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Mechanical and Electrical Design of Pump Stations

ENGINEER MANUAL

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Engineering and Design

MECHANICAL AND ELECTRICAL DESIGN OF PUMP STATIONS

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1. Purpose. This manual provides guidance and information to engineering, operations, maintenance, and to other individuals responsible for the mechanical and electrical design, operation, and maintenance of civil works (CW) pump stations including for flood risk management, environmental projects, lock dewatering and temporary pumping.

2. Applicability. This manual applies to all U.S. Army Corps of Engineers Headquarters elements, major subordinate commands, districts, laboratories, and field operating activities having responsibilities for the design and construction of CW projects.

3. Distribution Statement. This manual is approved for public release with unlimited distribution.

4. References. References are listed in Appendix A.

5. Records Management (Record Keeping) Requirements. Records management requirements for all record numbers, associated forms and reports required by this regulation are included in the Army's Records Retention Schedule - Army. Detailed information for all record numbers, forms, and reports associated with this regulation are located in the Records Retention Schedule - Army at https://www.arims.army.mil/arims/default.aspx.

6. Background. This manual update combines Engineer Manual (EM) 1110-2-3105 and EM 1110-2-3102 into one document. EM 1110-2-3102 is now obsolete. The manual is intended for designers and operators of CW pumping stations. Elements discussed include pumping equipment requirements, pump station layout and design, pump discharge system, pump drive selection, engines and gears, pump testing, power supply, power distribution, and pump station controls. Operation and maintenance (O&M) considerations are also addressed including O&M manual requirements.

FOR THE COMMANDER:

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(See Table of Contents)

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*This manual supersedes EM 1110-2-3105, dated 30 March 1994 and EM 1110-2-3102, dated 28 February 1995

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Chapter 1
Introduction

1.1 Purpose. The purpose of this manual is to provide information and criteria pertinent to the design and selection of mechanical and electrical systems for CW pump stations.

a. This manual is also pertinent to other engineering disciplines including structural, hydraulic and civil. This manual is applicable to many types of U.S. Army Corps of Engineers (USACE) stations such as flood risk management, lock dewatering, environmental management projects, wastewater stations and temporary pumping systems.

b. This manual also includes guidance for layout and intake design of CW pump stations primarily by referencing applicable Hydraulic Institute (HI) Standards. Elements discussed include equipment requirements, pump station layout and design, O&M manuals, pumping equipment and conditions, discharge system, trash rakes, engines and gears, pump drive selection, pump and station hydraulic tests, power supply, motors, power distribution equipment, control equipment, station wiring, station and equipment grounding, electrical equipment, and station service electrical system.

1.2 Applicability. This manual applies to all U.S. Army Corps of Engineers Headquarters elements, major subordinate commands, districts, laboratories, centers and field operating activities having responsibilities for the design and construction of CW projects.

1.3 Distribution Statement. This manual is approved for public release with unlimited distribution.

1.4 References. References to this manual, which include technical papers, engineering guidance, engineering manuals, industry standards and textbooks are provided in Appendix A.

1.5 General. The document is a revision and update of the information presented in the 30 March 1994 version of EM 1110-2-3105 and the 28 February 1995 version of EM 1110-2-3102, General Principles of Pumping Station Design and Layout. These documents are now combined and EM 1110-2-3102 is now obsolete.

a. Relationship to Other Manuals. This manual supersedes all previous versions of EM 1110-2-3105 and EM 1110-2-3102.

(1) It should be used in conjunction with EM 1110-2-3104, Structural and Architectural Design of Pumping Stations, EM 1110-2-2610, Mechanical and Electrical Design for Lock and Dam Operating Equipment, EM 1110-2-1424, Lubricants and Hydraulic Fluids, EM 1110-2-2902, Conduits, Pipes and Culverts Associated with Levees and Dams and Other Civil Works Structures and EM 1110-2-1913, Design and Construction of Levees and all other referenced engineering manuals, technical letters, and engineering reports for the design, inspection, maintenance, and operation of pumping stations.

(2) Other applicable references are listed in Appendix A. Although EM 1110-2-2610 was written for lock and dam operating equipment, many parts of the manual directly apply to pumping station design. This includes mechanical components such as couplings, gears, and bearings and also hydraulic systems. EM 1110-2-2610 also provides discussion of electrical power systems, electrical controls, power distribution, lighting, and surge protection.

b. Drawing Plates. Appendix B includes a number of drawing plates applicable to the design of CW pumping stations. The drawing plates are referenced and discussed throughout the manual.

c. Design Guidance. This manual is not intended as a comprehensive step-by-step solution to pumping station design. The designer is responsible for exercising sound engineering resourcefulness and judgment while using this manual. Used as a guide, it provides experience-oriented guidance and a basis for resolving differences of opinion among the competent engineers at all levels. Other material useful in pumping station design, which is readily available in standard publications is referenced herein and listed in Appendix A. HI standards are industry standards for pump station design and referenced accordingly in this manual.

1.6 Mandatory Requirements and Deviation from Design Criteria. This manual provides guidance for the design of USACE pumping station structures and equipment.

a. In certain cases, guidance requirements, because of their criticality to project safety and performance, are considered to be mandatory as discussed in Engineer Regulation (ER) 1110-2-1150. Those cases will be identified as “mandatory,” or the word “must” will be used in place of “should.”

b. For pump stations associated with dams or levee projects, deviations should follow the risk informed guidance in Engineering and Construction Bulletin (ECB) 2019-15, Interim Approach for Risk-Informed Designs for Dam and Levee Projects. When a deviation to mandatory requirements is believed necessary, the designer should also follow the guidance in ER 1110-2-1150 as applicable.

1.7 Design Procedures. The design should include the quality of the materials to be used and the workmanship involved. Designs should be as simple as practicable. Increased complexity tends to increase initial and future O&M costs. Designs and equipment and material selection that require less frequent maintenance are recommended. The goal of the design should be to ensure minimal maintenance. The goal should also be to ensure any required maintenance is simple, accessible, uses readily available parts and supplies, and reduces operator/mechanic/electrician burden.

a. Design Computations. All design computations should be provided and included in the project Design Documentation Report. Design computations should be clear, concise, and complete. The design computations should document assumptions made, design data, and sources of the data. All references (manuals, handbooks, catalog cuts, existing stations), alternate designs investigated, and planned operating procedures should also be provided.

Computer-aided design programs can be used but should not be considered a substitute for the designer's understanding of the design process.

b. Construction Review. During construction, the designer should be involved in the review of shop drawings and as-built drawings, preparation of the pump station O&M manual, and field and shop inspections. The designer should also be consulted when a field change is recommended or required.

1.8 Other Design Information. Important design information is available from sources besides the prescribed USACE manuals and standard handbooks.

a. This includes HI Standards as noted above and other references in Appendix A. Design documentation and drawings from other projects, manufacturers' catalog information, sales engineers, project O&M reports, field inspectors, O&M personnel, and the pumping station structural design personnel are all valuable and readily available sources.

b. All existing information should be carefully examined and evaluated before applying a new product. Relying on previous satisfactory designs requires that the design conditions and requirements be carefully compared for applicability. The design engineer should consult with field engineers and make field trips to pumping stations under construction. Consultation with pump station operators is also very helpful. Obtaining and evaluating information from field sources is improved by making personal acquaintances and observations at stations under construction or operating stations as well as by making visits to pump manufacturers' plants.

1.9 Safety Provisions. Certain safety provisions are required by EM 385-1-1, Safety and Health Requirements Manual, guide specifications, trade standards, codes, and other manuals referenced herein.

a. Additionally, the requirements of the Occupation Safety and Health Administration (generally referred to as Occupational Safety and Health Administration [OSHA] Standards) are to be considered minimum requirements in USACE design.

b. Areas of particular concern to mechanical and electrical design are safety, noise levels, personnel access provisions, working temperature conditions, air contamination, load handling provisions, and sanitary facilities. OSHA Standards are continuously being modified and expanded. Conformance to the latest published requirements is essential.

1.10 Appendices. Required and related references are provided in Appendix A. Appendix B provides the drawing plates as discussed previously. Appendix C presents a method to determine the size of a pump to meet pumping requirements; it also provides the dimensions for the sump and station layout once the pump has been selected. The different methods and formulas used to determine the head losses occurring in a pumping station are also given in Appendix C. Appendix D provides a format for an O&M manual for a typical pump station. Appendix E provides a sample form for requesting electric service data from a public electric utility company.

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Chapter 2
General Pump Station Requirements

2.1 General. There are a wide variety of USACE CW pump stations currently in service. The requirements for new stations will vary significantly from project to project.

a. Some CW pump stations designed and built by USACE are part of a flood risk management project while others are for environmental projects or lock dewatering or temporary pumping. Some pumping stations are designed to be in continuous service such as many of the interior drainage stations in New Orleans, Louisiana. Some stations may pump a combination of sanitary sewage and storm water.

b. Pump stations built by the USACE are usually maintained and operated by a local public sponsor through a project cooperation engagement with USACE. Pump stations in urban areas may have operators experienced in both the maintenance and operation of pump stations. However, pump stations in rural areas may not have this expertise and pump stations may be manned by operators who are not technically trained in the various pump station equipment. Therefore, the equipment installed in these stations should be highly reliable and, whenever possible, should require minimal maintenance and be simple and easy to operate.

c. There are pump stations operated by USACE. As an example, the Memphis District has four major flood risk management pump stations operated and maintained by USACE personnel.

(1) Huxtable Pumping Plant.

(2) Graham Burke Pumping Plant.

(3) Drainage District No. 17 Pumping Station.

(4) Drinkwater II Pumping Station.

d. Diesel drives and gearboxes are utilized on a number of larger stations and often used where no electrical power is available. Diesel drives are utilized on a number of stations in New Orleans. This is because of the need to maintain station operation during a hurricane event where it is expected that no electrical power will be available. It is recognized that large diesel engine drives require a great deal of maintenance and are quite complex to operate.

e. Some stations will be located in a corrosive atmosphere, especially those located along an urban sewer and those that are pumping a combination of sanitary sewage and stormwater. At these locations, proper equipment and material selection and proper station ventilation designs are critical to minimize the effects of the corrosive atmosphere. It is expected that some of the equipment for these types of stations will be custom built and thus more expensive than standard equipment that is commercially available. Recommendations of local interest preferences should also be considered.

f. The various types of pump stations are further discussed in Chapter 3. The various types of pumps are discussed in Chapter 4. Chapter 5 discusses specific pumping requirements. The majority of pump stations built by the USACE will require custom designed pumps and may require a significant lead time for manufacturing. That needs to be considered in the overall project schedule.

g. For pump stations as part of levee systems, there are other design objectives the designer must consider as noted in ECB 2019-15, ER 1105-2-101, Risk Analysis for Flood Damage Reduction Studies, ECB 2019-3, Risk Informed Decision Making for Engineering Work during Planning Studies and Planning Bulletin 2019-04, Incorporating Life Safety into Flood and Coastal Storm Risk Management Studies. The designer must determine the applicability of all these documents for any new station design or rehabilitation of any existing station.

h. The designer needs to identify all flood risk drivers associated with the project and understand how to efficiently reduce incremental risk to life safety (structurally and non-structurally) within the limits of the authorized project.

i. Pump stations are features or components of levees systems and should be designed, constructed, and operated to function as a part of the system (e.g., provide the flood risk reduction benefits as intended by the system).

2.2 Environmental Considerations. The planning, design, construction, and operation of pump stations should take full consideration of the project's environmental requirements. Many of these requirements are dictated by Federal or state statutes, by local sponsor's desires or by USACE policy. In any case, studies of pump station features should be undertaken to identify potential impacts and to define environmental objectives and constraints.

a. Pump stations affect the hydrology and water quality of both the receiving and supplying water bodies. The changed hydrologic and water quality conditions often affect other environmental parameters. The following list contains some of the potential adverse environmental impacts of a pump station:

(1) Reduced dissolved oxygen.

(2) Increased temperature.

(3) Increased turbidity and suspended solids.

(4) Lost habitat (riparian and aquatic).

(5) Change in hydrology and hydraulics.

(6) Noise generated by prime mover (diesel versus electric).

(7) Aesthetics.

(8) Waste fuel oil and lubricating oil and greases.

b. A pump station can and should have negligible adverse environmental impacts. Through proper planning, design, construction, and operation, many of the adverse impacts noted can be avoided or minimized. Remaining impacts should be mitigated and environmental enhancement addressed. The following steps should be taken to better ensure satisfactory compliance with the environmental objectives of pump station projects:

(1) Identify all environmental objectives and constraints, including statutory and policy requirements and sponsor's desires.

(2) Identify all potential environmental impacts, both adverse and beneficial.

(3) Incorporate design, construction, or operation features that avoid or minimize adverse impacts.

(4) Quantify unavoidable adverse impacts and incorporate appropriate mitigation features.

2.3 Design Life. The design life of a station will be greatly impacted by a variety of factors including how often it is used, operating conditions, climate, etc.

a. When designing a permanent pump station, the intent should be to design it as robust as possible for permanent installation with a goal of 50-year life. Even temporary pump stations may be in service for an extended period of time so that needs to be considered. Flood risk management projects are built for a permanent long-term lifecycle and equipment selection needs to reflect that.

b. In general, the equipment designed and selected should be built for the longest life span available. In some cases, it is necessary to do an economic analysis to determine the type of equipment to use. A minimum service life of 35 years with proper maintenance should be the goal for any equipment. For life cycle purposes, it should be noted that equipment such as pumps may require overhaul after 20 to 25 years. This should be a guide for preparing the design and the specifications for equipment including the pumps, controls, motors and drive assemblies.

c. Pump stations with wet pit sumps must be kept in a dry condition to extent possible during non-operative periods. This is to prevent corrosion and deterioration of equipment and to allow inspection. Station designs must provide a means for sump closure.

2.4 Materials of Construction. The primary cause of equipment deterioration in many pumping stations is simply from lack of operation and long durations of downtime and associated moisture problems caused by this downtime. These conditions should be considered when preparing designs and specifications. The designer should investigate the use of heaters in the housings of motors, motor control centers (MCCs), and switchgear to help mitigate moisture condensation.

a. For example, bearings and seals on pumps can deteriorate if not used or exercised on a regular basis. Excessive moisture in operating buildings can lead to rust and corrosion in electrical cabinets. The designer should give preference to those materials that require the least maintenance and have the longest life.

b. Guide specifications covering the materials and construction considered best suited to meet the usual service conditions have been issued for various pump station equipment. When applying the guide specifications to individual projects, modification of the specification provisions should be limited to those changes necessary for the operational requirements. Equipment problems caused by condensation and exposure to sewer gases in pumping stations used to pump sanitary sewage and storm water require additional corrosion resistant materials and sealants.

2.5 Dependability. Pump stations are one of the more vulnerable features of a flood risk management project. The failure of a pump station during a flood could result in considerable damage within the protected area. This would cause the loss of some or all of the benefits that justified construction of the project. Consequently, dependability must be the primary consideration during the pump station design, the selection of reliable power supply, and the pump selection process. The designer should reference ECB 2019-15 and ER 1105-2-101 for further consideration of risk-based approach to station design.

a. While the cost of the pumping station is generally a small percentage of the cost of the entire project, this does not mean that the designer is to proceed without any consideration of cost. Where there is infrequent operation of pump stations, efficiency can be sacrificed to a certain extent in favor of equipment with a lower first cost.

b. However, higher pump efficiencies can actually lower the installed horsepower (HP) requirements and reduce operating costs for large stations that have frequent usage. The extra costs to provide higher efficiency equipment should be studied on a life cycle cost basis over the project life. This economic study should consider both first cost and the cost of operation, maintenance, and replacement of equipment over the project life.

2.6 Large Pumping Stations. Pump stations having a capacity of 1,060 cubic feet per second (cfs) (30 m^3/sec) or larger should be engineered and designed by the Hydroelectric Design Center (HDC) described in the ER 10-1-53 ROLES AND RESPONSIBILITIES HYDROELECTRIC DESIGN CENTER. However, this is not a mandate.

a. USACE District, Portland, HDC is a Technical Center of Expertise (TCX) for pumping plant engineering and design. The services and level of involvement offered by the HDC are detailed in ER 10-1-53.

b. It is recommended the HDC be involved in the design of pump stations that have any unusual inlet conditions and require hydraulic modeling and computational fluid dynamics (CFD) analysis. The HDC should also be involved in any pumping stations designs that deviate significantly from standard criteria and are complex in nature.

2.7 Equipment Requirements. The equipment selected must be rugged, reliable, and well suited for the required type of service. The pump station structure should be sized to house and support the equipment. Refinements which make no realistic contribution to usability or dependability should be strictly avoided.

a. Architectural appearance will not be a governing criterion except in highly developed areas where concessions in regard to exterior treatment may be made as discussed in EM 1110-2-3104. It is highly recommended to install a building structure over the pump station whenever possible. The building helps protect the mechanical and electrical equipment and also provides a weatherproof structure for operating and maintaining the station.

b. Buildings should include heating and ventilating systems. Heating systems will also help mitigate moisture issues in the building. Cooling systems can also be considered depending on the climate. Equipment backup requirements should be evaluated both on the probability and the effect of a malfunction. Usually a backup is provided only for equipment that would cause the entire pumping station to be inoperable.

c. Spare equipment should be considered for equipment whose design is unique or one of a kind construction which would make replacement lengthy or very costly. Spare equipment for most pump stations should consist of bearings, impellers, shaft sleeves, temperature probes, relays, switches, lubricators, and any other types of auxiliary equipment being used on the pumping unit.

d. Spare equipment should also include a spare impeller and pump bowl section if there are a large number of pumping units at the project (typically five or more) or there are multiple stations using the same size and type of pump procured under the same contract. Spare parts should also be provided for the prime mover.

e. The selection of the type of equipment to be used should be based on alternative studies and a multi-criteria analysis. When a choice of different equipment is available and will perform the same function, all applicable types should be considered. The selection should be based on reliability and least annual costs. Since reliability cannot be easily assigned a cost, it should be evaluated on the basis of what affect an equipment failure would have on the operation of the station.

f. Reliability and ease of maintainability should be governing criteria. A piece of equipment whose failure would still permit partial operation of the station would be more desirable than an item that would cause the entire station to be out of operation.

g. The annual costs should include the first costs, operating costs, maintenance costs, and replacement costs based on project life. As certain items of equipment may affect the layout of the station including the location and suction bay and discharge arrangement, the structural costs associated with these designs should be included in the cost analysis. On major equipment items, this study should be included as part of the Design Documentation Report.

h. Proper lubrication is an important part of a good maintenance program. Dependable operation and the life expectancy of equipment requiring lubrication are almost entirely dependent on the use of proper lubricants at the right time intervals and in the proper quantities.

(1) All equipment requiring lubrication should be surveyed and appraised for the type of bearings, gears, and service conditions under which the equipment must operate. After these operating conditions are fully analyzed, then it can be determined what characteristics the proper lubricant should have, such as resistance to moisture, temperature range, whether an extreme pressure lubricant is required, and the proper viscosity range. The EM 1110-2-1424 should also be referenced and utilized.

(2) Some manufacturers recommend only the viscosity of the lubricant while others list the lubricants by trade name. The number of different types should be kept to a minimum. The frequency of lubrication used is recommended by the manufacturer and may have to be adjusted based on special use or experience.

(3) The equipment must be examined in detail when preparing lubrication instructions, so that every grease fitting and oiling location can be indicated in the maintenance instructions. Manufacturers' information does not always show enough detail to permit accurate preparation of the lubrication instructions. Photographs of the various pieces of equipment showing the locations of all the lubricating points are very useful. Chapter 4 further discusses lubrication requirements for pumping systems.

i. The pump anchorages are normally designed and recommended by the pump manufacturer. The pump's anchorage should be designed with proper consideration of the maximum torque of the pump driver. For a mechanical drive system, the maximum torque into the system has to be coordinated with the structural system. The mechanical and structural designer must coordinate as necessary to support these considerations. See Chapter 20 for more discussion on locked rotor torque.

(1) Anchor bolts must carry the combined dynamic, static and seismic loads imposed on the base plate. The designer should reference American National Standards Institute (ANSI)/HI 9.6.4 Rotodynamic Pumps for Vibration Measurement and Allowable Values. The designer should also determine and check equipment foundation mass ratio and natural frequency

separation margin between the supporting floor and the equipment to prevent resonance frequency from occurring on the floor or equipment.

(2) The designer should reference ANSI/HI 14.3 and 14.5 Rotor dynamics for Design and Consideration for Foundation and Anchor Bolts for more information and for analysis of loads both axial and horizontal into the structure. Chapter 5 further discusses dynamic analysis for pump installation.

2.8 Number of Pumps. The number of pumps selected should provide back-up capability in the case one or more pumps fail. However, it is required that all pump stations, with exception of temporary stations, must have at least two pumps of equal size to handle required pumping capacity. Even for temporary stations it is recommended at least 2 pumps be provided.

a. The number of pumps selected should be based on a life cycle cost and economic analysis if possible. Hydrology and hydraulic considerations also play an important role in the economics of pump stations especially for flood risk management stations. It may be cost prohibitive to consider all possible pumping scenarios when determining number or size of pumps. Increasing the number of pumps will provide more redundancy but will increase the O&M costs for the local sponsor. Conversely, reducing the numbers of pumps will reduce O&M costs but will decrease the redundancy.

b. It is highly recommended the designer provide the number, size and capacity of pumps that in the event one pump fails, the station will have at least 2/3 of the original required station capacity. The redundancy decision should be risk informed for flood risk management pump stations or pump stations part of a levee system. See ECB 2019-15. This requirement may also be project specific depending on the requirements of the local sponsor, Federal Emergency Management Agency (FEMA), etc.

c. General considerations. Pump station cost should be based on an annualized cost which should consider both first cost, operating and maintenance cost, and cost of equipment replacement over the life of the project. Generally, the lowest cost is obtained with a minimum number of pumps.

d. Again, all stations must have at least two pumps of equal size to handle the design station inflow requirements. This information will be provided by the hydrology and hydraulic engineers. A smaller base flow pump can also be added to accommodate small rainfall events. Base flow design for combined flow stations should have sufficient capacity for peak domestic and industrial flows, seepage, and runoff due to light rains.

e. Economic study. The number and resulting size of operating pumps must be determined by an economic study. This study should consider the consequences and related costs if one or more pumps malfunction. The consequences will vary significantly depending on what the station is used for. For flood risk management stations, risk informed decision making should be used to determine the number of pumps due to the potential for loss of life and economic damages. See ECB 2019-15.

(1) Flood risk management stations will likely have higher consequences than an environmental project for example. The greater the number of pumps, the smaller the reduction of the total station capacity if one pump malfunctions. This increased protection, however, results in higher equipment, facility, and O&M costs.

(2) The need to reduce the impact if one pump malfunctions will most likely be appropriate in urban areas where a pump failure could cause significant property damage and raise ponding more rapidly to life threatening depths. The extra costs cannot normally be justified in areas where there are adequate flood warnings or no life threat.

(3) Any decision to add more pumps or more capacity to reduce pumping time and/or ponding stage in the event one pump malfunctions must be well justified and the justification well documented. An economist will normally perform the economic study, closely coordinated with the hydrology and hydraulics studies and pumping station design engineers associated with the project. Whether pumps can be procured under a separate supply contract should also be investigated.

f. For stations pumping sanitary and industrial sewage, where one pump is required for the design capacity, a duplicate pump must be provided and installed of the same size and capacity. An economic study should be done to determine if additional pumping capacity is warranted.

2.9 Design Documentation and Drawing and Specification Production. The design documentation is prepared in the planning, engineering and design phase of a project. This phase begins the most intensive engineering effort and culminates with the preparation of contract plans and specifications. The applicable portions of ER 1110-2-1150, ENGINEERING AND DESIGN FOR CIVIL WORKS PROJECTS, will govern the contents and formatting of the various required submittals and the proper formatting of design documentation and plans and specifications.

a. The submittals required for a particular project will be discussed at the earliest design coordination meeting, and the listing of design documentation required will be established either at this meeting or as early as possible after this meeting. The following describes design documents developed during the design phase of a project. Other design documents, such as letter reports, can be substituted but should still contain the information and data required below.

b. For each project, there are different combinations of design documentation prepared before proceeding to plans and specifications. Station layout, sizing, and equipment selection should be investigated in sufficient detail, in the early design stage, to permit site layout of the station and preparation of a cost estimate. The building structure should be investigated at this stage. Hydrology and hydraulic studies should present the required pumping conditions and capacity used for selection of the pumps. The design memorandum should include dynamic analysis to the level appropriate and include references to the applicable HI standard guidance.

c. Information should include discussing the use of Government-furnished equipment if that method of pumping unit procurement is proposed. If there are a number of stations required on a project with similar pumping requirements, pumps can often be purchased ahead of the project under a supply contract. These pumps are then provided to the construction contractor as Government furnished materials.

d. Detailed mechanical and electrical design data and computations should be included to allow approval of the final layout and design before preparation of plans and specifications. The results of alternative studies for the station layout and equipment selection should be presented. Design computations to determine size, strength, rating, adequacy, and interrelationships of mechanical, electrical, and structural items should be shown in sufficient detail to allow an engineering review. All formulas and assumptions used should be indicated.

e. Copies of typical manufacturers' performance data for the proposed equipment and correspondence with manufacturers should be included. Any deviations from this manual must be indicated in the text portion of the memorandum. The memorandum should include an analysis of the schedules for the procurement of the pumping equipment and construction of the pumping station.

f. The design documentation must include any life cycle cost, multi-criteria analysis, and economic analysis for pump selection. The head loss calculations for pump selection must be included. The complete documentation for the selection of the pumps, motors, and drive system must be provided. Sizing criteria must be included for the selection of pumps and pump drives and motors.

g. Plans and Specifications production should follow the requirements listed in ER 1110-2-1150. The level of detail and complexity of plans and specifications will be project specific. Design drawings should provide proper geometric dimensioning of critical components such as pumps and motors and MCCs.

2.10 Operation and Maintenance Manuals. An adequate pump station O&M manual must be prepared to permit successful operation of any station. The level of detail will vary depending on the type of station.

a. For flood risk management projects operated by a local sponsor, a detailed O&M manual specific to the pump station must be considered a requirement before the project is turned over to the local sponsor and operator. The portion of the manual covering the mechanical and electrical equipment is generally prepared by the designers responsible for specifying this equipment. However, pump station O&M manuals are also specified in construction contracts and submitted by contractors utilizing prepared O&M manuals from pump

& equipment suppliers. It is the designer's responsibility to integrate these contractor manuals into the overall O&M flood risk management manual.

b. The pump station manual should provide a platform for carry-over of information from the designer to the operating personnel. The manual should be prepared to aid the operating personnel in understanding the equipment and to set the guidelines for maintenance procedures. A manual provides a detailed guide in the event of personnel changes in O&M of the station. The manual should include the complete mechanical and electrical shop drawings for the project and all relevant construction as-built drawings.

2.11 Office Facilities and Building Superstructure. A weatherproof building is highly recommended and should be provided for all pump stations. An enclosed office should be provided for all stations over 3 m^3/sec (100 cfs) total capacity. A desk, chair, and filing cabinet to store O&M manuals and as-built drawings should be provided. Sound proofing should be provided for stations with diesel prime movers. Heating and cooling should be provided as necessary. However, proper ventilation must be provided for all buildings.

a. Sanitary facilities. Sanitary facilities should be provided for all pumping stations as necessary and are required for stations that are permanently manned. This decision will typically be made in the preliminary design phase of the project in coordination with the local sponsor. These facilities will range from portable units for small stations with little operating time to more conventional facilities with showers for the larger stations and must meet the requirements of EM 385-1-1. For example, a larger station may have a total capacity over 90 m^3/sec (3,000 cfs) with a workforce of over 12 people.

b. Drinking water. An adequate supply of potable drinking water must be provided as described in EM 385-1-1 for stations that are permanently manned.

2.12 Safe Houses and Design for Coastal Areas. Some pump stations such as in New Orleans and in Florida are manned during hurricane events. The design of these structures should follow the guidance in the FEMA P-361, Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms, Third Edition (2015) available at https://www.fema.gov/media-library/assets/documents/3140.

a. There have been some instances where these structures have been called "emergency shelters" rather than safe houses but there is typically not any distinction except for the signage requirements per FEMA. FEMA requires safe houses to have specific signage and if the structure does not meet the signage requirements, USACE has called these emergency shelters.

b. For designers working on stations in South Florida on flood risk management stations, see Paragraph 2.15 and Chapter 3 of this document. The SFWMD has indicated that they occupy all of the flood risk management stations when a hurricane approaches. The SFWMD designs the structures per expected hurricane wind loads. The elevation of the pumping station floor, and the minimum for the occupied spaces, is set above the possible high-water level.

c. Louver design is an important consideration for stations in coastal areas and is further discussed in Chapter 14. The pump stations in Florida use louvers that are commonly referred to as Miami-Dade louvers for intakes and exhausts. These louvers are required to meet the Florida Building Code Testing Application Standards (TAS) 100(A), TAS 201, TAS 202 and TAS 203. These provide protection from wind-driven rain and wind-driven projectiles.

d. The SFWMD sometimes provides hoods over the louver intakes, but these can drive up costs based on the extra service bridge width that has to be provided so that vehicles do not hit the hoods. Since these structures have life safety implications, the design has to be coordinated with the local sponsor and the operators of the station.

e. The designer needs to consider the requirements for louvers based on project specific locations and operating equipment in the station and whether the stations are located in coastal areas. Diesel engines may be water cooled or air cooled and the radiator requirements will impact louver design. Chapters 12 and 14 of this manual provide further discussion including heating, ventilation, and air conditioning (HVAC) requirements.

2.13 Pumping Station Design. Pumping station capacity requirements (the number of pumps, pump flows, operating elevations, etc.) are normally determined by the hydrology and hydraulic engineers as described in EM 1110-2-1413, HYDROLOGIC ANALYSIS OF INTERIOR AREAS, This manual provides the basis for establishing pumping requirements for the maximum and minimum water stages permissible in the protected area.

a. The hydrology and hydraulic data provide the basic information needed for the selection of equipment and the layout of the station. In those special instances where an increase in pumping capacity will occur at some future date, consideration should be given to a station design that facilitates the installation of increased capacity in a manner that will give the greatest overall economy. Alternate studies of pumping stations that would satisfy the required pumping capacity should be made for all pumping station projects. As a minimum, the studies should include station location, station site layout, all equipment, sizing of pumps, type of operation, operating and maintenance costs, and first costs.

b. Pump Station Location. Experience has shown that a pumping station should be located in such a manner to produce the most direct inflow possible. Any location that produces asymmetrical flow into the pump bays may cause problems with circulation, uneven velocity distribution, vortices, and generally poor pump performance. The design of trench well stations further discussed in Chapter 6 are an exception.

(1) This is true for inflow confined within an inlet channel, sewer, or a large ponding area. Additional engineering studies and/or physical modeling may be required for many

pumping stations to help determine the performance of the pumping station design and whether any modifications will be necessary to enhance performance and correct deficiencies.

(2) Compromised station siting would likely require additional engineering studies and/or physical modeling when circumstances exist that prevent recommended station siting. Gravity flow structures, when provided, can be located in an offset position without additional cost and still perform adequately.

c. Line of protection. The location of stations with respect to the line of protection should be selected for safe operation.

(1) Construction of the station integral with a concrete floodwall will, in general, minimize the hazard of discharge line failure. On projects with an earth levee or where right-of-way restrictions exist, the station should be located at the landside toe of the levee.

(2) Physically, the station should be located to one side of the gravity discharge line and the sump (wetwell) gated so flow will not enter the station during gravity discharge. Another possibility to investigate with restricted right-of-way is to place the station in the line of protection. More hazardous locations (riverside of protective works) may be considered if a definite operational or economic advantage is presented.

d. Vehicle access to stations at all flood elevations must be provided and carefully considered in station location. The designer should incorporate adequate provisions to permit safe operation of service vehicles bringing in equipment and materials during construction and also future O&M. The future owners and operators of the station should be consulted early in the design phase to properly coordinate access to the station.

e. Operating Floor Space Requirements. The operating floor elevation should reduce the possibility of damage, caused by flooding, to the pumping equipment. This elevation is dependent upon the hydraulics and hydrology criteria, the location, and the physical layout of the pumping station. Primary considerations are to have sufficient space to both operate and maintain the pump station. Generally speaking, maintenance, removal or installation of the equipment will define the necessary size of the operating floor. Often the sump or inlet design will define a certain minimize size.

(1) The operating floor must also have adequate capacity for maintenance operations. The floor must be designed with adequate load capacity for these operations and for heavy components, it will normally be necessary to designate specific locations where these components must be placed. Provide adequate hoist and crane capacity, clearance and coverage based on the largest equipment to be moved. This needs to be considered by the designer early in the design process.

(2) A roll-up door or doors of sufficient size for transporting equipment into and out of the station should be provided. The designer should take into account a vehicle will likely be needed in the station for loading equipment.

(3) In general, equipment such as pumps should be located a minimum of 3 feet apart to allow sufficient space for maintenance.

(4) When the pumping station is located on the line of protection, the elevation of the operating floor will depend on whether the pumping station is subject to the discharge pool elevations or is protected by a flood wall. When the pumping station is subject to the discharge pool elevations, the operating floor should be no lower than the top of the levee and is recommended to be at least 0.3 m (1 ft) higher than the top of levee.

(5) When the pumping station is protected by and built into a flood wall, the operating floor elevation should be located at least 0.3 m (1 ft) above the interior level of design protection.

(6) When the pumping station is not located on the line of protection, the elevation of the operating floor should be at least 0.3 m (1 ft) above the interior level of design protection. The design documentation report should include sketches of all the proposed alternatives and note the operating floor elevation in regard to the interior drainage water elevations.

f. Pump stations should be designed for ease of exercising and testing. Stations should be commissioned during their initial construction. Generators at pump stations should be designed to automatically operate and test on at least a monthly basis. At all pumping stations, pumps should be exercised and tested at least 2 times per year. All HVAC equipment, hoist equipment, gates, trash rakes and controls should be tested and operated at least 2 times per year.

g. Pump Efficiencies. The designer should be aware of recent Department of Energy (DOE) rules pertaining to pump efficiency. These rules became effective in March of 2016 and compliance is required in January of 2020. The HI has also published HI 40.6 to be compliant with these new rules. The requirements primarily apply to clean water pumps and are detailed in 10 Code of Federal Regulations (CFR) 431.464 and 10 CFR 431.465. The DOE rules affect the nameplate and labeling of the pumps also.

(1) The types of pumps covered by the DOE rules include end suction closed coupled, end suction frame mounted, in-line, radially split multistage in-line diffuser casing and submersible turbine.

(2) For a pump to be covered by the DOE regulation it must be designed for pumping clean water, have a nominal speed of 1800 or 3600 revolutions per minute (RPM), be between 1 and up to 200 HP, have a flow rate of 25 gallons per minute (gpm) or greater at best efficiency point (BEP), have a maximum head of 459 feet at BEP, and have a design temperature range from 14° Fahrenheit (F) to 248° F (-10° Celsius (C) to 120° C).

h. Sump Unwatering. Provisions must be included in the station design to unwater the sump between pumping periods for inspection and maintenance. Sump pumps should be solids handling submersible type capable of being lifted out of the station by guiderails with the station hoist.

(1) Small stations 11 m^3/sec (400 cfs) or less should be designed so the station can be completely dewatered in 6 hours or less.

(2) Larger stations over 11 m^3/sec (400 cfs) should be designed so the station can be completely dewatered in 12 hours or less.

(3) Unwatering sumps are normally located outside the main pump sumps to avoid disturbing flow patterns to the main pumps. Discharge piping should be separated from the main pumps and any interconnecting piping should be kept to a minimum.

i. Cybersecurity requirements for pump stations should follow the requirements in ER 25-1-113. The designer should also reference Chapter 23 of this manual.

2.14 Hydraulic Institute Standards. The HI standards should be utilized for pump station design. The HI is the global authority on pumps and pumping systems and pumping station layout and configuration. From their website, "HI is a pump association of positive displacement and rotodynamic, centrifugal pump manufacturers and suppliers whose mission is to be a value-adding resource to member companies, engineering consulting firms, and pump users worldwide".

a. HI develops comprehensive pump standards, guidelines and guidebooks and serves as a forum for pump industry information and collaboration through volunteer participation and at pump conferences. HI standards cover pump design and applications, installation, O&M, pump testing, definitions and nomenclature and address such topics as allowable vibration, pump efficiency, nozzle loads, pump piping, viscosity correction and more.

b. In the past, designers of pump stations relied on recommendations by the British Hydromechanics Research Association and early HI Standards such as those published before 1998. Such publications, however, were confined to clean water.

c. In 1994, the HI appointed a committee of pump manufacturers and for the first time invited users, engineering consultants, and researchers to expand and improve the standards for clean water and, also for the first time, to consider designs for solids-bearing waters in detail. A new and entirely different standard resulted and, after consensus by public canvassing, was adopted as the American National Standard for Pump Intake Design, ANSI/HI 9.8 by both the ANSI and the HI.

d. ANSI/HI 9.8 is probably the most important and critical standard for pump station design. Every designer of pumping stations should have and understand ANSI/HI 9.8 plus all of the other pertinent ANSI/HI standards. A complete list of HI standards is provided in Appendix A. All ANSI/HI standards are revisited for review and revision every 5 years.

e. The HI standards also cover piping requirements for pump applications. After 1998, pump piping was broken out into its own standard 9.6.6.

f. All of the HI Standards are an industry standard and establish a benchmark for engineers and designers of pump stations. Engineering, application, and user groups have had the opportunity to comment on the standards, so they reflect both the opinions of all participants, and also the experience and defensible information on the subject.

2.15 SFWMD Guidelines. The discussion in this section is provided for reference for any design being completed on pump stations in South Florida operated by the SFWMD. A number of these stations have either designed by USACE or incorporated into USACE projects.

a. SFWMD publishes their own pump station design standards as detailed further in Chapter 3. The updated version of these standards is being published in 2020. These standards primarily affect the work of Jacksonville District in USACE and as such are considered local standards.

b. These are published as the MAJOR PUMPING STATION ENGINEERING GUIDELINES (MPSEG) and include all aspects of pumping station design. The SFWMD standard notes following: “This manual presents information and design criteria to be used as engineering guidelines to standardize the process for pumping station design including civil, structural, mechanical, instrumentation and control and electrical features, for major water control pumping stations. This manual establishes minimum standards for selection of mechanical and electrical equipment, pump machinery, and materials quality.”

c. Consideration to these local SFWMD design standards may be a factor when designing the pump station facilities in Florida; however, those local design standards must be weighed against USACE standards for adequacy of intent. It is mandated to document, establish and properly justify any cost increases using SFWMD standards and criteria early in the design phase and before proceeding to construction. The USACE Jacksonville District and SFWMD have already developed several working agreements as discussed in Chapter 3 in regard to this issue.

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Chapter 3
Pump Station Design

3.1 Station Type. USACE CW stations are used in a variety of applications and operate in a variety of environmental conditions.

a. The designer must account for all conditions the station will operate in. Some stations may never see freezing conditions such as in South Florida while others operate in cold weather conditions and ice and snow in North Dakota. The equipment in the station including HVAC must be designed accordingly based on the location of the station.

b. Many of the pump stations designed and built by the USACE are part of a flood risk management project and the design practices presented in this chapter are weighted more heavily towards that end. However, the considerations necessary when approaching design for a variety of pump station applications will be summarized in this section. The designer should reference ANSI/HI 14.3a Rotodynamic Pumps for Design and Application for detailed discussions of different types of pumps and specific applications for various pump types.

3.2 Drainage Stations. Drainage pump stations are used extensively on flood risk management projects and may pump any combination of stormwater, floodwater, seepage, wave overtopping, etc. These are the most common type of USACE station. These stations may provide drainage year-round, seasonally, or in conjunction with specific events such as high water and flood conditions. These stations also operate in storm events where other drainage mechanisms such as gravity flow are overwhelmed. Plates B.1 through B.6 in Appendix B show a variety of station types.

a. Drainage stations will vary greatly in size and head conditions and there are a number of configurations possible with drainage stations. Drainage stations can be set back from a levee, incorporated into a levee with an outlet structure or built into a floodwall. Figure 3.1 shows a station built into a floodwall. The architectural requirements for operating buildings will vary greatly depending on whether the station is located in an urban or rural area. Typically, these stations should be of the wet-pit (sump) type employing vertical mixed-flow or axial-flow pumps in the majority of cases. These pumping units may also be of the submersible type as shown in Plates B.4 and B.6 in Appendix B.

b. Large horizontal pumps (Figure 3.2) have been employed in the past on which the impeller is typically in the dry when not in use. This arrangement aids in servicing pump components, provides for very efficient operation when moving very large volumes of water at low heads and may result in a shallower intake sump.

(1) These types of pumps are also very slow moving. However, it typically requires a larger station footprint and additional vacuum priming equipment. The vacuum priming requirements can be complicated and typically require separate vacuum priming pumps. Many of the drainage stations within the City of New Orleans are this type of configuration.

(2) The designer should be aware for these very large horizontal pumps, the Net Positive Suction Head Available (NPSHA) relative to the vane as each vane passes through the 12 o'clock position can be marginal resulting in cavitation damage. It is the large horizontal pumps that are most vulnerable to this phenomenon. The NPSHA should be calculated at the top of pipe or the high point of the impeller.

(3) This type of station is not recommended unless the designer has specific experience with this configuration and project requirements favor its use.

c. Drainage pumping stations usually pump directly from open storage ponds, ditches, drainage canals or storm water sewers. It is required that provisions be made for exclusion of water from the pump sump or wetwell and for maintaining the sump in a dry condition during inoperative periods.

Figure 3.1. Flood Risk Management Drainage Station built into a floodwall

d. Submersible pumps are used in many stations today and are available from multiple manufacturers. These pumps offer the advantage of freeing up space on the operating floor since the motor and pump are combined. However, a means to lift the pump out of the well should be provided such as a bridge crane or a monorail crane.

e. For submersible pumps, the designer should reference HI 11.6 Rotodynamic Submersible Pumps for Hydraulic Performance, Hydrostatic Pressure, Mechanical, and Electrical Acceptance Tests. A submersible pump is defined as a close-coupled pump/motor unit designed to operate submerged in the pumped liquid. This definition includes submersible pumps operating in either a wet-pit or dry-pit environment.

f. Submersible pumps are also available which may be oriented at varying angles or horizontally, providing flexibility in installation. When horizontal or angled pumps are employed, NPSHA should be calculated at the highest point on the impeller to avoid cavitation.

g. A station for pumping water from an extensive open ponding and a channel is shown in Figure 3.3. This station is located at the edge of the ponding area, adjacent to the gravity drainage structure discharging through the line of protection. The station's inlet sump is at an elevation considerably lower than the gravity flow stream requiring the sump to be pumped dry for service.

