump stations: dry pit or wet pit. Wet pit stations are the preferred method used by MDOT.

#### Station Types

##### Wet Pit Stations

In wet pit stations, the vertical pumps are either fully submerged with the motors and controls located overhead, or fully submerged motor-mounted non-clog impeller submersible pumps with controls located elsewhere. For illustrations of wet pit stations, see Figure 10-2, Sample Submersible Pump Layout, and Figure 10-3, Sample Vertical Pump Layout. There are two types of configurations that are widely preferred for pump station plan layout: circular (caisson) or rectangular.

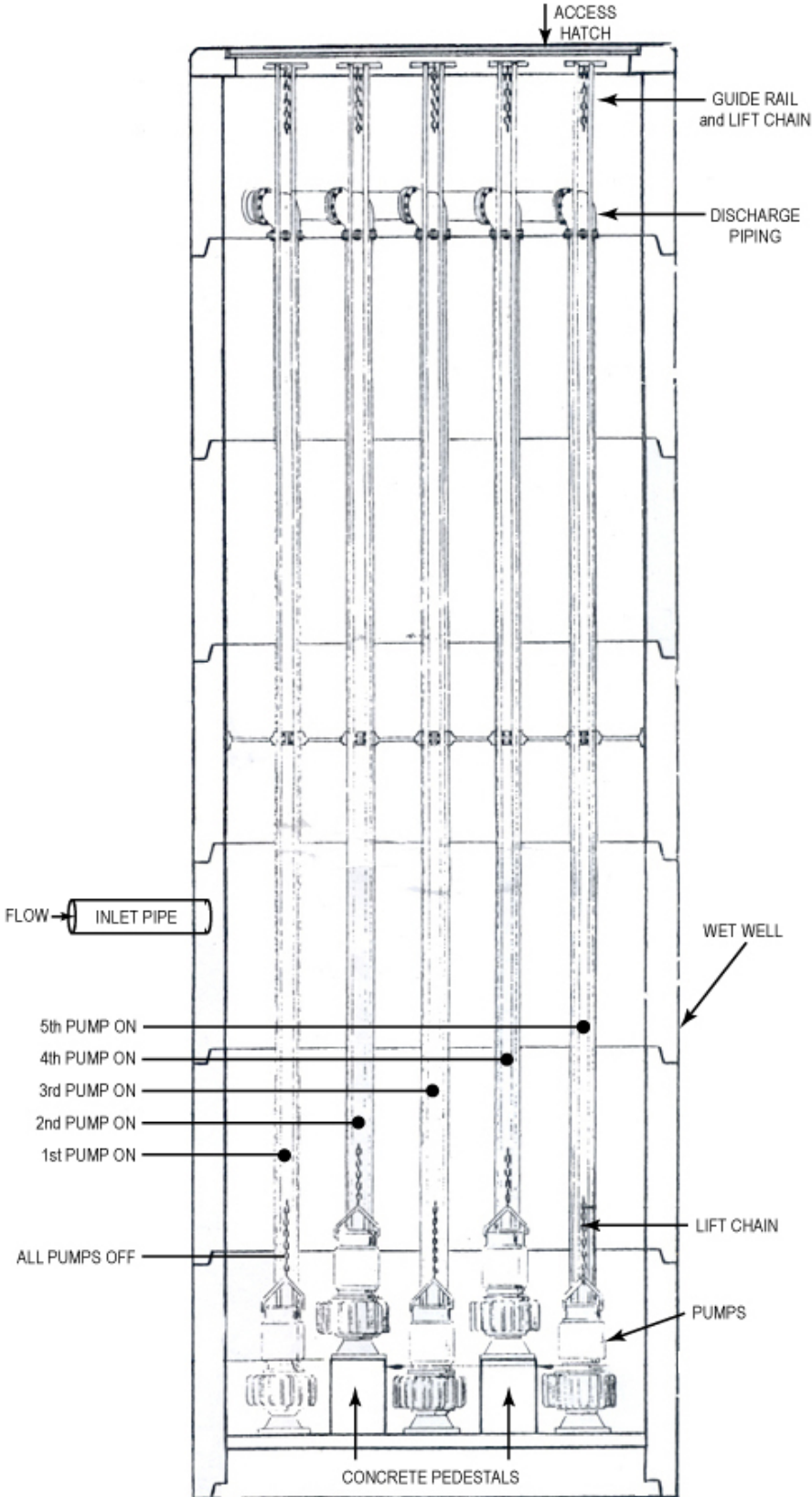


Figure 10-2 Sample Submersible Pump Layout

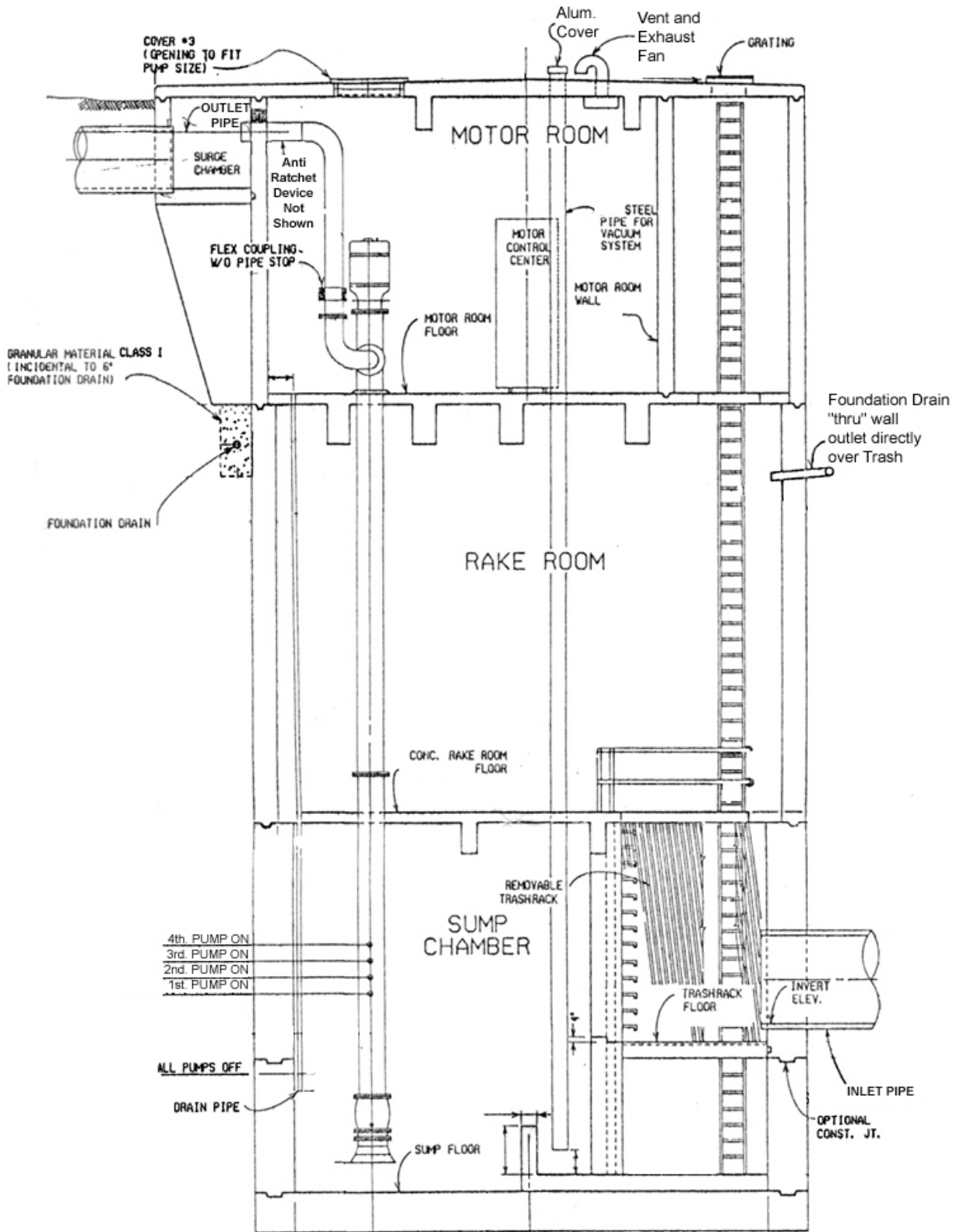


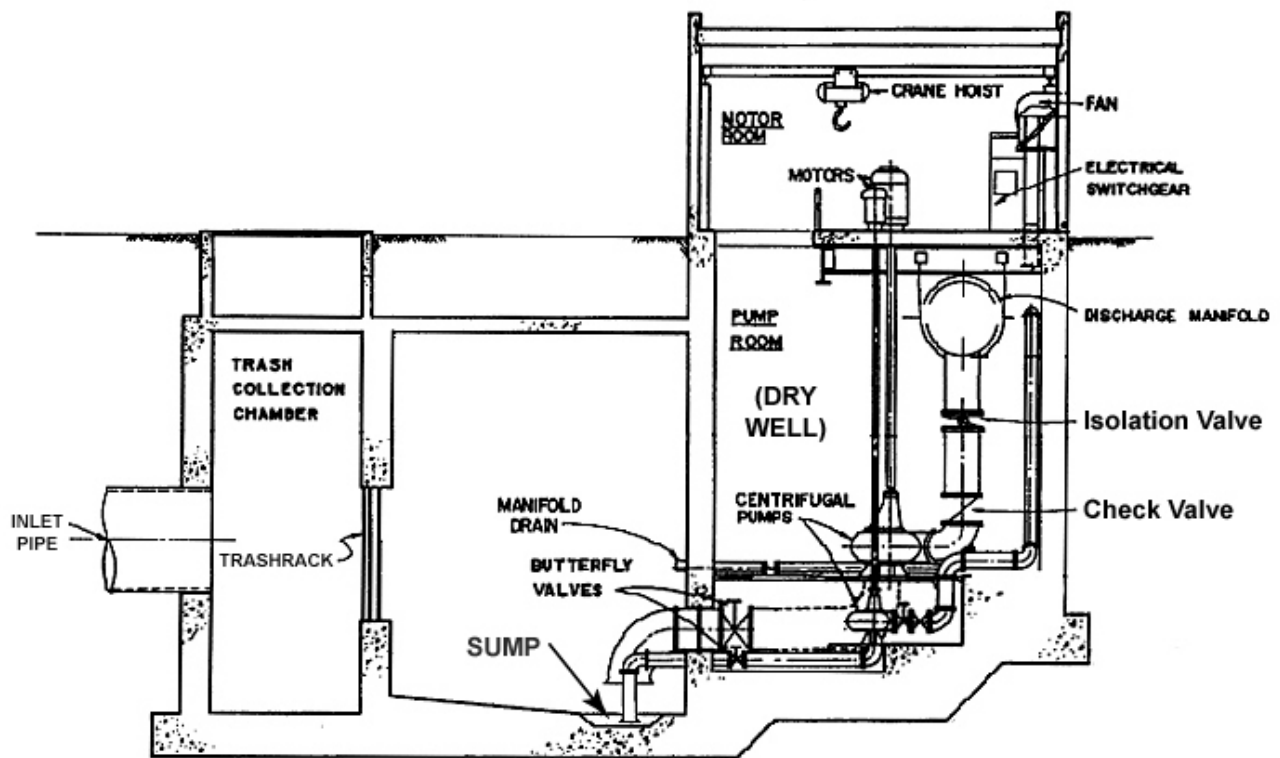
Figure 10-3 Sample Vertical Pump Layout

Note: Valving is not shown.

