

CHAPTER 10

PUMP STATIONS



NOTE: For trunkline projects, direct questions and comments to the Hydraulic Unit Supervisor, Environmental Services Section.

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If you require assistance accessing this information or require it in an alternative format, contact the Michigan Department of Transportation's (MDOT) Americans with disabilities Act (ADA) coordinator at [Michigan.gov/MDOT-ADA](https://www.michigan.gov/MDOT-ADA).

10.1 INTRODUCTION

This chapter describes the major components and design considerations for stormwater pump stations and recommendations to achieve a cost-effective design and installation. For trunkline projects, coordinate project-related work with the Municipal Utilities Unit Supervisor and the Hydraulic Unit Supervisor. The information in this chapter is a guideline to the design, construction, operation, and maintenance of MDOT pump stations and their configuration. Four categories are presented in this chapter:

- General Design Criteria (**Section 10.3**)
- Pumping System (**Section 10.4**)
- Electrical System (**Section 10.5**)
- 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, it is recommended to use pump stations when other systems are not feasible. When operation and maintenance costs are capitalized for a pump station, a considerable expenditure can be justified for a gravity system. Alternatives to pump stations include deep tunnels, siphons, and infiltration systems. This chapter complements information and general guidance found in various industry standards and guidelines, summarized in the references provided at the end of this chapter.

Pump station design presents a challenge to provide a cost-effective drainage system that meets the needs of the project. There are many considerations involved in pump station design including:

- Hydrology, collection systems, and storage (**Section 10.3.1**)
- Risk management and cost considerations (**Section 10.3.2.1.1**)
- New pump station versus restoration of existing pump station (**Section 10.3.2.1.2**)
- Location and vertical arrangement – (above-grade versus below-grade) (**Section 10.3.2.1.3**)
- Station Type – wet pit versus dry pit (**Section 10.3.2.2.1**)
- Type of pumps (**Section 10.4.1**)
- Number and capacity of pumps (**Section 10.4.2**)
- Outlet discharge system (**Section 10.4.8**)
- Standby power (**Section 10.4.2, 10.5**)
- Monitoring systems (**Section 10.6**)
- Maintenance requirements (**Section 10.7**)

Many of the decisions regarding these factors are based on engineering judgment and experience. To assure cost-effectiveness, assess each choice and develop economic comparisons of alternatives based on annual cost. Guidance provided in this chapter help minimize the design effort and the cost of these expensive drainage facilities.

For further information on the planning and design of pump stations, refer to the references provided at the end of this chapter. A guide for pump station design is presented in the flow chart included in **Appendix 10-C**.

For specific design requirements for equipment and materials, refer to MDOT's Standard Specifications for Construction.

10.2 DEFINITIONS

Allowable High-Water (AHW) Elevation - The maximum water surface elevation (hydraulic grade line, HGL) allowed in the wet well.

American National Standards Institute (ANSI) - ANSI facilitates and coordinates the U.S. voluntary standards and conformity assessment system.

American Water Works Association (AWWA) - A standards organization that develops and publishes voluntary consensus technical standards to describe the minimum requirements for design, installation, performance, manufacture, and testing used in the drinking water industry.

ASTM International (ASTM) - A standards organization formerly known as American Society for Testing and Materials that develops and publishes voluntary consensus technical international standards for a wide range of materials, products, systems, and services.

Axial Flow Propeller - A rotating element of a centrifugal axial flow pump, or propeller pump, that uses a propeller to move fluid in a direction parallel to the pump shaft.

Check Valve - A valve that only allows fluid to flow in one direction to prevent backflow in a piping system.

Collection System - A network of pipes, ditches, and other structures that collect and direct surface runoff from rainfall and snow melt to a designated location.

Dry Pit Pump Station - A pump station comprised of two separate chambers: a dry well to house pumping equipment and a wet well.

Flap Gate - A flow control device consisting of a heavy-duty hinged plate that functions as a check valve but are also used to restrict flow.

Gate Valve - A shut-off device that is used to isolate pumps and equipment for maintenance or removal.

Harmful Interference - Causing an increased stage or change in direction of flow of a river or stream that causes, or is likely to cause, any of the following: i) Damage to property, ii) A threat to life, iii) A threat of personal injury, iv) Pollution, impairment, or destruction of water or other natural resources. MCL 324.3103, R 323.1311g

Instrumentation - The hardware, software, and devices that monitor and display the status process equipment and systems.

Mixed Flow Impeller - A rotating component of a centrifugal pump that causes fluid to flow radially and axially to the pump outlet.

Non-Reversing Ratchet - A mechanism that prevents a shaft from rotating in reverse.

Pump - A device that uses suction or pressure to raise or move fluids. In other words, a pump adds energy to a body of fluid to move it from one point to another.

Pump Control - A device that activates a pump based on water level in the wet well. The control regulates the pump activity until the desired water level in the wet well is reached.

Pump Driver - A device used to provide power to a pump.

Pump House - A building, room, or structure that contains pump controls and electrical/instrumentation equipment for a pump station. A pump house may also contain pump drivers and valves.

Pump Station - A structure containing pumps and equipment for moving fluids from one place to another.

Radial Flow Impeller - A rotating component of a centrifugal (radial) pump that moves fluid outward from its center of rotation. The action of the impeller increases the fluid's velocity and pressure and directs it to the pump outlet.

SCADA (Supervisory Control and Data Acquisition) - A computerized system used to monitor and control process equipment and systems. Hardware and software systems collect and store data which operators analyze to assist with control, reporting, and system maintenance. Remote monitoring and control are possible with telemetry equipment.

Submersible Pump - An electric pump that has a hermetically sealed motor close-coupled to the pump body.

Sump - A pit below the bottom of a wet well, dry well, or building that collects liquid, solids, and debris.

Sump Pump - A pump installed within a sump. In a wet well, a sump pump is used to pump out the water remaining in the well after the water level has dropped and the primary pumps are no longer pumping. In a dry well or building, a sump pump is used to pump out water that has drained from the floor.

Telemetry - Automated measurement and wireless transmission of data from a source to receiving hardware to support remote monitoring and control.

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 sloping pipe upstream of a pump station.

Useable Storage Volume - The volume in a wet well between elevations where a pump starts and stops.

Variable Frequency Drive (VFD) - A motor controller that drives an electric motor by varying the frequency and voltage supplied to the motor.

Vertical Lineshaft Pump - Pumps that utilize a long shaft to connect the pump driver to the pump impeller or propeller.

Wet Pit Pump Station - A pump station is comprised of one or more wet wells and a pump house.

Wet Well - A chamber from which stormwater is pumped. Generally, a wet well, or wet pit is rectangular or circular.

Symbols and acronyms used in this chapter are listed in **Appendix 10-A**.

10.3 GENERAL DESIGN CRITERIA

The following recommendations are intended to minimize 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, Collection Systems, and Storage

10.3.1.1 Hydrology

Drainage systems, which include pump stations, are designed for a 2% Annual Exceedance Probability (AEP) (50-year) storm event. Check the drainage system for a 1% AEP (100-year) storm event to determine the extent of flooding and the associated risk and harmful interference.

Design the collection system to minimize the drainage area to the pump station. The design storm flow includes existing flow rates and future development flow rates with a 20-year outlook. Refer to Chapter 3, Hydrology.

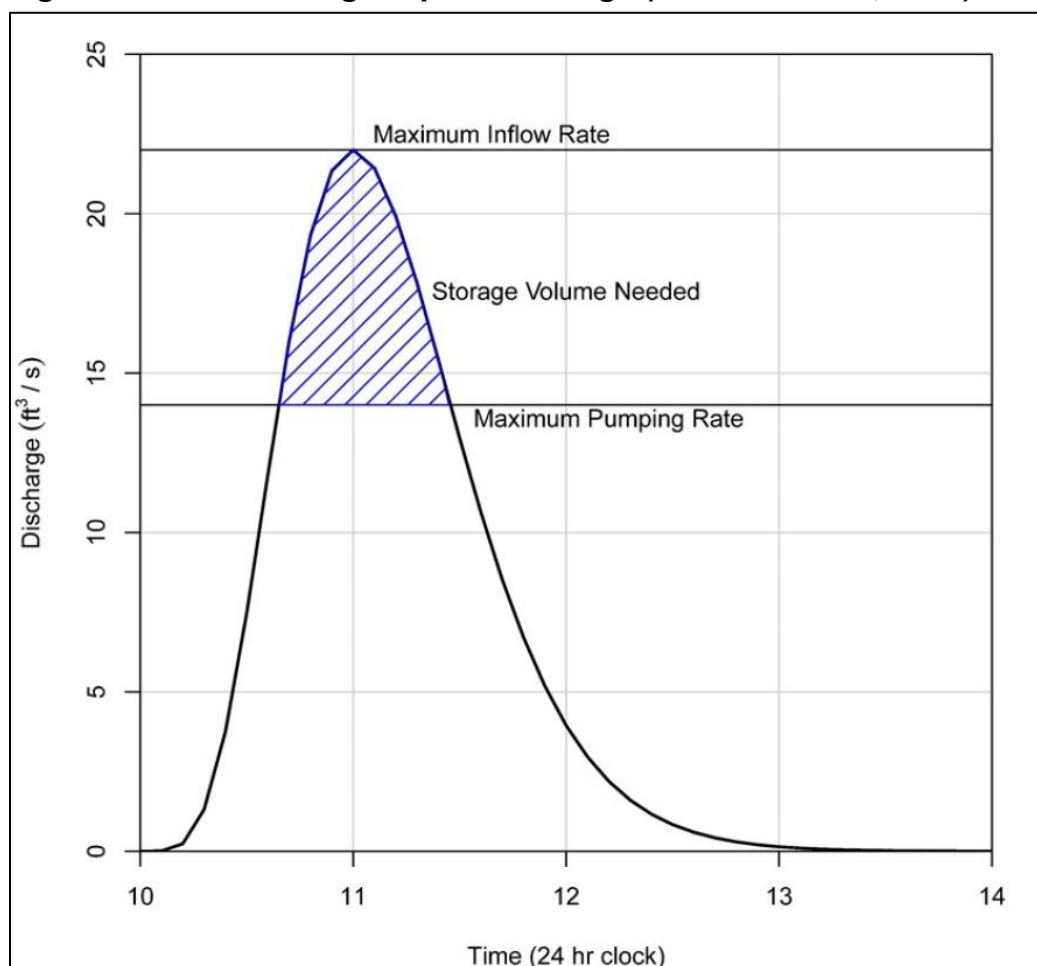
10.3.1.2 Collection Systems

Minimum depth and slope of the collection system are used to avoid deep pump stations. Increasing the depth of the pump station increases the total dynamic head and energy required to operate. 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) elevation requirements in the wet well govern the depth of the uppermost inlet to the pump station. Refer to discussion in **Section 10.4.3.6** under "Allowable High-Water Elevation."

Storm sewers leading to the pump station are designed in accordance with Chapter 7, Inlet and Enclosed Storm Drainage Systems. Terminate storm sewers at a common junction chamber and discharge directly into the wet well through a single inflow pipe. Design the inflow pipe to have a minimum straight run length of five times the inflow pipe diameter and enter the station perpendicular to the line of pumps to limit turbulence and air entrainment.

10.3.1.3 Storage

For most highway pump stations, high flows of the inflow hydrograph occur over a relatively short time. The discharge capacity of the pump station is often controlled by local regulations or physical factors. In situations where the receiving system capacity is limited to a rate lower than the collection system peak flow, storage is required to limit the peak pumping rate to equal the allowable flow capacity of the receiving system. The volume of water beyond the maximum pumping rate, as represented by the shaded area of the hydrograph in **Figure 10-1**, is the estimated storage volume. Wet well levels may impose backwater conditions on the collection system. The wet well levels are established with the collection system designer.

Figure 10-1. Estimating Required Storage (FHWA HEC-22, 2024)

Peak flow storage calculations are based on the Modified Puls routing procedure. Other methods for hydrograph routing are FHWA Hydraulic Toolbox and EPA SWMM. For trunkline projects, EPA SWMM requires approval from the Hydraulic Unit Supervisor. These procedures require inflow hydrographs, stage-storage relationship, and stage-discharge relationship. Storage volumes in a sloping pipe for various stages are based on the ungula volume equation provided in **Appendix 10-B**. Routing the inflow hydrograph through the storage using the Modified Puls procedure is described in Chapter 8, Stormwater Storage Facilities for Flood Control.