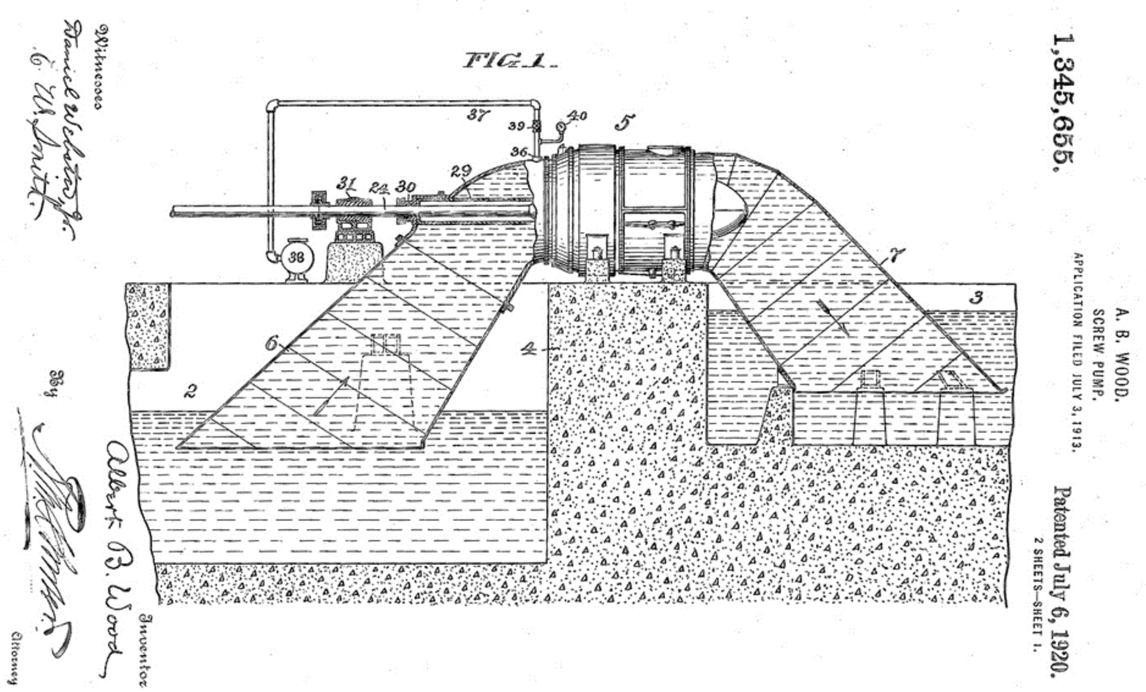

Figure 3.2. Horizontal Pumps from City of New Orleans

h. Occasionally stations will be located over streams or drainage canals and in such instances pumps must be protected from damage by runoff during inoperative periods. Since the liquids pumped by drainage pumping stations are generally not of a particularly corrosive nature, a wider latitude in selection of materials is permitted. In coastal environments, material selection may be more restricted.

Figure 3.3. Station Intake Located on an Open Ponding Area, Orleans Ave. Pump Station Louisiana

3.3 Sewage Lift Stations. Sewage lift stations may vary greatly in duty and pump size from small prefabricated packaged units to large municipal lift stations. Similarly, the qualities of the wastewater being pumped will vary with application. Ventilation requirements are critical for sewage lift stations for safety of the operators. These stations will normally require explosion proof motors for not only the pumps but all other mechanical equipment.

a. A submersible lift station is shown in Plate 8 in Appendix B. Applicable local codes or design standards should be utilized when available. Excessive quantities or sizes of solids may require screening or grinding of the influent prior to pumping, however, such equipment presents additional maintenance concerns and should be avoided where practical. Solids handling pumps should be utilized.

b. These stations may be of the wet-pit (sump) or dry pit type. If of the wet pit type, the pump should be equipped so that it can be raised for cleaning or repair, reducing the need for personnel to enter the sump.

c. Alternately, self-priming pumps may be considered if the suction lift is manageable. For dry pit installations isolation valves should be used at the pump intake. Sewage lift stations may employ constant speed (C/S), variable speed (V/S) or some combination of C/S and V/S pumps. C/S pump equipment is typically less expensive and more reliable but may require larger sumps. V/S pumping is generally preferred in large systems as continuity of flow is advantageous in the wastewater treatment process, where-as spikes in flow rate may be disruptive.

d. For C/S pumping, sumps should be of adequate size to prevent short cycling and the need for a smaller pump to handle low flows should be considered. Large sump volume is unnecessary for V/S or combination pumping. V/S pumping with trench well type sumps as discussed further in Chapter 6 have been used with much success. Sumps used with solids bearing water should include provisions for cleaning, such as hopper bottoms or trench type with curved ramp at the inlet. Further guidance on sump design may be found in ANSI/HI 9.8 and Chapter 6.

3.4 <u>Combination Flow Stations</u>. Combination flow stations are stations in which flows consist of some combination of stormwater and domestic and industrial wastes.

a. In order to avoid the environmental hazards associated with combined sewer overflow, current design practices separate sanitary and stormwater sewers for new construction. However, many existing combination systems are still in use and may be encountered requiring upgrade. Additionally, some municipalities are implementing mitigation efforts such as combined sewer overflow storage, which may involve design of new combination flow stations.

b. Combination flow stations are characterized by having to pump runoff containing undiluted waste. The possibility of fumes and vapors also need to be considered when designing the sump ventilation system and electrical features located in the sump. Like for sewage stations, explosion proof motors will often be required. When wastes are combined with stormwater, the need for a smaller pump to handle dry weather flows and runoff from light rains should be provided. This baseflow pump should be a submersible solids handling pump.

c. The baseflow pump should be located in the main sump area and equipped and designed so that it can be raised for cleaning or repair, reducing the need for personnel to enter the sump. For stations on sewers having a relatively short time of concentration, it is necessary to place the stormwater pumps in operation within a short time after the start of rainfall. If large sluice gates are used to close the opening between forebay and the main sump, power operation of the gates will be required.

d. Diluted domestic and industrial wastes will be present in the main sump. Protection against corrosive fumes and vapors is a greater problem than in stations handling only stormwater. All sump openings in the superstructure should be sealed airtight.

3.5 <u>Hydropower</u>. Hydropower applications may employ pumped storage plants. Pumped storage plants are used to pump water from lower storage pools to upper storage pools usually during off peak times for use in hydropower generation at a later time. Design heads are typically larger than those of a typical stormwater or sanitary sewage station, and pump efficiency is generally a higher priority on these applications. Pumped storage plants will not be covered in detail by this publication. Designs of pumped storage plants should be coordinated with the HDC as indicated in ER 10-1-53.

3.6 Process Pump Stations. Cooling water or process water or municipal water source pumping stations bring water into a facility from a source for some specific use, as opposed to just the conveyance of stormwater or sewerage away from a location.

a. Such stations may have more stringent requirements for trash screening or filtering. Additionally, intakes may be designed to minimize sediment load pulled into the system. If the process water is going to be returned to the source waterway location of the discharge should be downstream or separated enough from the intake such that adequate mixing occurs.

b. Environmental regulations pertaining to the discharge of water into public waterways generally involves strict limits on both physical and thermal pollution. Additionally, sensitivity of the process for which the water is intended to be used may recommend certain types of equipment over others.

c. Such things to consider may include the presence of lubricants in the water, air entrainment, or any other change to the characteristics of the pumped water which may affect its suitability for the intended process. The levels of redundancy should be appropriate to the criticality of the project.

3.7 Environmental Stations. Environmental pump stations may serve a variety of purposes. Stations may be used to divert fresh water to control salinity in coastal estuaries or convey sediment laded waters for targeted deposition. These stations have also been designed to help restore fish habitat in river backwater systems.

a. Pumping direction may need to be reversible or pumping equipment may be required to provide aeration for fish attraction or to for oxygenation. Station designs will depend on the specific goals and constraints of a given project.

b. Pump stations in environmentally sensitive areas may put greater emphasis on minimizing turbidity in the water, pollution from lubricants or refueling operations, thermal and noise pollution, or physical hazards to aquatic species. The level of redundancy appropriate may also deviate from a traditional flood protection project. Considerations include the tolerance of the system to outages and the associated ramifications.

3.8 Remote Operation. Any consideration for remote operation must follow the requirements in ER 1110-2-1156, Safety of Dams Policies and Procedures. CFR 208-10, though, requires that "competent operators must be on duty at pumping plants whenever it appears that necessity for pump operation is imminent."

a. Considering the reliable automatic features available and the type of operation required at some facilities, it is recognized that remote operation may be necessary. Any

USACE office considering the use of automatic or remote features should request and fully justify use of remote operation following the requirements in ER 1110-2-1156. This request should be done early in the design phase of the project. Cybersecurity requirements must be addressed.

b. Remote operating stations should provide adequate monitoring and control capability to verify proper operation and address minor issues that are likely to occur during operation. Interface capabilities likely only to be needed in conjunction with onsite troubleshooting or maintenance need not be replicated at the remote operating station.

c. The requirements of Supervisory Control and Data Acquisition (SCADA) systems or closed-circuit television monitoring should be coordinated with the end user during the design phase of the station. Small drainage stations or sanitary sewerage pump stations are frequently automated using float sensors or similar devices.

d. Automatic starting stations generally should also include redundant stop mechanisms for low level shut off and similar considerations to avert equipment damage in the event of a failure when no operator is present. Automatic or remote operated pump stations should include measures to ensure the safety of bystanders, audible signals indicating pump start when pump operations may produce a hazard.

e. Additionally, any projects considering remote operation should ensure that such features will be implemented in a way that is in conformance to the latest USACE Cyber Security requirements. See Chapter 23.

3.9 Locality Considerations. This document seeks to provide general guidance on a wide range of potential pumping plant applications. The recommendations and guidelines presented are based on best practices and experience with numerous pump station projects but are not exhaustive in regard to the specifics of every project or application that will be encountered.

a. For specific regions additional guidance may exist to complement the instructions offered in this document. Where available, such instruction may provide local knowledge and specific history of significant value to the project even on such instances when the direction given exceeds or deviates with what is presented in this manual. Where conflict exists, it is the role of the design engineer to determine the suitable course of action. Support is available through the TCX at HDC and within the respective USACE communities of practice.

b. Hurricane and Storm Damage Risk Reduction System Design Guidelines. USACE, New Orleans District published the interim Hurricane and Storm Damage Risk Reduction System Guidelines with revisions through June 2012.

(1) These guidelines were developed in conjunction with the large number of projects being completed following hurricane Katrina in order to establish consistent guidelines across all projects.

(2) The document provides additional guidance for pump station projects where they involve hurricane protection systems. The designer should verify whether the Hurricane and Storm Damage Risk Reduction System guidelines will apply before starting any pump station project in the New Orleans area.

c. SFWMD's MPSEG. The SFWMD is a regional governmental agency that oversees water resources from Orlando to the Florida Keys as discussed previously in Chapter 2. This agency is the local sponsor for most USACE work in south Florida affecting Jacksonville District.

(1) Due to the large number of pumping station projects that are planned under the Comprehensive Everglades Restoration Plan, the SFWMD wanted to develop standardized engineering guidelines to facilitate the designs of pumping stations. The ensuing document includes design guidelines for civil, structural, mechanical, electrical, and instrumentation and controls features for major water control pumping stations.

(2) The manual established minimum standards for selection of mechanical and electrical equipment, pump machinery, and materials quality. The guidelines established within this manual were based upon long-term operation experiences by the SFWMD. The SFWMD coordinated the guidelines with the USACE, Jacksonville District, and subsequently published the MPSEG.

(3) The SFWMD and Jacksonville District reached agreement on several design memoranda to help standardize projects under the Comprehensive Everglades Restoration Plan. Design Criteria Memorandum DCM-5 officially requires the use of the MPSEG on major pumping stations in the SFWMD's area. Major pumping stations are defined in the guidelines as stations having axial or mixed flow pump machinery with a minimum total station capacity of 42 m^3/sec (1,500 cfs) excluding seepage and low flow capacity or having individual axial flow pump machinery units with a minimum capacity of 11 m^3/sec (400 cfs).

(4) Pumping stations in which the total pumping capacity is less than 42 m^3/sec (1,500 cfs) and the capacity of each individual pumping unit is less than 11 m^3/sec (400 cfs) are not covered by this manual. However, smaller pumping stations or pumping systems may have some of the features or components referenced in the manual (vacuum pumps, siphon breakers, etc.). In this case, those items should be designed as indicated in the manual.

(5) The MPSEG is not intended to have conflicts with this engineering manual. Instead, the intent is to tighten requirements such as the impeller material (the MPSEG requires cast stainless steel, American Society for Testing and Materials (ASTM) A743 CF8, while this is an option in Section 35 45 01 VERTICAL PUMPS, AXIAL-FLOW AND MIXED-FLOW IMPELLER-TYPE of the Unified Facilities Guide Specifications (UFGS)). Further, the MPSEG requires that all critical items (e.g., cooling water pumps, generators, etc.) used in large flood-control pumping stations have one redundant unit to allow the station to operate continuously in the event a unit fails or is being maintained.

(6) Further, the criterion requires a redundant pump if the pumping systems are for flood risk management.

(7) For example, it states that the "failure of a pumping station during a flood could result in considerable damage within the protected area. This would cause the loss of some or all of the benefits that justified construction of the project. Consequently, station dependability must be the primary consideration, during the design and pump selection process."

3.10 Temporary Pumping. Temporary or portable pumping may be utilized in place of permanent pump stations either on an emergency basis or for planned outages or augmentations of existing pump capacity as shown in Figure 3.4.

a. Self-contained electric or engine driven pumps may be available for small pump flows. Larger submersible electric or hydraulic driven pumps are typical for larger applications. Hydraulic driven submersible pumps with engine driven hydraulic power units as shown in Figure 3.4 have proven particularly cost effective for limit durations requiring large pump flows.

b. Due to its temporary nature, materials and coatings need not necessarily meet the standards required for a permanent installation, as they need only function safely and reliably for the intended limited duration. This is especially the case for contractor-owned and contractor-maintained equipment.

c. Temporary pumping typically places less rigorous demands on ideal station hydraulics. This is not to say that hydraulic issues will not be present with these sorts of pumps, but the long-term maintenance is less of a consideration, and field installations are more easily adjusted compared to a permanent station.

d. Station designers planning temporary pumping, or implementing it on an emergency basis should try to address the following: Adequate, if not always ideal intake sumps; sufficient submergence and separation of pumps; some level of trash protection for the pumps by intake screen, boom or both; appropriate routing of discharge lines; accommodation for support equipment (hydraulic power units, generators, fuel systems) and provisions for O&M personnel.

Figure 3.4. Hydraulic driven submersible pumps for temporary pumping

3.11 Lock Dewatering. There are several locks in USACE that utilize dedicated dewatering systems including Bonneville, Chittenden and Soo Locks. The advantage of a dedicated dewatering system is it eliminates the need to bring in portable pumping equipment. The system can be designed to quickly dewater a lock. At the Soo Locks this is necessary because of the extreme cold weather during dewatering. The Soo Locks are typically dewatered in under 12 hours. New lock construction should consider dedicated dewatering systems early in the design phase.

Chapter 4
Pumping Equipment

4.1 General.

a. This chapter provides an introduction to the types of pumps used in the various applications identified in Chapter 3, selection of the general type of pump and basic arrangement, primary types of pump controls, and main types of pump sealing and lubrication. Chapter 5 provides further details for determining the best pump operating conditions. Chapter 6 provides detail on station geometry.

b. The following HI standards should be consulted for both their graphical details (including pump cross-sections) and further definitions, as well as the detailed guidelines and requirements for the pumps and their equipment. HI 14.3 includes vertical pump design and installation and considerations for loads into the structure.

(1) ANSI/HI 14.3-14.4 Rotodynamic Pumps for Nomenclature and Definition.

(2) ANSI/HI 3.1 to 3.5 Rotary Pumps for Nomenclature, Definitions, Application and Operation.

c. Depending on the region and industry, there are various terms used for pump components. Be sure to consult multiple sources when referring to pumps and their hardware in plans and specifications to increase the likelihood of utilizing the most universal terms.

d. Additional references including additional HI standards are indicated in Appendix A.

4.2 Pump Characteristics.

a. The type that should be used for any particular installation is dependent upon the service conditions, head requirements, and station layout. Figure 4.1 shows the approximate useful range of capacity and head for each type of pump that is described. The appropriate pump type should be chosen only after a detailed study of the possible choices.

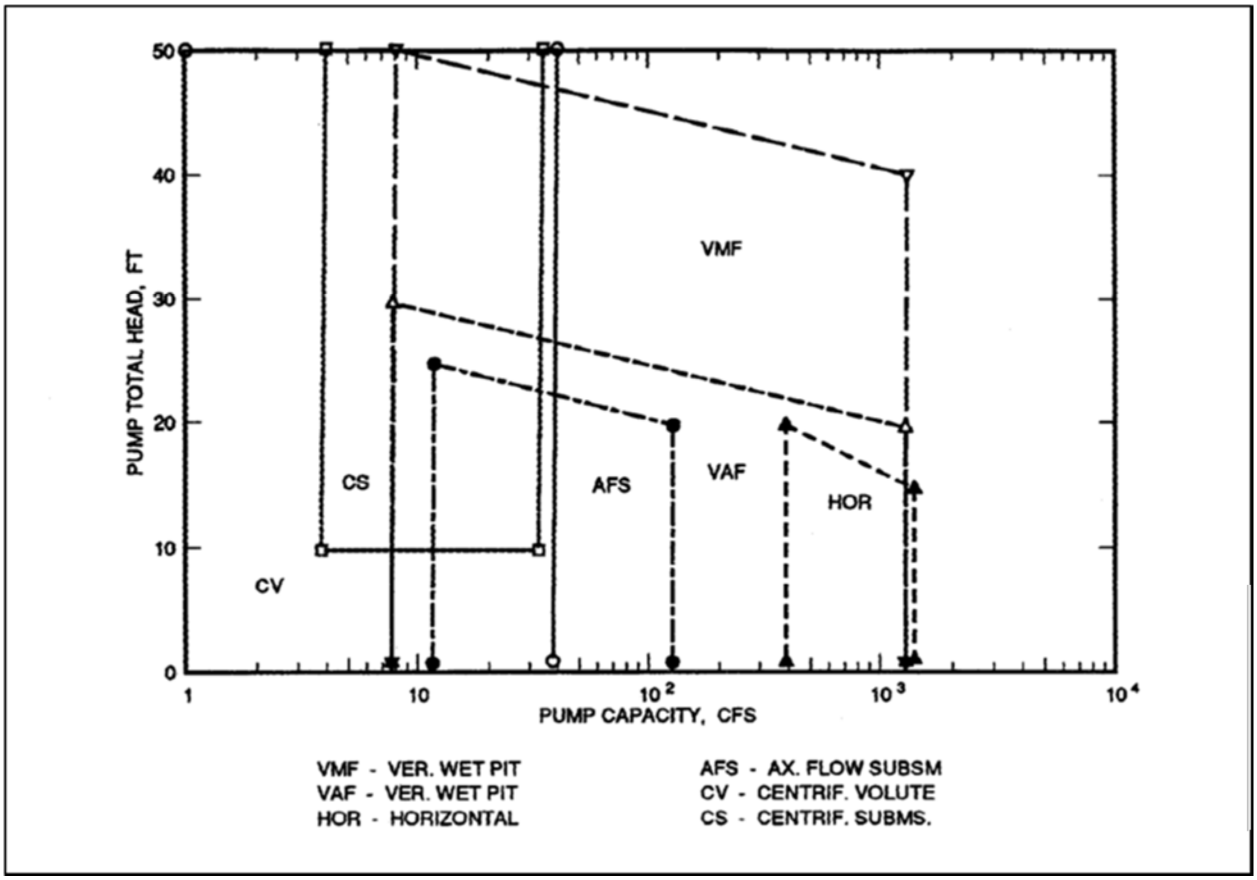

Figure 4.1. Useful Range of Capacity to Head by Pump Type (Approximate)

b. The following types of centrifugal class of pumps are often used:

(1) Axial-flow impeller type.

(a) Fixed-blade, vertical type.

(b) *Adjustable-blade, vertical type. (*Note: Designer should first pursue a controls-based means to provide variation in pump performance, such as employment of a V/S drive. Designing for mechanical adjustability affects the mechanical strength aspect of an impeller which can affect its service life when exposed to variable conditions presented by flood events including debris.)

(c) Fixed-blade, horizontal type.

(2) Mixed-flow impeller type.

(a) Fixed-blade, vertical type.

(b) Volute type.

(3) Centrifugal volute or radial-flow type.

4.3 Pump Design.

a. Pumps are usually classified by their specific speed. In English units, specific speed is defined as the speed a pump would have if the geometrically similar impeller were reduced in size so that it would pump 1 gpm against a total head of 1 foot. In International System units, N_s is called type number with Q in liters per second and H in meters. Specific speed is expressed as:

$$N_s = N_t(Q^{0.50})/H^{0.75} \quad \text{(Equation 4.1)}$$

where

N_s= pump specific speed, dimensionless
N_t= pump rotative speed, rpm
Q = flow at optimum efficiency point, l/s
H = total head at optimum efficiency point, m

b. Suction specific speed is a dimensionless quantity that describes the suction characteristics of a pumping system, designated as available, or the suction characteristics of a given pump, designated as required. The suction specific speed required must exceed the suction specific available to prevent cavitation. The suction specific speed available, based on the lowest head pumping condition. It is often used to determine the maximum permissible speed of the pump.

$$S = N_t Q^{0.5}/NPSH_A^{0.75} \quad \text{(Equation 4.2)}$$

where

S = suction specific speed available, dimensionless
N_t= pump rotative speed, rpm
Q = flow rate, gpm
$NPSH_A$= net positive suction head available, feet

4.4 Pump Types.

a. Axial flow. The impellers of these pumps have blades shaped like a propeller. This type of pump develops most of its head by lifting action of the blades on the liquid. The pumped fluid travels in a direction parallel to the shaft axis, hence the name "axial flow." It can also be constructed as an adjustable blade pump in which the pitch of the blades is varied to provide different pumping rates and/or reduced starting torque. Axial flow pumps are primarily used to pump large quantities of water against low heads and are typically used in open sump pumping stations in a vertical configuration. The value of N_s for this type of pump is typically above 9,000.

b. Mixed flow. The impeller of these pumps develops head or discharge pressure by a combination of both a lifting action and a centrifugal force. The path of flow through the impeller is at an angle (less than 90 degrees) with respect to the pump shaft.

(1) This pump can be constructed with multiple stages; however, for most USACE stations, a single stage will develop sufficient head to satisfy most head requirements. The pump can be constructed similar to an axial flow pump with water flowing axially from the pumping element, or the impeller can be placed in a volute (spiral casing), where the water flows from the pump radially.

(2) The volute design would be used either for large pumps where a volute would allow the pump to operate at lower heads or for small pumps where it is desirable to have a dry pit installation with the discharge pipe connected near the pumping element. The maximum value of N_s for this type of pump should be limited to 9,000.

c. Radial flow. The impeller of these pumps develops head only by centrifugal force on the water. The path of flow through the impeller would be at a 90 degree angle with respect to the pump shaft. A special design of this pump has a solids-handling impeller which makes it very useful for pumping sewage. This type of pump is used for pumping small flows and in applications where a dry pit sump is desirable. It is generally used in a vertical configuration and can be constructed to operate in a wet or dry sump. The value of the N_s is typically less than 4,000.

d. Rotary pumps. Rotary pumps are further described and defined in HI 3.1-3.5. Rotary pumps include axial piston pumps, gear pumps, sliding vane pumps and screw pumps among others. Screw pumps can be a consideration on some USACE CW projects. They are typically used for high volume and low head applications. Screw pumps are used in a variety of other industries including marine, power generation and chemical. They can handle a wide range of fluids besides water including fuel oils, lube oils and greases and high-pressure coolants.

(1) Screw pumps in CW applications for moving water can handle fairly large amounts of trash, have minimal submergence requirements and have few lubrication requirements. With large trash handling capability, screening can possibly be eliminated.

(2) Screw pumps for pumping applications in CW projects are patterned after the Archimedean screw, consist of a tube with spiral flights set in an inclined trough. The entire assembly consists of the spiral screw, an upper bearing, a lower bearing and a drive arrangement.

(3) The capacity of a screw pump is a function of the screw diameter, speed, number and pitch of flights on the torque tube, angle, level of liquid in the influent chamber, ratio of torque tube to outside diameter, and clearance between screw flights and the trough.

(4) There are both open and enclosed screw pumps. Open screw pumps consist of the spiral screw, upper and lower bearings and a drive arrangement. The open screw design uses a tube and spiral flights set in an open, inclined trough.

(5) The enclosed screw pump utilizes the same operating principles as an open screw pump. However, enclosed screw pumps are encased within a tube rather than an open trough and use either rotating or stationary outer tubes inclined at up to 45°, allowing the shortest horizontal space required for a given lift.

e. Net positive suction head (NPSH). This term is used to describe the suction condition of a pump.

(1) Two forms of NPSH are used. One is used to describe what suction condition is available to the pump, NPSHA, and is a function of the station layout and suction water levels. NPSHA is defined as the total suction head in feet of liquid absolute, determined at the suction nozzle and referred to datum, less the absolute vapor pressure of the liquid in feet of liquid pumped. See Appendix C for formula and terms used.

(2) The other term Net Positive Suction Head Required (NPSHR) is a property of the pump and indicates what suction condition is required for the pump to operate without cavitation.

(3) NPSHR is determined by the pump manufacturer by running cavitation tests on the pump and detailed further in ANSI/HI 14.6 “Rotodynamic Pumps for Hydraulic Performance Acceptance Tests” for most pumps utilized in USACE pump stations.

(4) The exception is submersible pumps, for which ANSI/HI 11.6 “Rotodynamic Submersible Pumps for Hydraulic Performance, Hydrostatic Pressure, Mechanical, and Electrical Acceptance Tests” would be applicable. ANSI/HI 9.6.1 “American National Standard for Rotodynamic Pumps-Guidelines for NPSH Margin” and ANSI/HI 40.6 “Hydraulic Institute Standards for Methods for Rotodynamic Pump Efficiency Testing” should be consulted for both understanding this subject further and requirements and methods.

4.5 Pump Arrangements.

a. Vertical (Or Vertically Suspended). Many pumps used in flood-control pumping stations are of the vertically suspended type. This type of pump has a vertical shaft and impeller, with the driver having a vertical or horizontal shaft arrangement.

(1) A vertical shaft arrangement has a vertical motor usually direct connected to the pump, whereas a horizontal shaft arrangement's motor or engine is horizontal, requiring the use of a right-angle gear. The vertical arrangement usually requires the least floor space per unit of pumping capacity. While the vertical motor could cost more than the right-angle gear reducer and higher speed horizontal motor combined, the decreased reliability and increased O&M costs due to the additional auxiliary equipment involved may offset the first cost savings.

(2) One problem associated with a vertical pump layout is that the pump dimensions may locate the discharge elbow higher than the minimum head required by hydraulic conditions. The higher head will require greater energy. In addition, the vertical pump and motor layout will result in a higher station height, which should be considered if there are any restrictions for the project for both height and bearing load on the stations build site.

(3) Other type layouts such as a siphon discharge or volute, horizontal, and flowerpot type pumps will permit lower minimum heads or in the case of a siphon only the discharge system losses. Vertical pumps are used with open or closed sumps, wet or dry, and are suspended from an operating floor or an intermediate floor. The vertical pump arrangement is self-priming due to the elevation of the impeller and intake water levels.

(4) Axial and horizontal loads into the supporting structure can be determined from the analysis provided in HI 14.3.

b. Horizontal. Horizontal type pumps are usually employed for applications where the total head is less than 6 meters (20 feet) and the quantity of water to be pumped is large.

(1) Horizontal pumps are seldom less than 2,500 millimeters (100 inches) in diameter. Smaller horizontal pump installations are generally more expensive than vertical installations due to the additional support structure and station square footage. However, they can be employed to reduce the vertical infrastructure when compared to a vertical pump layout, which can reduce the loading by area for the station reducing the amount of groundwork necessary.

(2) The horizontal pumps are not self-priming, and the design must provide a separate priming system, for which this systems reliability and availability is critical to the ability of the main pump to operate. The integrity of the intake and discharge conduit is also a factor for prevention of air intrusion and the resulting impacts to the pump's performance. The pumps must also avoid lower flow velocities in order to establish and maintain priming.

c. Submersible. Submersible pumps are generally considered for the main pumping role when the stations have pumping requirements with each pump having a capacity less than 6 m^3/s (200 cfs), even though some suppliers have developed larger units.

(1) These pumps can either have an electric motor close coupled to the pumping element or a hydraulic motor, with the entire pumping unit being submerged in water. The size and selection of these units are limited to the motor and gear units, if used, size resultant

encroachment on the water passage. For electric the motor size is by the number of poles in the motor, while for hydraulic it is the size of the manifold.

(2) These types of pumps should be removable from above the floor without any unbolting of the discharge piping. A rail or guide system internal to the piping is generally included in the arrangement to facilitate removable of the entire assemble, since periodic overall haul of the units require their full removal. Permanent or mobile crane access and capacity will need to be sized to accommodate the full removal of the units.

(3) Their use allows the superstructure of the station to be greatly reduced compared to vertical and horizontal options. Substructure requirements are approximately the same as for vertical pumps. Submersible units generally reduce the amount of drive shafting and the O&M associated with the shafting.

(4) A life cycle cost analysis should be performed when deciding between submersible and another type of pump. Submersible units generally require full unit overhaul at years that is generally performed offsite. In addition, since the entire assembly is submerged, inspection and troubleshooting involves removal of the entire unit.

(5) Depending on the housing design, field examination may not be possible without comprising of the housing seals, which may or may not be field serviceable. All can result in operational impacts if the unit has a sudden failure during an event. The pumps used for flood risk management pumping stations are of three different types: axial flow, mixed flow, and centrifugal volute. All submersible pumps are self-priming for the pump unit is placed at an elevation that has the entire pumping unit submerged.

d. Submersible axial or mixed flow. These pumps consist of an axial- or mixed-flow impeller close coupled to a submersible electric motor. The impeller may be on the same shaft as the motor or a set of gears may be between the motor and the impeller to permit greater variety of speed.

(1) The pump is suspended above the sump floor inside of a vertical tube that extends to the operating floor. The tube allows placement and removal of the pump and forms part of the discharge piping. These pumps are used in a wet pit-type sump. V/S drives are commonly implemented to allow for adjustment of pump output.

(2) Some pumps have been constructed so that the blades were detachable from the propeller hub and connected to the hub in a manner that allows a multitude of blade angle settings. The blade angle adjustment feature also permits changing the pump performance characteristics very easily. This permits a pump installation to meet a different future hydrology condition with adjustment of the blade angle.

(3) However, having detachable vanes directly affects the mechanical strength aspect of an impeller which can affect its service life when exposed to variable conditions presented by

flood events including debris, therefore using a controls based solution, such as V/S drives is recommended over detachable vanes.

e. Submersible centrifugal. These pumps consist of a volute casing close coupled to a submersible electric motor. The impeller and motor are on the same shaft.

(1) The pumping unit is guided to its operating position from the operating floor level by a system of guide rails or cables. The volute attaches to the discharge piping flange by means of a bracket using the weight of the pump to seal the connection.

(2) These pumps are typically used for smaller flows than the axial- or mixed-flow type and when pumping heads are high. They save space on the operating floor. These pumps are also suitable for use in a dry pit sump. These pumps are usually equipped with a water jacket surrounding the motor to cool the motor with pumped fluid. For special applications, these pumps can also be fitted with a different diffuser which allows them to be tube mounted similar to the axial-flow submersible pumps.

f. Formed Suction Intake (FSI). FSIs are not really a pump type but are suction arrangements that generally improve flow conditions to the pump. They are applied to vertical pumps and are used in place of the standard bell arrangement. Typical dimensions of a FSI are shown in Appendix B and are discussed further in the Chapter 7.

4.6 Pump Selection.

a. General Procedure. The type of pump is to be chosen by the speed and head capabilities, as well as the site limitations such as intake depth, intake approach, maximum unit height, maximum pump unit footprint. The descriptions and charts above can provide an initial start to narrow the type of pump that can be used. See Appendix C for the detailed process of selecting a pump.

b. Number and Size. The number and size of pumps is dependent on many factors. See Chapter 2 General Pump Station Requirements, Chapter 3, Station Design, and Chapter 5 Pumping Requirements for further information.

c. Commonality. When there are multiple types of pumps that could be used for a particular application then commonality should become a higher weighted evaluation factor. The ability to have personnel knowledgeable of the equipment either in the facility in question or operating a facility nearby, as well as the ability to share spare equipment will be operationally advantageous in critical station functional situations such as abrupt or long duration events, as well as economically advantageous for purchasing spares, replacement equipment, and training.

4.7 Pump Control.

a. General. The decision as to the type of control to specify for a flood risk management pumping station should be based on both providing maximum reliability consistent with economic design, as well as matching the control scheme to the needed flood risk management performance. Below is a general introduction into types of pump control from a functional perspective.

b. Manual Start. In the majority of cases, controls providing for manual start and automatic stop will be the most economical. From the standpoint of reliability, such controls are a preferred option because there are less failure modes possible with the equipment.

c. Automatic Controls. These do increase complexity of the station O&M due to the additional control equipment, greater cost, and programming. There are varying levels of "automatic controls".

(1) Fully automatic has little to no operational interface in order for the pump or station to perform its duties. Having only automatic start controls allows for ease of coordinating equipment that have to start simultaneously or have critical sequencing, avoiding potential operator timing errors. With the reliability of digital control equipment being superior to previous analog controls, the ability to have modes available to automatically operate equipment simultaneously meeting critical sequencing available to the operator(s) increases the reliability of the station.

(2) Some installations may find the use of automatic start and stop controls to be an advantage, such as where limited sump capacity and inflow conditions would make manual starting impracticable due to short operating cycles; where a station's pumping operation needs to adjust to match other stations or events causing varying inlet flows; or where economy is obtained by using pumps of different sizes operating in a predetermined sequence.

(3) The incorporation of soft starters to ramp up a pump to its fixed operational point instead of an abrupt step command can extend the life of pumping equipment. The control circuits of automatic stations must provide protection against simultaneous starting of all pumping units following a power interruption.

(4) Automatic controls, like most electronic equipment, are more susceptible to deterioration due to long periods of disuse and will require more frequent inspection and maintenance to keep them in working order when compare to manual controls. Personnel with the skill and knowledge required for maintenance of automatic control equipment and system programming should always be available.

(5) Proper equipment enclosures and location of equipment away from adverse environment conditions, including water intrusion should be included in the pump design process. Automatic controls must be compared with the justified alternate manual controls. The complete start-up, shut-down, and restart timing cycles should be examined for potential impacts on operational schemes. It may be necessary to adjust sequencing or timing of sub-system

operation or operational lock-out to correct an impact to the station's operational scheme. In order to improve operational reliability, a pump with automatic controls must have a manual control backup.

d. Programming. In addition to the stated start and start programing, the station and its equipment can be programmed to continuously adjust during operation. One main means of providing non-discrete flows through the station pumps is the use of Variable Speed Drives (VSDs). PLC can operate a pump or series of pumps throughout their operational curves. Chapter 5 has additional detail on programming for pumps and pump stations.

4.8 Pump Protection Features.

a. General. There are many methods for increasing the reliability, and the monitoring of pumps in order to reduce the possibility of failure during operation. As with all other aspects of the station and pump design, reliability and criticality of the equipment is to be balanced with the economics of the initial build and O&M of the equipment. However, some protection features are not to be part of a trade-off analysis and should be considered required.

b. Pump Reverse Rotation Protection. In order to prevent the reverse flowing of a pump from such items as the reverse siphonic action of a pump shutting down and its water column emptying, or other causes of back flow, a reverse rotation protection is to be included for the pump and its driver.

(1) The devices primary purpose to prevent the pump from forcing the gears and drive motor (electric, diesel hydraulic, or air) from being forced into reverse, potentially damaging the equipment.

(2) The motors must be equipped with an anti-reverse rotation device to address the worst-case reverse torque loading. The anti-reverse device should be on the high-speed shaft. The design should be proven by test to confirm design assumptions. A prototype of the device's design can be used for the full test if corresponding factory and field inspections and tests are performed to confirm homology with the fully tested prototype.

c. Back-flow prevention. This protection is discussed further in in Chapter 8. If the pump discharge is below the maximum discharge pool, two means to prevent backflow must be provided, one of which must be backflow gates. These back-flow prevention methods do not substitute for the need to have reverse rotation protection.

d. Siphon Breaker Valves. Some pump discharges utilize a siphonic design in order to reduce the loading on the pump and fuel usage. Because the siphonic action assists in elevating the water in the pump discharge, the siphon must be broken to prevent back siphoning upon pump shutdown.

(1) A protection feature for a design of pumping equipment utilizing a siphonic recovery discharge must include a siphon breaker valve at the crest of the discharge. A common layout is to have the siphon break be a bifurcated conduit coming from the discharge.

(2) One segment with a motorized valve for the primary valve for the siphon breaker piping, and a manual valve normally open. The other segment of the bifurcated line being a manual valve normally closed. The back-up manual valves allow for manual manipulation of the siphon breaker function.

e. Air Release Valve. A release valve should be placed in the high point(s) of the main pump discharge that will allow the air in the discharge to be released as it is filled with the discharged water.

(1) If the air is allowed to remain trapped, it can cause additional back pressure or fluctuations which can impact the performance of the pump. Location of the air release valves should take into account a potential discharge of water when the valve is reseating, which will not provide a dry well condition for equipment located near the valve.

(2) In some siphonic discharge designs, negative pressure will be generated throughout the highest portions of the discharge that will remove any air that is initially trapped in the discharge, but this can only be confirmed through an array of pressure taps being used to monitor during either model testing of the discharge or field testing of the discharge.

f. Vacuum Priming System. Due to their orientation and location above pool level, horizontal pumps require a means to prime the pump. The vacuum priming system is critical to the functionality of the pump and the station that relies on the performance of the horizontal pump to move water. Proper sealing of the pump conduit, conduit pressure sensors, and as well alternative means providing a back-up means are key elements in provision protection for horizontal pumps.

g. Bearing Temperature Monitoring. Pumping units larger than 61 cm (24 inches) diameter should be provided with resistance temperature detectors (RTDs) to determine the temperature of each pump bowl and motor bearing (top and bottom). The designer should also provide RTDs for line shaft bearings on pumps greater than 122 cm (48 inches) diameter. Bearing temperature can be monitored either directly, with measurement from the bearing or indirectly from the oil bath.

(1) For most systems, the temperature is monitored from the oil bath. In cases where oil is not used the direct measurement is employed often with a RTD. The pumps will usually have an initial warning setting to draw attention to the unit, and then a full shut-down setting to limit permanent damage to the unit.

(2) The system should consist of RTDs mounted so that they are in contact with the bearing, and a monitoring system that allows display of individual bearing temperatures and

alarms when preset high temperatures are exceeded. It is recommended that the monitoring and alarm system be designed as part of the electronic control system of the station and not part a separate system.

(3) Additional machine condition monitoring guidelines and details are provided in Chapter 9 and ANSI/HI 9.6.5 “Rotodynamic Pumps – Guideline for Condition Monitoring”.

4.9 Pump Lubrication and Sealing.

a. General. Proper lubrication is critical to the long-term functionality and reliability of a pump station pump and the overall performance and readiness of the station. The following is an introduction to the base types of pump lubrication: oil (including mineral oils and environmentally acceptable lubricants (EALs), water, and self-lubricating materials.

(1) Additional guidance concerning lubrication can be found in EM 1110-2-1424 LUBRICANTS AND HYDRAULIC FLUIDS. When procuring a new pump, the allowable type(s) of lubrication system can be specified. However, the actual lubrication system design and operating parameters are generally designed by the pump manufacturer. They establish what is necessary to have the system operate as required without degrading conditions. However, when procuring a new pump, the allowable type(s) of lubrication system can be specified. This can be an opportunity to incorporate EALs in a low risk manner.

(2) Proper laboratory and field testing should be performed to confirm the design of specified lubricants operate as planned. This testing is necessary not only on new pump designs but also on new pump applications. Operational environment will affect even a previously proven pump design. Additional information on the use of EALs can be found in the Engineering Research and Development Center (ERDC) technical note, ERDC/EL TR-18-15 Analysis of Environmentally Acceptable Lubricants (EALs) for U.S. Army Corps of Engineers (USACE) Dams.

(3) Care should be taken in making any modifications to existing lubrication systems. The factors considered and addressed by the original designer may not be apparent. Consultation with the manufacturer is highly recommended. Laboratory and field testing of any modifications to the system should be considered. What was successful for one type of pump or location may or may not have the same results in another application. Systems should be evaluated in their entirety when altering the design and operating conditions. Modifications to not only lubricating medium type but the amount and location can have adverse effects if not properly evaluated.

b. Grease Lubricated Pump Bearings. The most common USACE pump design utilizes grease for the pump bearing lubrication with a metallic bearing, the most common being a bronze bearing. This system should be used in applications where the water contains significant amounts of debris and silt.

(1) The method allows a direct means of providing an external control of the bearing temperatures. Grease lubricated have grease injected into the specific cavities by way of a pressure lubrication system, most commonly an automatic greaser. This allows for RTDs to be used to monitor the bearing temperature and tie directly into various programmed responses. It also allows for a pre start-up dry test including stabilization of bearing temperatures prior to placing in commission.

(2) Automatic grease lubrication systems should be provided. Each bearing should be provided with its own grease line. Grease lubrication systems should be PLC controlled and timed to provide the correct amount of grease per the pump manufacturer. A prelube cycle should be provided before the pumps are allowed to start. Manual greasing as a back-up should be provided in the event of a failure of the automatic grease system.

(3) The grease medium can accept various particulates that can be a byproduct of bearing operation or system idleness. As a baseline for most USACE employed designs, it has historical success, even accommodating the variable cycling that occurs for pumps involved with flood risk management.

(4) The biggest concern for grease lubrication systems is the potential to contaminate waterways. EALs can be an alternative to address contamination concerns.

c. Oil Lubricated Pump Bearings. Oil lubricated bearings are either encased in an oil bath fed by a gravity drip reservoir or positive circulation system or have oil spray system.

(1) As with the grease lubricated, this method allows a direct means of providing an external control of the bearing temperatures and allows for RTDs to be used to monitor the bearing temperature and tie directly into various programmed responses.

(2) The system can require a cooling system depending on volume of oil, which would include an air or water medium based heat exchanger system. An oil filtration system can be integrated into the heat exchanger system. The oil filter system should include a visual indicator of filter condition.

(3) For pumps to be utilized for flood risk management stations, the oil filter condition should not result in shut down of a unit. The filter system should go into bypass, allowing oil to continue past the filter element. The bypass setting should be set with margin before the filters condition will have an adverse impact on the unit and prevent the filter element from collapsing or shedding captured elements.