Dry Pit Stations

MDOT does not prefer the use of dry pit stations. Dry pit stations are typically more expensive than wet pit stations. Dry pit stations are more appropriate as pump and motor size increase, and in some instances for handling sewage, because of the potential health hazards to maintenance personnel. Some advantages associated with dry pit stations include ease of access for personnel to perform routine and emergency pump maintenance of pumps, valves, and appurtenances.

Dry pit stations consist of two separate elements: the storage box, or wet well, and the dry well. Stormwater is stored in the wet well which is connected to the dry well by horizontal suction piping. Centrifugal pumps are typically used. Close-coupled motors in the dry well or long drive shafts with the motors located overhead provide power. Submersible type pumps can also be used in a dry pit configuration, thus eliminating the long shafts, as long as adequate provisions are included for cooling the motors. See Figure 10-4, Sample Dry Pit Station Layout, for a typical design.



**Figure 10-4 Sample Dry Pit Station Layout**

Source: FHWA IP-82-17

### Station Depth

The station depth below the inlet invert should be kept to a minimum. Unless foundation conditions dictate otherwise, no more depth than that which is required for pump submergence and clearance should be used in the design. Consideration must be given to the volume required to prevent excessively short pump cycle times under all flow conditions.

Check with pump manufacturers for the current information on the minimum submergence requirements. Submergence and pump to inlet floor clearance will vary significantly with pump type (submersible and/or vertical shaft pumps) and manufacturer. As a general rule, radial/mixed flow pumps require the least submergence, while axial flow pumps require the most. The available net positive suction head (NPSH) may have to be computed to determine proper submergence. Floor clearances are very sensitive for submersible pumps, and the final floor elevation may have to be adjusted once the manufacturer of the pumps is known.

#### **10.3.2.3 Wet Well Design**

##### 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 critical parameter is the time between stopping and subsequently restarting an individual pump, not how long the pump runs after it starts. The wet well must be designed to provide sufficient volume for safe cycling, or sufficient volume must be provided outside the wet well. The volume required to satisfy the minimum cycle time is dependent on the characteristics of the power unit, the number and capacity of pumps, and the sequential order in which the pumps operate.

A pump cycling sequence called "cyclical running alternation" is recommended in the design method. The sequence is based on the logic "the first pump to start is the first pump to stop." The logic is alternated among all pumps in a sequential manner and it results in the smallest sump volume necessary to satisfy a given number of pumps and their minimum required cycle time.

After establishing the minimum cycle time and minimum number of pumps, an iterative procedure is used to determine the final number of pumps and dimensions of the wet well. Because the wet well volume varies indirectly with the number of pumps in the cycling sequence, the solution can be determined quickly. For a given volume, the final number of pumps required becomes dependent upon the station depth (distance between the allowable high water elevation and the inlet invert elevation). Because deep stations have more storage, fewer pumps are generally needed.

Incorporate the technique of "automatic sequencing of pump turn-ons," while designing the collection system layout and wet well storage requirement to optimize the number of "ons" per hour for the pump based on the horsepower of the motor used. In multiple pump installations, controls can be programmed for "first on/first off" operation to extend the cycle

time for each individual pump. This will reduce the required storage volume within the wet well system as long as the inflow is at least 50 percent of the rated pump design capacity.

The cycle time for a single pump operating is determined as shown below. Note that the least cycle time results where  $Q_{in}$  is equal to one-half the capacity of the pump:

- $Q_{in}$  = Flow rate into the pump station, cfs
- $Q_{out}$  = Capacity of the pump, cfs
- $V$  = Usable volume in wet well between elevations where pump starts and where it stops, cf

$$\begin{aligned} \text{Pump on time} &= V / (Q_{out} - Q_{in}) \\ \text{Pump off time} &= V / Q_{in} \\ \text{Cycle time} &= \text{pump on time} + \text{pump off time} \end{aligned}$$

The wet well storage volume should be minimized.

Alternating the first pump to start is sufficient for stormwater pump stations where more than one pump "on" will be rare and of short duration.

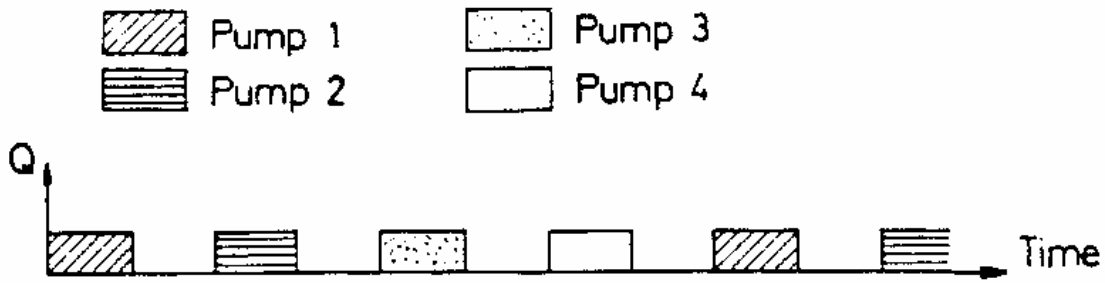
This alternation technique, coupled with the successive start/stop cycling sequence, requires the smallest total cycling volume possible. This total volume is computed as follows:

$$V_t = Q_p t_c / (4N) \quad (10.1)$$

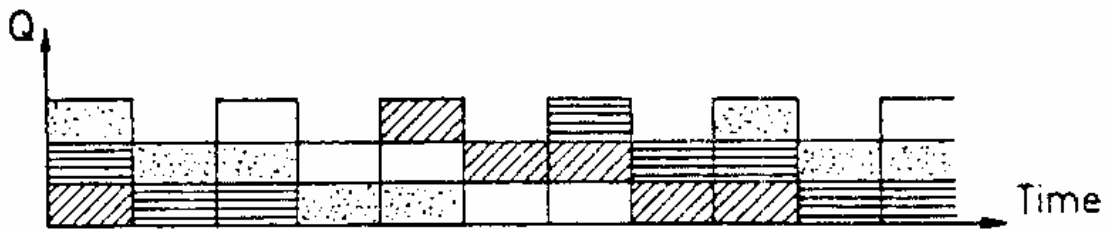
- where:
- $V_t$  = total cycling storage volume, cf
  - $Q_p$  = total capacity of all pumps, cfs
  - $t_c$  = minimum allowable cycle time, s (= 3,600/max. starts per hour)
  - $N$  = total number of equal-size pumps

