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Chapter 11 PUMP STATIONS

This chapter presents Design Standards and Guidelines (DSG) for Seattle Public Utilities (SPU) pump stations for potable water, stormwater, and wastewater facilities.

Standards appear as underlined text.

The information in this chapter should be used in conjunction with other DSG standards. Related DSG standards include *Chapter 7, Drainage and Wastewater System Modeling; Chapter 9, Electrical Design;* and *Chapter 10, Instrumentation & Control (I&C).*

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.

Note: *This 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
A	amperes
AASHTO	formerly American Association of State Highway and Transportation Officials now just AASHTO
ac	alternating current
ACI	American Concrete Institute
ADA	American Disabilities Act
ADF	average daily flow
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
API	American Petroleum Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers

Abbreviation	Term
ASME	American Society of Mechanical Engineers
ASTM	formerly American Society of Testing and Materials; now just ASTM
AWV	Alaska Way Viaduct
BEP	best efficiency point
CIP	Capital Improvement Program
CSI	Construction Specification Institute
CSO	combined sewer overflow
DOH	Washington State Department of Health
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	Hydraulics Institute
HMI	human machine interface
HP	horsepower
HVAC	heating, ventilation, and air conditioning
I&C	Instrumentation and control
ID	inner diameter
IEEE	formerly Institute of Electronic and Electrical Engineers now just IEEE
LOB	line of business
MCC	motor control center
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NSF	NSF International: a not-for-profit, non-governmental standards organization also trademarked as The Public Health and Safety Company
OD	outer diameter
OI	operator interface
O&M	operations and maintenance
PAC	programmable automation controller
P&ID	process and instrumentation diagram
POR	preferred operating range
PS	pump station
psi	pounds per square inch
psig	pounds per square inch gauge
RCM	reliability centered maintenance
SCADA	Supervisory Control And Data Acquisition
SDCI	Seattle Department of Construction and Inspections
SDOT	Seattle Department of Transportation
TDH	total dynamic head
V	volt
VFD	variable speed drive
WW	wastewater

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.
grinder pump	A centrifugal pump with a grinder assembly on an extension of the shaft, designed to grind solids larger than a fraction of an inch before they contact the impeller.
guidelines	Advice for preparing an engineering design. Guidelines document suggested minimum requirements and analysis of design elements in order 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.
horizontal pump	A pump mounted with its shaft horizontal.
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 (NPSHa)	The NPSH at which the pump in a given system operates at a given discharge rate.
Net positive suction head required (NPSHr)	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.

Term	Definition
system head curve	Curve of total dynamic head vs. flow for all flow rates within the capability of the pump station.
total dynamic head (TDH)	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.
volute	A centrifugal pump casing that provides a gradually expanding liquid path to change the direction of flow and convert velocity to pressure.
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. Also called a wet pit.

11.2 GENERAL INFORMATION

11.2.1 Policy

SPU has no official policy on pump station elements and design life. Until 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.

11.2.1.1 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 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 (yrs)
Structural	Buildings (aboveground) and most structural elements	100
	Roof (water pump stations only): Composite Metal	 20-25 35+
Mechanical	Valves Piping (within pump station) Backflow preventers HVAC	30-35
Electrical	Motors time period between each rewinding starters and motor control systems[1]	10-25 20
Pumps		

Component	Type	Design Life (yrs)
• Water	Dry well pumps (horizontal axial split pumps, single or dual stage)	35+
• Drainage and Wastewater	Dry well / wet well pumps (centrifugal)	30-35
	Submersible pumps < 5 hp	10-15
	Submersible pumps >25 hp[2]	15-25

[1] Electrical elements other than motor windings may last 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.

Most SPU pump stations are more than 25 years old and still use original pump housings, and, in some cases, original motors. SPU has changed out many elements of these pumps and motors over the years. For water pumps, SPU has tracked repairs for the past 5 years. As more information is collected on component replacement, the design engineer should compare that data with the O&M manual for the component. If repairs occur more frequently than expected, an evaluation may be warranted for design life, repair, or replacement.

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.

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, then asset management principles should be used to determine if 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 line-of-business service levels. For water pump stations, the 2007 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 psi at utility meters and no 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, the 2006 Wastewater System Plan includes the following relevant targets for SPU facilities to meet by 2020:

- No more than one sewer backup in 5 years, on average, at any location, caused by a problem with the SPU sewer system
- Combined Sewer Overflows (CSOs) should be limited to an average of one untreated discharge per outfall per year and zero dry-weather overflows from permitted CSO sites.
- No overflow is allowed on the sanitary sewer system.

The SPU wastewater system is tied to King County's wastewater collection system. The design engineer should consider the impact on King County's system before modifying the SPU system. Any impacts to King County must be reviewed within the context of SPU's contract with King County. Data on existing operating conditions for wastewater pump stations may not be readily available. It may be necessary to install flow meters at pump stations and outfalls before design in order to have a reliable data set. 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 is developing its first two drainage pump stations. One is for the South Park neighborhood; the other is for the Alaska Way Viaduct project. For a potential drainage pump station, the 2004 Comprehensive Drainage Plan identified the following targets for managing stormwater runoff within City of Seattle 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 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. Such projects should only be undertaken when projected demand shows a potential for delivery pressures in the water distribution system or insufficient capacity in the sewer system. As a rule, new facilities should be considered whenever data indicate that maintaining current operations would result in missing the targets within 2 calendar years.

Another important component to meeting established SPU level of service is to maintain full operation of the existing facilities. As equipment reaches the end of its service life, its performance deteriorates. Generally, existing facilities will need rehabilitation, upgrade, or even expansion. Mechanical equipment (such as primary pumping units) has a maximum service life of 25 years. Therefore, a rehabilitation project should be considered for implementation whenever major equipment is known to be within 2 years of the end of its anticipated service life. SPU uses asset management principles to help determine whether upgrades or rehabilitate are justified and appropriate.

Equipment performance can deteriorate due to unexpected operating conditions. For existing facilities, rehabilitation should be considered when operation is repeatedly observed to be about 15% lower than expected performance. In such cases, the current installation and service conditions should be assessed to determine if replacement is necessary, and if upgrade or expansion is more appropriate than replacement in-kind.

11.2.3 System Maps

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

- Base Maps
- SPU GIS Mapping Counter (SMT 47th floor)
- Combined Sewer Overflow (CSO) Control Facilities O&M folders (SMT 44th floor)
- 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 102 water, wastewater, and CSO pumping stations. SPU has one drainage pump station under development at the time of DSG publication.

11.2.4.1 Water Pump Stations

SPU currently operates 31 potable water pump stations. SPU water pump stations have a minimum 1 to a maximum 4 pumps each. The stations capacities range from 110 to 38,200 gpm. The primary function of a water pump station is to transport water to storage facilities to meet peak-day demand 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; 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. With the exception of four pump stations, all SPU pump stations are electrical powered—one pump station has a diesel motor and electric motors; the other three are hydraulically powered by turbines.

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For specific addresses of these SPU facilities, contact Young Kim at SPU – 206-684-5918 or young.kim@seattle.gov.

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11.2.4.2 Wastewater Pump Stations

SPU currently owns, operates, and maintains 68 wastewater and three CSO pump stations. The SPU wastewater collection system consists of various types of lift stations and pumping equipment. Mechanical equipment in the system includes wet pit / dry pit type stations, stations with wet pits only, and pneumatic-lift-type stations. Most SPU wastewater pump stations are relatively small. Only three stations can deliver more than 10,000 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 collection infrastructure or the King County regional trunk collection system.

SPU pump stations vary in type, ease of operation, wet-well configurations, capacity, safety, and code compliance. For specific addresses of these SPU facilities, contact Young Kim at SPU – 206-684-5918 or young.kim@seattle.gov.

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11.2.4.3 Drainage Pump Stations

Currently, SPU is developing stormwater pump stations in South Park and for the Alaskan Way Viaduct project. Typically, drainage pump stations are installed as a flood control structure within a drainage basin to alleviate any flooding by a severe rainstorm. For specific addresses of these SPU facilities, contact Young Kim at SPU – 206-684-5918 or young.kim@seattle.gov.

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11.2.5 DSG Design Resources

DSG design resources include technical or material specifications developed specifically for and found only in the DSG. Design aids such as example calculations and checklists are other resources available in the DSG. The following design resources are available from this chapter.

- **Example Technical Specifications**. Example technical specifications for pump stations are presented in Construction Specifications Institute (CSI) format (**Appendix 11A - Example Pump Station CSI Specifications)**. Notes to the design engineer are embedded within these specifications, which are tailored for each contract. The design engineer should verify all sections of each specification to determine its application to the project:
  - CSI Section 26 24 19. Motor Control Centers
  - CSI Section 35 20 17. Valves, Gates and Appurtenances
  - CSI Section 43 21 37. Submersible Wastewater Pump
  - CSI Section 43 21 39. Submersible Pumps constant Speed
  - CSI Section 43 21 38. Submersible Wastewater Pump Mounted in Dry Pit
  - CSI Section 43 21 43. Submersible Sump Pump
  - CSI Section 43 21 01. Horizontal Split-Case Centrifugal Pumps
- **Example Calculations.** Example calculations are available for sizing pump station elements and selecting pump equipment (**Appendix 11B – Example Calculations - Head Loss**). These calculations are for reference only and not intended as standards. It is at the discretion of the engineer to select a methodology.
- **Example Cost Estimate.** The design engineer should prepare and update a construction cost estimate. The estimate should detail material costs, labor to install, equipment rental costs, and other large bid items. An example cost estimate format is provided (**Appendix 11C – Example Cost Estimates**). This example is a suggested format and not a comprehensive estimate.
- **Equipment Data Sheet Template.** An equipment data sheet template is provided as an example only (**Appendix 11D – Equipment Data Sheet Template**). It can also be tailored for instruments.
- **Operational Checklists.** Two operational checklists are provided as examples only (**Appendix 11E – Operational Checklists**).

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 of Seattle requirements or regulations conflict, the design engineer should discuss the discrepancy with the line-of-business owner, operations manager, and owner of this DSG chapter before resolving the issue (see contacts in DSG section 11.11).

11.3.1 Industry Standards

All pump station design should consider the standards and guidelines provided by the Hydraulics Institute (HI), ASTM, Pumping Station Design edited by Robert L. Sanks (also known as the Sanks book), and Washington State Departments of Health and 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 American Water Works Association (AWWA) standards.

In addition, water pump stations must meet Washington State Department of Health standards.

11.3.1.2 Wastewater and Drainage Pump Stations

Wastewater and drainage pump stations must be designed to local and Hydraulics Institute (HI) industry-accepted standards for solids-bearing water.

Newly designed wastewater pump stations must, at a minimum, meet the Washington State Department of Ecology's (Ecology) Criteria for Sewage Works Design.

All wastewater facilities, including pump stations, must meet Washington State Department of Health 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.

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

Organization	Standard	Description
Industry standards		
ANSI	73.1	Horizontal, end-suction centrifugal pumps
ANSI/AWWA	E101	Vertical turbine and submersible pumps
ASHRAE	Standard 90	Energy conservation in new buildings
ASME	7.1 & 8.2	Displacement and centrifugal pumps
ASTM	Various	Forging and coating of mechanical piping
AWS	D – 1.1	Structural welding code
AWWA		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
ADA	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	60	Purity of chemicals for drinking water
NSF	61	Purity of products for drinking water
SBC		Seattle Building Code
SFC	Chapter 6	Seattle Fire Code (Building Services and Systems)

Organization	Standard	Description
UBC		Uniform Building Code
UFC		Uniform Fire Code
UL	1004	Electrical Motors
UMC		Uniform Mechanical Code

11.3.2 Regulations

All pump stations must be built to the applicable City of Seattle and Washington State and federal guidelines including local building, fire, safety, and electrical codes for pump stations. The Seattle Department of Construction and Inspections (SDCI) and Seattle Department of Transportation (SDOT) maintain current lists of City of Seattle construction codes. See the SDCI Construction Code List and SDOT Construction Code List. Table 11-6 shows City of Seattle and Washington State regulations for pump stations.

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

Code	Document
City of Seattle	
• Right-of-Way Improvements Manual	SDOT Director's Rule/SDCI DR 2-05 / SDCI Rule 22-2005
• Stormwater Code	City of Seattle Stormwater Code (SMC 22.800 – 22.808) • Volume 1: Source Control Technical Requirements Manual (SDCI 15-2009 SPU 2009-003) • Volume 2: Construction Stormwater Control Technical Requirements Manual (SDCI 16-2009, SPU 2009-004) • Volume 3: Stormwater Flow Control and Water Quality Technical Requirements Manual (SDCI 17-2009, SPU 2009-005) • Volume 4: Stormwater Code Enforcement Manual (SDCI 18-2009, SPU-2009)
• Side Sewer Code	Side Sewer Code (SMC 21.16) SDCI/SPU Requirements for Design and Construction of Side Sewers Directors' Rule 2010-02 (Drainage and Wastewater Discharges)
• Pavement Opening and Restoration	SDOT Pavement Opening and Restoration Rules
• 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	Uniform Plumbing Code 2006
• Seattle Building Code	International Building Code w/ Seattle amendments, 2003
• Seattle Electrical Code	National Electrical Code w/ Seattle amendments, 2005
• Seattle Mechanical Code	International Mechanical Code
• Street Use Code	Street Use Code, SMC 15
• Seattle Fire Code	International Fire Code w/ Seattle amendments, 2014
• Washington State	
• WAC 51-13	Ventilation and indoor air quality 2006

11.4 BASIS OF DESIGN

For this DSG, basis of design documentation communicates design intent to plan reviewers and future users of a constructed facility. By documenting the basis of design and archiving it with the project record drawings (as-built), future staff has access to design decisions.