(4) Cleanliness level of the oil will need to be monitored by both periodic examination of the filter condition indicator, as well as checking the oil itself, by either magnetic pull rod or the more determinant method of fluid sample analysis.

d. Water Lubricated Pump Bearings. Industry has been advancing the use of pump bearing lubrication systems that utilize water as the medium to lubricate bearing, usually Cutlass™ rubber.

(1) Like all other aspects of the pump, this system is designed specifically for the pump and its operating environment. Cleanliness and reliability of the water supply are critical to this system, which has limited its application in USACE facilities.

(2) Types and quality of the materials of construction will be application limited. A means of testing the system in the dry should be considered. Proper design and build for function, O&M should provide for a successful water lubricated system.

e. Self-Lubricating Bearing Systems. These systems utilize materials that do not require an external lubricating medium. Type of material, material production, installation controls, and operating environment significantly influence the effectiveness of utilizing this approach to bearing lubrication.

(1) Some systems can be retrofitted with this material, but it is generally more successful to design in the use of the material from the initial pump build. The types and use of this system are addressed further in EM 1110-2-1424.

(2) However, caution should be taken when utilizing the self-lubricating bearing systems for the main pump bearings. Since a medium such as oil or grease is not involved with this system, the monitoring of bearing temperature is not possible by conventional means, such as RTDs. For this, use of a self-lubricating bearing system for any of the main pump shaft bearings must not be allowed unless an equivalent or superior performing temperature monitoring system to that of the RTDs can be employed with ability to tie into any necessary programmed response.

f. Bearing Temperature System. Depending on the size and criticality of the pump and pump station for which it resides, varying levels of condition monitoring and programmed response will be employed for the units.

(1) At a minimum, any storm water pumps should have some form of bearing temperature monitoring system with programmed response (annunciation or automatic actions). Depending on the means in which the bearings are lubricated, this monitoring may be directly through the bearings or in the lubricating medium, such as the oil bath.

(2) Monitoring the bearings directly can be more complex but will provide the most time accurate means which can reduce system reaction time and ultimate damage to the systems components.

g. System Testing. As previously noted, proper laboratory and field testing should occur on new pump applications and modifications to the lubrication. Ability to field test the system is critical to future diagnostic capabilities. Additional detail on proper testing is provided in Chapter 9 of this manual.

h. Environment Considerations. Due to all pump stations involving waterways directly or indirectly, stations developed with USACE oversight must pursue design aspects to reduce the potential of negatively impacting the environment. This consideration concerning application of lubricants can be undertaken during the design phase for new builds and during the redesign phase for modifications of new stations. Designers have various methods to reduce the risk of the station's lubrication aspects impacting the environment.

(1) State and local laws and regulations must be followed at the time of the design development for environmental considerations.

(2) Containment and Spill Prevention. Designs should implement methods to have at least two forms of full containment where possible, especially for those components that contain significant amount of lubricant, such as a hydraulic power unit's reservoir and oil storage tanks.

(3) Pumps should have grease catches that are accessible and away from station drainage locations. Designing for containment should not only include conditions and events during normal operation, but also those conditions and events during maintenance, such as replacement of filters.

(4) Spill protection and prevention should be evaluated during the design process in order to identify permanent means where possible, and provisions for temporary measures for the other locations. Examine the placement of equipment potential leak points (such as fittings and weep holes) to reduce the risk of fluid loss into a waterway.

(5) Examine the station drainage layout, altering to reduce potential paths for loss of fluid. Correlate drains with the station's oil water separators. Means of removal and transport to designated recycling and disposal facilities should also be included in the station's design for containment and spill prevention.

(6) Accountability. Where possible, establish a method of monitoring and accounting for lubricant types and amounts used at a facility. Proper monitoring and evaluation of the results will lead to identification of loss points which then can be evaluated for corrective action to have containment, preventing any loss to waterways.

(7) Environmentally Acceptable Lubricants (EALs). Pursuit of EALs for a station's various mechanical systems (main pumps, by-pass gate operators, trash rakes, etc.) can reduce the potential environmental impact of a loss into a waterway.

(8) However, due to the various classifications and types available, loss of most EALs in a waterway are classified at the same level as a loss of a petroleum-based lubricant. Consult

with the station's local USACE district for local, state and federal regulations and laws in needed to evaluate if the use of a specific EAL.

(9) The Environmental Protection Agency (EPA) has recognized that EAL release has substantially less environmental impact than that of mineral oils (EPA 800-R-11-002).

(10) Like any lubricant replacement, use of an EAL in a component or system must be coordinated directly with the manufacturer and testing may be required. EALs will affect system seals and running surfaces differently than conventional petroleum-based lubricants. One must ensure that there is physical verification of compatibility with equipment in order to avoid adverse impact to functionality or component life. The types and use are addressed further in EM 1110-2-1424.

(11) Avoidance. Use of water lubrication or self-lubricating material where possible will inadvertently reduce the potential for loss of petroleum-based material to be lost into the waterways. However, these approaches have not been widely used in USACE projects due to performance concerns.

(12) A comparative study conducted by ERDC indicated that many commercially available EAL products have performance specifications similar to those of petroleum products and that in some areas (for example water washout) EALs substantially exceed those of the petroleum lubricants in comparison.

(13) EALs have been and are currently in use at several USACE projects and there is a long history of successful applications. Further, a detailed study conducted by the USACE HDC on EAL replacement grease indicated that the EAL product (Panolin grease in this case) could be used effectively. A study conducted by the Inland Navigation Design Center indicated that EALs could have several uses in navigation structures.

(14) There are a multitude of EAL references that include the following.

(a) EM 1110-2-1424 which is the USACE manual for lubrication and includes a detailed chapter on EALs.

(b) Medina, V.F., M.T. Wynter, T.M. Paulus, J.R Wilson. 2018. Analysis of Environmentally Acceptable Lubricants (EALs) for U.S. Army Corps of Engineers (USACE) Dams. ERDC/EL TR-18-15. The document includes a detailed comparison of EAL products with petroleum-based ones and a description of existing uses of EALs.

(c) Paulus, T., V.F. Medina, T.J. Keyser, B.T. Rundgren, M.K. Hess, and J.J. Sills. 2018. Mechanical Equipment Lubrication Standardization and Sustainability, Inland Navigation Design Center TR 2018-1. The document includes discussion on applicability of EALs in USACE navigation projects. This discussion is directly applicable to pump station applications.

Chapter 5
Pumping Requirements

5.1 General. This chapter includes information used for determining the best pump operating conditions. These operating conditions are determined based on the hydrology and hydraulic reports that outline the flow and head conditions needed at the pump station.

a. Some of these hydrology and hydraulic reports can contain several different operating conditions for the same pump station. Multiple station layouts and pump selections should be developed in sufficient detail as to permit cost analysis and design review without the need for outside sources.

b. The determination of the final station layout and pump selection should be included as part of the design documentation. For additional discussion of the topics discussed in this chapter, see also HI Standards, including ANSI/HI 14.1-14.2 for nomenclature and definitions for centrifugal and vertical pumps.

5.2 Pump Flow Capacity Determination. The total flow capacity of a pump station is determined by the hydrology and hydraulic requirements. The total flow of stormwater from a pump station should be divided between the individual stormwater pumps as discussed in Chapter 2. See Chapter 2 for requirements of the number of pumps and the recommendation for how the pump capacities should be divided.

a. Certain conditions such as foundation, submergence, inflow requirements, and pump-drive match may dictate the need for pumps of different capacity ratings. If more than one capacity requirement exists, pumps should be selected that will satisfy all of the conditions. This may mean that the combination of pumps will be over capacity for some of the requirements.

b. Variable capacity pumping units are an alternative option that may be economically justifiable. Variable capacity can be achieved by using VSDs or pumps that are equipped with variable pitch blades. Varying the size of the pumps may be required to minimize pump cycling where ponding storage is small compared with the base flows that must be pumped.

c. For stations that have a baseflow pumping condition, separate smaller pumping unit(s) should be provided to handle the baseflow. There can also be different capacity requirement for low and high river conditions; intermediate conditions can also exist, and also special requirements such as siphon priming may occur. See below for a discussion of siphonic discharge systems.

5.3 Head Determination.

a. General. The pump head requirement is called “total head;” total head is the term used to specify the amount of lift (head) a pump must overcome when pumping to pass flow.

Total head is composed of static head, head losses in the pumping circuit, and the velocity head developed during pumping.

b. Head losses originating in the portion of the pump that is supplied by the pump manufacturer (generally between the suction bell or flange and the discharge flange or the end of the elbow) are considered internal pump losses and are not included in any head loss determination included with the pumping equipment specification.

c. The head requirements of the pump are determined by hydrology and hydraulic requirements plus additional head losses from the pumping circuit. In those cases where the suction and discharge systems are complicated and form an integral part of the pump, a model test to determine the total head should be conducted. It is important that model testing be conducted by laboratories experienced in physical model testing of pump stations. A number of private laboratories and universities for example conduct model testing on a regular basis as does ERDC. The designer should reference Chapter 9 for further discussion on model testing.

d. The pump should be selected so that the highest efficiency point is near the head where the majority of pumping operations will occur. Some pumps, particularly axial flow type pumps, may have a curve which contains what is called a "dog-leg." This part of the curve consists of a dip in head which allows the pump to operate at as many as three different pumping rates, all being at the same head. Pump operation and priming at this head must be avoided due to unstable operation.

e. Static head. In most flood-control pumping station applications, the static head can be considered the difference between the pool elevation on the inside of the protective works and the pool elevation at the discharge point.

(1) Usually there are several different static head requirements for a given station layout or set of hydrology conditions. Consideration should be given to the differences in static head caused by the variation in pumping levels on the intake side between the project authorized level of protection and the minimum pumping level.

(2) The static head for satisfying the hydrology requirements is determined from many different sump elevations. These include the minimum pumping elevation, the pump starting elevation, and the average sump elevation. These elevations should be determined during the hydraulic/hydrologic studies. The lowest stopping elevation along with the highest elevation to be pumped against (this elevation is determined according to the type of discharge system being used or the maximum elevation of the discharge pool) is used to determine the maximum static head that will be used to select the pumping unit.

(3) A reduction in capacity for this maximum head condition is permitted and should be coordinated with the Hydraulic and Hydrology engineers. If the discharge is to operate as a self-priming siphon, the static head in the priming phase is the difference between the top of the discharge pipe at its highest point and the pump’s lowest starting level.

(4) For the priming phase of a siphon system and for a vented non-siphon system, it is assumed that discharge flows by gravity past the highest point in the discharge line, except as noted hereafter. Once the siphon is primed, the static head is the difference in pool levels. Discharge systems having long lengths of pipe beyond the crest of the levee may have a head profile greater than the top of the pipe at the top of the levee. Typical static head conditions for various types of stations are illustrated on Plates B.1-B.6 in Appendix B.

f. Losses. The losses consist of friction and other head losses in the conveying works, before the pump (intake losses), and after the pump discharge (discharge losses). Intake losses include trash rack, entrance gates, entrance piping losses, and any losses in intake channels.

g. Discharge losses include discharge pipes, discharge chamber losses, and backflow preventer valves. These losses should be considered for different numbers of pumps operating. Generally, the losses will be lowest with one pump operating and highest with all of the pumps in operation. For the majority of pumping stations, the entrance losses, except the loss across the trash rack, will be minor, and in most cases can be neglected.

h. External losses. These losses start at the station forebay or sump entrance. This is usually the sewer or ditch adjacent to the station. The losses would be from this point to the sump where pump suction occurs.

(1) The losses are calculated by applying "K" factors to the various elements of flow and then multiplying them by the velocity head occurring at that location. Based on observations at operating stations, the losses through the trash rack are usually assumed to be 150 millimeters (6 inches). The other losses are those occurring on the exit side of the pump piping and could include the losses occurring in the discharge chamber and its piping system to the point of termination as identified in the hydrology report.

(2) The losses in the discharge chamber and piping entrances, exits, and bends are calculated with "K" factors similar to those on the entrance side. A special case occurs in narrow discharge chambers where a critical depth of flow may occur causing the water level in the chamber to be higher than that occurring downstream of the chamber. This usually occurs only for the low head condition. Appendix C provides design information for handling this case.

i. Pump piping losses. These losses will include all losses in the connecting pipes to the pump including both the entrance and exit losses of this piping. The Darcy-Weisbach formula should be used for determination of piping friction losses. An explanation of the formula and terms used is shown in Appendix C. Methods and factors to be used in determining losses in fittings, bends, entrance, and exits are shown in Appendix C. Formulas and friction factors can also be found in Cameron Hydraulic Data published by the Flowserve Corporation, currently in its 20^{th} edition.

j. Velocity head. The velocity head represents the kinetic energy of a unit weight of liquid moving with velocity V and is normally represented as the difference of the kinetic energy of the suction and discharge piping. However, when the pump does not have any suction piping and is fitted with a suction bell, the velocity head is that calculated for the discharge pipe. The velocity head is considered a loss for free discharges and partially or totally recovered for submerged discharges. For the purposes of determination of system losses, and as a safety margin, the entire velocity head will be considered unrecoverable and thereby added to the other losses.

k. Total system head curves. A total system head curve is a curve that includes all the losses plus the static head in the pumping circuit plotted against the pumped capacity. The losses would include both the external and pump piping losses plus the velocity head.

(1) A different total system head curve occurs for each static head condition. In determining the total system head curves, the worst-case condition should be considered when multiple pumps of equal rating are used. In a multi-pump station, the piping system that has the greatest losses would be used to determine the total system curve for the highest head condition, while the piping system with the least losses would be used for the lowest total system head.

(2) For pumps discharging into a common manifold, the highest head occurs with the maximum discharge level and all pumps operating. The total system head curves for the final station layout must be submitted in whatever design document precedes the plans and specifications. See ANSI/HI 14.3 for a discussion of system and pump curves and Appendix C for an example.

5.4 Suction Requirements.

a. General. There are two suction values that need to be considered in pump selection: NPSHA and NPSHR.

(1) NPSHA and NPSHR are defined in Chapter 4. The method of computation of the NPSHA is shown in Appendix C. The NPSHA should meet the margins and limits indicated in Appendix C. NPSHA margin is discussed in greater detail in ANSI/HI 9.6.1, Guideline for NPSH Margin.

(2) Pumps not requiring the cavitation tests should be specified to meet the suction limits developed over the entire range of required pump operation and the suction limit criteria as indicated in Appendix C.

b. Submergence. The designer should recognize what submergence levels are necessary and required for the project. Submergence requirements include bell submergence, impeller submergence and FSI submergence. The most dominant reference to submergence in ANSI/HI9.8 is bell submergence and not impeller submergence. HI 9.8 applies the ANSI/HI calculated submergence to FSI applications and the reference elevation is defined for an FSI. Principal factors involved in the determination of submergence requirements are cavitation limits and the prevention of vortices in the suction sump.

(1) Minimum submergence requirements, based on estimated annual operating hours, are provided in HI 9.8 and also summarized in Appendix C. Submergence requirements, with respect to the inlet of the pump, to prevent the likelihood of strong air drawing vortices in the sump are discussed in detail in HI 9.8 and Chapter 7 and Appendix C.

(2) The information provided above, as noted, could yield more than one submergence requirement. However, the most conservative (largest) value of pump submergence should be selected. It must also be remembered that the impeller must be submerged at the start of pumping if the pump is to be self-priming.

c. Flow conditions. The layout of the station, the sump water levels, and the shape of the pump intake determine what flow paths occur in the sump. These flow paths can cause uneven distribution into the pump, which affects pump performance. The most observable detriments of these are vortices.

(1) Key sump dimensions, expressed in terms of multiples of pump bell diameters, can be found in ANSI/HI 9.8 and are shown in Appendix C. These dimensions are usable for all stations in which the upstream approach in front of the station is straight for a distance greater than five times the width of the pumping station. The designer should note that not all pump stations layouts in ANSI/HI 9.8 have been confirmed by model study.

(2) Stations with a sharp bend close to the station should be provided with a FSI. See Chapter 7. Alternatives to a FSI may be considered, but physical modeling is recommended to verify performance. The ERDC Hydraulics Laboratory personnel should be consulted concerning the station’s layout and design. ERDC may be able to apply lessons learned from previous model tests to make design or layout recommendations to avoid possible future operational problems. However, if an unusual entrance condition exists, a specific model test of the actual station may be required. The designer needs to determine this early in the design process.

5.5 Efficiency. Higher efficiencies available from the different types of pumping units are a consideration when the estimated amount of operation is great enough to affect cost considerations.

a. Usually for stations with capacities less than 14 m^3/sec (500 cfs) and operating less than 500 hours per year, differences in operating efficiencies of various types of pumping equipment need not be considered.

b. The highest efficiency that is commercially attainable should be specified for whatever type of pump is selected. This will not only control operating costs but will normally improve the operation of the pump through less vibration, cavitation, and maintenance requirements.

5.6 Other Considerations. Certain limitations sometimes guide pump selection.

a. Incoming electric service. The availability, reliability, or the adequacy of the incoming electric service may limit the HP rating of the driver or may not permit the use of electric motors.

b. Foundation conditions. Foundation conditions may increase the cost of excavation to the point where it may not be feasible to lower the sump to that required for some types of pumps.

c. Available space. The available space at the proposed station site may limit the size of the station.

d. Susceptibility to Clogging. Axial- and mixed-flow pumps are not well-suited for handling fluids containing solids and are more susceptible to clogging than a centrifugal pump with an appropriate solids handling designed impeller.

e. Water Hammer. Water hammer is the rapid increase in pressure in a piping system when the liquid velocity is suddenly changed by closing a valve or stopping or changing the speed of a pump. The resulting pressure surge can lead to damage in the pipe or pump system or to the pipe supports. Water hammer may be controlled by staging or slowing valve closure, or by adding surge chambers or relief valves. Calculations for the pressure surge caused by water can be quite involved and are beyond the scope of this document, but variables include the length and diameter of the pipe, valve closing time, fluid density, and pipe modulus of elasticity.

f. Siphonic Discharge. Siphonic discharge systems must include a siphon breaker valve at the crest of the discharge to prevent back siphoning upon pump shutdown.

(1) The capacity required for a self-priming siphon discharge should create a velocity of 2.2 meters per second (m/sec) (7 feet per second (fps)) in the discharge pipe at the crest of the protection. This value is conservative, and for large stations, a model test of the siphon discharge should be considered to determine the minimum priming velocity. An inability to reach this velocity could affect pump selection.

(2) If a siphon system is long or contains many dips, it should be model tested as the 2.2 m/sec (7 fps) velocity criterion may not prime the siphon. The source for the capacity determination should be indicated in the Design Documentation Report. Further discussion of siphonic discharge systems can be found in ANSI/HI 14.3.

(3) The installation of a vacuum priming assist system is an option to reduce the power needed to achieve a siphonic recovery. The energy required to operate a vacuum system along with the equipment and installation costs should be considered in a comparison of the costs of a vacuum priming system to that of a self-priming pumping system.

(4) A vacuum priming system uses vacuum pumps in combination with a submerged discharge. Usually, it is required that that the discharge water level be a minimum of 50% of the discharge tunnel height above the discharge invert elevation during the pump startup phase prior to vacuum assistance while pumping 50% of pump capacity flow. Vacuum systems should include two electric powered pumps, one of which is redundant. The pumps should also alternate.

g. Adverse Intake Conditions. Flow straightening vanes have been successfully installed on pump stations with intake configurations that lead to vortices being drawn into the pumps. These have been particularly useful in mitigating intake issues on existing pump installations. See Chapter 7 for more information on flow straighteners.

5.7 Dynamic Analysis.

a. When appropriate, dynamic analysis should be done to determine the effects of dynamic performance on equipment life and reliability. Analysis needs vary greatly due to the immense range of dynamics characteristics associated with the available range of pump sizes, pump types, applications, drivers, auxiliary pumping equipment, and site characteristics. A given installation may require no analysis, simple analyses, very complex analyses, or something in-between. There has been an accelerating trend in the use of VSDs making it increasingly more difficult to avoid resonance and vibration issues.

b. Guidance. With the continual advancement of technology, there are many choices as to analytical tools and techniques available. ANSI/HI 9.6.8 Dynamics of Pumping Machinery published by the HI provides guidance to address these challenges for dynamic analysis of pumps and pumping equipment across the immense scope of pump types and applications addressed by HI Standards.

c. The HI standard may be applied to new equipment, existing equipment, field modifications or re-rates (if dynamics characteristics are changed), and field troubleshooting. It serves as an information resource (not a normative standard), however, if applicable it should be cited in specifications and contractual agreements in conjunction with the particular dynamic analysis requirements.

(1) Three different types of dynamic analyses for pumps and associated equipment are addressed by the guideline as needing separate assessments:

(a) Rotor Lateral.

(b) Rotor Torsional.

(c) Structural, including Reed Frequency Analysis.

(2) For the purpose of categorization, three “levels” of analysis for each of the three analysis types are provided:

(a) Level 1 - Simple calculations performed using standard or derived equations.

(b) Level 2 - Intermediate methods involving basic mass elastic modeling using commercially available software tools such as finite element analysis.

(c) Level 3 - Advanced methods involving multiple specialty programs and complex methodologies, typically undertaken by specialists.

(3) To determine the appropriate analysis level, the following tools and discussions are provided:

(a) Decision Matrix and Uncertainty Values Table to help quantify risk and uncertainty.

(b) Market Influences considerations for various markets.

(c) Market Trends considerations for various markets.

(d) Cost and Lead Time considerations.

(4) It is the prerogative of the document user to decide on the degree of the analysis, including whether to perform additional analyses beyond those recommended as a standard approach. The pump manufacturer also can offer guidance on the type of analysis that is relevant for the specific installation and assist with application of guidelines.

d. Sample Specifications. Two appendices in ANSI/HI 9.6.8 contain sample specifications for use in contract specifications, facilitating the proper specification of dynamic analysis.

(1) ANSI/HI 9.6.8 Appendix E provides sample specifications for general applications, organized by analysis level, analysis type, and pump type (when applicable) assuming that the designer has decided upon the appropriate dynamic analysis and the desired minimum frequency separation margin to be obtained through the analysis.

(2) ANSI/HI 9.6.8 Appendix E discusses recommended separation margins to assist designers in the decision of separation margins. Different levels and separation margins may be used for each of the three analysis types (rotor lateral, rotor torsional, and structural) as applicable. ANSI/HI 9.6.8 Appendix F provides sample specifications for vertical applications involving motor reed critical frequency properties.

(3) With respect to ANSI/HI 9.6.8 Appendix F, the contents of Appendices C & D provide useful tutorial information that provides insight into characteristics of pump structures involving vertical motors. In consideration of the specified separation margin, as stated in Appendix E, from a practical perspective typically a 10% separation margin obtained in the field is satisfactory to avoid unacceptable vibration response amplification. However, a higher

separation margin than 10% by analysis is recommended, and it should be appropriate to the expected inaccuracy of the analysis used (refer to Appendix E).

5.8 Selection Procedure. The first step in developing a pump selection is to determine the approximate pump operating conditions. Total heads used for these approximate operating conditions can be determined from adding the static heads (discharge pool level or pump discharge elevation minus the lowest pump suction level) to an approximation of the system losses plus the velocity head.

a. Capacities. Use the capacities from the hydrology requirements, the approximate total heads, and Figure C.3 in Appendix C to determine the types of pump that may be suitable for the conditions. Using each pump type selected from the chart, a pump selection is made using the method indicated in Appendix C. A station layout for each type of pump can be developed.

b. Dimensions and Cost. Dimensions for the pumping equipment and sump dimensions can be obtained from the procedure given in Appendix C. It may be necessary to refine the heads and therefore the station layout due to changes in head when the equipment is selected and located in the station. The information from the final pump station layout should be sent to a minimum of two pump manufacturers requesting their selection of recommended pumping equipment for the given station layout.

(1) It is important that the communication with the pump manufacturers takes place during the design memorandum phase of the project. See Appendix C for a typical pump manufacturer data sheet. The information thus obtained should be used to correct, if necessary, the station layout and finalize the alternate study layouts and costs.

(2) Operation, maintenance, and equipment replacement costs must also be considered in the selection of the type of station to use. Operation costs should consider the cost of energy and operating labor when the station is in operation. In some cases, these costs are very small due to limited operation and the detail in those cases can be limited. When the estimated operating costs for a station exceed $10,000 per year, it is recommended to use a detailed energy cost analysis based on pump head, cycling effect, and any special considerations the supplier of the energy may require.

(3) Maintenance cost should be carefully considered since it goes on whether the station is in operation or not. The tendency is to underestimate this expense. Discussion with the eventual user could aid the designer in determining the maintenance methods that will be used. Replacement costs should be based on both wear out and obsolescence of the equipment.

(4) Equipment replacements are also made when the cost of maintenance becomes excessive and the reliability of the equipment is in doubt. Equipment manufacturers usually provide the expected life of their equipment while operating under normal conditions. When equipment operation will occur beyond the normal conditions, as defined by the manufacturer,

the expected life should be adjusted accordingly. Selection is then based on annual costs and reliability factors.

c. Pump Requirements. After analysis of the application is made as described in Appendix C and the pump operating conditions defined, a pump may be selected to satisfy the design conditions.

(1) A suggested data sheet containing information to be forwarded to pump manufacturers is shown on Figure C.11, Appendix C. Selections may be made by the designer from pump catalogs, but it is usually best to confirm this selection with the manufacturers. A selection by a minimum of two manufacturers should be obtained.

(2) In some instances, the selection by the manufacturer may be different enough that the station layout may require a change. Before making these changes, an attempt should be made to determine why the manufacturer's selection differs from that selected by the designer. The designer and the pump manufacturer should discuss the basis of the selection. Some differences, such as the next larger sized pump or the next faster or slower driver speed, are probably acceptable since the pump manufacturer may not have an equivalent to the one selected by the designer.

(3) In other cases where the pump manufacturer recommends a different type of pump, such as a horizontal pump where a vertical pump was proposed, the change should be evaluated. The studies and pump selections made in this manual are not made to pick a specific model pump, but to show the design, the type of pump to use for station layout, and to provide guidance on preparing the pump specifications and the type of pump tests to run.

d. Number and Size of Pumps. See Chapter 2 for a discussion on the number of pumps and standby capacity.

(1) Sump size. The size of the sump may affect the selection of sizes and number of pumps with regard to the minimum desirable operating cycle. The cycle time is defined as the time between start of pump, drawdown, refill, and start.

(2) For a given sump size, the number and size of pumps should be such that the minimum operating cycle would be 6 min for submersible pumps, 20 min for wet-pit pumps with motor size up to and including 75 kW (100 hp), and 30 min between starts for pumps over 75 kW (100 hp). Pumping units over 375 kW (500 hp) should be started according to data furnished by the motor manufacturer.

(3) Where bypasses or variable discharge pumps are to be used, the size of the sump has little effect on the size or number of pumps. Otherwise, the minimum cycle time occurs when the inflow to the station equals one half the capacity of the largest pump. See also Chapter 6 for more discussion and analysis related to station geometry. The minimum cycle time can be calculated with Equation 5.1 in customary English units.

$$t = \frac{29.9Ad}{Q} \qquad \text{(Equation 5.1)}$$

where

Q = Capacity of Pump, gpm (Use average capacity between minimum and Design Heads)
A = Area of sump, sq. ft.
d = Drawdown in ft. (Distance between maximum and minimum sump)
t = Minimum cycle time, minutes

e. Programming. Consideration of all pertinent factors may indicate that pumps of various capacities should be provided at some installations, so that suitable operation would be obtained with minimum sump size. For such installations, the maximum increment in pumping rates may be made equal to the smallest unit, making it possible to pump at a rate approaching that of the inflow.

(1) Programming should not be done when the number of pumps becomes unduly great, or the controls so complicated, resulting in excessive costs and decreased reliability. Experience has indicated that V/S motors for one or two of the pumps may be more advantageous than programming various size pumps.

(2) A note of caution about the use of VSDs: VSDs complicate pump selection, increase first costs and maintenance costs, and require a higher level of technical ability for maintenance. If the requirement for a higher level of technical ability is not accounted for and fail-safe features provided, the result may be decreased reliability.

f. Limitations of in-rush demand on transmission system. An investigation should be made to determine whether the maximum pump size is limited by the maximum in-rush demand for pump starting that can be tolerated by existing power facilities. See Chapter 17.

(1) Where the existing power facilities place a limitation on starting demand kVA, pumps having relatively flat input HP demand characteristics and adjustable blade pumps or V/S pumps should be considered.

(2) Engine-driven pumps should also be studied to determine if these are required due to inadequate power supply conditions. If pumping stations are primarily used during periods of hurricane conditions, it may be required for the pumps to be engine driven and for the station auxiliaries to be supplied with backup power by engine-driven generators, or engine-driven backup power be provided for the pumps and auxiliaries. See Chapter 18 for discussion of power reliability studies.

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Chapter 6
Pump Station Geometry

6.1 General. The sump design (or wetwell design) is critical to providing acceptable inlet conditions to the pump.

a. The sump design must provide adequate submergence, avoid vortices, rotation of flow, air in the intake at pump impeller, acceptable approach velocities and avoid excessive start and stops of the pump. Free fall of water into the sump needs to be avoided to prevent air entrainment. The designer should note that it is not just air drawing free surface vortices that are problematic but also submerged vortices.

b. The possible range of operating levels in the sump must be considered such that operating conditions for the pump are acceptable. Rectangular wet pit stations and FSI stations are the most commonly used within USACE CW. The general design guidance for these stations is provided in HI 9.8, Rotodynamic Pumps for Pump Intake Design. The 2018 standard is the latest in effect at the writing of this manual update. The HI 9.8 standard has limitations, however, in that it doesn't provide guidance for stations with storm sewer inlets common to many USACE CW projects. FSI stations are discussed in Chapter 7.

c. The FSI was developed in the early 1990's by the USACE Waterways Experiment Station (WES) or WES Hydraulics Laboratory. The WES is now referred to as ERDC. The FSI has demonstrated the ability to improve the poor hydraulic sump performance experienced with some rectangular wet pit stations and to compensate for poor inlet conditions. Pump stations should be located or sited in such a manner to produce the most direct inflow possible.

d. Any location that produces asymmetrical flow into the pump bays causes problems with circulation, uneven velocity distribution, vortices, and generally poor pump performance. This is true for inflow confined within an inlet channel, sewer, or a large ponding area. Gravity flow structures, as opposed to pump stations, can often be located in an offset position without additional cost and still perform adequately. A summary of the flow conditions in a sump that can create pump issues include the following:

(1) Aerated flow.

(2) Air entraining vortices.

(3) Submerged vortices.

(4) Swirling flow in sump.

(5) Turbulence in sump.

(6) Stagnant water in sump.

e. Air entrainment. Undesirable features noted in many sump designs include a free fall (no matter how short) from the inlet conduit into the sump or pool below with the consequent entrainment of air in the liquid and (with wastewater) the release of odors. The air bubbles, easily captured by currents and carried into the pumps, cause loss of capacity and damage to the equipment. Any air ingestion can cause reductions in pump flow and fluctuations of impeller load which result in noise and vibration with consequent physical damage.

f. Vortices. Free-surface vortices are caused by improper intake design and/or insufficient submergence. They are often associated with subsurface vortices, which may emanate from the floor and the back and side walls.

(1) Unsteady flow causes the load on the impeller to fluctuate, which can lead to noise, vibration and bearing problems. Swirl in the pump intake can cause a significant change in the operating conditions for a pump, and can produce changes in the flow capacity, power requirements and efficiency. Swirling at the impeller changes the angle of attack of the flow to the impeller blades and shifts the pump curve, often drastically.

(2) Flow of water from the sump entrance should be directed toward the pump inlets in such a way that the flow reaches the inlets with a minimum of swirl. In order to prevent the formation of air-entraining surface vortices in the sump, the walls must be designed and built to avoid stagnation regions in the flow. A properly placed wall close to the inlet can reduce the tendency toward localized swirl and vortices.

g. Abrupt changes in direction and swirl. Abrupt changes in flow direction upstream from the pump inlet connection must be avoided. In sumps, abrupt changes usually cause vortices. In intake manifolds and pump inlet piping, abrupt changes in direction may cause flow to become asymmetrical and thus overload pump shafts and bearings.

(1) Sump or inlet piping geometry that permits differential velocities and, thus, rotation of the fluid should be avoided. With the slightest rotation, the spin increases as the water approaches the pump suction inlet.

(2) Swirling in the suction pipe may reduce the local NPSHA in the core to zero and thereby cause cavitation, noise, and rapid wear even though the average NPSHA is adequate.

h. High velocities. Horizontal velocities in sumps near the pump inlets that are too high should be avoided. In general, such velocities should be less than 0.3 m/s (1 ft/s). Actual velocities usually differ greatly from calculated average velocities.

i. Discontinuities. Discontinuities such as corners without fillets and uneven distribution of currents caused by flow past pier noses often result in the formation of air-entraining vortices. Although there is usually no surface indication, subsurface vortices may also occur which can very damaging.

j. Trash rakes and trash racks. Trash racks and trash rakes should be provided for all stations and can collectively be called a trash collection system. See Chapter 13. The trash rack is considered the fixed structural portion of the system. The trash rake is either the manual or mechanical part of the system that actually cleans the trash rack. In nearly all cases, trash racks and rakes must be used to keep debris out of the sump and the pump inlets. In some cases, inlet screens may be preferable.

(1) Trash racks need to be placed near the inlet of the station and away from the pumps. HI 9.8 recommends installing at least 6D away from pumps where D is the bell diameter. The 6D requirement is for dual flow traveling screens.

(2) The HI standard notes requirements of 4D and 5D are for traveling screens and non-self-cleaning trash racks or stationary screens, respectively. Trash racks should have ample net area so that the velocity of the flow through the gross rack area does not exceed 0.76 m/sec (2.5 fps). Bar spacing should be coordinated with the pump manufacturer.

k. Stormwater or drainage pumping stations. These stations should be of the wet-pit (sump) type employing either vertical mixed-flow or axial-flow pumps in most cases. However, these pumping units may also be of the submersible type depending on station size (see Chapter 4).

(1) Stormwater pumping stations usually pump directly from open storage ponds, canals, rivers, ditches, or stormwater sewers. Provision must be made for exclusion of water from the pump sump and for maintaining the sump in a dry condition during inoperative periods. This normally requires inlet gates at the front of the station. Due to their structural design, some stations cannot be totally unwatered at one time. In this case, individual sump bays may be required that can be isolated from the rest of the station.

(2) Occasionally stations will be located over streams or drainage canals and in such instances pumps must be protected from damage by runoff during inoperative periods. Since the liquids pumped by stormwater pumping stations are generally not of a particularly corrosive nature, a wider latitude in selection of materials is permitted.

l. Combination flow pumping stations. These stations are discussed in Chapter 3. Stations in which flows consist of some combination of stormwater and domestic sewage and industrial wastes are noted as combination flow stations or combined sewage overflow.

(1) The possibility of fumes and vapors must be considered when designing the sump ventilation system and electrical features located in the sump. This requires designing electrical features for hazardous locations. All sump openings in the superstructure should be sealed airtight.

(2) When wastes are combined with stormwater, the need for a smaller pump to handle dry weather flows and runoff from light rains should be provided. This baseflow pump should

be a submersible, solids handling pump. The baseflow pump is located in the main sump and equipped so that it can be raised for cleaning or repair, reducing the need for personnel to enter the sump.

(3) For stations on sewers having a relatively short time of concentration, it is necessary to place the stormwater pumps in operation within a short time after the start of rainfall. If large sluice gates are used to close the opening between forebay and the main sump, power operation of the gates will be required.

6.2 Modeling. Additional engineering studies and/or physical modeling may be required when circumstances prevent proper sump design such as constrained station siting. In some medium to large size stations, model testing of the intake sump may be required. The volume, shape and geometry of the sump can be determined and refined through the intake model test. This is further discussed in Chapter 9. In some cases, sump volume must be designed in a manner to obtain acceptable pump cycling times. Remedial measures to correct poor sump design can be costly and time consuming. HI 9.8 Appendix A discusses some of these measures.

a. In addition to stations with non-standard flow conditions, geometry, or operation conditions, a model test is recommended for stations with total overall capacity over 14 m^3/sec (500 cfs) to allow for controlled evaluation of various operational conditions. The 14 m^3/sec (500 cfs) USACE criteria is far greater than the 6 m^3/sec (222 cfs) flow rate recommended by paragraph 9.8.7.1 in ANSI/HI 9.8 for model testing. As noted in that paragraph, certain intake types have lower flow rates that trigger the model study requirement.

b. Performing a station model test does require additional cost and can effect project schedule, however it can identify significant performance issues while there is time to address them in the design phase, avoiding significant reconstruction or functional limitations. A station model test must be performed for all stations over 28 m^3/sec (1000 cfs) total capacity in which the design is to be generated or finalized after award, such as in the case of a design build acquisition.

c. HI 9.8 recommends a physical hydraulic model study with one or more of the following features noted below. Some of these bullet points refer to intake types that are only suitable for clear liquids and can involve vanes and flow-straightening devices that cannot pass solids (open and closed bottom intake types (Figure 9.8.3.6.4 and Figure 9.8.3.6.5). It is noted that the classic rectangular intake and the Type 10 FSI intake are listed as intake types for clear liquids, but the USACE practice of using screens and racks ahead of these pumps as well as the size of pumps typically involved generally allows these intakes to work satisfactorily for flood risk management. The bulleted list below is provided from ANSI/HI 9.8 - 2018 edition:

(1) A suction intake arrangement with elevation relative to water level that does not provide the minimum submergence requirement of this standard, irrespective of pump manufacturer's stated submergence values.

(2) The intake design is not a standard intake design presented in this standard or the geometry (such as bay width, bell clearances, sidewall angles, bottom slopes, distance from obstructions, the bell diameter, submergence, or piping changes, etc.) deviates from this standard.

(3) There is no prior physical model study for the intake design considered in terms of physical features and flow rates.

(4) Nonuniform or nonsymmetric approach flow to the pump sump exists (e.g., intake from a significant cross-flow, use of dual flow or drum screens; use of elbows, bends, or multiple screens just upstream of a trench-type wetwell; or a short-radius pipe bend near the pump suction, etc.).

(5) Proper pump operation of a critical service or application as defined by the customer (such as a safety-related system).

(6) Pump repair, remediation of a poor design, and the impacts of inadequate performance or pump failure all together would cost more than 10 times the cost of a physical model study.

(7) Circular stations with four or more pumps.

(8) For trench type wet wells (clear or solids-bearing liquids) the pumps have flows greater than 1260 L/s (20,000 gpm) per pump or the total station flow with all pumps running would be greater than 3155 L/s (50,000 gpm).

(9) Circular pump sumps (clear or solids-bearing liquids) with flows exceeding 315 L/s (5000 gpm) per pump require a physical model study (see Sections 9.8.3.3 and 9.8.4.3).

(10) Circular pump sumps (clear liquids) per Figures 9.8.3.3.1c and 9.8.3.3.1f with station flows exceeding 315 L/s (5000 gpm) require a physical model study.

(11) The pumps of an open bottom barrel or riser arrangement with flows greater than 315 L/s (5000 gpm) per pump (see Section 9.8.3.6).

(12) The pump of a closed bottom can intake has flows greater than 440 L/s (7000 gpm) (see Section 9.8.3.6).

(13) The pumps have flows greater than 2520 L/s (40,000 gpm) per pump or the total station flow with all pumps running would be greater than 6310 L/s (100,000 gpm).

6.3 Size and Capacity Determination.

a. The determination of sump capacity requires close coordination with the entire design of the pumping station. HI 9.8 Appendix B also provides an extensive discussion of the required sump volume.

(1) Basic factors such as type of prime mover, number and size of pumps, and size and arrangement of the station are affected by, or have an effect on, sump capacity. Selection of design to provide adequate sump capacity should be based on a comparison of overall cost for each installation.

(2) Factors to be considered include cost of sump structure and superstructure, higher price of equipment accompanying any increase in pumping requirements, increased cost of variable-capacity in lieu of fixed capacity pumps, and cost of operation.

b. The dimensions and general layout of the sump must fulfill a number of requirements. Primarily, the selected design must provide adequate horizontal and vertical clearance and adequate approach conditions for the pumps to be used. The geometry of the pump station should follow HI standards to the extent possible. The operating floor space requirements also need to be considered. For open channel flow into the station, the design should follow HI 9.8 for sump layout and geometry requirements. Other reference material that could be used includes:

(1) Prosser "The Hydraulic Design of Pump Sumps and Intakes" from the British Hydromechanics Research Association.

(2) The European standard, Committee European for Normalization. Rotodynamic Pumps - Design of Pumps Intakes – Recommendations for Installation of Pumps (CR 13930).

c. The designer should note that the Prosser technical report is a lab report, whereas CR 13930 is a guideline. Neither are normative standards. The only worldwide normative intake standard is ANSI/HI 9.8, although use of this standard is voluntary.

d. Sump levels. Maximum water surface elevation in the sump of stations pumping from sewers will be fixed by project damage elevation, by the hydraulic gradient between the protected area and the pumping station, and by the condition of the particular sewer.

(1) A consideration of the type of pump provided and its minimum submergence level is critical. The designer needs to ensure the minimum pump submergence level allows adequate drainage of the protected area.

(2) For stations pumping from ponding areas, the maximum water surface elevation of the sump will be fixed by the maximum permissible ponding elevation. For sewers subject to structural damage from fluctuating water pressure, such as old brick sewers in questionable

condition, and sewers which are inadequate to pass the design storm runoff, the maximum sump operating level should be restricted to the elevation of the crown of the sewer at the point of entrance to the sump.

(3) For a well designed and constructed sewers, the maximum sump operating level may fall above the crown of the sewer, subject to consideration of the level of the hydraulic gradient with respect to "no damage" level along the sewer. The station-operating floor elevation should be at least 2 feet above the maximum water surface elevation in the sump. The sump must be kept dry either by gravity drainage or by sump pump(s). If the period of gravity drainage occurs less than 50 percent of the non-pumping period, then sump pumps should be provided to dewater the station's sump.

(4) The minimum water surface elevation in the sump is determined by the hydraulic and protection requirements of the protected area and economic considerations. This minimum sump elevation affects the station design and pumping equipment characteristics.

e. Minimum sump area. Minimum horizontal sump area will be that required to permit adequate spacing of pumps and intake systems to provide adequate space for installation of discharge and suction lines and associated equipment and flows to the pumps. Sump area based on these requirements normally will be adequate unless it is found desirable to increase the horizontal area of the sump either to provide more sump storage volume to obtain acceptable minimum pump operating cycles, or to alleviate surges caused by pump shutdown in the sump and connecting sewers.

f. The principal factors involved in the determination of submergence and vertical clearance requirements are cavitation limits and the means to preclude the formation of sustained vortices.

(1) Insufficient submergence can also lead to failure at start up (when the impeller inlet is not filled with liquid), inadmissible amount of cavitation or the entrainment of air or gas bubbles in the pump. The water depth also must be great enough to suppress surface vortices. A pump may have adequate submergence from a pressure standpoint and still be lacking in sufficient depth of cover above the suction inlet to prevent surface air from being drawn in.