The volume required for each pump will vary depending on the characteristics of the discharge system. It should be noted here that with these volumes, the minimum allowable cycle time would only be experienced when the proportionate inflow to each pump is exactly one-half the capacity of that pump. All other inflows will produce a cycle time longer than the minimum. Figure 10-5, Pumps with Cyclical Running Alternation, illustrates the sequence of pumps with cyclical running alternations.

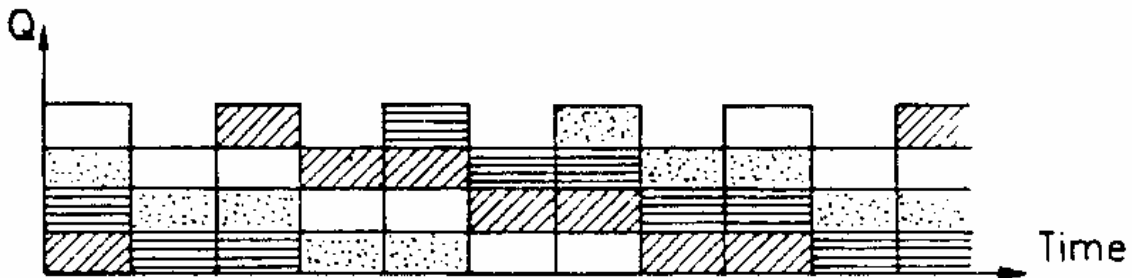




The pumps will, however, run only 1/8 of their cycle time (provided  $Q_{\text{pump}} = 2 \times Q_{\text{in}}$ ).



If  $Q_{\text{in}}$  is greater than the capacity of two pumps but less than three pumps, the pumps are operating 5/8 of their cycle time.



If the inflow is greater than the capacity of three pumps but less than the capacity of four pumps the pumps will operate 7/8 of their cycle time.

Figure 10-5 Pumps with Cyclical Running Alternation

### Lowest Pump "Off" Elevation

It is recommended that inlet invert elevation be located with in-line storage provisions. If plan dimension constraints exist, the "off" elevation can be lowered to accommodate site limitations. This elevation represents the maximum static pumping head.

### First Pump "On" Elevation

This should be set at the elevation that satisfies the alternating pump cycling sequence within the guidelines set out for the minimum cycle time for each pump. Starting the pumps as soon as possible by incrementing these volumes successively above the lowest pump off elevation will maximize what storage is available within the wet well and the collection system. The depth ( $H_x$ ) required for each volume is computed as follows, where  $V_x$  is the individual pump cycling volume:

$$H_x = V_x / \text{plan area} \quad (10.2)$$

The available volume for cycling should include the usable ungula volume as well. Usable storage does not include that part of the volume that is below the normal depth in the collection line. The assumption here is that the inflow maintains normal depth in the collection line and, therefore, any volume between normal depth and the invert in the collection line that is above the stop elevation is unavailable for cycling storage.

### Pumping Range

The recommended minimum distance between "on" and "off" elevations of individual successive pumps is 6 inches.

### Allowable High Water Elevation

The allowable high water (AHW) elevation in the station should be set such that the water surface elevation (hydraulic grade line, HGL) at the lowest inlet in the collection system provides 2 feet of freeboard below the roadway grade.

See Chapter 7, Road Storm Drainage Systems, for the procedure of calculating a HGL in a collection system.

### Sumps

A sump shall be designed into the wet well to facilitate dewatering of the facility. The sump shall be large enough to fit a temporary sump pump. Permanently installed sump pumps do not hold up well and are not recommended to be installed in MDOT pump stations.

#### **10.3.2.4 Collection Systems**

Depth and slope of the collection system should be minimized to avoid excessively deep stations. Minimum cover for the inlet pipe at the lowest point of the roadway in the vicinity of the pump station, or the depth of the allowable high water, AHW, requirements in the wet well, shall govern the depth of the uppermost inlet to the pump station. See discussion in Section 10.3.2.3 under "Allowable High Water Elevation."

Storm drains leading to the pumping station are designed in accordance with the criteria in Chapter 7, Road Storm Drainage Systems.

To ensure an even flow distribution, the inflow pipe from an intake structure (catch basin) should enter the station perpendicular to the line of pumps, and stormwater should not flow past one pump to get to another. An uneven distribution may cause strong local currents resulting in vortex formation, reduced pump efficiency, and undesirable operational characteristics. Unusual circumstances may require a special design of the intake structure to provide for optimum flow to the pumps. See Hydraulic Institute Standards for suggested pump pit dimensions.

Baffles may be required to ensure that flow distribution is achieved to all pumps. In this context, a baffle refers to a submerged weir installed between the influent trajectory and the pumps. This structure achieves uniform distribution to all pumps while trapping silt before entering the wet well pump chamber.

The collector lines should terminate at a catch basin, preferably, and then discharge directly into the wet well.

#### **10.3.2.5 Structure**

The method of construction has a major impact on the cost of the pump station. The type of construction chosen is primarily based on the geotechnical recommendations and the type of existing soil for the location of the pump station.