11.4.1 Basis of Design Plan Sheet

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

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

The sheet is not intended for construction and should **not** be included with the bid set. The sheet is inserted after the project has been bid. See *DSG Chapter 1, Design Process.*

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

PUMP STATIONS---

Pump Operating Conditions: _____________ gpm; _____________________ ft

Number of Pumps (provide info for each pump):

Size of Pump (range of gpm): ______________ Design Flow Rate: ___________________________

Pump Info: Impeller typ e_______________________; Maximum Sizing _____________________

Speed _________________; Efficiency ________________; Configuration ____________________

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

Pump Set Points: ____

Primary Power Source: ____

Backup Power Source: ____

NPSHA: ____________ ft Utility Power: _______________kWh Phase: _______________ V

Force main: size _____________; type ____________; length ___________________________

Static Head Elevation: _______________ft. Pressure Zone: _____________________________

Service Area: (Storm Only, Sanitary Only, Combined)___________________________________

Wet Well Storage: ___________________ hr

Manufacturer's pump curve, System Curve: ____

Project Specific/Special Information: ____

____

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 Each pump must be able to handle firm capacity
Pump Suction Sizing	Capable of handling minimum 3" solid
Maximum Pumping Cycle	Size dependent (consult manufacturer for recommended maximum pump cycle); no more than 1 to 8 per hour
Pump impeller Sizing	Not to exceed 90% of maximum impeller size
Pump Speed	Minimum 885 rpm Maximum 1770 rpm
Pump Efficiency	80% minimum for water pump station (PS) 60% minimum for wastewater and drainage PS
Submersible Pump Motor Seal	Tandem pump shaft seals w/ moisture sensing of space between seal
Pump Shaft Seals	Mechanical seal for wastewater and drainage (stormwater) PS

Description	Criteria
Bearing	Heavy duty. Minimum ANSI B-10 bearing life of 40,000 hr when pump operates at 25% of BEP capacity for impeller diameter supplied at maximum speed of operation
Piping	Ductile Iron Pipe CL52 *or* Standard Steel Pipe Schedule 40 with double-thick cement mortar lining
Force Main Velocity and Minimum Size Pipe	Minimum 2 fps Maximum 8 fps Minimum size 4" required
Net Positive Suction Head available ($NPSH_a$)_	5 ft greater than Net Positive Suction Head required ($NPSH_r$)
Check Valve	Horizontally placed swing check valve with outside lever and spring
Isolation Valve	Water PS see Table 11-24 Wastewater and Drainage PS see Table 11-23
Utility Power	Minimum 480V, 3-phase
Soft Starter	Required for pumps with 15 hp and higher
E-plug	Required for all wastewater and drainage PS without onsite generators
Back Flow Prevention System	Washdown water required for all PS
Electrical	See the Electrical section, of this chapter

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.

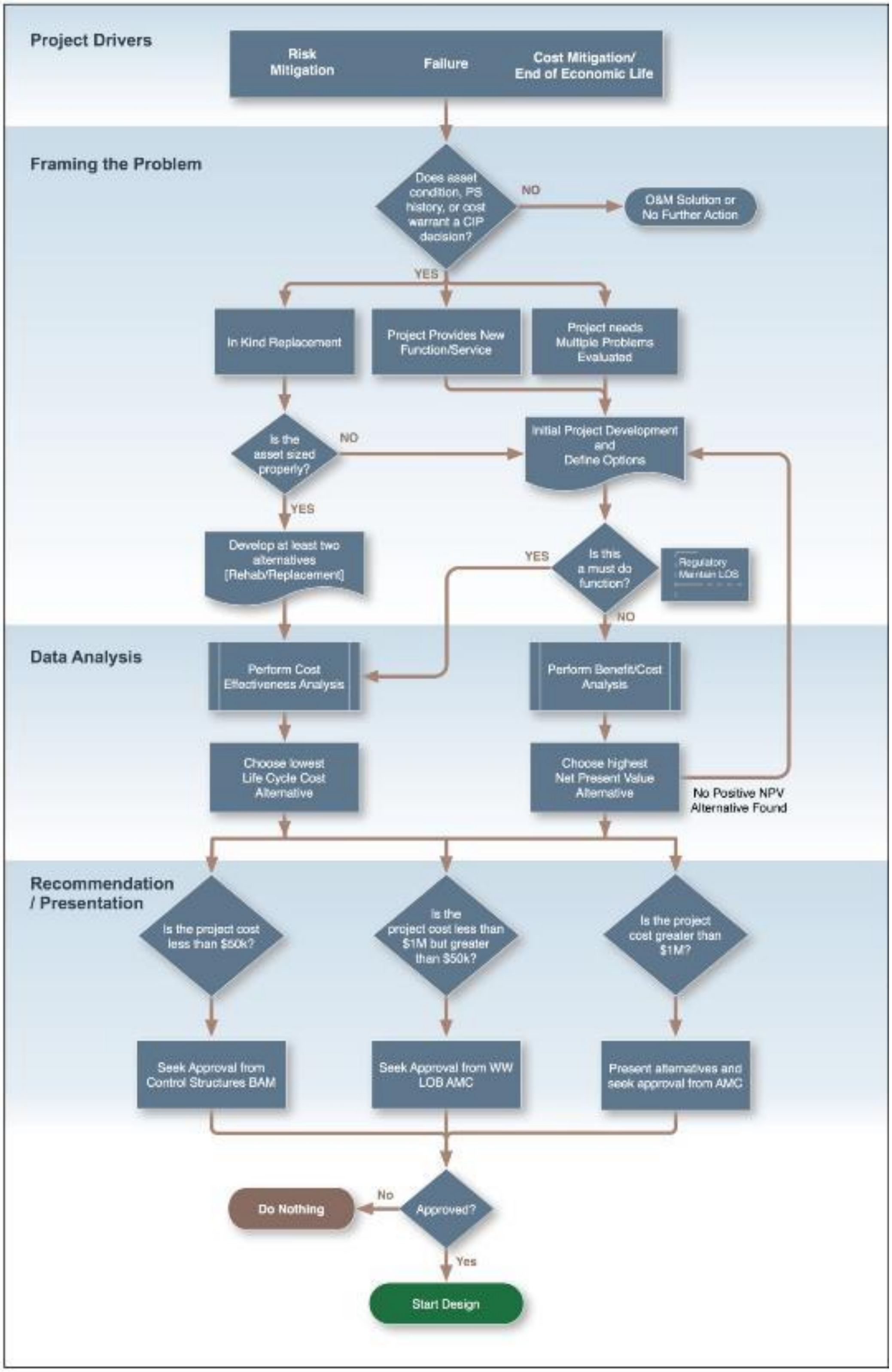
11.5.1 Planning

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. Line of Business (LOB) representatives use a four-step framework to develop Capital Improvement Program (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, 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.

Figure 11-4
Planning a Pump Station Retrofit



11.5.2 Design Process Documents

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

11.5.2.1 Preliminary Engineering Report

Typically, the preliminary engineering report for a pump station is submitted to the Washington State Departments of Health (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 (tanks, other stations, plants, etc.), 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 equipment layout, key building sections, electrical one-line diagram, prelim P&ID, control architecture, sheet &spec list finished design • Preliminary design calculations • SEPA Checklist

11.5.2.2 Design Calculations

Typical calculations for pump station design include hydraulic assumptions. These assumptions cover minor loss coefficients and friction factors and boundary conditions for the problem. 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).

Table 11-9
Typical Pump Station Design Calculations

Process / Mechanical	Structural	Electrical/ I&C	Geotechnical	HVAC / Plumbing
Hydraulic profiles and energy gradeline	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 (WW)	Loadings for cranes	Voltage drops		
Fuel storage demands	Equipment pad design	Utility/grid connection/protection		
Surge analysis and air/vacuum needs		PLC integration with existing SCADA.		
Pipe sizing				

11.5.2.3 30/60/90 Drawings

A 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).

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

Requirements	30%	60%	90%
Site Utilities (plans and profiles)	D	D	F
Pipeline Alignment Plans and Profiles	D	D	F
Construction Stormwater Plan			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
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 (P&ID)	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	F
Major Equipment Selection in Products Sections		D	F
Major Material Selections Completed (pipe, coatings, concrete, etc.)		D	F
General Requirements (sequence, constraints, work scope, asbestos determination, etc.)		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
Geotechnical Interpretive Report	D	F	F
Geotechnical Data Report	D	F	F
Geotechnical Baseline Report	D	F	F
Level I Environmental Assessment	E		
Level II Environmental Assessment (if required)		F	
Equipment List	D	D	F
Contractor/Subcontractor Qualifications Memo			F
SPU-Supplied Safety Checklist			F
O&M Impact Memo			F
Contract Time Memo			F
Calculations	D	D	F
Cost Estimate		D	F

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 items are *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 (power, fire flow, potable water, etc.). It should also list major safety considerations (whether or not 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 (i.e. overhead crane and monorails, hatches, pads, etc.). 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: NEMA ratings for all rooms, available corridors for routing electrical raceways and cable tray, and area classifications per NEC.
- 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.

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 are specific to pump station design:

- Hydraulic profile complete.
- Site plan with proposed final location of structures, roadways, and major site elements (fencing, gates, etc). 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 are 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.

11.5.2.4 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, 2015 edition (MF15). 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 MF15.

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

11.5.2.5 Equipment Data Sheets

During preliminary design, the design engineer should develop an equipment data sheet. At a minimum, an equipment data sheet must be developed for all equipment, instruments, and items that require power (including HVAC, plumbing, SCADA, security, and architectural items).

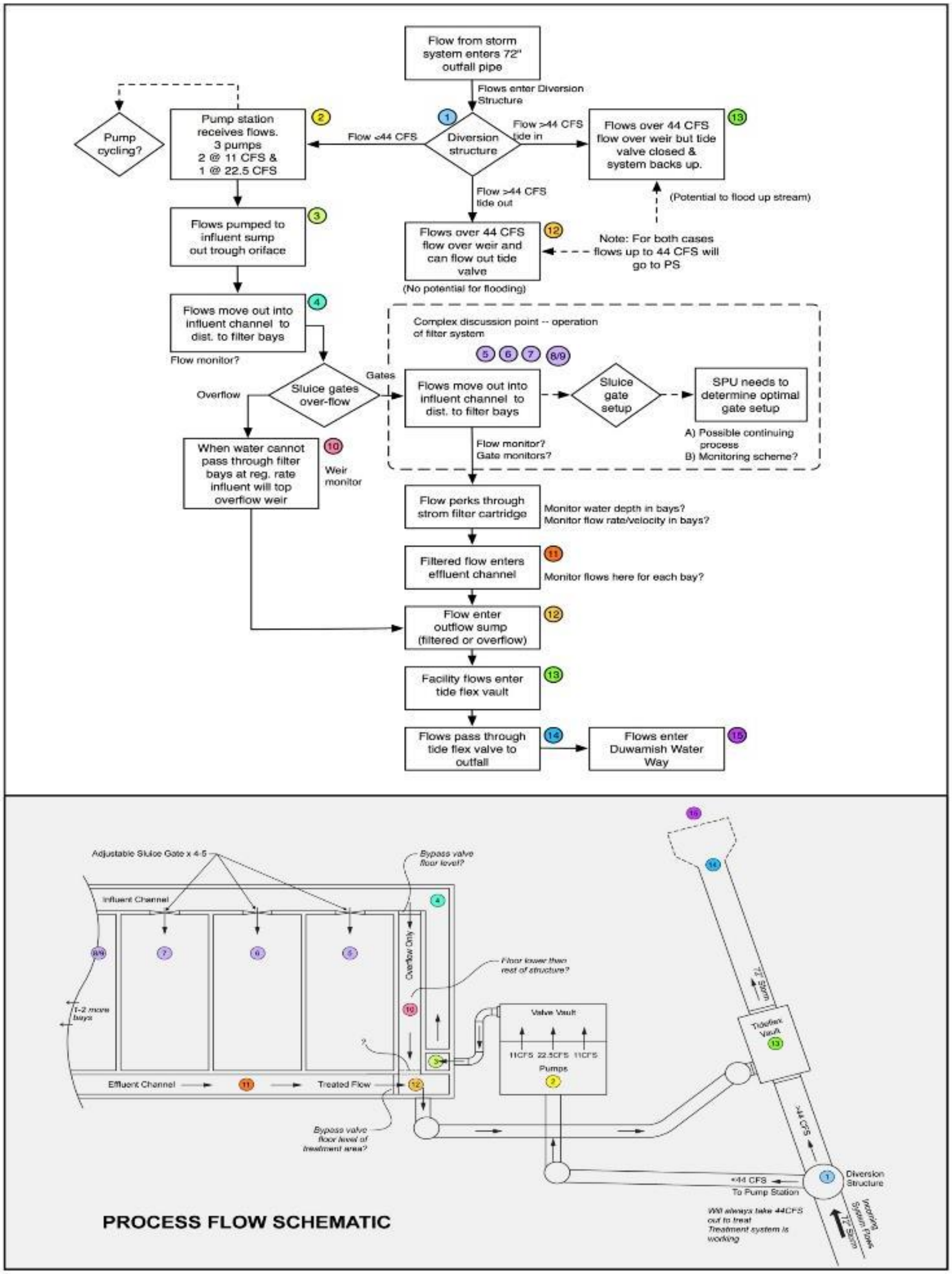
For an SPU template for equipment data sheets, see **Appendix 11D – Equipment Data Sheet Template.**

11.5.2.6 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. (Note: Figure 11-5 is project-specific.)

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 & Water Quality Facilities



11.6 OTHER DISCIPLINES

This section presents design considerations for pump station projects by design discipline. 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, pipeline corridors, bypass pumping, flood protection, water supply backflow prevention, parking, 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 the equipment completely out of the pump station. 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 vactor truck access to the wet well.

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-foot-high, 6-foot-wide double door
Access to Pump not at Grade	Stairs with step every 12 inches or less	Ladder, one per 10-foot vertical drop if total vertical distance is greater than 15 feet
Large Access Hatch for Lifting Equipment and Cleaning	Equipment dimension plus 10-inch minimum on all sides; overall minimum of 36" x 36"	Equipment dimension plus 6-inch minimum on all sides, overall minimum of 36" x 36" Hatch 6-foot wide and greater must be a double door
Lifting Mechanism	Boom truck preferred, then crane hoist. If roll up door is provided on grade, boom truck access not required	Crane hoist or overhead traveling crane
Clearance	8-foot minimum under lifting hoist, subject to overall equipment size	Largest equipment dimension in hoisting orientation, plus 2 feet between bottom of equipment and any other equipment in the station that must be crossed over

11.6.1.2 Parking

For facilities with offices and other staff spaces, see Seattle Land Use Code for parking requirements.