(2) Any wet-pit pump must have its suction inlet submerged at all times, and for continuous pumping every pump will have a fixed minimum submergence requirement. The minimum submergence for pumps should be provided by the manufacturer. The equation (Eq. 9.8.3.1.4-1) in HI 9.8 can also be followed to provide an approximation.

g. As pump size (and flow) increase, the inlet velocity may stay constant as the bell diameter increases, but at the same time, the impeller distance above the suction inlet becomes larger, so a fixed submergence value would lead to increased surface velocity, peripheral drawdown, and an increase in air intake. Submergence must increase with pump size. For the final determination, some balance must be struck between submergence and pit width to satisfy an average flow velocity of 1 to 1.5 ft/sec (maximum) in the sump.

6.4 Pump Cycle Times. In addition to the above-mentioned requirements for satisfactory pump operation, the station design should include a determination of the water volume between maximum and minimum operating elevations that will permit acceptable minimum pump operating cycles.

a. This water volume would include the capacity of the sump, trash rack chamber, interconnecting sewer, or ponding area. Sufficient storage is provided between the pump's starting and stopping elevations when the starting of any one pump will not be required more often than recommended by the motor manufacturer.

b. An inflow rate equal to one-half of the pumping rate of the pump should be assumed as discussed previously in Chapter 5, as this inflow will cause the most frequent number of repeated starts and stops of the pump.

c. Storage required above the stop elevation to ensure a minimum interval as indicated above between successive starts of a given pump is usually not possible. Since the maximum sump operating level is usually fixed by the project damage elevation or other considerations, any required increase in sump capacity can be accomplished only by lowering the sump floor.

d. The required operating volume of the sump, V, or the volume between the start level and the stop level of the pump, depends upon such factors as the cycle time for the pump (T), the pump capacity (P), and the rate of the inflow (Q). For variable inflow rate, the shortest cycle time occurs if $Q = P/2$ which gives the minimum required volume of the sump:

P = pump discharge capacity, in L/s (ft3/s)
Q = inflow to sump, in L/s (ft3/s), variable
T = total cycle time, in seconds
V = active sump volume to be determined

Time to fill sump = $T_1 = V/Q$
Time to empty sump = $T_2 = V/(P-Q)$
Time (T) for a complete pumping cycle is then:

$$T = T_1 + T_2 = \frac{V}{Q} + \frac{V}{(P-Q)} = \frac{VP}{Q(P-Q)} \qquad \text{(Equation 6.1)}$$

where the minimum cycle time occurs when Q=P/2. Rearranging the equation,

$$T_{min} = 4V/P$$

and

$$V_{req} = T_{min} \bullet \frac{P}{4}$$

For example, assume a pump capable of 10 starts per hour then the cycle time, T = 6 mins (360 seconds) and V then becomes:

$$V_{req} = 360 \bullet \frac{P}{4} = 90P$$

e. The minimum cycle time is determined by the number of pump starts with regard to the temperature rise in the motor. For a pump station with identical pumps, the required volume is smallest if the pumps start in sequence as the water level rises due to increasing inflow and stop in sequence as the water level drops due to decreasing inflow. To minimize the required sump volume, the first pump to start should be the first to stop and the last pump to start should be the last pump to stop (First on and First Off operation). The first on pump should always alternate.

f. The size of the sump may affect the selection of sizes and number of pumps with regard to the minimum pump cycle times. Some typical minimum operating cycles are 15 to 20 minutes for wet-pit pumps with motor size up to and including 75 kW (100 hp), and 30 minutes between starts for pumps over 75 kW (100 hp). These values all need to be confirmed with the pump and motor manufacturer. Pumping units over 375 kW (500 hp) should be started and cycled according to data furnished by the motor manufacturer.

g. Consideration of all pertinent factors may indicate that pumps of various capacities should be provided or pump motors should be V/S, at some installations, so that suitable operation would be obtained with minimum sump size.

(1) For example, primary or main pumps can be provided to handle large rain events and base flow pumps can be installed to handle smaller rainfall and run-off events. For such installations, the maximum increment in pumping rates may be made equal to the smallest unit, making it possible to pump at a rate approaching that of the inflow. This is often done on stormwater pump stations since the inflow rate can vary greatly.

(2) Providing multiple pump capacities should not be done when the number of pumps becomes unduly great, or the controls so complicated, resulting in excessive costs and decreased reliability. Experience has indicated that V/S motors for one or two of the pumps may be more advantageous than providing multiple pump sizes. A note of caution about the use of VSDs: VSDs complicate pump selection, increase first costs and maintenance costs, and require a higher level of technical ability for maintenance.

h. The use of bypass pumping gains equivalent sump capacity during periods of pump operation with small inflows and accomplishes that function by decreasing the net effective discharge of pumps operating. Bypass pumping should be considered where space and structural requirements cannot be changed, and sump capacity is inadequate to prevent excessively frequent starting of pumps.

(1) This is particularly the case where failure of one pump of a group operated on programmed control is a possibility and to compensate for a lag in the inflow from a sewer; and prevent surges in sewers and sumps which would be caused by rapid lowering and then raising of sump levels. Bypasses may be located so as to permit return flow from riverside discharge chambers into the sump, or direct flow from a pump discharge line into the sump at a point between the pump and its discharge.

(2) With the former arrangement, the bypass is effective regardless of which pump is operated. The latter arrangement is used where pump discharge lines pass over levees and require a bypass on each pump or a number of pumps to ensure satisfactory bypass capacity when any pump is out of service.

i. Where a single bypass from the discharge chamber to the sump is to be installed, its capacity at minimum head and maximum operating sump water elevations should be at least equal to the capacity of the largest incremental change in discharge capacity. When a bypass is located on a pump discharge line, its capacity under the same conditions of head should be sufficient to provide the desired operating cycle, usually one-half the capacity of the largest pump. In both cases, the increased capacity of pumps at lower than design heads should be recognized. Electrically actuated butterfly valves are normally used to control the bypass flow.

6.5 <u>Geometry Considerations</u>. All the major pump manufacturers also provide design guidance for pump station layout along with HI. The best flow conditions are obtained when the water approaches the pump from all directions with as uniform a velocity as possible and with minimum disturbance from the flow toward other pumps.

a. The placing of the sump intake to provide as near equal flow distances as possible to all the pumps is a good start toward satisfactory sump flow conditions. A key consideration in the geometry of the station is the bell diameter of the pump or “D”. All dimensions of the sump should be based on the bell diameter. This value is fairly straightforward for vertical type pumps and discussed extensively in HI 9.8.

b. Geometry of the pump station depends on many factors starting with the type and number of pumps selected for the application. In most situations for the type of pump stations considered here, either a wet well or FSI will be used. Primarily storm water applications are considered in this guidance.

c. From HI 9.8.5.2 Objective: “Designing a sump to achieve favorable inflow to the pump or suction pipe bell requires control of various sump dimensions relative to a pump suction bell or inlet pipe bell diameter. For example, the clearance from the bell to the sump floor and sidewalls and the distance to various upstream intake features is controlled in these standards by expressing such distances in multiples of the pump suction bell or inlet pipe bell diameter. Such standardization of conditions leading to, and around, the inlet bell reduces the probability that strong submerged vortices or excessive preswirl will occur. Also, the required minimum submergence to prevent strong free surface vortices is related to the inlet bell diameter (see Section 9.8.6)."

d. The HI standard continues as follows:

(1) "It is recommended that the inlet bell diameter be chosen based on achieving the bell inlet velocity that experience indicates provides acceptable inflow conditions to the pump. The bell inlet velocity is defined as the flow through the bell (i.e., the pump flow) divided by the area of the bell, using the outside diameter of the bell. Information on acceptable average bell inlet diameters and velocities is provided in Figures 9.8.5.2a and b, based on a survey of inlet bell diameters used by pump vendors and industry experience. The solid line represents the average pump bell diameter from the survey, corresponding to a bell inlet velocity of 1.7 m/s (5.5 ft/s)."

(2) This is the recommended velocity for the "design bell diameter" in ANSI/HI 9.8-2018 that is to be used when the pump supplier (and actual bell diameter) is not yet known. The allowable bell velocities in ANSI/HI 9.8-2018 are provided for use in evaluation of suitable bell diameters when the actual pump is known.

e. Industry experience indicates that the recommended inlet bell velocity V may vary as follows:

(1) For flows less than 315 L/s (5000 gpm), the inlet bell velocity must be 0.6 to 2.7 m/s (2.0 to 9.0 ft/s).

(2) For flows equal to or greater than 315 L/s (5000 gpm), but less than 1260 L/s (20,000 gpm), the velocity must be 0.9 to 2.4 m/s (3.0 to 8.0 ft/s).

(3) For flows equal to or greater than 1260 L/s (20,000 gpm), the velocity must be 1.2 to 2.1 m/s (4.0 to 7.0 ft/s)."

f. For submersible pumps, the value of the bell diameter, "D", is more difficult to determine. Submersible pumps also have a large volute that has to fit within the pump bays. There is also access hatches that the submersible pump has to fit through.

(1) As such, pump bays for submersible pumps often need to be 3D in width. The first step should be consulting with the manufacturer to establish this diameter.

(2) The bell diameter could also be approximated by utilizing the discharge diameter and increasing this dimension by 10% to 20%. Another option is to utilize HI 9.8 specifically equation 9.8.5.2(b) with the "recommended inlet bell velocity" of 5.5 ft/s and the design Q.

$D = (0.409Q/V)^{0.5}$ (English Units) (Equation 6.2)

where

V= Average bell velocity, ft/s;
Q =flow, gpm;
D =outside bell diameter

g. Horizontal clearances.

(1) Horizontal clearances for rectangular wet-pit sumps are generally satisfied if the distance between centerlines of adjacent pumps is equal to the sum of the suction bell diameters (plus the thickness of the divider wall), and if the centerline of each pump is a least one suction bell diameter away from the nearest sump side wall and three-fourths of a suction bell diameter from the rear wall. The use of suction umbrellas on vertical pumps does not change the above clearances. The nozzle inlet diameter (d) is nearly always smaller than the bell diameter (D). In general, the diameter of a propeller pump's suction bell (no umbrella) is around 1.5 to 1.8 times the nozzle inlet diameter (d). Stated another way:

$D = 1.5d$ to $1.8d$ (Equation 6.3)

(2) This is excerpted from an appendix in ANSI/HI 9.8-2018. It is VERY important to note that all of the appendices in ANSI/HI 9.8-2018 are informative and for general information only (not normative). This statement applies to all information excerpted from the appendices of ANSI/HI 9.8.

(3) The proper spacing of pumps in the wetwell is necessary to avoid interference between adjacent intakes. Space intakes no closer than 2.5 D centerline to centerline of pump.

(4) The Figure 9.8.3.1.4a in HI 9.8 is based on open channel flow or flow from a ponding area or a river. Often USACE CW stations are pumping from storm sewers. Guidance for this type of layout is also provided in Prosser and the older HI standards (HI Centrifugal Pump Design and Application – 1994 – 1.3.3.6 Suction Conditions and 1.3.3.6.1 Intake Design). The European standard, Committee European for Normalization. Rotodynamic Pumps - Design of Pumps Intakes – Recommendations for Installation of Pumps (CR 13930) can also be utilized.

h. Divider walls. Pumps should be installed in individual bays with divider walls between the pumps and are required for stations over 315 L/s (5000 gpm) per HI 9.8. The width of the gate bays should be 2D to 3D. HI 9.8.3.1.2 states the following in regard to divider walls: "If multiple pumps are installed in a single intake structure, then dividing walls placed between the pumps result in more favorable flow conditions than found in open sumps. Adverse flow patterns can frequently occur if dividing walls are not used. For pumps with design flows greater than 315 L/sec (5000 gpm), dividing walls between pumps are required".

6.6 Sump Layout Considerations. Again, the designer should utilize the latest version of ANSI/HI 9.8. Sump design and layout will be based on established and applicable HI standards. However, if the pump manufacturer disagrees with the USACE design and proves, through model testing a better design, then the contractor's design may be used. The contractor must then be held responsible for the sump design including any post construction repairs and retrofits that may be needed. Many of the major pump manufacturers including Flygt, KSB, Patterson, Fairbanks Morse, Cascade, Morrison and MWI can also provide design guidance for the sump layout.

a. Flow velocity. Inlet pipes into the station should have a velocity of 0.6 m/s (2 fps) or less. Average velocities in the sump should be below 0.5 m/s (1.5 fps). Velocities in the vicinity of the pump intake should be below 0.3 m/s (1fps).

b. Intake gate. An intake gate should be provided in front of each pump or in front of the entire station. Velocity through intake gates must be coordinated with the sump drawdown or operating range. In general, the velocity through intake gates should be as low as possible provided no special requirements or excessive increased costs are involved. In no case should the velocity through the gate be greater than 0.75 m/sec (2.5 fps). Abrupt changes in direction and velocity of flow should be avoided.

c. Vortex formation can be minimized by controlling the flow conditions into the sump and to the pump. Layout dimensions and ratios provided in HI standards along with straight inflow to the station intake should eliminate or reduce the intensity of vortices. If the station cannot be laid out to these dimensions and straight inflow does not occur, then either a sump model test should be considered or the FSI incorporated into the design. The FSI has demonstrated the ability to nearly eliminate vortices at the pump.

d. Sediment must not accumulate within the sump. Stagnant regions, or regions of such low velocity where sedimentation might occur must be avoided. A sloping floor and fillets or benching often help to prevent sedimentation. For large variations in flow, part of the sump can be dedicated to low inflows with a lower floor level and a small pump. Surface scum, floating sludge and small debris can accumulate in any relatively calm region of the water surface; and this material must be pumped away.

6.7 Prepackaged and Small Lift Stations. For small stations below 315 L/sec (5000 gpm), precast or concrete circular manhole stations can be utilized.

a. These stations can also be considered a "self-contained" station with all the components packaged into a single well. These stations could also be rectangular although that is not as common.

b. An example of a 2000 gpm capacity station in Devils Lake, North Dakota is shown below in Figure 6.1. These stations often utilize submersible pumps and no superstructure. Control panels are often then pedestal mounted. Several manufacturers provide pre-packaged stations in this configuration. If these stations are utilized, it is recommended to utilize only 2 pumps with 3 pumps maximum. Sizing criteria can be provided by the manufacturer or HI 9.8 can be utilized to provide initial sizing.

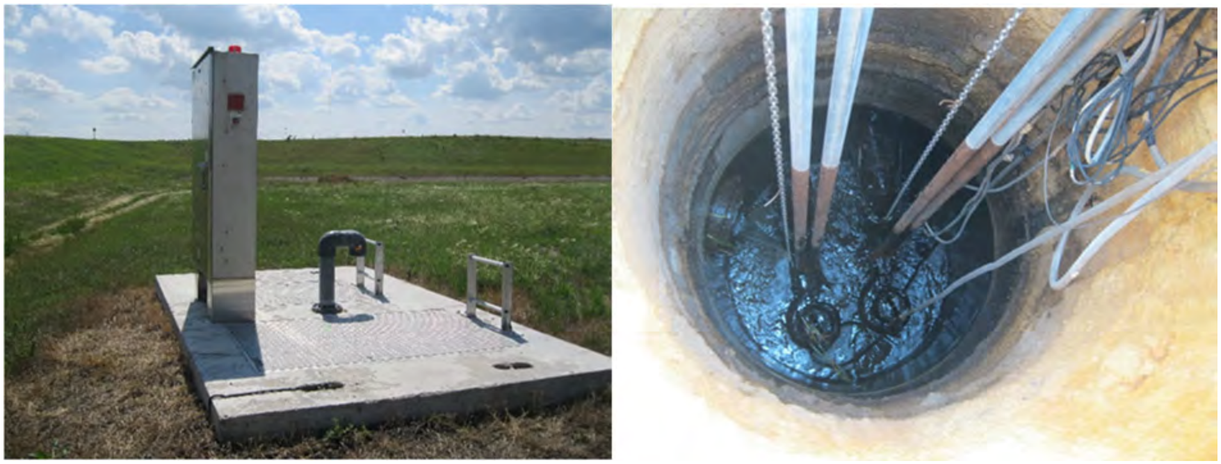

Figure 6.1. Devils Lake Highway 20 drainage station

6.8 Trench Well Stations. HI 9.8 and HI 9.8 Appendix C and HI 9.8 Appendix D all provide a more extensive discussion of these station types. Trench well stations should only be used where space and real estate constraints preclude the use of conventional pump stations. Trench well stations have flow entering from the side of the station perpendicular to the pumps. The long axis of the wet well should be aligned with the centerline of the upstream conduit or channel. Figures 6.2 through 6.5 show some examples.

a. From HI 9.8.3.4.4 Approach flow: The velocity in the approach channel or conduit, upstream from the wet well, must be no greater than:

(1) 1.2 m/s (4.0 ft/s) with the axis of the channel or conduit coaxial with the axis of the wet well for vertical pumps or submersible pumps.

(2) 0.9 m/s (3.0 ft/s) with the axis of the channel or conduit coaxial with the axis of the wet well for pumps with suction piping extending from the dry well into the wet well.

b. Trench type wet wells have pump intakes confined[1] in a deep, narrow trench in line with (but substantially lower than) the upstream inlet pipe. These stations typically have a much smaller footprint than a traditional rectangular wet well; however, they are generally deeper to allow the flow to be more uniformly directed to all of the pumps from above rather than across the pump intakes.

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[1] Input provided by Barr Engineering

(1) This arrangement assures that the pumps at the back of the trench are not starved by the pumps near the inlet. The inlet is placed higher than the pumps and the minimum water level is set to provide a maximum flow velocity of 0.3 m/s (1 fps) in the channel above the trench. When a trench type wet well includes an ogee transition between the inlet pipe and the trench floor, the wet well can be self-cleaned by using special procedures when operating the pumps and the intake gate.

(2) The cleaning occurs by creating a condition that generates a hydraulic jump inside the station that is slowly allowed to migrate to the end of the trench. The hydraulic jump stirs up sediments and other solids in the wet well and carries them to the end pump in the station where they are simply pumped out. In addition to flood and stormwater pumping, applicable uses for trench type wet wells include water supply, municipal wastewater, and industrial wastewater.

c. Submersible centrifugal pumps, submersible axial/mixed flow pumps, or vertical mixed/axial flow pumps with non-submersible motors can be used in trench type wet wells. The trench type configuration can also support dry pit pump intakes with horizontal pump suction pipes. Submersible centrifugal pumps can be considered for flows up to approximately 1261 L/s (20,000 gpm) per pump, as submersible pumps become very large at higher flow rates. Trench type wet wells have the following advantages:

(1) Significantly smaller footprint.

(2) Typically has lower construction costs.

(3) Deep set pumps typically result in ample NPSHA.

(4) Steeply sloped channel sides direct solids to the pumps.

(5) Configuration with an ogee ramp provides method of cleaning the station without personnel entry.

(6) Low visual impact if constructed without a building.

d. Trench type wet wells have the following disadvantages:

(1) Increased wet well depth can impact constructability, particularly in poor soils and/or high groundwater.

(2) Minimal storage capacity within the wet well; relies on exterior pond or collection system.

(3) Extensive concrete formwork.

e. Further guidance on trench type wet wells can be found in ANSI/HI 9.8 or in Pumping Station Design, 3rd Ed. (Sanks, et al.). An operating plan/manual should be provided to guide the Owner on the wet well cleaning procedure. If the inlet gate is exposed directly to the elements (in cold weather climates), a heated gate should be considered to enhance cold weather flood fighting capabilities.

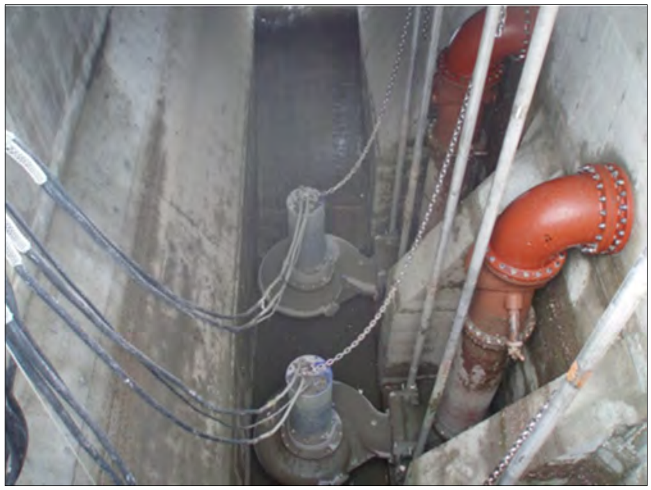

Figure 6.2. Trench well station with submersible pumps in Roseau, MN (courtesy Barr Engineering)

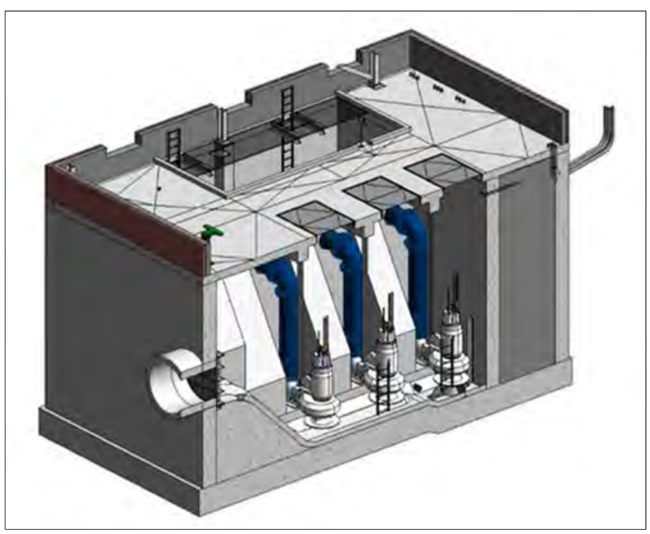

Figure 6.3. Isometric view of Perkett Ditch pump station, Minot, ND. (courtesy Barr Engineering)

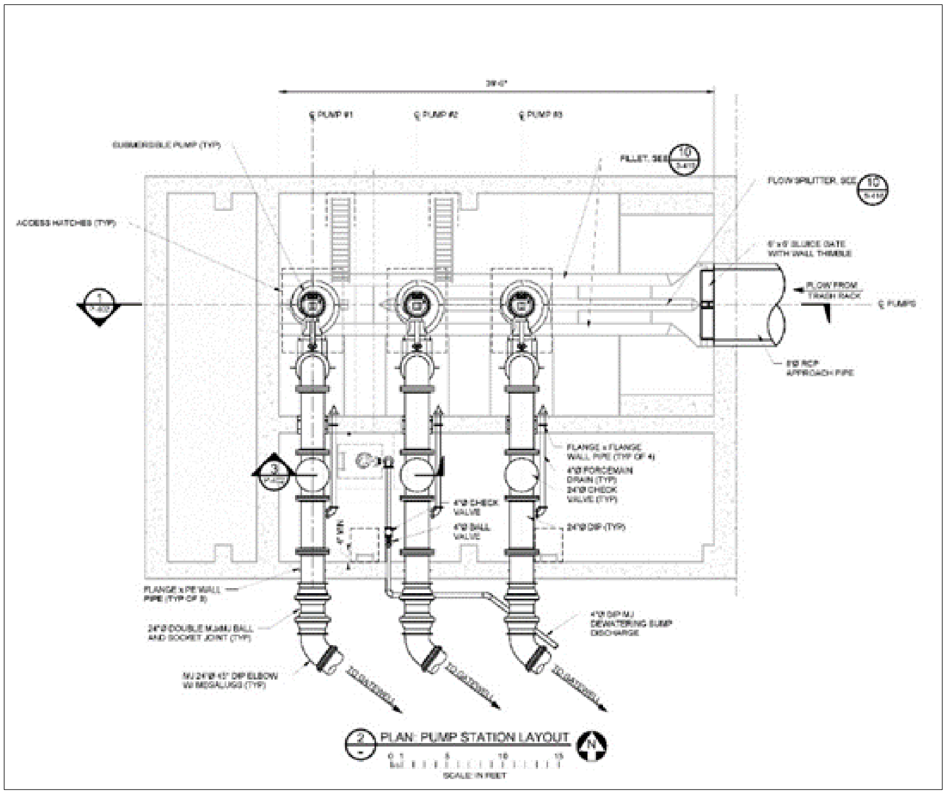

Figure 6.4. Plan view of Perkett Ditch pump station, Minot, ND (courtesy Barr Engineering)

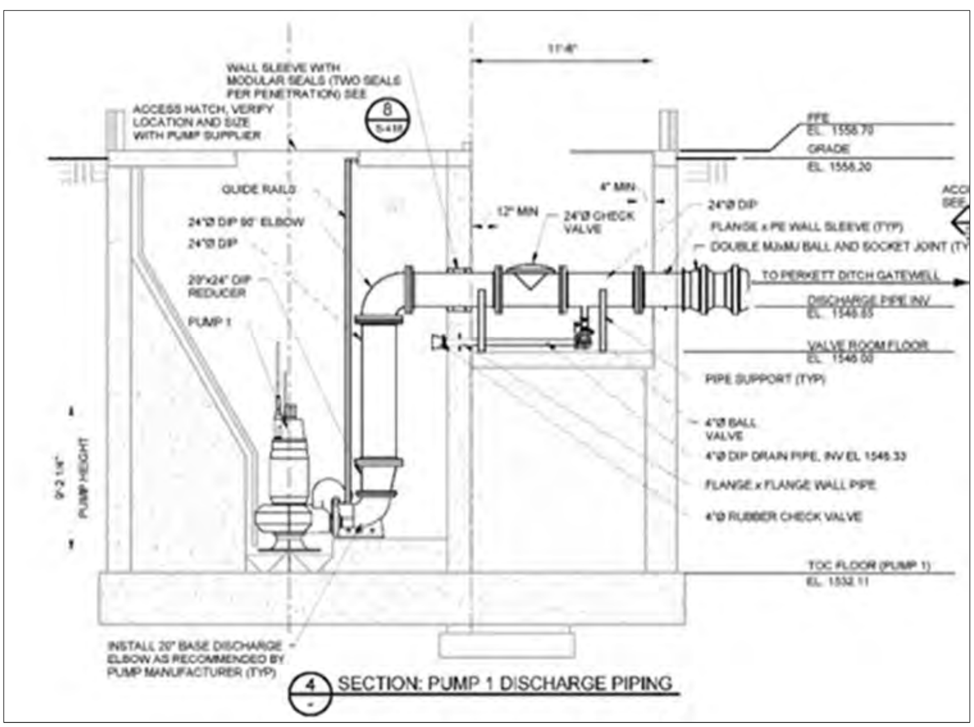

Figure 6.5. Section view of Perkett Ditch pump station, Minot, ND (courtesy Barr Engineering)

6.9 Pump Stations on Floating Platforms (unconfined intake).

a. These stations include floating pump stations on a river or lake. Figure 6.6 is an example. These stations are characterized where the intake has no guide walls, walls of a sump, or other flow-guiding structures. HI 9.8 provides design guidance for stations less than 315 L/s or 5000 gpm. As such, it is recommended these stations only be utilized for stations smaller than this capacity.

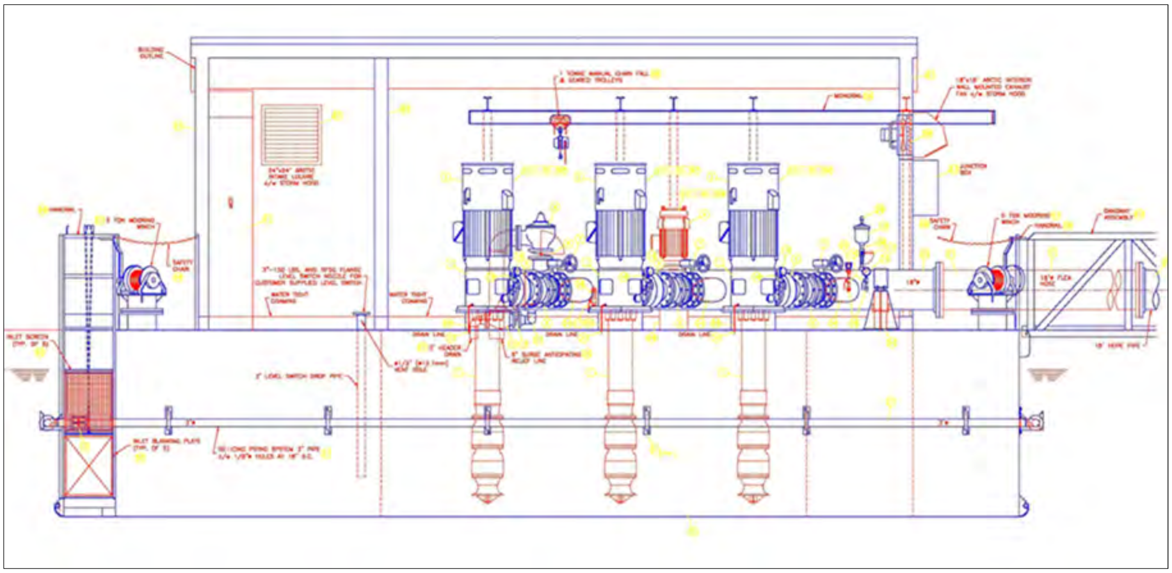

Figure 6.6. Floating Pump Station (courtesy Chamco)

b. These stations will normally not have any means to incorporate trash racks. Pumps need to be capable of pumping debris. Light debris loading may be accommodated by screens attached to the pump bell. Special design considerations are required to accommodate heavy debris loading. Large floating debris and ice that could damage the pump is also of concern. A barrier may be required to protect the pump. These barriers should not introduce wake disturbances into the pump.

6.10 Combined Sewage Overflow and Sewage Stations. There are many stations within USACE CW that could potentially pump water containing sewage and other industrial waste. The geometry considerations will generally be the same for these stations as stormwater stations. The main concern with these stations is solids-bearing liquids and the requirement for the removal of floating and settling solids. Again, HI 9.8 provides some design guidance.

a. From HI 9.8.4.1.6 Cleaning procedures, "Removal of solids from wet wells, designed with these principles, can be achieved by operating the pumps selectively to lower the level in the wet well until the pumps lose prime. Both settled and floating solids are removed by the pumping equipment and discharged to the force main (or discharge conduit). This cleaning procedure momentarily subjects the pumps to vibration, dry running, and other severe conditions. Consult the pump manufacturer before selecting the pumping equipment. The frequency of cleaning cycles depends on local conditions, and therefore should be determined by experience at the site."

b. HI 9.8 Appendix E, Aspects of design of rectangular wet wells for solids-bearing liquids also provides a discussion of these stations.

6.11 Surges in the Sump and Discharge. Surges or hydraulic transients need to be considered in the design of pump stations and should be avoided to the extent possible. Surges can occur in the sump or the discharge. Analysis may show the need for mitigating measures to control transients. In some cases, sump design and sizing may need to be refined. Pump control valves or pressure relief valves may need to be considered in some cases. Pump startup ramp rates are an important variable that needs to be considered in the design. For electric motor driven pumps, variable frequency drives (VFDs) or soft start motor starters might be possible mitigating measures.

a. Surges on the discharge side can occur when the pump shuts off and the discharge line drains back into the sump. In this case, pumps must not be allowed to start, and backspin timers must be incorporated to prevent pumps from starting after shutdown.

b. Surges may also occur in pipelines which flow full and are subject to sudden changes in rate of discharge. This is possible where the sump area and adjacent areas have too small a water volume. Serious damage could occur if proper consideration is not given to the effects of surges in designing the pump station. Surges and resulting rapid fluctuations of the water surface elevations in the sump could also affect the proper operation of the automatic stop and start controls of the pump.

c. The height to which the water will surge in the pump sump is a function of the length of a pipeline flowing full, the cross-sectional area of the pipeline, the volume of the sump, the change in pump discharge, and the friction losses. An exact mathematical solution of the problem is often practically impossible because of the many changes in pipe size and the numerous inlet points on a sewer system. However, approximate methods, permit mathematical treatment of the problem and give results sufficiently accurate for design purposes.

d. Means to Control Surges. Certain features inherent in the design of pumping stations and sewer systems automatically supply a dampening effect on surges. Various laterals and manholes of the sewer system, the operating sump, and intake and trash rack wells act as surge tanks. Use of adjustable-blade pumps or variable-speed motors will allow gradual reduction of pump discharge upon shutdown and would reduce operational difficulties arising from surges. In cases where the surge will be great, consideration of one of the following methods will aid in solving the problem.

e. Installing check valves on discharge line. This will prevent backflow into the station but provisions for opening the check valve and draining the discharge line still need to be provided especially in cold climates where the water can freeze.

f. Raising operating floor. Raise the operating floor of the pumping station above ground level and provide overflow openings below the station floor. In order to confine the effluent and facilitate its removal, a catch basin would have to be constructed adjacent to the forebay, with a gravity drain to return the overflow to the station. This method would protect the station from damage due to extremely large surges that might be caused by total station shutdown, but ordinarily would not alleviate the smaller surges due to shutdown of single pumps, which may cause operational difficulties. Often, however, from a cost perspective, this option is not feasible.

g. Stations having the operating floor above the high-water elevation or located outside the line of protection may have flap-gated bypasses from the station sump pump intake to a pressure discharge chamber or directly into the stream.

(1) This arrangement might require changes in the station design, particularly in the design of the operating floor which may be subject to upward pressures. This method can be used to protect the station from extremely large surges.

(2) The effectiveness of the method in reducing smaller surges would be dependent upon the elevation of the water surface in the discharge chamber or in the stream at the start of the surge and upon the elevation at which the bypasses are placed.

h. The horizontal cross-sectional area of the inflow sump could be increased to act as a surge tank. The sump dimensions should not be increased above that area required for proper sump flow.

i. A special surge tank or a surge basin could be used at some point on the pipeline near the pumping station. The effectiveness of this method is dependent upon the horizontal cross-sectional area provided by the elevation at which the surge tank becomes effective. This method is effective in reducing all surges, both in the sump and in the connecting sewer. However, for greatest effect at the pumping station, the surge tank or surge basin should be placed as close to the station as practicable.

j. For a large pipeline, an initial intake sump could be provided with a regulating weir into a second sump at one side in order to maintain a constant hydraulic gradient in the sewer. This method would prevent surges from moderate changes in pump discharge but may not greatly affect large surges resulting from total station shutdown and may not afford sufficient protection for the pumping station.

Chapter 7
Pump Intakes

7.1 General. This chapter is similar to Chapter 6 but focuses in particular on FSIs and general intake design of pump stations rather than the overall pump station geometry.

a. Pump inlet conditions are among the most overlooked and misunderstood aspects of pump station design, yet they probably constitute the single reason most responsible for the success or failure of a pump station. Pump performance is entirely dependent on the quality of the effort expended to ensure that adequate conditions exist at the pump intake. Regardless of the type of intake, such as pressurized, sump, or forebay, care must be exercised to avoid poor hydraulic conditions at the impeller. The pump intake design must satisfy the requirements for proper approach conditions by avoiding the following:

(1) Inadequate NPSHA or submergence at the pump inlet, especially at the most frequent operating conditions.

(2) Poor velocity distribution at the entrance to the pump.

(3) Excessive swirling in the pump intake piping.

(4) Air entrainment in the pumped flow.

(5) Unstable approach conditions in multiple pump operation.

(6) Vortices.

b. Although there are several key factors for successful pump station operation such as NPSH margin, allowable operating region, and allowable vibration, poor inlet conditions are probably the primary culprit for badly operating pump stations. Poor inlet conditions have a dramatic effect on pump and system performance in several ways, including:

(1) Pump cavitation and vibration that results in costly and frequently repeated repairs.

(2) Loss of pump capacity, head, efficiency, and inability to achieve installation design objectives.

c. Considerable effort has been expended in recent years to improve the knowledge base for the design of pump intakes. Much of this effort is reflected in the requirements established by the publication of ANSI/HI 9.8, American National Standard for Rotodynamic Pumps for Pump Intake Design, commonly referred to as “Pump Intake Design”. There are several different types of pump intakes in common use depending on the conditions and usage expected, sump design, and types of fluid being pumped (clear or solids-bearing). Intake designs include:

(1) Bell-mouth inlets, with or without flow straighteners and/or right-angle cones.

(2) Closed bottom can pumps.

(3) Open bottom can pumps, with or without flow turning vanes.

(4) FSIs and similar alternatives.

d. Submergence.

(1) As stated in Chapter 5, submergence is generally defined as the setting of the impeller eye of the pump with respect to the water surface in the suction sump area. However, minimum submergence (often denoted by the letter "S") may be defined using different reference points depending on the type of pump intake as noted earlier in Chapter 5.

(2) For horizontal pipe inlets and FSIs, ANSI/HI 9.8 measures submergence from the lowest anticipated water surface level down to the horizontal centerline of the inlet. The designer should note that HI 9.8 standard FSI submergence (relative to the datum defined in that standard) results in a higher water level than USACE guidance. The reason is that the equation for submergence in the HI 9.8 standard applies to all the intake types in the standard.

(3) The designer should also note since the FSI submergence equation in HI 9.8 ((Eq. 9.8.3.2.3-1) has a diameter as an input, an equation is provided to obtain an equivalent diameter for the FSI rectangular inlet to use in the submergence equation.

(4) Calculation of submergence per the HI standard HI 9.8 is likely to be too conservative for USACE pump station FSI's. However, this value should still be calculated and compared to USACE guidance.

(5) For Type 10 FSI's, submergence should be calculated per Plate 24 in Appendix B, depending only on FSI throat diameter. The principal factors involved in the determination of submergence are cavitation limits and to preclude the formation of sustained surface vortices, which can pull air into the pump.

(6) The designer should always make sure the impeller is fully submerged at the lowest water level as a practical approach when utilizing the Type 10 FSI. Note that "submergence" in this case is used to mean the minimum allowable pump submergence, at the lowest level which will be reached by the sump.

e. Cavitation. The impeller should always be completely submerged at the start of pumping. Cavitation can be reasonably predicted from the computational procedure in Appendix C. This procedure computes the required submergence based on test results of pumps at USACE pumping stations. See Chapter 9 for more information about cavitation tests.

(1) NOTE: For off-the-shelf pumps, the manufacturer provides values for NPSHR, typically based on "NPSH3", meaning it is the NPSH required to limit head loss due to cavitation vapor to 3%.

(2) For USACE pump stations, however, best practice is to design for no cavitation. For that reason, normal operating conditions should include a margin of NPSH above the manufacturer value, for pump longevity; see Appendix C for table of recommended additional submergence above NPSHR level. The designer should reference ANSI/HI 9.6.7 and guideline for effects of liquid viscosity on performance, for more details on NPSH3.

f. Flow Conditions. The layout of the station, the sump water levels, and the shape of the pump intake determine what flow paths occur. These flow paths can cause uneven distribution into the pump, which negatively affects pump performance. The most observable of these detriments are vortices.

(1) Vortex formation can be minimized by controlling flow conditions into the sump and to the pump, as well as by maintaining proper submergence. Station layout dimensions and ratios per Chapter 6 along with straight inflow to the station intake should eliminate vortices or significantly reduce their intensity.

(2) If the station cannot be laid out to these dimensions and straight inflow does not occur, then either a sump model test should be considered or the FSI should be incorporated into the design. The FSI has demonstrated the ability to nearly eliminate vortices at the pump; surface vortices with FSIs might be addressed by placing horizontal bars above the FSI inlet about 0.3 m (1 foot) below the minimum sump level. The USACE ERDC Hydraulics Laboratory should be consulted regarding pump intake design, and for high flows or unusual entrance conditions, a model test may be required.

g. Pump Inlet Piping. Pump manufacturer's requirements will govern allowable velocities, length of straight pipe (likely in multiples of impeller diameter) upstream of the pump, supports, and NPSHR, but HI 9.8 and 9.6.6 offer relevant guidelines. Inlet piping is likely to have a maximum allowable velocity of no more than 2.4 m/s (8 fps). If reductions are needed, any single reduction should be no more than one pipe diameter, preferably concentric, and in no case may the suction pipe diameter be less than the pump nozzle, due to cavitation concerns. Tees and elbows close to the pump will likely require some combination of flow vanes and lower velocities.

7.2 Bell-Mouth Pump Suction Intakes and Bell Diameter. In the past, the rectangular wet-pit sump with the conventional bell-mouth pump intake was the most common combination used. Experience has shown, however, that the hydraulic performance of this combination of sump and intake is very sensitive to inflow conditions, sump design, and pump operation.

a. Bell-mouth pump intakes can also be used in trench-type sumps or unrestricted sumps. Some advantages of this pump intake are availability, cost, and no addition to NPSHR.

For the purposes of friction loss calculations, bell-mouth pump suction inlets on vertical pumps are considered to be part of the pump and therefore add no losses.

b. A bell can also be an inlet to a suction pipe (whose losses must be considered) upstream of the actual pump, for instance in a wet-well/dry-well station where pumping equipment is on the dry side.

c. Bell Diameter. Bell diameter is determined by the pump manufacturer, typically sized for an average velocity of 1.5 to 1.8 m/s (5 to 6 fps) at the inlet. As described in HI 9.8 and elsewhere in this manual, sump dimensions and submergence are all dimensioned relative to the pump bell diameter when this type of pump intake is used.

d. Flow Conditions. When a model test or the manufacturer indicates that flow conditions are inadequate, it is often helpful to add corrective devices such as right-angle cones or flow splitters directly below the centers of these pump intakes. Right angle cones assist in creating more symmetrical flow to the inlet of the pump, suppressing floor vortices. Flow splitters inhibit swirl and sub-surface vortices. Addition of right-angle cones and/or splitters will be based upon the pump manufacturers' recommendations and model testing; adding such devices when they are not needed can make flow conditions worse instead of better.

7.3 Closed Bottom Can Pump Intakes. Open bottom or closed bottom can intakes may be used in some of the smaller pump stations. The purpose of the intake is to establish desirable pump inlet conditions for the pump. Most can pumps will be of a closed bottom design. Flow vanes in the can are recommended to prevent vortices and swirl. For flows above 189 L/s (3000 gpm), flow vanes are required. Concentricity of the can pump is critical, as is submergence.

7.4 Open Bottom Can Pump Intakes. Several variations of this type of intake may be used, with a horizontal header supplying flow and a 90 degree turning elbow on the pump inlet, horizontal header supplying flow and a vortex suppressor on the pump inlet, at the end of a suction header with a 90 degree turning elbow, or a 5D minimum length of straight pipe with a long radius elbow on the pump inlet. All of these are measures to prevent vortices and swirl to the pump inlet. For pumps of this type with flows greater than 315 L/s (5000 gpm), a model test is required.