##### Materials

Reinforced concrete is the usual choice for the substructure of a pump station, but the method of placement varies. Precast concrete units, which are prefabricated elsewhere, are sunk to the required level. The precast units are usually caissons and are suitable for vertical shaft pump stations. Precast concrete rectangular structures are most suitable for submersible type pump stations.

##### Pump Well Requirements

When vertical shaft pumps are used, each pump must be set in the wet well and its motor driver must be above the pump room floor (known as the motor room). A separate floor is required to facilitate removal of trash from the trashrack floor. Explosion-proof motor rooms

shall be required in Wayne County locations and other locations if safety issues dictate the need.

For submersible pumps, an opening in the roof is required to permit removal of the pump and associated fixtures. Pump volute, discharge pipes, and guide rods must be securely attached as recommended by the manufacturer.

For circular caisson wet wells up to 17 feet in diameter, the structure shall be precast conforming to ASTM C 76 manufacturing specifications. For larger caisson structures, design shall be based on the geotechnical recommendations as appropriate for the site location.

For all rectangular wet well structures, especially for the submersible pump operations, the pre-cast concrete "maxi-bridge" box culvert structures are very handy and are economical in terms of final construction cost and time saved over the other types of construction. Sizes are available up to 24 feet by 11 feet.

The wet wells should be designed with maintenance in mind. Access should be provided to pull pumps, clean the wet pit and trashrack, etc. A vacuum system should be provided to clean the wet pit from outside the pump station.

#### Access to Pump Equipment

The stormwater pump station house is an enclosing structure and must provide access to the pumps and other equipment. The enclosure must have doors, roof hatches, or covered openings through which equipment can be passed or debris can be removed with a mobile crane.

#### **10.3.2.5.1 Trashracks**

Using trashracks upstream from baffle walls may prevent large objects from entering the system and possibly damaging pumps. Screening large debris at surface inlets may be very effective in minimizing the need for trashracks.

Trashracks protect against damage to the pumps and clogging that may lead to surcharging of a collection system. Trashracks should be provided inside the wet well for all pump stations. For stormwater pumping stations, flat steel with round cross bar screens are adequate. Usually the bar screens are inclined with bar spacing at approximately 2 inches. Constructing the screens in modules facilitate removal during maintenance. If the grid is relatively small, an emergency bypass of the screens should be provided to protect against clogging and subsequent surcharging of the collection system. An operation and maintenance schedule should identify trashrack inspection frequency. Inspections will identify need for debris and sediment removal.

### **10.3.2.5.2 Roof Hatches**

It will be necessary to remove motors and pumps from the station for periodic maintenance and repair. Removable roof hatches located over the equipment is the suggested means to accomplish this. Mobile cranes can lift the equipment directly from the station onto maintenance trucks.

### **10.3.2.6 Equipment Certification and Testing**

Refer to MDOT's Standard Specifications on pumps (vertical shaft and submersible types).

Equipment certification and testing is a crucial element of pump station design. All centrifugal pumps should have certified performance curves developed in accordance with Hydraulic Institute Standards and should be submitted to MDOT prior to shipment to the project site. Pump performance tests can be witnessed by MDOT if requested. There are costs associated with witnessed tests that may exceed the value for relatively standard pumping units. Witness test requirements should be clearly indicated in the pump specifications.

### **10.3.2.7 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 can help minimize such failures and their consequences. Alarms may be installed for high water elevations, power outages, pump outages, and illegal entries. MDOT recommends hour-meter and start-meter installation on all pumps to aid in scheduling needed maintenance.

Telemetry is an option that should be considered for monitoring critical pump stations. Operating functions may be telemetered from the station to a central control unit. This allows the central control unit to initiate corrective actions immediately if a malfunction occurs. Functions such as power failure, pump operations, unauthorized entry, explosive fumes, and high water levels can be monitored effectively in this manner. 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.

### **10.3.2.8 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. Adequate ventilation, heating, and dehumidification are essential for efficient operation and maintenance of the pump station. If mechanical

ventilation is required to prevent build-up of potentially explosive gasses, the pump motors or any spark-producing equipment shall be rated explosion-proof.

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

### **10.3.3 Outlet Design/Discharge System**

The discharge piping should be kept as simple as possible. The discharge pipe from the pump station shall be horizontal and discharge freely without submergence into an engineered structure, known as a "surge chamber." Always use gravity discharge when possible; avoid a force main system. A force main system in a pump station consists of check valves, plug valves, air release valves, gate valves, and reducers, along with discharge manifold, elbows, and bends, among other things. Keeping these appurtenances free from sedimentation and silt build-up is a maintenance concern.

Pumping discharge systems that lift the 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. Designers should consider the effects of stormwater returning to the wet well after pumping stops. Individual lines may exit the pumping station either above or below grade. Frost depth shall be considered while deciding the depth of discharge piping. A partially frozen discharge pipe could exert additional back-pressure on pumps, preventing operation or significantly reducing capacity.

It may be necessary to pump to a higher elevation using long discharge lines. This may dictate that the individual lines be combined into a force main via a manifold. For such cases, check valves must be provided on the individual lines to keep stormwater from running back into the wet well and restarting the pumps or prolonging their operation time. Check valves should preferably be located on horizontal layouts rather than vertical to prevent sedimentation on the downstream side after the valve closing. Gate valves should be provided in each pump discharge line to provide for continued operation during periods of repair, etc. A cost analysis should be performed to determine what length and type of discharge piping justifies a manifold. The number of valves required shall be kept to a minimum to reduce cost, maintenance, and headloss through the system. Manifolds or force main discharge systems are not recommended by MDOT.

The need for erosion protection for surface discharge should be assessed, and the outlet system should be constructed so that people or animals cannot enter the pipe outlet.

## 10.4 MECHANICAL SYSTEM

The Project Manager should consult with the Design Engineer - Municipal Utilities Unit.