Most highway-related pump stations are associated with short underpasses or long depressed sections where it is not feasible to consider above-grade storage. Use upstream, above-grade detention storage, if available, to reduce the rate of flow to the pump station. Otherwise, oversizing of the collection system or the construction of an underground storage facility is required for depressed situations.

Sizing the storage volume is a trial-and-error procedure that is dependent on pump station configuration. Due to the high costs of pump stations, storage design is balanced with capital costs. 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 may not be cost-effective. Unless foundation conditions dictate otherwise, no more depth than that which is required for pump submergence and clearance is to be used in the design.

In the case of larger storage volume development, consider the wet well design principles discussed for minimum run time, pump cycling, etc. However, pumping differences exist as the volume of storage becomes larger. As the wet well becomes larger, there is less concern for meeting minimum run times and cycling times because the volume of storage is sufficient to prevent these conditions from controlling the pump operation.

The mass inflow curve procedure discussed in FHWA HEC-24 (2001) is used when significant storage is provided outside the wet well. Plotting the performance curve on the mass inflow diagram is a graphical tool for determining storage requirements and pump start/stop run times. If a pump failure occurs, the mass inflow curve is used to evaluate the storage requirement and the resulting flooding or. **Appendix 10-B** includes an example calculation for a mass inflow curve and pump discharge curves.

10.3.2 Pump Station Design

10.3.2.1 Design Considerations

10.3.2.1.1 Risk Management and Cost Considerations

Risk management is considered while evaluating cost with respect to new pump station construction and pump station restoration projects. Risks to consider include the following, on a project-specific basis:

- Risk of flooding roadway or pump station at the 1% AEP (100-year) event
- Harmful interference
- Risk of pumping failure and provisions for stand-by power
- Transient flow conditions
- Availability of replacement pumps or wearable components
- Traffic safety and protection of equipment from traffic
- Safety of operation and maintenance personnel
- Potential for vandalism

Operating costs do not significantly impact stormwater pump station planning because operation is intermittent and relatively infrequent.

10.3.2.1.2 New Pump Station versus Restoration or Retrofitting of Existing Pump Station

Locations with existing pump stations which are deteriorating, unreliable, or not performing adequately are evaluated for restoration or retrofitting, rather than

replacement with a new pump station. Review maintenance records to identify potential problems at the pump station and provide insight into pump station replacement or restoration.

Consider restoration of an existing pump station to restore performance to meet the original design intent or improve structural, mechanical, or electrical systems. Consider replacing pumps if the following situations arise:

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

When considering pump replacement, MDOT prefers retrofitting submersible radial pumps with vertical shaft pumps when cost is warranted to accommodate the vertical pump type. However, replacing submersible radial flow pumps in-kind is often more economical because retrofitting with vertical shaft pumps often requires structural modification or building expansion to house the motors.

Due to reconstruction of existing highways, the runoff rates and collection system may change. In some cases, the combination of the age of the existing system and the increase in flow to the pump station warrant a redesign of the system. In most situations, increasing the existing pump station capacity is not allowed to prevent overwhelming the receiving system. An increase in pump station capacity requires agreement with the receiving utility unless directly discharging to the Great Lakes and connecting waters. An increased design flow rate requires additional storage if the pump station flow capacity cannot be increased. Wet well storage is increased by installing submersible "minimum submergence" type pumps with minimum cycle times. It is necessary to perform mass curve routing and cycling checks to satisfy the pumping requirements. The sensor levels for the pump switching require adjustment to optimize the use of the new storage requirements.

Perform a planning level cost-benefit evaluation to compare the restoration of an existing pump station to the replacement with a new pump station, unless otherwise directed by MDOT.

Retrofit pumps may operate at a different frequency than the original pumps, which can lead to pump station damage due to vibration. Refer to guidance in ANSI/Hydraulic Institute (HI) 9.6.8 (2021) if a retrofit is deemed appropriate.

10.3.2.1.3 Location and Vertical Arrangement (Above-Grade versus Below-Grade)

Economic and design considerations dictate that the pump station is located near the low point of the highway. If possible, locate the pump station on high ground near a frontage road or overpass for easy access, especially in the event of the highway flooding. During the selection of the site, collect soil borings to determine the allowable bearing capacity of the soil and identify groundwater conditions or potential geotechnical problems.

Consider the following in the planning and designing of pump stations:

- Modern pump stations can be architecturally pleasing with a minimum increase in cost. Use masonry or textured concrete to improve appearance.
- Clean, functional lines improve the station's appearance.
- Provide screening walls to hide exterior equipment and break up the lines of the building.
- Use landscaping to improve the appearance of the site.
- Consider the risk of flooding and protection of electrical equipment.
- Above-grade electrical and control equipment may not require a building. Consider the size of the pump station and whether the above-grade equipment needs protection.
- Provide parking and working areas adjacent to the station for maintenance and repair vehicles, if possible given site constraints.
- Protect pump stations from traffic. If possible, locate pump stations away from vehicular traffic.

10.3.2.2 Station Type

10.3.2.2.1 Station Types

There are two types of pump stations: wet pit or dry pit. MDOT prefers the more cost-effective wet pit stations. Dry pit stations are considered for the larger stations, generally greater than 300 cfs pumping capacity. Consult with the Municipal Utilities Unit Supervisor when selecting station configuration for trunkline projects. Advantages and disadvantages of wet pit and dry pit pump stations are summarized in **Table 10-1**.

Table 10-1. Advantages and Disadvantages of Wet Pit and Dry Pit Pump Stations

Type	Advantages	Disadvantages
Wet Pit	• Lower construction cost • Lower footprint requirement	• Limited access to pumping equipment • Pumping equipment located in a hazardous atmosphere • Pumping equipment is removed from the pit for maintenance or wet well is isolated and emptied for in-place maintenance
Dry Pit	• Accessible pumping equipment • Pumping equipment located in a dry area • Lower risk of fire and explosion • Lower risk to operation and maintenance personnel from atmosphere and collected flow	• Higher construction cost • Requires larger footprint

10.3.2.2.2 Wet Pit Stations

MDOT wet pit stations are equipped with vertical (axial or mixed flow) or submersible pumps. Vertical pump impellers are fully submerged, with the motors and controls located above the 1% AEP (100-year) floodplain. Submersible pumps are motor-mounted, with controls located above the 1% AEP (100-year) floodplain. Vertical and submersible pumps are further described in **Section 10.4.1**. Consider the advantages and disadvantages of the pump types while planning the pump station configuration as summarized in **Table 10-1**. Illustrations of wet pit stations are shown in **Figures 10-2** and **10-3**.

Figure 10-2. Sample Wet Pit Submersible Pump Station (Qasim, 1994)

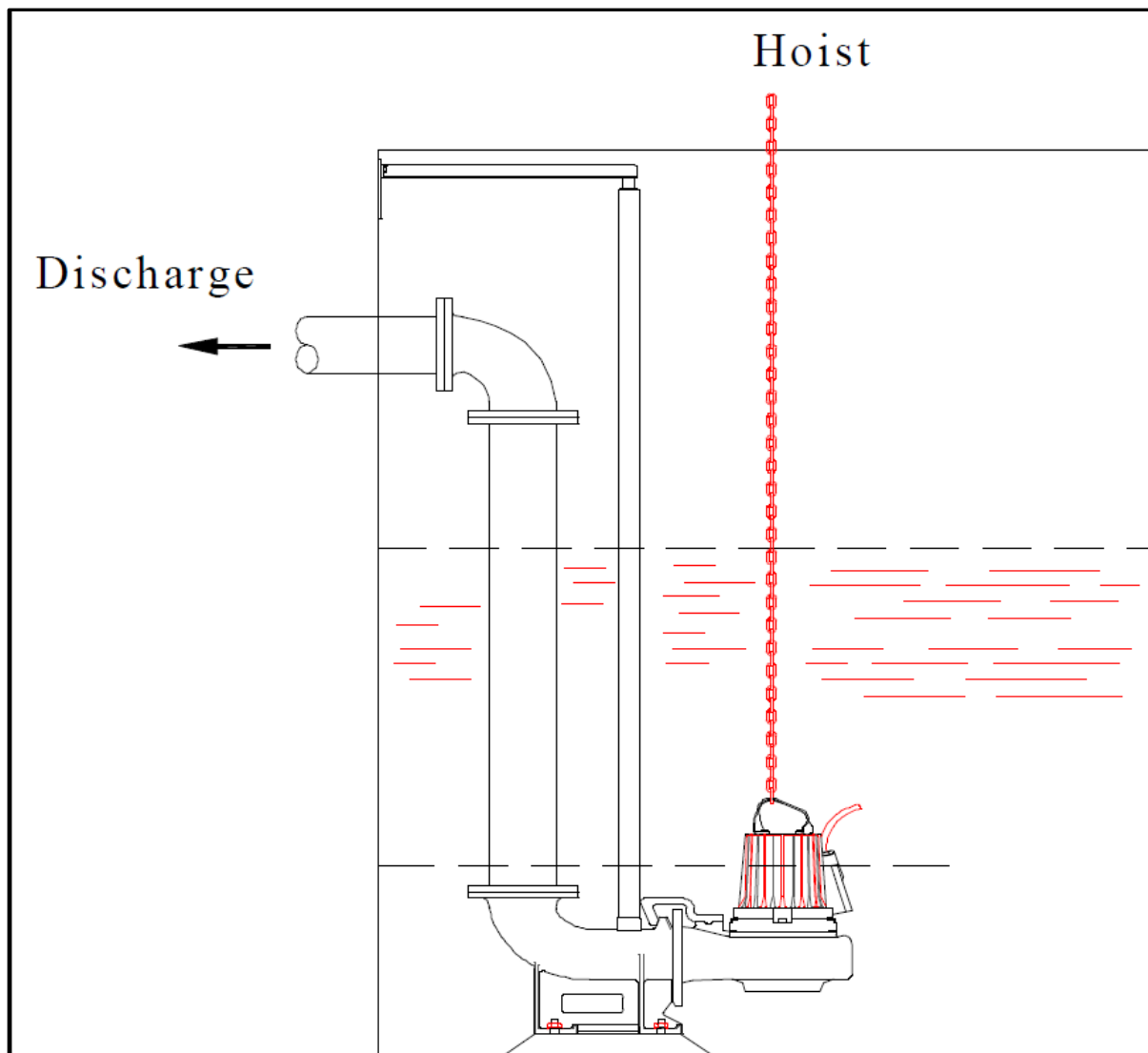
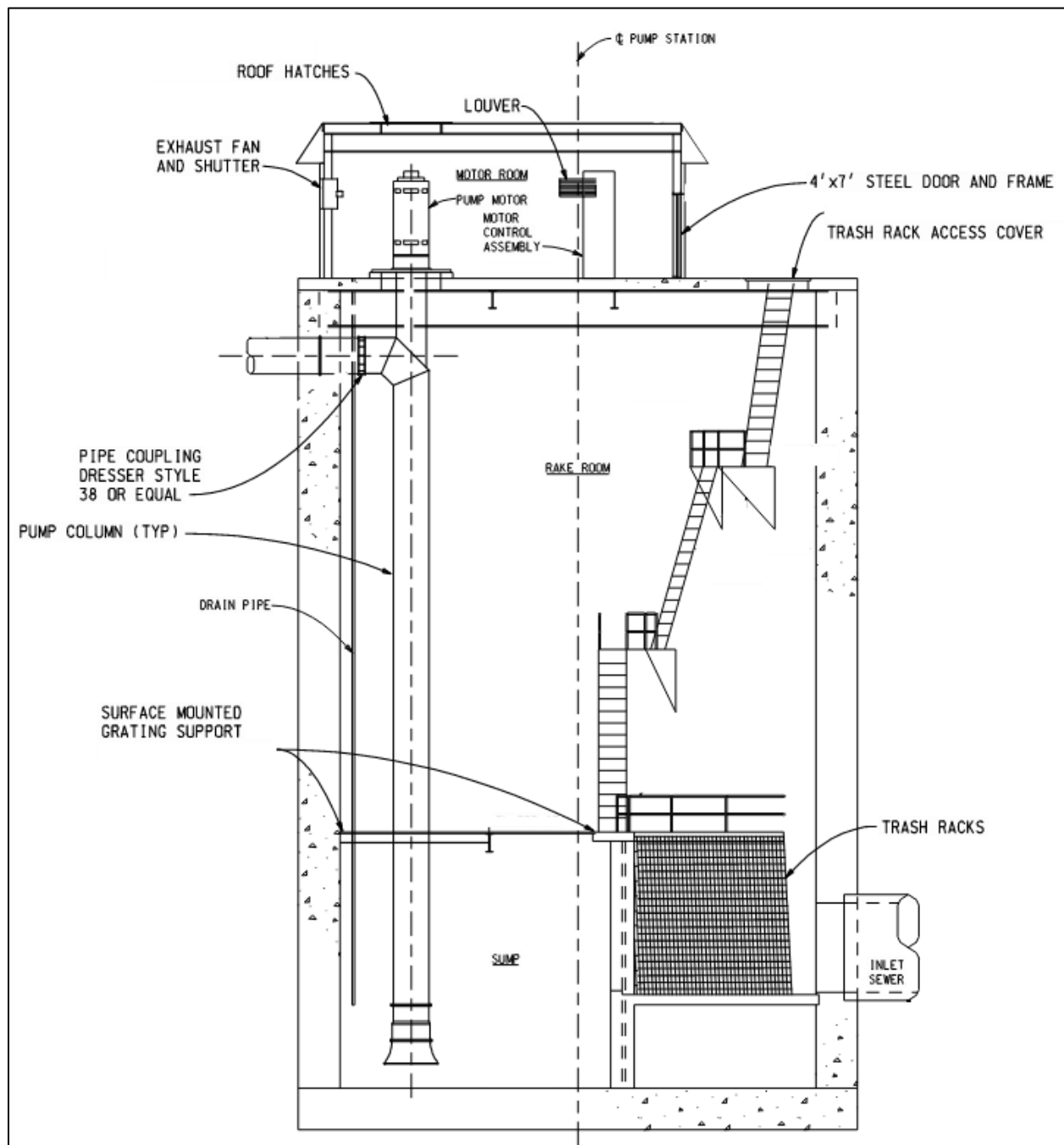