For all pump stations, a minimum of two parking spaces must be provided.

11.6.1.3 Fencing

A. Water Pump Stations

For water supply pump stations, SPU typically requires fencing fully around the site on or near the property line with sufficient vehicle access.

B. Wastewater Pump Stations

For wastewater pump stations, SPU prefers:

- Fencing around equipment and equipment enclosures and gates.
- Fencing to prevent access to any classified spaces.

11.6.1.4 Signage

Typically, pump station facilities have two types of signage on the outside: facility identification and public safety. Signage should be designed in accordance with Seattle's Sign Code (SMC 23.55). All warning signs must be in accordance with industry standards (NEC, OSHA, IEEE) and other applicable regulatory items.

Public safety signage warns the public of potential hazards on the pump station site. Hazards include chemicals stored onsite, wastewater, high voltage, relief valve discharge, etc. These signs should be placed in clear view in an easily accessible location without having to enter the property.

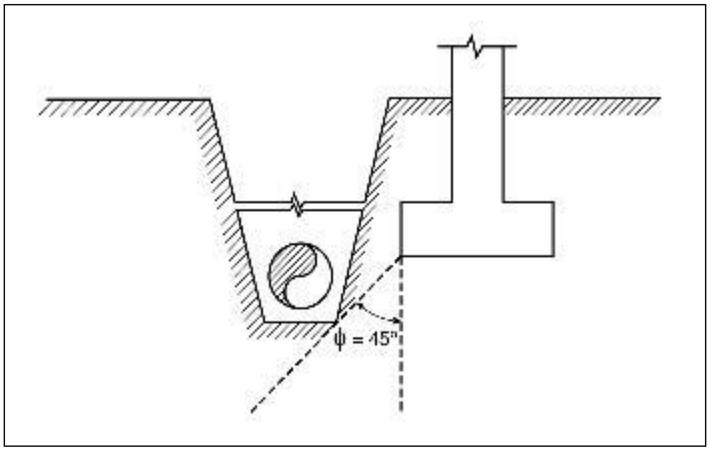
11.6.1.5 Pipeline Corridor

Corridors for pipelines to and from the pump station should be identified on the site layout early in the planning stage. The following are guidelines for laying out pipeline corridors:

- Pipes should not be located under buildings, except for entering and exiting the pump station. Straight piping runs should be provided into and out of pump stations to the extent possible. Pipes should be located away from building footings and outside of the footing influence zone, which extends down and out from the footing edge at a 45° angle (Figure 11-6).
- Parking is acceptable for normal vehicles and portable equipment over the pipeline corridor. Non-permanent or 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.

For minimum easement width, see *DSG Chapter 4, General Design Considerations.*

Figure 11-6
Pipe Corridor and Footing Influence



11.6.1.6 Bypass Capabilities

Bypass pumping capabilities must be included at all pump stations to maintain critical flows while the pump station is out of service. Such connections should be used when performing work at existing facilities.

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 discharge as part of the permanent piping system for wastewater stations.

Provide an isolation sluice gate to isolate the wet well during bypass pumping from the inlet flow to the pump station. For more information on bypassing, see *DSG Chapter 3, Design for Construction.*

11.6.1.7 Influent Screening

SPU does not typically provide screening (e.g. bar screens) on wastewater pump stations. However, drainage and wastewater pump stations should be screened to prevent large debris solids 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.

11.6.1.8 Fire Hydrants

Depending on facility size and operations, a protective fire loop may be needed around the facility. See Seattle Fire Department and SDOT for requirements.

11.6.1.9 Backflow Prevention

A. Water Pump Stations

Typically, backflow prevention is associated with water and fire service connections for pump stations for various uses (e.g. hose bibs, sinks, pump seals). See *DSG Chapter 17, Water Service Connections.*

B. Wastewater Pump Stations

All SPU wastewater pumps require cross connection control per the Washington State Department of Health (WAC 246-290-490).

11.6.1.10 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 property finished grade.

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 prefers 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.
- Raise building floors and equipment pads above the 100-year flood elevation.
- 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.

11.6.1.11 Future Expansion

During preliminary design, the design engineer should estimate the following future expansion needs for the facility:

- Permanent backup power supply
- Additional pumping equipment
- Additional wet well or dry well capacity
- Maintenance and storage facilities

- Parking
- Physical security

Site layout during design should include provisions for future facilities. Their locations should be clearly identified on the site plan drawings. Future facilities should be located to maximize the following functionality:

- Pumping equipment should be positioned close to the power source and electrical conduits installed (or space marked out) suitable for the power requirements.
- Backup power supply should be positioned close to the electrical room and be accessible to a generator fuel delivery truck.
- Construction of the expansion should not significantly disrupt ongoing facility operations.
- Valving and instrumentation should allow for the addition of new equipment while existing equipment remains in service.

11.6.2 Mechanical

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

11.6.2.1 Heating, Ventilation and Air Conditioning

Typically, HVAC systems are designed according to the American Society of Heating, Refrigeration 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

Location or Area	Air Changes/Hour
Equipment Rooms	15
Underground Vaults	12
Emergency Ventilation for Wastewater Head Space	15-60
Wet Pit – Class I, Div. 1	>12
Dry Pit – Class I, Div. 2	>8

Air change standards are of particular importance for wastewater for wastewater pump stations because they contain classified areas. Table 11-13 is the list of applicable codes and regulations that must be met for construction of all existing and new wastewater and drainage pump stations.

Table 11-13
Applicable Codes and Regulations

Codes and Regulations	Description
NFPA 820	National Fire Protection Agency
2012 Seattle Building Code	2012 International Building code (IBC) as Amended by the City of Seattle

Codes and Regulations	Description
2012 Seattle Fire Code	2012 International Fire Code (IFC) as Amended by the City of Seattle
2012 Seattle Mechanical Code	2012 International Mechanical Code (IMC) as Amended by the City of Seattle
2014 Seattle Electrical Code	2014 National Electrical Code (NEC) published by the National Fire Protection Association as NFPA 70, with State of Washington Amendments and City of Seattle Amendments
2012 Seattle Energy Code	2012 Washington State Energy Code (WSEC) as Amended by the City of Seattle

11.6.2.2 Design Standards for Seattle Public Utilities Wastewater and Drainage Pump Stations

To meet these objectives, the following criteria for ventilation systems must be met for construction of all existing and new wastewater and drainage pump stations.

- Dry well ventilation systems must be designed to receive an unclassified hazard classification as described in the National Electric Code (NEC) and National Fire Protection Association (NFPA) 820.
- Wet well ventilation system must be designed to receive a Class I Division I hazard classification as described in the National Electric Code (NEC) and National Fire Protection Association (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 National Electric Code (NEC) and National Fire Protection Association (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/from wet wells must have code-approved seal-offs.
- General Duct Criteria:
  - Sizing and Airflow Velocity: Minimum 6-inch-diameter, recommended airflow velocity of 1,500 feet per minute (ft/min); velocities up to 2,000 ft/min would be acceptable. See Table 11-14 for capacities of varies duct sizes based on the recommended and maximum velocities.

Table 11-14
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

  - Material:
    - Dry well: Galvanized steel or aluminum ducts. Anchors and supports should be either galvanized or stainless steel.

    - Wet well: Stainless steel or plastic (PVC, 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. Dampers are not required on wet well Interior Air Draw-Off and Supply 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 feet across) should use a supply diffuser with air throw distance and directionality as appropriate for the installation.
- Exterior Exhaust Outlet Locations:
  - Dry well: <u>A dry well discharge vent pipe must be at least 10-feet away from the supply air intake and any doors or hatches into the dry well, wet well, or electrical vault</u>.
  - Wet well: <u>A wet well discharge vent pipe must be at least 10-feet away from the supply air intake and any doors or hatches into the dry well, wet well, or electrical vault</u>.
- 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.
  - Material: Aluminum with corrosion-resistant coating.
  - Motor enclosure and voltage: TEFC or ODP, minimum 120-volt 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 Moving and Control Association (AMCA) Type A or Type B, minimum 120-volt single phase.
- Physical Separation of wet wells and dry wells:
  - <u>Any existing leaking piping/conduit penetrations must be sealed with non-shrink epoxy grout or similar type material</u>.

- All conduits going to/from wet wells must have code-approved seal-offs if not already installed.
- Existing access doors between dry wells and wet wells should be removed and the openings sealed if an alternate means of accessing the wet well is available. If no alternate means of access is readily available or cannot be made available at a reasonable cost, then the existing access door should be retrofitted and/or replaced with a door that can provide a gas-tight seal.
- Existing ventilation openings between wet wells and dry wells must be permanently sealed with non-shrink epoxy grout or a similar material.

- 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.
  - 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 should be provided in dry wells per NFPA 820.

11.6.2.3 Additional Considerations

- The impacts of outside temperature should be taken into account with the design of the dry well ventilation system. Ventilating the dry well at 6 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 impacts of very cold outside temperature should also be taken into account with the design of the dry well ventilation system. Ventilating the dry well at 6 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

Painting should be used to indicate the process service of exposed piping and equipment (Table 11-15). The paint should be an epoxy-based product suitable for the environment in which it is exposed. 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.

Table 11-15
Pump Station Recommended Paint Coloring Scheme

Piping System or Equipment	Solid Color	Color Band	Letter Code	Letter Color
Buildings				
• Buildings (Inside)	White			
• Ceiling Panels & Structural Steel	White			
• Drain – Gravity (Sewage)	Black		Drain	White
• Drain – Suction or Pressure (Process)	White		Drain	Black
Equipment – General				

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

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 stainless steel mesh screening, size ¼-inch.

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, Instrumentation & Control* for more information on motor temperature monitoring.

11.6.2.7 Plumbing

Most pump stations require very 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 practical, passive ventilation of the wet well is preferred over a forced air system.

11.6.2.9 Noise Control

Table 11-16 shows recommended 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. See Noise Ordinance (SMC 25.08).

Onsite generators must have a Quiet Site II Pack installed in residential areas.

Table 11-16
Noise Requirements

Location of Sound Source	Noise Limits		
	Residential (dB)	Commercial (dB)	Industrial (dB)
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 (electrical, water, sewer, and natural gas). 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 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 220/240V, 1-phase service. Most pumps require 460/480V, 3-phase. In such cases, new power lines must be brought to the site from a 460/480V transformer, which the local utility must design and install.

Typical utilities required for water supply and wastewater pump stations should be verified (Table 11-17).

Table 11-17
Typical Utilities Required for Pump Station Operation

Utility	Primary Uses	Wastewater Pump Stations		Water Pump Stations
		Small Facilities	Large	
Electrical	Pumps	460/480V (3-phase)	460/480 V (3-phase) Medium voltage may be required for very large facilities	460/480 V (3-phase)
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	Required		Recommended
Sewage	Internal plumbing External side sewer	Floor drains		Floor drains 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	¾ – 1 inch if required		Recommended

[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.

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:

- Wet wells should be lined with a plastic (T-Lock) or be epoxy coated. The minimum thickness should be 125 mils extending from the top of concrete of the upper slab to below the minimum water level. An alternative for smaller wet wells is to incorporate concrete additives that increase the natural H_2S resistance to up to 10 ppm.
- Ventilation should be designed per sections 11.6.2.1 and 11.6.2.2. Installing odor control equipment should be considered.
- All grating around the wet well should be fiberglass reinforced polyester (FRP). Uncoated metals should not be used for grating. Only type 316 stainless steel or other approved metals should be used for grating.

- All control panels should be designed for a minimum of NEMA 4X corresponding to type 304 stainless steel. See *DSG Chapter 10, Instrumentation & Control* for more detail on control panels.

Larger mechanical equipment, including pumps and combination air valves 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.

11.6.3 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.

11.6.3.1 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 variable frequency drives (VFD) where appropriate to reduce energy costs associated with the pump station.

11.6.3.2 Area Classifications

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

11.6.3.3 Utility Power Source

All SPU pump stations must have 480V, 3-phase, and 60Hz electrical power. Where additional substations, transformers, or switchgear are required, sizing and installations should conform to the requirements of *DSG Chapter 9, Electrical Design.*

11.6.3.4 Standby Power Source

All SPU pump stations must be provided at a minimum with a 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.

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 4 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.

11.6.3.5 Variable Frequency Drives

Variable frequency drives (VFDs) should be used where feasible. For motors up to 700 hp, 460V AC VFDs should be used. Higher voltage and horsepower 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 a motor control center. Larger drives should be furnished by the pump or equipment supplier.
- **Power Factor Correction.** SPU does not recommended 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 variable frequency drives.
- **VFDs for Existing Motors**. Restrictions on motor lead length 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 11-18). When summed to the fundamental frequency, the result is a distorted waveform that can create adverse conditions in a distribution system.

The IEEE has set the only recognized standard addressing harmonic limits: IEEE 519-1992, 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 11-18
Harmonic Mitigation Methods for VFDs

Method	Description
6-Pulse Drive	• Common, cost-effective • Typically, reactor per unit (p. u.) 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 2, 3 or 4 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 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 5th and 7th 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.

11.6.3.6 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. SPU does not currently have any VFD applications. 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.

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 pump motors in a dry pit that is an immersible or submersible type and will not be damaged if the pit floods. The motors should be mounted integral to the pumps. Motors should have cooling characteristics suitable to permit continuous variable speed operation in a dry pit. Motors must be capable of operating continuously.

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

11.6.3.7 Motor Control Centers

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.

11.6.3.8 Conduit and Receptacles

All wiring must be run in conduit. All conduits must be routed below-grade, inside walls, or within slabs to the extent possible. The minimum exposed conduit trade size must be ¾-inch, and minimum concealed conduit trade size must be ¾-inch. Spare conduits should be installed in major conduit runs for potential future requirements. Methods of conduit installation must be in accordance with Table 11-19.