### 10.4.1 Pump Types

The most common types of stormwater pumps are axial flow (propeller), radial flow, and mixed flow (using impellers that exhibit some of the characteristics of both radial and axial flow pumps). Axial flow and mixed flow pumps are often driven by a vertical motor shaft and, thus, are grouped in the following section as vertical pumps. Horizontal motor shafts usually drive radial flow pumps. A brief description of the characteristics and relative merits of each type is presented below.

#### 10.4.1.1 Vertical Pumps

Vertical pumps, also known as vertical shaft pumps are equipped with an axial diffuser (discharge bowl) rather than a volute. The bowl assembly is the heart of the vertical pump and consists of suction bell, discharge bowl impeller, pump shaft, bearings, and the parts necessary to secure the impeller to the shaft. The suction bell is designed to permit proper distribution of the liquid to the impeller.

Vertical pumps are used for low head pumping such as is typical for highway stormwater pumping stations. The vertical pumps are generally of the vertical single-stage, axial, and mixed flow types. Two-stage axial flow pumps are rarely used. Propellers are usually referred to as mixed flow impellers with a very small radial flow component.

A true propeller, in which the flow strictly parallels the axis of rotation, is called an axial flow propeller.

These pumps can be driven by motors or engines housed overhead in a motor room.

#### Axial Flow Pumps

Axial flow (propeller) pumps lift the water up a vertical riser pipe; flow is parallel to the pump axis and drive shaft. 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.

Axial flow pumps are suitable for low heads and high discharge specific speed situations; however, they are not suitable for highway locations where high volumes of effluent carrying heavy debris, fibers, and silt are anticipated. Horizontally mounted, axial flow pumps are high-capacity pumps that are typically used for low head, high discharge applications such as flood control.

### Mixed Flow Pumps

Mixed flow (impeller with vanes) pumps are suitable to high heads and very low specific speed situations; however, with the open type or closed type end impellers with vanes integral with a conical hub (bowl assembly), it can be retrofitted to achieve medium to high heads with low specific speed. This type of pump is ideal for all types of operating conditions. Mixed flow pumps are very similar to axial flow 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. They are used for intermediate head and discharge applications and handle debris slightly better than propellers.

### Pump Intakes

Suction umbrellas are effective on mixed and axial flow pumps to reduce the submergence requirements and, hence, the station depth. These types of "engineered" umbrellas are very effective when the intake velocity is greater than 4 fps. Optimize the intake velocity to 2 fps or less when sizing the umbrella. Refer to the Hydraulic Institute Standards and HEC-24 for additional guidelines for effective pump intake design practice.

#### **10.4.1.2 Radial Flow Pumps**

Radial flow (centrifugal) pumps are mounted horizontally (vertical volute) and utilize centrifugal force to move the effluent up the riser pipe; however, orientation of this type of pump with numbers of vanes in the impeller makeup is subject to sediment locking. Generally, newly constructed highway pump stations do not use radial flow pumps. However, radial pumps are often used during a retrofit to increase capacity of the station. They will handle any range of head and discharge, but are the best choice for high head applications. Radial flow pumps generally handle debris quite well. A single vane, non-clog impeller handles debris the best because it provides the largest impeller opening. The debris handling capability decreases with an increase in the number of vanes since the size of the openings decrease.

### Submersible Pumps

A submersible pump is a type of radial flow pump that allows the casing of the pump, which provides for the suction and causes the material to flow into impeller blades, to be submerged in the liquid in order to pump.

Submersible pumps frequently provide special advantages in simplifying the design, construction, and maintenance and, therefore, the cost of the pumping station. Use of anything other than a constant speed, single-stage, and single suction pump would be rare.

If the top cover is above the level of the liquid, air will enter the casing and prevent liquid from being discharged. When the casing is submerged, the pump will self-prime and start pumping.



Submersible pumps are close-coupled pumps driven by a submersible motor and are a vertical type of pump. There are pumps that have recessed impellers, while others have specially shaped non-clog impellers. The preferred submersible pumps are those with inflow, non-clog impellers that deliver higher efficiencies with lower life cycle costs than the recessed impellers.

### Dry Well Pumps

A dry well pump is a type of radial pump installed in a dry well with suction connecting the pump to the wet well. Dry well pumps are almost never used in highway stormwater pumping.

## **10.4.2 Pump Selection**

The selection procedure is to first establish the criteria and then to select from the options available a combination which clearly meets the criteria. Cost, reliability, operation, 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. Initial construction costs are usually of more concern than operating costs in stormwater pump stations since the operating periods during the year are relatively short. Providing the maximum storage by using two or three small electrically driven pumps minimizes initial costs.

MDOT's preference for highway stormwater pumping station includes non-clog centrifugal pumps, single-stage, axial flow type, or the mixed flow type pumps. Axial and mixed flow pumps are the most common pumps used. MDOT prefers electrical motors be installed in a motor room connected by a vertical shaft.

### **10.4.2.1 Pump Number and Capacity**

Pumping capacity shall be provided to equal the design inflow with all pumps operating. It is generally not needed to design for one pump out of service (firm capacity).

The designer will determine the number of pumps needed by following a systematic process. A minimum number of three pumps are recommended. This maximizes capacity lost, if one pump fails, to 33 percent. Consideration may be given to over-sizing the pumps to compensate, in part, for a pump failure. 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. MDOT does not recommend use of spare or standby pumps.

It is recommended that economic limitations on power unit size, as well as practical limitations governing operation and maintenance be used to determine the upper limit of pump size. The minimum number of pumps used may increase due to these limitations.

It is also recommended that equal-size pumps be used. Identical size and type enables all pumps to be freely alternated into service. This equalizes wear and reduces needed cycling storage. It also simplifies scheduling maintenance and allows pump parts to be interchangeable.

