Chapter 11 Pump Stations

Appendices

List of Figures

List of Tables

Chapter 11 PUMP STATIONS

This chapter of the Design Standards and Guidelines (DSG) presents guidance for Seattle Public Utilities (SPU) pump stations for potable water, stormwater, and wastewater facilities. The primary audience for this chapter is SPU engineering staff, who both design improvements to SPU pump stations and advise consulting engineers responsible for pump station design. DSG Standards are shown as underlined text.

The information in this chapter should be used in conjunction with other DSG standards, including *Chapter 7, DWW System Modeling*; *Chapter 9, Electrical Design*; and *Chapter 10, Instrumentation & Control (I&C) Supervisory Control and Data Acquisition (SCADA)*.

> ***Note:*** *This chapter of the DSG does not replace the experienced engineering judgment of a registered professional engineer. All pump station designs for both upgrades and new stations should be done under the supervision of an experienced, licensed engineer.*

11.1 KEY TERMS

The abbreviations and definitions given here follow either common American usage or regulatory guidance.

11.1.1 Abbreviations

Abbreviation	Term
AASHTO	formerly American Association of State Highway and Transportation Officials now just AASHTO
ac	alternating current
ACI	American Concrete Institute
ADA	Americans with Disabilities Act
AISC	American Institute of Steel Construction
AMC	Asset Management Committee
AMCA	Air Movement and Control Association
ANSI	American National Standards Institute
AOR	acceptable operating range
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASTM	formerly American Society of Testing and Materials; now known as ASTM International

Abbreviation	Term
BEP	best efficiency point
CIP	Capital Improvement Program
CSI	Construction Specifications Institute
CSO	combined sewer overflow
DOH	Washington State Department of Health
DWW	drainage and wastewater
Ecology	Washington State Department of Ecology
EGL	energy grade line
FRP	fiberglass-reinforced plastic
ft	feet
gpm	gallons per minute
HGL	hydraulic grade line
HI	Hydraulic Institute
HMI	Human-Machine Interface
HP	horsepower
HVAC	heating, ventilation, and air conditioning
I&C	Instrumentation and Control
IEEE	formerly Institute of Electrical and Electronics Engineers; now known as IEEE
LOB	line of business
MCC	motor control center
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NPSH	net positive suction head
NSF International	NSF International: a not-for-profit, non-governmental standards organization also trademarked as The Public Health and Safety Company
ODP	open drip proof
OI	Operator Interface
O&M	operations and maintenance
P&ID	process and instrumentation diagram
PLC	programmable logic controller
POR	preferred operating range
psi	pounds per square inch
RCM	reliability centered maintenance

Abbreviation	Term
SBC	Seattle Building Code
SCADA	supervisory control and data acquisition
SDCI	Seattle Department of Construction and Inspections
SDOT	Seattle Department of Transportation
TEFC	totally enclosed fan cooled
V	volt
VFD	variable frequency drive

11.1.2 Definitions

Term	Definition
backflow preventer	A device installed in potable water piping to prevent the flow of non-potable water into a potable system.
best efficiency point (BEP)	The discharge rate at which an impeller of a given diameter rotating at a given speed operates at maximum efficiency.
booster	A pump that takes suction from a pressurized piping system and discharges, at a higher pressure, to a second, isolated piping system.
cavitation	Vapor bubbles formed on a solid surface (often an impeller) in contact with a liquid. The vapor bubbles occur when the pressure in the liquid falls below the vapor pressure.
centrifugal pump	A rotodynamic pump in which the fluid is displaced radially by the impeller. Commonly, any rotodynamic pump in which the fluid is displaced radially, axially, or by a combination of both.
dry well	The below-grade structure of a pump station in which the pumped liquid is contained within piping valves and pumps.
engineering	Generic term for SPU engineering staff.
firm pumping capacity	Capacity of the pumping station with the largest pump out of service or on standby.
force main	Piping, external to the station and filled with liquid under pressure, through which the station discharges.
guidelines	Advice for preparing an engineering design. Guidelines document suggested minimum requirements and analysis of design elements to produce a coordinated set of design drawings, specifications, or lifecycle cost estimates. Guidelines answer what, why, when, and how to apply design standards and the level of quality assurance required.
impeller	A circular casting mounted on a rotating shaft with vanes to accelerate the fluid.
intake	A structure from which the pumps take suction.
net positive suction head (NPSH)	Absolute dynamic head of the pumped liquid at the suction eye of the pump.
net positive suction head available ($NPSH_a$)	The NPSH at which the pump in each system operates at a given discharge rate.

Term	Definition
net positive suction head required ($NPSH_r$)	The minimum NPSH at which a pump can properly operate for a given discharge rate.
packing	Semi-plastic material installed in a stuffing box to seal the shaft opening in the casing to restrict the leakage of liquid from the casing along the shaft.
pump	A machine that imparts kinetic and potential energy (from an external energy source) to a liquid to force a discharge from the machine.
pump station	A structure housing pumps, piping, valves, and auxiliary equipment.
runout	A point at which pump discharge lead increases rapidly.
soft start	Motor starting in which the inrush current is reduced.
standard	Drawings, technical or material specifications, and minimum requirements needed to design a particular improvement. A design standard is adopted by the department and generally meets the functional and operational requirements at the lowest lifecycle cost. It serves as a reference for evaluating proposals from developers and contractors. For a standard, the word must refer to a mandatory requirement. The word should is used to denote a flexible requirement that is mandatory only under certain conditions. Standards are underlined throughout the DSG.
submersible pump	A pump or pump and motor suitable for fully submerged operation.
total dynamic head	The total head at which a pump will operate at any given discharge rate.
total static head	The difference in elevation between the surface of the pond from which the pump draws water and the surface of the pool into which the outlet discharges.
water hammer	Rapid, severe, and often destructive changes in pressure in a piping system caused by a sudden change of liquid velocity.
wet well pump	A pump designed to be directly immersed in the liquid.
wet well	The below-grade compartment of a pump station into which liquid flows and from which pumps draw suction.

11.2 GENERAL INFORMATION

11.2.1 Design Life

Design life is used to perform a lifecycle analysis. It refers to a service period in which about 50% of a group of assets has a high probability of failure, as recognized by the manufacturer and/or SPU planners. Neither equipment nor structures will necessarily fail if left in service beyond their design life. However, design life is an important benchmark for indicating when SPU should consider rehabilitation or replacement.

SPU has no official policy on pump station elements and design life. Until a policy is available, refer to the basic understanding described here. The preferred design life of pump station equipment and structure(s) should be understood at the start of design.

SPU pump stations are structures that house mechanical equipment. The structure itself has an anticipated design life, as does each piece of mechanical equipment inside it (Table 11-1).

Table 11-1
Typical Design Life for SPU Pump Station Elements

Component	Type	Design Life (years)
Structural	Buildings (aboveground) and most structural elements	100
	Below grade concrete structures	150
	Roof (water pump stations only):	
	Composite	20-25
	Metal	35+
Mechanical	Valves Piping (within pump station) Backflow preventers HVAC	25
Electrical	Motors (time period between each rewinding)	15
	Starter and motor control systems)[1]	20
Pumps		
• Water	Dry well pumps (horizontal axial split pumps, single or dual stage)	35+
• Drainage and Wastewater	Dry well/wet well pumps (centrifugal)	25
	Submersible pumps < 5 hp	10
	Submersible pumps >25 hp[2]	15-25

Notes

[1] Electrical elements other than motor windings may last over 35 years. Many electrical elements are replaced sooner when more efficient systems are developed or when motors are repaired or replaced and require new starters or control systems. A cost-benefit analysis should be done to determine whether to replace electrical elements.

[2] Typically small submersible pumps (<25 hp) are replaced rather than repaired given their low cost versus the repair cost. Dry well pumps will likely need rebuilding of subcomponents such as bearings, couplings, seals, or impellers.

Acronyms and Abbreviations

hp: horsepower
HVAC: heating, ventilation, and air conditioning

Existing SPU pump stations are generally between 40 and 100 years old. Some pump stations have been rehabilitated over the years, while others operate using original equipment. In most cases, past equipment replacement or upgrades are not well documented in the Engineering Records Center. Therefore, existing conditions should be evaluated thoroughly at each facility before beginning design work.

Where maintenance information (such as Maximo Records) is available for major equipment, the design engineer should compare that data with the operations and maintenance (O&M) Manual for that equipment. If repairs occur more frequently than expected, an evaluation may be warranted for design life, repair, or replacement. In general, Maximo Records data should be available for maintenance completed in the past ten years.

11.2.2 Level of Service

Pump station modifications and development must meet the defined SPU level of service for the appropriate line of business (LOB).

If an existing system does not meet the specified level of service, it should be modified to do so. If an existing system does meet the level of service, asset management principles should be used to determine whether updating or adding new stations is justified. New stations may be justified if a new station can significantly reduce costs.

11.2.2.1 Water

The water pumping system is robust and sufficient to meet SPU's water LOB service levels. For water pump stations, the 2019 Water System Plan identifies these level-of-service objectives:

- Provide agreed-upon pressure and flow in the water transmission system for wholesale customers.
- Provide adequate pressures for drinking water supplies in the water distribution system. This includes delivering peak hour demands at a minimum of 30 pounds per square inch (psi) at utility meters and not drop below 20 psi during normal operations for delivery to retail customers.
- Meet efficiency goals in the water distribution system. This includes maintaining system leakage losses of no more than 10% of that supplied to the retail service area, as defined by Washington State Department of Health (DOH) guidelines.

To confirm these objectives, the designer should determine the actual pressure and flow for the existing facilities (review SCADA data) and the required pressure and flow at the locations serviced by the pump station (utilize water system model).

11.2.2.2 Wastewater

For wastewater pump stations, consider the following performance criteria when providing a recommendation on firm pumping capacity and design scope for a station being overhauled as part of the combined sewer overflow (CSO) Program or the Pump Station Program:

- Pump stations should have minimal sewer backups with specific guidelines based on interim drainage and wastewater (DWW) LOB sizing guidance for the Capital Improvement Program (CIP):
  - **Pump stations serving non-critical services.** No more than one sewer backup in 10 years (10% annual probability) at the wet well (through the wet well hatch or into an unpermitted point of overflow) or within the affected upstream or downstream combined or sanitary sewer lines.
  - **Pump stations serving critical services (e.g., hospitals and fire stations).** No more than one sewer backup in 25 years (4% annual probability) at the wet well (through the wet well hatch or into an unpermitted point of overflow) or within the affected upstream or downstream combined or sanitary sewer lines.
- CSOs should be limited to an average of one untreated discharge per permitted outfall per year. This limit is based on eliminating the basin's control volume. Control volume is a highly uncertain, climatic horizon dependent value that should be determined based on site context, infrastructure context, and financial context. The control volume

associated with the modeled 50th percentile 2035 climate horizon may be used for initial planning purposes. Consult the LOB for further guidance.

- The facility should be designed to produce zero dry-weather overflows into permitted outfalls.
- Zero overflows at unpermitted points of overflow, regardless of weather conditions.

The SPU wastewater system discharges to King County's regional wastewater collection system. The design engineer must consider the potential effects on King County's system when making a pump capacity and design recommendation. Any effects on King County must be negotiated with King County by the DWW LOB representative. Increases in firm pumping capacities typically require compensation for the effects on the regional system. The design engineer should identify ways to achieve the performance criteria described in the bullets above without affecting King County's system. The DWW LOB representative can provide regional and basin hydraulic and hydrologic models to assist in this analysis. For information on permitting and environmental review requirements with King County, see *DSG Chapter 2, Design for Permitting and Environmental Review*.

11.2.2.3 Drainage

Currently, SPU operates one temporary drainage pump station to manage runoff within the Alaskan Way Viaduct project area. A permanent drainage pump station in the South Park neighborhood is planned to begin operations in 2021. For a potential drainage pump station, refer to the Interim Conveyance Design Criteria for DWW Capital Projects (SPU Policy DWW-130) for level of service design criteria. Use the following targets for managing stormwater runoff within City of Seattle (City) right-of-way (ROW):

- Protect public safety and buildings from flooding, up to and including runoff from the 25-year, 24-hour design storm event.
- Allow access to and maintain functionality of critical services such as hospitals, fire stations, and schools up to and including runoff from the 100-year, 24-hour design storm event.
- Protect public safety and support mobility on the following:
  - Major transportation routes up to and including runoff from the 25-year, 24-hour design storm event.
  - Residential roads up to and including runoff from the 5-year, 24-hour design storm event.

Developing requirements for drainage pump stations can be challenging because reliable information is often not available on the amount and duration of flow. SPU does have extensive rainfall data that can be used to model flow and duration to develop pump station criteria.

11.2.2.4 Meeting Levels of Service

To meet the targets outlined above, SPU may need to enhance its infrastructure. Program management and project development for these projects are handled within the respective LOBs for water, drainage, and wastewater.

11.2.3 System Maps

SPU storm drainage, wastewater, and combined sewer system maps are available from the following sources:

- Base Maps
- SPU Engineering Records Center and GIS Mapping Counter (SMT 47th floor)
- CSO Control Facilities O&M folders (DWW Facility Manual SharePoint Site)
- SPU/King County Wastewater Sewer/Drainage Topography maps (SMT 45th floor)
- Seattle Department of Construction and Inspections (SDCI) Side Sewer and Storm Drainage Information desk (SMT 20th floor)

11.2.4 Pump Station System

SPU owns and operates approximately 104 water, wastewater, drainage, and CSO pumping stations of various types throughout the system.

11.2.4.1 Water Pump Stations

SPU currently operates 31 potable water pump stations. SPU water pump stations have a minimum of one to a maximum of four pumps each. The stations' capacities range from 110 to 38,200 gallons per minute (gpm). The primary function of a water pump station is to transport water to storage facilities to meet peak demand each day and to ensure that proper pressure is maintained while meeting fire flow requirements. In general, the SPU water pumping system is robust and meets service levels.

Most SPU water pump stations pump to storage facilities and two stations pump water from well fields. The remaining pump stations are in-line booster pumps that deliver water with appropriate pressure directly to the customer. Except for four pump stations, all SPU pump stations are electrically powered—one pump station has a diesel motor and electric motors, the other three are hydraulically powered by turbines.

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11.2.4.2 Wastewater Pump Stations

SPU currently owns, operates, and maintains 68 wastewater pump stations and four CSO facilities with drain pumps. The SPU wastewater collection system consists of various types of stations and pumping equipment, including wet well/dry well stations, stations with wet wells only (submersible), and pneumatic-lift-type stations.

SPU stations are typically equipped with two pumps. Currently, SPU operates a single three-pump station (Pump Station 35). Older stations may not have 100% firm capacity and regularly use both pumps to meet demand. Station firm capacities generally range from 50 gpm to 2,700 gpm, with most stations under 400 gpm.

The primary purpose of a pump station is to receive wastewater or drainage from a service area or drainage basin and convey that flow to a discharge point outside of the basin. A network of SPU-owned and maintained gravity pipes feeds the basin. Wastewater is pumped from a pump station via a pressurized force main pipe into either SPU’s downstream collection infrastructure or the King County regional trunk collection system.

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11.2.4.3 Drainage Pump Stations

Currently, SPU operates one temporary drainage pump station, with one new drainage pump station under development . Typically, drainage pump stations are installed as a flood control measure within a drainage basin to alleviate any flooding by a severe rainstorm.

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11.2.5 DSG Design Resources

DSG design resources include example technical and material specifications, example calculations, and checklists. For cost estimating guidance, refer to the SPU Cost Estimating Guide. The following design resources are discussed in this chapter and its appendices:

- **Example Technical Specifications.** Example technical specifications for drainage and wastewater pump stations are presented in Construction Specifications Institute (CSI) format (see **Appendix 11A - Example Pump Station CSI Specifications**). The example specification sections listed below include only those that are typically unique to pump stations. This is not a comprehensive set of specifications for pump station projects. Notes to the design engineer may be embedded within these specifications. Each specification section must be tailored for each contract. The design engineer must determine the full set of specifications necessary for each project and review each example specification for applicability.

- Section 01 35 05 Sewer Bypass Plan
- Section 08 31 00 Access Hatches
- Section 09 90 00 Painting and Coating
- Section 23 00 00 Ventilation
- Section 23 80 00 Odor Control Equipment
- Section 26 24 19 Motor Control Centers
- Section 26 29 13 Combination Motor Starter
- Section 26 29 23 Variable Frequency Drive Motor Controllers
- Section 40 07 00 Mechanical Identification
- Section 40 23 00 Pipe, Fittings, and Accessories
- Section 40 23 01 Pump Station Valves
- Section 40 90 05 Control Loop Descriptions – Variable Speed
- Section 40 90 05 Control Loop Descriptions – Constant Speed
- Section 40 91 10 Primary Elements and Transmitters
- Section 40 91 16 Magnetic Flow Meters
- Section 40 91 23 Staff Gage
- Section 43 21 13 Variable Speed Vertical Centrifugal Pumps
- Section 43 21 29 Sump Pumps

- **Example Calculations.** Example calculations are available for sizing pump station elements and selecting pump equipment (**Appendix 11B - Pump Station Design Calculator [Constant Speed]**, **Appendix 11C - Pump Station Design Calculator [Variable Speed]**, and **Appendix 11D - Example Calculations - Wet Well Sizing**). These calculations are for reference only and not intended as standards. It is at the discretion of the engineer to select a calculation methodology. The example calculations provided in Appendix 11D are for a duplex wet well/dry well wastewater station. Separate examples are provided for constant speed and variable speed applications.
- **Equipment Data Sheet Template.** An equipment data sheet template is provided as an example only (**Appendix 11E - Equipment Data Sheet Template**). It can also be tailored for instruments.
- **Operational Checklists.** Start-up and commissioning checklists are provided as examples only (**Appendix 11F - Operational Checklists**, **Appendix 11G - Equipment Testing Checklist**, **Appendix 11H - Operational Acceptance Checklist**, and **Appendix 11I - Systems Acceptance Testing**).

11.3 GENERAL REQUIREMENTS

The design engineer should be familiar with water, wastewater, and drainage industry standards and code requirements for pump station design. If industry standards and City requirements or regulations conflict, the design engineer should discuss the discrepancy with the LOB owner, operations manager, and SPU project engineer before resolving the issue (see contacts in DSG section 11.11). In general, the more stringent requirement should govern.

11.3.1 Industry Standards

All pump station designs should consider the standards and guidelines provided by the Hydraulic Institute (HI), ASTM International (formerly known as American Society for Testing and Materials Standards), Pumping Station Design edited by Robert L. Sanks (also known as the Sanks book), DOH, and the Washington State Department of Ecology (Ecology). All new SPU facilities should conform to all requirements cited in this section.

11.3.1.1 Water Pump Stations

Water pump stations must be designed to meet American Water Works Association (AWWA) and DOH standards.

11.3.1.2 Wastewater and Drainage Pump Stations

Wastewater and drainage pump stations must be designed to meet local and HI standards, as well as other industry-accepted standards for solids-bearing water.

Newly designed wastewater pump stations must, at a minimum, meet Ecology's Criteria for Sewage Works Design, in addition to other requirements stated throughout this chapter.

All wastewater facilities, including pump stations, must meet DOH requirements for cross-connection control between potable water supplies and wastewater systems.

Table 11-5 lists industry standards and relevant international and national codes for pump stations. It is the design engineer's responsibility to use the latest version of these standards. This is not an exhaustive list.

Table 11-5
Industry Standards and International and National Codes for Pump Stations

Organization	Standard	Description
Industry standards		
ANSI	B73.1	Horizontal, end-suction centrifugal pumps
ANSI/AWWA	E101	Vertical turbine and submersible pumps
ASHRAE	Standard 90.1	Energy conservation in new buildings
ASME	8.2	Displacement and centrifugal pumps
ASTM International	Various	Forging and coating of mechanical piping
AWS	D – 1.1	Structural welding code
AWWA	Various	Disinfection, piping, and other elements of drinking water systems
IEEE	Standard 446	Emergency and Standby Power
International and National Codes		
ACI	318	Building code requirements for reinforced concrete
ACI	350	Recommended practice for design of concrete sanitary structures

Organization	Standard	Description
ADA	28 CFR Part 36	Americans with Disabilities Act Guidelines for Buildings and Facilities
AMCA	300	Test Code for sound rating
IBC		International Building Code
NEC	Section 501 -8	National Electrical Code
NEMA		National Electrical Manufacturers Association
NFPA	37	Installation and use of stationary combustion engines and gas turbines
NFPA	58	Storage and handling of liquefied petroleum gases
NFPA	Standard 90A	Installation of air conditioners and ventilation systems
NFPA	820	Recommended practices for wastewater and transmission facilities
NSF International	60	Purity of chemicals for drinking water
NSF International	61	Purity of products for drinking water
UBC		Uniform Building Code
UFC		Uniform Fire Code
UL	1004	Electrical Motors
UMC		Uniform Mechanical Code
Local Codes		
Seattle Building Code		
Seattle Fire Code		
Seattle Mechanical Code		
Seattle Electrical Code		
Seattle Energy Code		

Acronyms and Abbreviations

ACI: American Concrete Institute
ADA: Americans with Disabilities Act
AMCA: Air Movement and Control Association
ANSI: American National Standards Institute
ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers
AWS: American Welding Society
AWWA: American Water Works Association
IBC: International Building Code
IEEE: Institute of Electrical and Electronics Engineers
NEC: National Electrical Code
NEMA: National Electrical Manufacturers Association
NFPA: National Fire Protection Association
UBC: Uniform Building
UFC: Uniform Fire Code
UMC: Uniform Mechanical Code

11.3.2 Regulations

All pump stations must be built to the currently adopted version of applicable City of Seattle and Washington State and federal guidelines, including local building, fire, safety, and electrical codes for pump stations. SDCI and Seattle Department of Transportation (SDOT) maintain current lists of City construction codes. Table 11-6 shows City and Washington State regulations that commonly apply to pump stations. This is not an exhaustive list.

Table 11-6
City and State Standards and Codes for Pump Stations

Code	Document
City of Seattle	
• Seattle Streets Illustrated	SDOT Director's Rule/SDCI DR 31-2017/SDOT Rule 04-2017
• Stormwater Code	City of Seattle Stormwater Code (SMC 22.800 – 22.808) • Volume 1: Source Control Technical Requirements Manual (SDCI 17-2017 SPU DWW 200) • Volume 2: Construction Stormwater Control Technical Requirements Manual (SDCI 17-2017 SPU DWW 200) • Volume 3: Stormwater Flow Control and Water Quality Technical Requirements Manual (SDCI 17-2017 SPU DWW 200) • Volume 4: Stormwater Code Enforcement Manual (SDCI 17-2017 SPU DWW 200)
• Side Sewer Code	Side Sewer Code (SMC 21.16) SDCI/SPU Requirements for Design and Construction of Side Sewers Directors' Rule 4-2011 (Drainage and Wastewater Discharges)
• Right-of-Way Opening and Restoration Rules	SDOT Right-of-Way Opening and Restoration Rules (SDOT DR 01-2017)
• City Standard Plans and Specifications	City of Seattle Standard Specifications for Road, Bridge, and Municipal Construction and Standard Plans for Municipal Construction
• Noise Ordinance	Noise Abatement, SMC 25.08
• Seattle Land Use Code	Seattle Land Use and Zoning Code, SMC 23
• Seattle Plumbing Code	Washington State Plumbing Code with Seattle amendments, 2015
• Seattle Building Code	International Building Code w/ Seattle amendments, 2015
• Seattle Electrical Code	National Electrical Code w/ Seattle amendments, 2017
• Seattle Mechanical Code	International Mechanical Code with Seattle amendments, 2015
• Street Use Code	Street Use Code, SMC 15
• Seattle Fire Code	Seattle Fire Code, 2015
Washington State	WAC 51-13, ventilation and indoor air quality

Acronyms and Abbreviations
DWW: drainage and wastewater
SDCI: Seattle Department of Construction and Inspections
SDOT: Seattle Department of Transportation
SMC: Seattle Municipal Code
WAC: Washington Administrative Code

11.4 BASIS OF DESIGN

Basis of design documentation communicates design intent to plan reviewers and future users of a constructed facility. Documenting the basis of design and archiving it with the project record drawings provides future staff access to historical design decisions.

11.4.1 Basis of Design Plan Sheet

The basis of design plan sheet (Figure 11-3) is a general sheet that shows a plan overview and lists significant design assumptions and requirements for major design elements.

- The design engineer must include a basis of design plan sheet in the plan set.
- The sheet must be archived with the record drawings.

The basis of design plan sheet is not intended for construction and should **not** be included with the bid set. The sheet is inserted after completion of bidding for the project. See *DSG Chapter 1, Design Process*.

Figure 11-3
Basis of Design Plan Sheet Data for Pump Stations

Pump Stations

Number of Pumps (provide information for each pump):

Size of Pump (range of gpm): __________

Design Flow Rate: __________

Total Dynamic Head: __________

NPSHA: __________ ft

Pump Info: Impeller type and size _______________

Maximum Sizing __________

Speed ________________

Power ________ hp

Efficiency _______________

Configuration ___________________

Type of Station: (ejector, submersible, drywell, wet well, booster, well, storage facility, other)

Pump Set Points:
____

Primary Power Source:
____

Backup Power Source:
____

Utility Power: ______________kW Phase: ______________ Voltage:__________

Drive Type (combination starter, soft start, VFD, other): _______________________

Force main: size _____________; type ____________; length __________

Static Head Elevation: _______________ft Pressure Zone: ______________________

Service Area: (Storm Only, Sanitary Only, Combined) ______________________________
Wet Well Storage: __________ gallons, __________ hours
Design Inflow Rate: __________
Project Specific/Special Information: ____ ____

Acronyms and Abbreviations
ft: feet
gpm: gallons per minute
hp: horsepower
kW: kilowatt
VFD: variable frequency drive

11.4.2 Design Criteria List

The design engineer must use a design criteria list to develop the basis of design plan sheet. The design criteria list is a shortened version of the most important items on the basis of design plan sheet (Table 11-7). This information is not intended for construction and should not be included with the bid set. If included with the bid set, the design criteria list should be labeled **Informational Only**.

The design criteria list is typically completed with the preliminary engineering report as a concise summary. However, the preliminary engineering report can provide a much lengthier description of design requirements.

Table 11-7
Design Criteria List for Pump Stations

Description	Criteria
Pump Setting	Must be a minimum dual pump system on parallel setting Station must provide required capacity with largest pump out of service.
Pump Solids Handling (wastewater only)	Minimum 3-inch soft sphere handling
Maximum Pumping Cycles	Motor Size dependent (consult manufacturer for recommended maximum pump cycles)
Pump impeller Sizing	Not to exceed 90% of maximum impeller diameter
Pump Speed	Minimum 885 rpm (900 rpm nominal) Maximum 1770 rpm (1800 rpm nominal)
Pump Efficiency	80% minimum for water pump station 60% minimum for wastewater and drainage pump stations
Submersible Pump Motor Seal	Tandem pump shaft seals w/ moisture sensing of space between seal

Description	Criteria
Pump Shaft Seals	Flush-less mechanical seal for wastewater and drainage (stormwater) pump stations
Bearing	Heavy duty. Minimum ANSI B-10 bearing life of 40,000 hours when pump operates at 25% of BEP capacity for impeller diameter supplied at maximum speed of operation
Piping	Minimum Ductile Iron Pipe CL52 (CL 53 for fabricated and process piping) *or* Standard Steel Pipe Schedule 40 with double-thick cement mortar lining (stations with higher operating pressures may require Schedule 80 or custom-fabricated steel pipe)
Wastewater Force Main Velocity and Minimum Size Pipe	Minimum 2 fps (5 fps where heavy ragging conditions are anticipated) Maximum 8 fps Minimum size 4 inches required
Net Positive Suction Head available ($NPSH_a$)	Minimum twice the manufacturer's stated Net Positive Suction Head required ($NPSH_r$)
Check Valve	Horizontally placed swing check valve with outside lever and spring
Isolation Valve	Water pump station (see Table 11-23) Wastewater and Drainage pump station see (Table 11-24)
Utility Power	Minimum 480V, 3-phase (retrofit projects will have unique power requirements)
Drive Type	VFD or soft starter required for pumps 15 hp or larger. Recommended for pumps 10 hp or larger.
Emergency Generator Plug	Required for all wastewater and drainage pump stations without onsite generators
Water Service	Minimum 1-inch water service required for all stations. For wastewater stations, backflow prevention is required. See DSG section 11.6.1.10 of this chapter.
Electrical	See DSG section 11.6.4 of this chapter

Acronyms and Abbreviations
ANSI: American National Standards Institute
BEP: best efficiency point
ft: feet
fps: feet per second
hp: horsepower
rpm: revolutions per minute
V: volt
VFD: variable frequency drive

11.5 DESIGN PROCESS

For a general discussion of the SPU design process, see *DSG Chapter 1, Design Process.* This section describes additional items for pump station design.