Figure 10-3. Sample Wet Pit Vertical Pump Station (D002 CS 82122, 82194, JN: 103729A, 108133A)



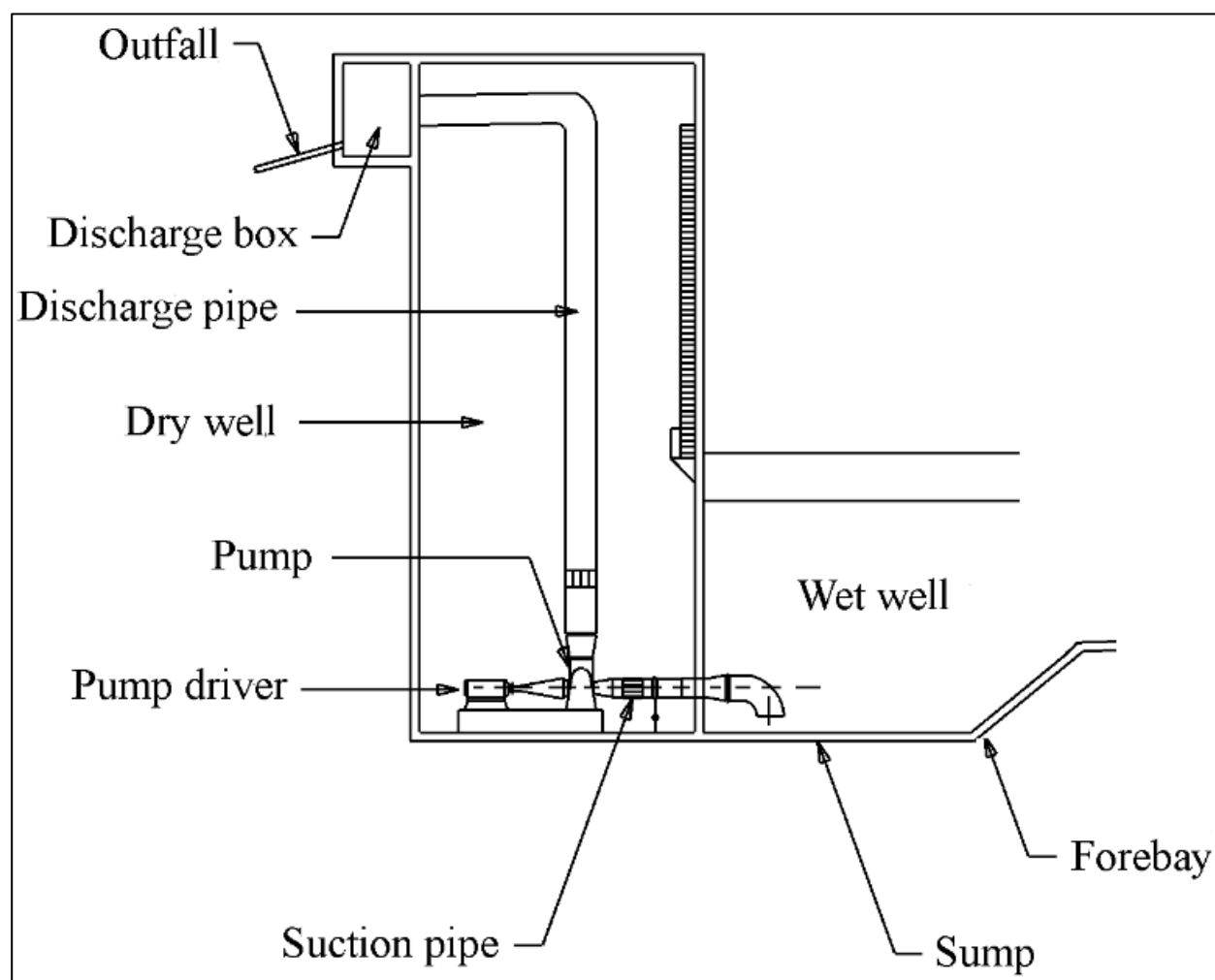
10.3.2.2.3 Dry Pit Stations

Dry pit stations consist of two separate elements: the wet well and the dry well. Stormwater is collected in the wet well which is connected to the dry well by horizontal suction piping. Dry pit stations are equipped with horizontal radial flow, vertical radial flow pumps, or submersible pumps. The pump types are further described in **Section**

10.4.1. Consider advantages and disadvantages of the pump types while planning the pump station configuration. An example of a dry pit station is shown in **Figure 10-4**.

Groundwater or other sources of water can accumulate on the dry side of the pump station. All equipment located on the dry side must be rated for submergence. Shafted vertical radial flow pumps are preferred to protect the motor. A sump in the floor is used to remove the water on the dry side of the pump station. Depending on the local code, water pumped from the dry side may be considered sanitary flow and will require proper disposal or discharge to a sanitary sewer. Check with local code officials for the specific project to confirm if a sump pump is allowable.

Figure 10-4. Dry Pit Station with Horizontal Centrifugal Pumps (FHWA HEC-24, 2001)



10.4 PUMPING SYSTEM

10.4.1 Pump Types and Selection Considerations

Design criteria that impact pump selection includes:

- Site constraints which impact the wet well design, such as
 - Storage requirements
 - Footprint limitations
 - Depth limitations
- Performance requirements (flow and total dynamic head, TDH)
- Reliability
- Operation, maintenance, and safety requirements
- Capital cost (Operating costs do not significantly impact stormwater pump selection because operation is intermittent and relatively infrequent.)
- Funding requirements (Confirm required materials meet funding requirements or otherwise, submit an application for variance to the reviewing authority)

Contact the Municipal Utilities Unit Supervisor when selecting pumps for trunkline projects. Consider the advantages and disadvantages of each pump type as summarized in **Table 10-2**. In addition, consider the cost of the pump station with each pump type considered.

Axial flow and mixed flow pumps are vertically driven and configured with a motor shaft or motor-mounted for submersible operation. Radial flow pumps are driven by a horizontal or vertical shaft and configured for dry pit or submersible operation. Shaft driven pumps are provided with non-reversing ratchet to protect the pump in the event of backflow. Submersible radial flow pumps can be installed in a wet pit or dry pit. Dry pit submersible pumps are required to be rated for continuous dry operation.

The most common types of stormwater pumps installed at MDOT pump stations are axial flow (propeller), radial flow (centrifugal), and mixed flow (axial and radial flow characteristics). MDOT's preferences for highway stormwater pump stations include vertical shaft single-stage axial or mixed flow pumps, with the motor and automatic grease lubrication system installed in a dry room. When cost is warranted, vertical shaft pumps are used for new construction or to retrofit a pump station with submersible pumps.

MDOT will consider submersible radial flow pumps for new construction of small pump stations (two (2) to three (3) pumps with 50 hp or smaller motors) or where site conditions limit construction of an above-grade structure. However, submersible radial pumps may be added to a wet pit during a retrofit to lower the minimum wet well operating level and increase storage volume. It is often most economical to replace submersible radial flow pumps in-kind because retrofitting with vertical shaft pumps often requires structural modification or building expansion to house the motors. MDOT rarely uses dry pit pumps, however, they are considered for larger stations, generally

greater than 300 cfs pumping capacity. Suction lift or vacuum pumps are only used in maintenance dewatering of the wet well.

The characteristics of each pump type are described as follows:

A. Vertical Pumps

Vertical pumps, or vertical shaft pumps, are driven by motors or engines housed overhead in a motor room or by a submersible motor close-coupled to the bowl assembly and housed in a discharge column. Vertical pumps are typically equipped with an extension shaft enclosed in a flow column extending below an above-grade motor base plate to a submerged diffuser (discharge bowl). Shaft bearings are lubricated with an automatic greasing system. The bowl assembly consists of suction bell, discharge bowl propeller or impeller, pump shaft, bearings, and the shaft coupling. The suction bell is designed to permit proper distribution of the liquid to the impeller.

Vertical pumps for stormwater pumping systems are single-stage, axial, and mixed flow types. Two-stage axial flow pumps are used for higher head installations. A two-stage axial flow pump will approximately double the head capacity of a single stage pump.

B. Axial Flow Pumps

Axial flow, or propeller, pumps lift the water up a vertical riser pipe. Flow is parallel to the pump axis and drive shaft. Axial flow pumps are suitable for low heads and high discharge situations. 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. These types of pumps are not suitable for highway locations where high volumes of stormwater carrying heavy debris, fibers, and silt are anticipated.

C. Mixed Flow Pumps

Mixed flow (impeller with vanes) pumps are suitable to high heads and low speed situations. Pumps with the open type or closed type end impellers with vanes integral with a conical hub (bowl assembly) can be retrofitted to achieve medium to high heads with low specific speed. This type of pump is ideal for all types of stormwater pumping conditions. Mixed flow pumps are very similar to axial flow except they create head by a combination of lift and centrifugal action. They are used for intermediate head and discharge applications and handle debris slightly better than propellers.

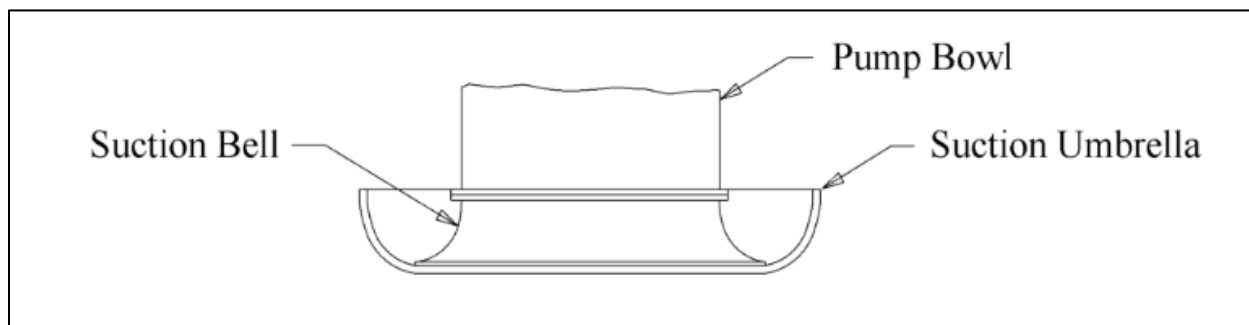
Submersible mixed flow column pumps are similar to shafted vertical pumps but are equipped with a submersible motor close-coupled to the bowl assembly. The pump and motor assembly are installed within a discharge column which serves as the pump housing and discharge pipe. The cost of a submersible mixed flow column pump is typically higher than a shafted pump, but selection may be appropriate

when a shafted motor cannot be protected from flooding or when there is inadequate space for a motor room.