#### **10.4.2.2 Final Pump Selection**

For the typical highway application, any of the pumps described earlier will usually suffice. Knowing the operating revolutions per minute (rpm), a computation can be made to check the appropriateness of the pump type. The system curve (flow versus total dynamic head, TDH) defines the energy required to pump any flow through the discharge system. It is especially critical for the analysis of discharge systems with force mains. When superimposed with the pump performance curves furnished by the manufacturer, it will yield the station operation point (design point). Suction specific speed may be defined as that speed in rpm at which a given impeller would operate if reduced proportionally in size so as to deliver a capacity of "X" gpm against TDH of "Y" feet. This is an index number descriptive of the suction characteristics of a given pump. Higher numerical values are associated with better NPSH capabilities. Once the pump type and capacity have been determined, the final selection of the pump can be made.

Details of calculating system curves are presented in HEC-24. An example is presented in Appendix 10-B.

## **10.5 ELECTRICAL SYSTEM**

The Project Manager should consult with the Design Engineer - Electrical Unit.

Electric power from a dependable utility provider is most desirable, if available. System voltages in the pump house usually include 120/240-volt single phase for general use, and motors may be single phase or three-phase. Motor voltages may be single phase ranging from 120- to 480-volt while three-phase vary anywhere from 208- to 4,800-volt. MDOT recommends constant speed, three-phase induction motors (National Electrical Manufacturers Association, Design B). The majority of MDOTs' motors operate on 480-volt three-phase systems.

When an electric utility company has a second electrical source available or a permanent generator is installed on-site, an automatic transfer switch should be utilized. If a second electrical utility source is not available, consideration should be given to whether the pump station is to have standby power (SBP). If MDOT still requires a standby source, MDOT prefers that stations have a manual transfer switch and a SBP receptacle compatible with MDOT's portable engine/generator set.

### **10.5.1 Requirements**

Contract documents and plans include a complete light, power, and control system including the incoming service, all wiring and conduit, lighting fixtures, wall switches, convenience outlets, motor control center, liquid-level control for the motors, in-coming feeder circuit breaker, automatic selector switch, transfer switch, and all other miscellaneous items required to form a complete, ready-for-operation electrical system.

The contract plans indicate the general design. Switches, outlets, and other items shown on the plans are indicated only in their approximate locations. The contractor shall take his own field measurements and shall be responsible for the proper fit and location of conduits and other items included in the electrical work.

All materials furnished and installed in the pump house shall be explosion-proof, Class I, Division I, with Underwriters' Laboratories, Inc. label of approval.

The contractor shall obtain from the pump manufacturer information giving the actual size and characteristics of the motors to be furnished, and he shall properly complete the electrical installation with regard thereto.

The Contractor shall furnish all material, labor, and equipment required for the completion of the electrical work, mechanical work, and miscellaneous items per contract documents and plans.

### **10.5.2 Code Compliance**

All material shall be new, and all work and material shall meet the current standards and practices of the National Electrical Code (NEC), American National Standards Institute (ANSI), the current Standard Specifications for Highway Construction, and the Occupational Safety and Health Act.

### **10.5.3 Operation**

The operation of the pumping unit shall be automatically controlled by means of a liquid-level control and magnetic motor starters. An automatic selector switch shall change the sequence in which the motors start and stop every time a motor is de-energized.

### **10.5.4 Power Supply and Service Connections**

Electrical power is the primary source for pump stations. The following note should be placed on all pump station plans:

"Incoming power feed shall be as follows for this project:

- phase,
- voltage, and
- number of wires."

The utility company will furnish all labor, equipment, and materials required to bring the power supply to an agreed upon location. The utility company will provide an itemized bill for work it will provide.

The contractor shall contact the utility company before construction is started and shall give 12 weeks notice before service is required.

### **10.5.5 Materials**

#### **10.5.5.1 Service Cables**

The service cables into the pump house from the utility company service box shall be copper, single conductor, rated for system voltage and current, Type USE with RHW insulation.

#### **10.5.5.2 Wire and Cable**

All wire and cable insulation shall be UL approved. Type RHW, 600 volts, except as otherwise noted.

All conductors shall be copper, stranded, and in accordance with NEC requirements for ampacity.

Motor feeders shall be stranded and have a current-carrying capacity of not less than 125 percent of the motor full-load current rating. No conductor smaller than No. 12 American Wire Gauge (AWG) shall be used.

Grounding conductors shall be soft drawn, bare stranded copper sized in accordance with NEC.

#### **10.5.5.3 Conduit and Fittings**

All conduit and fittings shall be steel conduit.

All conduit not specified for size on the plans shall be one size larger than the size specified by NEC.

All interior conduit, fittings, and junction boxes, if any, outside of the motor room shall be explosion-proof, Class I, Division I, in accordance with NEC.

#### **10.5.5.4 Light Fixtures**

Lighting fixtures shall be metal halide, vapor-tight with globe and guard.

#### **10.5.5.5 Switches**

Light switches shall have a minimum rating of 20 amperes, 120 volts. Switches in the motor room shall have a vapor-tight and weatherproof enclosure.

Transfer switches may be automatic or manual depending on the availability of electrical energy.

In no case shall the electrical ratings of the transfer switch be less than the main disconnect at each pumping station. The transfer switch rating shall be sized to accommodate the available portable generator.

The external operating handle on the transfer switch shall be interlocked with the door so that the handle must be in the "OFF" position before the door can be opened. The interlock shall allow bypassing by authorized personnel. The handle shall be arranged for padlocking in the "OFF" position so that when the operating handle is padlocked, the door will also be locked.

The contractor shall submit four sets of shop drawings for approval prior to any installation.

#### **10.5.5.6 Receptacles**

Receptacles shall have a minimum rating of 20 amperes, 120 volts, UL, 2-pole grounding type, duplex, weatherproof with gasketed spring door.