7.5 Formed Suction Intakes (FSIs). The FSI is used on pumps to improve flow to the impeller of vertical pumps; it has demonstrated the ability to improve the poor hydraulic sump performance sometimes experienced with the standard bell pump suction intake in a regular wet pit sump. See Figure 7.1, Plates B.22-B.24 in Appendix B and HI 9.8, Figure 9.8.3.2.2, noting that the practicality of design radii will be affected by whether the FSI is to be fabricated from plate or cast in concrete.

a. The dimensions for the USACE Type 10 fabricated FSI are shown in Plate 24 in Appendix B. NOTE: Over the years and publications describing FSIs, a persistent typo showing 0.02d as the radius from the top of the FSI's diffuser to the breast wall has been problematic.

This dimension was never intended to be so sharp; designs may call for a 0.2d up to a 0.25d radius at this location.

b. Additionally, minimum submergence “S” has not always been clearly dimensioned; it is measured from the water surface to the lowest roof elevation of the FSI. Submergence should be calculated per Plate 24, but since measurement to the lowest roof elevation of the FSI is not convenient, the dimension to the invert of the diffuser may be a more practical dimension to check in the field. “Type 1” FSIs offer no advantage for new construction but are shown in Plate 23 in Appendix B as a reference for any existing installations.

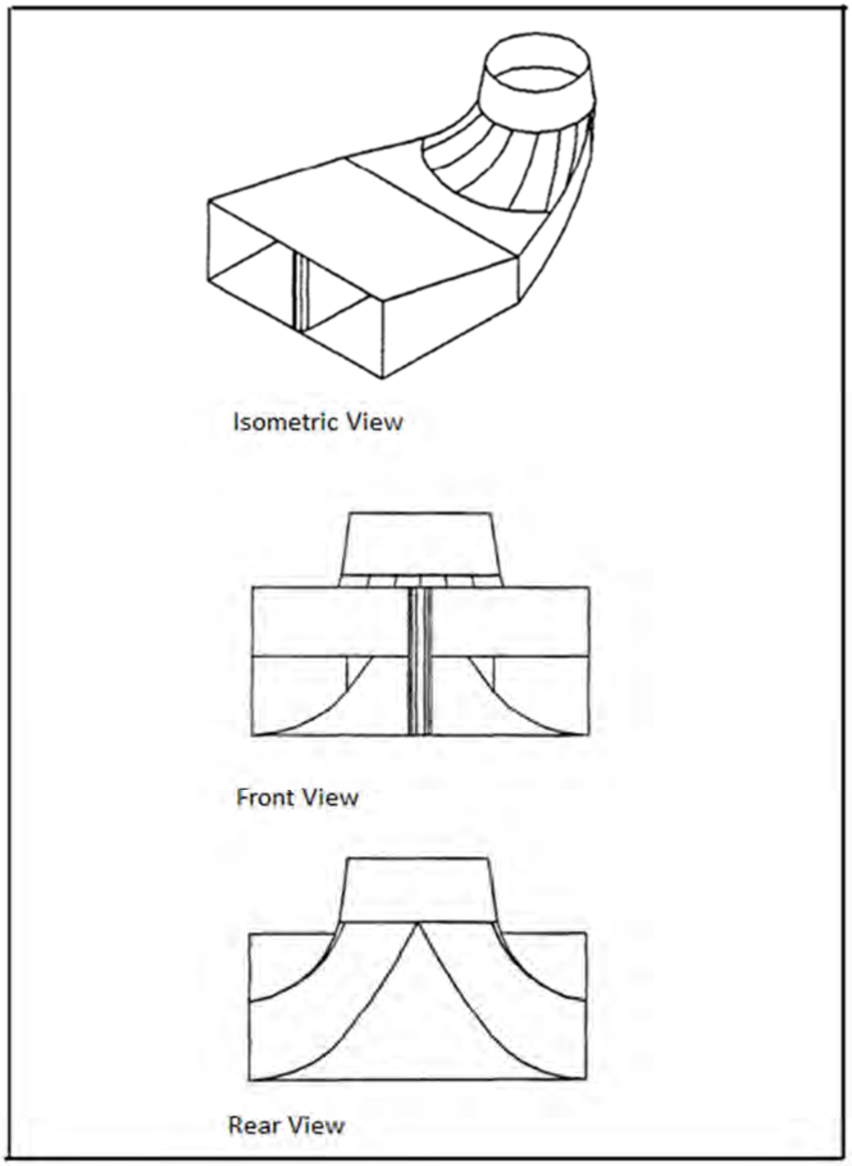

Figure 7.1. General arrangement of an FSI

c. The FSI may eliminate the need for extensive retrofit of stations with poor inlet conditions. The FSI is relatively insensitive to the direction of approach flow and skewed velocity distribution at its entrance.

d. In applying the FSI design, consideration should be given to the head loss in the FSI that will affect to some extent the system curve calculations, and the NPSH available to the pump impeller, typically located near the FSI exit. The FSI can be used on almost any pumping application. It is especially recommended, however, when adverse flow conditions occur upstream. The FSI can be used on small pumps; however, the small openings could clog or silt-in during nonoperational periods. FSIs can be embedded in concrete or formed in concrete and can be used in trench-type or rectangular wet wells or in dry wells.

e. Note that FSIs have no advantage with respect to air entrainment in the pumped flow. With the FSI, as with any other, it is important to minimize air entrainment, such as by delivering water to the sump below the water level when possible.

f. Typically, the Type 10 FSI design is more cost-effective. Earlier versions of the FSI design had a fairly large height. The Type 10 design reduces this height to extent possible. Reducing the height of the FSI impacts favorably on the design of a pumping station. It raises the sump floor and reduces the elevation of the impeller. This in turn reduces excavation and increases the available static suction head on the pump impeller.

g. History. FSI design was originally developed by the WES Hydraulics Laboratory with Technical Report HL-90-1, Formed Suction Intake Approach Appurtenance Geometry (Fletcher 1990). A number of different types of FSIs with different geometries were evaluated.

(1) The abstract from that technical report states: “Physical hydraulic model tests were conducted to investigate the hydraulic characteristics of a selected FSI design subjected to various hydraulic conditions. A variety of pump bay lengths and widths were evaluated. Hydraulic performance was evaluated by measuring flow distribution, swirl angle, and vortex intensity. Test results revealed that the FSI provided satisfactory flow to the pump with adverse flow in the approach. Test results are presented in dimensionless terms in plots and sketches.”

(2) Though now inactive, USACE ETL No. 110-2-327, GEOMETRY LIMITATIONS FOR THE FORMED SUCTION INTAKE, 31 December 1992, is part of the history of FSI use in the USACE. This ETL provided guidance for reducing the height of the FSI. The ETL 110-2-327 evaluated both a FSI Type 1 and FSI Type 10.

(3) A summary of the ETL stated the following: “Tests confirmed that the Type 1 FSI is hydraulically sensitive to excessive modifications to its internal geometry”. The report went on to state: “Tests also indicated that the maximum height reduction could be obtained with the Type 10 design.”

(4) It should also be noted the error in the radius from the top of the FSI's diffuser to the breast wall was incorrect in the ETL and was copied in subsequent versions of EM 1110-2-3105. The type 10 FSI as discussed in ETL 1110-2-327 represents the optimum design, i.e., a design with the minimum permissible height. By reducing the cone height from 0.45d to 0.22d and the height of, the roof curve above the floor from 0.56d to 0.49d, the type 10 design changed the overall height of the Type 1 design from 1.58d to 1.28d. This provided a 19-percent reduction in the overall height.

(5) These test results are the basis of the recommendation that the height of the FSI not be less than 1.28d and that the cone height and the height of the roof curve above the floor not be less than 0.22d and 0.49d respectively. The dimensions of the FSI are provided in terms of the throat diameter d.

(6) Recent experience has shown that performance will improve significantly with a slightly deeper submergence. Where the submergence on Plate 24 in Appendix B was previously shown as 0.94D, it is now shown as a range including the preferred 1.2D submergence value, with a corresponding increase in the reference dimension from the floor of the FSI to the water surface.

h. Description. An FSI is composed of three main elements, the diffuser, the bend, and the cone, which together normalize velocities and redirect flow to the pump impeller.

(1) The first element is commonly referred to as a diffuser, but would more appropriately be called a concentrator, since the direction of flow goes from the large cross-section towards the smaller cross-section. This serves to converge flow lines, increasing uniformity. The convergence of flow continues through the transition between the diffuser/concentrator and the bend, which serves to redirect flow vertically towards the pump impeller.

(2) Much like a pipe elbow, the radius of the back wall of an FSI helps preserve the fairly uniform velocity across the cross-section of flow. Then the short truncated cone section above the bend and below the impeller slightly converges the flow lines further. FSIs might be referred to as "draft tubes" due to similarity with the elbow-type draft tubes seen at most USACE powerhouses for the discharge from a hydro turbine.

i. FSI size determination. An FSI is connected directly to the suction flange below the impeller. This diameter, d, will determine the size of the FSI. The selection of the pump will be the same as that used for the vertical wet pit pump except for the additional suction loss.

(1) Whereas the conventional vertical pump with a bell uses a suction loss of zero, the pump equipped with an FSI should use a loss of $K = 0.15$. After the pump has been selected, it is necessary to determine the suction flange connection inside diameter (I.D.), d.

(2) For axial flow pumps, d will be the same diameter as that determined for the impeller. For mixed flow impellers, d can be estimated to be 0.85 of the impeller diameter d. After d has been determined, the rest of the dimensions of the FSI can be found by applying the ratios indicated in HI 9.8, Figure 9.8.3.2.2, “Formed suction intake”. In a typical pump selection, the suction diameter will vary with different pump manufacturers. To permit maximum biddability, the FSI must be sized to allow sufficient manufacturers to bid.

j. FSI connection. For vertical wet pit pumps which are suspended from the operating floor, the connection between the FSI and the pump is determined by the pump manufacturer after the pump manufacturer performs a dynamic analysis of the pumping unit to determine the critical speeds of the pump.

(1) The connection between FSI and pump should be included in any dynamic analysis. Thermal contraction and expansion are also concerns particularly if a vertically rigid connection was originally installed.

(2) Current industry standard is an axially flexible connection which offers lateral support and provides for removal and reinstallation of the pump. It is recommended that the FSI be formed or cast integral with the sump concrete.

k. FSI Material. The FSI can typically be constructed of either steel or formed concrete. For pumps 1219 mm (48 in) or smaller, it is recommended to utilize steel for the FSI. Steel construction in this size range will generally be more price competitive. FSI construction above 2133 mm (84 in) concrete FSI is recommended simply because the cost of the steel fabrication becomes prohibitive. The designer must provide an analysis between concrete and steel FSI during the design phase. FSI design will need to be coordinated with the structural designer. It is imperative that the inside surface finish of the FSI be as smooth as possible. In this regard the steel FSI will have an advantage.

l. When to use an FSI. FSIs geometry serves to reduce or eliminate backwall vortices, sidewall vortices and floor vortices that are seen in suction bell inlets in rectangular wet-pit arrangements.

(1) The FSI may eliminate or reduce the need for design of approach channels and features to provide satisfactory inlet conditions to the pump, thereby reducing the footprint of the plant when you cannot have flow enter directly in front of sump bays. When flow enters at a 90-degree angle to pump bays, FSIs may be the only solution.

(2) The FSI is generally much less sensitive to unfavorable approach conditions or flow approach angle than a bell inlet. Additionally, FSIs are useful for pumps which would otherwise require intake piping larger than 400 mm (16 inch) because eccentric plug valves for isolation in such sizes are massive and expensive, likely interfere with flow and require ~3D distance from the pump, whereas sluice gates, which are light and relatively cheap, are more appropriate for intake structures upstream of FSIs.

(3) Knife gate valves, originally designed to sever paper pulp to allow valve closure, can also be used for isolation, but note that some engineers reject such usage, so the designer should be cautious in using them by investigating similar situations.

m. When not to use an FSI. If pump intakes are a small diameter, or if the site offers a direct approach to the pump bays and space is not a constraint, it may not be worth the expense of FSI construction and the extra head losses upstream of the pumps. In a retrofit situation, it may be challenging to add an FSI to an existing pump suction bell. If the existing pump is suspended, additional caution is needed to avoid resonance. (A 900 RPM pump with a 3-vane impeller has a forcing function of 2700 RPM, for instance.)

n. Alternative FSI designs. ANSI/HI standards describe an FSI geometry which differs from the USACE Type 10 FSI, though they are similar. There are also alternative FSI designs which can be referenced, though a model test would be recommended.

(1) One alternative which uses fewer curves for easier construction is included in Appendix I of HI 9.8.

(2) Another alternative FSI with a plain radius and flat plates is described as a possible solution when trying to retrofit an FSI to an existing suction bell, in “An Alternate Formed Suction Inlet Design for Large Vertical Turbine Pumps” by Werth and Cheek, 4th American Society of Mechanical Engineers- Japanese Society of Mechanical Engineers Joint Fluids Engineering Conference Honolulu, July 6-10, 2003. Note that any arrangement which successfully passes model testing is acceptable.

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Chapter 8
Discharge System

8.1 General. The discharge system of a pumping station is used to convey the pumped water from the pump station to the receiving body of water. The method and structures required to transport pumping station discharge are determined largely by the type of protection works adjacent to the pumping station, the location of the station with relation to existing sewers, and the desirability of avoiding layouts involving long pressure conduits, especially under levees.

a. Pressure conduits under protective works can be avoided by carrying the discharge over the levees by individual pipes. In general, it is preferred to provide arrangements where pumps discharge into gravity channels or open discharge ponds after relatively short runs of discharge pipe.

b. The designer must also reference and utilize EM 1110-2-2902, Conduits, Culverts, and Pipes, for the discharge system from pump stations and HI 9.6.6, Rotodynamic Pumps for Pump Piping. HI 9.6.6 discusses both suction inlet piping and discharge piping from the pump. This manual and EM 1110-2-2902 must be used in conjunction with each other for pump station discharge.

c. The discharge system also has to be coordinated with the structural, civil, and geotechnical engineers on the project. If the protection works consist of a floodwall, pressure conduits should be avoided by locating the pumping station on the protection line and making the discharge through the discharge side wall of the pumping station into a gravity conduit or open discharge chamber. If the pumping station is offset from the floodwall, special arrangement of the discharge pipes may be required.

d. Pipe Installation. Proper installation of discharge piping is essential for pump operation. HI 9.6.6 notes the following: “Three of the more common detrimental effects caused by poor pump piping designs include: 1) excessive loads that the piping can place on a pump because of pipe misalignment with the pump connections, 2) failure to properly restrain the pump to the foundation support structure, and 3) excessive loads on piping resulting from unsupported or poorly supported valves, fittings, or vertical in-line pumps.

e. Excessive nozzle loads at the pump discharge can be caused by thermal expansion of the pipe, unsupported piping and equipment weight, axially unrestricted couplings, and misaligned piping. Excessive pump nozzle loads lead to misalignment of the pump shaft with the driver shaft, mechanical seal failures, bearing failures, binding or rubbing of the pump rotor, and in extreme cases, failure of pump nozzles or mounting feet”.

f. In addition to direct loading on the pump, improperly designed discharge systems may lead to loss of integrity of the discharge system resulting in leaks, loss of prime, up to partial or complete structural failure of the discharge system. Failure of the discharge system may also contribute to deterioration of the adjacent protection system, such as by providing pathways for backflow, or erosion of material by leakage.

g. Discharge Velocity. The maximum discharge velocity in pump station pipelines should be limited to 12 feet/s (3.6 m/s). HI 9.6.6 notes the following: "The maximum velocity at any point in the outlet (discharge) piping is 4.5 m/s (15 ft/s). This limit must, however, be reduced if there is a check valve in the outlet piping that will generate a hydraulic shock when it closes.

h. Note that pump discharge nozzle velocity may exceed this value. Therefore, the straight discharge pipe length at the pump discharge nozzle, which is typically the same diameter as the discharge nozzle itself, cannot be subject to this velocity limitation. System pipe friction losses (see Appendix A.1), life-cycle costs, and process considerations normally dictate the size of the discharge piping and fittings."

8.2 Discharge Types. The type of discharge is sometimes set by the location of the station. See EM 1110-2-2902 for further discussion. Pump stations can be built at the levee toe, into the levee, or built into a floodwall. These different locations all affect the pump station discharge. The majority of USACE stations do not utilize siphons or a siphon assist. In that case, the maximum head differential is based on the interior ponding level and the maximum discharge line elevation.

a. Over the protection. Discharge lines over the protection consist of individual lines for each pumping unit or a manifold discharge with one discharge line running from the station over the protection. The invert of the highest point of the discharge line should be the same as the top of the protective works at the pump station site. Pipes over the levee require an air release and a siphon breaker at the crest. This discharge arrangement is shown in Plate 1 in Appendix B. A variation where the discharge ties in with the gate well structure on a gravity drainage system is shown in Plate 2 in Appendix B.

b. Through the protection. Installing pumping station discharge lines under or through levees or floodwalls and subjecting these lines to flow under pressure should be avoided whenever possible.

(1) It is realized, however, that conditions may exist which require or dictate their use. As an example, a large discharge line may be carried under a floodwall when right-of-way for a pumping station would necessitate several bends. When it is not practicable to avoid a pressure line under the levee or wall, the pipe will have ample strength and be provided with joints that will provide flexibility with restraint to limit axial movement.

(2) Flexible couplings with bolted flange type connections are recommended over compression sleeve type if used on buried pipe when substantial settlement is expected. Whenever it is necessary to install discharge lines under or through levees or floodwalls, the design must follow the requirements as indicated EM 1110-2-2902 including any provisions for

seepage control. In general, two means must be provided to prevent backflow when the discharge is through the protection.

c. Hybrid systems. There are pump station discharges with raised inverts similar to an over-the-levee arrangement for which the invert is below the line of protection. Typically, this occurs when the elevation of protection is raised at the site of an existing pump station without upgrading the station equipment. This presents a discharge system which should address both the venting requirements of an over the levee system, and the positive shutoff requirements of a through protection discharge. Again, the designer must follow the requirements as indicated in EM 1110-2-2902.

d. Siphon discharge lines. Over-the-levee discharge lines should be studied to determine if their use as a siphon is economical. Usually a siphon can be justified on power saved due to the lower head when primed. Siphons may be used when the station is located behind the levee or as an integral part of the levee. In those cases where different types of discharge arrangements could be used, a study of alternatives should be made.

(1) The designer must also utilize EM 1110-2-2902 for this analysis. Selection is based on a life-cycle cost analysis. Some of the variables would be operating, equipment, and structure costs. Operating costs would include the costs of energy, manpower, and operating supplies and maintenance costs. Energy and manpower needs should be determined using available hydraulic/hydrology data to determine amount of operation time and discharge levels.

(2) Forecasts of future energy costs can usually be obtained from the utility that furnishes the energy. Equipment costs could vary due to the difference in discharge head requirements of the various discharge systems. In most cases, only the driver size would change. Although over the levee discharges with a siphon recovery make pump selection more difficult due to the fact that the pump is required to operate over a greater head range, it does reduce the operating costs of the station. The static head for a siphon recovery discharge is based on the pool-to-pool head, whereas the static head for a non-siphon discharge is based on the maximum elevation of the discharge line.

(3) Pumps should be selected to operate over the entire range of heads provided by siphon usage. The pumping unit must be capable of self-priming the discharge pipe. The lowest discharge level should not be lower than atmospheric pressure and should be a maximum of 28 feet (8.5 meters) from the top of discharge pipe (this limit, as illustrated in Appendix C, does not include piping losses, velocity head, etc.).

(4) Where discharge water levels do not provide for adequate submergence at this level, two types of discharge pipe terminations may be used for siphon systems: concrete structures with a weir to submerge the pipe end or a turned-up discharge pipe end (saxophone) Figure 8.1. Both types are acceptable, and selections can be based on costs of construction and operation.

(5) The saxophone type discharge piping may be continued up to a second lower free vented invert and then continue downward to the discharge pool Figure 8.2. Conventional discharge arrangements may be used if the pump discharge is ensured adequate submergence during pumping operations. Valves on the end of the discharge pipe should not be used to hold a siphon in the pipe. Discharge pipe diameters 60 inches (152 cm) and less can usually be operated as a self-priming siphon if the flow velocity at the crest is 7 fps (2.2 m/sec) or greater when priming is initiated.

(6) Model tests should be considered for discharge pipes of greater diameter or those of an unusual discharge arrangement. Problems in priming the siphon can occur when the changes in discharge line gradient occur on the discharge side of the protection. The section of pipe after the down leg should he as flat as possible to prevent these problems.

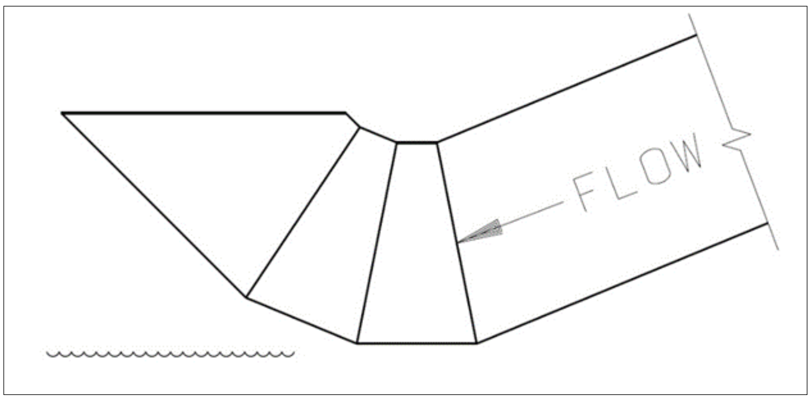

Figure 8.1. Saxophone Discharge

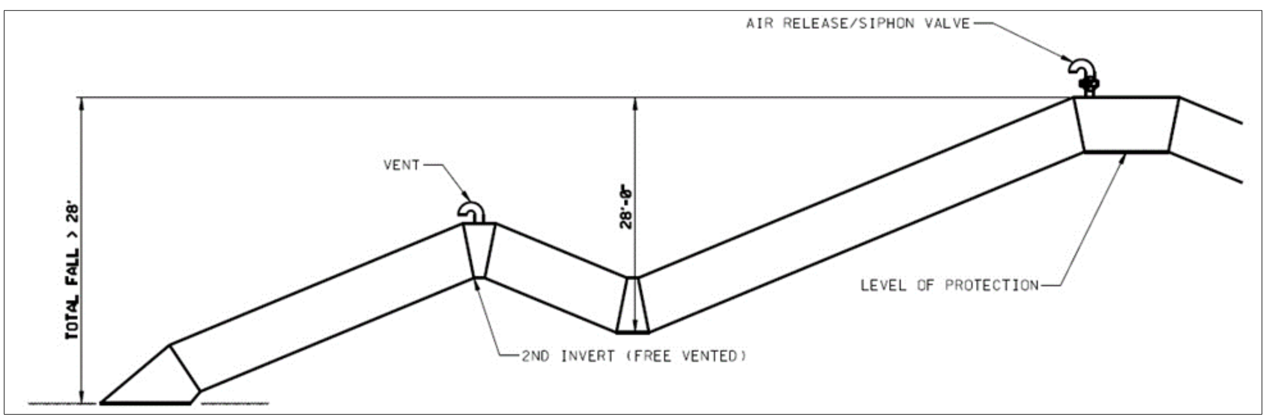

Figure 8.2. Siphon Discharge with 2nd invert

8.3 Backflow Prevention. The type of pumps usually used for flood risk management pumping stations generally do not provide any restrictions to backflow. A suitable means must be provided to prevent backflow in the pump discharge lines. In planning pump station installations, the practices outlined below should be followed. The designer should also reference EM 1110-2-2902 and follow the requirements in that manual.

a. General. The basic requirement for pump discharge lines, in which backflow can occur without siphon action, is to provide two means of preventing backflow. One means would be for normal use and the other for emergency use in the event of failure of the normal method.

(1) For example, a flap valve can be installed at the end of the discharge pipe. The back-up or emergency method may then consist of a check valve located in the discharge pipeline. The check valve will stop backflow in the even the flap valve was stuck open.

(2) The basic requirement for pump discharge lines, in which backflow cannot occur without siphon action, is to provide two means of siphon breakage. Any manual actuators should be provided access and be mounted at an orientation and height above that point of access.

b. Through the protection. Where discharge lines pass through a system of flood protection below the elevation of protection a primary means such as flap gate, butterfly valve, gate valve, or slide gate should be used to prevent backflow. A second emergency means of closure should be provided for redundancy and to service the primary closure device.

c. A secondary valve or gate may be used for redundancy purposes. Bulkheads are generally preferable in terms of both cost and that they rarely require any maintenance actions for which dewatering would be required. As such the redundant bulkheads also may provide a maintenance dewatering closure for the primary closure device if positioned downstream.

d. Over levee or floodwall. Discharge lines over the levee or floodwall should have the invert of the high point of such discharge lines at or above the design protection elevation, except where unusual conditions exist that would justify deviation. All such deviations must be approved by HQUSACE higher authority.

(1) Discharge lines having the invert at a lower elevation than the design protection elevation should be treated as through protection discharges and be provided with means of positive shut off accordingly. Any valve, gate or bulkhead should be accessible at all flood levels. Closure devices may require motor operation if the discharge pipe diameter size is greater than 18 inches (450 mm).

(2) On motor-operated valves or gates a means should be provided for decoupling the motor such as by clutch and operating manually by hand wheel or similar mechanism. When discharge lines have an invert at or above design line of protection redundant siphon breaking provisions are usually sufficient for backflow prevention.

(3) Where increases to the elevation of protection are anticipated, such as during a flood fight, or when there is sufficient need to access the discharge lines for maintenance purposes, providing an emergency means of stopping backflow such as bulkheads should be considered.

e. Discharge chamber. A discharge chamber or gated outlet is commonly used for USACE flood risk management pump stations.

(1) For discharge lines terminating in the discharge chamber adjacent to the station, a single set of valves or gates alone may be considered adequate protection against backflow for normal operation if provisions for emergency bulkheads are included.

(2) The design of the structure should afford access to the valves at all flood stages. The walls of the discharge chamber should be constructed to at least the protection elevation. This will allow, in the event of the failure of a gate or valve, bulkheads to be placed at the exit of the chamber and dry access to repair the disabled device.

f. Valve Wells. When discharge lines running under or through protective works cannot be avoided and the pipes are terminated in a headwall, flap valves alone are considered inadequate.

(1) If flap gates, butterfly valves, or knife gate valves are used, a separate well should be constructed to the protection elevation from which access to the valve, comparable to that described above for a discharge chamber, is possible.

(2) This structure should be located and designed such that during periods of idleness of the pump station the tendency for silt, loose rock, debris, and floatable material to collect in sufficient amount to interfere with gate operation is minimized. An alternate procedure would be to provide a shutoff valve in each discharge pipe in addition to the flap gate.

g. Check Valves. Underground discharge lines in small pumping stations should have a check valve on each pump discharge line to prevent backflow. On pumps greater than 12 inches in discharge diameter (30 cm), butterfly valves become economically preferable to check valves.

(1) Manually operated valves require closure by operating staff upon cessation of pumping in order to prevent backflow. Valves with actuators may be tied to pump operation to close automatically when pumping ceases. In addition to cost, head losses resulting from check valves generally do not make them a desirable addition for larger pump discharges.

(2) Rotating disc or knife gate valves are typically more expensive but may be appropriate for applications where a clear discharge way free of obstructions is preferable. On smaller lines gate valves should always be provided on the discharge side of such check valves to permit maintenance of the check valves. Since check valves hold back water, in northern climates, provisions should be made to manually open the check valve and drain the discharge line.

h. Bulkhead Closures. Emergency or maintenance closures may require a removable bulkhead or stoplogs. These should be furnished where openings need to be closed in a short time period or for predictable maintenance needs. Incorporate sluice gates and/or bulkhead slots in discharge gatewells. Stoplogs and bulkheads slots should be made of corrosion resistant materials and closure devices should be of ample strength to sustain the imposed loads. They should be provided with hooks to permit handling by means of a lifting device. Bulkheads should be designed for placement under all operating conditions using a mobile crane if required by the weight of the bulkheads.

i. Air suppression. A means to allow application of compressed air, from an emergency source, to the high point of the discharge line would be an acceptable method to prevent backflow in an emergency situation only.

(1) Air suppression systems should not be utilized as the normal means of backflow. The submergence of the intake and discharge must be greater than the elevation of flood side water above the pipe invert in order for air suppression to inhibit back flow.

(2) Air systems generally require active operation and management to maintain backflow prevention, and accordingly are less reliable than positive shut off options. On pump stations with vacuum priming, the required apparatus necessary for air suppression generally are already present, making it an economical system to incorporate for redundancy.

j. Flap Valves. Discharge lines through the protection may be terminated with a flap gate to prevent back flow.

(1) In addition to the flap gate, provisions should be made for emergency shutoff valves, emergency gates, or individual stop log slots to place bulkheads in case of flap gate failure. An actuated form of positive closure may be used in place of flap gates in applications where the head loss induced by flap gates is not favorable to project conditions or when the likelihood of debris preventing closure is unacceptable.

(2) All discharge lines with flap gates should be fitted with a vent pipe located just upstream of the flap gate to prevent excessive vacuum bounce of the flap gate. The vent should extend 600 millimeters (2 feet) above the highest discharge water level. Flap gates must be of the type suitable for pump discharges and designed specifically for that application.

(3) This type of gate is of heavier construction and is typically constructed of cast or ductile iron, and the arms that support the flap are double hinged so that the flap will fully close. Bearings are also lubricated. All non-cushion type flap gates used on pump discharges should have a rubber seat which aids in sealing and eliminating some of the closing shock. Station utilizing flap gates are shown on Plates B.3 and B.6 in Appendix B.

k. Duckbill valves. Large duckbill style backflow preventers constructed of various types of rubber are commercially available which function in a similar capacity to check valves.

(1) USACE has limited experience with these types of valves but they are purported to work well in some applications. These valves generally have higher head losses but have the ability to seal around debris.

(2) On applications where sedimentation or debris blockages of a discharge may occur duckbill type valves may offer improved self-clearing abilities over flap gates. Materials and construction of this type of valve should be selected to ensure UV resistance and adequate design life.

l. Actuated valves. Butterfly valves and rotating disc or knife-gate valves provide effective means of positive closure. Gate valves may be slightly less susceptible to debris and may have lower losses but the differences are generally minor and cost considerations favor butterfly valves. On larger discharges slide gates (formerly termed sluice gates) tend to be more economical than large butterfly valves. On discharge lines from large pumps, a transition from round pipe to square concrete box culvert terminating in a discharge structure housing the slide gates has been used to provide positive closure.

8.4 Air Release and Siphon Breaking.

a. Air vents. All over-the-levee discharge lines should be provided with an unobstructed (free) air vent at the highest point. Through protection discharge systems may still require venting depending upon the discharge geometry. If the pipe system does not operate as a siphon, a permanent vent opening can be used.

b. Where discharge pressures are such that elevation of the vents is not adequate to prevent discharge of water, float operated type air relief valves may be utilized. Float operated air release valves generally function to open on negative pressure to prevent the formation of syphon and allow venting of air back into the pipe on pump shut-off. On siphonic systems vents should be equipped with air release valves which allow for the holding of a siphon. Suitable protection should be provided to prevent the vent being rendered inoperative by vandalism.

c. Siphon valves. For pipes operating as a siphon, a valve must be utilized to vent the pipe at start-up and break siphon at shut-down while maintaining siphon during pumping.

(1) These valves may be operated by a lever and paddle extending into the discharge which close with forward flow and open with reverse flow. Alternately the desired sequence of operation may be achieved utilizing actuated valves controlled automatically or by the pump station operators.

(2) Care should be taken when using flow operated that they are designed for heavy duty operation and are adjusted correctly after installation to prevent air leakage into the pipe. Over time the lever/paddle operated valves may fail to seal properly, inhibiting siphon formation. A remotely operated valve to break the siphon may be tied into the pump control system or controlled by the station operator. If operated automatically by the pump control system, a float

sensor may be employed to indicate a full pipe, however a time delay from pump start is generally adequate to initiate valve closing at start-up.

(3) Opening should be at pump shut-off. This valve may be pneumatic or electric operated depending upon available station infrastructure. Cost and maintenance consideration should also be evaluated when selecting valve actuation machinery. Pneumatic valves generally should be selected for spring open, operate closed such that the failure mode will generally be in the open/syphon break position except in applications where reduction of pump capacity presents a greater risk than backflow.

(4) Electric operators should be specified to include a manual hand wheels in event of failure. A redundant manually operated valve generally should be placed in parallel (tee arrangement) to break siphon in event of a failure. In applications where loss of pump capacity is critical, a second redundant valve in series with the actuated valve may be employed to ensure closure, though this is generally excessive if a manual operator is provided for the primary actuated valve. Manually operated valves may be adequate for pump stations of small sizes or non-critical applications.

d. Sizing. Air release and siphon valves are sized according to the formula provided below. When the calculated result indicates a non-standard size valve or piping, the next larger standard sized valve and piping should be used. Manufacturers of air and vacuum valves should be consulted for proper valve sizing. Vent size can be calculated using the following formula.

In English Units:

$$D_v = 0.25\ D_p \times (2/h)^{0.25} \qquad \text{(Equation 8.1)}$$

In International System Units:

$$D_v = 0.25\ D_p \times (0.61/h)^{0.25}$$

where

D_v = diameter of vent, ft or m
D_p = diameter of discharge pipe, ft or m
h = minimum submergence over outlet, ft or m

8.5 Discharge Construction. All piping within a pump station structure must be ductile iron or steel with flanged joints or welded joints. In general, a single discharge pipeline should be installed for each pump. On large lines with submerged outlets, the discharge should be terminated in a cone to reduce flow velocity and corresponding exit losses. Downturn angle may vary but the flare of the discharge cone should be limited to 10° maximum (5° off centerline) to avoid flow separation (Figure 8.3).

a. Combining discharge lines together can be evaluated as part of a project design. This needs to be documented in the project Design Documentation Report. The size of the pipe is usually determined by a cost analysis of the energy used due to friction loss versus pipe cost. In the case of pumping stations of small capacity 315 L/sec (5,000 gpm) or less, it may be more economical to have two pumps connected to the same line. The connection should be made inside the pumping station or a valve vault outside of the pumping station.

b. Check valves and gate valves should be inserted in each individual connecting line to prevent reverse flow through an idle pump when the other pump(s) are operating. A manifold system combining pump discharge lines into a single line is generally cost effective only for small pumps and when siphon recovery will not be used. When considering a manifold system, a cost comparison should be made between the cost of individual discharge lines and the extra shutoff and check valves needed in a manifold system.

c. On large diameter pumps discharging over the line of protection the discharge may be flattened in order to reduce pump head to top of pipe (Figure 8.4).

(1) Some large stations have been constructed where the pump column terminates at the elevation of protection directly into an open concrete discharge chamber, with the chamber floor at or below the discharge level.

(2) Dropping the floor below the pipe discharge may create a longer weir length (at the pipe circumference rather than the width of the discharge chamber) thus further reducing discharge head. This type of discharge (flowerpot, Figure 8.5) minimizes the height of the flow above the invert, thus reducing pumping power, and eliminates much of the discharge construction. It also eliminates the effect of large variances in tail water level on pump load, simplifying to a single design point.

(3) No siphonic recovery is possible however with this arrangement. With the speed reducer mounted on the concrete structure above the chamber, rather than at the top of a fabricated pump column, alignment of the pump during install is more dependent upon the station structure than a conventional design, however.

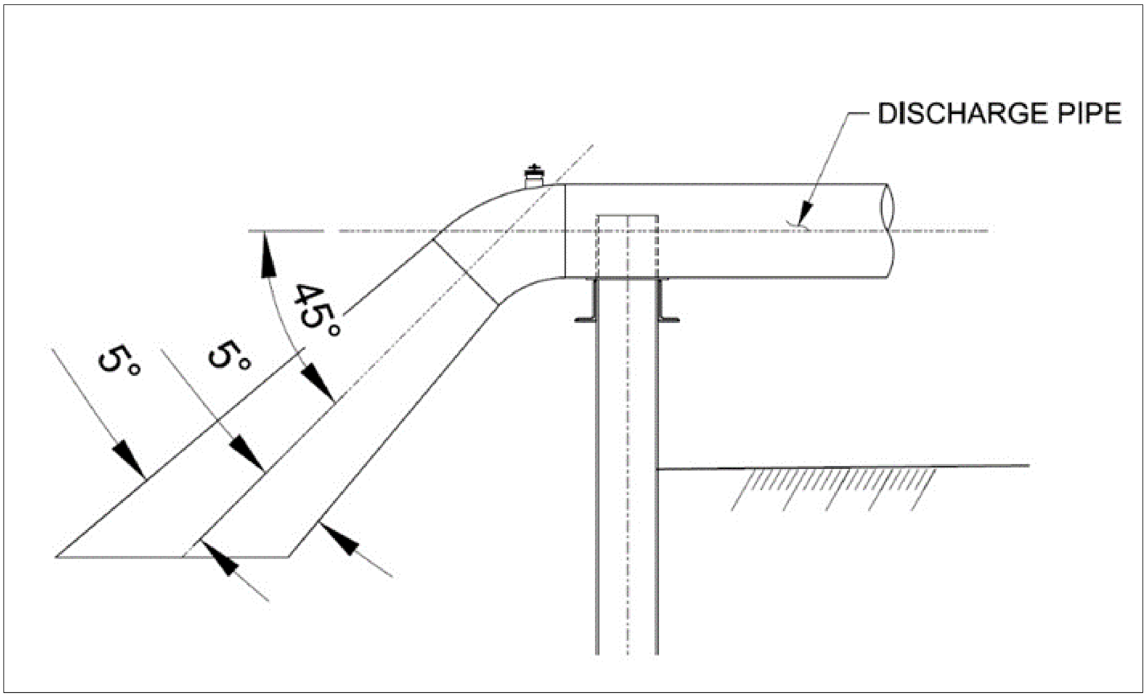

Figure 8.3. Discharge Cone/Discharge Bell

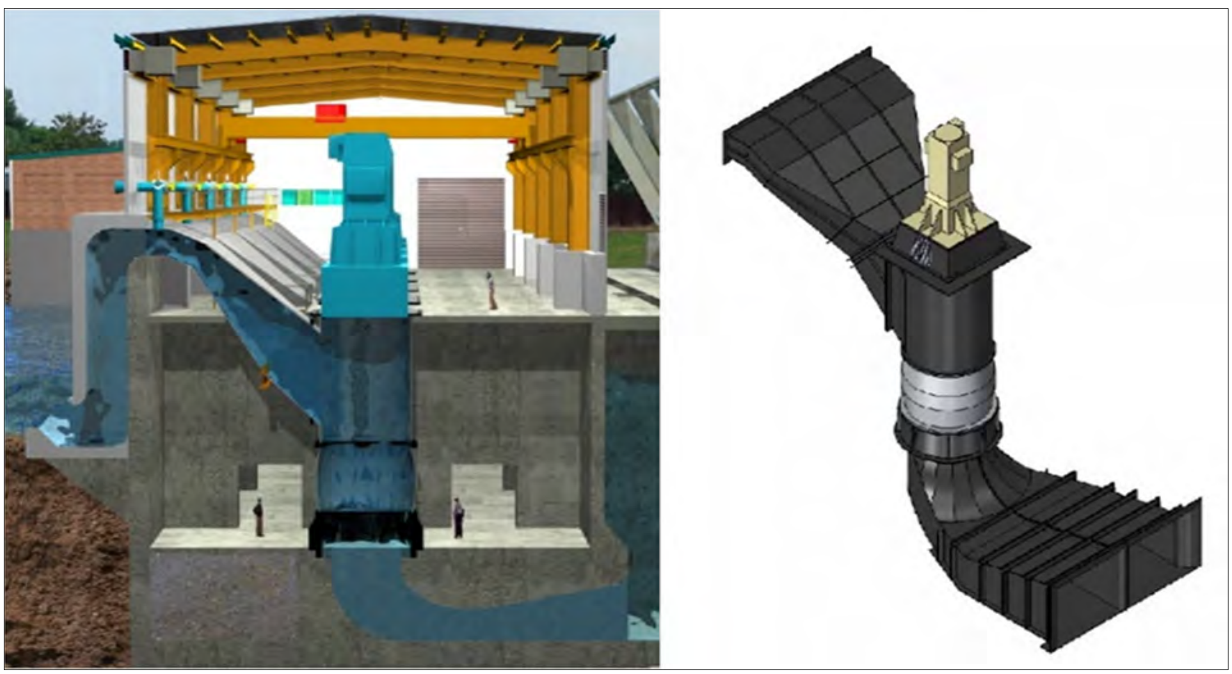

Figure 8.4. Over-Protection Discharge on Large Diameter Pumps

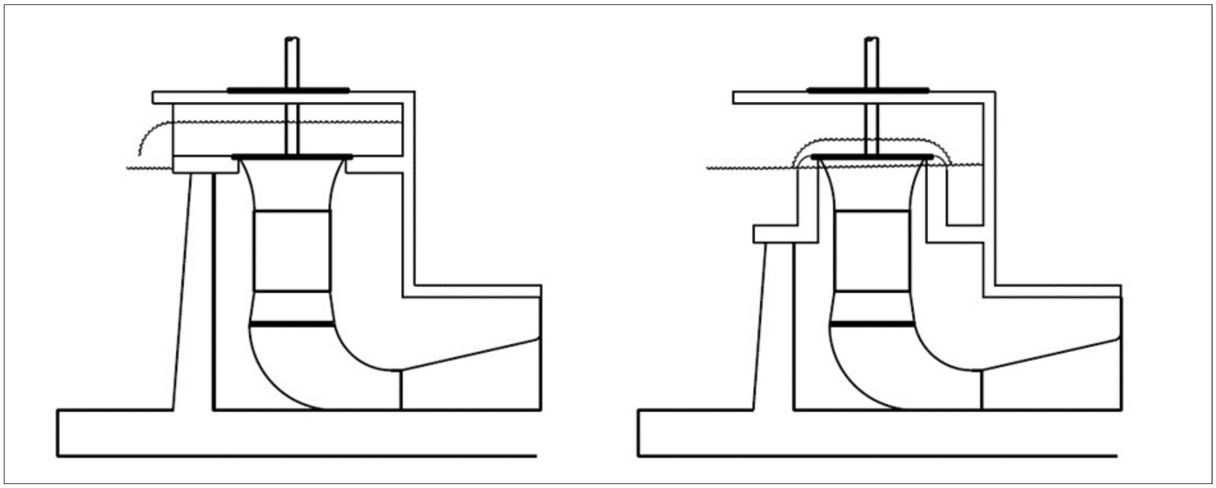

Figure 8.5. “Flowerpot” Discharge

d. Pipe Supports. Piping supports within the station are a critical design consideration. Where any piping connects to a pump, it should be supported so that the pump does not support any of the weight of the pipe or its contents.

(1) Where pipe is elevated or requiring structurally founded supports, spacing should be determined by pipe diameter and wall thickness but typically should not exceed 40 feet even for large pipes. Saddle supports or stiffening rings may be used to limit pipe deformation at support bents. Adjustable pipe supports should be used where substantial settlement is expected and may be used to aid in alignment during installation.