D. Vertical Pump Intakes

Mixed and axial flow pumps require a minimum depth (submergence) above the suction inlet to prevent vortex formation which may draw air into the impeller. Minimum submergence is a function of flow rate and inlet bell diameter. Strategies to minimize vortices can reduce required submergence. For example, a suction umbrella, as shown in **Figure 10-5**, reduces the potential for vortex formation, which reduces submergence requirements and minimizes the station depth. Refer to ANSI/HI standards and FHWA HEC-24 (2001) for additional guidelines for effective pump intake design practice.

Figure 10-5. Suction Umbrella (ANSI/HI 9.8, 2024)



E. Radial Flow Pumps

Radial flow (centrifugal) pumps are mounted horizontally (vertical volute) or vertically (horizontal volute) and utilize centrifugal force to move the effluent up the riser pipe. Radial flow pumps are available in a dry pit or wet pit configuration. Vertical radial flow pumps are driven by motors or engines housed overhead in a motor room or by a submersible motor close-coupled to the volute. Radial flow pumps handle a wide range of head and discharge but are the best choice for high-head applications.

A single vane, non-clog impeller provides a large impeller opening, allowing debris to pass through. The debris handling capability decreases as the number of vanes increases, which decreases the size of the openings. Pumps with closely spaced vanes are subject to sediment locking. Design strategies are available when sediment is a concern. One strategy is to bypass part of the pump discharge back into the wet well through submerged mixers to suspend sediment. The wet well design includes provisions for handling sediment. Refer to **Section 10.4.3** for more information regarding wet well design.

F. Dry Pit Radial Pumps

A dry pit radial pump is a horizontal or vertical pump installed in a dry pit with suction piping connecting the pump to the wet well.

Horizontal dry pit pumps are equipped with close-coupled motors, which minimizes maintenance. Horizontal pump motors require confined space entry for maintenance and are subject to damage if the dry pit were to be flooded.

Vertical dry pit pumps with long drive shafts require increased maintenance to support shaft alignment and minimize vibration. Vertical pump motors are typically located in an above-grade superstructure, but may be located in a motor room below-grade if a superstructure is not necessary and the risk of motor flooding is low.

A sample dry pit pump station with horizontal centrifugal pumps is shown in **Figure 10-4**. A similar configuration is used if the pump station is equipped with vertical or submersible pumps.

G. Submersible Radial Flow Pumps

Submersible radial flow pumps are vertical close-coupled pumps driven by a submersible motor. They are available with recessed impellers out of the stream of flow, or specially shaped non-clog impellers. Recessed impellers offer high solids handling capability, but at a significantly lower efficiency compared with a non-clog impeller. The preferred submersible pumps are those with non-clog impellers that deliver higher efficiencies with lower operating costs.

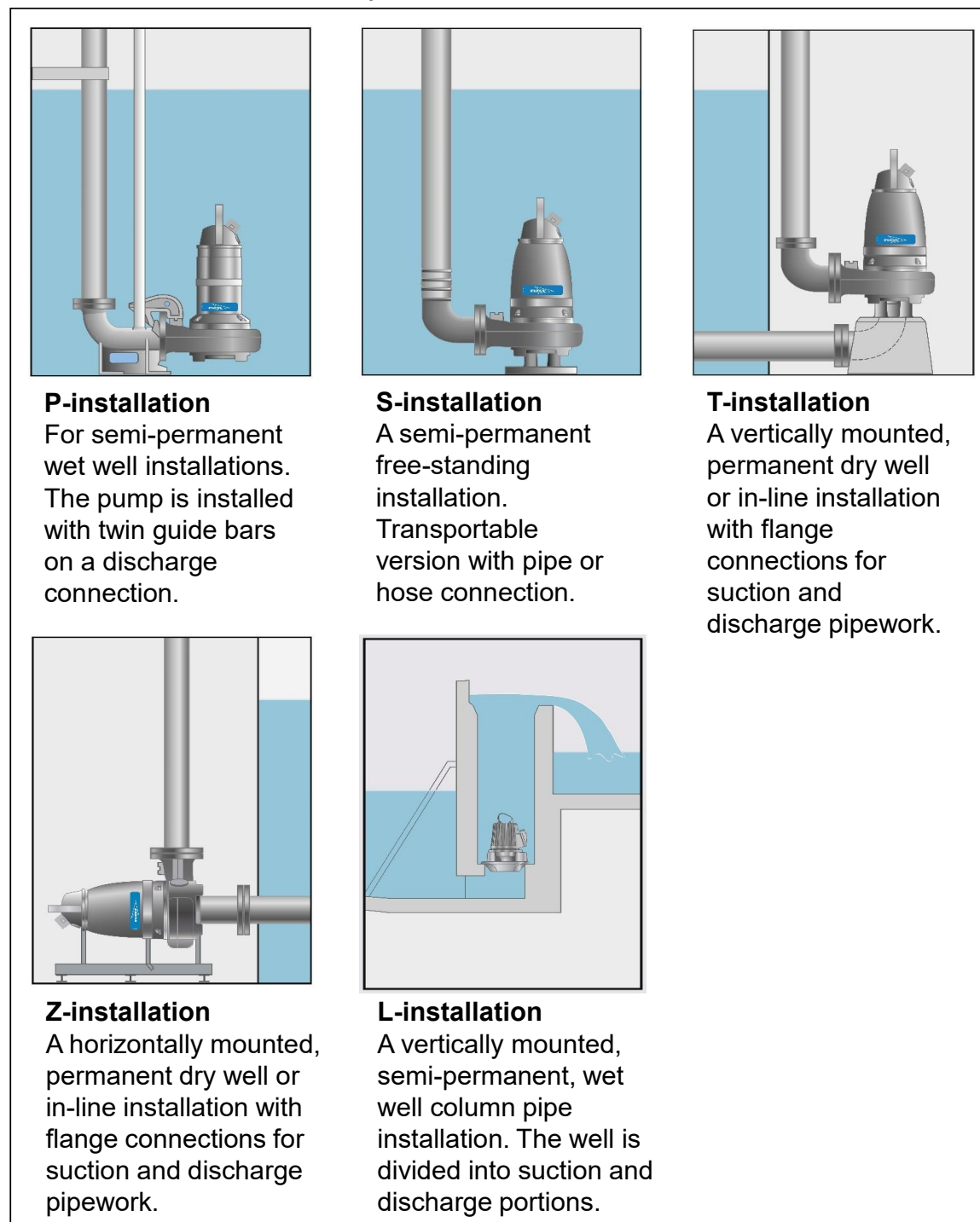
The volute is submerged in the liquid for the pump to function. If the top cover is above the level of the liquid, air will enter the volute and prevent liquid from being discharged. When the volute is submerged, the pump will self-prime and start pumping. Submergence of the motor during operation naturally cools the motor.

Submersible pumps provide special advantages in simplifying the design, construction, and maintenance and, therefore, reduce the cost of the pump station.

Submersible pumps do not require shaft alignment, are protected from flooding, and can be readily removed and reinstalled from above-grade, without the need for confined space entry.

When installed in a dry pit, use submersible radial flow pumps rated for continuous dry operation. Various configurations of a submersible pump are shown in **Figure 10-6**.

Figure 10-6. Various Submersible Pump Configurations (Flygt Water and Wastewater Solutions, 2024)



Advantages and disadvantages of each pump type described in **Section 10.4.1** are summarized in **Table 10-2**. Consider the advantages and disadvantages of pump type when selecting the pump type and pump station configuration.

Table 10-2. Advantages and Disadvantages of Stormwater Pump Types

Pump Type	Advantages	Disadvantages
Vertical (axial or mixed flow)	• Dry pit not required • Low maintenance • Long service life • Motor accessible at or near grade level • Small footprint	• Motor room required • Shaft and bearing maintenance required • Axial flow propellers are susceptible to damage from large hard debris • Passes smaller solids versus radial flow • Submerged impeller requires isolation and draining of wet well and work in hazardous atmosphere or complete removal of pump column for maintenance • Complete pump removal requires larger lifting equipment • Ventilation required to cool motor room • Shaft length typically limited to 40 ft • Minimum submergence requirements may require increased wet well depth to maintain minimum submergence
Submersible (wet pit, axial or radial flow)	• Dry pit not required • Available with non-clog impeller or recessed impeller (recessed impeller improves solids handling with reduced efficiency) • Radial flow submersible passes larger solids versus vertical • Motor room not required • Motor ventilation not required (motor is naturally cooled by immersion in stormwater) • Motor is protected from flooding	• Typically higher cost of pump and motor • Typically shortest service life • Potentially larger wet pit footprint required to provide adequate pump spacing • Complete removal required to service motor or pump (axial flow pumps are more difficult to remove than radial flow pumps) • Minimum submergence requirements may require increased wet well depth to maintain natural cooling

Pump Type	Advantages	Disadvantages
	• Shaft and bearing maintenance not required • Ease of removal and replacement (radial flow easier to remove than axial flow) • Seal water and bearing lubrication system not required	
Submersible (dry pit, radial flow)	• Available with non-clog impeller or recessed impeller (recessed impeller improves solids handling with reduced efficiency) • Passes larger solids versus vertical motor room not required • Ability to isolate pump from wet well • Motor is protected from flooding • Shaft and bearing maintenance not required • Seal water and bearing lubrication system not required	• Potentially large dry pit footprint required for discharge piping • Typically higher cost of pump and motor due to cooling provisions for dry operation • Typically shortest service life • Ventilation may be required to supplement cooling the motor • Complete removal required to service motor or pump
Radial (horizontal)	• Low maintenance • Passes larger solids versus vertical • Typically longest service life • Ability to isolate pump from wet well • Pumping equipment may be serviced in-place • Typically less wet well depth required	• Potentially large dry pit footprint required for motor • Shaft and bearing maintenance required • Motor subject to dry pit flooding • Low efficiency • Ventilation required to cool dry pit

Pump Type	Advantages	Disadvantages
Radial (vertical)	• Low maintenance • Passes larger solids versus vertical axial/mixed flow • Typically longest service life • Ability to isolate pump from wet well • Motor may be close-coupled or remote with shaft extension motor accessible at or near grade level (with shaft extension) • Pumping equipment may be serviced in-place • Typically less wet well depth required	• Potentially large dry pit required for discharge piping • Shaft and bearing maintenance required (long shaft will require increased maintenance) • Motor subject to dry pit flooding unless shaft extends to motor above the flood elevation • Low efficiency • Ventilation required to cool motor room (with shaft extension) or dry pit (close-coupled)

10.4.2 Pump Number and Capacity

Provide pumping capacity equal to the design discharge rate with all pumps operating. MDOT typically does not design stormwater pump stations with more than five pumps and does not plan for spare or standby pumps. It is recommended that equal-size pumps be used. Identical size and type enable all pumps to be freely alternated into service. This equalizes wear and reduces cycling storage volume. It simplifies scheduling maintenance and allows pump parts to be interchangeable. Refer **Section 10.4.3** for more information on pump cycling and wet well volume.

Size and the number of pumps are controlled by site constraints such as facility footprint limitations and provisions for portable standby power. Economic limitations on power unit size and voltage, as well as practical limitations governing operation and maintenance determine the upper limit of pump size. When permanent stand-by power is not provided, pump sizing depends on the availability and capacity of portable generators.

Developing an economic balance between storage volume and pumping capacity is the goal of pump station hydraulic design. Providing the maximum storage needed for two or three electrically driven pumps minimizes initial costs. However, a minimum number of three pumps is recommended. Consider over-sizing the pumps to compensate for a pump failure. For example, with three pumps, if one pump fails, 33% of the capacity is lost. The consequence of failure, or resulting damage caused by the loss of one pump, is a driver for determining the size and number of pumps. Increasing the number of pumps results in longer cycle times, decreasing wet well volume and depth requirements which is advantageous when storage is limited.

As the number of pumps increases, the wet well footprint increases. A larger wet well has more volume per foot of depth, requiring less depth between "on" and "off" elevations. The recommended minimum distance between on-off setpoints of individual successive pumps is 6-inches due to turbulence at the water surface and/or limitations in the sensitivity of controls.

After establishing the minimum cycle time and minimum number of pumps, an iterative procedure determines the final number of pumps and dimensions of the wet well. For a given volume, the final number of pumps required is dependent upon the station depth (distance between the AHW elevation and the inlet invert elevation). Because deep stations have more storage, fewer pumps are needed. Compare wet well dimensions and depth requirements based on three-, four-, and five-pump alternatives and select the number of pumps based on the optimal configuration.