11.5.1 Planning

SPU routinely monitors pump station performance. When a problem is identified and an O&M solution cannot fix it, the facility is further assessed within a standard decision-making framework. LOB representatives use a four-step framework to develop CIP projects (Figure 11-4):

- **Identify the project drivers.** Examples are exceeding design life and risk of failure, backups if a component failed, and risks of damage to other infrastructure.
- **Frame the problem.** Functionality and performance of the component are evaluated and weighed against expected criteria.
- **Analyze the data.** Cost/benefit analysis is conducted to estimate lifecycle cost and net present value.
- **Make recommendations.** A final decision is made following asset management process and presented in a business case.

Each time the evaluation occurs, the LOB looks at sole replacement-in-kind of the pump station element, reconsiders the service levels and functionality of the pump station, and considers opportunities for fixing other known problems with the pump station.

11.5.2 Project Scoping

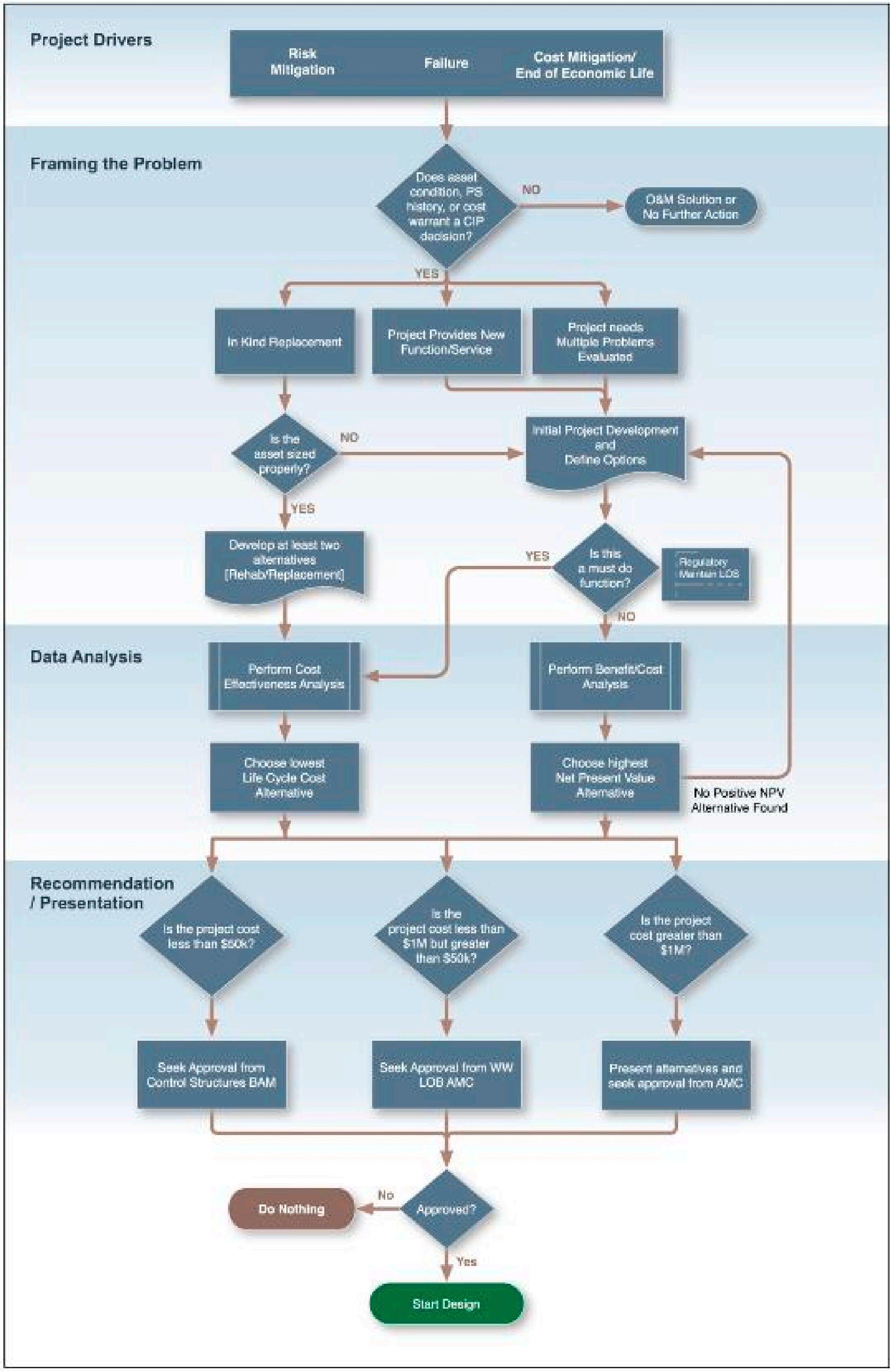
Scoping for pump station projects, especially retrofits, must be developed in a team setting with engineers, operations crews, and the LOB representative. The team should review existing conditions in the field with Operations staff to identify operational needs and existing difficulties that could be improved through the project.

Retrofit projects should strive to comprehensively address existing performance issues, deficiencies, and code compliance issues. Completed projects should leave the facility in like-new condition, ready to serve for the next major lifecycle. Piecemeal projects are not efficient and are strongly discouraged. SPU has had poor experience with partial projects generating costly rework during subsequent upgrades.

11.5.3 Design Review

In addition to normal review circulations specified in *DSG Chapter 1, Design Process*, SPU Operations staff must review designs for pump stations just before each major design milestone. Operations reviews should take place in a workshop setting with the design team and representatives of each operations discipline. Workshops should cover proposed equipment, layouts, access, maintenance procedures, and any potential deviations from design standards. Use visual aids such as 3D CAD models, photographs, or other exhibits to clearly illustrate each topic. These workshops are essential to delivering functional and readily maintainable facilities.

Figure 11-4
Planning a Pump Station Retrofit



Acronyms and Abbreviations
AMC: Asset Management Committee
BAM: Business Asset Manager
CIP: Capital Improvement Program
LOB: line of business

11.5.4 Design Process Documents

This section describes design process deliverables for a typical pump station replacement or new facility.

11.5.4.1 Preliminary Engineering Report

Typically, the preliminary engineering report for a pump station is submitted to DOH (water pump station) or Ecology (wastewater and drainage pump station) for approval before final design. The report may be used to develop environmental documentation. It should focus on alternative analysis and development of design criteria and details for the selected alternative (Table 11-8).

Table 11-8
Typical Content of a Preliminary Engineering Report for Pump Station Design

Section	Description
Section 1: Introduction	Project background info and objective: desired level of service, need for project, and facilities to be constructed.
Section 2: Business Case Documentation	Standalone document (summary) submitted to Asset Management Committee (AMC) for business case 2 approval, which includes background, objective, options, benefit/cost analysis, and recommendations.
Section 3: Facility Selection	Alternatives (if any) for site locations, facility configurations and layouts. Must discuss geotechnical characteristics. Should include alternative analysis and risk/value modeling and site plans of most viable alternatives.
Section 4: Pump Selection	Discussion of number of pumps and their capacities, design discharge pressures, and motor sizing. Includes a process flow diagram.
Section 5: Facility Operation & Control	Discussion of upstream and downstream system elements (e.g., tanks, other stations, and plants), process mechanical for pump station piping and valves, and pumping unit controls and instrumentation.
Section 6: Electrical	Description of potential service supply, proposed electrical loads, voltages, motor starting, and lighting.
Section 7: Structural and Architectural	Description of structural and building codes and assumptions for pump station design. Presents criteria facilities are expected to comply with (e.g., exterior building shell types). For above-grade, includes an architectural rendering.
Section 8: Building Mechanical	Description of the building mechanical codes and assumptions for pump station design. Presents criteria that the facilities are expected to comply with (e.g., required air changes per hour).
Section 9: Project Controls	Planning level cost estimate and detailed project schedule.
Appendix	The following items included (as appropriate): • Business case and cost estimate • Draft specs for major equipment • Equipment data sheets for major equipment • Geotechnical Report • Hydraulic calculations and pump selection analysis • Key project meeting minutes or decision documents • Memo on Project Delivery Analysis (design build or conventional procurement) • PE drawings: cover sheet, location map, Design Criteria Sheet, code compliance sheet, site plan (buildings, staging, roads, major drainage features and sensitive areas), architectural rendering, facility floorplan and facility roof plan, process flow, major

Section	Description
	equipment layout, key building sections, electrical one-line diagram, prelim P&ID, control architecture, sheet &spec list finished design • Preliminary design calculations • State Environmental Policy Act (SEPA) Checklist

11.5.4.2 Design Calculations

Typical calculations for pump station design include hydraulic assumptions. These assumptions cover minor loss coefficients, friction factors, and boundary conditions for the station's operation. Unit conversion factors are a frequent source of error. Calculations should be presented with enough description to understand the assumptions made, the mathematical theories or equations employed, and the design criteria that must be met.

At a minimum, the following typical calculations must be developed as part of a pump station upgrade or new design project (Table 11-9). Additional project-specific calculations may be required.

Table 11-9
Typical Pump Station Design Calculations

Process/Mechanical	Structural	Electrical/ I&C	Geotechnical	HVAC/Plumbing
Hydraulic profiles and energy grade line	Sizing base slab, walls, and roofs	Light and various load calculations	Soil borings and bearing pressures	Air exchanges per hour with sizing of louver and ventilation fans
System curves and pump selection	Reinforcement sizing and schedule	Generator, transformer, and MCC sizing	Soil classification and friction angles	Potable water and gas demands
Wet well volume	Loadings for cranes	Voltage drops		
Fuel storage demands	Equipment pad design	Utility/grid connection/protection		
Surge analysis and air/vacuum needs	Loadings for gratings and framing	PLC integration with existing SCADA.		
Pipe sizing	Piping support	Arc flash hazard analysis		

Acronyms and Abbreviations
HVAC: heating, ventilation, and air conditioning
I&C: Instrumentation and Control
MCC: motor control center
PLC: programmable logic controller
SCADA: supervisory control and data acquisition

11.5.4.3 30/60/90 Drawings

The following checklist must be used for items that are included in the 30/60/90 draft and final submittals for a pump station design (Table 11-10). Design packages must also comply with the standard design package deliverable checklists in *DSG Chapter 1, Design Process*.

Table 11-10
Checklist for Pump Station Design Documents Draft (D) and Final (F)

Requirements	30%	60%	90%
General Drawings			
Title Sheet	D	F	F
Location and Vicinity Map	D	F	F
Drawing Index	D	F	F
General Symbols and Legends	D	F	F
Abbreviations	D	F	F
Design Data and Criteria (process flow diagrams, safety considerations, utility needs)	D	F	F
Hydraulic Profile	D	F	F
Key Map	D	F	F
Notes and References	D	F	F
Civil/Site Work Drawings			
Existing Site and Utility Plans	D	F	F
Proposed Site and Utility Plans	D	D	F
Proposed Site Grading		D	F
Site Utilities (plans and profiles)	D	D	F
Pipeline Alignment Plans and Profiles	D	D	F
Construction Stormwater Plan		D	F
Civil Details		D	F
Landscaping Drawings			
Conceptual Landscaping (plans and details, including green stormwater infrastructure)		D	F
Architectural Drawings			
Buildings (plan, elevations, and sections)	D	D	F
Structural Drawings			
Foundation (plans and sections)	D	F	F
Buildings (plans, sections, and details)	D	D	F
Below Grade Structures (plan and sections)	D	D	F
Mechanical Drawings			
Major Equipment and Piping Layout (plans, sections, and details)	D	D	F

Requirements	30%	60%	90%
HVAC/Plumbing Plans and Sections	D	D	F
HVAC Schedules and Schematics		D	F
Electrical Drawings			
One-Line Diagrams	D	D	F
Site Electrical – Plan	D	D	F
Power Plans, Control Diagrams, and Schedules		D	F
Lighting Plans and Reflective Ceiling Plans		D	F
Major Equipment (MCCs, substations, and transfer switches) Layout and Electrical Room Plans	D	D	F
Instrumentation Drawings			
Process and Instrumentation Diagram	D	F	F
Control Panel Layouts and Details		D	F
Control Architecture Schematics and Design	D	F	F
Riser Diagrams		D	F
Project Manual (Specifications)			
Table of Contents	D	D	F
First Draft of Specialty Specifications		D	F
Major Equipment Selection in Products Sections		D	F
Major Material Selections Completed (e.g., pipe, coatings, and concrete)		D	F
General Requirements (e.g., sequence, constraints, work scope, and asbestos determination)		D	F
Memo on Recommended Modifications to General Conditions			F
Physical Security			
Physical Security Program requirements incorporated.	D	F	F
Other Submittal Items			
Basis of Design Tech Memo	D	F	F
Bypass Plan and Procedures	D	F	F
Geotechnical Interpretive Report	D	F	F
Geotechnical Data Report	D	F	F
Geotechnical Baseline Report	D	F	F
Level I Environmental Assessment	F		
Level II Environmental Assessment (if required)		F	
Equipment List	D	D	F
Contractor/Subcontractor Qualifications Memo			F
SPU-Supplied Safety Checklist			F

Requirements	30%	60%	90%
O&M Impact Memo			F
Contract Time Memo			F
Calculations	D	D	F
Cost Estimate	D	D	F

Acronyms and Abbreviations
D: draft
F: final
HVAC: heating, ventilation, and air conditioning
MCC: motor control center
O&M: operations and maintenance

A. 30-Percent Design

At 30% design, a pump station submittal should include all the applicable items described in *DSG Chapter 1, Design Process*. The following list provides additional guidance specific to pump station design:

- Basis of design plan sheet established and depicted in an acceptable format.
- A final design criteria list that includes all major equipment sizing information, and general design assumptions. Pump type, size, head and flow, and assumptions for redundancy should be clearly stated. The list should include all project utility needs (including power, communications, fire flow, and potable water). It should also list major safety considerations (whether an area is classified, occupancy ratings, and fire rated walls).
- Hydraulic profile sheet showing the current design and any future requirements.
- Plans and profiles of pipelines that locate major utilities and piping corridors (horizontal and vertical). Property acquisition and easements necessary for permitting and construction should be identified.
- Preliminary mechanical plans and sections that show location of major equipment and major piping alignments to verify clearances and general configurations. Plans should indicate proposed equipment maintenance features (e.g., overhead crane and monorails, hatches, and pads). Plan should identify areas requiring noise abasement. HVAC/plumbing plans that depict location of major equipment and major piping alignments.
- Preliminary electrical one-line diagrams and site electrical plans. Preliminary layout of electrical rooms in adequate detail to determine size requirements and clearances. The following should be identified: National Electrical Manufacturers Association (NEMA) ratings for all rooms, available corridors for routing electrical raceways and cable trays, and area classifications per NEC/National Fire Protection Association (NFPA).
- Process and instrumentation diagrams (P&IDs) that depict the mechanical equipment, piping, and I&C equipment interlocking. P&IDs should be at a more advanced level than other documents in the submittal (at least 60% complete).
- Level I Environmental Assessment and work plan for Level II Environmental Assessment.

- Physical security requirements.
- Design calculations.
- Plan and procedure for temporary bypassing of the facility during construction.

B. 60-Percent Design

At 60% design, a pump station submittal should include all the items described in *DSG Chapter 1, Design Process*. The following list provides additional guidance specific to pump station design:

- Hydraulic profile complete.
- Site plan with proposed final location of structures, roadways, and major site elements (e.g., hatches, vents, fencing and gates). Include proposed contractor staging, storage, access, and offsite corridors (traffic routing plans).
- Site plan with horizontal control and proposed grading.
- Plans and profiles of pipelines with final proposed alignments (horizontal and vertical). Easement limits identified and included on drawings.
- Details of maintenance holes, pavement, and trench sections, as well as other civil details.
- Proposed landscaping plan and schedules.
- Architectural plans, sections, and elevations that depict the proposed final exterior architectural theme, materials of construction, and floorplan of structures.
- Structural plans, sections, and details—this should be coordinated with other design disciplines. Large structural penetrations should be identified and potential conflicts with mechanical and electrical features should be resolved. Foundation plans, floorplans, and roof plans should include dimensional information and structural member sizes with reinforcement detailing partially complete.
- Mechanical plans, sections, and details with proposed final location of major equipment, piping, and appurtenances. Minor piping partially complete (adequate corridors should be identified). Location of equipment maintenance features finalized.
- HVAC/plumbing plans and sections adequately complete to verify SPU standards and building code compliance. Equipment schedules and system schematics should be sufficient to allow review of system configuration and design intent. Fire protection system design (if required) should be included.
- Proposed final electrical one-line diagrams, control room layouts, and panel layouts.
- Power plans, control diagrams, and schedules adequately complete to review layout and design intent.
- Proposed final lighting plan and reflective ceiling plan.
- P&IDs developed to detail including revisions based on proposed final equipment selection and configuration. P&IDs and control architecture should be 90% complete.

- Draft specifications coordinated with project-specific information included and non-pertinent information removed. First draft of construction sequence, milestones, and constraints. Draft control loop descriptions and I/O and instrument lists.
- Required physical elements incorporated and contract finalized.
- Level II Environmental Assessment (if required) that evaluates worker health and safety and identifies suspect, contaminated, and hazardous materials of concern for the project.

C. 90-Percent Design

At 90% design, a pump station submittal should include all the items described in *DSG Chapter 1, Design Process*. The following list provides additional guidance specific to pump station design:

- Hydraulic profile complete.
- Final electrical one-line diagrams, control room layouts, and panel layouts.
- Power plans, control diagrams, and schedules complete and coordinated with process/mechanical design.
- Final lighting plan and reflective ceiling plan coordinated with other disciplines.
- Final P&IDs developed to greater detail and including revisions from previous comments and coordinated with final operational control strategies.
- Physical security construction site plan submitted.
- Arc flash hazard analysis.

11.5.4.4 Project Manual

This section provides specifics on project manuals for pump stations.

A. Technical Specifications

SPU technical specifications for pump stations are general design specifications presented in CSI format. Unless the pump station is part of a large project formatted in APWA style, it must use CSI format. APWA specifications are generally written for roadway projects and do not work well for electrical and mechanical projects. Pump stations contain a great deal of electrical and mechanical equipment. Specialized subcontractors are needed on large electrical/mechanical projects. For each specialty, specifications are generally presented in more detail than is typical in APWA format.

The most recent edition of the CSI standards is the MasterFormat, 2018 edition. SPU has adopted CSI as its standard for construction specifications on pump station and electrical projects.

B. Master Specifications

SPU Master Specifications govern many specific work items for construction contracts. However, not all SPU Master Specifications have been converted to CSI.

For a list of example specifications for pump station installations, see **Appendix 11A - Example Pump Station CSI Specifications**.

11.5.4.5 Equipment Data Sheets

During preliminary design, the design engineer should develop equipment data sheets for major pieces of equipment. At a minimum, an equipment data sheet must be developed for all equipment, instruments, and items that require power (including heating, ventilation, and air conditioning [HVAC], plumbing, SCADA, security, and architectural items).

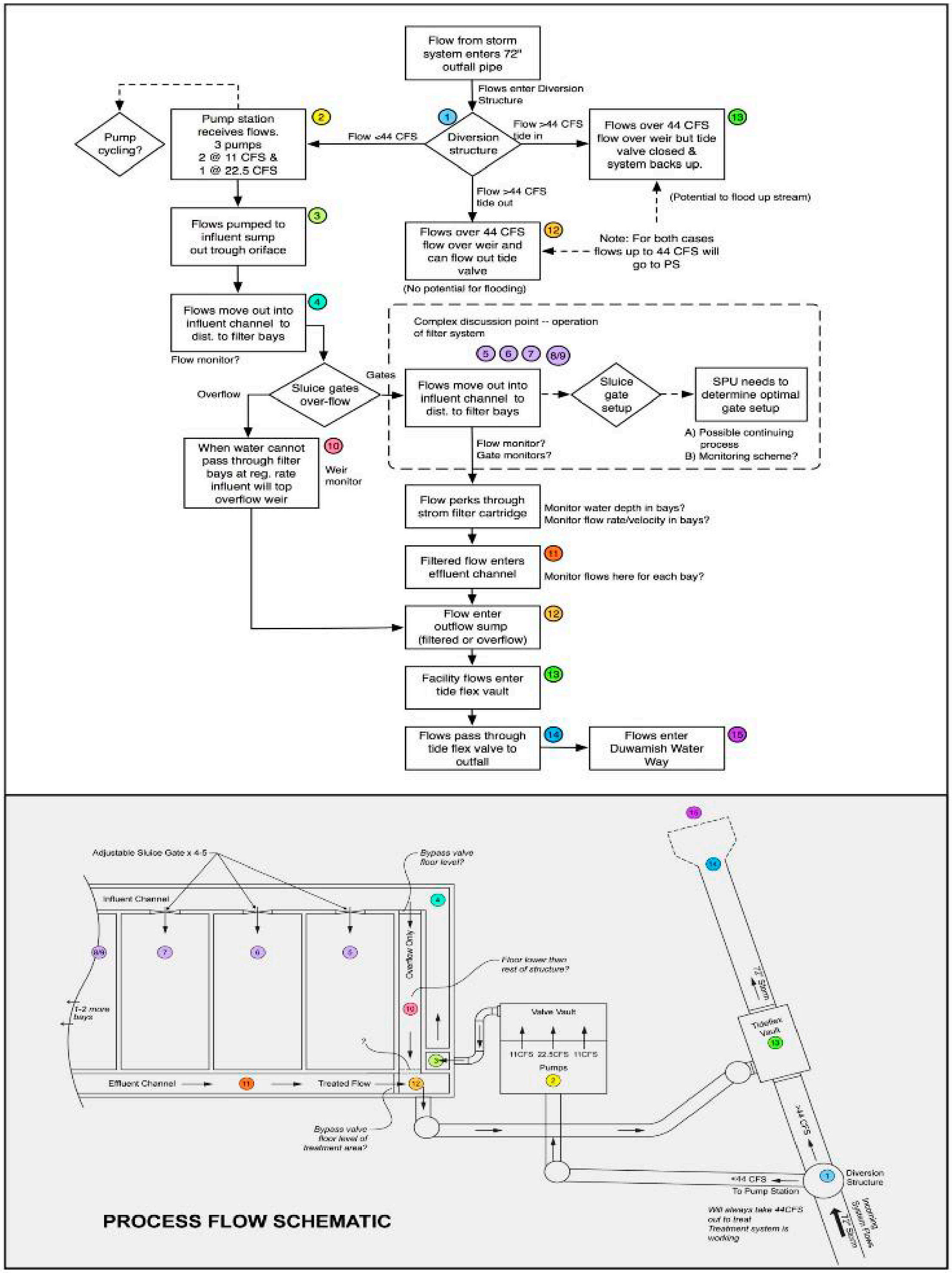
For an example for equipment data sheets, see **Appendix 11E - Equipment Data Sheet Template**.

11.5.4.6 Process Flow Diagrams

Process flow diagrams are simplified drawings that clarify a process. For pump station design, the diagrams should demonstrate the intended flow paths, hydraulic controls and monitoring points, as shown in Figure 11-5, which is a project-specific example.

If I&C is associated with the process, the technical specifications should include a description of the control process.

Figure 11-5
Example Process Flow Schematic: South Park Pump Station and Water Quality Facilities



Acronyms and Abbreviations

CFS: cubic feet of water per second
PS: pump station

11.6 DISCIPLINE-SPECIFIC DESIGN CONSIDERATIONS

This section presents design specific to individual disciplines within the pump station design team, including civil; mechanical; structural; electrical; and instrumentation, monitoring, and controls. See *DSG Chapter 4, General Design Considerations* for general design considerations that apply to any SPU project.

11.6.1 Civil

Additional civil engineering design considerations for pump stations include access, parking, electrical vehicle charging stations, pipeline corridors, bypass pumping, flood protection, water supply backflow prevention, future expansion, physical security elements, hydrants, and influent screening.

11.6.1.1 Access

Pump stations must be arranged to allow a boom truck to lift major equipment, such as pumps, motors, and valves, completely out of the pump station. Verify that adequate flat, firm ground is available for boom trucks. If site constraints prohibit equipment lifting by boom truck, fixed equipment lifting hoists and conveyance systems must be provided. Both wet and dry wells should be equipped with a large hatch located over all major equipment for equipment installation and removal (Table 11-11).

Wastewater stations must allow for vacuum truck access to the wet well. This includes a clear path from the wet well access hatch to the bottom of the well. Working platforms located directly below the hatch must include hinged or removable grating panels.

Coordinate access hatch locations, sizes, and features with SPU Operations. Hatches for personnel access must provide enough space for a retrieval tripod to be set up over the opening or for the hatch to be equipped with a removable davit arm. Hatches must include a padlock hasp that can accommodate SPU's standard padlocks.

Table 11-11
Equipment Access Recommendations

Item	Most Desirable	Acceptable
Access to Pumps at Grade (if applicable)	Pump station to be located on grade and a rollup door provided to move equipment in and out	7-ft-high, 6-ft-wide double door
Access to Pump not at Grade	Internal stairwell	Ladder, one per 10-ft vertical drop if total vertical distance is greater than 15 ft
Large Access Hatch for Lifting Equipment and Cleaning	Equipment dimension plus 10-inch minimum on all sides; overall minimum of 36 inches x 42 inches	Equipment dimension plus 6-inch minimum on all sides, overall minimum of 36 inches x 36 inches Hatch 6-ft wide and greater must be a double door
Lifting Mechanism	Boom truck preferred, then crane hoist.	Crane hoist or overhead traveling crane. Lifting points must be centered

Item	Most Desirable	Acceptable
	If roll up door is provided on grade, boom truck access not required	over equipment, and accessible from working surfaces (gratings). Gratings under lifting points must have removable panels.
Clearance	8-ft minimum under lifting hoist, subject to overall equipment size	Largest equipment dimension in hoisting orientation, plus 2 ft between bottom of equipment and any other equipment in the station that must be crossed over, plus rigging height

Acronyms and Abbreviations
ft: feet/foot

11.6.1.2 Parking

Refer to section 4.3.1.1 of *DSG Chapter 4, General Design Considerations* for general parking requirements. A minimum of two parking spaces must be provided for all pump stations.

11.6.1.3 Electric Vehicle Charging Stations

Pump stations must include charging stations for at least two electric vehicles. Stations must comply with the City of Seattle standards for charging stations currently in place at the time the project is designed.

For sites without fencing or where electric vehicle charging stations cannot be practically secured, charging stations may be omitted.

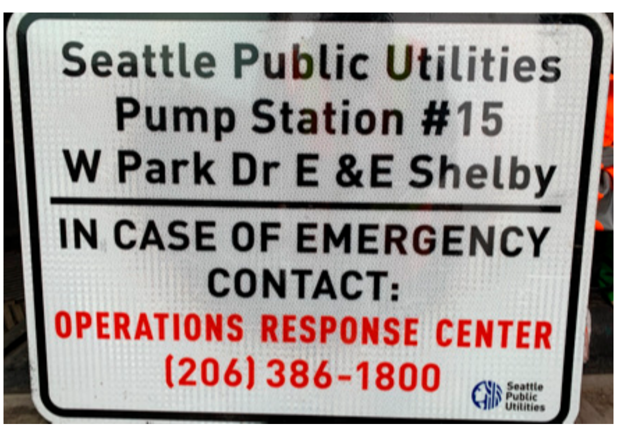
11.6.1.4 Physical Security

Refer to *DSG Chapter 15, Physical Security* for security requirements at SPU pump stations.