(2) Structural pipe supports may be fixed or sliding, only supporting the pipe in the vertical direction allowing movement (with or without stops) in the horizontal. HI 9.6.6 notes the following: “Proper installation of piping, supports, and restraint fixtures is imperative to obtain optimum performance and reliability from attached pumps and rotating equipment.

(3) Pumps require precise shaft alignment to operate properly. The installed piping should be supported by the surrounding structure, not by the pump itself. Pipe supports are used to hold the weight of the pipe off the pump nozzles, while restraints and guides are used to redirect the forces generated by thermal effects away from the pump nozzle. Pipe supports may be designed to handle vertical, horizontal, axial, thermal, and seismic forces.”

e. Pump Connection. For vertical pumps, discharge piping to pump connections is generally made by means of a flexible coupling with harness bolts across the connection. Rigid or flanged connections could be used for pullout design pumps and for those pumps that may be cast into the structure.

(1) Submersible pumps will be installed on a guiderail and then connected to a fixed discharge elbow. All buried piping needs to be connected with flexible couplings with harness

bolts whenever the pipe runs into or out of a concrete structure, at bends, and at other points where differential settlement or normal expansion or contraction of the pipe is anticipated.

(2) The designer must also follow EM 1110-2-2902 for the pipe layout requirements. Where piping leaves a structure, the first flexible coupling should be placed within 1.5 meters (5 feet) of the wall with an additional flexible coupling placed 1.5 meters (5 feet) farther downstream. What would otherwise be large transverse misalignments at a single coupling, may thus be accommodated by small angular misalignments at two couplings.

(3) All pipe sections should be adequately supported to avoid inducing shear loads across couplings. Where differential settlement is anticipated to exceed the manufacturer's allowance for the couplings' misalignment, then adjustable pipe supports should be used, with monitoring and adjustment instructions included in the station's operations and maintenance instructions.

(4) An embedded wall flange should be provided for all piping passing through concrete walls which are being cast into the wall. Alternately, the pipe may be sleeved through the wall and supported independently. Pipe selected should be of the minimum wall thickness that will satisfy the requirements of the installation and, if possible, should be of a standard stock wall thickness.

(5) Where corrosion may be a problem, an increase in thickness of 25 percent may be considered for steel pipe. In addition to the tensile circumferential stresses resulting from the normal internal water pressure, stresses due to the following may be a consideration in the design of some pump discharge lines.

(a) Excess stress due to water hammer.

(b) Longitudinal stresses due to beam action of the pipe when the pipe is exposed and supported by piers or suspended supports.

(c) Stresses caused by external loading.

(d) Stresses caused by collapsing pressures due to formation of vacuum in the pipe.

(e) Stresses due to temperature changes.

(f) Stresses due to differential settlement.

f. The discharge pipe and its support system including anchors, thrust blocks, and tie rods should he designed in sufficient detail so that the above considerations can he checked. The EM 1110-2-2902 provides requirements for all these support systems and must be utilized. American Water Works Association (AWWA) Manual M-11 should be referenced for recommended design and installation practices for steel pipe. Preparation of detailed pipe shop fabrication drawings should be made the responsibility of the Contractor subject to the approval of the Contracting Officer.

g. Couplings. A variety of pipe coupling systems are available and may be utilized in discharge piping for a number of ends. Pipe couplings may be employed to facilitate field connections (and disconnection) of pipe segments. For smaller pipes or pipe systems without interior access, couplings allow for preservation of interior pipe coating systems which would otherwise be damaged by welded assembly.

h. Pipe couplings with varying degrees of flexibility are available. Flexible couplings may be utilized to address initial or induced misalignment, provide small intentional changes to pipe alignment, and isolate thrust or vibrational loading along pipe systems. Smaller pipes may employ a grooved coupling connection between pipe sections. Large pipes may utilize a flanged connection with or without a flexible assembly or employ a coupling system designed for plain end pipe.

i. Plain end pipe couplings generally are of the sleeve type, where a pliant gasket material is compressed around the exterior of the pipe ends. Sleeve types generally fall into two arrangements. The compression may be axial to the pipe, where rings compress rubber wedge material between the pipe and a solid outer sleeve. Alternately the sleeve may be segmented, to form a compressive band when tensioned circumferentially over a gasket.

j. Flexible couplings may be used at expansion joints, transitions between foundations, or to otherwise accommodate a small amount of misalignment. Coupling manufacturers should be able to quantify the allowable amount of translational and angular misalignment for their product.

k. Sleeve type couplings tend to be more resistant to static misalignment present at the time they are installed, than misalignment incurred after they have been tightened, and may need readjustment if substantial movement occurs. Pipe end should also not be out of round and mismatched pipe ends can lead to problems sealing at the coupling. One means of ensuring matched ends is to field cut expansion joints in pipe after it has been set in the field. It should be noted that coupling manufactures' requirements for plain end pipe geometry tolerances may be substantially more restrictive than typical requirements for piping otherwise specified.

l. When couplings are used, this discrepancy should be addressed in the project specifications. The compression rings of axial type couplings have a tendency to force the pipe round making them slightly less susceptible to this than split sleeve type couplings. Weld beads or other irregularities should be avoided at coupling locations. Some manufactures of sleeve type couplings indicate that one of the compression rings may be welded in place. This is not recommended as it may complicate disassembly for future adjustment or replacement.

m. Split sleeve type couplings tend to be more easily installed for retrofits or quick field changes. Couplings which have integral pipe flanges generally are less prone to leak as the result of static or dynamic misalignments.

n. Flanged couplings will however induce a residual load on the pipe based on the deflection of the coupling. Restraint lugs should be used with flexible couplings to limit the maxim range of movement allowed. Restraint lugs may not be necessary for flanged couplings based on the manufacturer's recommendations and loading. When buried in protective works, flange type couplings are recommended if the designer cannot verify that expected pipe settlement will not induce misalignments beyond the manufacturer's recommendations.

8.6 Material. Material selection is also outlined in EM 1110-2-2902 and any selection of discharge piping needs to follow the requirements in EM 1110-2-2902.

a. In general, discharge piping should be constructed of steel or ductile iron although high-density polyethylene (HDPE) piping is allowed and may provide some advantages for conduit over levee sections where significant settlement is expected. The feasibility of HDPE should be evaluated during the design phase.

b. Exposed steel piping inside of stations may be flanged or flexible coupling connected. Whereas ductile iron pipe should be fitted with mechanical joints or flanged. Steel pipe 6 inch (150mm) and larger should conform to AWWA C200 and ductile iron pipe should conform to AWWA C151.

c. All discharge line pipe should be protected on the inside with a smooth coating. Buried pipe should also be provided with an outer protective coal-tar coating and possibly wrapping. Shop coatings should be used to the maximum extent possible due to the better quality control.

d. Flanges should conform to AWWA specifications for the pressure rating required. The applicable AWWA standards are listed in Appendix A. Valves should be selected that will be easily maintained. Unless larger than 1,200 millimeters (48 inches), gate and butterfly type valves are preferred. Gate valves with cast iron bodies should be bronze fitted. Butterfly valves should be rubber seated. The type of valve operator, either electric or manual, is the designer's choice based on site-specific requirements, e.g., accessibility, frequency of use, and anticipated loads.

e. HDPE Pipe. EM 1110-2-2902 provides more discussion on the use of HDPE. High density polyethylene pipe has been used extensively in water distribution systems and is available in both ductile iron pipe and iron pipe sizes. An example of HDPE for pump discharge is shown in Figure 8.6.

(1) The flexibility of HDPE enables it to accommodate significant settlement and deflection without the need for flexible couplings. This has made it favorable for use in quickly installing discharge lines for temporary pumps on grade.

(2) HDPE pipe should be connected the pump system with fused mechanical adapters. Dimension ratio and resin number (PE3608, PE4710, etc.) should be specified for a given design. HDPE piping generally does not have corrosion issues but may require more protection from physical damage. Surface scratches can significantly decrease working pressures, and particular care should be taken in selection of bedding material when installing HDPE pipe.

Figure 8.6. HDPE Discharge Pipe Installation, East Ditch Station North Dakota

f. Steel Pipe. Steel pipe provides a strong and versatile option for discharge piping offering welded, flanged, or coupled pipe connections. A variety of coating systems are available. Liquid epoxy coating systems conforming to AWWA C210 or Polyurethane Coatings conforming to AWWA C222 are appropriate for exposed steel pipe. On buried steel pipe, interior cement-mortar protective lining conforming to AWWA C205 and exterior coal tar protective coatings conforming to AWWA C203 have proved effective. Steel pipe 150mm (6 in) and larger should be designed using AWWA C200.

g. Ductile Iron Pipe. Ductile Iron Pipe inside the pump station should be flanged. Mechanical joints should be utilized outside the station. AWWA Manual M41Ductile-Iron Pipe and Fittings is recommended for the design of ductile-iron pipe and fittings. For pump stations constructed outside the United States it may be necessary to source ductile iron piping conforming to International Organization for Standardization standard ISO 2531. It should be noted that the standardized dimensions are of ISO 2531 and AWWA C151 are mutually incompatible.

Chapter 9
Pump and Station Hydraulic Tests

9.1 General.

a. The performing of hydraulic tests for both station and pump designs are not only necessary to confirm that they will perform the hydraulic action needed but will be performed it in a manner that is not detrimental to the life of the equipment.

b. This chapter discusses the general testing performed in connection with new station builds, as well as recommendations for evaluating hydraulic modifications of existing stations and equipment. Chapter 10 of this EM provides further detail on USACE preferred practices concerning commissioning. Model testing, factory testing, field performance testing all should connect and correlate for confidence in the design to address unit and station operation during both event conditions and any associated maintenance events such as periodic exercising.

c. Two types of tests are generally performed in connection with a pumping station and its pumping equipment before the station is built. One type are the tests ran on pumps, either full size or model, to determine their performance and to demonstrate that the performance of the pump complies with specification requirements. The second type are physical hydraulic model tests of the pumping station substructure may also be conducted to assess its hydraulic performance for both event conditions and any associated maintenance events such as periodic exercising.

d. For modifications to existing station and equipment, an assessment will need to be made to determine what level of test and evaluation is needed to reduce the risk of performance issues or reduction in component life. The more significant the modification, the higher likelihood that a hydraulic test should be performed. If there are any significant concerns as to whether or not a modification changes the performance of a station or its equipment, then some form of hydraulic testing should be performed. If there are changes to pump design, or significant changes to the flow approach of the station, the intakes of the pumps, or the discharges of the pumps, hydraulic test should be performed.

e. Other tests and evaluation tools may be used to augment, and not replace, parts of the overall pump or station hydraulic testing. These may be used to focus evaluation on a certain aspect of the pump or stations, such as performing physical model testing of just a pump intake or just the discharge. They may also be used to evaluate the viability of design options in order to reduce the variations of design approaches that will be physical model tested, saving schedule and cost.

f. CFD is an ever-advancing analysis tool, which given the proper model indexing, operator skill level, and physical confirmation data can be advantageous to guide design approaches and reduce risk of adverse operational conditions. CFD is discussed further in this chapter including the risks and limitations associated with the inclusion CFD in a project’s modeling and test approach. Overall, clear requirements for correlation between tests and actual conditions is necessary in order to obtain accurate results.

g. Initial design tests themselves will not address all risks to performance and functional life of a station or pump design. A cohesive evaluation plan that collectively considers and coordinates analysis, controlled development testing, factory testing, and field testing should be generated to properly reduce risk.

h. In addition to the requirements and recommendations below, ANSI/HI 14.6 "Rotodynamic Pumps for Hydraulic Performance Acceptance Tests" should be followed for most pumps utilized in USACE pump stations except submersible pumps, for which ANSI/HI 11.6 "Rotodynamic Submersible Pumps for Hydraulic Performance, Hydrostatic Pressure, Mechanical, and Electrical Acceptance Tests" would be applicable.

i. ANSI/HI 9.8 "Rotodynamic Pumps for Pump Intake Design" includes further details on the necessity of physical model testing, recommended model characteristics, and both categorization and recommended acceptance criteria for model results.

9.2 Pump Tests.

a. General. The pump performance tests are generally conducted at the pump manufacturer's facility, where the pump can be evaluated in a controlled environment but can be performed at a separate facility.

b. Field testing to prove the pump's full range of performance at the completed station is more difficult and costly if not impossible in many cases due to common limitations in creating and sustaining controlled flow conditions in the field.

c. All pumps, especially custom designed, should be factory tested to determine their capacity, total head, efficiency, and HP requirements. Pumps normally should also have a cavitation test performed. This test is usually performed on a model and pump manufacturers will likely already have this data available. Baseline model testing details and parameters can be found in HI Standards. Uniqueness vs equivalence of design should guide the designer to level of modeling needed, and the level of complexity necessary for equivalency evaluation.

d. Description. A pump test consists of determining the total head, efficiency, and brake HP for a range of capacities. Factory pump tests are either performed on full-size pumps or performed on a model pump of the full-size pump.

e. If a model pump is used, at a minimum it should be geometrically similar to that of the full-size pump and of the same specific speed. The level of geometric equivalence needed, including acceptable error, should be evaluated prior to issuance of the procurement contract (for Design-Build contract, it must be identified in the RFP). Size of pump, limitations of existing field data on pump design, and criticality of pump performance are directly proportional to the level of equivalence.

f. Testing a full-size pump or a model pump of the full-size pump are both acceptable to check the ratings of the pump. However, because of size limitations, most manufacturers limit full size tests to pumps of less than 2 m^3/s (75 cfs) capacity. The performance factors measured during the testing includes capacity, pressure head, horsepower, and suction pressure when cavitation performance is to be determined.

g. All testing should be witnessed by the District office design personnel performing the station design, including factory pump tests. In some cases, this level of oversight will require foreign travel, which can present complications. It may be necessary to contract with an independent entity to oversee the testing. Alternative means to provide the oversight should be addressed early in the procurement process.

h. Evaluating the dimensions of the model and prototype impellers should be made by using drawings, measurements, and scaling factors. Some suppliers will consider their impeller design to be propriety. The government should be sensitive to this situation but must address homology verification requirements in the procurement contract.

i. Key dimensional parameters of the impeller must but identified prior to the testing of any models. Those parameters will then not only be verified on the model(s) impellers (pre and post testing) but will need to become critical dimensions/features on the final impellers with inspection points during manufacturing. As detailed in HI standards, the impeller model minimum equivalence to the actual impeller should be Froude Number Equivalence, where the Froude Number for Model divided by the Froude Number for Actual equals 1.

j. Further Evaluation Testing of Specific Parts of the Pump. To further reduce the risk of performance issues, it may be advantageous to model and test sections of the complete pump design. Such testing can allow further detailed testing and evaluation and can also allow for testing of a closer to a 1:1 scale of model versus actual. These tests are commonly a pump intake model testing, pump discharge model testing, back-flow prevention including siphon breaker testing, and vacuum priming, as identified in Chapter 4.

k. Like with the full pump model testing and station model testing, it is critical not only have geometric equivalence, but to also have specific performance points that can verify equivalence in order to reduce the risk of discontinuity between the model testing and the actual fielded units.

l. Performance tests. All pumps for flood-control pumping stations should have their performance verified by tests. For installation of identical pumps in a station, only one of the pumps needs to be performance tested in the following manner. Tests on similar pumps used for another station will not be acceptable as equivalent tests.

(1) The test setup should permit, and the specifications require, the pump to be tested over a range of heads starting at least 600 millimeters (2 feet) greater than the highest total head requirement or at shutoff and extending down to the lowest head permitted by the test setup. The test should, if an unstable range ("dog leg" in the head curve) exists. Sufficient test points should be run to adequately define the unstable range. This allows the pump manufacturer to demonstrate that their pump does not operate in the unstable range.

(2) The lowest head tested should be at least equal to the total head that occurs for 95 percent of the operation time during low head pumping conditions. For pumps with capacities greater than 11 m^3/s (400 cfs), the model tests should be required to cover the complete head range required by the specifications including down to the lowest total head specified. All performance tests should be run at the same head at which the pumps will operate during actual duty. The readings of capacity and brake HP along with the total head will be used to determine the pump efficiency.

(3) For model tests, no correction factor for efficiency due to size differences will be allowed. Tests will be performed at water levels similar to that which will occur during actual operating conditions. An actual scale model of the station's inlet and discharge systems is not warranted except for pumps over 14 m^3/s (500 cfs). This requirement should also be used when the sump is not designed by the Government and is a part of the pump contract or has some complicated flow passage which has not had a sump model test.

(4) The pump test is used to ascertain the performance of the pumps, not how it reacts in the prototype sump except in the cases listed below. It is expected that the factory sump would be free of vortexes and adverse flows so that good results are obtained.

(5) Manufacturers are responsible for furnishing a pump that conforms to the specifications and meets the performance in the sump to be provided by the Government. The pump manufacturer should be held responsible for poor sump design, evidenced by vortices and bad flow conditions within the sump, when the contract specifications require the sump to be designed by the pump manufacturer.

(6) Except for this special case, the pump manufacturer warrants performance of the pumps only, not the sump, and the activity within the sump would be the responsibility of the Government. Duplicate model pump sumps should include the sump from the inside of the trash rack. Any pump using a FSI should be tested with this FSI. Vertical pumps should be tested only in the vertical position.

m. Cavitation tests. Cavitation tests are performed to indicate the operating conditions in which the pump will start to experience cavitation. For purposes of design, it is assumed that cavitation starts when the pump performance starts to decrease as the effective sump level is reduced.

(1) The inception of cavitation definition has not been agreed upon by all the pump suppliers and users. A typical pump test consists of operating the pump at a fixed capacity while reducing the pressure on the suction side of the pump. As the suction pressure is reduced, a point is reached where a plot of the head-capacity curves deviates from a straight line.

(2) The USACE specifies the start of cavitation at a point where the curve starts to deviate from the straight line. Others use as the start of cavitation, a point where a 1 or 3 percent deviation in performance from the straight line occurs. Submergence requirements, as used in this manual, are based on the USACE criterion of zero deviations from the straight line portion. In most cases, some cavitation has already started at either point; therefore, a design allowance of extra submergence should be provided in addition to that indicated by the tests results.

(3) The submergence allowance is based on the estimated number of operating hours expected annually. The amounts of allowance are indicated in Appendix C. In all cases, the cavitation tests should be performed in a test setup that uses a variation of water levels on the suction side of the pump. For Cavitation Testing Submersible Pumps ANSI/HI 11.6 should be utilized as a guide for the test set-ups and evaluations, but with the more stringent USACE criteria for cavitation and additional submergence allowance stated above.

n. Field testing of pumps. Each situation will be unique for the ability to perform field testing of pumps. The purpose of this testing is to not only further confirm that the pumps will operate as designed, but to have physical verification that both the manufacturing and field assembly (including proper alignment) of each unit has yielded a viable system providing confidence to both USACE, any future operator and the public.

(1) The testing should include a run-in wet test (unit conveying water) to evaluate performance aspects of the pump the associated support systems, including but not limited to bearing temperatures, vibration and noise levels, power draw, start-up and shutdown timing and control events, etc. Testing of the pumps running in the dry (without the conveyance of water) prior to the wet testing should be considered for it can provide further confidence in the cooling system and pump operation without the water flow to mask or dampen early warning signs.

(2) The field testing should include operating the pumps in conditions that both verify each pump to its performance curve and their interaction with the other pumps of the station. Due to their criticality, field testing of Pump Reverse Rotation Protection, Back-Flow prevention and Vacuum Priming, as identified in Chapter 4, should be field tested in a manner that correlates directly with any model testing to further confidence in these aspects of the design.

(3) Chapter 10 of this manual provides additional detail on field testing of pumps. CAUTION: The following conditions should be considered before relying only on field testing: 1) The ability to properly instrument the test set-up in the field; 2) The availability of controlled conditions, especially the availability of water; 3) Limitation of access for visual examination. It is highly recommended where possible to perform model testing to fully examine a condition or

design in a controlled testing environment, and then use field testing for specific conditions that are available in the field in order to validate the model testing results.

o. Data monitoring and recording. The amount and fidelity of data acquisition during testing is dependent on the complexity of the model being tested and how accurate the data is needed to be for comparison between performance parameters and other models.

(1) In some cases the use of monometers connected to only a couple locations from intake to discharge is adequate. But in others, utilization of continuous data monitoring is necessary. In a case where there is a separation of components into various sub-models there is a need for indexing points to allow for correlation.

(2) Properly used data acquisition and recording will allow for less error in comparison of data, as well as connecting/overlaying various data by time. In addition, cases where fluctuations in flow or pressure will impact analog measuring devices, such as manometers, a digital data acquisition system can be used to limit the impact by either filtering or data adjustment. There are some variations induced by the test set-up that may need to be taken into account.

(3) Since most testing stands will need to have a system that inputs flow, there is always a risk of the induction of error or interference from this external system. The test stand set-up should be examined for proper dampening or isolation of any interference. If there is any potential for variation caused by the test stand input flows, then it is recommended to instrument the test stand to determine the interference.

(4) With this information, the designer can determine whether or not the test stand condition is causing interference, if the interference is at a level of concern for the validity of the test results, or if an adjustment of the stand or data is necessary. An example of this is including instrumenting between the intake reservoir and the pump intake in order to isolate actual pump condition from test stand supply pump’s pressure and flow fluctuations.

p. Vibration assessment and monitoring. As part of pump field testing, an assessment of each pump and supporting system should have a vibration assessment performed. The assessment should not only include evaluation in simulated event conditions but also associated maintenance events such as periodic exercising in order to aid future evaluation and trouble-shooting events.

(1) Consult the following for applicable requirements and recommendations for the testing and evaluation of the test results: ANSI/HI 9.6.4 “Rotodynamic Pumps for Vibration Measurements and Allowable Values.”: ANSI/HI 11.6 “Rotodynamic Submersible Pumps for Hydraulic Performance, Hydrostatic Pressure, Mechanical, and Electrical Acceptance Test”; Applicable Parts of ISO 101816 “Mechanical Vibration – Evaluation of Machine Vibration by Measurements on Non-Rotating Parts”.

(2) The sampling points should be well documented and easily repeatable in order to correlate any follow-up assessments, including the implementation of periodic or permanent monitoring elements. Additional guidelines are provided in ANSI/HI 9.6.5 “Rotodynamic Pumps – Guideline for Condition Monitoring”.

q. Dry pump testing. The test parameters for dry testing a pump are detailed in Chapter 10. A dry pump testing is where a fully field assembled pump is set to run in the dry, freely spinning without water.

(1) A dry run test is free of hydrodynamic effects and the pump will have vibration characteristics caused by mechanical imbalance and misalignment, with levels corresponding an established vibration chart. The dry test allows the unbalance and misalignment to be assessed and dealt with (if needed) prior to the pump being placed fully watered and operational.

(2) Not all pump designs allow for running a pump in the dry, the bearing materials and lubricating system must be capable of operation in the dry, as detailed in Chapter 4. Requiring the pump to be designed to run dry is an essential requirement that must be detailed in the contract specification for the pump designer and supplier.

9.3 Station Model Tests.

a. General. A decision should be made on the requirement for model testing during the General Design Memorandum stage so that the results of any testing are available during the design of the station and the process of obtaining a test facility can be initiated.

(1) Chapter 6, “Pump Station Geometry” details the USACE guidance and industry recommendations for the decision. ERDC’s Coastal and Hydraulics Laboratory is the USACE source for hydraulic model tests of pumping station sumps and discharge systems, and stations with unique or unusual layouts.

(2) Other non-USACE facilities exist such as Alden Research Laboratories, Utah State, St Anthony Labs, Clemson University, and Northwest Hydraulics Consultants. The procedure in ER 1110-2-1403 should be followed when requesting model tests and outlines the approval procedure for contracting with a non-USACE facility.

(3) It is recommended that the model(s) should not only simulate and evaluate the operational conditions but also periodic exercising conditions, especially if that station near navigable waterways. Check circulation conditions and if there are any limitations for number, which pumps can be exercised or if channel protection improvements are need (rip rap issues vs modifying channel vs extending lining/protection). Such an approach increases the initial design cost but can greatly reduce unplanned construction costs to mitigate, and operational limitations for both maintenance and events.

b. Sump or Pump Intake Model Tests. The approach flow used in model and factory testing has a direct influence on the accuracy of the testing results. It is best to start the model boundaries at a location of uniform flow or less complex flow in order to reduce model induced error in the results.

(1) The model should include sufficient distance upstream of the station to a location where changes in geometry will not affect flow conditions in the sump and provide minimal pre-swirl from the test equipment's components.

(2) For a station intake test, it is critical to have representative flow conditions (velocities and patterns) generated at the starting boundaries of models. Correlating analytical modeling and field data with the model initial flow conditions will reduce error between the model and actual field conditions.

(3) As much as possible avoid extrapolation of data to connect model and field conditions to reduce the risk of error in the test results. The actual prototype-to-model ratio is usually determined by the testing agency, but it should not be so large that adverse conditions cannot be readily observed. The model should be sized to ensure that the Reynolds number in the model pump column is equal to or exceeds a value of 1×10^5. Reynolds number is defined by the following equation:

$$R = dV/r \qquad \text{(Equation 9.1)}$$

where

R = Reynolds number
d = column diameter
V = velocity
r = viscosity of water

(4) Further physical model similitude evaluation can be accomplished with similitude considerations of ANSI/HI 9.8 for a Reynolds number and Weber number based on the pump bell entrance, or equivalent diameter for noncircular openings.

(5) The primary purpose for performing a model test of a pumping station sump is to develop a sump design that is free of adverse flow distribution to the pump. Any contract or procurement documents for the pumping station and pumps should contain clear performance requirements concerning what is unacceptable flow and detail the limitations for options in correcting adverse flow conditions.

(6) Optimal flow into a pump impeller should be uniform without any swirl and have a steady, evenly distributed flow across the impeller entrance. Adverse hydraulic conditions that can affect pump performance include free and subsurface vortices, swirl approaching the pump

impeller, flow separation at the pump bell, and a non-uniform axial velocity distribution at the suction should be avoided.

(7) However, it is usually not possible to obtain the optimal flow conditions without considerable added expense. Acceptable pump operation will occur when a deviation in the ratio of the average measured velocity to the average computed velocity is 10 percent or less and when the swirl angle is 3 degrees or less. Swirl in the pump column is indicated by a vortimeter (freewheeling propeller with zero pitch blade) located inside the column.

(8) Swirl angle is defined as the arc tangent of the ratio of the blade speed at the tip of the vortimeter blade to the average velocity for the cross section of the pump column. There should not be any vortex formations allowing entrance of air into the pump. ANSI/HI 9.8 details requirements and recommendation on physical model studies of intake structures and pump suction piping, including classification of free surface and subsurface vortices, and test acceptance criteria.

(9) If any conditions yield model test results contrary to the acceptance criteria, effort must be made for the aspects causing those conditions to be designed out. Only in special cases should mitigation devises be utilized limit the impact of these contrary results on the pumps and its associated support systems. The mitigation device type, location, and materials of construction should take into life cycle costs to monitor and maintain and provide the least maintenance complexity and failure modes possible.

c. Discharge model tests. These tests are performed to evaluate the performance of a discharge system. Usually two types of systems are investigated, discharges which form a siphon and/or through the protection discharges for large stations where the friction head loss would be a substantial portion of the total head of the pump.

(1) Siphon tests. The siphon tests are run to determine that a siphon will prime the system in the required time. This test is recommended when the down leg of the siphon system is long or it contains irregular flow lines and for pumps of 20 m^3/s (750 cfs) or greater having a siphon built into the station structure.

(2) Discharge tests. A head loss test should be considered only for pump discharges with capacities of 20 m^3/s (750 cfs) or greater and where the accuracy deviation for estimating the total head exceeds 20 percent of the total head. Other considerations would be the sizing of the pump and its driver.

(3) In some cases, a safety factor of 10 to 20 percent of the total head may not change the pump unit selection, and therefore the expense of a discharge test may not be warranted. For those stations where the size of the driver is close to its rating, a test may be in order to ensure that the driver would not be overloaded due to error in head determination.

(4) In addition, a discharge test can evaluate the pressures and flow conditions throughout the discharge in order to confirm adequacy of design and sensitivity of construction tolerances. It can identify if additional support features are needed, a common concern for the negative pressure regions of a siphon discharge, or if flow straitening measures are needed to address flow fluctuations that could lead to material fatigue or adverse vibration.

(5) Other tests. Additional tests may also be required to fully prove the station acceptable. These could include energy dissipation tests of a saxophone outlet and a stilling basin or apron. Tests can also be made on models of existing pumping station sumps where operating difficulties have been experienced.

(6) Modifications. Modifications made to the intakes and discharges (such as vortex breaker bars and flow vanes) that are critical to preventing detrimental operational conditions for the pumping equipment should be considered part of the intake or discharge when evaluating design life.

(7) Materials and coatings used, access for inspection and replacement, and overall viability and robustness should be considered during design. If possible, the condition creating the need for the modification should be "designed out", but in some cases either due to cost, schedule or complexity, these modifications are necessary. It critical to design the modifications with lifetime maintenance as a significant parameter.

9.4 Computer Modeling Use and Limitations. Computer modeling, including CFD can be used to simulate and analyze multiple configurations of geometry and input arrangements. It can be performed with minimal time or money to adjust the model when compared to adjusting a physical model.

a. The process can guide the design, and otherwise reduce the amount of iterative physical model testing while increasing the confidence in the station or pump design. However, CFD should only be utilized to augment the physical model testing and must not be a replacement of physical testing of a model or field testing. Like any other computer modeling, the results are only as accurate as skill level of the user and the data used to establish the model.

b. Direct data is needed to validate the computer model. Limitations (accuracy, applicability, and quantity) in the physical data used to validate the model will reduce the accuracy of the CFD models for the conditions being examined. Data from a physical model is less accurate than that of the full-size field data due to the impacts of model scaling and artificial boundary conditions. However, physical models allow conditions where more accurate data can be obtained from multiple locations while the field may limit the locations and fidelity of the data obtained.

c. The user of the CFD modeling program and the user of the results of the modeling must be aware of the limitations and understand that CFD can't fully replace physical modeling without accepting the risk of significant variation between the CFD results and the full station/pump build or system modification. In addition, the less humongous the geometry or condition for which the validation data was generated from to that of the conditions for with the CFD is producing results, the less accurate the CFD results.

d. The user must avoid over extrapolation of the data used to generate the CFD model as well as the results. Such conditions will only lead to further discontinuity between the CFD model and the full build, which increased risk of performance and overall pump and station operation shortfalls.

9.5 Existing Stations and Systems.

a. General. Testing of existing pumping stations and systems generally occurs to evaluate the performance of an aspect the station or pump, either in its existing state or with potential modification. The testing and evaluation detailed above for the new builds should be considered for this existing system testing.

b. In addition to funding and schedule, the approach taken for testing will be dependent on what existing information is available on the station and its equipment. A gathering of drawings of the station and equipment, O&M manuals and previous factory and field testing should occur at the onset of the plan development.

c. The station and equipment will also need to be examined to assess how much overtime aspects might have changed. Both the aging of the equipment as well as any changes in with the intake and discharge (such as silt accumulation) should be assessed for inclusion in the test plan. As with the new build testing, oversimplification, limited testing conditions, and high equivalency error will increase risk of having different performance than those produced by the testing.

d. Modifications. Modifications to existing stations range from minor changes of specific components, to major changes such a installing a new pump design, changing the station intake approach, changing the pump discharge design, or changing the pump intake.

e. Caution should be taken during the initial planning and evaluation period for the project to avoid over limitation of the scope of any model or field testing, or increased simplification of the evaluation to avoid a performance shortfall.

f. Similar to the new build testing of parts of a design, there will be a need to have the testing index with field data or previous perform data in order to validate the testing. If recent test data to confirm the performance of the stations or pump is not available, then an evaluation should be made of name plate verses actual for the performance of parts such as motors and impellers before utilizing older data. Not performing a proper assessment of the current equipment will increase the likelihood of the modification having an unknown adverse effect in the field.

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Chapter 10
Testing and Commissioning

10.1 General. The commissioning of a pump station involves bringing a recently constructed station into proper working order.

a. Principally it involves the integration of all component mechanisms into a single system through adjustment of settings and other operating parameters. It also involves operational testing to ensure the station is free of defects, either inherent to the design or inadvertently incorporated during facility construction or manufacture of equipment. It is not always possible to foresee all issues during the design stage, and alterations during construction may produce unintended consequences.

b. Some level of troubleshooting and adjustment should not be unexpected during the formal commissioning stage at completion of construction. This chapter will seek to specify preferred practices and identify areas of specific attention such that through thoughtful diligence during all stages of project development issues can be identified and resolved at the earliest point practical.

c. In keeping with this intent, commissioning should not be viewed as strictly taking place at the end of construction, but as a process integral to both the design and construction stages of a project as well as the testing and acceptance period.

10.2 Commissioning During Design. Two key activities take place during the design phase in regard to the commissioning of the station. First, all the functions of a station and their interactions with one another must be planned out by the design team. Second, all testing and commissioning requirements for the project are specified during this stage. The former tends to be the focus of designers, where-as the latter often is enacted as the inclusion of the standard language in the guide specifications.

a. Guide specifications provide a good starting point, however adequate attention should be spent developing practical testing and commissioning requirements to efficiently verify all project functions and design intents are achieved. Even the best design will not succeed if poorly executed with insufficient quality assurance requirements. Alternately, overly burdensome testing regimes may offset economic savings from time spent diligently optimizing project features.

b. Holistic Design. The design of individual features composing a pump station are the focus of various other portions of this manual. Many of the issues that arise during the commissioning process occur at points of interaction between systems or across discipline lines. Most designers, tradesmen, and fabricators have some level of competency in their specific area of focus. This does not ensure that all their efforts will seamlessly integrate.

c. Good communication will promote continuity of thought and allow for early identification of points of concern for resolution. Beyond preparing the portion of the design for which an individual is responsible, members of the design team should make a reasonable effort of familiarizing themselves with all aspects of the project to ensure the intents and assumptions of other team members are consistent with their own.

d. Similarly, flawless coordination by the prime construction contractor should not be considered automatic and instead should be facilitated by the designer. It is not uncommon for sections of the design documents to be parceled out to individual subcontractors pertinent to their specialization for preparation of bids.

e. This can be problematic, for example, if electrical and control requirements are not properly coordinated with the pump supplier and the wrong size motor starters are furnished. Providing information in a logical place with adequate cross referencing can improve awareness of all parties responsible for the construction of a pump station and reduce the friction and delays which result from poor communication.

f. The exercise of referencing and verifying references can also help ensure that contract documents do not provide inconsistent or conflicting instructions to subcontractors. Such practices should in-turn improve the coordination between constituent components and facilitate the commissioning of the pump station.

g. Factory vs. Field testing. Factory and field testing both play a complementary role in the testing and commissioning process for pump stations.

(1) Factory testing generally occurs much earlier in the construction process and thereby reduces the impact of any remediation necessary in the event of an unsatisfactory test. Factory testing also may benefit from the ability to isolate systems, closely monitor under controlled conditions, and facilitate thorough inspection by factory staff. Factory tests also benefit from a clear delineation of responsible party, and a vested interest by both the construction contractor and the factory in not releasing a defective item which later may prove to be a liability.

(2) Late in a project when field testing typically occurs, the contractor’s quality control team may apply fewer resources to discovering problems in installed equipment, and disputes over responsibility for problems may arise between the installer and supplier.

(3) Accordingly, there is a definite value to factory testing, and it should be utilized where appropriate and as closely matching field conditions as practical. This includes such factors as environmental conditions, and machinery duty cycle.

(4) Field testing ensures both that the individual equipment has remained defect free, and that the design and installation are both performing as intended. In addition to testing individual components, testing in situ generally allows for full system tests of the entire station

functioning together. This exercise is essential to the fine tuning and adjustment central to the commissioning process.

h.   Pump testing. Quality of inspection, testing and installation will determine the success or failure of the pumps.

(1)   Factory testing of large fabricated pumps usually is limited to prototype or model testing of the design to establish pump performance although this depends on the pump manufacturer. Some of the larger pump manufacturers are capable of testing larger pumps at their facilities.

(2)   UFGS 35 45 01 includes tailoring options for when to require model or prototype tests or when to give the Contractor an option. Due to the length of the pump column, the manufacturer may elect to only test the bowl assembly. Full scale model testing of pumps up to 48” or larger may be available depending upon the vender’s test facility.

(3)   When pump size becomes prohibitively large, scaled model testing should be used to establish pump performance curves. If the station has a non-conventional intake arrangement, or if the vendor is providing proprietary or otherwise non-standard geometries the specifications should call for a model study including intake (and possibly discharge) designs to determine if the pump station performance meets contract requirements.

(4)   Additional factory testing includes fit up assembly and balancing of components. For smaller manufactured pump units, full factory testing of each individual pump unit should be provided by the pump manufacturer.

(5)   In addition to factory testing, all pumps should be field tested to ensure correct installation. The first stage of field testing is generally a 4-hour dry test. One of the purposes of the dry testing is to establish baseline bearing performance and vibration levels in the absence of hydrodynamic effects. This test may exceed 4 hours if the bearing temperatures do not reach a steady state during that period.

(6)   If the pump utilizes medium cooled bearings, temporary measures may need to be constructed to provide cooling water to the bearings during the dry testing. Following dry testing, typically once the site has been re-watered, wet testing occurs to evaluate the pump’s operation under normal priming and pumping conditions. When planning station commissioning activities, it is important to ensuring the availability of water when developing testing requirements for field testing.

(7)   Back-flowing through gravity drainage structures or adjacent pumps may be necessary to provide water for the full duration of the wet testing. Additionally, a cofferdam on the discharge may be necessary to simulate a design point if it includes unusual conditions, such as pumping against the elevated water levels of a storm surge.

(8) Wet testing evaluations typically involve vibration monitoring, flow observations for eddies etc., and may also include flow-meter testing, either on the discharge system or in the approach channel, to evaluate pumping capacity. Another important consideration when developing field testing plans is to ensure correct control logic and functional system testing with all ancillary systems operating together.

i. Prime Mover. Electric motors and engines should be factory load tested including a functional test of shutdowns or alarms/monitors, sound level monitoring, temperature readings or thermal imaging. Factory testing of motors should include megger testing. Prime Movers should be field tested in conjunction with pump testing. Field testing of the pump is also typically when the control and supports systems for the pump, gear reducer and prime mover are tested together as a system.

j. Gear Reducers. The designer should specify whether factory gear box testing should be loaded or unloaded (spin) testing. Loaded factory testing is preferred but may be prohibitively expensive for larger gear reducers. Factory testing should include vibration and temperature monitoring, oil inspection, functional test of shutdowns or alarms/monitors, sound level measurements, and a factory inspection of gear faces upon completion. Gear reducers should be field tested in conjunction with pump testing.

k. Lubrication systems. Manufactured components of the lubrication system should have documentation of any factory testing or inspections, provided prior to install and system field testing. In addition to functional testing of the lubrication system, adjustment of settings for pressures, flow rates, and lubrication intervals should be undertaken during the commissioning process to maintain optimum bearing temperatures without dispensing excess lubricant. Prior to testing, any fabricated piping systems should also be cleaned and flushed to ensure they are free of debris and welding slag.

l. Equipment cooling systems. Cooling system should be checked for functionality prior to and during field testing. Careful inspection for leaks, and fluid level and condition should be monitored during commissioning. Validating correct fluid levels in conjunction with expansion tank capacities often must be finalized during the commissioning process. Prior to testing, any fabricated piping systems should also be cleaned and flushed to ensure they are free of debris and welding slag.

m. Pump control system. During field testing functional testing of all pump control system actions and sequences should be checked to a degree which is feasible. Operations which either cannot be achieved, or in doing so would produce a hazard or damage the equipment, should be simulated to the extent that the required control system function is enacted.

n. Valves. Commissioning of valves includes functional testing of valves, any actuators, monitors and limit switches as well as checking valves for leakage.

o. Fuel system. Commissioning of the fuel system involves establishing logic of operation of floats alarms, shut-offs, level monitoring and other sensing and control mechanism, as well as validating set points and their repeatability.

(1) It is not unlikely that indicated tank levels will need to be adjusted slightly from prescribed to account for tank geometry and sensor sensitivity and range. The fuel level at which overflow protection valves actuate, and the level of restriction they apply to flow for instance may vary over a significant range.

(2) Flow rates and shut-off times may also need adjustment to ensure overflow does not occur. Commissioning plan should indicate pneumatic vs hydrostatic leak testing. Hydrostatic testing generally is considered safer in the event of a failure; however, it requires slightly more effort than pneumatic to dry the piping following testing.

(3) Commissioning plan should also include test ports and low point drains to facilitate testing and minimize isolation work. Prior to testing, any fabricated piping systems should also be cleaned and flushed to ensure they are free of debris and welding slag. In addition to flushing pickling of uncoated pipe interiors should be completed prior to functional testing.

p. Generators. Generators should be factory load tested including a functional test of shutdowns or alarms/monitors, sound level monitoring, temperature readings or thermal imaging. Factory testing of generators should include megger testing. Generators should be field tested in conjunction with pump testing. In addition to functional testing, generator loading under actual operating conditions should be evaluated during commissioning. Since under-loading diesel generators may result in wet stacking, determination for need of a load bank should be assessed during commissioning.

q. HVAC. Functional testing of all HVAC components, optimization of system parameters, and all requirements prescribed in the testing and balancing requirements of the specifications should be performed during commissioning.

r. Plumbing. Commissioning of the plumbing system should involve inspection and test of function for all standard components. Large specialty items such as booster pumps or oil water separators may require additional attention or factory testing. All system component settings such as water heater temperature, should be adjusted to optimize performance.

s. Fire Protection. Commissioning of the fire protection system should be coordinated by the designated fire protection engineer/specialist in conjunction with the requirements of the adjudicating fire marshal or authority having jurisdiction. Commissioning of the fire protection system should begin early in the construction process to ensure all approvals are obtained in a timely manner and that the job site has adequate fire protection, such as available hydrant flows throughout the construction process.