10.4.3 Wet Well Design

There are two configurations to consider for pump station plan layout: circular or rectangular. Rectangular wet wells include open or confined (trench-type) arrangements. Circular and rectangular wet wells perform similarly when properly designed. Baffle walls are installed in open rectangular wet wells to reduce flow disturbances from adjacent pumps, restricting the area where solids can settle and maintaining higher velocities near the suction inlet to keep solids suspended and pumped out of the station. The primary benefit of a rectangular confined wet well is sediment and grit management due to scouring velocity through a narrow flow path. Although MDOT does not have pump stations with confined wet wells, a confined wet well is advantageous in a location subject to heavy grit loading, such as an area serving a roadway maintained with chip seals.

Refer to **Figures 10-7, 10-8, and 10-9** for sample wet well configurations. Factors to consider when selecting the wet well configuration include pump station capacity, cost, and site constraints. Consult with the Municipal Utilities Supervisor when selecting wet well type.

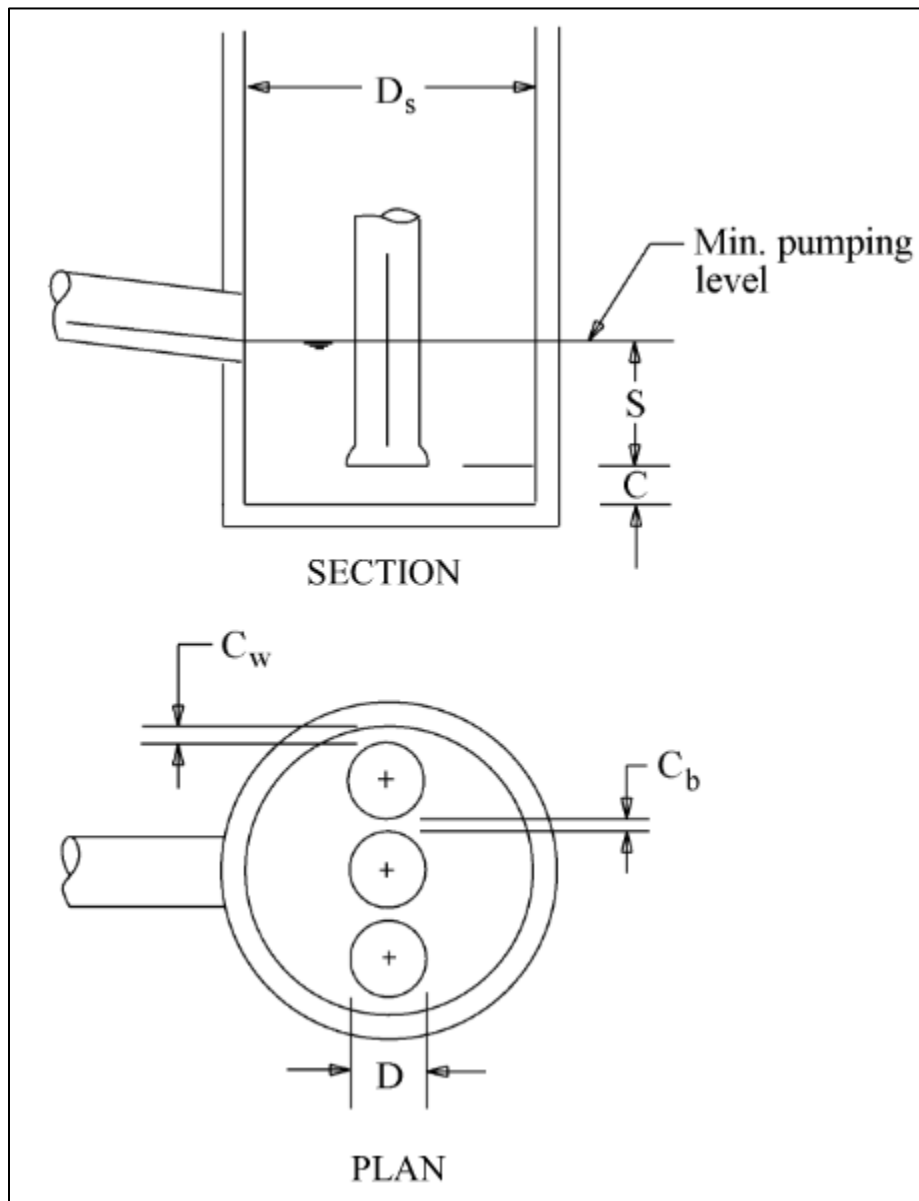
Figure 10-7. Sample Circular Wet Well Plan and Section (FHWA HEC-24, 2001)

Figure 10-8. Sample Rectangular Open Wet Well Plan and Section (ANSI/HI 9.8, 2024)

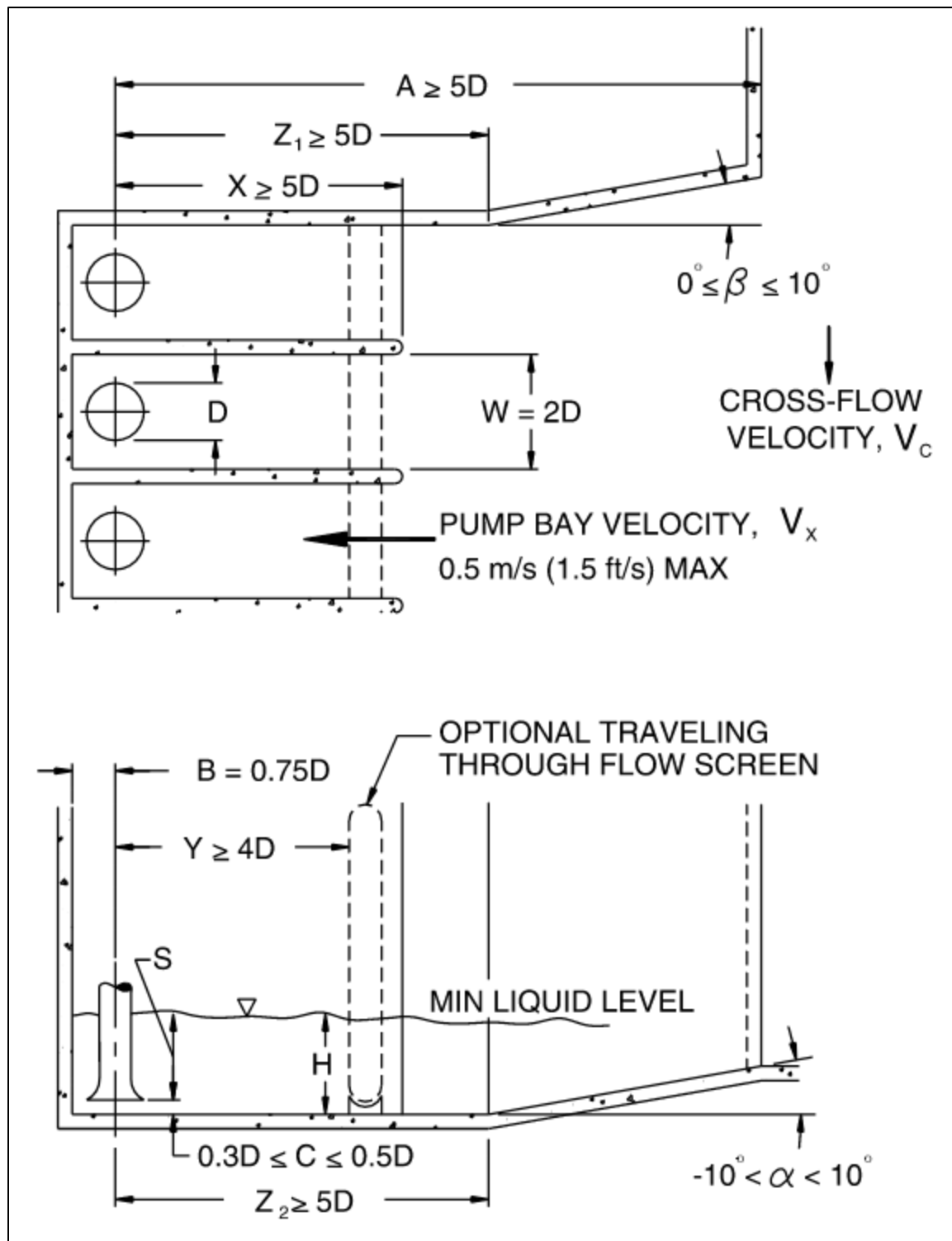
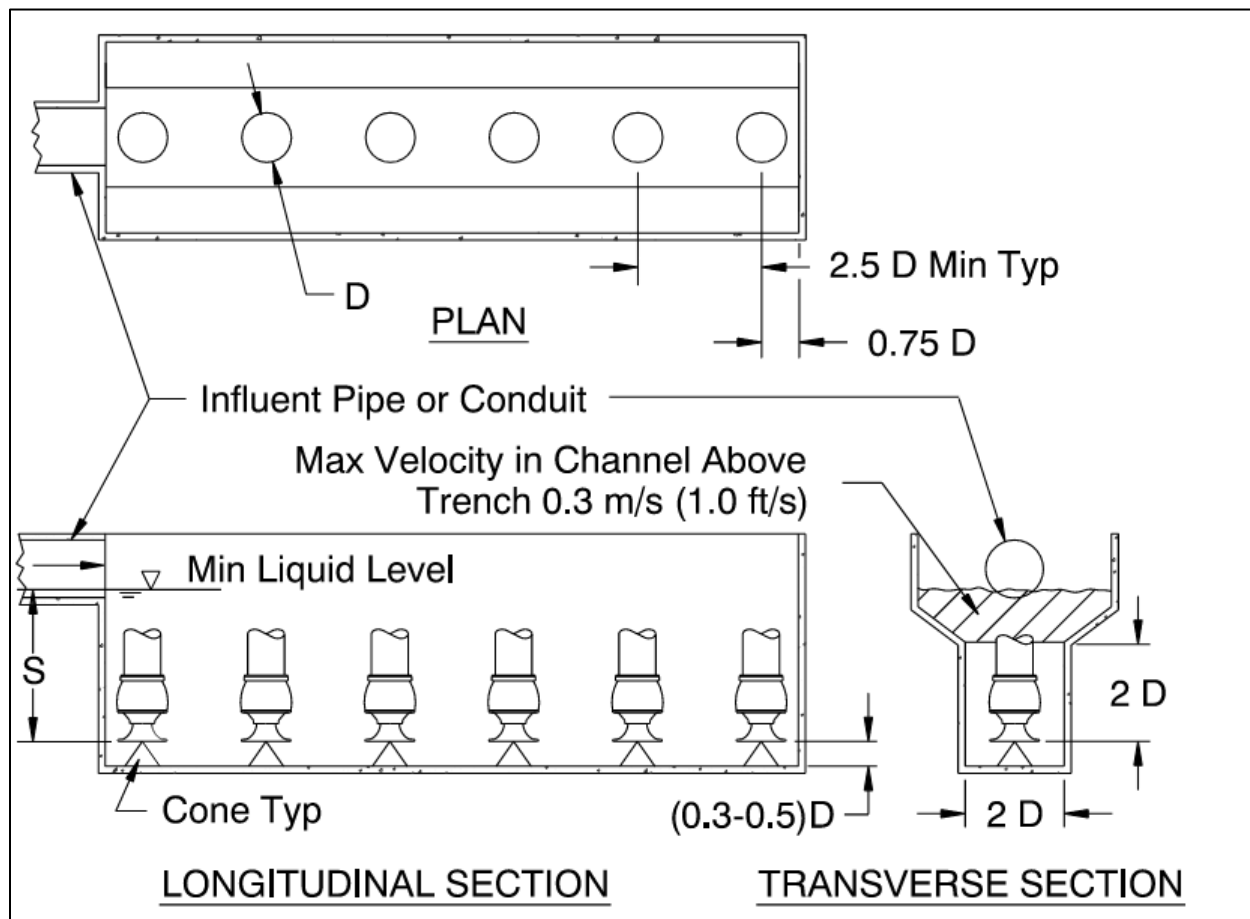


Figure 10-9. Sample Rectangular Confined Wet Well Plan and Section (ANSI/HI 9.8, 2024)



Inadequate pump suction conditions cause many pumping system problems. Stormwater should not flow past one pump to get to another, except in a rectangular confined wet well. An uneven flow distribution to the pumps causes strong local currents resulting in vortex formation, reduced pump efficiency, and undesirable operational characteristics.