11.6.1.5 Signage

Refer to section 4.14 of *DSG Chapter 4, General Design Considerations* for signage requirements at SPU facilities. Pump station facility identification signage must be 18 inches by 24 inches and retroreflective following the standard design shown in Figure 11-6 below.

Figure 11-6
Typical Pump Station Identification Signage



11.6.1.6 Pipeline Corridor

For conduit, force main, and other pipeline corridor design elements, including easement requirements, see *DSG Chapter 4, General Design Considerations.*

The following additional guidance is specific to pump stations:

- Pipes should enter and exit structures perpendicular to the structure wall whenever possible.
- Parking over the pipeline corridor is acceptable for normal vehicles and portable equipment. Non-permanent or non-critical features such as landscaping may also be located over the pipeline.
- If the corridor is under a crane setup area, extra pipeline protection, such as concrete encasement or additional cover, should be provided to protect from heavy loads.

11.6.1.7 Bypass Capabilities

Bypass pumping capabilities must be included at all pump stations to maintain critical flows with temporary equipment while the pump station is out of service.

Temporary portable pumps connected to the existing process piping are ideal for bypass pumping and typically are used for smaller capacity pump stations. To accommodate these bypass pumping operations, additional tee fittings with isolation valves and blind flanges or cam lock couplings must be installed on the force main or discharge process piping system for wastewater stations. Drains must be included to allow for temporary hoses to be drained prior to disconnection.

Bypass connections should be installed immediately outside of the pump station in a separate vault, when possible. Tees for temporary connections should not be more than one diameter smaller than the force main itself. Tees with branches larger than 4-inches must be equipped with reducers to allow connection to 4-inch temporary hoses. Reducers provide compatibility with SPU's portable bypass pumps for short-term or emergency response. SPU's standard connection for bypass tees is a flanged male camlock fitting with a dust cap. For long-term, full-capacity bypassing, reducers and camlock fittings may be removed to allow additional flow. An example bypass vault for wastewater stations is shown in **Appendix 11J - Example Bypass Vault Layout**.

When possible, pump stations should be equipped with a nearby upstream maintenance hole that can serve as a reservoir for bypass pumping during maintenance of wet wells. In all cases, provide an isolation sluice gate on the inflow line to isolate the wet well from incoming flow. For more information on bypassing, see *DSG Chapter 3, Design for Construction.*

11.6.1.8 Influent Screening

SPU does not typically provide screening (e.g., bar screens) on wastewater pump stations. However, design engineers may consider adding screening on select drainage and wastewater pump stations to prevent large debris build-up in the wet well and to reduce cleaning requirements. Screening should be designed to keep debris larger than 3 inches from entering the wet well. Screening requirements should be reviewed with SPU Operations and the LOB representative on a case-by-case basis.

11.6.1.9 Fire Hydrants

Depending on facility size and operations, a protective fire loop may be needed around the facility. For hydrant requirements, see Seattle Fire Department and SDCI requirements, in addition to *DSG Chapter 5, Water Infrastructure*.

11.6.1.10 Water Service and Backflow Prevention

A. Water Pump Stations

Provide a domestic water service (minimum 1-inch diameter) on the premises for maintenance and washdown needs. Backflow prevention is not typically required for water pump stations, unless a site-specific hazard exists, such as an irrigation system or fire suppression system. In general, water services for water pump stations should be designed to avoid the need for backflow prevention.

B. Wastewater Pump Stations

All SPU wastewater pump stations must have a domestic water service (minimum 1-inch diameter) on the premises for maintenance and washdown needs. Cross-connection control must be provided in accordance with DOH requirements (WAC 246-290-490).

11.6.1.11 Flood Protection

A. All Grades

To reduce flooding risk and facilitate easy cleanup, the floors of buildings and outdoor equipment pads at all grades must be built at least 6 inches above the surrounding finished grade. Sites must be graded to ensure that surface waters drain away from hatches, doors, and other openings.

B. 100-Year Flood Zone

All pump stations must remain in operation during a 100-year flood event in accordance with Ecology's *Washington Criteria for Sewer Works Design*. The 100-year flood levels are shown on FEMA flood maps. These maps are available from the FEMA Map Service Center or as hardcopy FEMA maps from SPU or SDCI GIS. Where there is a risk of site flooding, SPU recommends site grading as the method for elevating the structures above the 100-year flood level.

When a water or drainage and wastewater facility requires installation within the 100-year flood zone, special provisions must be incorporated into site and facility design to allow the facility to operate when flooded. These special provisions may include one or more of the following:

- Provide equipment that can be operated while submerged, e.g., submersible pumps, motors, power cables, and connections. For wet well/dry well stations, use immersible motor pumps with integrated closed-loop cooling systems.
- Raise building floors and equipment pads above the 100-year flood elevation.
- Raise access and equipment hatches above the 100-year flood elevation line and/or install watertight access hatches.

- Provide an earthen embankment around the site to a height above the 100-year flood elevation, with a small pump station for removal of stormwater collected within the earthen embankment; this method may result in higher operating cost.

Protection of water supply pump stations from 100-year flood waters is critical to protecting public health during a flood. Extra care should be taken during design and construction to prevent contamination of the water supply by flood water.

In all facility types, the electrical equipment including motor control centers (MCCs), variable frequency drives (VFDs), main panels, and backup power supplies must be protected from 100-year flood waters.

For waterfront pump stations potentially exposed to future rises in sea level, coordinate flood-proofing requirements with the LOB representative.

11.6.1.12 Future Expansion Considerations

For general future expansion planning requirements, see *DSG Chapter 4, General Design Considerations*. The following additional guidance is specific to pump stations:

Expansion planning for pump stations should be determined by the LOB representative during project scoping. Future elements for pumping stations could include:

- Permanent backup power supply
- Additional pumping equipment and associated motor controls
- Additional storage capacity
- Force main replacement
- Odor control

Clearly identify planned future improvements on the design drawings so that design intent can be documented. When possible, install provisions for future equipment to ensure installation can be completed with minimal disruption to ongoing facility operations. This can include routing empty conduits and ducts to future equipment locations and providing empty pump bays and empty MCC sections or buckets. Where future pumps are planned, provide piping connection points with isolation valves.

11.6.2 Mechanical

Additional mechanical engineering design considerations include HVAC, painting, plumbing, insect screening and temperature, odor, noise control, and sump pumps.

11.6.2.1 HVAC

Typically, HVAC systems are designed according to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards.

The number of air changes required is dependent on the location and area (Table 11-12).

Table 11-12
Air Change Standards – Wastewater Pump Stations

Location or Area	Minimum Air Changes/Hour
Equipment Rooms	15
Underground Vaults	12
Emergency Ventilation for Wastewater Head Space	15-60
Wastewater Pump Station Wet Well, where Odor is not a Concern – Class I, Div I (NFPA 820)	12
Wastewater Pump Station Wet Well, where Odor is a Concern – Class I, Div. I (NFPA 820)	Greater of 4 ACH or maximum influent rate
CSO Facility Storage Tank	Greater of 2 ACH or maximum influent rate
Wastewater Pump Station Dry Well – Unclassified (NFPA 820)	>8

Acronyms and Abbreviations
ACH: air changes per hour
NFPA: National Fire Protection Association

Air change standards determine, in part, the electrical classification, and thus design requirements, for each space in a wastewater pump station. Table 11-5 lists applicable codes and regulations that must be met for construction of all existing and new wastewater and drainage pump stations.

For water pump stations, including below-grade spaces, follow applicable building and mechanical codes and standard practices for industrial buildings when determining the required number of air exchanges. For facilities with water chemical addition (e.g., chlorine), the design engineer must research applicable codes and requirements.

11.6.2.2 Design Standards for SPU Wastewater and Drainage Pump Stations

The following criteria for ventilation systems must be met for retrofit and new construction of all wastewater and drainage pump stations, as described below:

- Dry well ventilation systems must be designed to receive an unclassified hazard classification as described in the National Electrical Code (NEC) and NFPA 820.
- Wet well ventilation system must be designed to receive a Class I Division I hazard classification as described in the NEC and NFPA 820.
- Ventilation system for electrical spaces (both above and belowground) must be designed to allow these spaces to receive an "unclassified" hazard classification as described in the NEC and NFPA 820. Electrical spaces must be provided with ventilation systems similar to those required for dry wells.
- All piping/conduit penetrations must be gas-tight.
- All conduits going to and from wet wells must have code-approved seal-offs.

- Dry wells must be physically separated from adjacent wet wells.
- General duct criteria:
  - Sizing and airflow velocity: Minimum 6-inches in diameter, recommended airflow velocity of 1,500 feet per minute (ft/min); velocities up to 2,000 ft/min are acceptable. See Table 11-13 for capacities of various duct sizes based on the recommended and maximum velocities.
  - Duct Material:
    - Dry well: Galvanized steel or aluminum. Anchors and supports should be either galvanized or stainless steel.
    - Wet well: Stainless steel or plastic (polyvinyl chloride [PVC], fiberglass-reinforced plastic [FRP]) ducts. Anchors should also be stainless steel. Supports should be stainless steel or FRP.
- Balancing dampers: Materials to match the duct and should be provided on all dry well ducts so the ventilation system can be balanced to maintain a positive pressure of 0.1 inch WC relative to ambient.
- Discharge:
  - Dry well: Spaces within typical SPU pump stations tend to be small and air draw-off or discharge within the space is typically not a primary concern since adequate mixing will occur in the spaces due to duct discharge and intake velocities. Where possible, the supply air should discharge into the upper level of each dry well "floor" or "level" and the exhaust draw-off location should be located near the bottom of these spaces.
  - Wet well: The supply air should be discharged at a level above any grating/landing level or High Alarm level, whichever is highest. Exhaust systems in wet wells should be located above the overflow level and pull air from under the roof deck as close as possible.
  - Egg-crate type registers are recommended for exhaust air inlets on all pump stations and may be used on supply air discharges for small to mid-size pump stations. Large pump stations (greater than 15 ft across) should use a supply diffuser with air throw distance and directionality as appropriate for the installation.
- Exterior exhaust outlet locations:
  - Dry well: A dry well discharge vent pipe must be at least 10 ft away from the supply air intake and any doors or hatches into the dry well, wet well, or electrical vault.
  - Wet well: A wet well discharge vent pipe must be at least 10 ft away from the supply air intake and any doors or hatches into the dry well, wet well, or electrical vault.
- Dry well supply and exhaust fans:
  - General: Supply and exhaust fans should have the same capacity to allow for easier balancing.
  - Type: In-line centrifugal with speed control. Speed control must be located within the fan housing (not readily accessible to tampering).
  - Material: Aluminum with corrosion-resistant coating.

  - Motor enclosure and voltage: totally enclosed fan cooled (TEFC) or open drip proof (ODP), minimum 120-volt (V) single phase.
- Wet well exhaust fans:
  - Type: In-line centrifugal.
  - Material: FRP, where available, aluminum with corrosion-resistant coating elsewhere.
  - Motor enclosure and voltage: Air Movement and Control Association (AMCA) Type A or Type B, minimum 120-V single phase. Explosion-proof rated motors are required for fans located within classified spaces.
- Physical separation of wet wells and dry wells:
  - Any existing leaking piping/conduit penetrations must be sealed with non-shrink epoxy grout or similar type material.
  - All conduits going to and from wet wells must have code-approved seal-offs if not already installed. Seal-offs must be installed if not included on an existing conduit. All existing seal-off fittings should be inspected for adequate sealing compound.
  - Existing access doors between dry wells and wet wells should be removed and the openings sealed. Alternate means of access to wet wells may need to be constructed.
  - Existing ventilation openings between wet wells and dry wells must be permanently sealed with non-shrink epoxy grout or a similar material. Separate ventilation systems for wet and dry wells must be provided.
- Dry well ventilation monitoring and alarm requirements for unclassified space:
  - Operation of the ventilation equipment is required to be continuously monitored per NFPA 820. A flow detection device that is connected to the SCADA building data monitoring system must be provided for each fan. Thermal dispersion flow switches are SPU's preferred flow detection device.
  - As required by code, non-audible signals consisting of a dual light (go/no-go or green light/red light) alarm system must be provided at the entrance of the dry well. This device should be located just inside each dry well access hatch or door, such that it is easily visible from outside.
  - Fire extinguishers must be provided in dry wells per NFPA 820.
- Filtration: For waterfront stations with exposure to salt-bearing marine air, moisture removal filters must be installed on the suction side of supply air intakes (dry well and wet well). Filters generally use a combination of stainless-steel mesh and other filtration media to remove salty and corrosive moisture from the air stream before it enters the pump station. Filters such as the American Metal Filter Company's HM series are suitable for this application.

Table 11-13
Recommended Duct Sizing

Duct Diameter (inches)	Recommended Velocity (ft/min)	Airflow Quantity (cfm)	Maximum Velocity (ft/min)	Airflow Quantity (cfm)
6	1,500	290	2,000	390
8	1,500	520	2,000	690
10	1,500	810	2,000	1,090
12	1,500	1,170	2,000	1,570

Acronyms and Abbreviations
cfm: cubic feet per minute
ft/min: feet per minute

11.6.2.3 Additional Considerations

The design engineer should account for the effect of outside temperature with the design of the drywell ventilation system. Ventilating the dry well at six air exchanges per hour (ACH) and higher will heat the space if the outdoor temperature is higher than the indoor temperature. This can be problematic in spaces with temperature-sensitive electrical equipment and periods of extreme outdoor air temperatures.

The design engineer should account for the effect of low, outside temperatures on the design of the dry well ventilation system. Ventilating the dry well at six ACH and higher can potentially create temperatures below freezing in the ventilated space. Supplemental space heating may be advisable in some locations.

11.6.2.4 Painting and Coatings

Painting should be used to protect the integrity of structures, piping, and equipment and to indicate the process of exposed piping and equipment (Table 11-14). In general, paints should be a heavy-duty, abrasion-resistant coating system suitable for the environment to which it is exposed. <u>For piping, the flow direction of the fluid or gas conveyed must be shown on the exterior of the pipe to help facilitate O&M activities</u>. Manufactured process labels may be used in lieu of painting.

Table 11-14
Pump Station Recommended Paint Coloring Scheme

Piping System or Equipment	Solid Color	Color Band	Letter Code	Letter Color
Buildings				
• Buildings (Inside)	White			
• Wastewater Dry Wells (Walls and Ceiling)	Light Green (Fed Std Color 24583)			
• Wastewater Dry Wells (Floors)	Burgundy (Fed Std Color 30152)			
• Ceiling Panels & Structural Steel	White			
• Drain – Gravity (Sewage)	Black		Drain	White

Piping System or Equipment	Solid Color	Color Band	Letter Code	Letter Color
• Drain – Suction or Pressure (Process)	White		Drain	Black
Equipment – General				
• Exit Doors – Industrial			Exit	
• Fire Hydrants – Potable: • Barrel & Dome • Nozzle Cap, Top Nut & Shield	Silver Green	Dk Blue/ White	PW	White
• Fire Hydrants – PWC • Barrel & Dome • Nozzle Cap, Top Nut & Shield	Silver Green	Lt Blue/ Yellow	PWC	White
• Gates & Operators	Black			
• HVAC Unit	Dark Gray			
• Hydraulic Fluid	Orange		Hyd Fluid	White
• Meter Station Cabinets	Russet			
• Natural Gas	Red		NG	White
• Oil	Orange		Oil	White
• Overflow – Emergency	Gray	Brown	Overflow	White
• Pumps, Motors, Gear Drives	Green			
• Safety Equipment Storage	Green			
• Sample – Sewage or Sludge	White	Brown	Sample	Black
• Sewage – Raw	Black		Sewage	White
• Structural Steel	Black			
• Valve Heads & Operators (Inside)	Red			White
• Valve Heads & Operators (Outside)	Red			
• Vent (Odor Control)	White		Vent	Black
• Vent (Sewage)	Black		Vent	White
• Ventilation Units – Inside	Gray or Alum			
• Ventilation Units – Outside	White			
• Water – Fire	Dk Blue		Fire	White
• Water – Hot Potable	Dk Blue	White	HW	White
• Water – Hot Service	Lt Blue	Red	HW	White
• Water – Non Potable, Non Chlorinated	Lt Blue	Brown	Sec Effluent	White
• Water – Plant Water Chlorinated	Lt Blue	Yellow	PWC	White
• Water – Potable	Dk Blue	White	PW	White
• Water – Service	Lt Blue	Red	SW	White

Piping System or Equipment	Solid Color	Color Band	Letter Code	Letter Color
• Water – Service, Return	Lt Blue	Red	SW Ret	White

Floor coatings for areas subject to water and washdown should include a non-skid aggregate treatment unless otherwise requested by SPU Operations.

11.6.2.5 Insect and Pest Screening

To prevent insects and other small animals from entering facilities through openings required for HVAC equipment, SPU recommends 3/16-inch, stainless-steel mesh screening. Screening must be provided on all louvers for equipment cabinets and enclosures, as well as vent intakes and outlets.

11.6.2.6 Temperature Controls

The recommended temperature for pump stations is between 50 °F and 90 °F to prevent equipment and process lines from freezing or overheating. Heat tracing can be used to supplement ambient heating. Increased ventilation and air exchanges can be used to supplement cooling if temperature is a concern. See *DSG Chapter 10, I&C (SCADA)* for more information on motor temperature monitoring. For below-grade wastewater pumping stations, heating and cooling are generally not provided.

11.6.2.7 Plumbing

Most pump stations require little plumbing. Detailed plumbing design is beyond the scope of the DSG. For additional guidance on plumbing, consult the Seattle-King County Department of Health.

11.6.2.8 Odor Control

SPU currently does not have standards and guidelines for pump station odor control but prefers using proper circulation (ventilation) for reducing odors at wastewater pump stations. Where odors are a concern, reduced wet well air changes should be implemented, as shown in Table 11-12. Work with the LOB representative to determine additional odor control requirements for wet well ventilation on a site-by-site basis.

11.6.2.9 Noise Control

Table 11-15 shows sound level limits for pump station design. These requirements were established for the hours of 7 AM to 10 PM on weekdays and 9 AM to 10 PM on weekends. However, as part of community engagement, SPU recommends additional noise reduction measures for equipment that will run frequently. Nighttime noise reduction of stationary equipment used to convey water by a utility is considered exempt. Refer to the City's Noise Ordinance, SMC 25.08 for up-to-date requirements.

On-site standby generators installed in residential areas must be equipped with a sound-attenuating enclosure, including exhaust silencer. SPU has successfully used Cummins Power Generation's Level III sound enclosures at many existing facilities.

Table 11-15
Noise Requirements

Location of Sound Source	Noise Limits at Receiving Property (in decibels)		
	Residential	Commercial	Industrial
Rural	52	55	57
Residential	55	57	60
Commercial	57	60	65
Industrial	60	65	70

11.6.2.10 Utilities

All pumping facilities require one or more utility services (e.g., electrical, water, sewer, natural gas, and communications). The availability and capacity of existing utilities should be investigated and compared with the estimated demands of a new facility. Power lines at or near the site do not guarantee that ample electrical capacity or the appropriate type of service will be available. New services or additional capacity may be required.

One common example of additional capacity need is a small pump station for a residential area. While the residential power lines may have excess capacity, they may only provide 240V, 1-phase service. Most pumps require 480V, 3-phase. In such cases, new power lines must be brought to the site from a 480V transformer, which the local utility must design and install.

Typical utilities required for water supply and wastewater pump stations should be verified (Table 11-16).

Table 11-16
Typical Utilities Required for Pump Station Operation

Utility	Primary Uses	Wastewater Pump Stations		Water Pump Stations
		Small Facilities	Large Facilities	
Electrical	Pumps	480V (3-phase)	480V (3-phase) Medium voltage may be required for large facilities	480V (3-phase) Medium voltage (4,160 V) is used at several existing larger facilities
Communications	SCADA/Telemetry	CenturyLink phone connection, as directed by SPU SCADA		
Natural Gas	Space heating and standby power	None	As needed Minimum ¾ inch connection	As needed Minimum ¾ inch connection
Potable Water Supply	Restrooms, drinking fountains and fire protection	Backflow prevention provisions required. See *DSG Chapter 17, Water Service Connections*		
Washdown Water[1]	Cleaning	Minimum 1-in service required		Recommended
Sewage	Internal plumbing	Floor drains		Floor drains

Utility	Primary Uses	Wastewater Pump Stations		Water Pump Stations
		Small Facilities	Large Facilities	
	External side sewer			Bathrooms recommended
Storm Drain	External Service Drain	4 inch if required	6 inch or larger per site requirements	6 inch or larger per site requirements
Flushing Water[2]	Pump seal flushing	3/4 inch to 1 inch if required		Recommended

Notes

[1] Washdown water system connected to a potable water supply or a reclaimed water source must have step-down pressure valve and backflow protection as required by the DOH and the Uniform Plumbing Code.

[2] Flushing water systems, if supplied by a potable water source, must have an air-gap separation from the potable supply system. In-line pressure reduction and backflow preventions are not allowed for this application.

Acronyms and Abbreviations
DOH: Washington State Department of Health
SCADA: supervisory control and data acquisition
V: volt

11.6.2.11 Wet Well Corrosion Control

Wastewater pump stations can experience high levels of hydrogen sulfide (H_2S), a by-product of decomposing waste. Large wet wells can amplify the problem because quiescent flow conditions allow solids to settle. Longer detention time in the wet well increases H_2S production.

H_2S exists in two forms: dissolved and atmospheric. The latter is the primary concern for corrosion. The following measures should be incorporated in wet well design to combat corrosion:

- Ventilation should be designed per DSG sections 11.6.2.1and 11.6.2.2. Installing odor control equipment should be considered.
- Gratings, structural beams, anchors, and railings in the wet well must be constructed of galvanized or stainless steel. FRP gratings are not a consideration for SPU at the time of publication.
- All control panels should be designed for a minimum of NEMA 4X rating. See *DSG Chapter 10, I&C (SCADA)* for more detail on control panels.

Larger mechanical equipment, including pumps and combination air valves located in wet wells or vaults, must be specifically designed to operate in corrosive environments. The manufacturer of each piece of equipment should be consulted to verify the equipment is suited for operation in the intended location.

Wet well linings should be considered when designing new pump stations. Typical linings for wet wells at SPU stations are high-build epoxy coatings on all concrete surfaces. For retrofit projects, wet well coatings should be evaluated on a case-by-case basis in coordination with SPU Operations. Wet well linings must be installed at existing pump stations that show visible evidence of concrete deterioration.

Epoxy coatings should also be considered for force main discharge structures, which typically have high H_2S exposure due to flow turbulence. Where epoxy coatings are used in areas that may have foot traffic during maintenance (e.g., wet well floors), a non-skid aggregate surface treatment should be included.

11.6.2.12 Sump Pumps

Select robust sump pumps capable of handling solids and debris, with a minimum 2-inch threaded outlet. Sump pump piping systems must include a shutoff (gate) valve, a check valve, and unions as needed to remove the valves and pump for maintenance. Use full bodied valves wherever possible. Sump pumps must use an adjustable float trigger.

Select 120V, single-phase sump pumps wherever possible. All sump pumps must plug into a standard wall receptacle. Sump pumps may not be hardwired.

11.6.3 Structural

DSG Chapter 8, Drainage and Wastewater Infrastructure provides general structural engineering requirements for SPU facilities. This section provides additional guidance specific to pump stations.

11.6.3.1 Design Codes

Table 11-17 lists typical structural codes and manuals that govern the design elements for pump stations. Pump stations are typically within Occupancy Group "U" in the Seattle Building Code (SBC).

Table 11-17
Typical Structural Codes

Code	Name
ASCE 7	Minimum Design Loads for Buildings and Other Structures
ACI 318	Building Code Requirements for Structural Concrete
ACI 350	Code Requirements for Environmental Engineering Concrete Structures
ACI 350.3	Seismic Design of Liquid-Containing Concrete Structures
AISC 360	Specification for Structural Steel Buildings -
ANSI/NAAMM	Metal Bar Grating Manual

Acronyms and Abbreviations
ACI: American Concrete Institute
AISC: American Institute of Steel Construction
ANSI: American National Standards Institute
ASCE: American Society of Civil Engineers
NAAMM: National Association of Architectural Metal Manufacturers

11.6.3.2 Analysis of Existing Structures

When upgrading internal mechanical, electrical, and minor structural components of an existing pump station (e.g., ladders, landings, and stairs), upgrading the primary structure to current code requirements for structural loads is generally not required. Unless there is indication of structural distress, the pump station's primary structural components (e.g., top slab, walls, and base slab) can be assumed to provide adequate structural capacity.

If modifications are made to the primary structure or new loads are applied to the structure, the capacity of the existing structure must be considered. The design engineer can use available design plans for the existing structure to determine the existing load capacity. If no plans are available, the design engineer must use best judgement based on experience.

Common modifications that affect the capacity of the existing structure are new openings in the walls or top slab or demolition of portions of walls or beams that support the wall or top slab. When such modifications to the existing structure occur, the structure typically must be strengthened.

11.6.3.3 Design Loads

This section describes the typical design loadings assumed for SPU pump stations, including walls, slabs, platforms, and other features. Load combinations should be per ASCE 7, chapter 2.

A. Exterior Walls

Structural loads sustained by exterior walls of SPU pump stations generally include soil, surcharge, seismic, and hydrostatic lateral loads. Because of the rigid nature of the pump station walls being supported laterally at the base and top slab, typical lateral soil loads for most pump stations are from at-rest soil. Surcharge loads are due to vehicles, equipment, or piled soils adjacent to the walls. Numerous design manuals provide methods for estimating lateral soil loads created by distributed, line, or point loads. SPU projects commonly refer to the Naval Facilities Engineering Command (NAVFAC) Design Manual (DM) 7.1. Surcharge loads need only be applied to 10 ft below ground surface. Lateral seismic loads are calculated based on expected ground accelerations and soil types and are determined through geotechnical exploration and analysis. Hydrostatic loads result from groundwater. Groundwater elevation, and thus hydrostatic loads from groundwater, is determined geotechnical exploration and analysis. Table 11-18 below shows typical lateral loading parameters, which can be used if no geotechnical analysis is available.

Table 11-18
Typical Lateral Loading Parameters

Parameter	Value
At-rest lateral load, above groundwater	60 pcf equivalent fluid pressure
At-rest lateral load, below groundwater	35 pcf equivalent fluid pressure
Soil surcharge	120 psf
Soil seismic	20 x interior wall height, psf
Hydrostatic	62.4 psf fluid pressure

Acronyms and Abbreviations
pcf: pounds per cubic foot
psf: pounds per square foot

B. Interior Walls

Interior walls in SPU pump stations are generally located between the wet well and dry well. Interior walls are typically required to handle hydrostatic and seismic lateral loads. Hydrostatic loads are calculated based on water surface elevations in the wet well. The maximum possible water surface elevation should be considered. Seismic loads are calculated based on lateral accelerations generally determined through geotechnical analysis. If no analysis is available, acceleration coefficients can be obtained using the online U.S. Geological Survey (USGS) ground motion calculator. If using the USGS calculator and the soil type is unknown, input soil type based on a conservative assessment. After determining an acceleration coefficient, the structural engineer can determine the seismic loads applied to the interior wall using guidance provided by ASCE 7, Chapter 12. Because of the typical wet well size in SPU pump stations, sloshing waves need not be considered. If the wet well size requires that sloshing waves be considered, American Concrete Institute (ACI) 350.3 can serve as a design guide.