10.3 Testing and Commissioning During Construction. Active engagement by the engineering support team during construction facilitates the formal commissioning at completion of a project.

a. Principle tasks at this stage contributing to a successful commissioning are review of construction submittals, responding to contractor requests for information (RFI), site visits, witnessing factory testing, and preliminary steps for preparation of the operations and maintenance manual. The inspector or inspecting engineer should read and understand the contract plans and specifications (technical and nontechnical). Referenced industry standards should be obtained and pertinent sections should be read.

b. Submittals and RFIs. It is essential that the design engineer be involved in all phases of construction. The review of pump equipment shop drawings are the best opportunity for the design engineer to ensure contract requirements will be met. It also is the best and least costly time to implement any changes to the plans or specifications required due to design deficiencies, equipment changes, or to implement design improvements.

c. As well as reviewing to ensure submittals satisfy contractual requirements for specific items, reviewers should also be attentive to the compatibility with regard to related components, to ensure functional operation with the design intent. Dimensional information from shop drawings and product cut sheets should be reviewed to ensure the installation will function and provide access as envisioned during design.

d. In addition to procurement and fabrication submittals, informational submittals covering manufacturers' O&M instructions will provide additional operating requirements on equipment which must be vetted for consistency with project operation.

e. Shop drawings should be reviewed by the design engineer to ensure contract specification requirements for fabrication, equipment, materials and finishes are met. They should be detailed and include all information as described in the pertinent UFGS sections and should include requirements for manufacturing and assembly drawings that ensure that the pump is being built to the contract requirements, industry standards, and good practice.

f. The installing contractor and pump manufacturer's representative should have approved shop drawings on-site. It should also be verified that installation instructions including weights of pump components (shaft, pump impeller, impeller and diffuser bowls, columns, shaft enclosing tubes, bearings, etc.), required rigging equipment (crane, straps, chains, wire cables, etc.) and required drawings are on-site.

g. Submittals from the pump manufacturer should include requirements to have a two-plane dynamic balancing of impeller at rated operating speed and at 110% of that speed.

h. The pump manufacturer should provide shipping information on how to remove and install the pump. They should also provide information on supporting or bracing of the pump enclosing tube, especially at bearing locations (see Figure 10.1) if being shipped completely assembled and ready for installation at the construction site. This is to ensure that the shaft does not bend and bearings are not damaged.

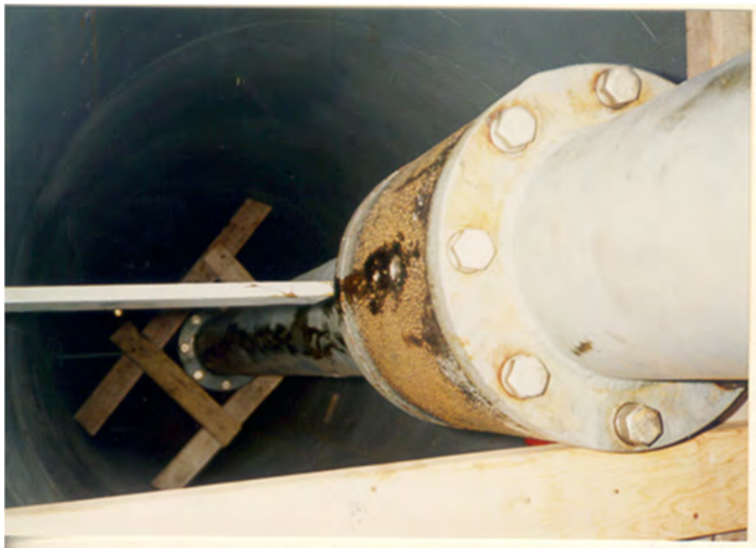

Figure 10.1; Shaft Enclosing Tube Prepared for Shipping
(Note Wood in Background for Support)

i. After reviewing and approving the shop drawings, the next phase is to do a model and/or prototype test for the pumps and factory testing and inspections for other station equipment.

j. Submittals for factory testing plans and test reports are key to the process of commissioning a pump station. On large projects, stipulating the contractor maintain an updated schedule for anticipated testing dates may assist in avoiding conflicts and ensure appropriate government witnesses are available.

k. As construction progresses and the contractor begins integrating systems, questions about design intent, functionality, possible issues or optional ways of implementing items will likely result in contractor RFIs. The RFI response process is often the early stage of working out issues will arise in the commissioning process. Maintaining organized records of RFI resolutions which will likely have an impact on operations and maintenance documentation or as-built drawings is also recommended.

10.4 Site Visits and Factory Testing. Routine site visits during construction generally reduce the number of issues faced during formal commissioning. Insight unique to project designers and the expertise specific to mechanical and electrical disciplines should be complementary to the efforts of the construction inspection team.

a. Good communication should be made with field inspectors, and site visits should be coordinated with the appropriate progress in construction activities. At the start of the site visit, inspectors should be queried for any particular concerns they may have, areas of particular interest to evaluate and the general course of the project. At conclusion of the site visit, a brief discussion with field inspectors of issues noted or possible concerns should aid them in their duties.

b. An informal trip report may also be used to convey this information. Any notes or observations should be documented in a timely manner for future reference. It is also recommended that ample photographs be taken of any items which may be of interest at a later date.

c. It is preferable that factory tests be witnessed by persons involved with the project. Specification test requirements and approved testing plan submittals, however, should be detailed enough to permit any qualified persons from other USACE facilities to perform as the government witness.

d. Datasheets, measurement devices, calibration reports, etc. should all be provided with the test plan prior to testing. Spot check verifications of values being recorded by test personnel should be made as practical at the discretion and judgment of the government witness. At the completion of testing, factory or contractor personnel often present a sign-off sheet for test observers.

e. Clarification or instruction on authorization regarding signature should be resolved with the contracting officer prior to testing. The form should typically just be an acknowledgement that the test was witnessed, and not any specific endorsements of its results or the suitability or fitness of the tested item.

f. Where possible, copies of test reports or notes should be provided at the conclusion of the testing. Where permitted, adequate photographs and/or video recordings of testing should be made. A trip report summarizing test proceedings and noting any observations or concerns should be done and provides additional documentation and record of the testing.

g. Factory Inspection. Large vertical column pumps are complex and built to close tolerances, requiring highly skilled craftsmen (machinists, foundry workers, and welders), castings (impeller), forgings (shaft), and weldments (column).

(1) Each pump is typically built independently, specifically for a special storm water application. Manufactured components should be checked in the shop to ensure that they conform to the pump manufacturer’s shop drawings and contract specification requirements including all dimensions and tolerances.

(2) For example, bearing housings should be spot checked by checking bearing openings with an inside micrometer to ensure components are built to manufacturing drawing specifications and tolerances. Improper clearance between bearing surface and shaft/sleeve could cause bearing failure.

h. The pump manufacturer should provide to the inspector quality assurance documents showing the measurement of critical dimensions (including parallel or perpendicular tolerances). Contract specifications should state that the bearing grooves must not have sharp edges, any sharp edges should be chamfered or removed. This should be inspected to ensure bearings do not have sharp edges. If edges are left sharp, this could lead to premature failure of a pump bearing.

i. Machined surface finishes should be checked against the contract specifications. Recommended finishes are as follows: Bearings and sleeves (32 rms), shafts (32 rms at bearing locations), sleeves at seal locations (16 rms), journals and impeller bowl and flanges (125 rms). Incorrect surface finish could lead to premature bearing failure.

j. Impeller balancing should be government witnessed or quality assurance documentation should be provided to ensure two plane dynamic balancing is accomplished and that weights, if required, are installed outside of water passages and contract requirements.

k. See Figures 10.2 through 10.5 for example of balancing machine and correction information and weight stamp requirement for impeller. Sometimes, it is necessary to remove small amounts of the blade to allow for two plane balancing. This should be avoided if at all possible. But, if it is required, it should be discussed with the pump manufacturer's hydraulic engineer to ensure that it does not affect water hydraulics and performance.

Figure 10.2. Impeller Balancing Machine for Two Plane Balancing

Figure 10.3. Correction Information that is obtained for Two Plane Balancing

Figure 10.4. Weights Welded to Back of Impeller Out of Water Passage for Two Plane Balancing Corrections

Figure 10.5. Pump impeller with weights and keyway (Note Weight Stamper on Impeller

l. The shaft should be spot checked for proper run-out (see Figure 10.6) typically accomplished on a bearing table or in a lathe. This is very important at bearing locations. If run-out is too great, it will lead to premature bearing and pump failure. The shaft and enclosing tube alignment should be checked using laser alignment tools to determine shaft is centered in enclosing tube.

Figure 10.6. Checking Shaft TIR/Runout with Dial Indicator

m. Material specifications should be checked to ensure that they meet contract specifications and manufacturing shop drawings requirements. Castings should have quality assurance documentation and procedures for repair of imperfections.

n. Any welded repair procedures to castings must be approved before repair. See Figures 10.7 through 10.9 for example of procedures for non-destructive testing of impeller for voids and damage areas to castings that could require repair. The pump contractor should have testing done by a qualified inspector to determine areas of concern and provide recommendations for repairs. This needs to be submitted, reviewed and approved before any type of repair is done to castings.

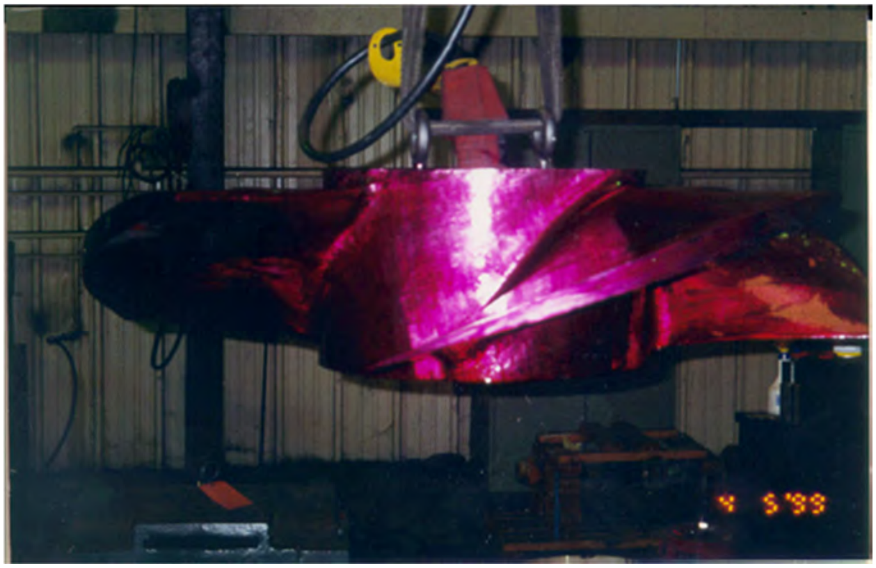

Figure 10.7. 1st Stage Dye Penetrant Non-Destructive Testing of Impeller for Damage to Casting

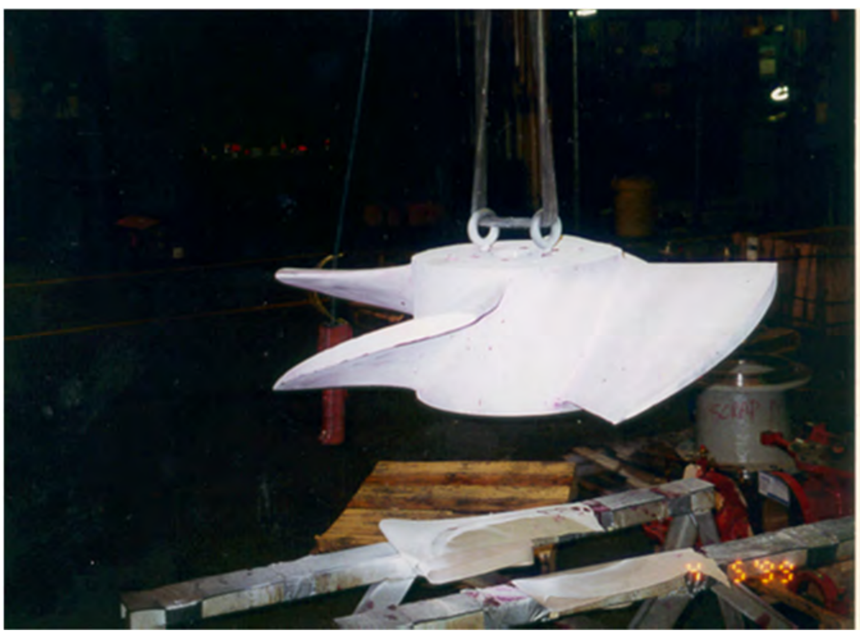

Figure 10.8. Completed Dye Penetrant Test

Figure 10.9. Examination of Potential Areas of Cavities Found During Dye Penetrant Testing

o. Other considerations:

(1) The minimum required flange thicknesses should be verified to meet contract specifications.

(2) The pump enclosing or shaft tube is required to be straight so that the shaft has proper clearance. If the tube is not straight within 0.05 mm (0.002 thousands of an inch), this could lead to premature pump failure.

(3) The alignment of wetted surfaces should be verified to meet contract specifications.

(4) The minimum number and weight of anodes for galvanic protection should be verified.

(5) It should be verified that stainless steel bolts and bronze nuts are being supplied as specified.

(6) Manufacturing details and material for keyways, keys, coupling and split rings should be checked to ensure they fit properly and inspected for defects, such as nicks in a keyway or a loose-fitting key. These defects could cause metal fatigue and break the shaft.

(7) It should be verified that flanges meet requirements of AWWA per contract specifications.

(8) At least one lubrication system should be tested in the factory to ensure that it meets contract requirements for delivery and pressure. It should be verified that the proper type of lubricant is being used, typically extreme pressure NLGI 2 type grease. If it is a water lubricated pump, ensure that proper clearances are obtained for a marine type bearing, and that water is being supplied to the enclosing tube for all bearings.

(9) Paint thickness at key spots should be measured to ensure contract compliance. Minimum paint thickness is typically 16 mils at any point per UFGS 09 97 02 System 6-A-Z (C-200a) coal tar epoxy for example. UFGS 09 97 02 should be revised by the designer to include holiday testing for this system to avoid pinholes that will lead to early corrosion on steel materials.

10.5 Factory Testing Procedures. The pump manufacturer must provide all necessary documents for factory testing procedures, including a diagram or drawing layout of testing facility with all equipment used in testing. If possible, it is recommended the actual supplied pump be factory tested.

a. For any model tests or cavitation tests, this could be either a model test of blade design for cavitation as shown in Figure 10.10 or prototype (first pump) built. Figure 10.10 shows a model factory test indicating cavitation on the blades with use of a strobe light. Often the pump manufacturer will already have cavitation tests done on the pump. Documentation should be provided as required by the pertinent UFGS sections. The designer should review construction submittals of all testing requirements and procedures including checking to ensure that all equipment has up to date calibration certificates.

b. Testing equipment as specified in UFGS should be used. Electronic equipment for flow measurements should be used. The use of weirs to test flow characteristics of pumps should not be allowed. The design engineer should attend factory testing to ensure that there is no instability of pumping equipment as outlined in UFGS for performance and cavitation testing, if required.

c. While doing the performance testing for flow and head, the water should be observed for surface vortices. The inspector should listen using (mechanic's stethoscope or some type of wood or metal rod) for cavitation on pump column (will sound like rocks being thrown through a pipe). If found, discontinue testing and inform factory personnel performing testing to discuss causes and possible solutions (typically with pump manufacturer's hydraulic engineer).

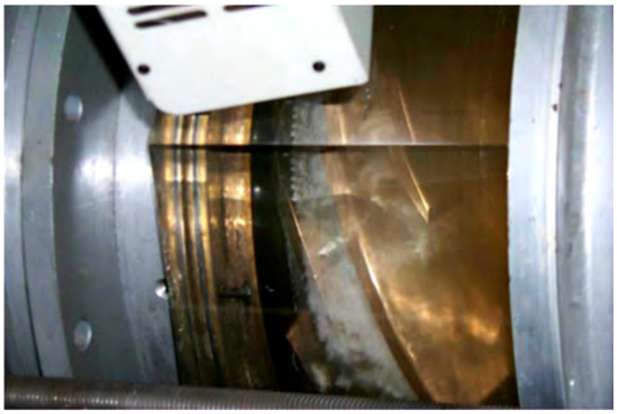

Figure 10.10. Axial/ Mixed Flow Pump Propeller

10.6 Miscellaneous Items Affecting Quality of Construction. The cleanliness of the shop is important to ensure that there is no contamination by sand, silt or foreign particles entering the shaft enclosing tube or bearing housings which can cause bearing failures. The pump manufacturer's assembly personnel should ensure tubes, shafts and insides of bearings are cleaned and free from foreign materials.

a. The design engineer should visit the pump manufacturer's facility to witness assembly and disassembly and also ensure that the pump manufacturer match marks parts of the pump to be field installed at site. This will also provide valuable information in the review of the O&M manuals. It will also facilitate review of field installation forms and ensure that the erection engineer installs per the approved O&M manuals.

b. The design engineer should attend startup/field tests and witness pump manufacturer's erection engineer or representative installing pump and performing vibration testing as required by applicable HI standards and wet testing in conformance to HI standards as they apply to the type of equipment.

c. If the pump cannot be installed in a timely manner when arriving at site, or it is known that the pump will need to be stored at the site specifications should be edited for storage requirements.

10.7 Operation and Maintenance Information. During the construction process the engineering support team should begin assembling O&M information including contractor provided manuals and product cut sheets as well as drafting an overall station sequence of operation.

a. O&M manual preparation should be consistent with ER 1110-2-401, OPERATION, MAINTENANCE, REPAIR, REPLACEMENT, and REHABILITATION MANUAL FOR PROJECTS AND SEPARABLE ELEMENTS MANAGED BY PROJECT SPONSORS.

b. Sufficient completion of O&M manual elements should be made prior to the completion of construction to inform the planning of field testing and commissioning. Specifically, sequences of operation should be defined such that operational testing may demonstrate intended operation.

c. Major maintenance tasks should be identified in order to evaluate if constructed station configuration adequately facilitate execution of those tasks or if additional provisions should be included. Additionally, the period of time between installation of major machinery components and formal turn-over of the station to the party responsible for O&M may require interim maintenance activity by the contractor or another entity.

10.8 Pump and Discharge Field Installation.

a. New or rebuilt vertical column type axial/mixed flow pumps should be installed on a machined soleplate to match the machined surface of bottom of pump baseplate. The pump should be leveled with the use of a machinist level to 0.0002 inches, so it is plumb. The pump discharge should be installed through a block-out in the wall so that it lines up with the pump elbow.

b. Do not allow contractor to use winches or jacking devices to pull the pump to align up with the discharge line. This will cause the pump to be out of plumb and will lead to premature bearing failures due to shaft binding.

c. Block-outs should have a wall plate around the discharge pipe and be grouted in place after the pump elbow and discharge piping has been aligned properly with a required flexible coupling and harness lugs with bolts, see Figure 10.11 for a misalignment of pump elbow to discharge piping and equipment. If a transition piece is required, it needs to be coordinated with the pump manufacturer (recommendation would be no more than 15 degrees of angle based on length of transition).

d. If the pump is assembled on site, all flanges should be ensured to be clean of debris or protection material (such as Cosmoline™ used to prevent flanges from rusting during shipment). Failure to remove material could result in misalignment of flanges in the pump column causing bearing failure.

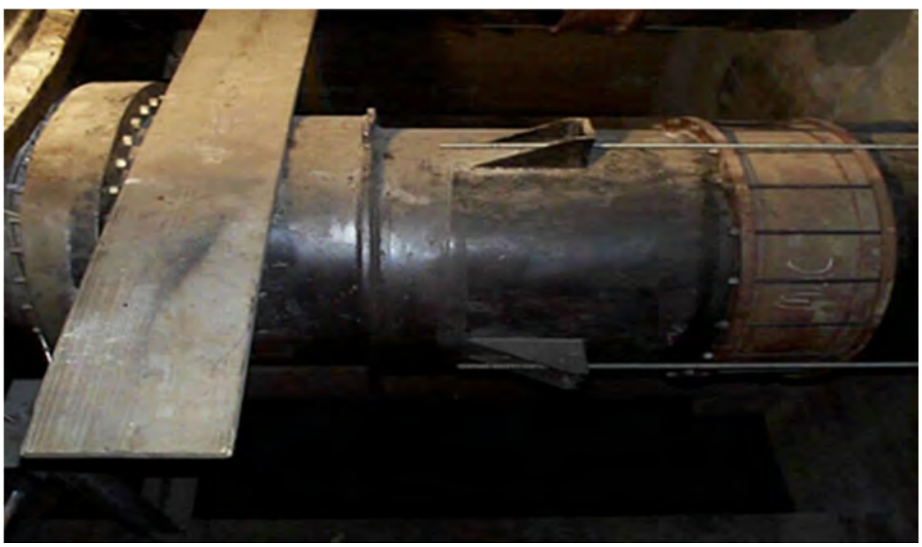

Figure 10.11. Pump Discharge not in line with pipe thru wall, this requires a transition piece to avoid cavitation within the piping

10.9 Formal Commissioning. When station construction progresses to the stage where equipment is being installed and systems are becoming operable the formal process of commissioning may start in earnest.

a. As uncertainties in the construction process and schedule diminish, the construction party responsible for testing and commissioning should begin planning the commissioning sequence. The process typically begins with formal inspection and functional testing of components as they are installed, and factory acceptance testing of others. More complex aspects of the station may be functionally tested when all components and related systems are functional.

b. Temporary measures or substitutions of necessary functions may be utilized to test one aspect of a station prior to completion of some other mechanism necessary to that operation. This approach can accelerate the commissioning process, allowing functional testing and troubleshooting earlier than would otherwise be possible.

c. However, the commissioning plan should still provide for full system functional and performance testing in the final constructed configuration to the extent necessary to satisfy the government that a correctly functioning station has been constructed. As systems become accessible for training purposes staff of the operating and maintaining entity is brought in for formal training sessions.

d. Once all individual systems have been checked for function and performance tested as appropriate, the station should undergo comprehensive system functional testing. This testing should involve checking all major functions of the station concurrently as close to design field conditions as reasonably practical. All major variations concerning operation should be demonstrated during this process (e.g., simultaneous operation of all pumps, operating on utility and back-up power, local or manual control as well as remote control or automatic function, etc.).

e. Throughout the testing and commissioning process it should be expected that issues will be encountered, questions will be raised, and troubleshooting will occur. When all testing has been accomplished and inspections have been completed, maintenance staff should then be properly trained. Along with the training, operating and maintenance procedures should be finalized, and final station configuration documented and turned over to the operating entity. The quantity of any spare parts or special tools provided as part of the project should be turned over.

f. Rewatering. The rewatering of the structure is often a key milestone in the commissioning of the station.

(1) This is especially true for stations constructed with a substantial cofferdam or on which dewatering of the pump intake or discharge bays is difficult or otherwise prohibitive. It is a point where activities such as dry testing and inspection of certain areas must occur prior to, but also an action that must be accomplished before others, such as wet testing may be accomplished.

(2) Even on projects where dewatering bulkheads are being provided, and must be demonstrated, their use is generally minimized to the required testing and closely coordinated with other commissioning actions that are facilitated by a dewatered intake or discharge bay.

g. Spare parts. On projects to be operated and maintained by the federal government or when project terms otherwise allow for it, the station should be fully stocked with the appropriate spare parts and consumable items to operate for a reasonable period of time.

(1) On projects turned over to non-federal entities for O&M, it is not uncommon for federal funding to be prohibited by the terms of those agreements from supplying of spare parts.

(2) Usable excess materials, or manufacturers standard included spare parts may nonetheless be present on site at the completion of a project without explicit contractual requirements that they be provided. In the event that any spare parts are being turned over, they should be clearly identified and cataloged. On all projects, a listing of recommended spare parts should be included regardless of whether or not the parts are being furnished as part of the project.

Chapter 11
Pump Drive Selection

11.1 General. Several options are available to the designer when considering the selection of a pump drive for pumping stations.

a. The two factors that must be investigated when making this selection are reliability and cost. Alternative studies should be made early in the design process considering these two factors. This also needs to be documented in the design report. The ability of the local sponsor or owner to operate and maintain the station also should be a consideration.

b. The two types of drives to be considered are electric motors and internal combustion engines. Gear drives are required as part of the drive system when using engines. Engines also allow the possibility of V/S operation without a VFD system required by electric motors.

c. Gear drives can also be used with electric motors permitting the use of a less expensive higher speed motor while still allowing the selection of optimal pump speeds.

11.2 Cost Considerations.

a. General. Unless reliability considerations are important enough to decide what type of drive to use, annual cost comparisons should be made of all systems under study.

b. The annual costs should include the installed, operating, maintenance and replacement costs. After all costs have been established, a life-cycle cost analysis can be performed. An in-depth source for life-cycle cost analyses is found in the HI technical document, Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems. This HI document covers all aspects of life cycle costs for pumping systems including drivers, electric motors, maintenance and energy costs. It also includes methods for estimating life cycle costs of existing systems.

c. Installed costs. The installed costs include the construction costs of all the equipment plus the electric power supply costs, which usually would include the cost of the substation plus the power line to the station. These costs should be figured on an annualized basis using the number of years determined for the project life.

d. Operating costs. The operating costs would include the cost for energy and manpower expenses. To accurately estimate the total energy costs, an estimate of the amount of pumping required for each month of the year must be obtained.

e. The source of pumping time should be obtained from hydrology period-of-record routing studies. The current price schedule for electric power from the supplying utility or the market price of engine fuel can be used to determine the costs for all stations except for large stations.

f. For large stations, a study of future energy costs over the life of the project is justified. In determining the total cost of electricity, it is important to include both the cost for the energy used (kilowatt hours) plus any demand (capacity) charges. Demand charges by some power companies may be a major part of the energy costs.

g. Maintenance costs. Maintenance costs include manpower and materials for both preventative and major repairs. Unless the station has specialized equipment, these costs are usually estimated using the following percentages of the installed equipment costs listed here in Table 11.1:

Table 11.1
Maintenance Cost by Station Size

Station Size	Percentage (%)
25 m^3/s (1.0 cfs)	0.5
15 m^3/s (530 cfs)	5.0

h. Percentages for intermediate station sizes are determined proportionally with the above values. The maintenance cost of unusual or specialized equipment would be determined separately and would be an additional amount. For larger stations over 1000 cfs the designer should determine maintenance costs specifically for the station.

11.3 Rehabilitation and Replacement Costs. Rehabilitation and replacement costs include those costs required to keep the station operable for the project life.

a. For a normal 50-year station life, most of the equipment would be rehabilitated or replaced at least once, except for very large pumping stations. The periods between the rehabilitation/replacement could be shorter if the operating time were great. Major items such as pumps, drivers, and switchgear are figured to be rehabilitated or replaced once during the 50-year life. This major equipment rehabilitation or replacement is usually estimated to occur between 20 and 40 years after placing the station into operation.

b. Rehabilitation costs for major equipment can be estimated to be 35 to 45 percent of replacement costs depending on the condition of the equipment. Other items of equipment may be replaced several times during the project life depending on their use or may require only partial replacement. It is most likely that equipment, except for the pump and motor, may not be replaced in kind. Therefore, the replacement cost should include all engineering and structural modification costs as well as the equipment costs.

c. The equipment removal costs including the cost of all rental equipment plus the installation cost of all new equipment should be included.

11.4 Reliability. The primary consideration in the selection of any pump drive is reliability under the worst conditions likely to prevail during the time the station will be required to operate.

a. The reliability of the electrical power source should be determined from power company records of power outages in that area and their capability to repair any outages. Consideration of power from two different power grids within a company may be advisable for large pumping stations.

b. If engine driven pumps are considered, the reliability of the fuel supply must be considered whether natural gas or diesel. It is imperative the fuel supplies be maintained on site and are also capable of being delivered during emergencies or flood events. On-site fuel storage can be complex to design and maintain.

c. The reliability of the various different types of equipment must also be studied. Electric motors and engines are usually very reliable while the necessary accessories to operate these units are less reliable. Without considering the reliability of the power supply, electric motors can be considered more reliable than engines.

d. It may be found that depending on the power supply reliability, that electric motor driven pumps with a backup engine generator for when commercial power fails is the most reliable arrangement. This may not be practical for very large pump stations.

e. A reliability study of the alternatives could be useful in making the best drive selection. The complexity to operate and repair the piece of equipment by the operating personnel should also be considered. Equipment repair requiring specialized service personnel may require much greater time to put it back into service.

11.5 Gear Driven Submersible. Submersible pumps that utilize gear reduction are not recommended.

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Chapter 12
Engines and Gears

12.1 General. Much of the discussion in this chapter is intended for pump drives but may also apply to stationary generators at pump stations.

a. Internal combustion engines used for pump drivers are typically of the diesel or natural gas-fueled type. There are advantages and disadvantages of both types of engine drives.

b. Gasoline engines are not typical for pump drives except perhaps for very small stations. Both diesel drives and natural gas drives require similar exhaust systems and cooling systems.

c. Diesel engine drives have fuel for operation at the pump station site. They are not reliant on local utilities (natural gas or electric) remaining in service and their use precludes the need to have a massive backup generator at the site. However, diesel drives require large fuel tanks and the associated mechanical systems including pumps. The tanks also require spill containment.

d. Natural gas systems eliminate the need for large on-site fuel tanks and the requirements for spill containment. However, there are more safety concerns when using natural gas. The cost of a natural gas engine may be higher than a diesel engine. In terms of energy consumption, the designer would need to determine the specific cost difference for the specific application. In general, there may not be a significant difference in energy costs.

e. For large pumping systems, diesel and natural gas-fueled pump drives are advantageous in that they reduce the size of the electrical infrastructure. Further, engine pump drives offer the advantage of V/S (without electronic controls), which may be a benefit during priming of a pump that has a siphon discharge. The V/S operation also allows the pump to better match the incoming flow conditions. Selection criteria for internal combustion engines and electric motors are provided in Chapter 11.

12.2 Engines. Engines of the four-cycle type are used for pump drives. Natural gas engines may have a life cycle cost advantage depending on engine size, but the natural gas supply may be compromised after a major storm event. The designer must take into account the consequences of the failure of the pumping systems when determining the pump drives to be used. Skid-mounted engines should be used when possible with all the auxiliaries except the day tank and fuel tank mounted thereon.

a. Cooling systems. Engine pump drives may be cooled by two basic types of systems: radiator and heat exchanger. Keel cooler heat exchanger systems are further discussed in Paragraph 12.8. Selection criteria include engine size, space availability, raw or sump water supply, initial cost, O&M cost, and environmental concerns.

b. Radiator systems should be designed by the engine manufacturer. It is important that the designer provide the proper amount of ventilation air and the station louvers are sized correctly. This requires coordination between the designer and the engine manufacturer.

c. A radiator system may have the radiator mounted on the engine base or remotely mounted. The radiator will always be located where an adequate supply of cooling air is available. For larger engines, the physical size of the radiator may make it an impractical choice.

d. The selection of the fan and radiator location would include the noise level, heat produced, and size requirements. For locations that may have periodic hurricanes, putting a large opening in the pump station wall through which the air through the radiator is rejected may not be acceptable due to compromised structural integrity and the potential for wind-driven rain through a large, louvered opening.

e. The heat exchanger cooling system should be the closed type. It can be an elaborate system with raw or canal water supply pumps, a shell and tube heat exchanger, and a traveling water screen (to screen the raw water to the supply pumps) to cool the engine's jacket water. It could also be a simplified submerged pipe type, also known as a keel cooler discussed further in Paragraph 12.8. This type circulates engine jacket water through pipes submerged in the pump sump.

f. If possible, raw water pump intakes (for raw water cooling systems) or keel coolers should be located low enough in the intake canal so that they are always below ground water levels. This will allow the engines to be exercised even if the water level is too low for pumping.

g. Selection will be based on engine cooling requirements and the recommendation of the engine manufacturer. Some engines may require two heat exchangers to meet EPA emissions requirements. Problems that are sometimes associated with heat exchanger cooling include freezing climates, foul cooling water, rejecting heated raw water to the canal, and engine testing restrictions when the intake sump lacks sufficient water.

h. Control equipment. All engines must be designed for manual starting. Automatic starting can also be incorporated as applicable and necessary.

(1) Manual and automatic control devices should be of the types regularly furnished by the engine manufacturer for similar service. Automatic engine shutdown is required for engine overspeed.

(2) Visual and audible alarms and automatic engine shutdown (as a minimum) should occur for high jacket water temperature, high lubricating oil temperature, low lubricating oil pressure, gear reducer high lubricating oil temperature, or gear reducer low lubricating oil pressure.

(3) The type of speed control devices will depend upon the desired scheme of operation, but a governor to maintain speed and a suitable speed indicator should be provided in all cases. Provide an engine shutoff method for low sump water elevation to keep the pump from cavitating.

(4) Engine instrumentation and controls are generally located adjacent to the engine. Redundant remote instrumentation and controls may be located in an operating office via a SCADA system for large pumping stations.

(5) The control system should be designed so that the engines can be started and operated when the electric power to the station is interrupted and automatic engine shutdown should not occur due to minor fluctuations in commercial power.

(6) A flood risk management pumping station will often require a separate engine-generator to provide electrical power for the control system, ventilation system, trash rake, etc. The controls should permit operation of the engine’s jacket water pump to allow cool down of the engine if required by the engine manufacturer. If the jacket water pump is engine driven, then an auxiliary motor driven jacket water pump should be considered for cool down, if required.

(7) A means must be furnished to shutoff the intake air supply to the engine manually to provide for critical shutdown. Crankcase explosion relief valves should be provided for diesel engines.

i. Engine equipment and auxiliaries.

(1) Clutches. Engines less than 450 kW (600 HP) may be equipped with a manual clutch mechanism, which allows the engine to be started and operated without running the pump. This permits testing of the engine without regard to water levels that may not allow pump operation.

(2) Flexible drive shafts. Flexible drive shafts eliminate the need for critical alignment of the engine to the gear reducer. The drive shaft consists of a center section with a flexible joint on each end. One of the flexible joints incorporates a splined slip joint that permits longitudinal movement to occur. The drive shaft manufacturer’s published rating at the maximum engine speed should be at least 1-1/2 times the maximum torque of the pump that usually occurs at its maximum head condition.

(3) A drive shaft minimum length of 900 millimeters (36 inches) is desirable to allow for intentional or accidental misalignment. A vertical difference of approximately 15 millimeters (0.5 inch) for 900 millimeters (36 inch) shaft length should be provided between the engine output shaft and the gear input shaft to provide continuous exercise for the flexible joints. There are other types of engine-to-gear connections, such as direct through flexible couplings. This can be investigated if site conditions prevent the use of the drive shaft described above.

(4) Starting system. The engine starting system should be electric (via batteries) except for very large engines. Very large engines should be started via pneumatic air systems. The air system should contain a reservoir of sufficient size to permit two starts of each unit without recharge by the air compressor. The time for the air compressor to recharge the reservoir should not exceed 2 hours. Two air compressors should be provided for reliability. Unless a standby generating unit is provided for the station, one of the air compressors should be engine driven so that the air pressure can be built up during electric power outages.

(5) Pre-lubrication. Engine manufacturers should be consulted as to any requirements for a pre-lubrication pump. Factors that are normally used to determine the need for pre-lubrication requirements are engine size, the expected period of time between operations, and the environment (temperature, humidity, etc.) in which the engine will be installed.

12.3 EPA Requirements. Engine drives for pump stations will typically be classified as stationary. Stationary internal combustion engines are common combustion sources that can have a significant impact on air quality and public health.

a. The EPA has standards for engine emissions that are based on whether the engines are for standard use or emergency use only. The United States EPA issued a number of rules to control emissions of toxic air pollutants from existing stationary reciprocating internal combustion engines. The rules, entitled National Emission Standards for Hazardous Air Pollutants for Reciprocating Internal Combustion Engines, are intended to reduce emissions of toxic air pollutants such as formaldehyde, acetaldehyde, methanol and other air toxics from several categories of previously unregulated stationary engines.

b. The National Emission Standards for Hazardous Air Pollutants regulations for stationary engines are published in Title 40, Part 63, Subpart ZZZZ (63.6580) of the CFR. Regulatory documents as well as fact sheets and related information can be also found in the US EPA stationary engine pages.

c. Most engines used for driving pumps at USACE pumping stations will likely be used for more than emergency uses. Technology changes quickly, but currently, some diesel engine manufacturers use a diesel exhaust fluid (DEF) system to allow the engines to meet EPA requirements. These systems require extra space near each engine for the DEF system panel and extra space for a DEF tank (or tanks) that is accessible to the DEF supplier, which is also likely the diesel fuel supplier.

12.4 Engine Design Requirements and Capacity. All ratings should be based on continuous duty operation. The engine should be rated 10 percent in excess of the maximum operating requirements that include the maximum pump HP requirement and losses through the drive system. The engine should also be capable of operation at 110-percent full-load rating at rated speed with safe operating temperatures for periods of 2 hours in 24 consecutive hours. Engine speed should be as indicated in Table 12.1 below.

Table 12.1
Engine Rating and Speed

Engine Horsepower Rating	Maximum Speed - RPM
1,120 kilowatt (kW) (1,500 HP) and over	900 – 1,000
Less than 1,120 kW (1,500 HP)	1,800

12.5 Testing Requirements. All engine pump drives should be inspected and tested at the factory in the presence of USACE personnel. The inspection should cover all components including governors, the instrumentation panels, the engine starting system, the intake and exhaust (as much as practical), the lubrication system, cooling system, and fuel system.

a. At a minimum, the tests should include simulated emergency or overspeed trip tests, a sustained operation test at rated full load and partial loading, fuel consumption tests, operation at no load to demonstrate that the governor and its associated engine manifold shutoff valve function properly. Test data should be taken at a minimum of 30-minute intervals and recorded on the manufacturer's engine test data sheets.

b. Field testing of engine pump drives can be difficult during construction. There may be insufficient water available to pump water, or the ultimate location of the discharge water may not be constructed in a timely manner. Either of these can keep the engine from being tested under a reasonable load in the field.

c. A full load is not reasonable to expect, because it is dependent on weather conditions and water availability, for which the contractor has no control. Further, if the engine pump drives are cooled via a system that requires canal water (keel cooler or a raw water system), sufficient canal water needs to be available for cooling. If possible, however, the contractor should be required to perform safety run tests of the engine pump drives. Potential safety run tests that should be considered are listed in the UFGS for fueled engine pump drives.

12.6 Maintenance Requirements and Engine Systems. Maintenance requirements of engine drives can be extensive. As such, the designer needs to be aware of the capabilities of the end user.

a. The engine specification should be edited so that it requires the contractor to provide an O&M Manual for the engine pump drives and their accessories (e.g., day tanks, DEF system). The manual should be kept in a dry, safe location at the pumping station site so that the operators will have information on how to start and stop the engines and how to maintain the engines properly.

b. Engines have many systems that need to be monitored constantly. These include coolant temperature, lube-oil temperature and pressure, day tank fuel level, etc. Modern engines have the capability of providing much information to an Engine Control Center via the engine's internal monitors. The designer will need to determine what should be provided for the specific type of pumping station. All engines drives must be exercised on a periodic basis. This information will be provided by the engine manufacturer but will typically be once per month.

c. Block Heaters. Depending on the climate where the engine pump drive will be installed, an engine block heater should be included in the engine package. A block heater may make a diesel engine easier to start in a cold weather environment. A block heater may also reduce the amount of condensation that forms on the metallic portion of the engine during moist, cool evenings.

d. Warm Up and Cool Down Cycles.

(1) Because diesel engines rely on compression for ignition, they tend to run rough when the engine is cold. However, an engine running under a low load does not produce much heat. Excessive idling and warm up periods can cause a problem in diesel engines known as "wet stacking." Wet stacking is the process by which relatively cool combustion temperatures results in an incomplete combustion event, which can cause partially and unburnt fuel to stick to the cylinder walls. This should be minimized.

(2) Conversely, placing a diesel engine under full load when it is dead cold can have its own set of consequences. The oil in a cold engine is more viscous. The viscosity of oil is related to both its flow and lubrication properties.

(3) Therefore, during the design process, coordinate with engine manufacturers to help determine an appropriate warm up time period for the size engine being used and the typical ambient temperatures in which it will be used. Consider allowing the engine supplier to determine the recommended warm up period and provide the information in the operating and maintenance manual. The contractor can then program the engine to warm up for that period. Warm-up periods should be similar to those in Table 12.2:

Table 12.2
Acceptable Engine Warm Up Times

Ambient Temperature	Acceptable Warm Up Period
< 0° F	up to 7 minutes
0° F - 50° F	3 to 5 minutes
50° F	1 to 2 minutes

(4) Allowing a turbocharged diesel engine to cool down before turning it off is important. Because their operating conditions are severe, turbochargers are manufactured with low tolerances and high precision. Lubrication of the turbocharger bearings is important to ensure turbocharger longevity.

(5) The warmer the ambient temperature, the lower the recommended warm up idling period. However, the opposite is not necessarily true. There is a point of diminishing return and, therefore, extended idling (greater than seven minutes) is typically not advised and provides no benefit regardless of ambient conditions. A diesel engine will require operating to reach full operating temperature. The warm-up process is more oriented toward increasing the combustion chamber temperature and not placing any excess load on an engine while its components soak in heat and begin to slowly expand.

(6) Consider the following in determining an appropriate warm up procedure based on specific needs:

(a) Diesel engines often have block heaters, which should be used as stated by the manufacturer’s recommendations. Block heaters reduce warm up idle times and significantly aid starting in cold weather. When using a block heater, the aforementioned acceptable warm up periods can be reduced.

(b) Keep the engine speed low until an engine reaches its normal operating temperature. However, if the pumping system uses product-lubricated (water being pumped through the system) pump bearings, the engine needs to be at the speed necessary to lift water to the highest bearings in a timely manner to cool the bearings sufficiently. Coordinate with pump and engine manufacturers for the requirements of the pumping systems.

(7) Engine cool down periods allow for circulating engine oil to remove heat from the turbocharger so that the engine oil does not "cook" in the turbocharger upon shutdown. While not always necessary, it’s considered good practice and will promote longevity and reliability of a turbocharger.

(8) The engine cool down period should be based on the engine manufacturer’s recommendations. There are many similarities to bringing the engine up to operating temperature when using product-lubricated pump bearings. The engine speed needs to be high enough to provide a pump speed that is sufficient to lift water to the highest pump bearings in a timely manner to cool the bearings adequately. In general, low-head or normal-head pump operations may require a shorter cool down period than higher head conditions.

e. Engine Governor Systems.

(1) Engines must be provided with governors to control the rotational speed of the engine in response to changing load (head) requirements. Governors should be configured for safe manual adjustment of the speed during operation of the engine, without special tools. The speed fluctuation at any load should not exceed 2 percent. A raise/lower speed control should be mounted on the engine instrument board.

(2) An emergency governor with overspeed trip (or an overspeed switch) must be provided on each engine to shut down the engine if the speed exceeds a predetermined speed,

such as 10 percent greater than the rated speed. If the overspeed setting is reached, it should be set to actuate an alarm contact and the safety shutdown circuit for the engine.

12.7 Fuel Supply Systems. Fuel systems will typically be diesel or natural gas. Both fuel systems have specific characteristics and maintenance requirements.

a. Diesel fuel. The type of diesel fuel used should be as recommended by the engine manufacturer for the type of environment in which the engine will operate.

(1) In general, the fuel should be No. 2-D, ultra-low sulfur diesel fuel conforming to ASTM D 975. An adequate supply of diesel fuel is required to ensure station operation without the need for emergency replenishment.

(2) The volume of the storage tank system should provide for a minimum of two days of continuous operation of all diesel engine pump drives and backup generator units operating at maximum horsepower.

(3) The volume provided should be increased to provide fuel for as much as a week for those stations that are remote or of such a size that quantities required would not permit ready replenishment.

(4) The capacity of the fuel tanks may also be dependent on the potential for long periods in which commercial power may be out due to potential flood-causing events such as hurricanes.