Table 11-19
Conduit Materials

Conduit Run Location	Conduit Type
Exposed in Interior Electrical Room/Bathroom	Electrical Metallic Conduit
Exposed in Process Area	Rigid Metal Conduit
Below Concrete Slab	Schedule 40 PVC or rigid metallic conduit
Connections to Process Equipment	Liquid Tight Flexible Metallic Conduit

Electrical receptacles must be duplex type and rated for 120V, 20 amps. Receptacles should not be powered from circuits used for supplying light fixtures. Receptacles must be spaced at a minimum of every 25 feet for process areas. No location along an electrical room wall should be more than 6 feet from a receptacle.

11.6.3.9 Grounding

A grounding system must be provided to protect SPU staff and equipment.

Grounding electrodes of ground mats or embedded rods and cables must be designed to a maximum resistance to ground 5 ohms. Where more than one rod is required, rods must be installed at least one rod length apart. The soil resistivity should be analyzed and additional depth of soil should be specified when necessary. A minimum of one access point must be provided for testing and inspection. Where an existing ground grid exists, new electrodes should be bonded to the existing system.

All grounds must be bonded together at the main grid in accordance with the NEC. Electronic grade panels and surge protection device equipment, where required, should be grounded using an insulated ground wire connected according to manufacturer's recommendations. In some situations, isolation transformers and UPS equipment may also require special grounding to provide common mode noise rejection. A single-point grounding system should be provided for communication and computer systems.

A. Lightning Protection

A lightning protection risk assessment must be performed in accordance with NFPA-780. Where the assessment indicates the need for a building or structure lightning protection system, a UL master labeled system should be specified. Lightning protection systems should be specified with a performance specification. Detailed design should be left to specialty contractors.

B. Transient Voltage Protection

Pump station design must include lightning and surge protection for the electrical service and distribution system.

Lightning arresters and surge capacitors must be provided at the terminals of all medium-voltage motors.

Surge protection devices can be specified for MCCs and low-voltage distribution equipment. Surge protection device receptacles should be provided for sensitive loads such as computers.

11.6.3.10 Lighting

Lighting levels, measured in maintained foot-candles, should be designed to meet the recommendations of Illuminating Engineering Society (IES) Volume 2, Latest Edition of the IES Lighting Handbook, and *DSG Chapter 9, Electrical Design*.

A. Interior Lighting

Zonal cavity or point-to-point calculations should be performed according to IES procedures for each space to determine foot-candle levels for maintained illumination. All spaces should be individually addressed. Calculations should be cross-referenced to room names and descriptions shown on the architectural plans to maintain consistency across the design.

1) Mounting Heights

Mounting heights should be determined for each individual room or area taking into consideration any conflicting piping, ductwork, and other interferences. Fixture orientation and spacing should be coordinated with the structure support beam grid. Fixture placement in reflected ceiling plans should be coordinated with sprinklers, diffusers, ductwork, etc. Accessibility for re-lamping and maintenance should be a primary consideration when locating fixtures. Fixtures should never be located above open tanks or other hazards.

2) Luminaires

Where practical, luminaires should be circuited and switched to provide multiple lighting levels, or by switching alternate ballasts. Unswitched “night lighting” circuits should be included to illuminate egress paths in normally occupied or regularly traveled areas. Exit signs must be connected to night lighting circuits unless self-contained. These circuits must be fed from central inverter or emergency generator systems. Self-contained battery units and exit signs should be unswitched. The units must be connected to the circuit that feeds the normal lighting in the room to sense failure of normal AC voltage.

3) Energy Efficient Lamps

Energy efficient lamps should be specified for fluorescent tube light fixtures. The use of incandescent lamps should be strongly discouraged. Incandescent lighting should only be used in areas or spaces that are infrequently used (e.g. closets or inactive storage rooms). Compact fluorescent lamps should be used in lieu of incandescent.

High-intensity discharge (HID) lamps should be used in large open interior spaces or high bay applications where calculations indicate fluorescent lamps would be inadequate for the tasks to be performed. Color-corrected lamps should be specified whenever possible. Mogul base type high-pressure sodium and metal halide lamps should be specified whenever possible. Many medium base lamps have a shorter rated lamp life. High-pressure sodium or metal halide lamps are preferred for exterior lighting.

No indoor area should be illuminated solely by HID light sources. An egress path, illuminated by fluorescent lamps, should be provided from all interior spaces to prevent blackouts during HID re-strike. Where this is not practical, auxiliary quartz lamps can be specified with HID fixtures.

Energy efficient electronic ballasts should be used whenever possible. Low-temperature ballasts should be specified for outdoor or unheated space applications. High-intensity ballasts should be incorporated to minimize ballast noise in sensitive areas.

B. Exterior Lighting

Outdoor illumination should be provided in areas that require 24-hour attention. These areas include walkways, ladders, catwalks, and pits. <u>The physical security manager must be consulted for coordination of exterior lighting</u>.

Security lighting should be provided along roadways and on buildings at entrances. Exterior lighting is to be designed to prevent excess illumination beyond the boundaries of the facility. Placement of lighting should be coordinated with security cameras, where applicable.

Outdoor lighting in landscaped areas and areas of visitor access, or areas visible to the public, should be coordinated with the placement of tree lighting. Placement should consider the mature size of trees and landscaping (not just new plantings).

Final calculations and computer reports for site lighting should be placed in the project documentation. Foot-candle distribution maps directly on a CAD version of the site plan should be developed using a lighting software program. This task can be supported by lighting manufacturer representatives.

Most exterior lighting should be controlled by photo cells. Lighting contactors should be instructed where banks of lighting fixtures are to be controlled by a single photo cell. Non-essential site lighting should be separately circuited through a time clock to allow scheduled shutoff. All site lighting should have centralized manual override for emergencies.

Concrete bases for pole-mounted lighting fixtures should be buried to a depth dictated by soils conditions. Poles located within parking areas or where subject to vehicular damage should be mounted on pole bases that extend up 30 inches above finished grade. Poles located in grassed areas should be flush with the grade to allow mowing.

Poles should be stationary type when the access to the lamps can be gained easily and safely from a lift truck or portable lift. Where the lamps cannot be easily replaced or where the re-lamping or repair will place the maintenance person in an unsafe position, the pole should be furnished with a lowering mechanism or be hinged.

Table 11-20 summarizes minimum illumination guidelines. It does not replace the calculations and procedures described above.

Table 11-20
Recommended Illumination Levels

Area	Minimum Illumination (in foot candles)
Electrical Rooms	30
Indoor Process Areas	30
Mechanical Equipment Rooms	30
Outdoor Process Areas	5
Restrooms	20

C. Emergency Lighting

Emergency illumination should be provided in all appropriate spaces as required by code to provide life safety, property, and equipment protection. Adequate lighting levels should be provided to maintain safe building egress path and illumination of critical process areas. Emergency lighting should be located near distribution switchgear, motor control centers, generators, and any equipment locations that need to be accessed to restore normal power.

11.6.3.11 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 480V panelboard one-line diagram and front elevations
- Symbols and abbreviations
- Typical construction details

11.6.4 Instrumentation and Monitoring Control

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

11.6.4.1 Instrumentation for Wastewater

Pump instrumentation will allow for control and monitoring of the pump and station equipment. Monitoring will also include all trending and alarming 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 and installed on the discharge of each pump rather than a single flow meter being provided on a discharge header. Totalizing functions should be performed through the SCADA system or directly in the corresponding PLC.

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

Switches should typically be adjustable from 0 to 15 psi and should provide a low suction pressure trip directly to the pump controls for equipment safety. Transmitters and gauges should have the same usable range and should be used for PLC control and monitoring and local reading, respectively. The switch trip should also be sensed at the PLC, either through a dual switch contact or repeated from the pump local control panel. The analog signal should only be wired to the PLC. The low-suction pressure switches should specifically use a local control panel reset to restart the pumps. This set-up requires SPU to do a local inspection before pump restart.

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

Transmitters and gauges should operate from 0 to 100 psi. The transmitter should have programmable contacts for high pressure to directly shutdown the pump controls and should provide an analog signal to the PLC for control and indication.

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

These limit switches should be equipped with dual contacts. One set of contacts should be used for local pump control panel interlocks. The other set is used for PLC control and monitoring. Alternatively, single contact switches can be used and the signals repeated from the local control panel to the PLC.

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 2 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

SPU's current requirement for level sensing is the Birdcage water pressure sensor.

G. Level Sensors/Control (Wastewater)

SPU's current standard for level sensing is the Birdcage water pressure sensor.

11.6.4.2 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 or Human Machine Interface (OI/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, Instrumentation & Control*.

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.

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

C. 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.

All flow meters for SPU pump stations must be a Krohne mag meter.

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 (L-O-R) switch. The status of each pump must be monitored by the SCADA PLC.

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 L-O-R 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 L-O-R switch is in 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 to 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 to 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 1 to 5-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 11-21):

Table 11-21
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. • New power monitors for each pump not recommended. Additional cost not justified by benefits.

11.6.4.3 Control Functional Requirements

A. Programmable Logic Controller (PLC)

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, Instrumentation & Control*.

B. Control Narratives

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

11.6.4.4 Project I&C Design Documents

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

- Piping and Instrumentation Diagrams (P&ID)
- Control system architecture/block diagram
- Control panel front view and layout
- Instrument loop diagram
- Instrument schedule
- PLC input/output schedule
- Construction details

11.6.4.5 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. <u>Each vibration monitor must have the following features</u>:

- 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 2 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.

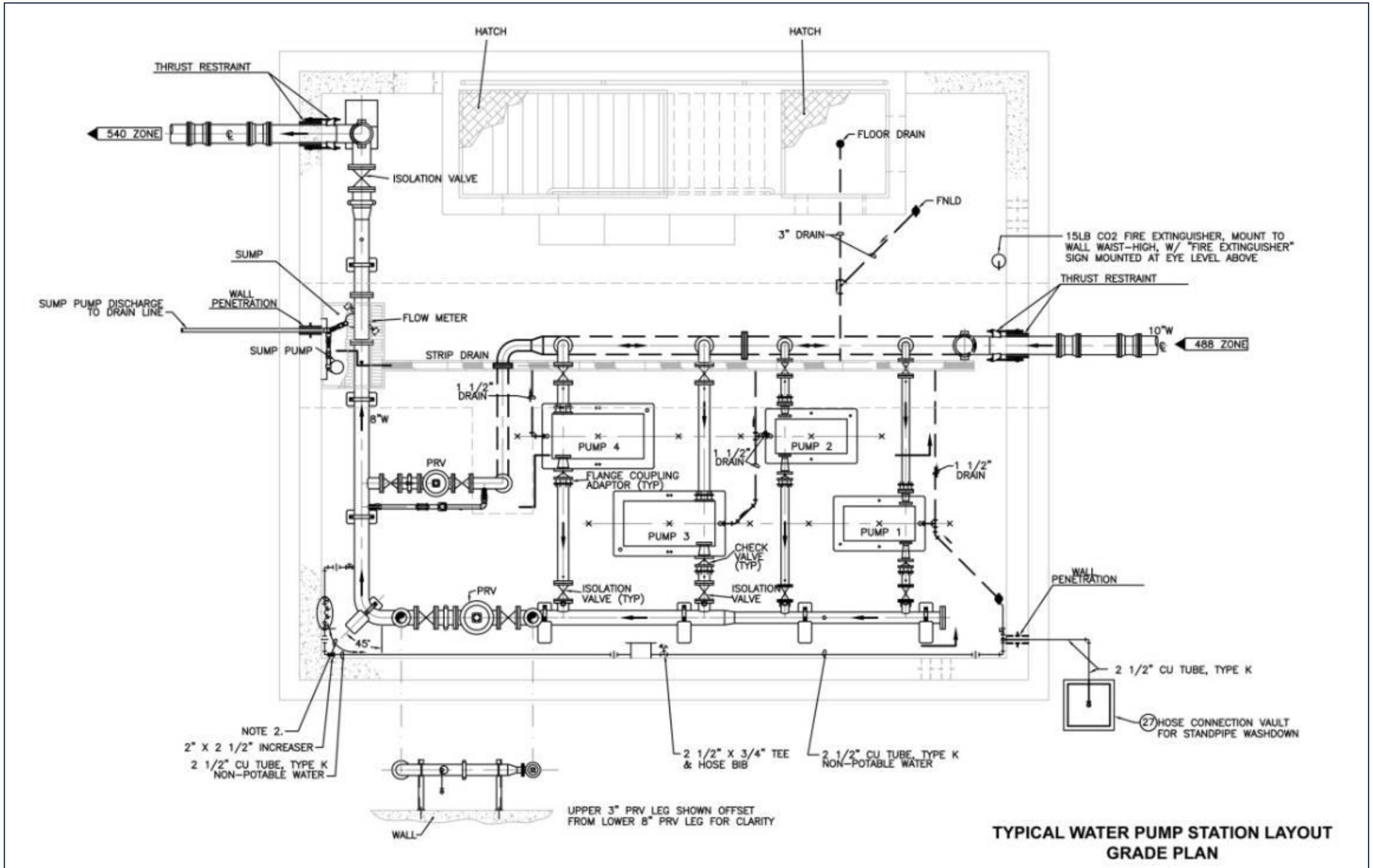
11.7.1.2 Water Pump Station

A water pump station 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 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 dryer than wastewater stations and are not classified areas. Therefore, it is not as critical to place electrical equipment (i.e. 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 Station

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 valve and combination air release valves, sump, sump pumps, force main, pipes, pipe supports, ventilation system, motor control center, e-plug, generator, motor control center, 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 configurations.