C. Top Slabs

SPU pump station top slabs are generally buried or at grade. Top slabs are typically required to resist the following types of loads:

- Concrete roof, with a typical dead load of 150 pounds per cubic ft (pcf)
- Soil, with a typical dead load of 120 pcf.
- Pavement, either concrete or HMA 145 pcf.
- Aggregate base under pavement 130 pcf.
- Snow load up to 25 pounds per square ft (psf).
- Vehicle loading when vehicle access is possible over top slab, with loads consisting of 32-kip axle load at 14-ft spacing or tandem 25-kip axle loads at 4-ft spacing. American Association of State Highway and Transportation Officials [AASHTO] HL 93 can serve as a design guide. For top slabs with 2 ft or less soil cover, a 1.3 impact factor should be added to this vehicle live load. Where top slab is inaccessible to vehicle traffic, SPU recommends a minimum 300 psf live load.
- Construction loads should be determined on a project specific basis. Wall backfill prior to top slab construction is one possible example.

D. Bottom Slabs

SPU pump station bottom slabs are typically required to handle bearing loads and uplift from hydrostatic water pressure. Bearing loads generally consist of dead and live loads on the top slab, weight of the walls, and weight of the bottom slab distributed over the area of the bottom slab. Structural engineers may also need to consider stability-related foundation reactions when evaluating bearing loads on a bottom slab.

E. Suspended Platforms

Suspended platforms and associated framing at SPU pump stations should be designed to handle the following live loads:

- 100 psf over entire surface area.

- 350 pounds (lbs) pedestrian point load (at controlling location) plus 40 psf distributed load.
- Equipment loads, if equipment maintenance could result in placing heavy loads (such as pumps or motors) on the platform. Combine any equipment loads with 20 psf distributed load.
- Dynamic loads do not need to be considered if all of the above loads are considered.

F. Grating

Many of the suspended platforms at SPU pump stations are constructed with grating supported by beams. The grating should be designed to handle the same loads as the associated suspended floor design. At minimum, the grating should be designed for a load of 100 psf with a maximum deflection of ¼ inch. The NAAMA Metal Bar Grating Manual provides grating design guidance. Hot-dip galvanized grating, which allows for future field modifications, should be used in most cases. Grating design and support systems must consider and allow for future penetrations for piping and conduit. Often framing is required to support the grating edges around such penetrations. Grating should be fully banded along all edges and openings. SPU generally does not allow use of FRP gratings at this time.

G. Guardrail

Per ASCE 7, chapter 4, pedestrian guardrail design load must be 200 lbs at any point and in any direction along the top rail, or a uniform load of 50 lb/ft along the top rail. Pedestrian guardrails are required to meet Occupational Safety and Health Administration (OSHA) requirements for fall protection open spacing, which requires a two-rail system. <u>If the public has access to the pump station, as defined in SBC, the pedestrian guardrail must not allow a 4-inch ball to pass through the guardrail.</u>

H. Ladders

Ladders at SPU pump stations should be designed to handle the following loads:

- Ladder supports (standoffs) should handle two 250-lb loads located between two consecutive ladder supports.
- Ladder rungs must be capable of handling a 250-lb load at the center of the rung.
- Minimum ladder rung length between side rails is preferred to be a minimum of 16 inches.
- A minimum of 15-inch clearance between wall and the center of the ladder is required.

The above ladder load requirements are based on OSHA 1926.1053.

I. Slide Gate Supports

When gate operator loads are placed on the structure, such as on interior platforms or top slabs, the design loads of the load-bearing feature should be the load created by the gate operator's stall torque of its actuator motor. This may be as much as four times the rated load.

11.6.3.4 Load Cases

A. Stability and Buoyancy

Generally, the design of buried pump stations does not need to consider overturning stability. However, overturning stability should be considered if the pump station is partly buried, with one side more exposed than the opposite side. In this situation these uneven soil loads need to be considered when calculating overall stability and foundation reactions. The pump station should be designed to ensure that resultant of the stability reactions is within the mid-1/3 of the base, resulting in bearing pressure over the entire foundation. Stability cases should consider static, dynamic, and buoyancy loads.

Design of below-grade structures must consider buoyancy. The groundwater surface should be as recommended by the geotechnical engineer. If no geotechnical information is provided, the groundwater surface should be assumed to be at the ground surface for design purposes. The uplift load due to buoyancy is equal to the volume of water displaced. The resisting loads include the dead load of the structure, possible overburden over the top of the structure, possible soil load over any foundation extension beyond the exterior wall, and soil surface friction. For soil load over foundation footing extensions, the design should use the buoyant unit weight of the soil. It is recommended to ignore soil friction against the exterior wall surface because friction can be greatly reduced in the event of soil liquefaction during a seismic event. The minimum factor-of-safety for buoyancy must be 1.2.

B. Durability

The structural engineer can ensure durability for concrete construction using the following methods:

- Concrete mix, a minimum 28-day compressive strength of 4,000 psi and a maximum water/cementitious ratio of 0.42. This guideline generally follows the requirements of ACI 318.
- Use of the appropriate cement type in the concrete based on possible soil conditions. Concrete using type II cement (moderate sulfate resistance) is typically adequate. If a soil investigation indicates more severe sulfate attack, type V cement may be appropriate. Generally, type III cement (high-early strength) should be avoided because of its higher heat of hydration, which can result in additional cracking.
- Concrete cover over reinforcement for both interior and exterior walls should be 2 inches.
- Minimum reinforcement requirements (for crack control) should follow ACI 350's guidance for higher reinforcement requirements based on distance between control joints.
- Concrete mix requirements regarding alkali/silica reactivity should be included in the project structural concrete specifications. Such requirements are included in the City of Seattle Standard Specifications but may not be included by default in a CSI type specification.

C. Anchors

Anchor bolts are designed in accordance with ACI 318, chapter 17. This includes cast-in-place, adhesive type (epoxy), and mechanical type (expansion) anchors. Anchors should be constructed of the same type of material as the member being anchored. However, aluminum or fiberglass members should use stainless-steel anchors. When anchoring machinery, use cast-in-place or adhesive type anchors. For wall-mounted anchors such as pipe supports or ladders, either adhesive or mechanical type is acceptable. For ceiling mounting, mechanical anchors are recommended.

11.6.4 Electrical

DSG Chapter 9, Electrical Design, provides overall code compliance and general guidelines. This section describes electrical items specific to pump station operation and control. There are no pump station-specific requirements for conduits and receptacles, grounding, and lighting. For requirements on these electrical considerations, refer to *DSG Chapter 9, Electrical Design.*

11.6.4.1 Energy Considerations

Most of the energy consumption at pump stations is that required to run the primary pumps. The ability to include equipment that meets system requirements at the highest possible efficiencies will minimize overall energy consumption.

The design engineer should follow SPU asset management requirements to develop a full lifecycle analysis of the existing condition and all proposed alternatives. The analysis should consider the benefit of high-efficiency motors and VFDs where appropriate to reduce energy costs associated with the pump station.

11.6.4.2 Area Classifications

Wastewater pump stations must be classified according to NFPA 820. Electrical equipment, enclosures, and installation must comply with NEC. See *DSG Chapter 9, Electrical Design*.

11.6.4.3 Utility Power Source

New SPU pump stations must have 480V, 3-phase, and 60Hz electrical power. When a large horsepower (hp) motor, such as 400 hp or above, is required, a medium voltage (4,160V) system must be considered. Existing SPU pump stations use a range of power configurations, including 240/120V, 1-phase; 240/120V 3-phase; 208/120V, 3-phase; 480/277V, 3-phase; and 4,160/2,400V, 3-phase (water pump stations only). Where additional substations, transformers, or switchgear are required, sizing and installations should conform to the requirements of *DSG Chapter 9, Electrical Design*.

11.6.4.4 Standby Power Source

All SPU pump stations must be provided at a minimum with a generator power plug and manual transfer switch and must be connected to the main electrical service. The plug is used to connect the portable generator that provides standby power to the pump station. SPU's standard for portable generator connection is the camlock plug.

SCADA control panel power must be backed up by an Uninterruptible Power Supply (UPS) to allow pump station monitoring during a utility power outage. The UPS must be sized to power the SCADA equipment and all instruments for a minimum four hours of utility power outage. The UPS must not power environmental controls (HVAC), including those in the SCADA control panel, due to the large power needs required by such devices.

11.6.4.5 Variable Frequency Drives

VFDs should be used where feasible. For motors up to 400 hp, 460V alternating current (AC) VFDs should be used. Higher voltage and hp ratings should be considered on a case-by-case basis.

A. Requirements

The following are design guidelines for VFDs:

- **Manufacturer.** If possible, VFDs should be designed and specified to be the product of a single manufacturer. Drives up to 200 hp may be mounted in an MCC. Larger drives should be furnished by the pump or equipment supplier.
- **Power Factor Correction.** SPU does not recommend using individual power factor correction capacitors or banks of capacitors on distribution systems with VFDs or other non-linear loads. Capacitors with tuned filters may be required to eliminate the potential of a resonant frequency developing on the distribution bus. On large distribution system capacitor banks with automatic controls, tuning filters may be considered. Unfiltered power factor correction capacitors should never be added to any bus directly connected to VFDs.
- **VFDs for Existing Motors.** Restrictions on motor lead length and winding insulation class due to reflected voltages can be a problem when applying VFDs to existing motors. The VFD manufacturer should be consulted to determine if a problem potentially exists. Output reactors or cable terminators may be necessary. SPU recommends replacing the motor with a new inverter duty motor if possible.
- **6-Pulse Systems.** When 6-pulse systems with line reactors do not meet the harmonic limitations imposed by the Institute of Electrical and Electronic Engineers (IEEE 519), or where standby generators are used as a power source, specify low harmonic multi-pulse or “clean power” VFDs.
- **Location/Enclosure.** Investigate all potential VFD manufacturers and provide adequate space inside the pump station for a worst-case scenario.

When possible, equipment should be installed in environmentally conditioned electrical rooms. Environmental conditioning should include temperature and humidity control as well as the removal of dust and corrosive vapors from the supply air.

Supply air should not be taken from process areas. Alternatively, equipment cabinets may be furnished with self-contained cooling equipment, with rejected heat vented outdoors.

VFD enclosures should be rated NEMA 1A. Such enclosures are completely metal enclosed and sectionalized to isolate and minimize the effects of internal short circuit currents. The structures should consist of framework of preformed steel channels or angles covered with bolted steel sheets.

B. Harmonics

VFDs are non-linear devices that develop harmonics. Harmonics are integer multiples of the fundamental frequency (Table 11-19). When summed to the fundamental frequency, the result is a distorted waveform that can create adverse conditions in a distribution system.

IEEE has set the only recognized standard addressing harmonic limits: IEEE 519-2014, the Recommended Practice and Requirements for Harmonic Control in Electrical Power Systems. This standard stipulates specific limits for current and voltage distortion at a point of common coupling; traditionally for pump stations, this is the point where the utility connects to multiple customers (i.e. line side of the utility transformer).

Table 11-19
Harmonic Mitigation Methods for VFDs

Method	Description
6-Pulse Drive	• Common, cost-effective. • Typically, reactor per unit impedance is 3% to 5%. • Providing drive with a line reactor can eliminate the most severe effects. • Increasing impedance of line reactor does not reduce harmonics linearly. A practical minimum can be reached simply by adding inductance. • Cost and size vs. the theoretical minimum comparison and optimization lead typically to 3% to 5% line reactors.
Multiple Pulse Rectifiers	• In 12-, 18- or 24-pulse drives the two, three, or four rectifiers are parallel-connected and fed by a phase shifting transformer. • Harmonic compensation is effective at the primary side of the transformer. • 18- and 24-pulse systems are not economical for floor space, losses, and power factor when compared with other low harmonic solutions. In an 18-pulse drive, the efficiency is typically 96%. • Multi-pulsed systems always require a dedicated transformer for the drives because the cancellation is reached on the primary side. • Power factor in 18-pulse systems is poor (typically 0.95). Current distortion when these phase shifting transformers are used is total harmonic distortion (THD) = 3% to 15% depending on parameters such as pulse number, line imbalance, and balancing of windings.
Passive Filter Designs	• Trap or shunt filters are tuned to a certain frequency component. For example, connecting several traps (multiple arm filters) can be effective for filtering out the fifth and seventh harmonic component. • This type of solution may be sensitive to resonance phenomena with other network components and may introduce a high leading power factor. • Can cause voltage drop and thus reduce the drive capacity.
Active Filters	• Compensate actively harmonic components in a network by generating the same harmonic components in an opposite phase. This technology is realized with modern power electronic devices. • Cost is relatively high, compared to passive filter.
Insulated Gate Bipolar Transistor (IGBT)	• Typically used when regenerating is required. • Generates low harmonic voltage and current distortion levels. • Cost is higher than a passive filter.

11.6.4.6 Pump Motor Selection

Premium efficiency motors with a 1.15 service factor and Class B temperature rise must be specified per NEMA standards, except for valve actuators and submersible motors. Motors must be sized to not run in the service factor.

Constant or variable speed motors less than ½ hp should be specified for 120V, 1-phase power for the sump pump only.

All 480V motors used in VFD applications must be inverter duty and equipped with protective over-temperature switches embedded in the motor windings. Power factor correction capacitors should not be included because they are not compatible with VFD systems. All 3-phase motors located in damp, wet, or process areas should be provided with motor winding space heaters. All motors used in VFD applications must be equipped with a shaft grounding device.

Motors installed in hose-down areas and outdoors should be furnished with anti-condensation space heaters or trickle current devices for this purpose. Heaters should be switched off when the motor is running.

All motors driving equipment associated with the treatment process should be located in an area that is easily accessible for O&M. If required, large motors should be provided with ladders and platforms for maintenance. The design engineer should make sure that doors and cranes can accommodate large motors.

The lead design engineer may choose to install immersible or submersible type pump motors in a dry well that will not be damaged if the well floods. The motors should be mounted integral to the pumps. Motors should have cooling characteristics suitable to permit continuous variable speed operation in air. Motors must be capable of operating continuously.

Each new electric motor should be equipped with motor winding and bearing RTDs.

11.6.4.7 Motor Control Centers

MCCs house all motor starters for the pump station. The following are SPU standards for MCCs:

1. Pump controls must be provided in a separate SCADA panel.
2. MCCs must be rated 600V, NEMA 1A and consist of a series of metal enclosed, free-standing, dead front vertical sections bolted together.
3. Individual vertical sections must be 90 inches high, 20 inches wide, and 20 inches deep unless special space requirements are identified.
4. Bottom channel sills should be mounted on both the front and rear of the vertical sections extending the full width of each shipping split. The top of each section should have removable plates with lifting angles.

Removable units should connect to the vertical bus in each section with tin-plated, self-aligning, pressure type copper plug connectors. Removable units should be aligned in the structure on guide rails or shelves and secured with a cam latch mechanism or racking screw.

A. Combination Starters

Constant speed motors sized from ½ to 15 hp must be a combination starter with a motor circuit protector (MCP) and across-the-line full voltage starter sized according to

NEMA. The MCP is a means of short circuit protection. Motor starters are magnetic line voltage type with individual control power transformer, 120V secondary fuses and 3-phase bimetallic overload protection. Primary side fuse overcurrent protection should be provided on all control power transformers.

B. Reduced Voltage Soft Starters

Constant speed motors sized more than 15 hp, must use a reduced voltage starter to minimize the instantaneous draw from the utility at pump start-up. Soft starters must be solid-state design with isolation and bypass contactors.

When the pump reaches full speed, and after a short time delay, the soft starts electronics will be bypassed and isolated and the pump will run on utility power through the bypass contactor. Taking the electronics out of the circuit creates less wear and tear on the starter and provides operation that is more efficient.

11.6.4.8 Project Electrical Design Documents

The following are project (contract) drawings typically required to properly detail the electrical design of pump stations:

- Control schematics
- Duct bank sections
- Miscellaneous one-line diagrams
- Panel and lighting schedules
- Power distribution one-line diagram
- Pump station lighting plan
- Pump station power wiring and grounding plan
- Site plan: lighting and communications
- Site plan: power distribution and grounding
- Switchgear, MCC, and panelboard one-line diagram and front elevations
- Symbols and abbreviations
- Typical construction details

11.6.5 Instrumentation and Monitoring Control

DSG Chapter 10, I&C (SCADA) describes overall code compliance, standards, and general guidelines for I&C systems. This section describes instrumentation specific to pumping station monitoring, operation, and control.

11.6.5.1 Instrumentation for Wastewater

Pump instrumentation will allow for control and monitoring of the pump and station equipment. Monitoring will also include all trending and alarm functions. The following is the minimum pumping control instrumentation.

A. Magnetic Flow Meters at Discharge of Pump

The programmable logic controller (PLC) should be programmed to calculate the flow totalizing function. The flow meters should be specified with reverse flow sensing capability to detect a check valve malfunction for systems that will not have motor operated discharge valves. Magnetic flow meters should be used to the extent possible, with submergence ratings, and remotely mounted transmitters. Magnetic flow meters should be in-line type. For wastewater pump stations, a single flow meter should be provided on the discharge header for smaller stations. For stations with firm capacities exceeding 2,500 gpm, consider providing a flow meter for each pump. Totalizing functions should be performed through the SCADA system or directly in the corresponding PLC.

Wastewater pump stations may use meters by Krohne, Toshiba, Siemens, or Endress + Hauser. Flow meters must be installed in accordance with the manufacturer's recommendations for upstream and downstream straight runs of pipe. Isolation valves and dismantling fittings must be provided to allow flow meters to be removed for maintenance purposes. Provide a corp stop and ball valve adjacent to the flow meter for installation of a temporary pressure gauge.

B. Low-Pressure Pump Suction Pressure Gauges, Transmitters, and Mechanical Switches on Suction Side of Each Pump

Permanent pressure gauges or instruments are not required at wastewater pump stations. A corp stop and ball valve must be included on the suction side of each pipe for installation of a temporary pressure gauge.

C. High-Pressure Pump Discharge Pressure Gauges and Transmitters on Discharge Side of Each Pump

Permanent pressure gauges or instruments are not required at wastewater pump stations. A corp stop and ball valve must be included on the suction side of each pipe for installation of a temporary pressure gauge.

D. Open/Close Limit Switches for all Pump Isolation Valves

Limit switches are not required for isolation valves in wastewater pump stations.

E. Pump and Motor Vibration Switches

The motor for each pump above 50 hp should be monitored for vibration. The vibration monitors should be specified to be as manufactured by PMC/BETA Corporation, or equal. Each vibration monitor must have the following features:

- Two limit switches for each pump: one for alarm and one for pump shutdown; each limit should be independently adjustable
- A display to show the current status of the velocity level
- Manual reset button to reset the monitor and relays to the non-alarm state
- Test button for each channel to trip the alarm for testing with and without pump shutdown
- Time delay for each limit to be independently adjustable from two to 15 seconds

- An illuminated indicator per channel and limit to light after the time delay when any set point is exceeded
- A trip light to illuminate immediately when any set point is exceeded and before alarm or shutdown is initiated
- A circuit checker with illuminated indicator to continuously light when the pickup circuit is working properly

F. Wet Well Level Transmitters and Sensors

SPU's current standard for level sensing is the KPSI 750 pressure transducer. Select an appropriate pressure range for each facility's wet well (e.g., 5 psi, 10 psi, or 15 psi).

G. Pump Station Flood Alarm Switch

The pump station flood alarm switch detects a high-water level or flood condition in the dry well or other equipment spaces. Flood switches must be readily accessible for testing without special tools or equipment. SPU prefers the GEMS LS-1900 for this application.

H. Pump Station Electrical Power Fail Alarm

The pump station electrical (AC) power fail alarm detects power conditions through a power fail relay or a more sensitive phase failure relay that monitors the incoming power at the pump station.

I. Pump Run Contact

Pump run status is monitored by a run contact in each pump motor starter. The run status signal is sent to the PLC and then to the SCADA operator workstation.

J. Motor Connected Contact

The motor connection status is monitored via a contact in the motor disconnect plug for each pump.

K. Pump Local-Off-Remote Switch

Each pump in the pump station must be equipped with a local-off-remote (LOR) switch. The status of each pump must be monitored by the SCADA PLC.

When the switch is in the Local position, a run signal is sent to the pump and it will no longer accept remote commands. When the switch is in the Off position, the pump will not accept any run command. When this switch is in the Remote position, the signal is a permissive for a pump remote start command to the respective pump. All SPU pump stations currently include this status signal.

The Off and Local position status signals must be added as basic data inputs to the PLC and monitored by the SCADA system.

L. Pump Start and Stop Commands

The PLC sends a pump start or stop command to each pump motor starter when the pump is required to run or stop. The PLC outputs the pump start/stop command only when the pump LOR switch is in the Remote position and the operator inputs a command in the Human Machine Interface (HMI).

M. Pump Available Status – Calculated

The PLC calculates the pump's status as available when the LOR switch is in the Remote position and there are no pump alarms. Include this status signal in the SCADA system to allow the remote operator and automatic control applications to prepare for pump start.

N. Pump and Motor Bearing High Temperature Alarms

Bearing inboard and outboard high temperature switches must be interfaced with the PLC. An additional relay may be required to add a dry contact for PLC input.

O. Motor Overload Alarm

Motor overload relays must be interfaced with the PLC. An additional relay may be required to add a dry contact for PLC input.

11.6.5.2 Instrumentation and Monitoring for Drinking Water Pump Stations

The pump station data/instrumentation standard includes all SPU drinking water pump stations for the distribution system. Typical pump station standard equipment and signals are described is this section.

A. SCADA Control Panel

The equipment that controls a pump station must be housed in a SCADA PLC panel. The panel contains a pump station PLC, supporting instrumentation, and accessories and appurtenances required to control and monitor the pumps. Additional control interfaces may be needed to monitor buildings auxiliary HVAC, fire alarm, and security systems.

A local Operator Interface (OI) or HMI can be provided as an option on the SCADA panel for local control and indication. The OI has the capability to display, store, and reset alarm conditions and trends.

For detailed information on SCADA panel requirements, see *DSG Chapter 10, I&C (SCADA)*.

At most SPU sites, standard control panel signals are provided on the existing SCADA. Additional signals should be added at any sites that do not include all standard signals. Standard control panel signals include the following:

- Control Panel AC Power Failure Alarm
- Control Panel PLC Battery Voltage Alarm
- Control Panel PLC Battery Charger Alarm
- Control Panel Door Open Alarm
- PLC Key State (PROGRAM-REMOTE-RUN)
- PLC Communication Fail Alarm
- Batteries Voltage – Analog Signal

B. Pump Station Suction Pressure

The suction pressure monitoring at a pump station measures the pressure at the upstream side of the pump suction connections and downstream of the station inlet or storage facility connection.

All SPU pressure transmitters for pump stations must be Rosemount 2088.

C. Low-suction pressure alarms, typically below 15 psi, must be installed as a basic instrument at all pump stations. Pump Station Discharge Pressure

A pump station discharge pressure transmitter measures the pump station discharge pressure and sends the signal to the PLC, then to the SCADA operator.

The discharge pressure transmitter Rosemount 2088 must be installed as a basic instrument at all pump stations.

D. Pump Station Discharge Flow

Pump station discharge flow rate is measured by a flow meter between the pump discharge header and the discharge zone. For wastewater stations, flow is typically measured just before the force main exits the station. A corp stop and ball valve should be included near the flow meter for installation of a temporary pressure gauge.

All flow meters for SPU water pump station must be Krohne mag meters. Flow meters must be installed in accordance with the manufacturer's recommendations for upstream and downstream straight runs of pipe. Isolation valves and dismantling fittings must be provided to allow flow meters to be removed for maintenance purposes.

E. Pump Station Discharge Pressure High Alarm

The discharge pressure high alarm signal is provided either by a pressure switch connected to the pump station discharge line or by PLC logic, which monitors the analog signal from the discharge pressure transmitter. The alarm can be used either to provide an alarm only to the SCADA operator or to stop the pumps with either PLC logic or a hardwired interlock. An alarm is sent to the SCADA operator.

Discharge pressure high switches must be added at all pump stations as a basic instrument.

F. Pump Station Flood Alarm

The pump station flood float switch detects a high water level or flood condition in the pump station building.

G. Pump Station Fire Alarm

The pump station high heat sensor detects a possible fire in the pump station building and a fire alarm signal is registered in the SCADA PLC.

H. Pump Station Electrical Power Fail Alarm

The pump station AC power fail condition is detected with a power fail relay or a more sensitive phase failure relay that monitors the incoming power at the pump station.

I. Pump Running

Pump running status is monitored by a run contact in each pump motor starter. The run status signal is sent to the PLC, then to the SCADA operator workstation.

J. Pump Local-Off-Remote Switch

Each pump in the pump station must be equipped with a local-off-remote (LOR) switch. The status of each pump must be monitored by the SCADA PLC.

When the switch is in the Local position, a run signal is sent to the pump and it will no longer accept remote commands. When the switch is in the Off position, the pump will not accept any run command. When this switch is in the Remote position, the signal is a permissive for a pump remote start command to the respective pump. All SPU pump stations currently include this status signal.

The Off and Local position status signals must be added as basic data inputs to the PLC and monitored by the SCADA system.

K. Pump Start and Stop Commands

The PLC sends a pump start (or stop) command to each pump motor starter when the pump is required to run (or to stop). The PLC outputs the pump start/stop command only when the pump LOR switch is in the Remote position, and a command is received from the operator HMI.

L. Pump Available Status – Calculated

The pump available status is calculated by the PLC and is true when the LOR switch is in the Remote position and there are no pump alarms. SPU should add this status signal to allow the SCADA operator and automatic control applications to prepare for pump start.

M. Pump and Motor Bearing High Temperature Alarms

Bearing inboard and outboard high temperature switches must be interfaced with the PLC. An additional relay may be required to add a dry contact for PLC input.

N. Motor Overload Alarm

Motor overload relays must be interfaced with the PLC. An additional relay may be required to add a dry contact for PLC input.

O. Pump Discharge Valve Status

Where pump discharge valves are installed, the open and closed status must be monitored by the SCADA system PLC to provide an alarm if the valve is not open when the pump is running. The pump discharge valve position status switches should be added as a basic data requirement.

P. Intrusion or Security

Intrusion switches and vault security alarms should be added as basic data for water quality security and site security purposes at pump station sites.

Q. Pump Station Electrical Power Consumption (optional)

Electrical power total consumption in kilowatt (kW) and energy consumption rate in kilowatt hour (kWh) should be measured at the station, input to the PLC and sent to the SCADA system and operator at less than 15-minute intervals. SPU does not currently monitor electrical power consumption at its pump stations.

Power monitoring should be added at SPU pump stations as advanced data.

Electrical power consumption data can be used to check the power company billing information on a monthly interval and is required at one to five-minute intervals to calculate pump efficiency.

One of the three alternatives for electrical power consumption monitoring should be installed as advanced data at all pump stations (Table 11-20).

Table 11-20
Alternatives for Monitoring Electrical Power Consumption

Name	Description	Advantage/Cost
Alternative 1 Interface to Existing Power Company Meter	• Power consumption can be monitored by SCADA system by having the power company install an interface between the PLC and the electric power company billing meter. This interface provides a contact closure pulse output to the PLC discrete input with a specific number of kWh per pulse. PLC logic totalizes the pulses and converts the value to kW.	• Lowest cost of the three alternatives for power monitoring.
Alternative 2 New Power Monitor in Electrical Switchgear for Pump Station	• An additional electrical power monitor that must be installed between the electrical service entrance meter and the MCCs with the motor starters for the pumps. • Requires installation of current and potential transformers to monitor and calculate power consumption. • Provides additional benefit of monitoring and storing electrical power variables and alarms that can be used for maintenance and troubleshooting.	• More accurate power consumption total and rate information. • Electrical variables (e.g., kW, kWh, voltage, and power factor) and alarms (e.g., high- and low-voltage and power failure) can be monitored and data stored to provide more information on electrical problems. • Cost is more than Alt 1 due to additional equipment and installation cost. • Alt 2 has additional electrical data that can be used to troubleshoot electrical supply and load induced problems.
Alternative 3 New Power Monitors in MCC for each Pump Motor	• Same power monitor described for Alternative 2 can be installed in the MCC for each pump motor.	• Much more accurate power consumption total and rate information. • Additional electrical information is available for each pump motor that can be used to resolve station and motor electrical problems. • Cost is higher than Alts 1 and 2 because of additional new equipment and modifications to each starter.