Generator Receptacle: All generator receptacles (Posi-Lok system) shall be of the sized to accommodate the available portable generator. The receptacles and panel shall be: Crouse-Hinds, "Posi-Lok Plugs and Panels."

Acceptable manufacturers will be: Killark and Appleton. The contractor shall submit four sets of shop drawings for approval prior to any installation.

#### **10.5.5.7 Motor Control Center**

The motor control center shall meet all requirements of UL 845 (motor control centers).

The motor control center shall be the completely enclosed, dead-front type with operating handles, push buttons, name plates, etc., mounted on the front and all arranged to present a neat appearance. It shall consist of vertical sections divided into isolated compartments for the individual motor starters and other major equipment. The contractor shall mount the control center on 4-inch channel iron sills bolted to the floor.

The control center shall be manufactured by the same firm that manufactures the motor starters, complete with equipment shown on the wiring diagram.

The motor control center shall be furnished with control connection to a terminal board adjacent to each unit cubicle. A wiring diagram shall be furnished for each unit cubicle and a copy mounted on each cubical door.

Vertical sections shall be constructed for front mounting of combination starter units.

Starter units shall be magnetic full-voltage combination circuit breaker type with all components and wiring readily accessible for ease of maintenance.

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 can help minimize such failures and their consequences. Alarms may be installed for high water elevations, power outages, pump outages, and illegal entries. MDOT recommends hour-meter and start-meter installation on all pumps to aid in scheduling needed maintenance.

#### **10.5.5.8 Automatic Sequence Selector Switch**

The automatic sequence selector switch shall have contact ratings of proper current and voltage. The switch shall be capable of changing the sequence in which the motors start and stop every time a motor is de-energized. The switch shall be of the rotating drum variety with silver contacts.

### **10.5.5.9 Miscellaneous**

Metal or bakelite nameplates with enamel-filled letters shall be provided for control center equipment as designated on the plans. All painted steel work shall be bonderized after cleaning and finished in medium black or gray enamel baked on.

Fully encased space heaters shall be furnished and installed in the motor control center for the purpose of preventing condensation on interior surfaces.

### **10.5.5.10 Lighting Transformer**

The transformer shall be a dry-type, 5KVA single phase, 480 - 120/240 volt.

### **10.5.5.11 Lighting Distribution Panel**

The lighting panel shall be 10-circuit minimum, 120/240 volt, single phase, 3-wire, 100-ampere minimum main and neutral lugs, complete with 20-ampere circuit breakers.

### **10.5.5.12 Transformer Disconnect**

The transformer disconnect shall be circuit breaker with number of poles, ampere, and voltage rating as required.

### **10.5.5.13 Main Power Disconnect**

The main power circuit breaker shall be rated with number of poles, ampere, and voltage rating as required.

## **10.5.6 Installation and Wiring**

All wire connections shall be made with pressure type (solderless) connections. All wire terminal connectors or lugs with a current rating of 30 amperes or larger shall be provided with Allen-head set screws.

Wire terminals with a current rating of less than 30 amperes shall be solderless crimp-on type.

All conduit in the motor room shall be run exposed, horizontal or vertical. Conduits shall have tight waterproof joints and be so placed that they are self-draining.

Conduit shall be routed to avoid blocking openings for removal of equipment.

### **10.5.7 Grounding**

The motor frames, control cabinet, conduit, and all the noncurrent carrying metal parts of all electrical equipment shall be securely grounded to the ground cable.

Grounding cables shall be attached to equipment with solderless ground lugs and bolts and nuts or machine screws.



## 10.6 RETROFITTING

Retrofitting is generally performed when the capacity of the station needs to be increased and the existing infrastructure is in good condition. Due to reconstruction of existing highways, the runoff rates and collection system may change; in some cases, the combination of age of the existing system and increase in load to the pump station may warrant a complete redesign of the system. Maintenance records should provide some insight into the type and possible cause of the problem. The designer should evaluate the entire system to determine if non-structural or less expensive structural measures are more appropriate than complete replacement.

### Design Considerations

Pumping capacity can be increased by installing additional submersible "minimum submergence" type of pumps with minimum cycle times. These minimum submergence pumps emanate from "in-line" storage concepts, which result in higher storage volume for pumps. It is cost-effective to adopt the cyclical running alternation design process with additional available in-line/wet well sump storage volume. This process assures the longevity of the pumps while requiring minimum structural retrofitting of the pump station structure.

It is likely that the sensor levels for the pump switching will require adjustment to optimize the use of the new storage requirements as well. It will be necessary to perform mass curve routing and cycling checks to satisfy the pumping requirements.

Consider replacing pumps only if the following situations arise:

- Pump and driver have exceeded useful life.
- Life cycle cost of new pumps is lower than operating cost of existing pumps.

## 10.7 MAINTENANCE

The input of maintenance personnel is extremely important for diagnostic procedures, computerized history and inventory, and elimination of future expensive repairs. As a reminder, it should be noted that pump stations are classified as "confined spaces." According to MIOSHA requirements, anyone entering a "confined space" must be equipped with the proper safety equipment and training.

Maintenance of pump stations is very complex. The reader is referred to the MDOT *Operations and Maintenance Handbook*, Volume One, Section 2.12.2.

If a pump station is out-of-service, see the list of contact names given in the MDOT *Operations Maintenance Handbook*.

**References**

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Hydraulic Institute, *Engineering Data Book*, 1990.

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Michigan Department of Transportation, *Operations and Maintenance Handbook*, April 1999.

## **Weblinks**

Hydraulic Institute

[www.pumps.org](http://www.pumps.org)

FHWA, Hydraulic publications

[www.fhwa.dot.gov/bridge/hydpub.htm](http://www.fhwa.dot.gov/bridge/hydpub.htm)

Hydraulic Engineering Circular 24, Highway Pump Station Design