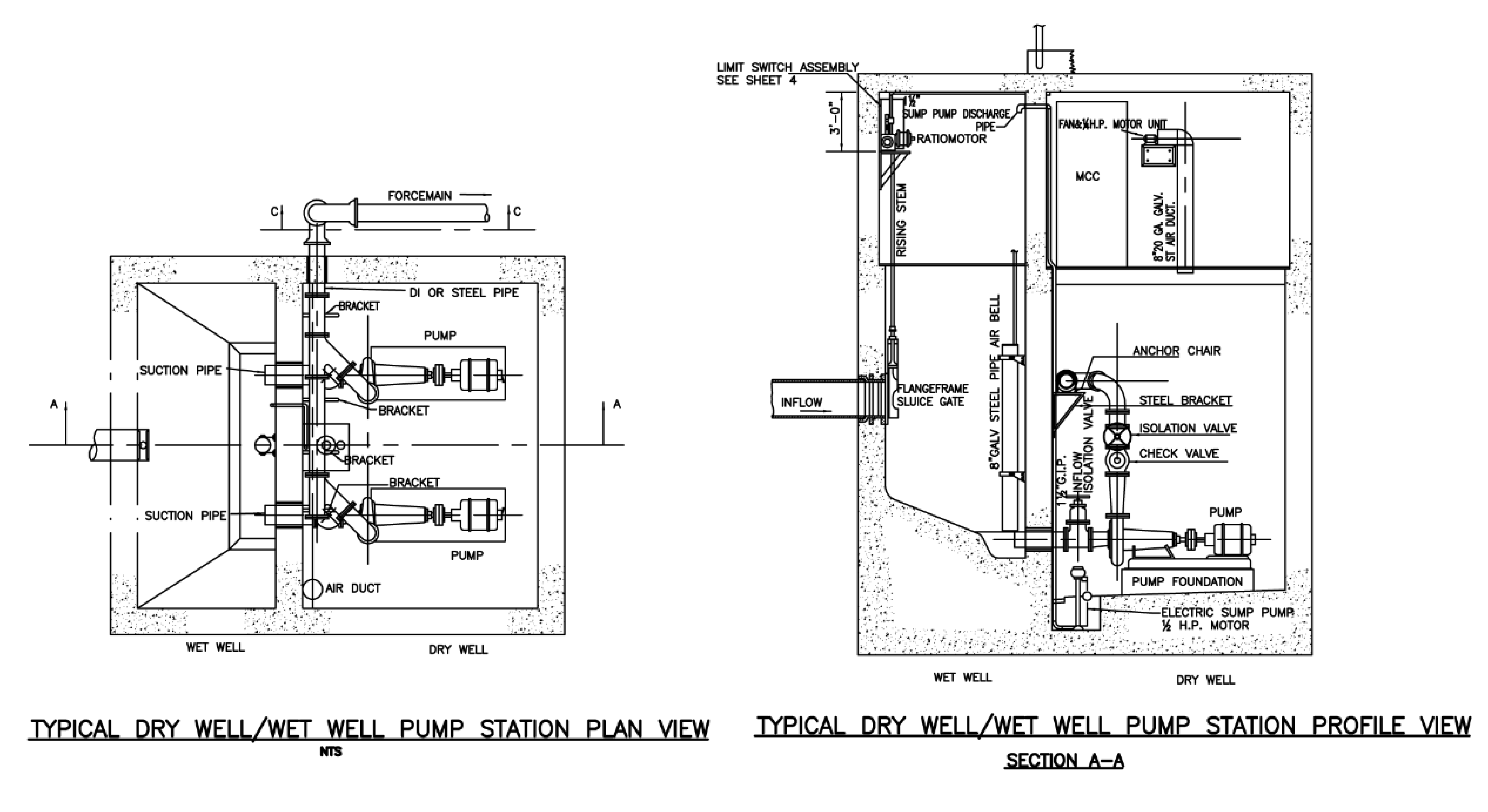
Advantages:

- 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.
- Flooded suction improves motors at grade.
- With long shaft and flood-protected motors at grade, electrical leads are short.

Disadvantages:

- Greater cost due to excavation and build below-grade. Expensive if ground water is high, if soils are very poor or if blasting is high.
- 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



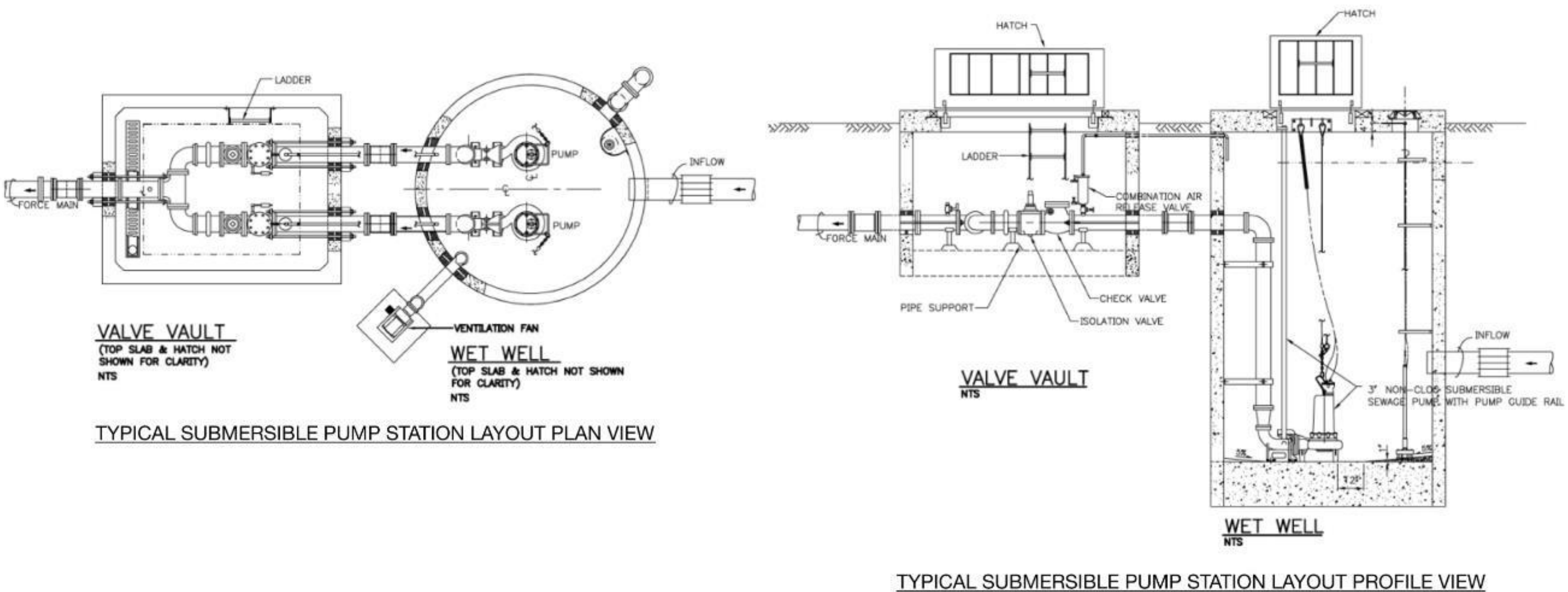
B. Submersible (Wet Well) Layout

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 11-22
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 pit 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. Can't be inspected during operation. • Very 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 very 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.

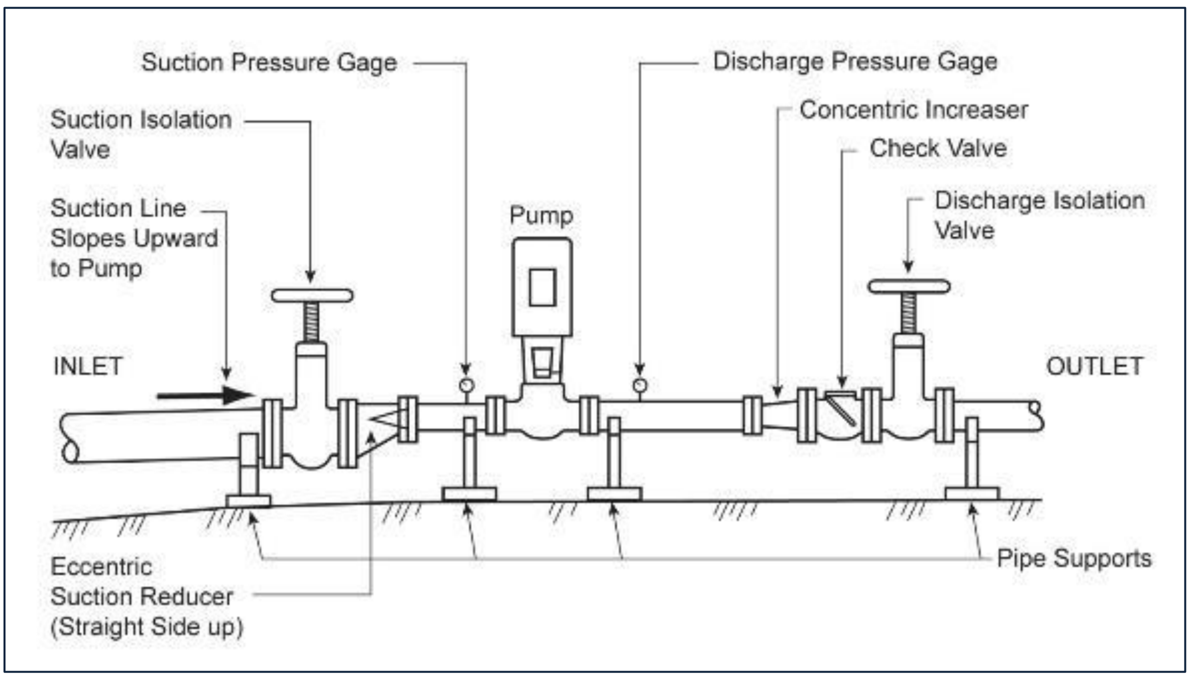
11.7.2.1 Inlet Piping

Pump intake design must follow Hydraulic Institute (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. This arrangement allows air to be released when the pump idles. Expulsion is important because air pockets move away from high points as flow occurs in the pipeline

Figure 11-10
Typical Inlet and Outlet Configuration



B. Wet Well Piping to Drainage and Wastewater Intake Pumps

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 prefers 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.

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, 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.

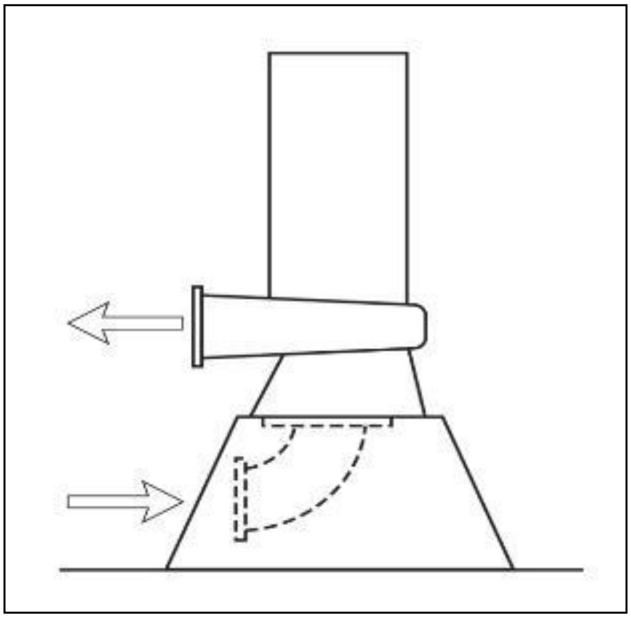
The following are guidelines for pipe reducers:

- Eccentric reducers should be located at least one pipe diameter away from the pump inlet or pump suction elbow for every pipe size reduction.
- 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 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). The dashed line in Figure 11-11 represents the pump suction elbow of a submersible pump mounted in a wet pit. The elbow resides between concrete walls on either side to maintain proper pump hydraulics.

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.

A. Fittings

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 this fitting. 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 11-23.

Table 11-23
Velocities for Pump Inlet (Suction) and Discharge Piping for Individual Pumps

Location	Minimum Velocity (fps)	Maximum Velocity (fps)
Inlet Piping	2	8
Discharge Piping	2	8

A. Minimum Velocities

Certain technical constraints affect pipe size selection. For force mains conveying sewage, minimum velocity must be 2 fps for wastewater and 2 fps for drainage pump stations during initial operation.

B. Maximum Velocities

To maintain head losses at reasonable values, the maximum velocity in wastewater force mains must be 8 fps. For very short (< 100 ft) force mains, SPU allows exceptions to the 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 and Materials

When fluid temperatures are constant, station pipe sizing is often based on Manning's Equation. That equation uses the minimum and maximum velocities and results in nominal pipe sizes (pipe diameter).

A. Force Mains

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 Spec 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 pipe must be either ductile iron or carbon steel and must be restrained joint pipe within the pump station structure.
- At a minimum, ductile iron pipe must be Class 52. All ductile iron pipe must follow Standard Spec 9-30.1(1).

- Steel pipe design must follow AWWA M11. All steel pipe must follow Standard Spec 9-30.1(4).

Material selection should be as consistent as is practical throughout all pump station piping to minimize the need for transitional appurtenances (e.g. di-electric flange insulation kits). Flanged pipe should not be used in buried applications. Typically, ductile iron pipe is flanged at all connections, while carbon steel pipe is either flanged or welded for pump station piping inside the pump station

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 pipe will have a fixed inside diameter of almost exactly 20 inches. A 20-inch carbon steel pipe 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 pipe:

- 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 pipe should conform to the requirements of AWWA M11.

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. Therefore, 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.

11.7.3 Valve Selection

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 when possible.

11.7.3.1 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 11-24 lists appropriate valve types for the SPU water pump stations.

Table 11-24
Valves for SPU Water Pump Stations

Function	Acceptable Types	Comment
Isolation	Butterfly Gate (12") Ball (<4") Globe (<4")	• Required on all pump discharges • If on piped suction, should be at least 5 pipe diameters upstream of the pump suction.
Check Valves	Swing check Double disk	• Required on all pump discharges upstream of isolation valve • 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		• To minimize pump surge from starting and stopping pumps

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.

11.7.3.2 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 11-25 lists recommended valve types for SPU drainage and wastewater pump stations.

Table 11-25
Valves for SPU Drainage or Wastewater Pump Stations

Function	Acceptable Type	Comment
Isolation	Ball valve (<4") Plug valves (>=4") Gate valves (>4")	• Required on all pump discharges • If on piped suction, should be at least 5 pipe diameters upstream of the pump suction
Check Valves	Swing check	• Required on all pump discharges upstream of isolation valve

Function	Acceptable Type	Comment
		• Must be installed horizontally • Consult manufacturer for other installations
Combination Air/Vacuum[1]		• Must be rated for wastewater applications. • Must only be used with overall water hammer control scheme • Should be provided with back flushing capabilities
Air Release		• Required on most pump discharges. • Must be rated for wastewater applications • Must be piped to wet well
Wet Well Installation	Sluice valve (gate or swing)	Used to isolate wet well from inflow to station

[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.