Name	Description	Advantage/Cost
		• New power monitors for each pump not recommended. Additional cost not justified by benefits.

Acronyms and Abbreviations
kW: kilowatt
kWh: kilowatt hours
MCC: motor control center
PLC: programmable logic controller
SCADA: supervisory control and data acquisition

11.6.5.3 Control Functional Requirements

A. Programmable Logic Controller

The pump station PLC collects operational data that will be available to the operators in the Utility Operations Center via the SPU SCADA system.

The PLC should consist of the necessary CPU, communication, and I/O modules to support the control and monitoring functions. These functions should provide communications with the Utility Operations Center, onsite Operator Terminals (optional), analog and discrete digital I/O for pump control, and I/O sufficient for the additional monitoring of auxiliary systems where required.

The PLC control panel should have environmental controls if necessary to heat or cool the control panel. The use of room HVAC may mitigate the need for this.

For more detail on PLC requirements, see *DSG Chapter 10, I&C (SCADA)*.

B. Control Narratives (Control Loop Descriptions)

A control narrative must be developed for each pump station to facilitate programming and operation of the system, both locally and remotely, with equipment and staff safety as primary considerations.

11.6.5.4 Project Instrumentation and Control Design Documents

The following are typical contract drawings for I&C for pump stations:

- P&ID for each process (pumping, HVAC, etc.)
- Control system architecture/block diagram
- Control panel front view and layout
- Instrument loop diagram
- Instrument schedule
- PLC input/output schedule
- Construction details

11.6.5.5 Vibration Monitoring

The motor for each pump above 50 hp should be monitored for vibration. The vibration monitors should be specified to be as manufactured by PMC/BETA Corporation, or equal. Each vibration monitor must have the following features:

- Two limit switches for each pump: one for alarm and one for pump shutdown. Each limit should be independently adjustable.
- A display to show the current status of the velocity level.
- Manual reset button to reset the monitor and relays to the non-alarm state.
- Test button for each channel to trip the alarm for testing with and without pump shutdown.
- Time delay for each limit to be independently adjustable from two to 15 seconds.
- An illuminated indicator per channel and limit to light after the time delay when any set point is exceeded.
- A trip light to illuminate immediately when any set point is exceeded and before alarm or shutdown is initiated.
- A circuit checker with illuminated indicator to continuously light when the pick-up circuit is working properly.

11.7 PUMP STATION DESIGN

This section describes pump station design.

11.7.1 Station Layout

11.7.1.1 General

All pump stations must be equipped with a permanent space dedicated for a portable standby generator unless a complete permanent standby power system is provided.

The space should be completely isolated from the rest of the pump station. Isolation allows a less stringent area classification to be maintained for electrical facilities and lower capital costs for electrical equipment. Electrical equipment will also have a longer life if kept in a dry area.

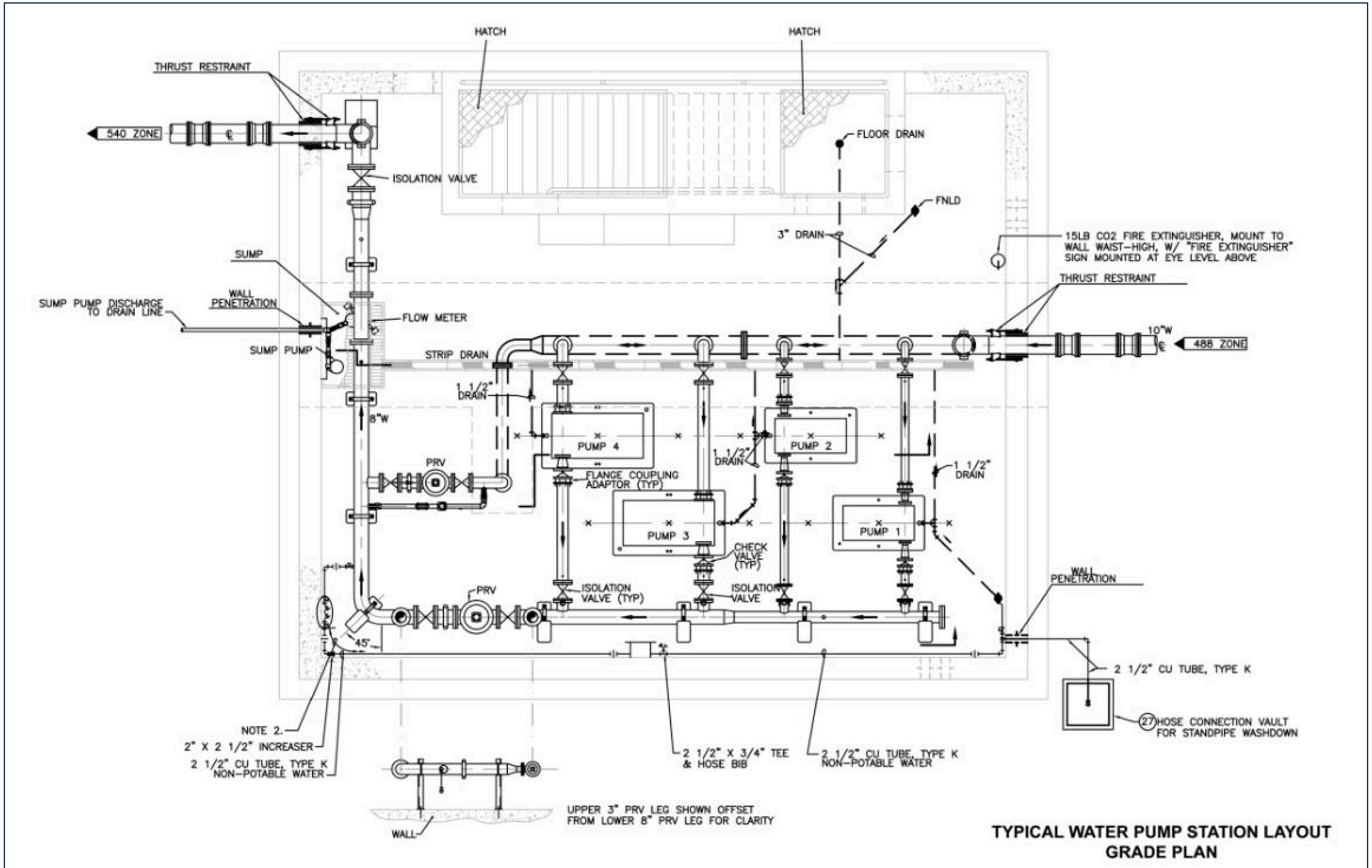
11.7.1.2 Water Pump Stations

A water pump station typically consists of a concrete structure with hatches or door, pumps and pump foundations, isolation valves, check valves, pressure regulating and sustaining valves, pipes, pipe supports, flow meter, couplings, sump, sump pump, floor drain, HVAC, MCC, and I&C.

Potable water pumps are typically horizontal centrifugal pumps at grade. They are not connected to a wet well. Potable water systems must be certified NSF International 60/61 for use with potable water and the system must be completely disinfected to AWWA standards. Cross-connection control measures need to be carefully considered. Potable water pumping stations tend to be cleaner and drier than wastewater stations and are not classified areas. Therefore, it is not as critical to place electrical equipment (e.g., controllers and MCCs) in a separate room from the pumps. It is, however, desirable if space allows. Electrical equipment separated from the rest of the process is more cost effectively temperature controlled and can require less stringent NEMA classifications.

Figure 11-7 shows a typical layout of an SPU water pump station.

Figure 11-7
Typical Water Pump Station Layout



11.7.1.3 Wastewater and Drainage Pump Stations

Wastewater and drainage pump stations can be of two different configurations: dry well/wet well or submersible (wet well). These facilities include submersible pumps, pump foundations, isolation valves, check valves, inflow sluice valves and combination air release valves, sumps, sump pumps, force main, pipes, pipe supports, ventilation system, MCC, e-plug, generator, and I&C.

A. Dry Well/Wet Well Layout

A dry well/wet well configuration consists typically of a single wet well piped through to a separate dry well area (Figure 11-8). The dry well area houses all process mechanical equipment including pumps, piping, valves, and appurtenances. Generally, this configuration allows greater equipment access, longer equipment life, easier maintenance, and safer working conditions.

The use of pumps with submersible motors should be considered for both dry and wet well configurations.

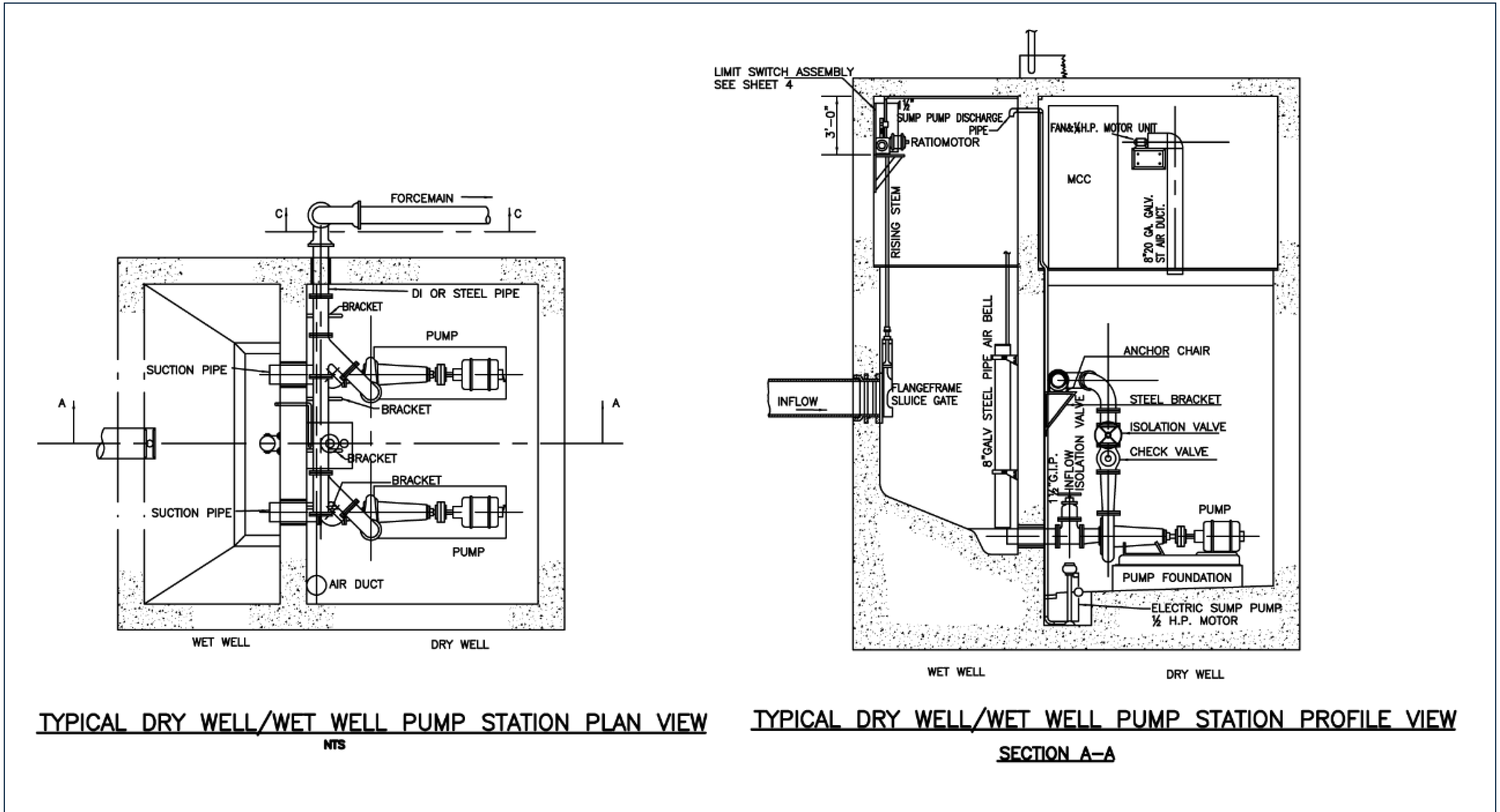
Advantages:

- Easy access for maintenance.
- Most routine maintenance can be done in place.
- Wider range of head and capacity.
- Wider choice of driver arrangement.
- Possible to use flood-protected motors.

Disadvantages:

- Greater cost due to excavation and build below-grade. Expensive if ground water is high, if soils are poor, or if blasting is required.
- Greater risk of outage from flooding. Dry well must be kept dry.
- Flood-protected motors (in the dry well) are expensive.
- Long leads to motor (in dry well) from control panel if motors are frame mounted to pumps.

Figure 11-8
Typical Dry Well/Wet Well and Wet Well Layout



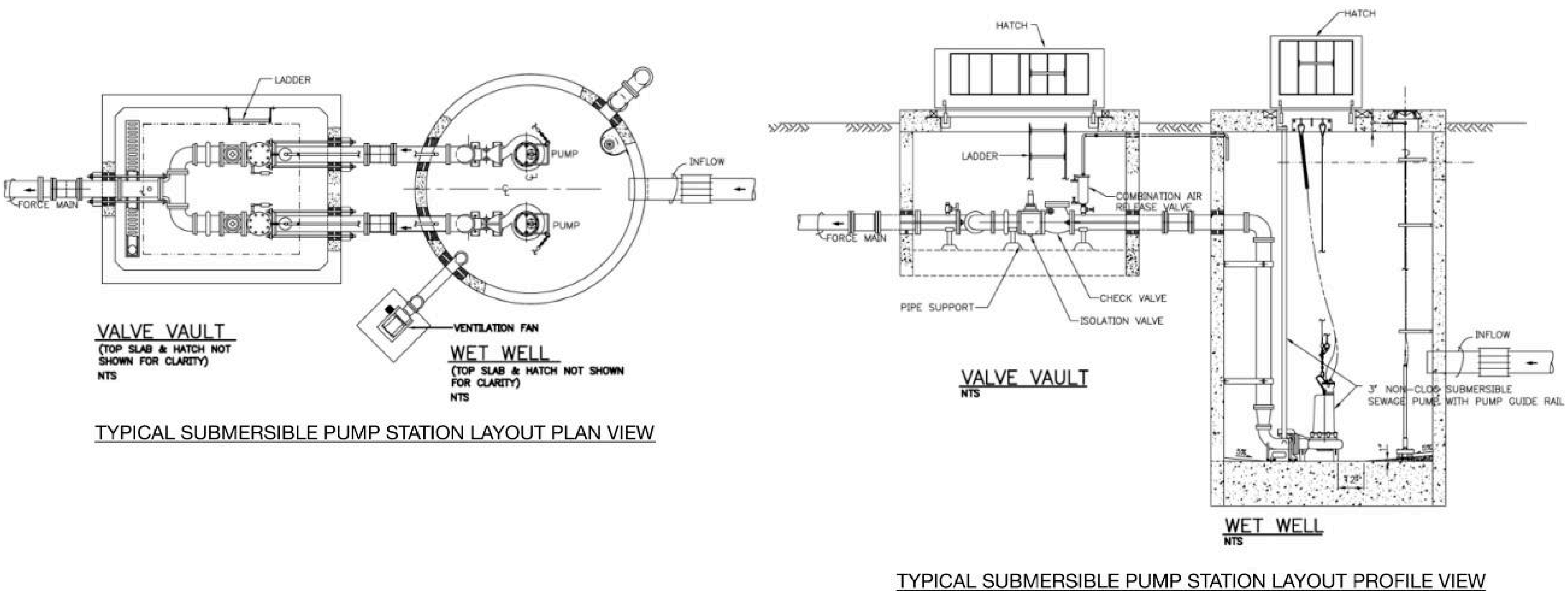
B. Submersible (Wet Well) Layout

A submersible pump station configuration consists of a single wet well in which all mechanical equipment is housed (Figure 11-9). When space allows, valves and appurtenances must be installed above the maximum water surface elevation in a separate dry vault to allow better access for maintenance. Table 11-21 below summarizes the advantages and disadvantages of submersible wastewater pump stations.

Table 11-21
Advantages and Disadvantages of Submersible Layout

Advantages	Disadvantages
• No dry well; excavation and concrete reduced. • No superstructure required except for engine-generator or cabinet for motor controls. • Functionally best suited for on/off operation with relatively narrow band of head requirements. • Good when equipment is centrally located for servicing. • Excess heat from pumps is dissipated into liquid (not load added to building cooling requirements). • No seal water system, no long shafts with steady bearings required. • No flood hazard to motors. • Reduces the land area needed. • Quick removal and replacement in emergencies. • Well adapted for increasing the capacity of a pump station using existing wet and dry wells. • No daily or weekly maintenance. • Units removable for shop servicing, minimizes field work. • Quiet operation. • Safety from flooding. • Can balance lower first cost of submersible pumping station w/ its lack of regular, frequent maintenance against cost of complete overhauls by specially trained mechanics or service center.	• Pumps are larger. • Wet well will probably need to be wider than with non-clog, dry well pumps, thus requiring more wet well air flow and odor scrubbing capacity. • Pumps can get extremely heavy in larger sizes. • Unit must be removed and disassembled for routine servicing. Cannot be inspected during operation. • Limited manufacturer's ability to custom engineer for heavy-duty service. • Pumps and motors not as well suited for variable speed operation. • Difficult to diagnose vibration or leaks. • Tandem seals on larger units are expensive, $5,000 or more. These are routine replacement items. • Generally non-adjustable (e.g., not possible to adjust impeller-wear ring clearance to prolong component life). • Valves and headers must be accessible in one of these: 1) adjacent vault; 2) small above-grade superstructure; or 3) by exposing the header above-grade. • Not possible to adjust impeller-wear ring clearance to prolong component life. Needs overhaul every few years based on motor size. • Valves and headers must be accessible in either: 1) in adjacent vault; 2) in small above-grade superstructure; or 3) by exposing header above-grade. • Pump must be removed and disassembled for inspection and maintenance. Heavier pumps require hoist or crane and specially trained mechanics. Often more difficult to remove pumps than manufacturers admit. • Hazard of pumps jamming on guide rails or not seating. • Larger units tend to break down more often than smaller units and require higher maintenance cost. • Special motors, seals, and moisture monitoring required. Moisture probes are useless for leaks via power cable. • Performance and quality of pump/driver unit may differ greatly. High impact on maintenance and lifecycle cost. • Warranty valid when repairs are made by pump manufacturer's authorized service center.

Figure 11-9
Typical Submersible (Wet Well) Layout



11.7.2 Pipe Design

Pipe design for pump stations includes process and force main piping. Process piping refers to all piping inside the pump station. The pump suction piping configuration is critical to delivery of acceptable hydraulics to the pump intake. Subtle differences in piping configuration can greatly determine whether a pump inlet receives well-distributed or severely skewed flow.

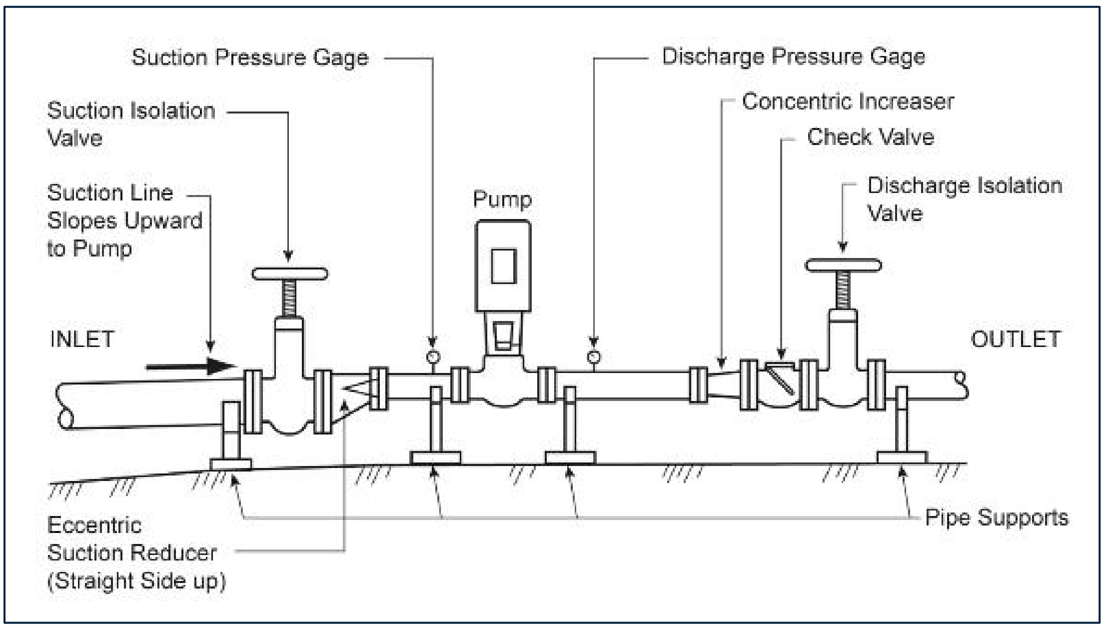
11.7.2.1 Inlet Piping

Pump intake design must follow HI section 9.8.

A. Typical Inlet and Outlet Configurations

The inlet (suction) side of the pump typically includes an isolation valve, a pressure tap, and a reducer to match the piping to the size of the pump inlet (Figure 11-10). The outlet side of the pump typically includes an increaser, an air relief valve (at the high point), a pressure gauge or transmitter, a check valve, and isolation valve and a flow meter. Occasionally, sample taps may need to be provided on the discharge piping. To prevent accumulation of air pockets, all points along an outlet pipe should be made lower than the static water level at the end of the pipe, with a consistent upward slope. This arrangement allows air to be released when the pump idles. Expulsion is important because air pockets can move away from high points as flow occurs in the pipeline.

Figure 11-10
Typical Inlet and Outlet Configuration



B. Wet Well Piping and Pump Intakes (Drainage and Wastewater)

Wastewater and drainage pumps are connected by pipe to wet wells and piped through a force main to SPU systems. The flow configuration through a wet well can result in a separation of solids from liquid, head loss, and a vortex effect. To reduce flow separation and unnecessary head loss, it is beneficial to provide a flared inlet (turned-down elbow with a flared inlet or a horizontal flared inlet) that can create smooth acceleration of flow as it enters the inlet pipe.

1) Turned-down Inlet

Generally, a turned-down elbow is more effective than a horizontal inlet when there is low velocity in the wet well.

2) Horizontal Inlet

SPU recommends a horizontal inlet. It is less prone to generation of pre-swirl in the suction piping than is a turned-down elbow. Pre-swirl is flow rotation approaching the pump inlet, which is a common source of impeller cavitation damage and vibration. SPU recommends horizontal inlets for turbulent wet wells that have higher velocity flows and circulation patterns. Horizontal inlets do, however, require greater submergence than turned-down elbows to prevent surface vortex formation. Flared inlets should be flush with the partition wall.

C. Header Piping to Water Pumps

Unlike wastewater pump stations, typically, water pump stations are not connected to a wet well or reservoir but are hard piped in the transmission system. In this case, a larger header is brought into the station and each individual pump pulls suction from the header. The main feeder header may be located under the pump station slab (which will require access vaults) or may come in overhead depending on hydraulics. The piping from the feeder to the pumps should be straight and short runs when possible.

11.7.2.2 Pipe Reducers

Reducers are frequently required in pump inlet piping to match the suction pipe diameter with the pump size. When placed in horizontal piping, suction reducers should be eccentric type, oriented with the flat side on top to prevent air from accumulating in the intake piping.

The angle of convergence of an eccentric reducer increases for each pipe size reduction. As the reducer convergence angle increases, the flow disturbance generated becomes more severe. This flow disturbance requires additional lengths of equivalent straight pipe between the reducer and the pump inlet or pump suction elbow to reduce the disturbance to the pump.

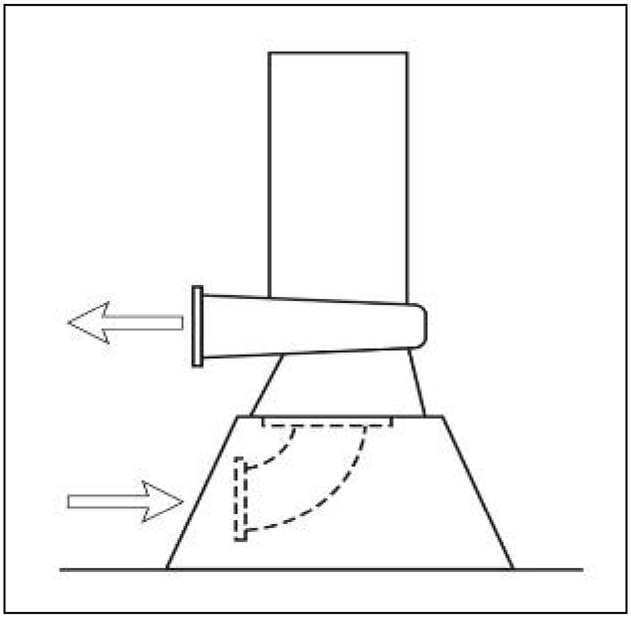
The following are guidelines for pipe reducers:

- Eccentric reducers should be located at least one pipe diameter away from the pump inlet or pump suction elbow for every nominal pipe size reduction.
- As an example, a standard 16-by-12-inch reducer should be located at least two pipe diameters (24 inches) away from the pump inlet because it provides a reduction of two standard nominal pipe sizes. Generally, standard pipe sizes in this range are increments of even whole number nominal diameters.

11.7.2.3 Pump Inlet and Discharge Elbows

Vertically mounted wastewater pumps require a 90-degree elbow upstream of the pump. The elbow is typically attached directly to the pump inlet (Figure 11-11) and is usually furnished by the pump manufacturer as a part of the mounting base. The dashed line in Figure 11-11 represents the pump suction elbow of a submersible pump mounted in a wet well. For large pumps with case-in-place bases, the elbow resides between concrete walls on either side.

Figure 11-11
Pump Suction Elbow Leading to Pump Body



In some circumstances, the pump suction elbow has been cited as a major concern associated with pump vibration and increased maintenance. Physical modeling shows that pump suction elbow geometry affects hydraulics at the pump inlet. It is critical to use a reducing elbow because a standard (non-reducing) elbow will deliver a severely skewed velocity profile to the pump inlet.

To deliver a flow that meets HI velocity distribution criteria, the ratio between the inlet and outlet sides of the elbow must be a ratio of 1:1.5. The inside diameter of the pump throat is typically a smaller diameter than the pump inlet flange and can be used for this calculation in lieu of the downstream diameter of the pump suction elbow. Use of long radius elbow is preferred in this configuration. However, short radius reducing elbows can also be effective.

For most submersible pumps, the fitting immediately downstream of the pump discharge is typically a 90-degree elbow required to orient the pumped discharge flow vertically and route it through the balance of the downstream mechanical equipment. These fittings can experience significant and highly variable thrust forces, especially at startup. SPU recommends that the pump manufacturer be closely consulted to determine what, if any, additional reinforcement may be required for fittings attached to the pump nozzle. Such provisions may affect the final dimensions and should be considered when designing concrete bases and supports to accommodate this equipment.

11.7.2.4 Drainage and Wastewater Pump Inlet and Discharge Piping Velocities

For drainage and wastewater pump stations, the minimum and maximum velocities allowed through pump inlet (suction) and discharge pipes must meet those shown in Table 11-22.

Table 11-22
Velocities for Pump Inlet (Suction) and Discharge Piping for Individual Pumps

Location	Minimum Velocity (fps)	Maximum Velocity (fps)
Inlet Piping	2	8
Inlet Piping (High Rag influent)	5	8
Discharge Piping	2	8

Acronyms and Abbreviations
fps: feet per second

A. Minimum Velocities

Certain technical constraints affect pipe size selection. For force mains conveying sewage, minimum velocity must be 2 ft per second (fps) for wastewater and 2 fps for drainage pump stations during initial operation. For stations subject to ragging or above-average solids in the influent, higher minimum velocities (at least 5 fps) are recommended.