For best results, refer to the ANSI/HI standards for guidance on wet well configuration, layout of pump suction piping and station inlet piping (suction piping clearances from floors, walls, and adjacent pumps), depth, volume, etc.

The preliminary design of the wet well, station inflow piping, and pump suction piping is based on ANSI/HI standards. Follow recommended clearances to minimize the risk of sedimentation problems. The key focus of ANSI/HI standards is minimizing turbulence and air entrainment at the pump suction by maintaining adequate submergence, using proper pipe sizes and configurations, and ensuring a straight, smooth flow path into the pump (referenced in ANSI/HI 9.8, 2024). Verify these systems meet specified pumping equipment manufacturers' recommended requirements prior to final design.

Undesirable flow conditions at the pump inlet impact pumping performance and pumping system reliability and, in severe cases, cause catastrophic damage to pumping equipment. A physical model study is used to troubleshoot and identify the most economical means of correcting undesirable flow conditions. Perform ANSI/HI recommended physical model testing, conducted by a hydraulic laboratory using personnel that have experience in modeling pump intakes, to verify suitable wet well and pump inlet conditions if any of the following conditions apply:

- Minimum intake submergence does not meet ANSI/HI standards, regardless of the pump manufacturer's stated submergence values
- Sump, intake, or piping geometry deviates from standard designs presented in ANSI/HI standards
- No prior physical model study has been conducted for the intake design in terms of physical features and flow rates
- Non-uniform or non-symmetric approach flow to the pump sump exists
- Proper pump operation is a critical service
- Cost to remediate inadequate performance or failure would exceed 10 times the cost of a physical model study
- Circular wet well with four or more pumps
- Circular wet well with flows greater than 5,000 gpm (7.2 MGD or 11.1 cfs) per pump
- Pumps of an open bottom barrel or riser arrangement with flows greater than 5,000 gpm (7.2 MGD or 11.1 cfs) per pump (atypical arrangement for stormwater pump stations)
- Pumps of a closed bottom can intake with flows greater than 7,000 gpm (10.1 MGD or 15.6 cfs) per pump (atypical arrangement for stormwater pump stations)
- Trench-type wet well with flows greater than 20,000 gpm (28.8 MGD or 44.6 cfs) per pump or total pump station capacity greater than 50,000 gpm (72.0 MGD or 111.4 cfs)
- Flow per pump is greater than 40,000 gpm (57.6 MGD or 89.1 cfs)
- Pump station capacity is greater than 100,000 gpm (144.0 MGD or 222.8 cfs)

10.4.3.1 Wet Well Depth

Determine wet well depth starting from the invert of the influent sewer. The bottom of the wet well elevation depends on the following:

- Inflow sewer invert elevation (minimum operating depth)
- Pump type, dimensions, clearance requirements, and related submergence requirements or net positive suction head required (NPSHr) by the pump manufacturer
- Suction piping diameter, configuration, fittings, and valves (friction loss impacts NPSH)
- Minimum clearance between the bottom of the suction bell and the floor

An economical design will minimize the wet well depth unless foundation conditions dictate otherwise. Design the wet well to provide an AHW elevation that results in a water surface elevation in the collection system of at least 1 foot (2 feet desirable) below the lowest point of the gutter line.

Minimum submergence and NPSHr is based on ANSI/HI recommendations and verified with pump manufacturers at the time of pump selection. Radial flow and mixed flow pumps typically require the least submergence, while axial flow pumps require the most. Submergence and pump to inlet floor clearance vary significantly with pump type (submersible and/or vertical shaft pumps) and manufacturer. Floor clearances are sensitive for submersible pumps, and the final floor elevation is adjusted once the manufacturer of the pumps is known.

The available net positive suction head (NPSHa) is calculated and compared with pump manufacturer NPSHr curves to confirm proper submergence. NPSHa and NPSHr for radial flow and submersible pumps are measured from the centerline of the pump impeller to the minimum water surface in the wet well. NPSHa and NPSHr for vertical axial and mixed flow pumps are measured from the suction inlet to the minimum water surface in the wet well.

10.4.3.2 Cycling Sequence and Volumes

The most economical design keeps the wet well volume at a minimum. Minimum volume is accomplished based on the selected pump dimensions, minimum submergence depth, minimum clearance requirements as recommended by ANSI/HI standards, and volume required to meet pump cycling requirements. Wet well volume is minimized by designing the wet well and collection system to provide in-line storage. In-line storage strategies are described in **Section 10.3.1.1**. Wet well volume is also minimized by equipping pump motor starters with variable frequency drives (VFDs) or reduced voltage soft starters (RVSS). VFDs minimize pump cycling and reduce wet well volume by closely matching total pumping rate with influent flow rates. RVSS drives increase the number of allowable starts per hour, thus reducing minimum wet well volume requirements. Refer to **Section 10.5.6.11** and **Section 10.5.6.12** for more information on VFD and RVSS drives.

Criteria for selecting the motor starter type is discussed at the end of **Section 10.4.3.7**. It is recommended to initially assume use of across-the-line motor starters to size the wet well as an initial basis for comparison with wet well dimensions if equipped with VFD or RVSS motor starters. The cycling sequence and volume design guidance described as follows assumes the use of across-the-line motor starters and storage provided entirely within the wet well.

Consider the volume required to prevent excessive pump cycling under all flow conditions. Cycling is the starting and stopping of pumps. Limit the cycling frequency 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 and the "on" and "off" elevations (or on-off setpoints) are

designed to provide sufficient volume for safe cycling. The volume required to satisfy the minimum cycle time depends on the characteristics of the motor (rated maximum starts per hour), 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 of "the first pump to start is the first pump to stop." The logic is alternated among all pumps in a sequential manner and results in the smallest wet well volume necessary to satisfy a given number of pumps and their minimum required cycle time.

Incorporate the technique of "automatic sequencing of pump turn-ons," while designing the wet well storage requirement to optimize the number of "ons" per hour for the pump based on the horsepower of the motor used. To extend the cycle time for multiple pump installations, controls are programmed for "first on/first off" operation and "First on/first off" sequencing. This configuration reduces the required storage volume within the wet well system as long as the inflow is at least 50% of the rated pump design capacity.

The cycle time for a single pump operating is determined as follows:

$$\begin{aligned}
 Q_i &= \text{Flow rate into the pump station, cfs} \\
 Q &= \text{Capacity of the pump, cfs} \\
 V &= \text{Usable volume in wet well between elevations where pump starts and} \\
 &\quad \text{where it stops, cft} \\
 \text{Pump on time} &= V / (Q - Q_i) \\
 \text{Pump off time} &= V / Q_i \\
 t &= \text{Cycle time} = \text{pump on time} + \text{pump off time, s}
 \end{aligned}$$

Minimize the wet well storage volume while meeting the maximum starts per hour (SPH) requirement of the motor. The *AASHTO Drainage Manual* (2014) recommends the following, depending on the size of the motor:

Table 10.3. Minimum Cycle Time and Maximum SPH for a Range of Motor Sizes

Motor Size	Minimum Cycle Time	Maximum SPH
0-11 kW / 0-15 hp	5 minutes	12
15-22 kW / 20-30 hp	6.5 minutes	9.2
26-45 kW / 35-60 hp	8 minutes	7.5
48-75 kW / 65-100 hp	10 minutes	6
112-149 kW / 150-200 hp	13 minutes	4.6

Follow the *AASHTO Drainage Manual* (2014) recommendations and confirm the proposed maximum allowable SPH is acceptable to the pump manufacturer. Increase cycle times/reduce SPH if required by the pump manufacturer.

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:

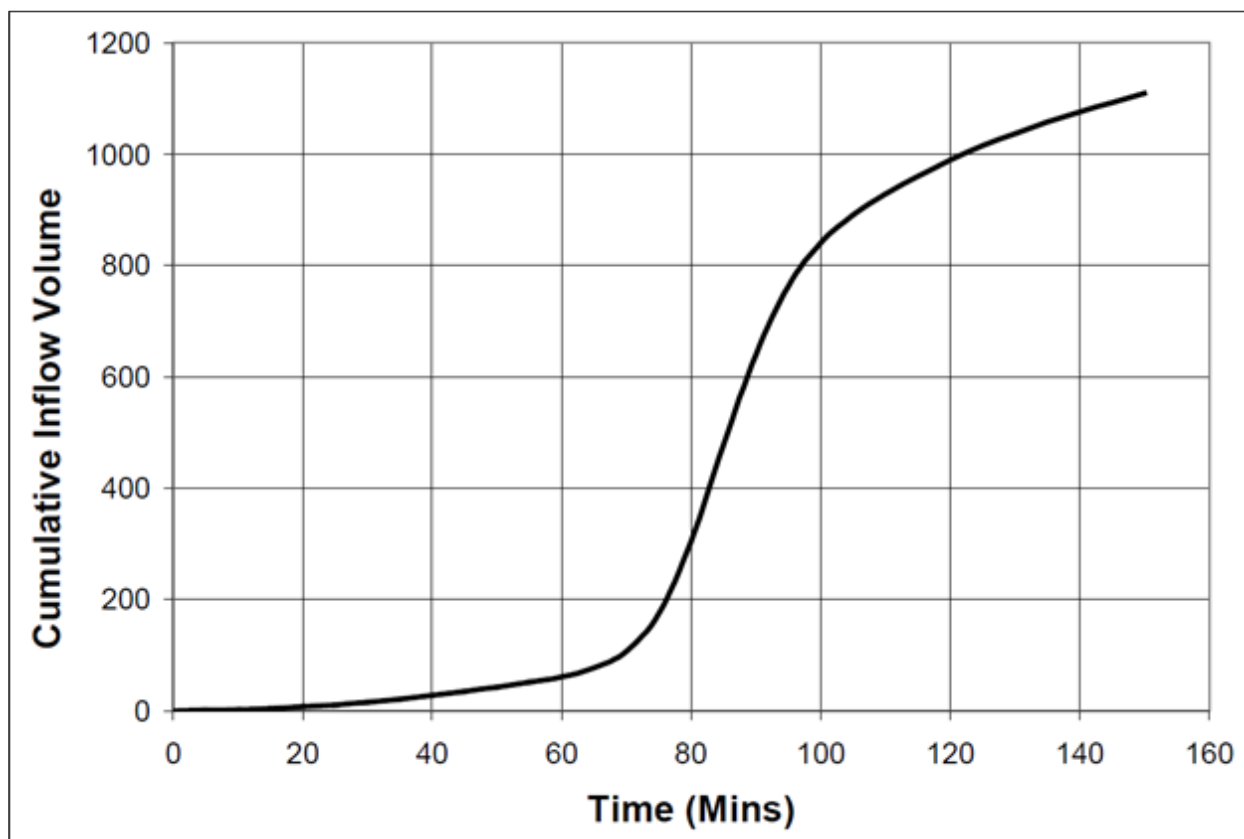
$$V_t = Q \left(\frac{t_c}{4N} \right) \quad (10.1)$$

Where:

- V_t = minimum required volume for pump cycling, cft
- Q = total capacity of pump(s), cfs
- t_c = minimum cycle time, s (= 3,600/max. starts per hour)
- N = total number of equal-size pumps

The volume required for each pump varies depending on the inflow mass curve. Using these volumes, the minimum allowable cycle time occurs when the proportionate inflow to each pump is exactly one-half the capacity of that pump. All other inflows produce a cycle time longer than the minimum.

The minimum storage volume required for each pump is determined by plotting the incremental cumulative pump flow rate over time with the mass inflow over time. This plot represents the mass curve routing diagram. Plotting the cumulative pump flow rate over time requires developing an inflow mass curve, stage-storage curve, and stage-discharge curve. The inflow mass curve is developed using the inflow hydrograph and plotting the cumulative volume over time as shown in **Figure 10-10**. The stage-storage curve plots wet well depth versus useable storage volume with pump start and stop levels. The stage-discharge curve plots wet well depth versus cumulative pump discharge rate. Finally, the mass curve routing diagram plots the mass inflow and pump discharge flow rate versus time, which is used to determine the required storage volume. Refer to **Appendix 10-B** for more detail.

Figure 10-10. Cumulative Flow versus Time Diagram (FHWA HEC 24, 2001)

10.4.3.3 Lowest Pump "Off" Elevation

It is recommended that the minimum wet well depth is not lower than the inlet invert elevation to minimize turbulence and trapped air from entering the pump suction. This "off" elevation represents the maximum static pumping head. The "off" elevation also is required to meet minimum submergence or NPSHr for the pumps.