11.7.4 Pump Design

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

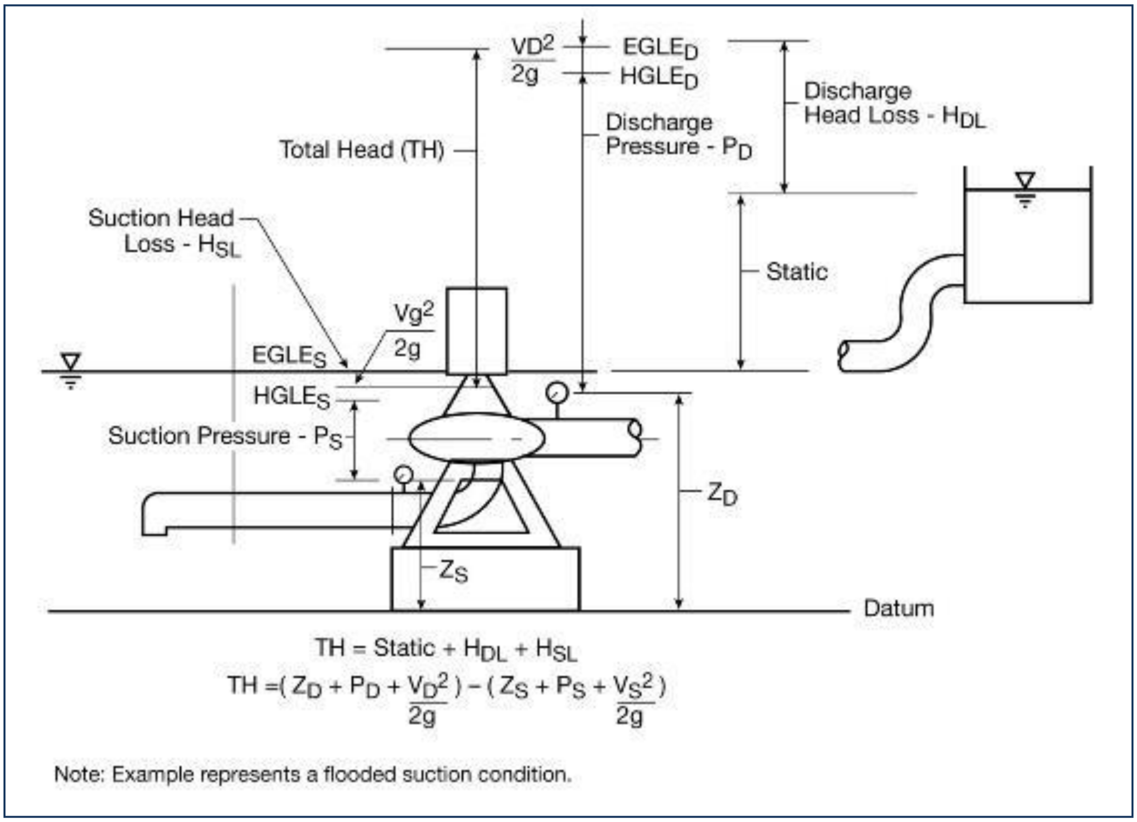
11.7.4.1 System Curve Development

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 an improperly sized pump station that operates inefficiently. 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 was 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.

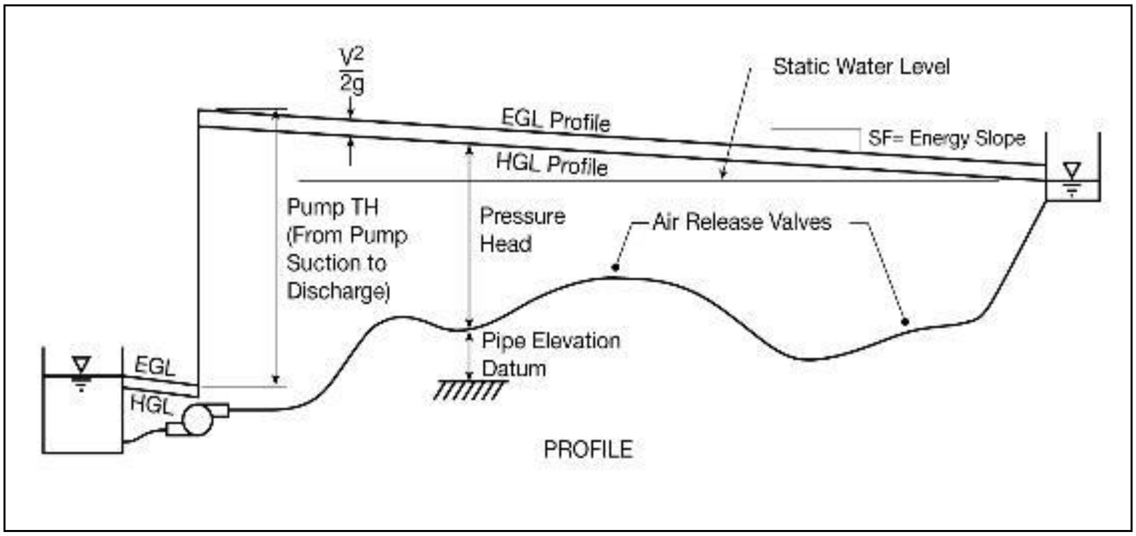
Figure 11-12
Common Pump and Piping System Terms



B. Hydraulic and Energy Grade Line Profiles

Hydraulic and energy grade line profiles plot the energy and head along a pipe route. Hydraulic grade line (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 energy grade line (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 Hydraulic Grade Line and Energy Grade Line



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 are commonly estimated by one of the following equations:

- **Hazen-Williams Equation**

- **Darcy-Weisbach Equation**
- **Manning's Equation**

The Hazen-Williams equation must be used to calculate friction losses for pumped flow for all pipes less than 2,000 feet 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:

hL = 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. Such information should be obtained for the specific pipes being considered and anticipated design life. For existing pumping systems, a pump test should be done to determine system head loss characteristics and this information used to develop a "C" factor for the actual system.

The Hazen-Williams equation should be cautiously used for pipes of either significant length (>2,000 feet) 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 is used without further verification because the piping is typically less than 18-inch diameter and less than 2,000 feet in length (Table 11-26).

Table 11-26
"C" Values 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
PVC	150
Old Pipe (in moderate service 20+ yrs*)	
Ductile, cast iron or steel , uncoated	100
Ductile, cast iron or steel, cement-mortar lined	100

*For old pipes, calculate the C value whenever possible in lieu of using these values

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 (V2/2g) 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):

$$hL = K*(V2/2g)$$

Where:

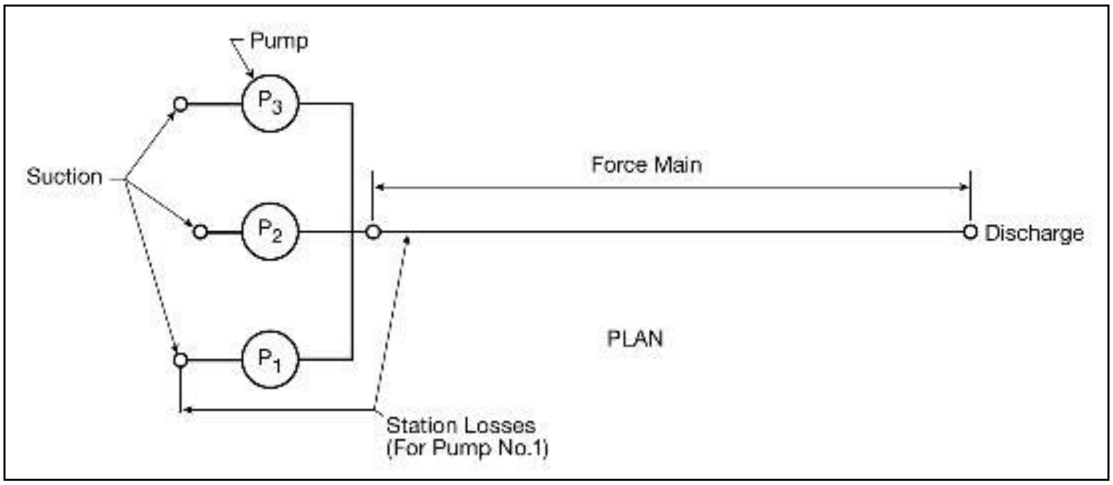
hL = head loss (ft)

K = Friction Factors (see Table 11-22)

V = pipe velocity (ft/sec)

G = gravitational constant (32.2 ft/sec2)

Figure 11-14
Pump Station Schematic



Typical K values for a limited number of common fittings are listed in Table 11-27. All K values for pump station design must follow Hydraulic Institute (HI) Engineering Data Book Tables 32(a) and 32(b).

Table 11-27
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. Bellmouthed entrance (flush or re-entrant)	0.05

Type of Transition or Fitting	Typical K Value
Pipe Exit, where downstream velocity equals zero:	
a. Abrupt transition	1.0
b. Bellmouthed transition	0.8
Reducers/increasers:	
Gradual reducers (pipe wall flare <40°):	0.1
Smooth bends:	
Regular radius 90° (10-in. diameter or less)	0.3
Regular radius 90° (>10-in. diameter)	0.2
Long radius 90° (10-in. diameter or less)	0.2 0.10.1
Long radius 90° (>10-in. 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)

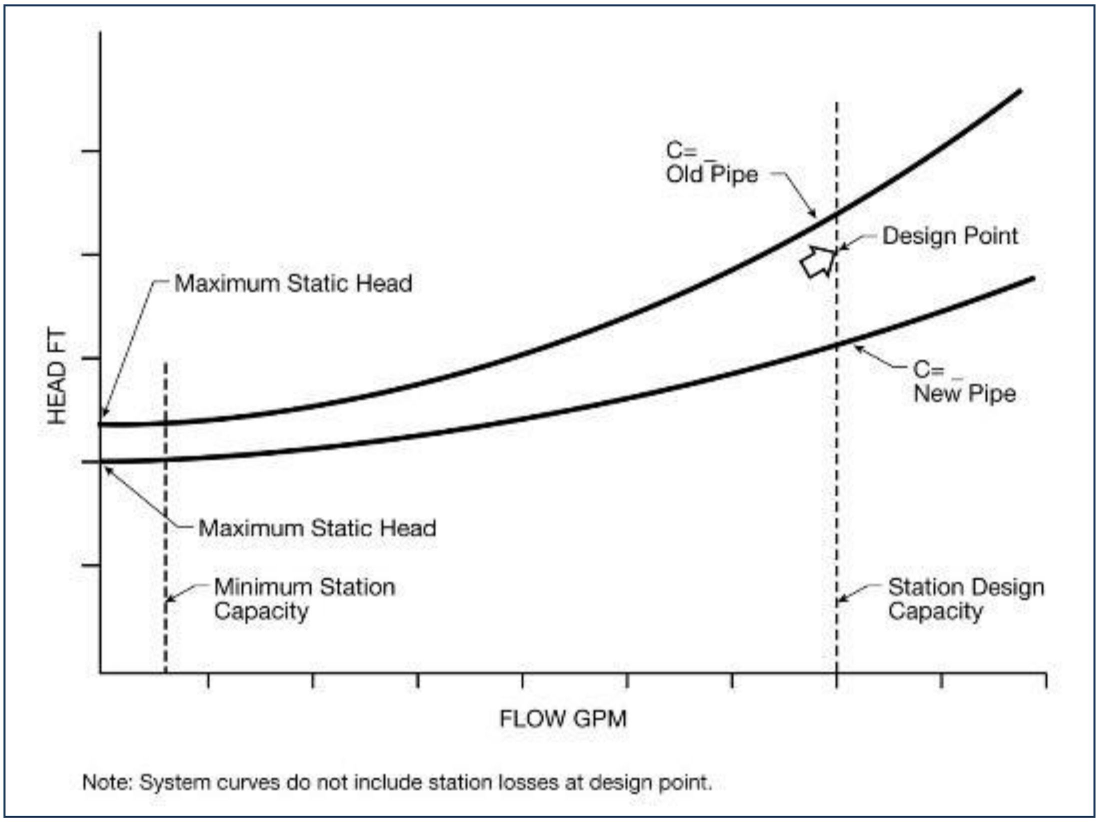
G. System Curves

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



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* (NPSHr) varies with discharge, type of impeller, and pump speed. The NPSHr is provided by the pump manufacturer. The *available net positive suction* head (NPSHa) indicates the actual total energy available on the suction side of the pump as shown in the equation below. To provide a comfortable margin of safety, SPU requires that the NPSH should exceed the NPSHr by a minimum of 5 feet.