B. Maximum Velocities

To maintain head losses at reasonable values, the maximum velocity in wastewater force mains must be 8 fps. For short (< 100 ft) force mains, SPU allows higher velocities (up to 10 fps) on a case-by-case basis. Pipe wall erosion from grit is a concern when velocities exceed 10 fps.

11.7.2.5 Pipe Sizing, Materials, and Jointing

A. Wastewater Force Main Sizing

Force mains must be 4 inches or greater to allow for inspection and cleaning. Pipe size should not compromise minimum and maximum velocity requirements.

When installing a new force main or rehabilitating an existing force main, consider alternative installation methods to reduce cost. For information on trenchless technology, see *DSG Chapter 8, Drainage and Wastewater Infrastructure*.

Wastewater force mains must be tested according to Standard Specification 7-17.3(4)F.

B. Materials

The following are SPU standards for pump station pipe materials. Other materials may be acceptable if approved by SPU:

- All piping within the pump station structure must be either ductile iron or carbon steel and must be designed with restrained joints.
- At a minimum, ductile iron piping must be service Class 52. Flanged, grooved, or otherwise fabricated ductile iron pipe must be service Class 53 minimum. All ductile iron piping must follow Standard Specification 9-30.1(1).
- Steel piping design must follow AWWA M11. All steel piping must follow Standard Specification 9-30.1(4).

- Wastewater force mains beyond the pump station structure may be constructed of restrained joint ductile iron pipe service Class 52 or thicker, or of high-density polyethylene (HDPE) (thickness as required, not to exceed a dimension ratio (DR) of 17).

Material selection should be as consistent as is practical throughout all pump station piping to minimize the need for transitional appurtenances (e.g., dielectric flange insulation kits).

Material selection and pressure classes, or pipe wall thicknesses, may significantly affect hydraulics. For example, ductile iron piping is controlled by the inside diameter (ID) while (depending on size) carbon steel piping may be controlled by the outside diameter (OD). As a result, 20-inch ductile iron piping will have a fixed inside diameter of almost exactly 20 inches. A 20-inch carbon steel piping could have a significantly reduced inside diameter depending largely on the selected pipe schedule (a metric associated with pipe thickness).

The following are other important factors to consider for pump station pipes:

- Exposed piping may require insulation and/or heat tracing provisions to protect against the elements.
- Buried piping may be subject to depth of cover requirements or special provisions related to local geotechnical conditions. Buried steel piping should conform to the requirements of AWWA M11.
- Buried metallic piping should be evaluated for cathodic protection needs (see *DSG Chapter 6, Cathodic Protection*).

C. Jointing

Typically, ductile iron piping uses flanged connections, and carbon steel piping uses either flanged or welded connections for piping inside a pump station. Flanged pipe should not be used in buried applications.

Where in-line equipment (e.g., pumps, valves, or flow meters) is installed, jointing must be provided on either side of the equipment, to allow for disassembly and removal. For this application, SPU generally recommends dismantling joint fittings, grooved couplings, or other fittings that allow length adjustment and disassembly clearance. In most cases, flanged joints are not appropriate for equipment removal. Flexible, rubberized couplings should not be used to connect equipment to the piping system.

Force mains, ventilation ducts, and other pipe penetrations must include a flexible joint at the entrance to, or exit from, a structure. Joints must be located a distance from the outside wall of the structure of 12-inches or one pipe diameter, whichever is greater.

11.7.2.6 Water Hammer

Water hammer is the name given to changes in pressure brought about by abrupt changes in flow within a pipeline. Any change in flow will produce a change in pressure. The most common abrupt change in pipeline flow occurs from a power failure to a pump station, or the normal stopping of a constant speed pump actuated by a signal from a flow level switch.

Any significant abrupt or rapid change in flow will produce an abrupt change in pressure.

For most small pump stations, pressure surges caused by water hammer are not severe and no water hammer control equipment is needed. All pumping and pressure pipeline systems should be investigated for water hammer where flow can be rapidly accelerated and/or decelerated.

A comprehensive computer modeling study must be completed to fully understand the potential effects of pressure surges on force main operation. For wastewater pump stations, SPU recommends considering a comprehensive modeling study when the force main meets at least one of the following criteria:

- Crosses under a river or other water body
- Has local high and low points along the alignment that require air/vacuum valves
- Is longer than 500 ft and larger than 6 inches in diameter
- Has other unusual or unique operating conditions prone to abrupt changes in flow velocity, siphoning effects, or air pockets

A completed modeling study will inform the need for, and location of, any required surge mitigation devices. Required devices based on modeling could include air/vacuum relief valves, surge tanks, and pump flywheels. Force mains should be designed to avoid the need for surge mitigation devices wherever possible. When air/vacuum relief valves are required for wastewater service, SPU recommends the Vent-O-Mat RGX B valve with piped outlet (that is, an outlet routed to nearby gravity sewer main). Modelling studies should be started at the 30% design milestone and finalized by the 90% design milestone.

11.7.2.7 Valving

Valve selection is critical to properly control flow and pressure through a pipe system. SPU generally provides a check valve immediately downstream of the pump. Isolation valves should be included on either side of any piece of equipment that will be routinely isolated and removed from service. At a minimum, isolation valves should be incorporated on both the suction and discharge side of each installed pump or major piece of equipment.

A. Water Pump Stations

Water system piping should use resilient seated gate or butterfly valves for piping greater than 4 inches in diameter and ball or globe valves for smaller lines. Drain valves must include an air gap and be directed to a floor drain. All connections to the potable water system must provide backflow preventers.

Table 11-23 lists appropriate valve types for the SPU water pump stations.

Table 11-23
Valves for SPU Water Pump Stations

Function	Acceptable Types	Comment
Isolation	Butterfly Gate (12 inches) Ball (<4 inches) Globe (<4 inches)	• Required on all pump discharges. • If on piped suction, should be at least five pipe diameters upstream of the pump suction.
Check Valves	Swing check	• Required on all pump discharges upstream of isolation valve.

Function	Acceptable Types	Comment
	Double disk	• Must be installed horizontally. Consult manufacturer for other installations.
Pressure Relief Valves		• Commonly included on downstream side of pump to maintain upstream pressure. Should be connected to floor drain.
Combination Air/Vacuum		• Air/vacuum valves should be provided on piping at high points on sections to be drained.
Air Release Valve		• Likely be required on discharge side of pump and at all high points in the line. • Will sometimes "spit" water. Should be piped to a floor drain.
Pump Control Valve	Ball valve Globe valve	• Minimizes pump surge from starting and stopping pumps (motor or hydraulic operated).

Other valves associated with ancillary systems for pump stations include those for a potable water source for hose bibs, fire protection, or drain and flushing valves for the system. Smaller valves for these connections should be ball valves for isolation and globe valves for draining.

B. Drainage and Wastewater Pump Stations

Valves used on drainage and wastewater system piping should be fully ported valves that are compatible with liquid-bearing solids fluid. Fully ported valves are important when the valve is located within four pipe diameters of a pump inlet. Flow acceleration and non-uniform flow distribution caused by reduced port valves can propagate downstream from the valve. This condition can cause non-uniform flow distribution at the pump inlet or flow rotation in conjunction with the pump suction elbow.

Table 11-24 lists recommended valve types for SPU drainage and wastewater pump stations.

Table 11-24
Valves for SPU Drainage or Wastewater Pump Stations

Function	Acceptable Type	Comment
Isolation	Gate valves	• Required on all pump discharges • If on piped suction, should be at least five pipe diameters upstream of the pump suction • Double-disc gate valves generally preferred by SPU Operations
Check Valves	Swing check	• Required on all pump discharges upstream of isolation valve • Must be installed horizontally • Consult manufacturer for other installations • Must include outside weight or spring and level (rubber on bronze seat)
Combination Air/Vacuum[1]		• Must be rated for wastewater applications. • Must only be used with overall water hammer control scheme

Function	Acceptable Type	Comment
		• Should be provided with back flushing capabilities and threaded or flanged outlets • SPU recommends Vent-O-Mat RGX B
Air Release		• Required on most pump discharges. • Must be rated for wastewater applications • Must be piped to wet well
Wet Well Installation	Slide gate	• Used to isolate wet well from inflow to station (stainless steel)

Notes

[1] Air release valves (or some other device by which air can be released from a discharge pipe) should be placed at all significant high points along the discharge pipe. If these locations are not vented, air that comes out of solution will accumulate in high points of the pipe and create additional head in the system and can accelerate corrosion due to the accumulation of hydrogen sulfide.

11.7.3 Pump Design

This section describes pump design, which consists of system curve development, pump hydraulics, and pump selection.

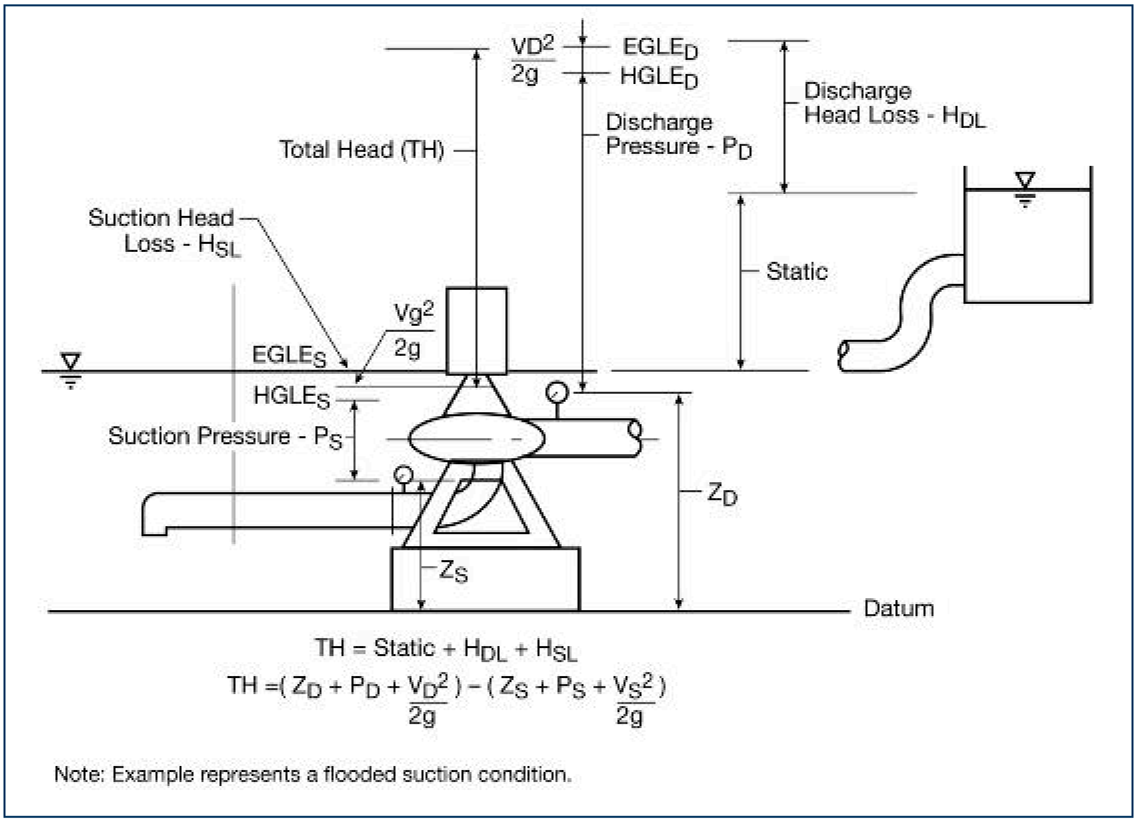
11.7.3.1 System Curve Development

System curves represent the variation in total dynamic head with pumping rate through the pumping system. At zero flow, total dynamic head is equal to total static head. As the pumping rate increases, the velocity head, friction losses, and pump losses increase. Thus, total dynamic head increases with pumping rate. This section describes design considerations associated with system curves.

A. Basic Hydraulic Considerations

Both under-sizing and over-sizing pumping systems can result in inefficient operation. A key parameter needed to select a pump is the pressures it has overcome to convey flow. Head is defined as the distance above or below a base elevation (datum) that a free water surface would reach if it were not confined (e.g., in a pipe). If the distance is below datum, the distance is negative. If the distance is above the datum, the distance is positive. Figure 11-12 shows common pump and piping system terms.

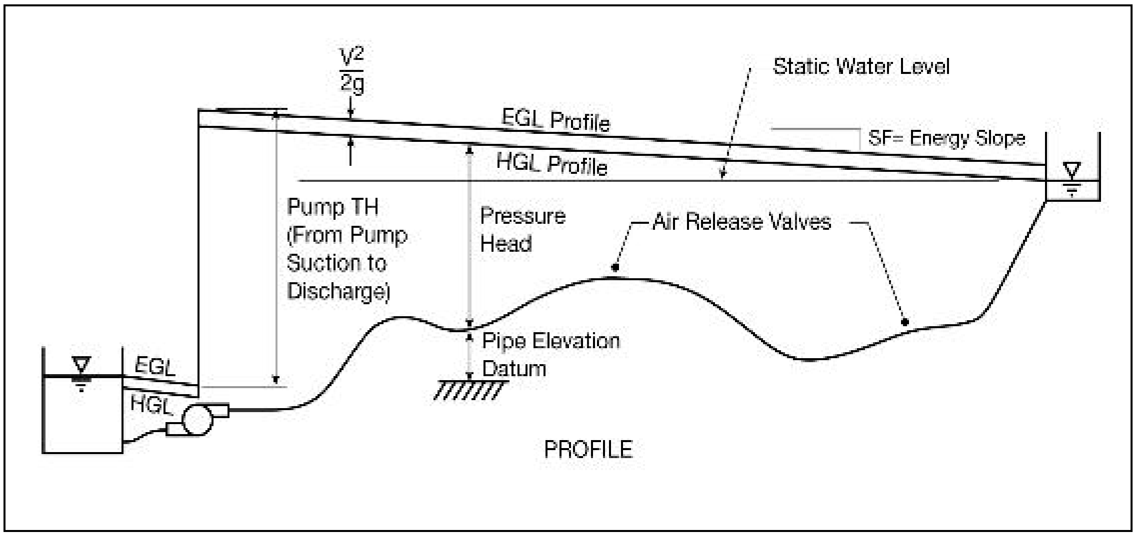
Figure 11-12
Common Pump and Piping System Terms



B. Hydraulic Grade Line and Energy Grade Line Profiles

Hydraulic grade line (HGL) and energy grade line (EGL) profiles plot the energy and head along a pipe route. HGL elevation at any point along a pressurized discharge pipe is the water surface that would be attained in a conveyance connected to a piezometer tap oriented perpendicular to the direction of flow. The HGL elevation consists of the pipe's elevation (relative to a datum), plus the pressure head. The EGL elevation at any point consists of the HGL elevation plus the velocity head (V2/2g) at that point along the pipe. Figure 11-13 shows a typical HGL and EGL.

Figure 11-13
Typical HGL and EGL



Acronyms and Abbreviations
EGL: energy grade line
HGL: hydraulic grade line
TH: total head

C. Total Static Head

Total static head is the difference in elevation between water level on the suction side and water level on the discharge. Because water elevations or pressures vary, a minimum and maximum static head should be computed.

D. Suction Static Head

Suction static head is the elevation difference between the centerline of the pump impeller and the water surface. This static head may be either a suction lift (wet well level below the pump) or a flooded suction (wet well level above the pump). Whenever possible, a flooded suction configuration is desirable. A suction lift configuration requires close coordination with the pump manufacturer.

E. Discharge Static Head

Discharge static head is the elevation difference between the centerline of the pump impeller and the water or energy elevation at the discharge point.

F. Dynamic Head Losses

Head losses associated with pumping systems are largely caused by pipe wall friction and turbulence through pipe fittings (elbows or valves). These head losses are referred to as friction losses and fittings losses, respectively. Friction and fitting loss (minor) equations provide only approximate results, not exact values. It is important to strive for accuracy when considering appropriate head loss ranges to avoid being overly conservative or liberal.

1) Friction Losses

Friction losses in closed conduit flow are commonly estimated by one of the following equations:

- **Hazen-Williams Equation**
- **Darcy-Weisbach Equation**

The Hazen-Williams equation must be used to calculate friction losses for pumped flow for all pipes less than 2,000 ft in length or less than 18 inches in diameter:

$$h_L = \left(\frac{V}{1.318 \times C \times R^{0.63}}\right)^{1.85} \times L$$

Where:

h_L = head loss (ft)

V = pipe velocity (ft/sec)

C = Hazen-Williams C coefficient of friction

R = hydraulic radius (ft)

L = pipe length (ft)

Ensure that the above units are consistent with project information. Ranges of Hazen-Williams C coefficients for various pipe materials, diameters, and ages are available from manufacturers and various sources in technical literature. Such information should be obtained for the specific pipes being considered in addition to the anticipated design life of the pipes. When existing pipe is reused for upgrading or rehabilitating a pump station, the actual C coefficient must be calculated through field testing. For water stations, use a minimum of two hydrant flow tests for each size and material of piping. For wastewater pump stations, use a minimum of two closely agreed (preferably more) pressure and drawdown tests at the station. Table 11-25 lists the typical Hazen-Williams coefficient values.

The Hazen-Williams equation should be cautiously used for pipes of either significant length (>2,000 ft) or large diameter (>18 inches). In these cases, the Darcy-Weisbach equation is a more accurate estimation of friction loss. It should be used to verify the results obtained using the Hazen-Williams equation.

For most SPU installations, the Hazen-Williams Equation can be readily used because the piping is typically less than 18 inches in diameter and less than 2,000 ft in length.

Table 11-25
Typical C Coefficients for Pipe Types used in SPU Pump Stations

Material	Hazen-Williams C
New Pipe	
Ductile or cast iron, uncoated	130
Ductile or cast iron, cement-mortar lined	145
Steel, epoxy or cement mortar lined	140

Material	Hazen-Williams C
PVC	150
Moderate service, 20+ years	
Ductile, cast iron or steel, uncoated	100
Ductile, cast iron or steel, cement-mortar lined	100
Long-Term Service, 50+ years	
Ductile, cast iron, or steel	80–90

Acronyms and Abbreviations
PVC: polyvinyl chloride

2) Fittings (Minor) Losses

The head losses caused by flow separation and turbulence through pipe fittings are expressed by stating the head loss as a multiplier (K) of the velocity head ($V^2/2g$) through the fitting (EQ 11.2). The discussion here concerns evaluation of force mains to develop system curves. The same principles, however, apply when station losses are considered. Figure 11-14 shows the limits of the force main.

The following is the Fittings Losses Equation (EQ 11.2):

$$h_L = \frac{KV^2}{2g}$$

Where:

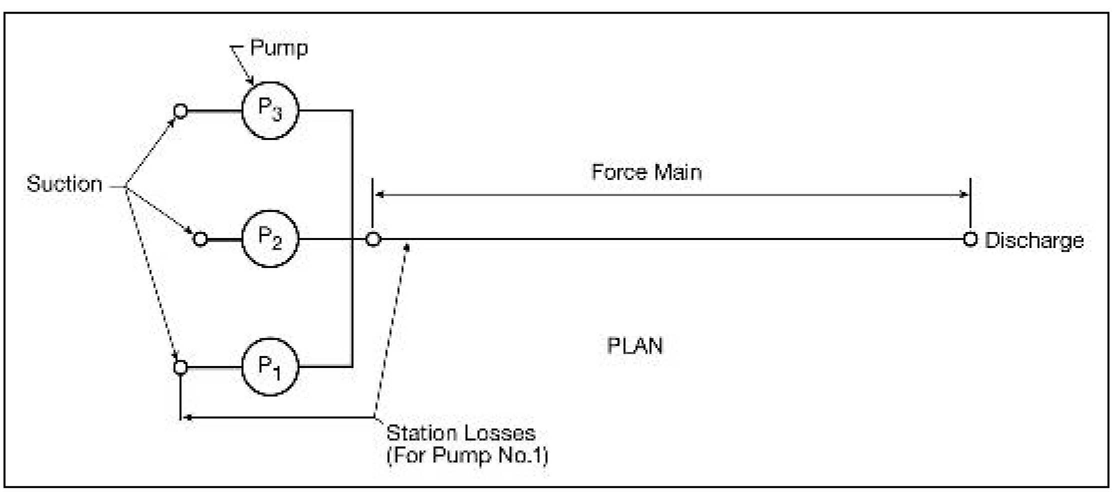
h_L = head loss (ft)

K = friction factors (see Table 11-21)

V = pipe velocity (ft/sec)

g = gravitational constant (32.2 ft/sec2)

Figure 11-14
Pump Station Schematic



Typical K (minor loss coefficient) values for a limited number of common fittings are listed in Table 11-26. Use coefficients provided by the valve or fitting manufacturer where available. Otherwise, K values for pump station design must follow HI Engineering Data Book Tables 32(a) and 32(b).

Table 11-26
Typical K Values/ Fittings (Minor) Loss Coefficients

Type of Transition or Fitting	Typical K Value
Pipe entrance, where upstream velocity equals zero:	
a. Pipe projecting into tank (re-entrant)	0.8
b. End of pipe flush with tank (square-edged)	0.5
c. Slightly rounded entrance	0.25
d. Bell-mouthed entrance (flush or re-entrant)	0.05
Pipe exit, where downstream velocity equals zero:	
a. Abrupt transition	1.0
b. Bell-mouthed transition	0.8
Reducers/increasers:	
Gradual reducers (pipe wall flare <40°):	0.1
Smooth bends:	
Regular radius 90° (10-inch diameter or less)	0.3
Regular radius 90° (>10-inch diameter)	0.2
Long radius 90° (10-inch diameter or less)	0.2 0.10.1
Long radius 90° (>10-inch diameter)	0.1
45°	0.1
22.5°	0.05
Valves: (see manufacturer's literature for actual values):	
a. Angle	2
b. Butterfly	0.3 to 1
c. Swing check (if spring-loaded, head loss may increase by 2 psi or more)	2 to 2.5*
d. Rubber flapper check	1 to 2
e. Slanting disc check valve	1.1
f. Foot	0.8
g. Gate	0.1
h. Globe	5.5 to 6.0
i. Plug (port area 85% of pipe area)	0.7
h. Ball or cone	0 (for full flow through area)

Notes
[1] K values for check valves will vary widely with the brand of valve and flow velocity. Consult with valve manufacturers for actual K values for use in design calculations. K values for fittings are typical reference values only and may scale with size.

Acronyms and Abbreviations
psi: pounds per square inch

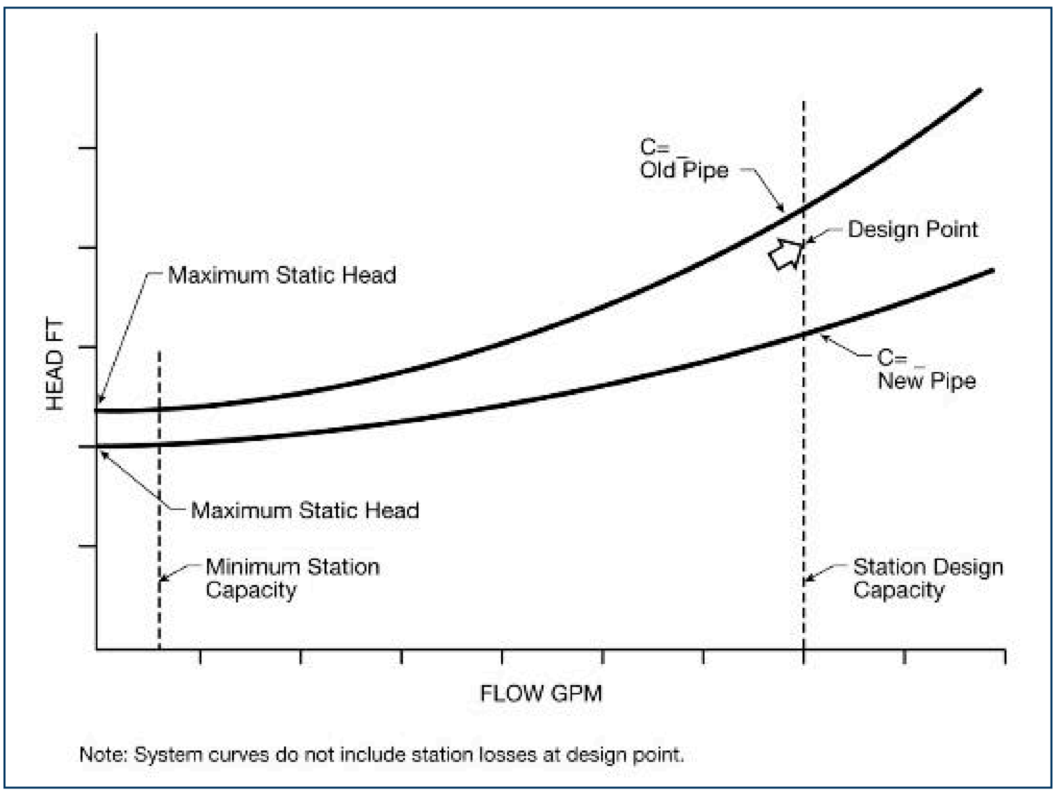
G. System Curves

The system curve is a graphical representation of total dynamic head versus discharge flow. The total head equals the system static head plus the dynamic head losses. Minimum and maximum system curves should be plotted. Other critical points of operation—such as common operating conditions—should also be identified.

The boundary defined by the minimum and maximum system curves provides the range of operation for system head requirements. One curve should show the maximum static head with loss. The other should show the minimum static head with loss (Figure 11-15). Except for systems where flow is to be externally controlled, system curves of the range of conditions the pump will encounter should be provided to the manufacturer.

Tip: *Provide pump manufacturers with a reasonable estimate of what station losses are likely to be. Pump selection should always strive for highest efficiency at the most frequent pumping rate(s).*

Figure 11-15
System Curve



Acronyms and Abbreviations
gpm: gallons per minute

H. Net Positive Suction Head

Net positive suction head (NPSH) is a measure of the total energy head on the suction side of the pump, relative to the centerline of the pump impeller (Figure 11-16). A pump's required net positive suction head ($NPSH_r$) varies with discharge, type of impeller, and pump speed. The $NPSH_r$ is provided by the pump manufacturer. The available net positive suction head ($NPSH_a$) indicates the actual total energy available on the suction side of the pump as shown in the equation below. SPU recommends that the $NPSH_a$ be at least two times the manufacturer's required value. In all cases, $NPSH_a$ must exceed the manufacturer's NPSHr by at least 5 ft.