10.4.3.4 First Pump "On" Elevation

The first pump "on" elevation is set relative to the lowest pump "off" elevation. This operating band provides the minimum volume required to satisfy the minimum pump cycle time for each pump. Starting the pumps as soon as possible by incrementing these volumes successively above the lowest pump "off" elevation maximizes the use of storage 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:

$$H_x = \frac{V_x}{\text{wet well area}} \quad (10.2)$$

The available volume for cycling includes the usable ungula volume. Usable storage does not include that part of the volume that is below the normal flow depth in the collection line. It is assumed 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.

10.4.3.5 Pumping Range

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

10.4.3.6 Allowable High-Water Elevation

The AHW elevation in the pump station is set such that the water surface elevation (hydraulic grade line, HGL) at the lowest inlet in the collection system provides a minimum 1 foot (2 feet desirable) of freeboard below the roadway grade for the design storm.

Refer to Chapter 7, Inlet and Enclosed Storm Drainage Systems, for the procedure of calculating the HGL in a collection system.

10.4.3.7 Motor Starter Selection

Pump selection depends on the type of motor starter. VFD or RVSS drives can reduce wet well depth, which can reduce the maximum system curve, or maximum duty point. VFD drives allow pumps to operate at reduced speed, which allow a pump or set of pumps to operate efficiently on the minimum system curve, whereas the same pump may operate outside of its allowable operating range (AOR) if equipped with an across-the-line starter. MDOT prefers VFD or RVSS motor starters when the benefits warrant the cost. Perform a planning level cost-benefit evaluation to compare the use of across-the-line, VFD, and RVSS motor starters. Consider advantages and disadvantages of each, as well as the differences in wet well volume as it relates to size and depth of the structure. Advantages and disadvantages of each drive type are provided in **Table 10-4**.

Table 10-4. Advantages and Disadvantages of Pump Motor Drive Types

Drive Type	Advantages	Disadvantages
Across-the-line	• Lowest capital cost • Lowest maintenance • Highest reliability • Longest service life • Simplest operation • Lowest heat load	• Lowest cycling frequency • Greatest wet well volume • Pump selection is critical to be sure the pump operates within the AOR • Limited allowable differential between minimum and maximum system curve • 'Hard starts' can damage mechanical equipment

Drive Type	Advantages	Disadvantages
RVSS	• Increased allowable cycling frequency (SPH) • Reduced wet well volume • Reduced starting load protects mechanical equipment • Minimal programming required	• Pump selection is critical to be sure the pump operates within the AOR • Limited allowable differential between minimum and maximum system curve • Additional asset to maintain • Increased capital cost (can be offset by reduced cost of wet well) • Increased complexity • Loss of efficiency (< 5%, infrequent operation)
VFD	• Increased allowable cycling frequency (SPH) • Reduced wet well volume • Reduced starting load protects mechanical equipment • Maintains pump operation within the AOR, protecting pumps • Improves pump efficiency when operating below the maximum system curve • Wide range in pumping system flow control	• Additional asset to maintain • Highest capital cost (can be offset by reduced cost of wet well) • Highest complexity • Increased programming complexity • Loss of efficiency (< 5%, infrequent operation, typically offset by improved efficiency at lower operating speeds) • Greatest heat load

10.4.4 Final Pump Selection

Once the pump type, pump capacity, and wet well operating range have been determined, the final selection of the pump can be made. The system curve (flow versus TDH) defines the energy required to pump flow through the discharge system. The system curve is especially critical for the analysis of discharge systems with force mains.

A study of pump performance curves is necessary for each design. A design point is selected on the system head curve and a pump is selected to match that point. Each pump has a unique performance curve developed by the manufacturer. The pump curves are plotted over the system head curves to compare pumps. Each pump may have a family of curves that represent variations such as impeller size or VFDs. The optimal pump that meets the performance requirements at the highest efficiencies when operated between the minimum and maximum system head curves is selected for the design. Higher horsepower motors which operate at lower speed have a longer service

life and are preferred over lower horsepower motors which operate at higher speed to meet the equal pumping performance requirements.

Details of calculating system curves are presented in FHWA HEC-24 (2001). An example is presented in **Appendix 10-B**.

10.4.5 Structure

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

10.4.5.1 Materials

Reinforced concrete is commonly used for the substructure of a pump station, but the method of placement varies. Precast concrete units, which are prefabricated elsewhere, are typically sunk as a caisson to the required level. Precast concrete structures are circular or rectangular. Cast-in-place concrete is required for larger stations. The design is based on the geotechnical recommendations as appropriate for the site location.

10.4.5.2 Wet Well Requirements

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

Precast structures are used for circular wet wells, unless the required diameter is not feasible based on fabrication or shipping limitations.

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

Wet wells are designed with maintenance in mind. Provide access to remove pumps and clean the wet well and trashrack. Provide a vacuum pumping system or provisions for accessing the wet well via vactor truck to clean the wet pit from outside the pump station. A vactor truck or vacuum system does not work in deep wet well pump stations. Vacuum heights are limited by the vapor pressure of water. Deep wet wells require openings for manual removal of debris. Consider provisions for lifting waste receptacles from a deep wet well.

Wet wells are coated to protect concrete. Refer to Previously Approved MDOT Special Provision for Corrosion Resistant Coatings.

10.4.5.3 Access to Pump Equipment

The stormwater pump station house is an enclosed structure that provides access to the pumps and other equipment. The enclosure is required to have doors, roof hatches, or covered openings through which equipment is passed or debris is removed with a mobile crane. Submersible pump volutes, discharge piping, and guide rails are securely attached and extend from the pump to the opening as recommended by the manufacturer.

10.4.5.4 Access Hatches and Removable Covers

Hatches or removable covers provide visual monitoring, personnel entry, and removal/installation of equipment from a pump station. Depending on the location, an access hatch or cover is required to be water-tight or gas-tight. Size hatches and covers appropriately for their intended use. Access covers are constructed of aluminum, galvanized steel, stainless steel, or concrete. Hatches and covers subject to traffic loading are rated accordingly. Exterior hatches and covers accessible from the grade level must be lockable or only removable with the use of equipment. Refer to Previously Approved MDOT Special Provision Pump Station Metal Work, Miscellaneous for specific requirements of access hatches and covers.

10.4.5.5 Trashracks

Trashracks, located upstream from baffle walls, prevent large objects from entering the system and damaging pumps. Screening large debris at surface inlets minimizes the need for trashracks.

Trashracks protect against damage to the pumps and clogging that may lead to surcharging of a collection system. Trashracks are provided inside the wet well for all pump stations. For stormwater pump stations, flat steel with round cross bar screens are adequate. Ferrous steel is required to be hot dip galvanized after fabrication. Usually, the bar screens are inclined with bar spacing at approximately 2 inches. Alternate bar spacing depends on the solids handling capability of the selected pump. Constructing the screens in modules facilitates removal during maintenance. If the grid is relatively small, an emergency bypass of the screens is provided to protect against clogging and subsequent surcharging of the collection system. An operation and maintenance schedule identifies trashrack inspection frequency. Inspections identify the need for debris and sediment removal.

Consider provisions for cleaning the trashrack. MDOT does not typically use mechanically cleaned trashracks, however, some locations may warrant the use of mechanically cleaned trashracks or supplemental electric operated lifting equipment to facilitate cleaning.

10.4.5.6 Sumps

A sump is included in the wet well design to facilitate dewatering of the facility. The sump is sized large enough to fit a temporary sump pump and be accessible from the

grade level directly above the sump. Permanently installed sump pumps do not hold up well and are not typically installed in MDOT pump stations.

10.4.6 Equipment Certification and Testing

Equipment certification and testing are crucial elements of pump station commissioning.

All pumps are required to have certified performance curves developed in accordance with ANSI/HI standards. Submit certified performance curves to MDOT prior to pump shipment to the project site. MDOT may request to witness pump performance tests. There are costs associated with certified performance curves and witnessed tests. Witness test requirements are to be clearly indicated in the pump specifications.

The pump manufacturer's representative may be required to supervise the pump installation dependent on MDOT specifications. All pumps, liquid level, gas detection, and monitoring equipment require testing by a manufacturer's representative on site, after installation and prior to being put into service.

All piping and valves are required to be hydrostatically pressure tested on site, after installation and prior to being put into service. Pressure testing is in accordance with AWWA C600 for ductile iron pipe, AWWA C605 for polyvinyl chloride (PVC) pipe, and ASTM F2164 for high-density polyethylene (HDPE) pipe. The required test pressure is twice the designed working pressure for the piping system for 30 minutes. Tests demonstrate the system is tight at the test pressure with no leakage. The Engineer is required to witness all testing.

Prepare MDOT Special Provisions for the selected equipment to include detailed certification, testing, and commissioning requirements. Previously Approved MDOT Special Provisions for similar equipment may be available.

10.4.7 Safety

All elements of a pump station are carefully reviewed for safety of operation and maintenance. Ladders, stairwells, and other access points facilitate safe use by maintenance personnel. All floor openings are provided with floor grating, covers, hatches, or guard rail. Prefabricated hatches are provided with safety grating. Adequate space is provided for the operation and maintenance of all equipment. Particular attention is given to guarding moving components, such as drive shafts. Providing proper and reliable interior and exterior lighting is a priority. Adequate ventilation, heating, and dehumidification are essential for efficient operation and maintenance of a pump station.

Pump motors and any potentially spark-producing equipment are explosion-proof rated, unless located outside of hazardous atmospheres.

Some areas of a pump station may be classified as a confined space, in which case, access requirements along with any safety equipment are all defined by code. Consider

providing air testing equipment in the pump station so maintenance personnel are assured of clean air before entering without the use of portable sensors. Pump stations are designed to be secure from entry by unauthorized personnel.

Provide a pump station identification sign with the emergency contact name, telephone number, station address and instructions for responding to an alarm condition or other emergency. Provide visible safety placards, as required by OSHA 1910.145.

10.4.8 Outlet Discharge System

Simplify the discharge piping to the extent possible. Whenever possible, discharge pipe from the pump station is to be horizontal and discharge freely without submergence into an engineered structure, known as a "surge chamber." MDOT prefers pumping discharge systems that lift the stormwater vertically and discharge it through individual lines to a gravity storm drain as quickly as possible. Individual pump discharge lines are the most cost-effective system for short outfall lengths. Consider the effects of stormwater returning to the wet well after pumping stops. Install check valves where there is a potential for backflow through the pumps. Shafted pumps subject to backflow are protected with a non-reversing ratchet in the event of a check valve failure. Individual lines may exit the pump station either above-grade or below-grade. Locate all discharge pipe below the frost depth. A partially frozen discharge pipe could exert additional back pressure on pumps, preventing operation or significantly reducing capacity.

Force mains increase pumping system complexity and are avoided for trunkline projects. Consult with the Hydraulic Unit Supervisor when force main discharge is recommended by the designer.

Protect the system outlet to prevent people or animals from entering the pipe outlet. Steel bar grates and/or flap gates are used to secure an outlet. Use flap gates when the outlet is below the receiving system high-water level. Erosion protection is required at outlets with energy dissipation outlet structures or properly designed well graded or heavy riprap as appropriate. Coordinate outlet protection and erosion protection for trunkline projects with the Hydraulic Unit Supervisor.

10.5 ELECTRICAL SYSTEM

Consult the Municipal Utilities Unit Supervisor about the electrical system design.

It is preferred that a pump station have two sources of power, however this may not be applicable to every design. For a pump station with two sources of power, the primary source is the local electric utility and the secondary source is a redundant utility feed, a generator, or a combination of a second utility and generator. Based on the size of the pump station and the availability of a second utility feed, the following power distribution options are recommended:

- **Utility/Utility:** Recommended for large pump stations and if both utility feeds originate from different substations. Recommend double ended switchgear with main-tie-main circuit breakers resulting in each utility providing power to one-half of the pump station. In case of one utility feed failure, the switchgear transfers the affected half to the remaining utility. Each utility feed needs enough capacity to power the whole pump station.
- **Utility/Utility/Generator:** Same as the Utility/Utility configuration except for the added generator. Tie the generator into the switchgear on both ends of the tie circuit breaker. This allows the generator to power the whole pump station if both utilities fail.
- **Utility/Generator:** Recommended for small or large pump stations and necessary when only one utility feed is present. Based on the size of the pump station, utilization voltage, or MDOT preference, a permanent or portable generator can be used. A permanent generator is tied into the distribution system with an automatic transfer switch. A natural gas or diesel engine is used to power the generator, although natural gas is preferred when a source is available. A portable trailer mounted generator is tied into the distribution system with a standby power receptacle and a manual transfer switch. Consult with MDOT for compatibility with their available trailer-mounted generators.