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

NPSHa = Harm + Hsub – Hvp – Hl

Where:

Hatm = Head, in feet of water, corresponding to the absolute pressure on the surface of the liquid being pumped

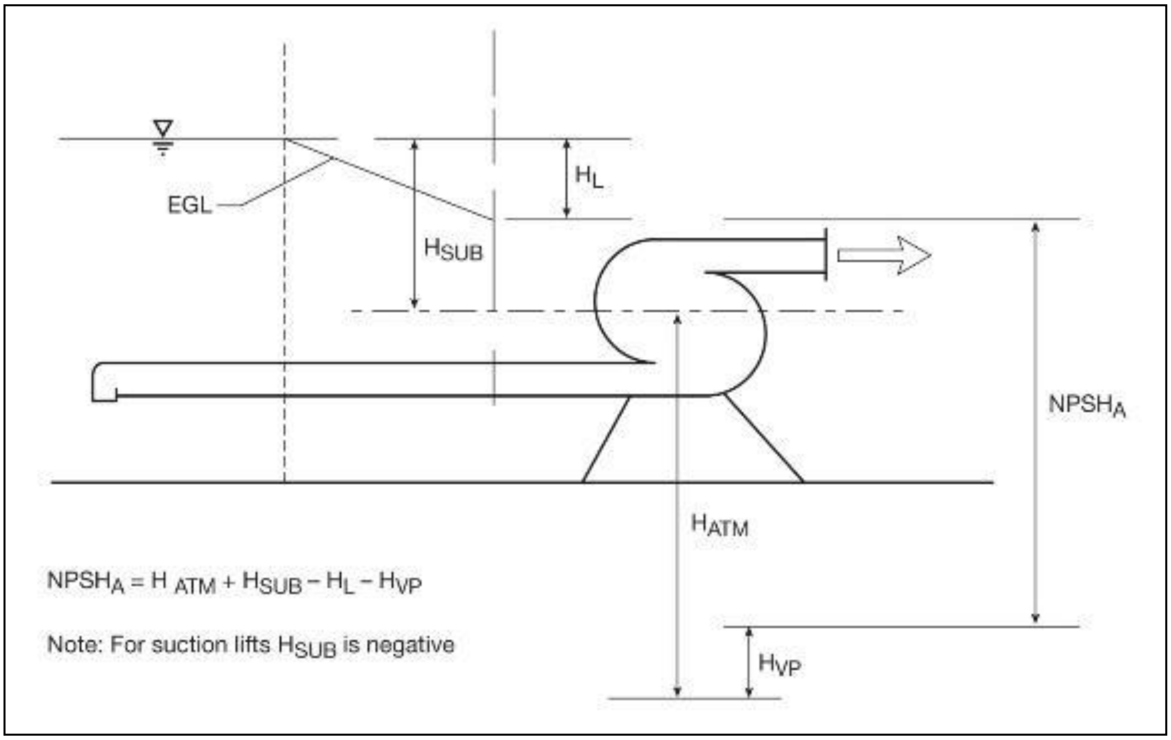
Hsub = Difference between centerline of pump impeller and liquid level in the wet well

Hvp = Vapor pressure of liquids, dependent on type and temperature of liquids

Hl = Head losses in suction pipe (friction and fitting losses)

Note that the calculation must include Hatm at actual altitude elevation of the pump.

Figure 11-16
Net Positive Suction Head



11.7.4.2 Pump Hydraulics

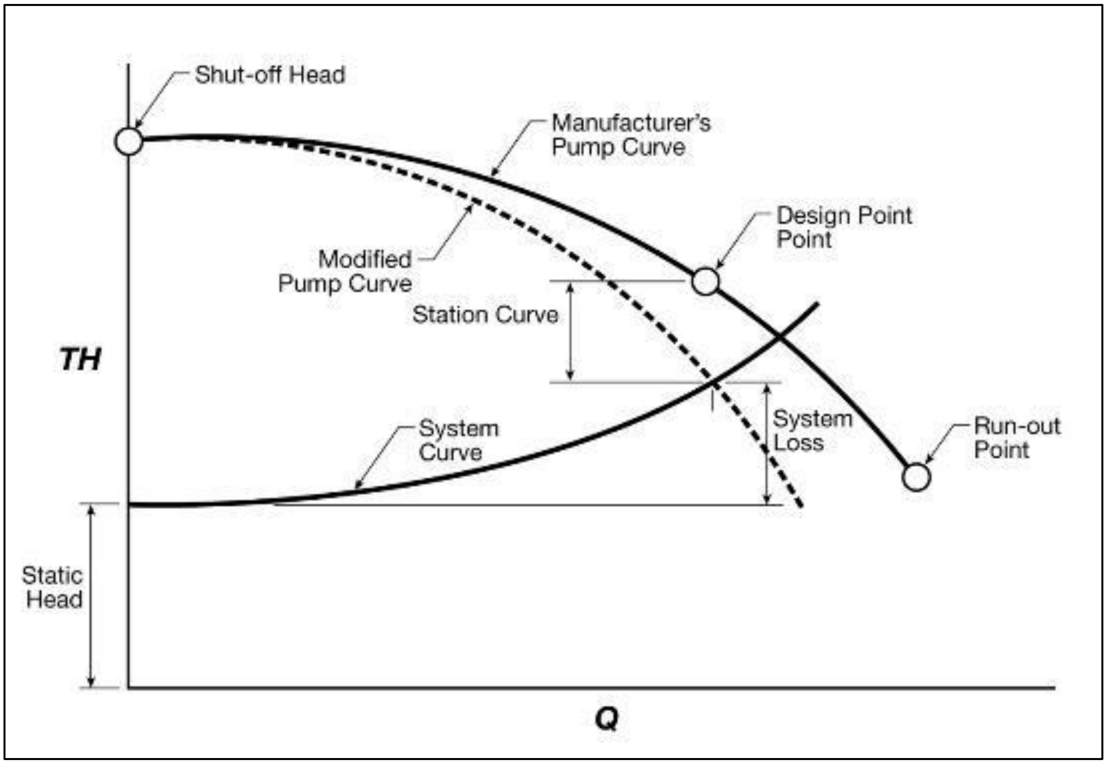
This section describes design elements of pump hydraulics.

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 are not permitted. Pump characteristic curves are unique and therefore are provided by the pump manufacturer or their representative.

When two or more manufacturers' pumps operate 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 currently operates pumps in parallel setting. TH = Total Head. Q = Flow.

Figure 11-17
Typical Modified Pump Curve



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 so little back pressure and pushing so much flow that the pump is 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, high horsepower, and an area of 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.

D. Acceptable Operating Range (AOR)

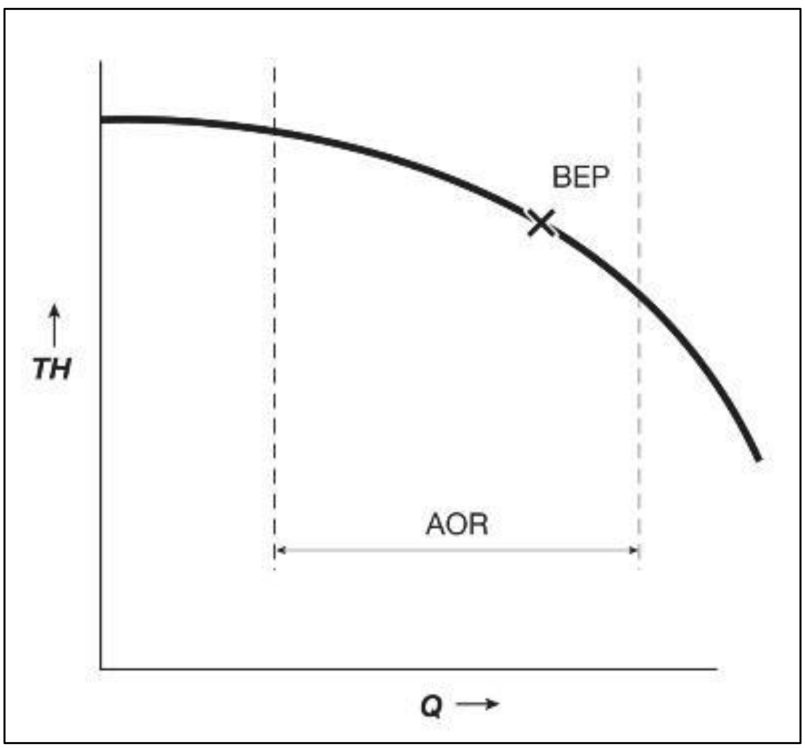
Acceptable Operating Range (AOR) is the range of flows over which the service life of the pump will not be seriously compromised. If run outside of this range, bearing life may be reduced, and noise, vibration, and component stresses may be increased. Pump manufacturers will typically provide the AOR, which is best shown directly on the pump characteristic curve. See ANSI/HI 9.6.3-2004.

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 horsepower may be exceeded.

11.7.4.3 Best Efficiency Point (BEP)

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



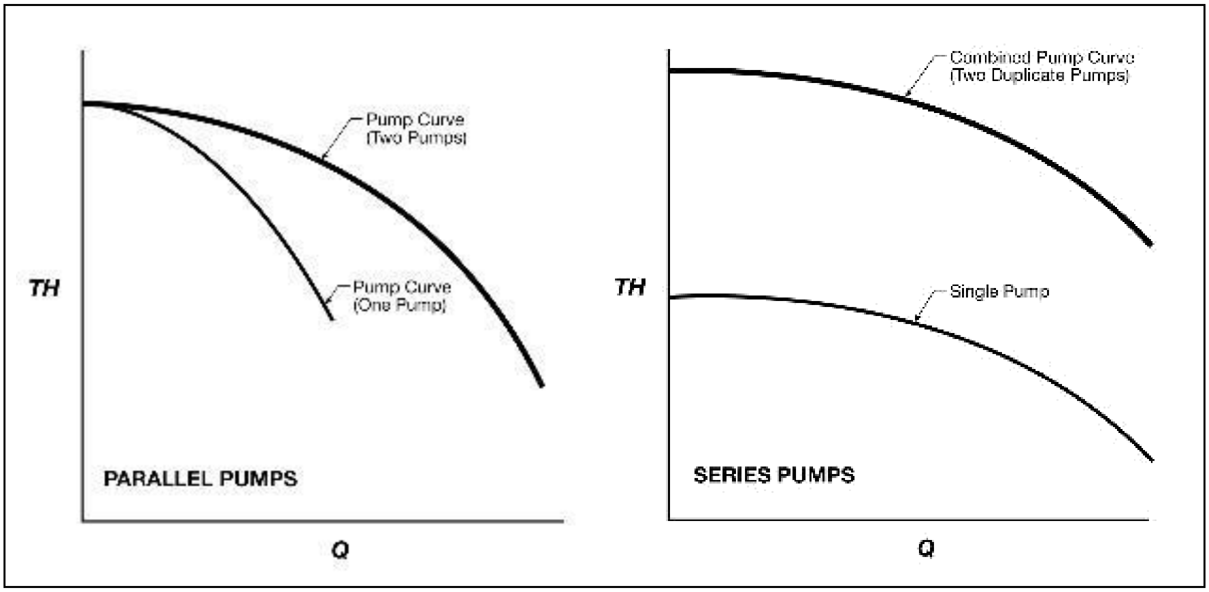
A. Preferred Operating Range (POR)

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 9.6.3-1997.

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



11.7.4.4 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)

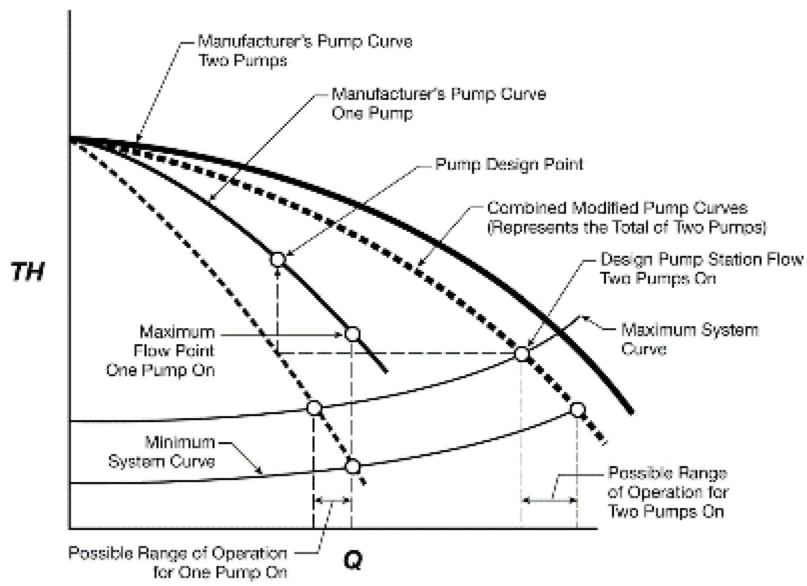
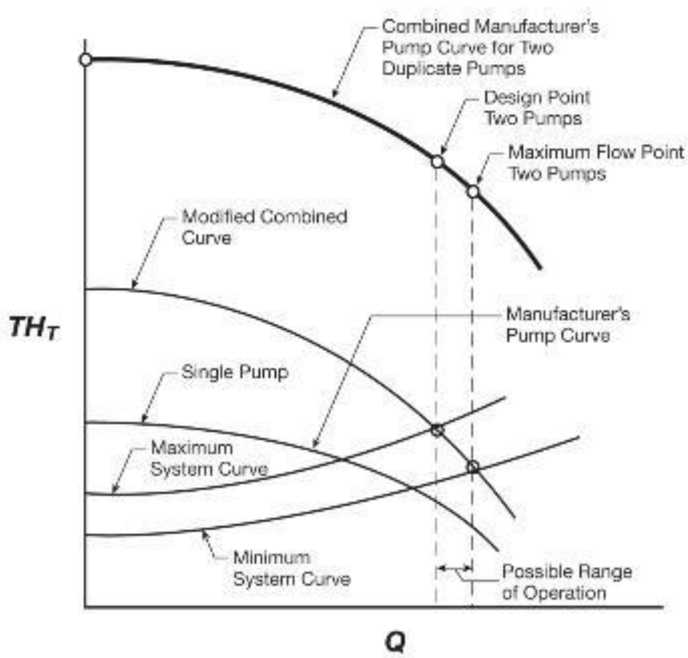


Figure 11-21
Typical Modified Pump and System Curve (Series Pumping)



11.7.5 Pump Selection

11.7.5.1 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 typically operating condition is one pump operating. 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 to 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.

11.7.5.2 Pump Selection Criteria

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

- Impellor Capacity: Minimum 90% of maximum impeller size
- Minimum Pump Efficiency: 80% for Water and 60% for Wastewater and Drainage
- Minimum Speed –Wastewater: 885 rpm
- Maximum Speed – Wastewater: 1770 rpm
- Solids Handling – Wastewater: 3-inch sphere

For more detail on pump design criteria, see DSG section 11.4.2.