The Hazen-Williams equation (see EQ 11.1) is used to calculate the NPSHa:

$$NPSH_a = H_{atm} + H_{sub} - H_{Vp} - H_L$$

Where:

H_{atm} = head, in feet of water, corresponding to the absolute pressure on the surface of the liquid being pumped

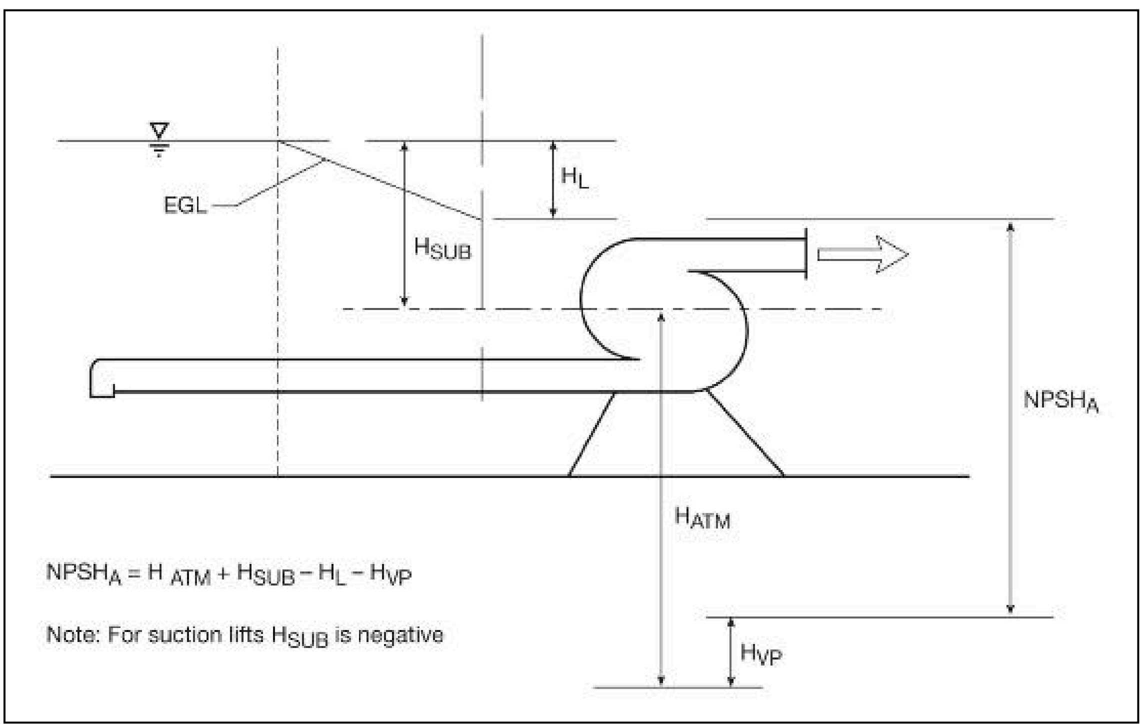
H_{sub} = difference between centerline of pump impeller and liquid level in the wet well

H_{vp} = vapor pressure of liquids, dependent on type and temperature of liquids

H_L = head losses in suction pipe (friction and fitting losses)

Note that the calculation must include H_{atm} at actual altitude elevation of the pump.

Figure 11-16
Net Positive Suction Head



11.7.3.2 Pump Hydraulics

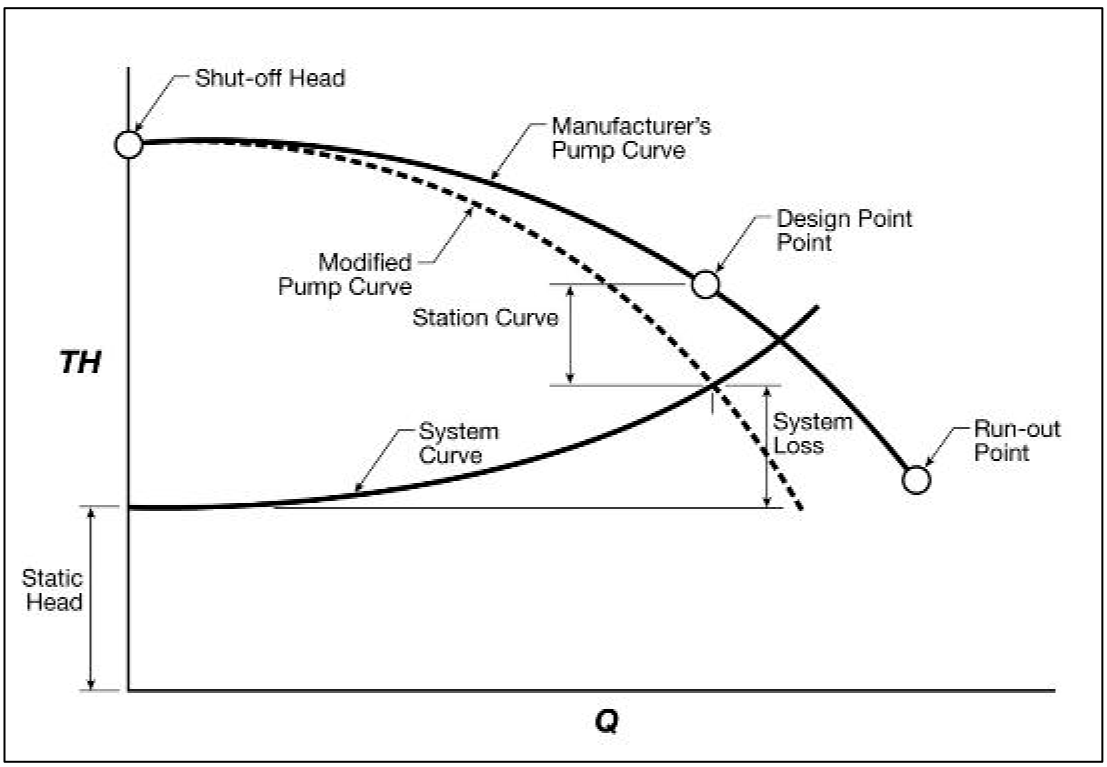
This section describes design elements of pump hydraulics.

A. Pump Characteristic Curve

The pump characteristic curve is a graphical representation of the discharge that a pump can supply against a particular head or total head (TH). In general, the pump's head capacity curve should be selected and specified to be of the type that is "constantly rising" towards the shut-off head. Operation of pumps at dips (reverse slopes) or flat spots in the pump curve is not permitted. Pump characteristic curves are unique and therefore are provided by the pump manufacturer or their representative.

When two or more pumps are operated in parallel, the station losses should not be added to the system curve. Instead, subtract the losses from the manufacturers' individual pump characteristic curve. This correction eliminates compounding station losses when evaluating overall pump station operation. Modifying the pump curve from the manufacturer results in a more accurate understanding of how each pump will operate. The resulting curve is called a modified pump characteristic curve or modified pump curve for short. Figure 11-17 shows an example modified pump curve. SPU operates wastewater pumps in parallel setting.

Figure 11-17
Typical Modified Pump Curve



Acronyms and Abbreviations
Q: flow
TH: total head

B. Shut-Off Head

The head produced by a pump at zero discharge is called the shut-off head. SPU does not recommend operating pumps continuously at or near the shut-off head. For large pumps, even operation for a few minutes at shut-off head may damage the pump. Adverse effects of operation at shut-off head are heat build-up and excessive vibrations.

C. Pump Runout

The last or maximum discharge point shown on the manufacturer's pump curve is referred to as the pump runout point. Runout implies “close to running away,” which refers to operating against little head and pushing enough flow that the pump operating on the extreme right of, or beyond, the end of the manufacturer’s published performance curve. Operation on this part of the curve is outside the manufacturer’s recommended operating region and is a region of low efficiency and high-power consumption and causes vibration and cavitation damage. This condition is often made worse by the fact that conservative engineering can overestimate pipe friction. Pumps should primarily be selected for where and how they will operate most frequently. To help avoid this condition, the design engineer should evaluate proposed pumps across the entire range of possible pipe friction losses.

D. Acceptable Operating Range

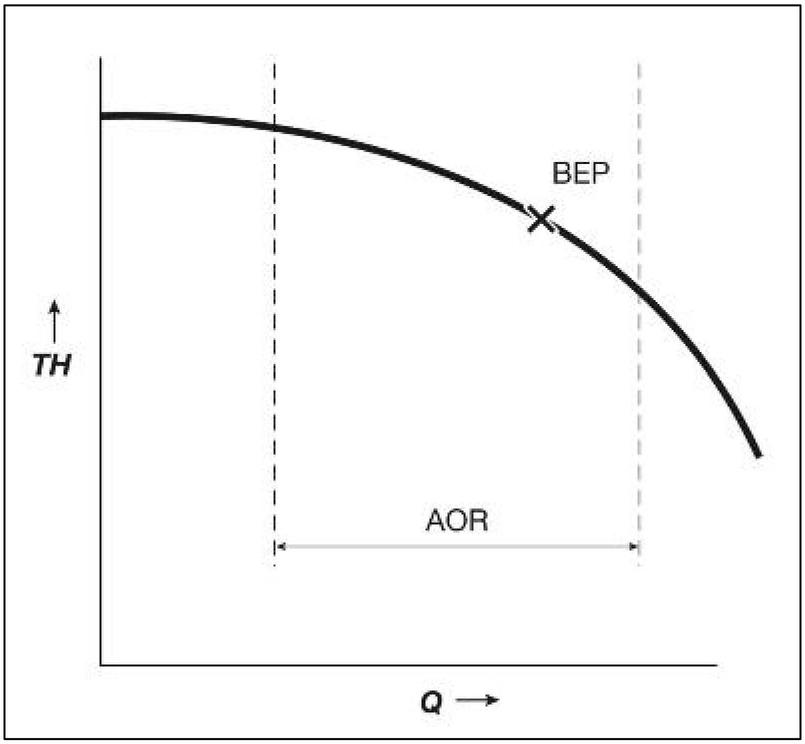
Acceptable operating range (AOR) is the range of flows over which the service life of the pump will not be seriously compromised. If run outside of this range, bearing life may be reduced, and noise, vibration, and component stresses may be increased. Pump manufacturers will typically provide the AOR, which is best shown directly on the pump characteristic curve. See American National Standards Institute (ANSI)/HI 9.6.3.

The far-right side of the published pump characteristic curve is generally considered to be the maximum flow limit of the AOR. However, the minimum flow is designated separately. Operation outside the AOR may cause cavitation, excessive vibrations, and larger than usual radial forces on the impeller shaft. Maximum allowable pump discharge may also be limited by the NPSH and motor hp may be exceeded.

11.7.3.3 Best Efficiency Point

Best Efficiency Point (BEP) is the point on a pump curve where the pump achieves maximum hydraulic efficiency. Typically, pump BEP is shown on a pump characteristic curve that the manufacturer provides. Figure 11-18 shows a typical pump characteristic curve with the BEP and AOR from a manufacturer.

Figure 11-18
Typical Pump Characteristic Curve



Acronyms and Abbreviations
AOR: acceptable operating range
BEP: best efficiency point
Q: flow
TH: total head

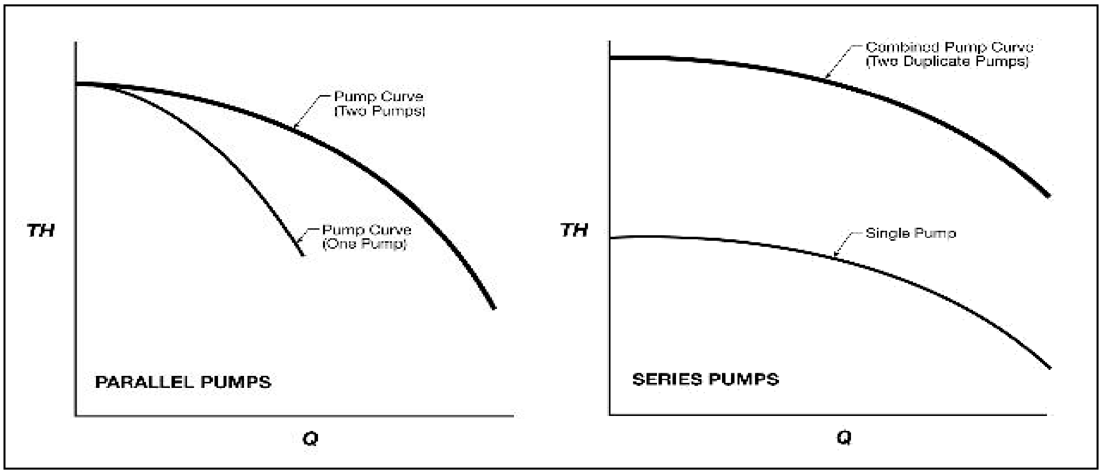
A. Preferred Operating Range

Preferred operating range (POR) is the range of flows over which the pumped flow is highly controllable. Within this range, the service life of the pump is not significantly affected by hydraulic loads, vibration, or flow separation. The POR for most centrifugal pumps is from 70% to 120% of BEP. For smaller pumps (0.5 hp), the manufacturer may recommend wider POR. See ANSI/HI 9.6.3.

B. Multiple-Pump Operation

When pumps are operating in parallel, pump head stays the same but the amount of flow increases (Figure 11-19). When pumps are operating in series, the TH increases but the flow remains the same. SPU currently only operates systems in parallel.

Figure 11-19
Pump Curves for Parallel Pumps and Series Pumps

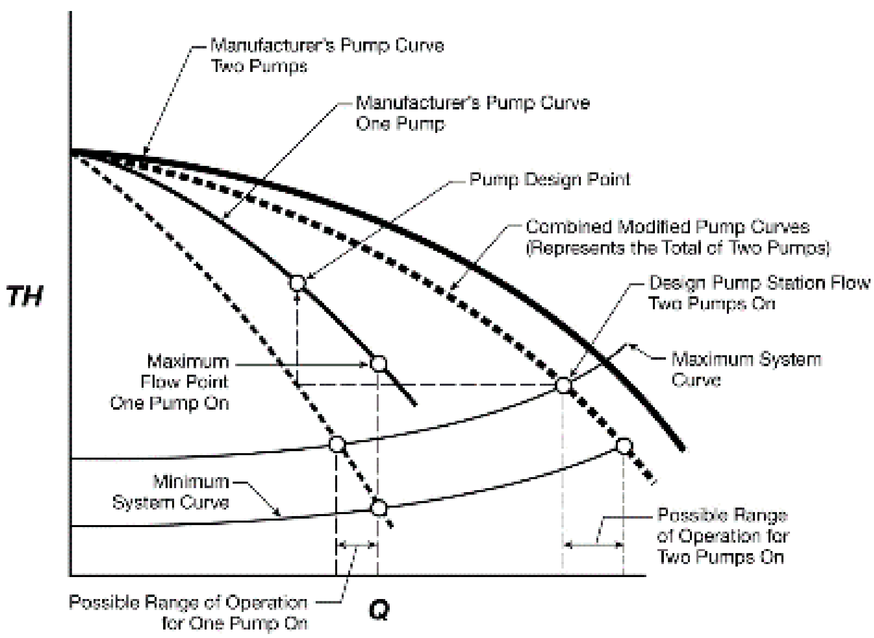


Acronyms and Abbreviations
Q: flow
TH: total head

11.7.3.4 Comparison of Pump Curves and System Curves

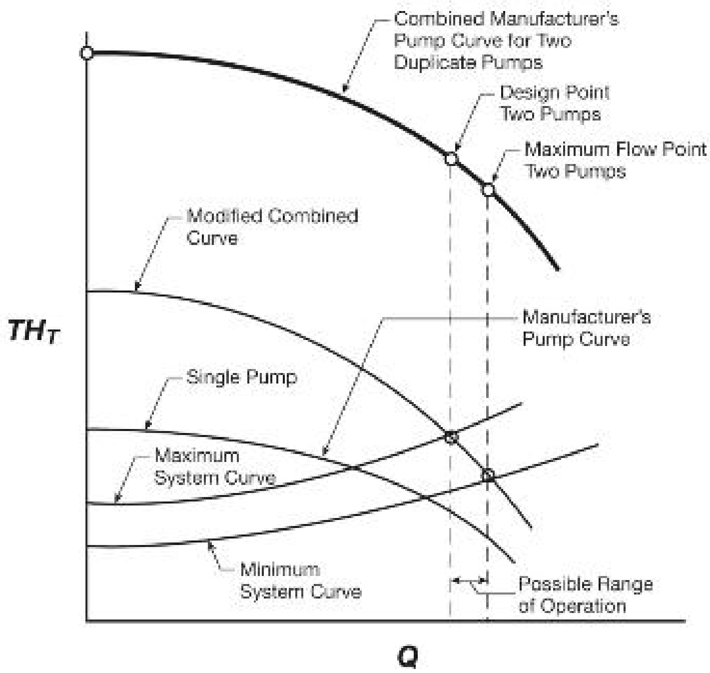
The design engineer should select a pump characteristic curve that, when modified to account for station losses, will intersect the maximum system curve at the design discharge. If possible, the pump should operate at or near BEP during typical conditions (Figure 11-20 and Figure 11-21).

Figure 11-20
Typical Modified Pump and System Curve (Parallel Pumping)



Acronyms and Abbreviations
Q: flow
TH: total head

Figure 11-21
Typical Modified Pump and System Curve (Series Pumping)



Acronyms and Abbreviations
Q: flow
TH: total head

11.7.4 Pump Selection

11.7.4.1 General

Pump selection for either variable or constant speed applications must consider typical operating conditions expected. In most systems, pumps will operate outside the POR for certain conditions. However, most system operating conditions can typically be met within the POR through careful pump selection and station design.

For SPU, the typical operating conditions are single pump lead-standby or dual pump lead-lag in parallel configuration. SPU recommends a strategy of selecting a pump where the most common operating condition on the system curve intersects the pump curve to the right of the pump's BEP, but to the left of the maximum limit of the POR when operating at 100% speed. This approach facilitates the maximum range of pump speeds and flows within the POR along the system curve.

Systems with relatively low static heads compared with friction losses can operate within the POR over greater design speed ranges than those systems with higher relative static head.

The following are basic principles that govern overall pump selection in order of importance:

- Pumps must be capable of meeting all design operating conditions.
- Pumps should operate within the POR for the most frequent operating conditions.

- Unless approved by all acceptable manufacturers for a particular project, pumps must operate within the AOR, even for less frequent operating conditions such as minimum and maximum pumping rates.

11.7.4.2 Pump Selection Criteria

Pump selection must be based on the following standards unless otherwise authorized by SPU:

- Impeller diameter: Not to exceed 90% of maximum impeller size
- Minimum pump efficiency: 80% for water and 60% for wastewater and drainage
- Minimum speed – wastewater: 885 revolutions per minute (rpm) (900 rpm nominal)
- Maximum speed – wastewater: 1770 rpm (1800 rpm nominal)
- Solids handling – wastewater: 3-inch sphere

Exceptions for efficiency requirements may be considered for pump stations that require specialized pumping equipment for rag handling. If impeller sizing requirements cannot be met, contact the SPU project engineer. For more detail on pump design criteria, see DSG section 11.4.2.

A. Constant Speed Pump Selection

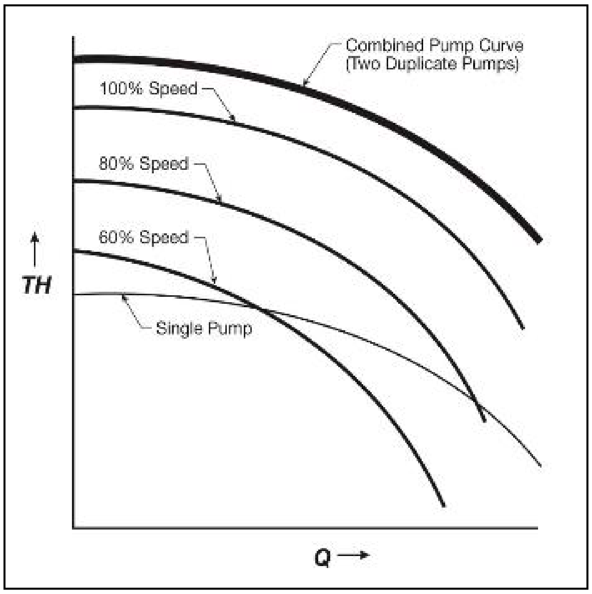
For constant speed pumping applications, pump selection is relatively straightforward. Pumps should be selected that most closely match the pump BEP with the most frequent operating point from the system curves.

B. Variable Speed Pump Selection

Pump affinity laws govern pump operation at multiple speeds. Figure 11-22 shows how pump characteristic curves are translated at different pump speeds. For detailed explanation, see Pumping Station Design (ed. Robert Sanks).

Variable speed pump selection introduces an additional dynamic to pump selection. Proper hydraulic selection will allow the pumps to operate through a maximum range of speeds and flows within the POR. Efforts should be made to maximize the time that the typical operating conditions fall within the POR, while ensuring that other extremes (e.g., maximum and minimum flows) can be met with the selected pumps.

Figure 11-22
Variable Speed Pump Curves



Acronyms and Abbreviations
Q: flow
TH: total head

1) Water Pump Stations

For potable water pump stations, selection of variable speed pumps should be carefully considered. Because of successful water conservation, SPU water pump stations may have ample, or even excess, capacity. On these pump stations, pumps with variable speeds may provide a relatively simple way to significantly reduce power costs, improve operational control, and add flexibility. Modern variable speed pumps are cost effective and reliable. When modifying or upgrading existing pump stations, the design engineer should evaluate using variable speed pumps.

2) Wastewater Pumps Stations

For wastewater pump stations, the increased use of variable speed pumping may increase pump clogging. The source of the problem is often operating the pump in a range below the POR. When the pump operates below the POR, suction recirculation can occur. Recirculation tends to wrap debris around the pump impeller blades and generates additional debris in the suction piping. The debris can eventually accumulate on the impellers. When operating within the POR, suction recirculation is limited and debris passes through the pump more easily. Proper selection and operation of pumps is critical to minimize pump clogging. The design engineer should be aware of the following:

- **Multiple Pump Operation with BEP at Peak Flow Rate.** This can result in single pump operation intersecting the system curve outside the AOR throughout most of the pumps operating range. It also causes the pump to operate frequently at or near runout conditions, resulting in increased maintenance and hydraulic inefficiencies.

- **Variable Speed Operation at or left of BEP at Full Speed.** For pumps intended to operate at multiple speeds, this approach can severely limit the range of speeds over which system performance will fall within the POR or AOR. As pump speed is decreased, the POR and AOR effectively move to the left relative to the system curve. That means less of the total POR or AOR will overlap with the system curve(s) at all other speeds.

11.7.4.3 Impeller Selection for Drainage and Wastewater Pumping

Several types of impellers are available for drainage and wastewater pumping. Each impeller type is designed for a specific type of product and operating condition. SPU uses all impeller types throughout the system. The design engineer must coordinate with SPU Operations and the pump manufacturer to select the impeller type and material of construction most appropriate for the hydraulic conditions and the amount of solids/rag loading of the expected influent at a pump station. Contact SPU Operations and SPU Source Control for information on existing ragging issues at particular stations. The available impeller types and the associated uses for application at SPU pump stations are described in detail in the sections below.

A. Enclosed ('non-clog') Impellers

Enclosed, or non-clog, impellers have long been industry standard recommendation for wastewater pump stations. These impellers offer excellent efficiency, smooth operation, and minimal NPSH requirements. However, enclosed impellers are prone to ragging and clogging. These impellers should not be used at stations with known ragging issues.

B. Semi-Enclosed ('delta') Impellers

Semi-enclosed, or delta, impellers generally omit the bottom shroud found on enclosed impellers. Delta impellers sacrifice some efficiency and increase potential for vibration in exchange for improved rag handling capability and reduced clogging.

C. Cutter Impellers

Cutter impellers feature a fixed blade on the pump suction plate that acts against rotating blades on the bottom of the impeller. This design generates a scissoring effect that reduces the size of rags and directs rags through the pump. These impellers offer excellent performance in stations with moderate ragging, with minimal loss of efficiency. In many cases, cutter impellers can be retrofitted into existing modern pumps.

D. Chopper Impellers

Chopper impellers are unique to specific types of pumps. They generally provide very poor hydraulic efficiency but operate under the most severe ragging conditions.

E. Screw-Centrifugal

Screw-centrifugal impellers are a unique hybrid type that offer excellent hydraulic efficiency and excellent rag-handling capabilities. Pumps with screw-centrifugal impellers typically require more vertical space and are generally only serviceable by specialized machinists. SPU operates screw-centrifugal pumps at only a small number of stations that are subject to extreme ragging conditions.

F. Impeller Material Selection

Impellers are available in a wide range of materials and coatings. Cast iron impellers are appropriate in most situations. The design engineer should consult with the pump manufacturer to select the most appropriate impeller material and coating (if applicable) for each situation. Stations with corrosive or rock and grit-laden influent, especially stations fed from beach lines, may require impellers constructed of stainless steel or other exotic metal alloys.

11.7.4.4 Pump Redundancy

A. Water Pump Stations

Redundancy and flexibility are extremely important for the water transmission system. The overall system must be designed to remain fully functional when any one major component is out of service.

The following are guidelines for water pump station redundancy:

- For critical water pump stations, it may be justified to provide three pumping units each sized at 50% capacity. In this scenario, even if two pumps are not operational, the station can still accommodate 50% capacity.
- A business case and risk analysis should be performed before selecting this method.
- Consult with utility operations staff about redundancy needs early in the planning process.

B. Drainage and Wastewater Pump Stations

SPU requires a minimum of two pumps for drainage and wastewater pump stations. When two pumps are used, one must be a 100% duty unit and one must be for 100% standby. Pumps must alternate duty and standby roles with each pumping cycle.

If another layout or configuration is selected, the firm capacity must be met with the largest unit out of service.

11.7.4.5 Multiple Pump Operation

Multiple pumps may be required for pump stations that have frequent operation at two or more required flows/pressures that are significantly different from one another. The further apart the most frequent operating points are from each other on a system curve, the more difficult it becomes to identify a pump that can operate efficiently across all system demands. Multiple pumps may also be required when a local utility cannot deliver the service required to operate larger, single pumps. Local utilities may limit the maximum power or other such parameter of any single piece of equipment in certain areas to protect their service base.

For stations with multiple pumps, the effect of multiple pumps being out of service should be considered when determining the level of redundancy that should be provided. Facilities must meet the required firm capacity with the largest unit out of service.

The following are the most important factors for multiple pump operation:

- For pumps operating in series, pump discharge pressures are additive while total flow remains constant. The discharge of Pump 1 is connected to the suction of Pump 2 with no other (normally open) process connections.
- For pumps in parallel, pump discharge flows are additive while pressures remain constant. The discharges of Pumps 1 and 2 are normally open and connected to a common discharge header and both pumps are in operation.

11.7.4.6 Motor Cycling

Pump motors and starters need to cool a sufficient time between starts or they will overheat causing thermal overload protectors to trip out and stop the motors. The time needed between pump starts—called cycle time—increases with motor size. Recommended maximum values for across-the-line (from idle to full operation) motor starts per hour are provided in Table 11-27. The corresponding required cycle times should always be verified with the motor manufacturer, especially if the number of starts per hour will exceed the values shown below. Submersible motor manufacturers may allow additional starts per hour depending on the installed conditions.

Table 11-27
Recommended Motor Starts per Hour

Type	Size (hp)	Maximum Starts (per hour)
Horizontal Split Case Pumps	< 20	6
	20 to 50	4
	60 to 200	2
	> 200	1
Non-Submersible Motors Installed in Dry Well	< 20	6
	20 to 50	4
	60 to 200	2
	> 200	1
Submersible Motors Installed Submerged in Wet Well	100 or less	8
	> 100	6
Submersible Motors Installed in Dry Well	100 or less	6
	> 100	4

Acronyms and Abbreviations
hp: horsepower

The following is the formula for the required wet well volume based on pump cycle time:

$$V = \left(\frac{t \times Q}{30}\right)$$

Where:

V = wet well volume (ft^3)

t = motor cycle time (minutes)

Q = pump flow rate (gpm)

The pump station wet well sizing example (**Appendix 11D - Example Calculations - Wet Well Sizing**) shows how to calculate wet well volume. One method for reducing the required wet well volume is incorporating control strategies that stagger pump operation in multiple pump installations. In a two-pump installation, alternating the pumps will result in an effective overall motor cycle time for each pump. That time will be only half as long as it would have been if one pump served as the sole duty pump and the other as standby. As motor cycle time decreases, so does required wet well volume.

11.7.4.7 Pump Seals

Flush-free mechanical seals must be used on all wastewater and drainage pump stations. Availability of flush-free mechanical seals, and their performance at the anticipated system pressures, should be verified with the pump manufacturer. When possible, use readily available flush-free mechanical seal components, such as the John Crane brand. Avoid use of proprietary seals.

11.7.4.8 Manufacturer Preferences

Table 11-28 shows the manufacturer preference for SPU water and drainage and wastewater pumps in order of preference. When possible, select manufacturers with local service centers and parts warehouses. If pumps with long-lead or unique spares must be used, consult with SPU Operations to identify which spare parts should be procured and stored with the pumps.