Utilization voltages of a pump station include one or more of the following: 120/240-volt, single phase for general use; 120/208-volt, three-phase for general use and small motors; and 277/480-volt, three-phase for most motor applications. 277/480 is the preferred voltage for three-phase motors. Medium voltage (4,160V or 4,800V) are required when the low voltage cannot adequately serve the pumps. Pump stations requiring motors 300 hp and greater or a total combined load of 600 hp and greater warrant a cost-benefit analysis to confirm the optimal power supply voltage.

10.5.1 Requirements

Contract documents and plans include a complete light, power, heating, ventilation, 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 drivers, incoming feeder circuit breaker, automatic selector switch, transfer switch, and all other miscellaneous items required to form a complete and functioning electrical system.

The contract plans indicate the general design. Approximate locations of switches, outlets, and other items are shown on the plans. The contractor is responsible for their own field measurements and the proper fit and location of conduits and other items included in the electrical work.

All materials furnished and installed within a hazardous area are required to be explosion-proof, Class I, Division 1, with Underwriters Laboratories, Inc. (UL) label of approval.

As part of the Special Provision, the contractor is required to obtain a submittal from the pump manufacturer listing the actual size and characteristics of the motors to be furnished. Electrical installation requirements are included in the approved pump submittal.

10.5.2 Code Compliance

All material is required to be new, and all work and material is required to meet the current standards and practices of the National Electrical Code (NEC), National Fire Protection Association (NFPA) 820, ANSI, the current Standard Specifications for Highway Construction, and the Occupational Safety and Health Act.

10.5.3 Operation

The pumping unit's operation is automatically controlled by a liquid-level in the wet well. Constant speed pumps require full voltage across the line starters or reduced voltage soft starters depending on the size of the motor, special starting requirements of the pumps, electric utility restrictions and capabilities of a generator. Variable speed pumps require VFDs. An automatic selector switch changes 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. Include information about the incoming power feed including the voltage, phase, and number of wires on the pump station plans. Electrical power is coordinated with the utility company during design.

10.5.5 Area Classifications

Dry space locations: Materials, equipment, and incidentals in areas identified as dry space comply with NEC and NEMA requirements for dusty locations. Enclosures installed in conditioned space locations comply with NEMA 12 requirements.

Wet and corrosive space locations: Materials, equipment and incidentals in areas identified as corrosive comply with NEC and NEMA requirements for corrosive locations. Enclosures installed in corrosive locations comply with NEMA 4X requirements.

Outdoor non-corrosive space locations: Materials, equipment and incidentals in areas identified as corrosive comply with NEC and NEMA requirements for outdoor locations. Enclosures installed in corrosive locations comply with NEMA 3R requirements.

Hazardous space locations: Materials, equipment, and incidentals in areas identified as hazardous comply with NEC and NEMA requirements for the Class 1, Division 1 classification.

10.5.6 Materials

10.5.6.1 Service Cables

The service cables into the pump house from the utility company service box are required to be copper, single conductor, rated for system voltage and current, Type USE-2 (underground service entrance).

10.5.6.2 Wire and Cable

All wire and cable insulation are required to be UL approved. Type USE-2, 600 volts, 90 deg C, except as otherwise noted.

All conductors are required to be copper, stranded, and in accordance with NEC requirements for ampacity.

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

VFD cable are required to be used for feeders for motors connected to VFDs.

Grounding conductors are required to be soft drawn, bare stranded copper sized in accordance with NEC.

Wire color coding: The required insulation color coding is as follows. For wire sizes where specified colors are not available, colored tape are used at each termination and every 3 feet on centers where cables are exposed inside enclosures, like pull boxes, motor control center (MCC) wireways, and conduit bodies.

The required insulation colors are:

- 120/240 single-phase
 - Phase A – black
 - Phase B – red
 - Neutral – white

- 120/208V three-phase
 - Phase A – black
 - Phase B – red
 - Phase C – blue
 - Neutral – white
- 277/480V three-phase
 - Phase A – brown
 - Phase B – purple
 - Phase C – yellow
 - Neutral – gray
- 120V single-phase AC control – red
- Equipment ground wire – green
- DC power – blue
- DC signal
 - Positive – red or clear
 - Negative – black
 - Ground – green with yellow stripes

10.5.6.3 Conduit and Fittings

All exposed conduit and fittings are required to be rigid galvanized steel and meet the requirements of ANSI C80.1 and UL-6.

All concrete encased or direct buried conduits are required to be PVC schedule 80 rated 90 deg C and meet the requirements of NEMA TC-2, NEMA TC-3, UL 514, and UL 651.

Conduits emerging from concrete encasement are required to be PVC coated galvanized rigid steel and meet the requirements of C80.1, UL-6 and NEMA RN1.

Liquid tight flexible steel conduits comply with the UL 360 requirements.

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

All interior conduit, fittings, and junction boxes, installed within a hazardous area, are required to be explosion-proof, Class I, Division 1, in accordance with NEC.

10.5.6.4 Light Fixtures

Lighting fixtures are required to be light emitting diode (LED), vapor-tight with globe and guard. Lighting fixtures in Class 1, Division 1 areas must be explosion proof.

10.5.6.5 Ventilation

Power ventilation is required in all occupied areas of a pump station. Air change requirements are dependent on the rating for the space being ventilated. Ventilation equipment in Class 1, Division 1 areas are required to be explosion proof.

10.5.6.6 Heating

MDOT may request the heating areas of a pump station. Heating is often provided by electric unit heaters. Heating equipment in Class 1, Division 1 areas are required to be explosion proof.

10.5.6.7 Switches

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

Transfer switches are automatic or manual depending on the type of generator provided. The electrical ratings of the transfer switch cannot be less than the main disconnect at each pump station. The transfer switch rating is sized to accommodate the available portable generator. The external operating handle on the transfer switch is interlocked with the door so that the handle is in the "OFF" position before the door is opened. The interlock is required to allow bypassing by authorized personnel. The handle is arranged for padlocking in the "OFF" position so that when the operating handle is padlocked, the door is locked.

Motor disconnect switches are required to be heavy-duty rated with enclosure types in accordance with the area classification and located per the NEC article 430. Switch handles are required to be pad lockable in the OFF and ON positions.

Switches installed in Class 1; Division 1 areas are required to be explosion proof.

10.5.6.8 Receptacles

Receptacles are required to have a minimum rating of 20 amperes, 125 volts, UL, 2-pole grounding type, duplex, weatherproof with gasketed spring door.

Generator Receptacle: All generator receptacles are sized to accommodate the available portable generator. The contractor is required to submit shop drawings for approval prior to any installation.

Any receptacles installed in Class 1; Division 1 areas are required to be explosion proof.

10.5.6.9 Motors

Motors are required to comply with the National Electrical Manufacturers Association (NEMA) requirements. Motors less than 1/2 hp are single-phase and motors greater than 1/2 hp are three-phase. Three-phase motors are required to be NEMA design B, squirrel cage induction motors with voltages varying from 200V to 460V (460V is preferred). Medium voltage motors (4000V and higher) are only considered when low voltage motors and distribution system cannot adequately serve the pump. Motors in wet or corrosive areas are specified to meet Institute of Electrical and Electronics Engineers (IEEE) IEEE-841 requirements and have totally enclosed fan cooled (TEFC)

enclosures. Provide space heaters for motors if condensation within the motor is expected. Inverter duty type motors are used with VFDs or RVSS complying with NEMA MG-1 Part 31 requirements. Provide thermal protection for motors greater than 50 hp and connected to VFDs.

Specify premium efficiency motors per NEMA MG-1 standards. Consider the utility service fee, energy bill rate, capital, and operational costs when specifying motor efficiency and drive type. Capital cost governs stormwater pumping station design because the operation occurs for a few days per year.

10.5.6.10 Motor Control Center

The motor control center complies with the requirements of UL 845, Motor Control Centers.

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

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

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

Vertical sections are constructed for front mounting of combination starter units.

Starter units are a magnetic full-voltage or reduced voltage soft start, combination circuit breaker type with all components and wiring readily accessible for ease of maintenance.

Fully encased space heaters are furnished and installed in each motor control center vertical section to prevent condensation on interior surfaces.

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, help minimize such failures and their consequences. Alarms are used 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.

10.5.6.11 Variable Frequency Drive

VFD and all components are designed, manufactured, and tested according to the latest applicable standards of ANSI, NEMA, and IEEE, including UL508C, NEMA ICS 7.0 and IEEE 519. Each VFD is required to be compatible with the driven equipment and

motors. The VFD is matched to the specific load requirements for each system. Operation of the VFD cannot overstress the motor insulation. To centralize responsibility and ensure that all equipment is properly coordinated, VFD is obtained from the driven equipment supplier. Coordinate sizing of the VFD with the pump designer. Slower speed motors (1200 or 900 RPM) draw more current than standard 1800 RPM motors of the same horsepower and require a larger VFD. Harmonic distortion calculations are performed in accordance with IEEE 519. Necessary harmonic mitigation equipment is specified to keep harmonic distortion of the facility within IEEE 519 guidelines. Provide an impedance device (line reactor or pulse shifting transformer) between each VFD and the electrical distribution system.

10.5.6.12 Reduced Voltage Soft Starters

RVSS and all components are designed, manufactured, and tested according to the latest applicable standards of ANSI, NEMA, and IEEE, including UL508C, NEMA ICS 2.0. The RVSS consists of an electronic controller to provide soft starting and stopping of the motor. The RVSS requires a contactor that bypasses the controller when the motor reaches full voltage (speed).

10.5.6.13 Automatic Sequence Selector Switch

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

10.5.6.14 Miscellaneous

Engraved plaques with gray or black background and white letters are required for control center equipment as designated on the plans.

10.5.6.15 Lighting Transformer

The transformer is a dry type, 5KVA minimum single phase meeting the requirements of NEMA ST20, NEMA TPI and UL 1561. Secondary voltage 120/240-volt.

10.5.6.16 Lighting Distribution Panel

The lighting panel is a 12-circuit minimum, 120/240-volt, single phase, 3-wire, 100-ampere minimum main and neutral lugs, complete with 20-ampere circuit breakers. Panelboards comply with the requirements of UL 50, UL 67 and NEMA PB1. Minimum short circuit withstand rating of 10,000-amperes root mean square (RMS) symmetrical.

10.5.6.17 Transformer Disconnect

The transformer disconnect is a circuit breaker with the number of poles, ampere, and voltage rating as required.

10.5.6.18 Main Power Disconnect

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

10.5.6.19 Installation and Wiring

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

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

All conduit in the motor room is exposed and have horizontal or vertical alignments. Conduits are self-draining and require tight waterproof joints

Conduit is routed to avoid blocking openings for removal of equipment.

10.5.6.20 Grounding

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

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

10.6 MONITORING, CONTROL AND COMMUNICATION

Pump stations are vulnerable to a wide range of operational problems, from malfunction of the equipment to loss of power. Monitoring pump stations helps minimize problems and their consequences. There are several types of monitoring.

The best overall monitoring is the implementation of regularly scheduled maintenance and record keeping by trained, experienced personnel. This is required at MDOT pump stations.

MDOT recommends hour-meter and start-meter installation on all pumps to aid in scheduling needed maintenance.

On-site warning lights and audible alarms are required at all MDOT pump stations for:

- High water levels
- Low water levels
- Power outage
- Pump seal failure
- Pump over temp

Additional warranted alarms include:

- Illegal entry
- Explosive or hazardous atmosphere
- Moisture detection
- Motor over temp
- Motor vibration

Consider telemetry to provide remote monitoring of the pump station. Operating functions and sensor readings are telemetered from a station to a central control unit. This allows the central control unit to initiate corrective actions immediately if a malfunction occurs.

In addition to telemetry, SCADA may be installed to relay the telemetry data to a remote location for operation and maintenance staff use. Coordinate telemetry and SCADA requirements with MDOT for trunkline projects.

10.7 MAINTENANCE

The input of maintenance personnel is important for diagnostic procedures, computerized history and inventory, and elimination of future expensive repairs. Pump stations are classified as "confined spaces." According to MIOSHA requirements, proper safety equipment and training is required for confined space entry.

For pump station maintenance, follow the work methods described in the MDOT Maintenance Activity Guide 1530, Pump Station Maintenance.

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