A. Constant Speed Pump Selection

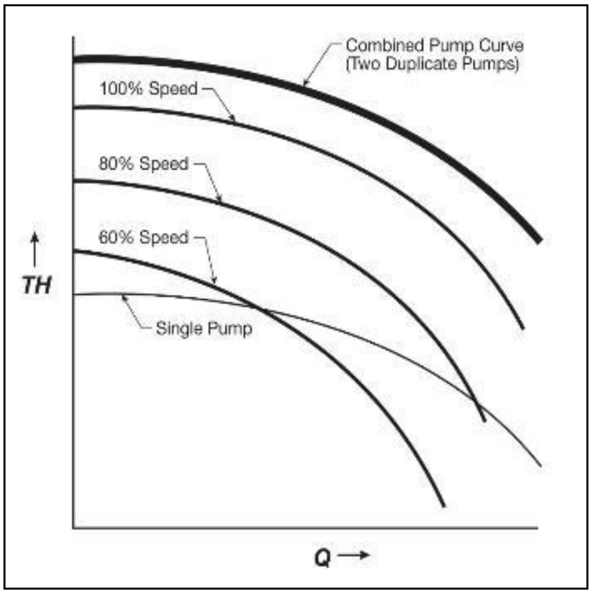
For constant speed pumping applications, pump selection is relatively straightforward. Pumps should be selected that most closely match the pump BEP with the most frequent operating point from the system curves.

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 *Pump 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



1) Water Pump Stations

For potable water pump stations, selection of variable speed pumps should be carefully considered. Due to successful water conservation, SPU water pump stations have ample and even excess capacity. On these pump stations, variable speeds pumps 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 designer should be aware of the following:

- **Multiple Pump Operation with Best Efficiency Point 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 Best Efficiency Point 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.

11.7.5.3 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.

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

11.7.5.4 Multiple Pump Operation

Multiple pumps may be required for pump stations that have frequent operation at two or more required flows/pressures that are very different from one another. The further apart the most frequent operating points are from each other on a system curve, the less probable 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 horsepower or other such parameter of any single piece of equipment in certain areas to protect their service base.

For stations with multiple pumps, the impacts of multiple pumps being out of service should be considered when determining the level of redundancy that should be provided. The standard minimum redundancy equal in capacity to the largest pump is required.

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

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

11.7.5.5 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 11-28. 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 in particular may allow additional starts per hour depending on the installed conditions.

Table 11-28
Recommended Motor Starts per Hour

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

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

$$V = (t * Q) / 30$$

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 11B – 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.

11.7.5.6 Pump Seals

Mechanical seals must be used on all wastewater and drainages pump stations. Availability of mechanical seals, and their performance at the anticipated system pressures, should be verified with the pump manufacturer. See DSG section 11.8 for more information on wet well sizing.

11.7.5.7 Manufacturer Preferences

Table 11-29 shows the manufacturer preference for SPU water and drainage and wastewater pumps in order of preference.

Table 11-29
Preferred Manufacturer for Water and Wastewater Pumps

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

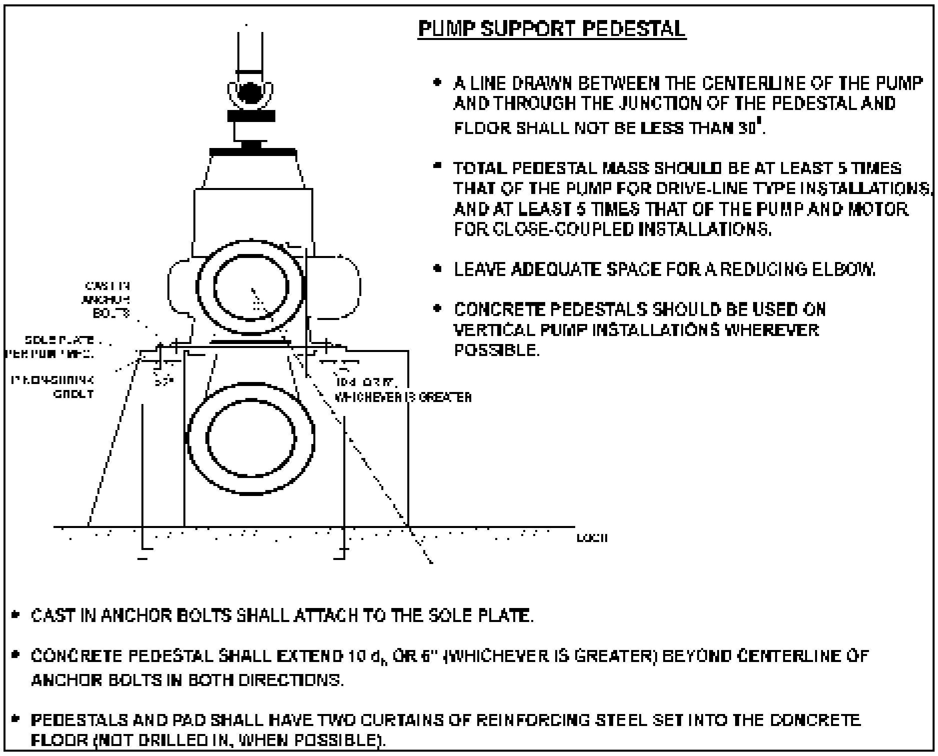
11.7.6 Pump Base Design

A proper base support is essential to minimize vibration on all rotating equipment. To minimize potential pump base problems concrete bases should be used in preference to steel frames.

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 pit. 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



11.7.7 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*.

11.8 WET WELL DESIGN

Wet wells are required for wastewater and drainage pump stations. The design engineer should follow the Hydraulic Institute (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 wells sizing is nearly always a function of required storage, not 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 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 11-30 summarizes important characteristics of each style of wet well.

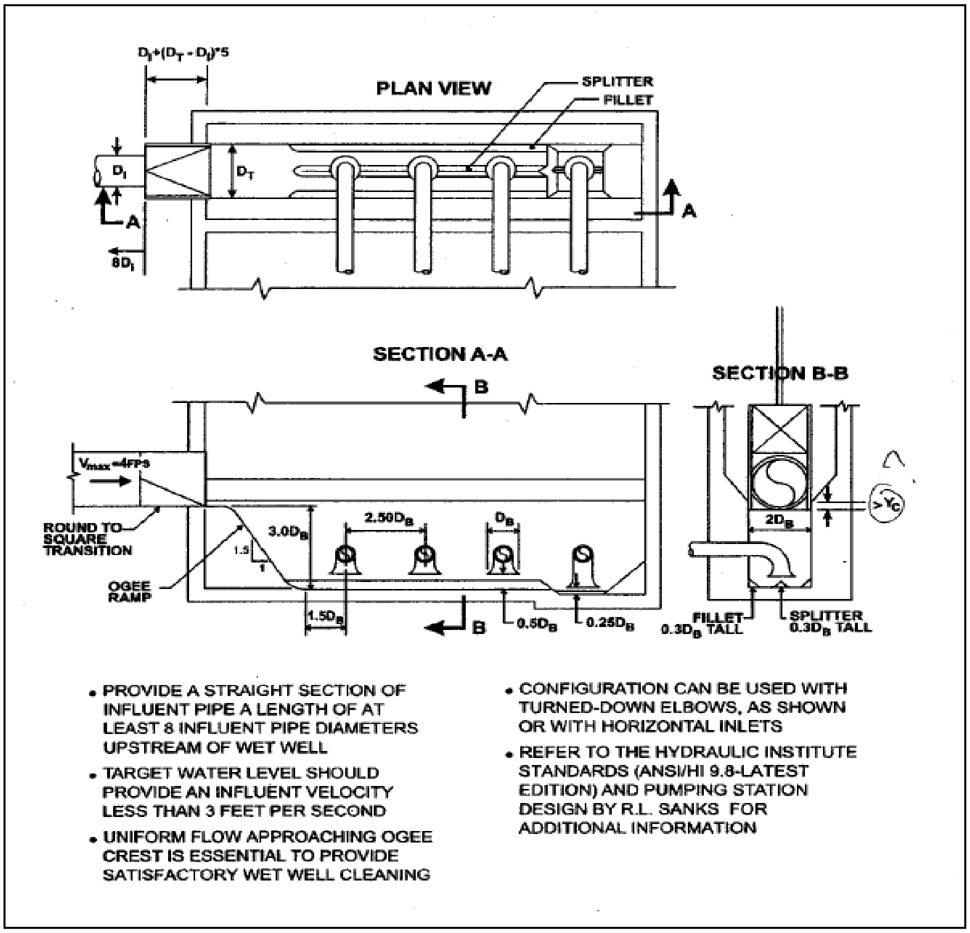
Table 11-30
Wet Well Self-Cleaning Trench vs. Rectangular Style

	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

11.8.1.1 Self-Cleaning Trench Wet Well

SPU prefers the self-cleaning trench style wet well for water-containing solids (Figure 11-24). The Hydraulic Institute (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



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

- These wells are very 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 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 net positive suction head 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 ⅔ 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.
- 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 Hydraulic Institute (HI) pump intake design standard, details for the rectangular wet well design can be obtained from ITT Flygt.

11.8.2 Wet Well Storage

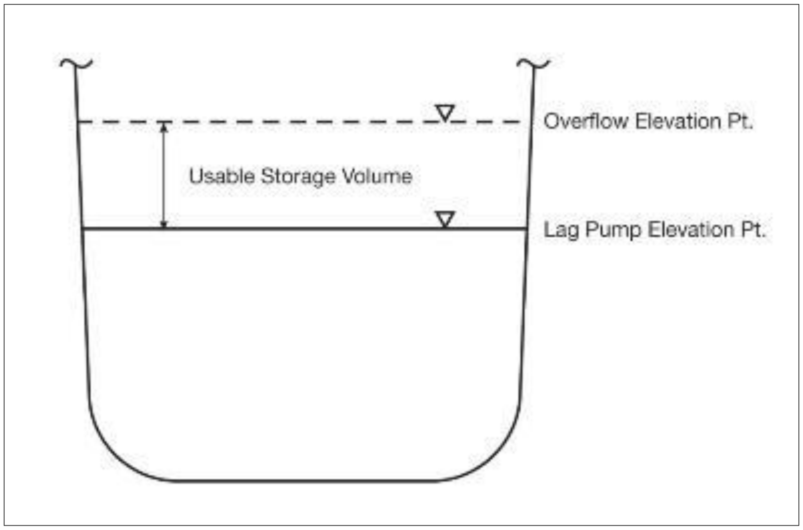
Adequate storage is required to reduce the risk of accidental overflow from pumps failing to start. SPU wet wells should have a minimum of 4 hours of storage from high wet well alarm to overflow. All new pump station installations should be provided with adequate storage. Pump station renovation should include modifications to meet these requirements.

The following are SPU standards for wet well storage:

- New pump stations must have more than 1 hour of wet well storage.
- If storage is less than 1 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 wet well storage flow has a significant impact on the required wet well storage volume. It can also be somewhat subjective. For most wastewater applications, it is ideal to use the maximum value for average daily flow (ADF) observed over the course of at least 1 calendar year for existing facilities or the anticipated maximum ADF for new facilities.

The maximum ADF should correspond to an observed, severe wet-weather event. This assumes that at least hourly flow data are available. Using maximum hourly flow data is overly conservative because the associated detention time is typically multiple hours. Recognizing that peak flow conditions are most likely to cause a potential problem (e.g. power outage), the maximum value for ADF is a more appropriate metric than an average value of ADF. Similarly, if no maximum ADF data is available—or only spot measurements of flow are possible—an appropriate peaking factor should be incorporated. Using the appropriate peaking factor helps assure that the emergency storage flow selected will represent a value comfortably above the average dry weather flow.

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), 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 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 1 hour of storage must have an onsite generator.
- Existing pump stations with larger flows (1 mgd) and less than 1 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 proposed equipment meets all requirements of the specifications
- 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 motors, 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.

For large pumping equipment with motors that exceed 200 hp or that have a capacity of more than 5,000 gpm, a witnessed factory pump performance test is suggested. 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 performance tests:

- Pump manufacturer should guarantee pump performance at the flow, head, brake horsepower, and efficiency specified.
- Testing setup should conform to the requirements and (Hydraulics Institute (HI) standards (ANSI/HI 1.6 – latest edition). Testing must have a performance tolerance consistent with acceptance level "A" 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.

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 impellers until the specified operating conditions are met.

In general, it is not recommended that motors or variable frequency drives (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

The pump manufacturer should be required 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 11E – Operational Checklists**.

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 48 hours), a post-operational test is done. This test should ensure that flow rates, grout cracking, vibration, and other factors that affect system integrity have not been compromised.

11.10 O&M

SPU Operations staff (previously Field Operations and Maintenance) is 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 any negative environmental impact. SPU requires a minimum of six copies of the O&M Manual to be on hand at the Utility Operations & Maintenance Division in Shared Services Branch within SPU.

11.10.1 Routine Maintenance

SPU pump stations are inspected on a regular schedule. The frequency of the inspection is determined on a station-by-station basis based on Reliability Centered Maintenance 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
- Impellers
- Motors
- Other ancillary equipment
- Pumps
- Seals
- Wear clearances
- Wet wells

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

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.

Another consequence of equipment wear is reduced 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. American National Standards Institute (ANSI):
   a. ANSI / AWWA D100, Welded Steel Tanks for Water Storage, and NACE Standard PRO 178-89, Item No. 53041
   b. ANSI / AWS D1.1, Structural Welding Code0
   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. American Society for Testing and Materials Standards (ASTM)
5. American Water Works Association (AWWA): ANSI / AWWA D100, Welded Steel Tanks for Water Storage, and NACE Standard PRO 178-89, Item No. 53041 and E101, Vertical turbine and submersible pumps
6. City of Seattle
   a. Plumbing Code (2003 Uniform Plumbing Code)
   b. SDOT Right-of-Way Improvements Manual (ROWIM)
   c. Seattle Energy Code (2004)
   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; updated 2006)
   i. Seattle Building Code (SBC): 2003 (consists of the 2003 International Building Code (IBC) with Seattle amendments)
   j. Seattle Department of Transportation (SDOT)
   k. Seattle Public Utilities (SPU): 2007 Water System Plan, 2006 Wastewater Systems Plan, 2004 Comprehensive Drainage Plan
7. Hydraulic Institute (HI):
   a. American National Standard for Pump Intake Design (ANSI/HI 9.8-1998)
   b. American National Standards for 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 9.6.3-1997
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. National Electric Code (NEC): Section 501-8
10. National Fire Protection Association (NFPA) 820, Recommended Practices for Wastewater and transmission facilities
11. National Sanitation Foundation (NSF): Standard 61
12. *Pump Station Design 2nd Ed.*, Editor-in-Chief Robert L. Sanks (the Sanks Book)

Websites

http://www.pumps.org/

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