Table 11-28
Preferred Manufacturers for Water and Wastewater Pumps

Pump	Company
Water	Aurora
	Fairbanks & Morse
	Worthington
Drainage/Wastewater	Cornell
	Fairbanks & Morse
	Aurora

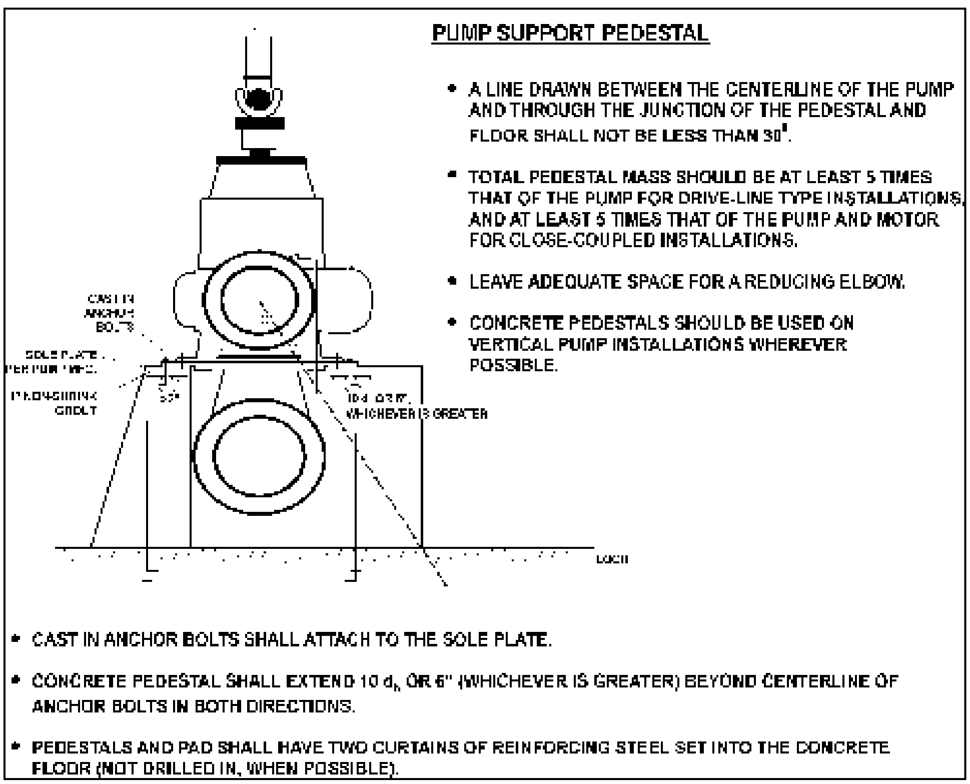
11.7.5 Pump Base Design

A proper base support is essential to minimize vibration on all rotating equipment. Pumps that are 50 hp or smaller may successfully use manufacturer-provided mounting bases. To minimize potential pump base problems, SPU recommends using concrete bases over steel frames for larger pumps.

Concrete pump pedestals should be used for pump supports and designed for easy maintenance access (Figure 11-23). The pedestals can be designed with vertical sides to maximize the amount of concrete mass beneath the pumps. Tapered sides can be used to improve access between pumps. Incorporation of a sole plate on top of the pump pedestal allows the pump to be accurately leveled and eases pump removal and maintenance. It is critical that the sole plate be properly grouted into place to provide firm contact between the pump and the pedestal. Cast-in-place J or headed anchor bolts should be provided to affix the sole plate to the pump pedestal. The pump pedestal should be anchored to the pump station floor using cast-in rebar curtains wherever possible, although epoxy grouted connections are acceptable for retrofits.

Pump bases are unique for submersible pumps installed in a wet well. Their geometry can significantly affect the pump intake hydraulics. Sufficient exposure is required to the wet well volume or pump suction appurtenances.

Figure 11-23
Pump Base Support



11.7.6 Piping Support Design

Proper installation of piping, supports, and restraint fixtures is required for optimum pump performance and reliability. The installed piping must be supported by pipe supports connected to the surrounding structure and not by the pump itself. Extra loads on the pump nozzles can be created by lack of or inadequate pipe support systems, leading to misalignment of the pump shaft with the driver shaft, binding or rubbing of the pump rotor, and in extreme cases, the breaking of pump nozzles or feet. Another piping problem is natural frequencies of the piping system causing the pump to operate out of range. A properly designed pipe support system holds the weight of the pipe rather than imparting such loads on the pump nozzles, while restraints and guides are used to redirect the forces generated by thermal effects and thrust away from the pump nozzle. Pipe supports must be designed to handle vertical, horizontal, axial, thermal, and seismic forces. See *DSG Chapter 4, General Design Considerations*. Do not connect piping to pump nozzles with flexible rubberized couplings, as these may result in piping misalignment when they are improperly installed.

11.8 WET WELL DESIGN

Wet wells are required for wastewater and drainage pump stations. The design engineer should follow the HI American National Standard for Pump Intake Design (ANSI/HI 9.8-1998). Critical design considerations for solids-bearing fluids include:

- Flow should not decelerate between the wet well and the pump inlet
- The wet well should incorporate minimal horizontal surfaces and should be free from low-velocity zones where solids are most likely to accumulate
- Wet well geometry should discourage large-scale flow circulation patterns
- Provisions should be included to periodically create turbulence in the wet well to re-entrain settled solids, floating grease, and debris

Wet well sizing is nearly always a function of required storage rather than pump hydraulic performance. Wastewater pump station wet wells require storage capacity to avoid excess cycling of pump motors and for storage. This storage is required to accommodate pump start failure and to provide time for maintenance crews to respond to power failures or other problems. The storage required for managing pump cycling differs from that required for adequate storage. Each should be considered and the larger value used whenever possible. Cost and space limitations may limit size. At a minimum, the impacts to motor cycling and emergency response time (a function of adequate storage volume) should be noted for the wet well size (volume) chosen.

Improperly designed wet wells can result in excessive capital and O&M cost and can compromise pumping equipment reliability. Adverse hydraulic conditions at the pump intake are among the most common source of pump station problems. These problems include vibration, cavitation, pump failure, unnecessary pump maintenance, and excessive wet well cleaning and maintenance.

11.8.1 Typical Wet Well Arrangements

Three typical configurations of wet wells are (1) self-cleaning trench, (2) rectangular style, and (3) circular. The following discussion focuses on wet well arrangements. However, the same principles apply to the dry well/wet well configuration. Table 11-29 summarizes important characteristics of each style of wet well.

Table 11-29
Wet Well Self-Cleaning Trench vs. Rectangular Style

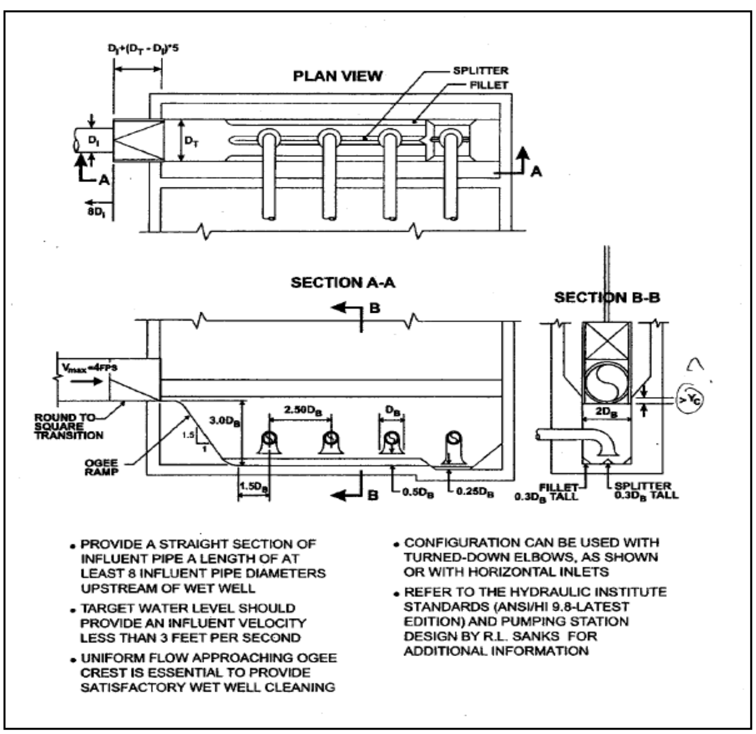
	Self-Cleaning Trench	Rectangular
Usable Wet Well Volume Relative to Total Size	Small	Large
Required Pump Inlet Submergence	High	Average
Most Beneficial Application	Variable speed pumping with minimal motor cycling time	Constant speed pumping with highly variable wet well operating volumes
Maximum Recommended Capacity	None	About 8 mgd

Acronyms and Abbreviations
mgd: million of gallons per day

11.8.1.1 Self-Cleaning Trench Wet Well

SPU recommends the self-cleaning, trench-style wet well for solids bearing water (Figure 11-24) when constructing new facilities. The HI pump intake standard provides guidance for design of the self-cleaning wet well. However, additional information is necessary to effectively implement this design.

Figure 11-24
Self-Cleaning Wet Well Configuration



Acronyms and Abbreviations
Vmax: maximum influent velocity
Di: inflow pipe diameter
DT: width of trench
Db: diameter of intake bell

The following are design criteria for a self-cleaning, trench-style wet well:

- These wells are sensitive to the uniformity of wet well approach flow. To ensure proper influent hydraulics, a minimum of eight equivalent diameters of straight influent conduit are recommended upstream of the wet well.
- A smooth and uniform transition between the influent pipe and the ogee ramp is required to clean the wet well. To facilitate this transition, the narrow portion of the trench should extend above the invert of the transition section by a distance greater than the critical depth of the maximum influent flow during the cleaning cycle. The narrow portion of the trench should be the same width as the transition section unless a sluice gate is installed at the wet well entrance. For installations with sluice gates, space should be provided to allow the gate frame to fit within the narrow portion of the trench.
- The top radius of the ogee ramp must be designed so that flow does not separate during the cleaning cycle.
- Trenches can develop air-entraining surface vortices that can enter the pump inlet. For this reason, these trench designs require more pump inlet submergence than other wet well designs. The minimum submergence for this trench-style wet well should be 2.5 times the diameter of the inlet bell. It is generally good practice to provide a vertical distance of 2.5 inlet bell diameters between the invert of the influent sewer and the bottom of the turned-down flared inlet. For flared horizontal inlets (not unflared horizontal pipes), 2.5 inlet diameters are required between the invert of the influent sewer and the centerline of the intake. Additional submergence may be required based on the NPSH requirements of the selected pump. Close coordination with the pump manufacturer is required.
- Fillets and a center splitter are required to suppress subsurface vortex formation for the turned-down type inlet. Fillets and the center splitter should terminate into the ogee ramp, providing a smooth transition of the high velocity flow from the ogee ramp to the wet well floor during the cleaning cycle. The height of the fillets and center splitter should be equal to about 2/3 the bell to floor clearance.
- Because it has a small working volume, this trench-style wet well is most useful in variable speed pumping applications where influent flow can be matched by the pumping rate, thereby minimizing pump cycling and required storage.
- Where the influent sewer is used to increase either wet well working volume or storage volume, the slope of the surcharged portion of the influent sewer should be increased to facilitate scouring velocities during wet well cleaning. The influent configuration must be designed to prevent high-velocity influent flow from separating from the ogee ramp.

11.8.1.2 Rectangular/Circular Wet Well Design

The rectangular/circular design has been widely used and extensively tested through hydraulic modeling. It is a compact design more suited for constant speed pumping applications than the trench design. This style will, however, provide reasonable performance for variable speed pumping applications. Until the release of the next HI pump intake design standard, details for the rectangular wet well design can be obtained from ITT Flygt. Most existing SPU facilities employ rectangular, semicircular, or round wet wells.

11.8.2 Wet Well Storage

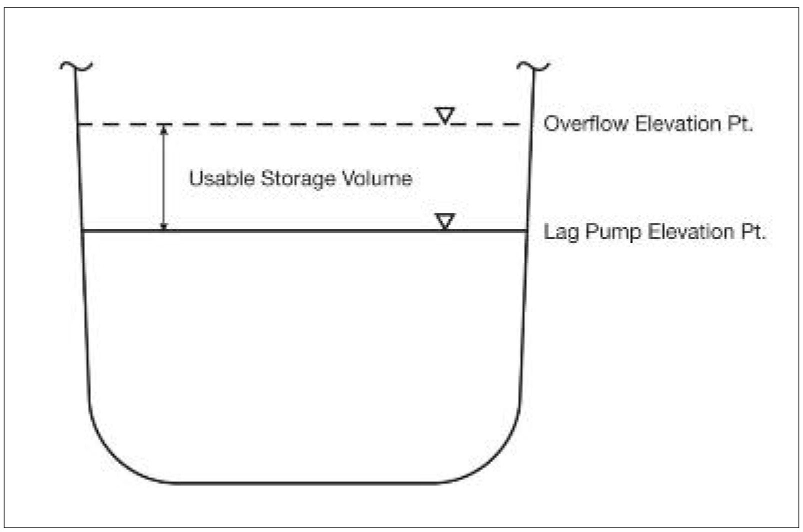
Adequate storage is required to reduce the risk of accidental overflow and allow SPU crews to respond to mechanical or electrical breakdown. All new pump station installations should be provided with adequate storage. Pump station renovation should include modifications to meet these requirements wherever possible.

The following are SPU standards for wet well storage:

- New pump stations must have at least one hour of wet well storage. Four hours of storage is desirable.
- If storage is less than one hour, the pump station must have an onsite generator.
- All SPU pump stations must have an e-plug (portable generator plug) if no onsite generator is present.

Figure 11-25 shows usable wet well storage volume.

Figure 11-25
Usable Wet Well Storage Volume



Wet well storage volume can consist of any combination of the following:

- Pump station usable wet well storage volume (lag pump elevation to overflow elevation).
- Capacity in gravity pipelines upstream of the pump station (up to a pre-determined water surface elevation that corresponds in some fashion to a system overflow condition before flooded basements).
- Separate detention basin that is normally dry but connected to the pump station specifically to provide additional storage volume (drainage only).

Choosing the condition at which wet well storage is evaluated has a significant effect on the required wet well storage volume. SPU evaluates response time based on analysis of historical inflow data under four different conditions:

- Average spring-summer inflow (April to September)
- Average winter inflow (October to March)
- Average wet weather inflow (SCADA wet weather tag for the active facility based on nearby rain gauge data)
- 95th percentile inflow

As available, at least two years of data should be used in calculating storage time. Storage time for all four conditions must be reported in the Basis of Design regardless of which value is used for calculating response time. This information is used to plan and guide future maintenance work at the facility. When estimating the available storage time, the design engineer should select the condition based on the nature of the inflow at a facility. Spring-summer inflow may not be used for this calculation. For new facilities, the anticipated maximum daily inflow indicated by hydraulic modeling should be used for calculating required storage volumes if flow monitoring data are not available.

Exercise judgment when determining how much, if any, capacity in the collection system can be used for wet well storage volume. Typically, a water surface elevation in the upstream gravity pipelines will correspond to an overflow or similar condition (e.g., the invert of a connected pipeline). The available volume of a collection system that can be used for emergency storage should be determined case by case depending on system geometry, pipe routing(s), backwater effects, and criticality of operation. The balance of the emergency storage volume must be met by either increasing the pump station wet well volume or incorporating a separate, dedicated detention basin that is normally dry, as noted above.

11.8.2.1 Provisions for Limited Wet Well Volumes

If it is not practical to provide a wet well of adequate size to meet the required wet well storage volume, the following provisions should be included as a minimum:

- New or redesigned pump stations should evaluate the need for a permanent generator using a cost/benefit analysis. Items to be considered should include volume of station, emergency storage time, history of power outages in the area, and other consequences.
- New pump stations with less than one hour of storage must have an onsite generator.
- Existing pump stations with larger flows (1 million gallons per day [mgd]) and less than one hour of onsite emergency storage during peak hourly flow must be evaluated for a permanent generator.

If permanent standby power system is not provided, all pump stations, regardless of storage capacity, should be equipped with space dedicated to and provisions for a portable standby generator.

11.9 CONSTRUCTION

This section describes construction design elements for pump stations. See also *DSG Chapter 3, Design for Construction.*

11.9.1 Submittals

Submittals are required for all equipment and materials provided by the Contractor as defined in the technical specifications. For pump stations, the following items should be carefully reviewed and approved:

- Materials verifying that proposed equipment meets all requirements of the specifications, paying particular attention to pumps, motors, motor starters and MCCs, SCADA equipment, and HVAC equipment
- Layout shop drawings for process piping
- Layout shop drawings for electrical equipment and conduit routing
- Manner and methods to performing activities such as installation and testing
- O&M instructions and requirements
- Certifications of compliance and completion of testing
- Testing and startup plan

Submittals are then reviewed in detail against the Project Manual. Pumps should be reviewed against the equipment data sheets developed in design and included in the specifications. Particularly careful review is required when a manufacturer and or model number other than the first named product is submitted.

11.9.2 Pump Station Testing and Startup

A well-defined plan is critical to successful testing and startup. This process begins with factory performance testing of the equipment (where applicable) and is completed with final approval of all checklist items and successful operation of the pump station through the test period.

11.9.2.1 Factory Performance Testing

Factory performance testing should be conducted for all water and wastewater pumps installed that have motors 5 hp and greater. For pumps smaller than 5-hp, the pump manufacturer may provide equipment based on previously performed tests for the specified pump design and similarly sized impellers to determine the operating characteristics. Pumping equipment may be accepted based on the manufacturer's normal quality assurance/quality control (QA/QC) testing, except for:

- For pumps in excess of 30 hp or 2,000 gpm, non-witness factory performance testing is required.
- For large pumping equipment with motors that exceed 200 hp or that have a capacity of more than 5,000 gpm, factory performance testing is required. Witnessed testing is preferred. The witnessed test should be observed by a representative of SPU that is familiar with the project and is qualified to understand the technical aspects of the factory test.

The following are typical SPU requirements for factory pump performance tests:

- Pump manufacturer should guarantee pump performance at the flow, head, brake hp, and efficiency specified.
- Testing setup should conform to the requirements and (HI standards (ANSI/HI 1.6 – latest edition). Testing must have a performance tolerance consistent with acceptance level 1U, as defined in the HI standards.
- Factory performance test should include at least five data points evenly spaced from minimum to maximum flow to define the shape of the pump curve.
- For variable speed pumps, testing should be conducted at full speed. Affinity laws can be used to establish reduced speed operating conditions.
- Pump curves developed during the factory test should be certified to guarantee performance.
- It is acceptable to test performance with a factory calibrated motor as opposed to the job motor. However, for large equipment that will have witnessed factory tests, SPU may decide it is more appropriate to use the job motor for the testing. Submersible pumps should be tested with the job motors.

Factory performance testing is also required for motors. See typical testing requirements in the example specifications (**Appendix 11A – Example Pump Station CSI Specifications**, within the pumping equipment specifications).

If the equipment does not meet the specified operating conditions during the factory performance test, the pump manufacturer should make the necessary modifications to the pumps until the specified operating conditions are met.

In general, it is not recommended that motors or VFDs be transported to the pump manufacturer's factory for performance testing. Although testing the motor and VFD at the factory with the pump could turn up operational problems, this testing approach is costly. It also presents unnecessary risk that the equipment could be damaged in transport.

11.9.2.2 Field Operational Testing

Field operational testing tests pump performance and the hydraulic design of the entire pumping facility. Field testing allows evaluation of pump intake design, force main hydraulics, pump and piping installation, and pump field performance.

The initial field test of a pump system should be done with the manufacturer's representative present. All acceptance criteria must be demonstrated under the full range of design flow and head conditions. Testing should be documented and signed off by the Contractor, vendor, engineer, and owner. The test will require that test equipment similar to that used for the factory testing be available. Much of the test equipment may be installed as part of the pump station design and should include:

- Flow meter
- Pressure gages on the pump suction and discharge piping
- Tachometer
- Power analyzer

Because the level of environmental controls is lower in field testing as opposed to factory testing, care must be taken to obtain a reasonable level of accuracy during field testing. Field data should be compared to factory testing data to confirm pump performance. Minor changes from factory performance should not cause alarm. Many factors affect performance, including data collection inconsistencies and differences in pump intake hydraulics. Significant differences between field tests and factory tests would be a more than 5% change in head and should be evaluated further. Field testing results should be used as a baseline condition to determine change in performance during future testing.

On large installations, specifications may require an independent company to do vibration testing. These tests document that equipment vibration does not exceed limits outlined in the equipment specifications. Many factors can cause excessive vibration: misalignment or imbalance of rotating equipment, improper pump support, or natural frequency of the pump and piping that is coincident with the pump rotating speed or a multiple of the rotating speed. If vibration levels exceed specified values, the root cause of the vibration should be identified and corrected promptly before it can cause long-term damage to the equipment.

11.9.2.3 Training

Project specifications should require the pump manufacturer to provide training for proper O&M of the pumping equipment. The trainer should have complete knowledge of this subject and should train for a minimum of two 8-hour sessions for small equipment and up to five 8-hour sessions for larger, more complex equipment. Training should be provided to representatives of the owner's O&M and engineering staff. The content of the training should include proper O&M of the equipment with both classroom and hands-on experience.

11.9.2.4 Checklists

Many items are confirmed during startup of a pumping system and each system varies. Whenever possible, particularly on large installations, a startup expert should be provided with a copy of the mechanical layout, specification information, and control write-up. The startup expert should develop a site-specific checklist for installation. For an example startup checklist, see **Appendix 11F - Operational Checklists**, **Appendix 11G - Equipment Testing Checklist**, **Appendix 11H - Operational Acceptance Checklist**, and **Appendix 11I - Systems Acceptance Testing**.

A. Pre-Operational Checklist

A pre-operational checklist is a tool for all parties to ensure that the pumping system has been correctly installed, checked by the Contractor, vendor, and owner's representative, and is ready for operation. It should be completed by the construction manager for the owner.

B. Initial Operational Checklist

The initial operational checklist compares actual pump performance to its advertised factory performance. The certified pump curve should be used for this comparison. During the test, pressures and flows at different operating points are plotted over the certified performance curve. These values should be checked to make sure they are within design tolerances. This checklist is also used to ensure that auxiliary systems that support pumping operation are operating effectively at their designed set points.

Information collected during the test should be used as baseline pump performance data for maintenance purposes.

C. Post-Operational Test Checklist

Once the pumping system is put into operation and has operated for a test period (typically seven days), a post-operational test is done. This test should ensure that flow rates, have not been compromised and no detrimental grout cracking, or vibration have occurred.

11.10 OPERATIONS AND MAINTENANCE

SPU Operations staff are responsible for maintaining pump stations in reliable and ready condition. If equipment fails, the staff should be able to respond and make repairs quickly and safely to prevent or minimize negative environmental impacts. Specifications must require that the Contractor submit O&M manuals in both printed (three copies) and electronic format (PDF and editable Microsoft Word format). Manuals, including electronic copies, must be indexed by system and piece of equipment. Electronic manuals are stored by SPU Operations' as well as on the SOPA DWW Facilities SharePoint page for universal access.

11.10.1 Routine Maintenance

SPU pump stations are inspected on a regular schedule. The required frequency of inspection is determined on a station-by-station basis using the reliability centered maintenance (RCM) strategy.

A schedule listing the preventative maintenance and inspection frequency is maintained for each station. Typically, preventative maintenance activities for pump stations include routine inspection of the following:

- Air release valves
- Bearings
- Couplings
- Drives
- Generators
- HVAC equipment
- Impellers
- Motors
- Other ancillary equipment
- Pumps
- Seals
- Wear clearances
- Wet wells
- Grounds and landscaping

Periodic service and calibration of all instrumentation such as level sensors, alarms, flow meters, and SCADA equipment should also be conducted as a part of routine maintenance activities.

11.10.2 Reliability Centered Maintenance

RCM is an engineered process used to determine what must be done to ensure that any physical asset continues to do what its user wants it to do in its present operating context. The RCM process identifies all of the functions and performance standards of the asset being evaluated and then determines all of the ways that asset can fail. The RCM process also defines what risks are associated with the asset in terms of safety and environmental integrity, customer service and so on. RCM identifies a suitable failure management policy for each failure mode in the light of its consequences and technical characteristics. Failure management policies may include predictive or preventive maintenance, training, or redesign of existing systems. RCM offers the following:

- Greater safety and environmental integrity
- Improved operating performance (output, product quality, and customer service)
- Greater maintenance cost-effectiveness
- Longer useful life of expensive assets
- Comprehensive database of maintenance requirements
- Greater motivation of individuals from improved knowledge of equipment
- Better teamwork through common language and understanding of what must be done

SPU has developed a program to evaluate existing systems including pump stations. All new pump station facilities must have an RCM analysis done before startup and testing. The analysis will include a detailed operating context for the station, failure modes and effects analysis, and preventive maintenance tasks. Results of the analysis must be implemented through MAXIMO.

11.10.3 Performance Testing/Energy Audits

To maintain acceptable pump station capacity, annual performance testing is conducted on all wastewater and drainage pump stations and on stations that are near design capacity.

Pump station performance testing consists of collecting flow and head data for each of the pumps and comparing the data to the certified pump curves provided by the pump manufacturer. The performance testing is similar to that done at startup. The performance data collected at startup should be the baseline performance to which subsequent performance testing data are compared. The amount of acceptable degradation of pump performance can vary depending on design requirements and size of the pumping equipment. Generally, if pump performance has degraded by 5% from baseline, equipment maintenance should be considered. Minimum acceptable performance levels before maintenance overhauls are performed should be established for each pumping station.

Equipment wear can also reduce pumping efficiency. During evaluation of performance testing data, the efficiency of the pumping equipment should also be evaluated. The wire-to-water pumping efficiency can be determined during performance testing and can be converted to determine the energy consumption of the pumping station. Evaluation of energy consumption and amount of maintenance required for each pumping station will reveal where system upgrades would be most beneficial.

11.11 RESOURCES

Documents

1. ANSI:
    a. ANSI/AWWA D100, Welded Steel Tanks for Water Storage, and NACE Standard PRO 178
    b. ANSI/AWS D1.1, Structural Welding Code
    c. 73.1, Horizontal end-suction centrifugal pumps
    d. E101, Vertical turbine and submersible pumps
2. American Society of Civil Engineers (ASCE): Seismic Design (ASCE 7-02)
3. American Society of Mechanical Engineers (ASME): Boiler and Pressure Vessel Code, Section VIII, Pressure Vessels and 7.1, 8.2, Displacement and centrifugal pumps
4. ASTM International
5. American Water Works Association (AWWA): ANSI/AWWA D100, Welded Steel Tanks for Water Storage, and NACE Standard PRO 178, Item No. 53041 and E101, Vertical turbine and submersible pumps
6. City of Seattle (most current versions):
    a. Seattle Plumbing Code
    b. SDOT Streets Illustrated
    c. Seattle Energy Code
    d. Seattle Municipal Code
    e. Seattle Parking Requirement Code
    f. Sign Code (Seattle Land Use Code Ch. 23.55)
    g. Stormwater, Grading and Drainage Control Code (SMC 22.800-22.808)
    h. Environmentally Critical Areas (ECA) Ordinance (SMC 25.09)
    i. SBC
    j. SDOT
    k. SPU: Interim CIP Guidance
7. HI:
    a. Pump Intake Design (ANSI/HI 9.8)
    b. Rotodynamic Pumps for Pump Piping (ANSI/HI 9.6.6)
    c. Pump Intake Design Standard
    d. Standards (ANSI/HI 1.6 – latest edition)
    e. ANSI/HI 9.6.3
8. National Highway Institute: “Highway Stormwater Pump Station Design” Hydraulic Engineering Circular No. 24, USDOT Federal Highway Administration, Publication No. FHWA-NHI-01-007, February 2001
9. NEC: Section 501-8
10. NFPA 820, Recommended Practices for Wastewater and transmission facilities

11. NSF International: Standard 61
12. *Pump Station Design 3rd Ed.*, Editor-in-Chief Robert L. Sanks (the Sanks Book)

Websites

http://www.pumps.org/

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