(5) The location and type of fuel storage (e.g., aboveground or underground fuel tanks) should be determined after review of the applicable local, state, and national EPA regulations.

(6) Because they avoid underground leaks, aboveground fuel tanks may prove advantageous in locations in which space is not an issue. However, in some remote areas, vaulted tanks should be considered to avoid the potential of leaks being caused by vandalism. In any case, properly designed containment systems must be provided per applicable National Fire Protection Association (NFPA) and EPA regulations and codes.

b. Natural gas. Stations equipped with engines operating on natural gas supplied from a utility system need to be provided with a stored gas backup system if reliability of the source could cause the station to be out of operation for more than 24 hours for a non-flood risk management station.

(1) For a flood risk management station, the potential for a lack of gas flow is a much greater concern. If historical data indicates that utility-supplied gas flow is sometimes interrupted for more than an hour, consider not using natural gas to operate the engine pump drives for a flood risk management station.

(2) When provided, the volume of the gas storage system should provide for a minimum of two days of continuous operation of all units operating at maximum load. The storage usually consists of one or more pressure tanks above ground.

(3) All gas tanks should be installed with foundations attached to the tanks, which preclude floating of the tank in case of flooding. A station with natural gas-operated engines must be provided with devices capable of measuring air content for explosive conditions and indicating this condition with alarms both inside and outside the station.

(4) The ventilating system must be suitable for operating in an explosive atmosphere and capable of being turned on from outside the station. The sump should be ventilated in a similar manner. All installations need to be designed and installed as required by the NFPA.

12.8 Keel Cooler Systems. A properly designed cooling system is critical for all engine drives as previously discussed in Paragraph 12.2. A basic design decision will need to be made whether the engine is radiator cooled or cooled using a heat exchanger system. A keel cooler is one type of heat exchanger system that can be considered by the designer.

a. Keel Coolers. Keel coolers are simply a type of heat exchanger that utilizes water from the ponding area or river to cool the engine. A key consideration is that an adequate water supply needs to be available for cooling. A keel cooler is a closed-circuit cooling system mounted externally and below the waterline. The concept of a keel cooler is similar to a radiator on a car. Water is circulated through the keel cooler, which transfers heat from the coolant before it returns to the engine. The keel cooler is in constant contact with water allowing the cooling system to efficiently transfer heat between the coolant and water.

b. Keel coolers may be an appropriate solution when placed in predictable, non-turbulent flow traveling along the length of the cooling tubes. Avoid areas where trash could accumulate, reducing cooling capacity or causing impact to coolers. Ensure constant water supply flow and temperature are available in the desired area. The designer should calculate required cooling capacity during design.

c. If the engine needs to run for long periods with no water (say during dry testing), that needs to be accommodated. On poorly executed installations they can be problematic and cause significant maintenance issues. Keel coolers are utilized on ships and may also be provided as a commercial off the shelf item. This is something the designer can verify depending on requirements. Duramax Marine and Walter Marine are two manufacturers of keel coolers for ships.

d. On flood protection projects, sometimes water can be siphoned from the flood side back to the protected side to provide water for a keel cooler. The feasibility of this approach needs to be determined by the designer. Another consideration is to place heat exchangers in the intake bays behind dewatering bulkheads on the discharge side.

e. The cooling capacity of heat exchangers is critical for proper operation of the engine. The designer should always determine keel cooler and heat exchanger capacity by both calculations and physical testing. The engine manufacturer can also provide performance and selection data.

f. It should be noted that manufacturers of unique-geometry keel coolers do not always have in-house engineering staff equipped to perform similar verification calculations, but often provide full-size performance test data as a substitute. Provided geometry and hydraulic similarity of test conditions are appropriate, this may be deemed acceptable but ultimately is the designer's judgment.

g. Materials. The designer should utilize stainless steel manifolds to extent possible. Other options include assemblies out of rectangular 90/10 cu-ni alloy tubing. The latter has brazed joints, not welded. However, the material may be prone to fatigue failure if installed in too turbulent of flow.

12.9 Gear Drives for Pumps.

a. Most applications for pumping stations will use a vertical pump with a right-angle gear to transmit power from the horizontal engine shaft to the vertical pump shaft. Gear drives may also be used with horizontal electric motors driving vertical pumps. This permits the use of less expensive high-speed horizontal drive electric motors.

b. Horizontal pump installations may use chain drive or parallel shaft gear reducers. The gear units should have a service factor of 1.25 when driven by an electric motor and 1.5 when driven by an engine. The service factor should be based on the maximum HP requirement of the pump.

c. Right-angle drives should be of the hollow shaft type to permit vertical adjustment of the pump propeller at the top of the gear. All right-angle gear drives should be designed to carry the full vertical thrust from the pump. The gear unit should be equipped with an oil pump directly driven from one of the reducer shafts and be capable of delivering sufficient oil to all parts when operating at less than rated speed.

d. The transmission of power through the gear produces significant heating of the lubricating oil, and some means must be provided to reject this heat. The heat removal can be accomplished by placing an oil cooler in the engine's cooling water system or by using a separate heat exchanger or by using a separate oil radiator placed in the air stream from the engine-driven fan or located with its own fan.

e. Engines that use heat exchangers should also use a similar system for cooling the reduction gearing. All gears should be equipped with a thrust-bearing temperature thermometer, an oil pressure gage and temperature thermometer, and oil level indicators. Automatic shutdown of the pumping unit and visual and audible alarms should be provided for high thrust-bearing temperature, high oil temperature, or low oil pressure.

f. When cold weather operation is expected, oil heaters should be used in the gear to reduce oil thickening between operational periods. Full synthetic gear oil should be utilized if the drive is operating in severe cold or heat conditions or if water accumulation in the gear box is an issue.

g. A backstop device should be attached to the low or intermediate shaft of the gear reducer to prevent reverse rotation of the pump and engine. Types of gear drives include right angle and planetary. The manufacturing quality of gears reducers and their design is a critical consideration. As such, the designer should reference to American Gear Manufacturers Association (AGMA) quality level and bearing life calculation requirements, including factory and field testing requirements. Some significant AGMA standards as follows:

(1) AGMA 201.02 Tooth Proportions for Coarse-Pitch Involute Spur Gears.

(2) AGMA 2001-C95 Fundamental Rating Procedures for Involute Spur and Helical Gear Teeth.

(3) AGMA 2003-B97 Rating the Pitting Resistance and Bending Strength of Generated Straight Bevel, Zerol Bevel and Spiral Bevel Gear Teeth.

(4) AGMA 2015-1-A01 Accuracy Classification System-Tangential Measurements for Cylindrical Gears.

(5) AGMA 6013-A06 Standard for Industrial Enclosed Gear Drives.

(6) AGMA 6113-A06 Standard for Industrial Enclosed Gear Drives (Metric Edition).

(7) AGMA 9005-E02 Industrial Gear Lubrication.

h. The designer should also reference USACE EM 1110-2-2610 for more specific requirements of gears and gear drives and gear reducers.

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Chapter 13
Trash Rakes

13.1 General. This chapter provides detailed information about the selection of trash racks and trash raking equipment. As discussed earlier, the trash rack is the fixed structural element and the trash rake and trash raking equipment provides either manual or mechanical cleaning of the rack. Several types of mechanical raking are discussed in this chapter.

a. The decision to use either hand or mechanical raking should be based on the amount and characteristics of the debris, station configuration, safety, and engineering judgment.

b. Operating personnel must not hand rake or handle debris coming from a sanitary or combined sewer. Also, mechanical raking should be used if the station configuration presents a danger for personnel. For example, a very deep sump, a significant amount of debris, or excessive weight of debris will all require mechanical lifting capability. The types of raking devices used to remove trash from the trash racks depends on the size of the plant, frequency of operation, type and size of the pumps, and type of inflow facilities (pipe, open ditch, etc.).

c. Suitable provision must be made in design of the trash raking systems and sump chambers to permit storage and removal of accumulated trash with reasonable ease. Truck access to locations where trash is deposited upon removal from the trash rack chamber should be provided in order to avoid laborious transfer procedures in final trash removal.

d. Except for stations of minor importance and sewage type pumping stations, all flows into flood risk management pumping stations should be screened before reaching the pumps. An exception is possibly where flows are adequately screened prior to entry into the collecting system by grated catch basins or other methods, trash racks may be omitted. However, omission of trash racks must be based upon sound engineering judgment and economic considerations and must be justified and explained in the design analysis.

e. Trash racks are generally constructed of structural steel and are either attached to the face at the forebay side of the structure or inserted into formed slots near the intake face of the substructure. Conventional bar screens (trash racks) are the preferred method of screening.

f. Suction strainers on pumps should be avoided as they clog readily and are difficult to clean. Trash racks must be located to allow incoming flows to pass through the rack before reaching any pump intake, flow to be evenly distributed over the submerged rack surface, and raking to be accomplished coincident with pump operation.

g. Trash racks located in the sewer which flows by the pumping station should be readily removable, and minimal means should be provided to allow the racks to be raised above the maximum sump level and secured when the station is not in use. Trash racks should always be located outside the station superstructure in order that operating areas are not exposed to the moisture and fumes usually present during raking operations and to facilitate disposal of trash accumulations.

h. Trash racks and trash raking equipment are manufactured in a variety of configurations, each applying forces to the structure in different ways and to varying degrees. Before final design of the intake area and trash deck is begun, the type of raking system must be determined and these forces identified.

i. In the design of both trash racks and trash raking equipment, durability under adverse operating conditions and harsh environment must be considered. These items should be designed to function dependably with a minimum of maintenance over the life of the station.

j. For some large plants, the trash deck may be designed for heavy vehicular traffic and can be used as a work area for a truck mounted crane and trash hauling equipment. This arrangement might be used in conjunction with, or in lieu of, conventional trash raking equipment. The method of trash removal and handling should be coordinated early in the design process, and provision for removal of trash from the intake channel and from the trash deck should be considered as a fundamental part of the station layout and design.

13.2 Design. Trash racks should be structurally designed for a minimum of 1.5 m (5 feet) of head differential acting toward the pumping station for small to medium sized plants. For larger plants, higher head differentials may occur. Trash racks should have ample net area so that the velocity of the flow through the gross rack area does not exceed 0.76 m/sec (2.5 fps).

a. The clear opening between bars needs to be coordinated with the final pump selection by the designer. Some centrifugal pumps can pass 101 mm (4 inch) solids while other types of pumps have very limited solid handling capability. It is recommended, however, that trash racks have no larger than 102 mm (4 inch) openings.

b. The head loss must be considered when calculating available NPSH for the pump and bar spacing should be coordinated with the pump manufacturer. However, for the majority of USACE stations that utilize a wetwell, the head loss through the trash rack can be neglected.

c. Table 13.1 indicates some of the comparison factors that can be used to evaluate trash raking equipment and their application. Trash raking equipment is classified in three general categories including cable hoist, mechanical, and catenary.

d. For trash rake selection, intangible factors may also need to be considered such as local operating agencies’ requests. In most cases it will be necessary to make a comparison for a minimum of two different type trash rakes and obtain estimated costs from the manufacturers. The results of this study and reasons for selection should be presented in the design documentation. The types of trash to be handled are classified in Table 13.2 and discussed further in the paragraphs following this table.

e. Design considerations. Many items must be considered in the selection of the type of raking equipment and whether the rake should be manually or power operated. Some of these items are the type of trash expected, the quantity of trash and how quickly it occurs, the number and size of the pump bays to be raked, the hazard created with a rake failure, and the first costs and operating and maintenance costs.

Table 13.1
Selection Factors for Pump Station Trash Rakes

Selection Factors							
Type of Rake	Guided Cable	Unguided Cable	Mech. Climber	Mech. Elbow Arm	Mech. Sliding Arm	Catenary Guided	Catenary Unguided
Handles all types of trash	A	P	A	G	A	A	A
Quantity of trash handled	A	A	G	A	G	A	A
First costs	L	L	H	L	L	M	M
Operating costs	M	M	M	M	M	M	M
Maintenance Costs	M	M	M	M	M	M	M
Rack can be manually raked upon breakdown	G	G	P	G	G	P	P
Large trash can be removed from in front of the rake	G	G	A	G	G	P	P
Speed of operation	L	L	H	L	L	M	M
Abbreviations Used:							
G – Good A - Average P - Poor H - High M - Medium L - Low							

Table 13.2
Trash Classification

Trash Material Classification	
Class	Description
1	Very light weight debris or no debris
2	Light weight floating debris - small limbs or sticks, agricultural waste, orchard prunings, corn stalks, hay and leaves.
3	Medium weight floating debris - limbs or large sticks and small logs up to 76.2 millimeter or 3 inch diameter)
4	Flowing debris - water grass, water-logged debris and refuse such as tires, rugs, and mattresses
5	Heavy weight floating debris - large logs or trees

f. Type and quantity of trash. A physical survey of the contributory area and consultation with the local interests and operators at nearby pumping stations should be conducted to determine the type and quantity of trash expected.

g. Pumping stations located on open ditches will have the trash arrive at an even rate, and the trash can be handled with a minimum number of raking units. Pumping stations located on sewers in urban areas will have most of the trash arrive during the first flush of the runoff during storm events, and the raking system should be designed to remove this first flush quickly in order to prevent a buildup that may damage the trash rack.

h. It is usually best to plan for a greater amount of trash than current conditions may indicate since it is very costly to make changes to the raking system after the pumping station has been constructed.

i. Other considerations. The rated lifting capacity of the rake should be large enough to lift the majority of the trash expected. In most cases for smaller stations, a capacity of 454 kilograms (1,000 pounds) is sufficient. Larger stations the raking capacity will need to be determined specifically for the station. It is imperative the designer work with the local operator and maintenance staff to properly determine the trash raking equipment capacity.

j. The speed of operation is also a consideration. Some rakes, due to their design, do not permit fast raking of the entire trash rack. The maximum time for the rake system to be able to rake the entire pumping station trash rack should be less than 1 hour.

k. The hazards that may be created with a rake failure should be considered when deciding on the number and type of rake to use. Where the entire pumping station capacity is expected to be used on a regular basis and trash may occur which would clog the trash rack limiting pump operation, multiple units or units with good raking capability should be used. If trash is larger than capable of being handled by normal raking, such as large parts of trees, an auxiliary crane in front of the raking area should be considered.

l. Access and Maintenance. Accumulated debris in front of the racks should be removed to prevent structural damage or damage to the pumps due to restricted flow into the sump. Trash racks must be accessible for cleaning, and removable for repair and maintenance. Buildup of trash must be limited to maintain head losses and velocities within the range of the design. The designer should investigate the need for and the feasibility of operating raking systems during pump operation.

13.3 Vortices, Vibrations, and Fatigue. Trash racks can create vortices. Trash racks should be designed to ensure bars are not subject to fatigue failure due to fatigue from flow-induced vibration[2]. The natural frequency of the trash rack bars should be safely above the forcing frequency due to Von Karman vortex shedding. In lower velocity designs, this may be easy to achieve. The forcing frequency can be determined from the following formula.

$$f = Sr \times V/l \qquad \text{(Equation 13.1)}$$

where:

f = forcing frequency
Sr = Strouhal number[3]
V = flow velocity
l = characteristic length (thickness of the bar)

a. It is not typically the trash racks themselves which fail, however. Most failures are at the connections supporting the trash racks.

b. This is especially in cases where guides are installed or replaced after initial construction, requiring that concrete anchors be installed after the concrete has cured, special attention is required to the design and installation of anchors including choosing anchors that are explicitly documented to have passed relevant vibration testing. For installations where flow will be reversed through the trash rack under certain conditions, attention to the anchorage is even more critical.

[2] Hydroelectric Power Plant Trashrack Design, Lloyd E. Sell, US Army Corps of Engineers Omaha District, Journal of Power Division, 1971, Vol. 97, Issue 1, Pg. 115-121. Note: Although this reference was written for hydropower plants, the same principles apply to pump station trash racks.
[3] For rectangular bars, refer to International Journal of Fluid Dynamics, Simulated Flow around Long Rectangular Plates under Cross Flow Perturbations, B.T. Tan, M.C. Thompson and K. Hourigan, Figure 4.

13.4 Trash Rake Classifications Cable Type. Cable hoist trash raking systems use wire rope hoists to move the rake up and down to clean the trash rack. The rake portion can be the guided or unguided type.

a. Guided raking systems. A guided cable trash rake is shown in Figure 13.1 and Figure 13.2. The trash removal capability of the guided cable hoist trash rake would include material classes 1, 2, 3, and 4. The handling ability of class 4 debris depends on the size of the rake and how far the teeth of the rake clear the rack when the rake is being lowered. The vertical travel will typically be greater than an unguided rake system since the rake is supported on both sides, but this needs to be coordinated with the manufacturer.

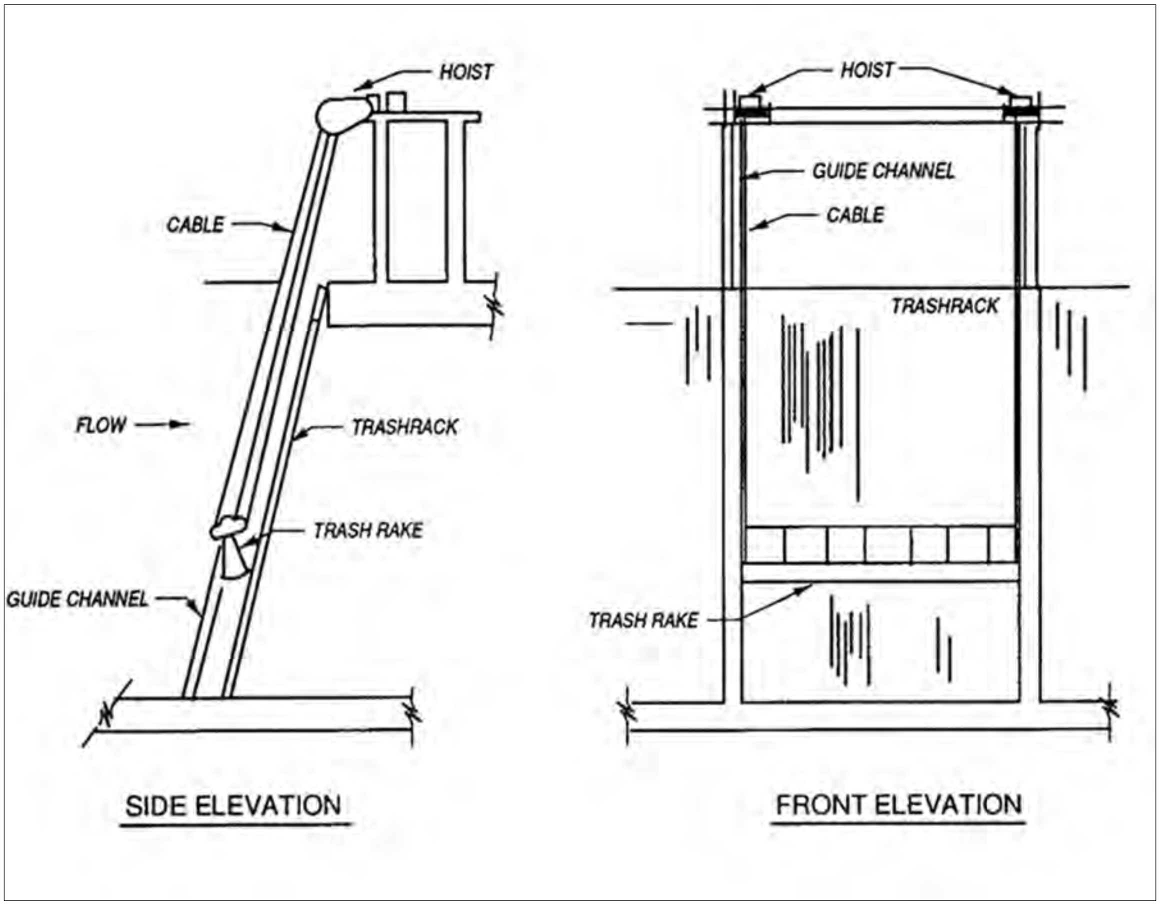

Figure 13.1. Guided Cable Hoist Trash Rake Arrangement

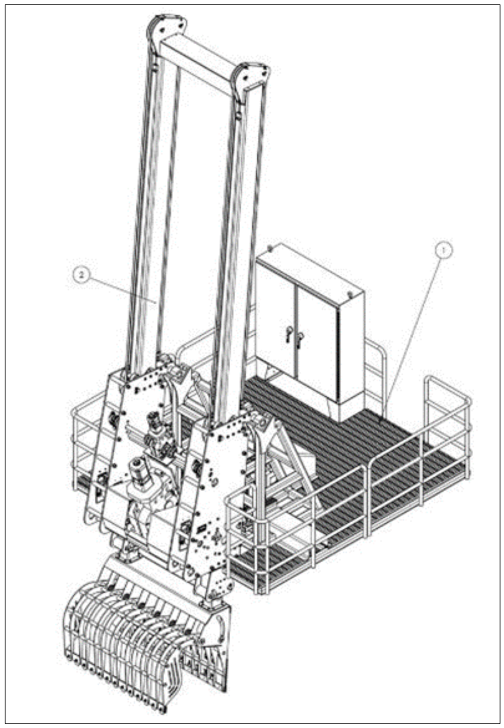

Figure 13.2. Guided Cable Hoist Trash Rake Arrangement

b. Unguided cable raking systems. Unguided cable hoist trash rakes are similar to the guided types except that the rake is not restrained by guides on the sides (Figure 13.3). Except for the guided provisions, the unguided mechanism is very similar to the guided cable hoist trash rake. The width of these rakes is typically limited to approximately 10 feet, and the vertical travel ranges up to 40 feet. The trash removal capability of the unguided cable hoist trash rake would include material classes 1, 2, 3, and 4. This type of rake tends to lose trash when being raised. If being considered, this type of trash rake should be evaluated during the initial design phase.

Figure 13.3. Unguided cable trash rake

13.5 Trash Rake Classifications Mechanical. Mechanical trash rakes use chains, levers or arms, hydraulic cylinders and gears to move the rake up and down to remove the trash from the rack. Four types of mechanical trash rakes are described below. The types are climber, elbow arm, sliding arm, and self-cleaning chain driven.

a. Climber Type. The climber-type mechanical trash rake consists of a rake that covers a full bay width and is raised and lowered along guides and driven by sprockets on the rake assembly that mesh with a fixed roller chain or rack attached to the side guides.

(1) The rake assembly rotates around a pivot which permits the rake to rise from the rack when lowered and mesh with the trash rack when raised. The rake is driven positively during both the up and down movements.

(2) The rake is supported by a superstructure above the operating level. The side guide bars, motor drive mechanism, and other moving parts are located above the operating floor level.

(3) A climber trash rake would be required for each pump bay since they are fixed at one location. A climber trash rake can be obtained that are up to 9 meters (30 feet) wide and 12 meters (40 feet) deep. The rack needs to be inclined for this type of rake.

(4) The electric controls consist of lower and upper limit switches along with motor overload provisions. The controls can permit a complete operation cycle of the rake with one activation.

(5) A typical arrangement of the climber type mechanical trash rake is shown on Figure 13.4 and Figure 13.5. The trash removal capability of the climber type mechanical trash rake would include trash material classes 1, 2, 3, and 4. The handling ability of classes 3 and 4 depend on the length of the trash item and its effective diameter. The width of the rake and the distance the teeth retract from the face of the trash rack determine the rakes capacity to remove large trash.

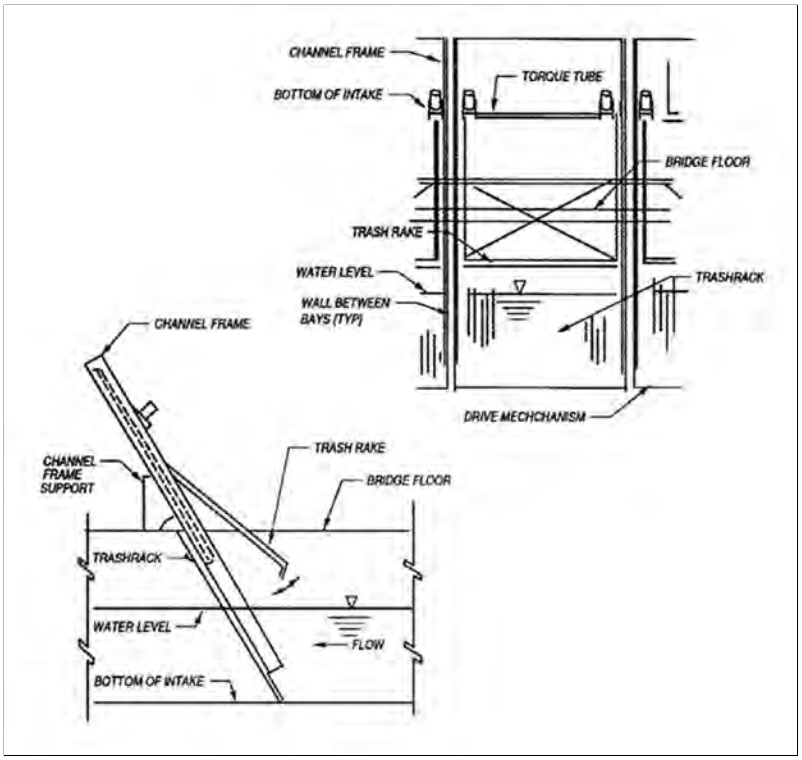

Figure 13.4. Mechanical Climber Screen Arrangement

Figure 13.5. Mechanical Climber Screen Arrangement

b. Elbow arm-type raking system. The elbow-type unit consists of a rake on the end of a two-piece arm similar to that used on a backhoe.

(1) The arm is moved by means of a hydraulic cylinder. In addition to the up and down movement of the rake, it also can be made to pivot where attached to the operating platform, thus allowing it to sweep a greater width and provide unloading capability adjacent to the rake unit.

(2) For a station with multiple pumps, the rake unit is mounted on a traveling platform allowing its operation in front of any pump bay. The rake is typically limited to a width of 3.0 meters (10 feet), and the raking depth can vary to 8.7 meters (25 feet).

(3) Manual control of the rake is performed by an operator from a cab located on the platform. This rake also has the advantage of power down movement rather than depending on gravity forces to lower the rake.

(4) A typical arrangement of the elbow type trash rake is shown on Figure 13.6. The trash removal capability of the elbow-type rake would include material classes 1, 2, 3, 4, and 5.

Figure 13.6. Mechanical Elbow Arm Arrangement

c. Sliding arm raking systems. Sliding arm or telescoping arm rakes consist of a pivoting boom assembly supported from a frame.

(1) The boom assembly supports a sliding rake arm that allows the rake to be lowered and raised. Pivoting of the boom assembly also allows the rake arm to be moved away from or to the trash rack.

(2) The frame supporting the rake can be permanently fixed at one location for raking only one trash rack or can be mounted on a rail-supported platform which would permit one unit to rake multiple trash racks. The rake can empty into a cart onto the operating platform.

(3) This rake can be obtained in widths up to 4.6 meters (15 feet) and rake racks to 8.7 meters (25 feet) deep. The controls can permit a complete operation cycle of the rake with one activation.

(4) A typical arrangement of the sliding arm trash rake is shown in Figure 13.7. The trash removal capability of the sliding arm trash rake would include material classes 1, 2, 3, and 4.

(5) The ability to handle classes 3 and 4 depends on the rake arm being able to clear the trash on the downward movement of the rake arm.

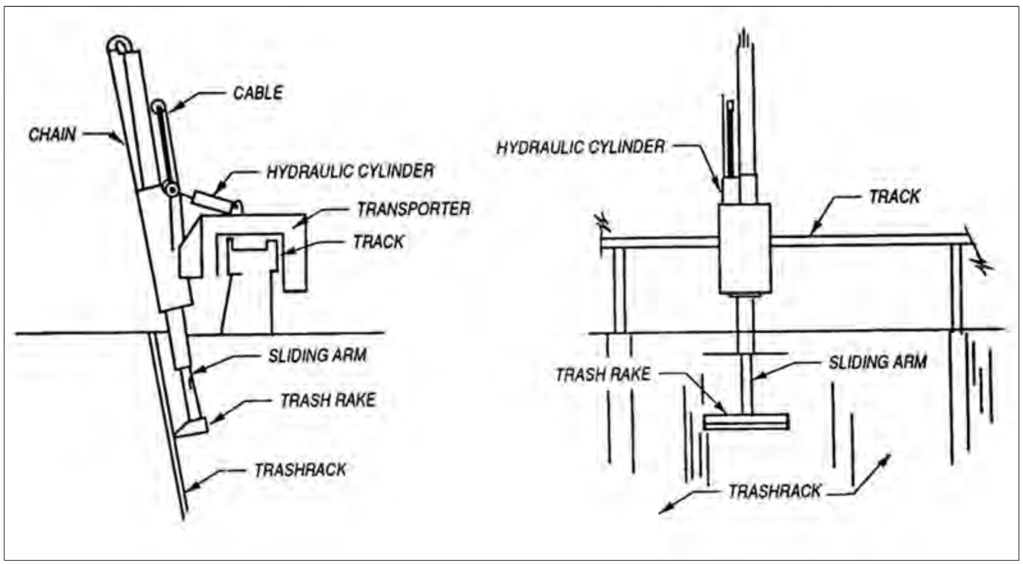

Figure 13.7. Sliding Arm Trash Rake Arrangement

d. Chain driven self-cleaning trash rake. Self-cleaning trash rakes consist of a chain drive that runs within fixed guides. See Figure 13.8.

(1) Lifting cars are plates or rods that are fixed to the chain and extend normal to the trash rack. These rakes have the advantage of not requiring extensive superstructure design and have a much lower profile as a result.

(2) These rakes come in segments of ranging from 1.5-3 meters (5-10 feet) wide and may be designed for varying depths. It is recommended the bar screen assembly be constructed of stainless steel.

(3) Each segment has its own integral gear motor which runs its own segment independently. This style of trash rake can be programmed to run automatically and does not require an operator to start its operation during a storm or flood event. For continuous operation, a debris conveyor system should be installed to keep accumulation down and debris clear. A conveyor system is also recommended on any flood risk management station. Due to the simple nature of this design, very little maintenance is required. This type of trash rake is equipped to handle debris classes 1-4.

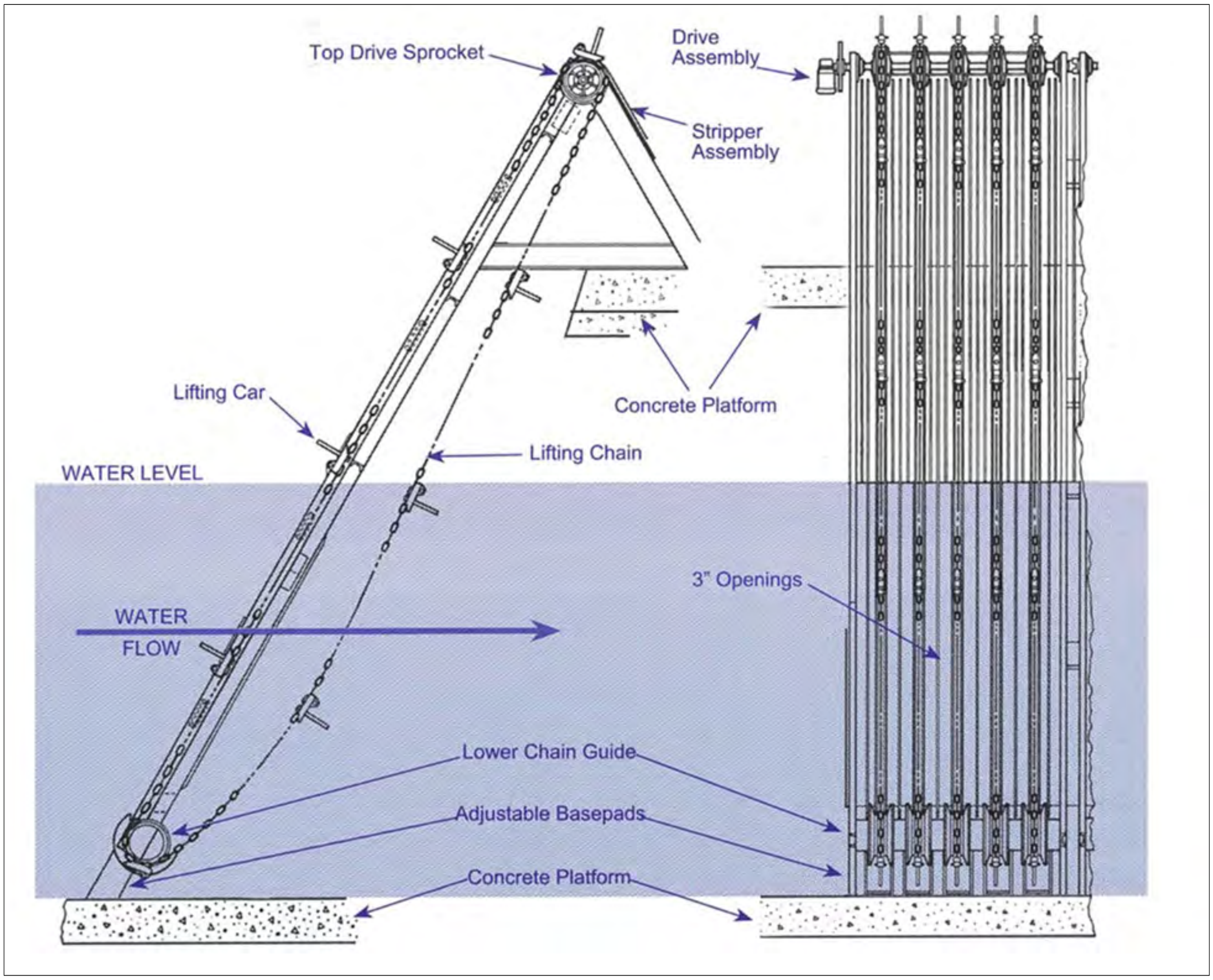

Figure 13.8. Self-Cleaning Trash Rake (inward winding) courtesy Duperon

e. Figure 13.8 shows an inward winding trash rake from Duperon. This type of trash rake has the potential for “carry-over” of debris downstream of the trash rack since the cars travel into the downstream section. Figure 13.9 shows a self-cleaning trash rake which circulates outward. This leaves no possibility of “carry-over” because any caught debris will be circulated upstream of the trash rack.

Figure 13.9. Self-Cleaning Trash Rake (outward winding)

13.6 Trash Rake Classifications Catenary. The catenary rake system was originally developed in the 1950s for the New Orleans Drainage District and was later adopted by the Galveston USACE for their storm water pumping stations in SE Texas.

a. Storm sewers in these areas were mostly below sea level and storm flows had to be pumped to keep from flooding the surrounding communities. The pump stations were designed to operate under emergency conditions, since any serious pump failure could have led to a disaster.

b. Catenary screens were developed to be more dependable than rope or cable operated reciprocating rakes that were typically used at the time to clean the intake forebays of storm water pumping stations. Two types of catenary trash rakes are unguided (free hanging) and guided. Both types consist of a chain on each side, supported by two sprockets that hang down the front of the trash rack.

c. Several beams with teeth attached (rakes) have each end connected to each chain. The continuous movement of the chain drags the beams across the rack. The beams are held into the rack by gravity. A catenary trash rake from E&I Corporation is shown in Figure 13.10.

d. This type of rake can be used for racks up to 12.2 meters (40 feet) wide with depths up to 12.2 meters (40 feet). The chains are motor driven utilizing gearing and drive shafts similar to dam tainter gate machinery. Since the beams rub along the trash rack, care must be given to the alignment of the racks so that it provides a smooth surface without any projections for the rake beams to catch on.

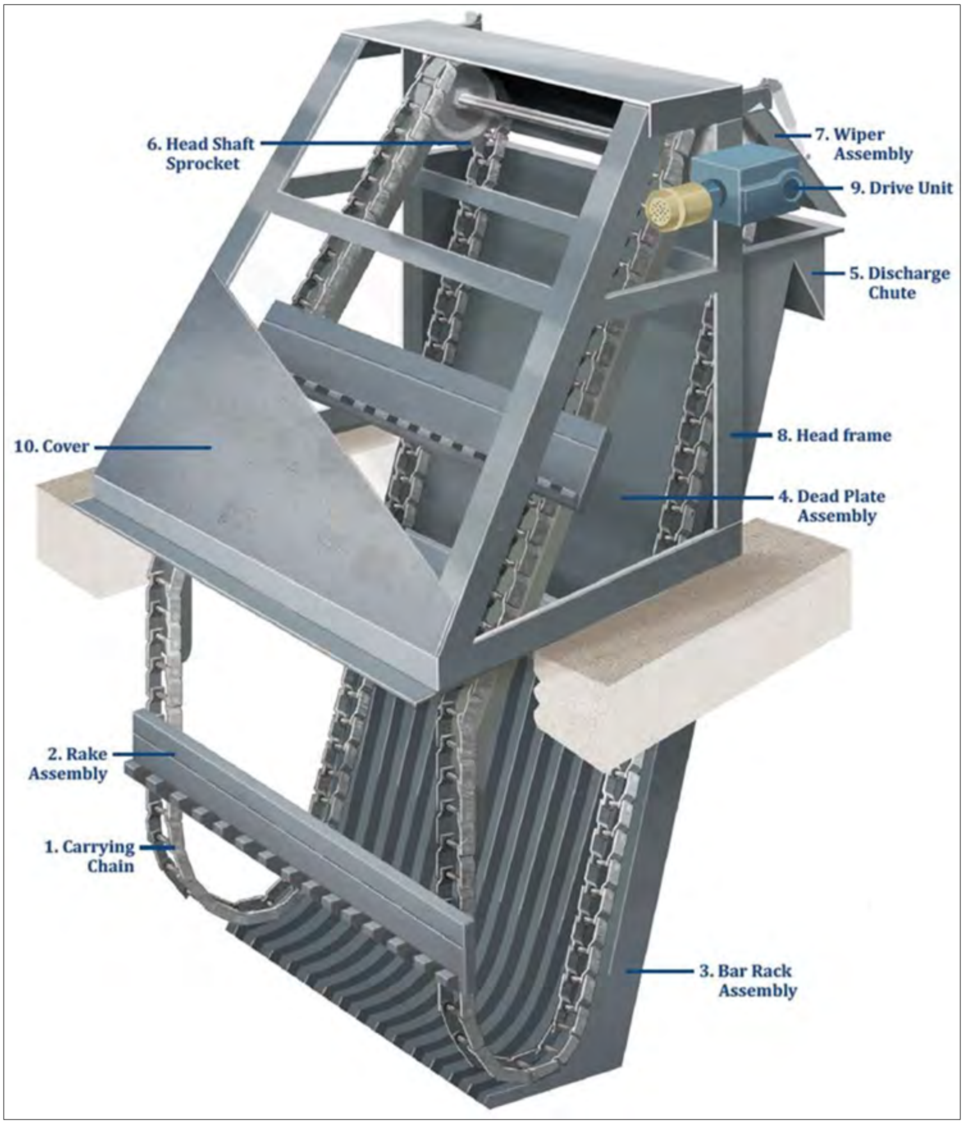

Figure 13.10. Catenary Trash Rake – courtesy E&I Corporation

e. Unguided catenary trash rakes. The unguided catenary trash rake consists of a free-hanging chain with rake beams spaced approximately every 3.0 to 4.6 meters (10 to 15 feet) along the chain.

(1) The chains are supported by an idler sprocket at the top of the trash rack and a driven sprocket located at the same elevation as the idler sprocket and a sufficient distance from the trash rack so that the free hanging chain makes contact with the bottom of the rack.

(2) A typical unguided catenary trash rake is shown on Figure 13.11. The trash removal capability of the unguided catenary trash rake would include material classes 1 and 2 with some limited capability of classes 3 and 4. Items of size greater than the depth of the rake beams are usually not removed by the rakes.

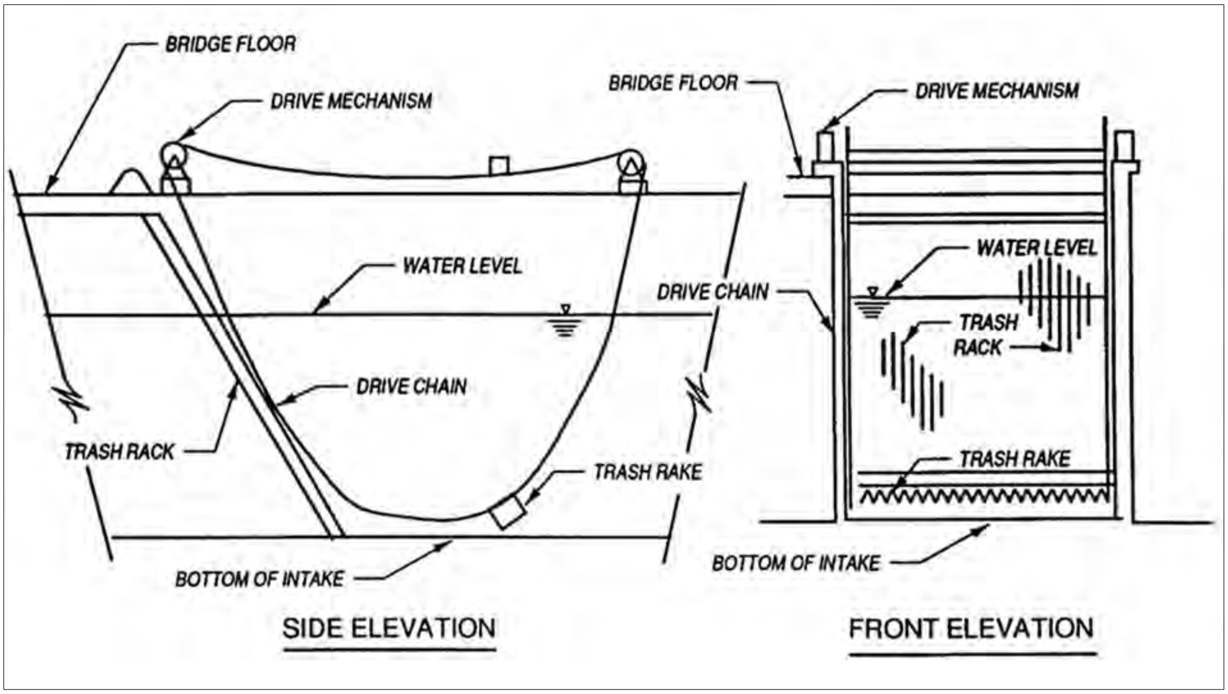

Figure 13.11. Unguided Catenary Arrangement

f. Guided catenary trash rakes. The guided catenary trash rake is the same as the unguided catenary trash rake except that the down leg of the chain from the driven sprocket is guided to ensure that the chain reaches the bottom of the rack. A typical guided catenary trash rake is shown on Figure 13.12. The trash removal capability of the guided trash rake would include material classes 1 and 2. As with the unguided type, this rake can on a limited basis handle some class 3 and 4 material depending on its size.

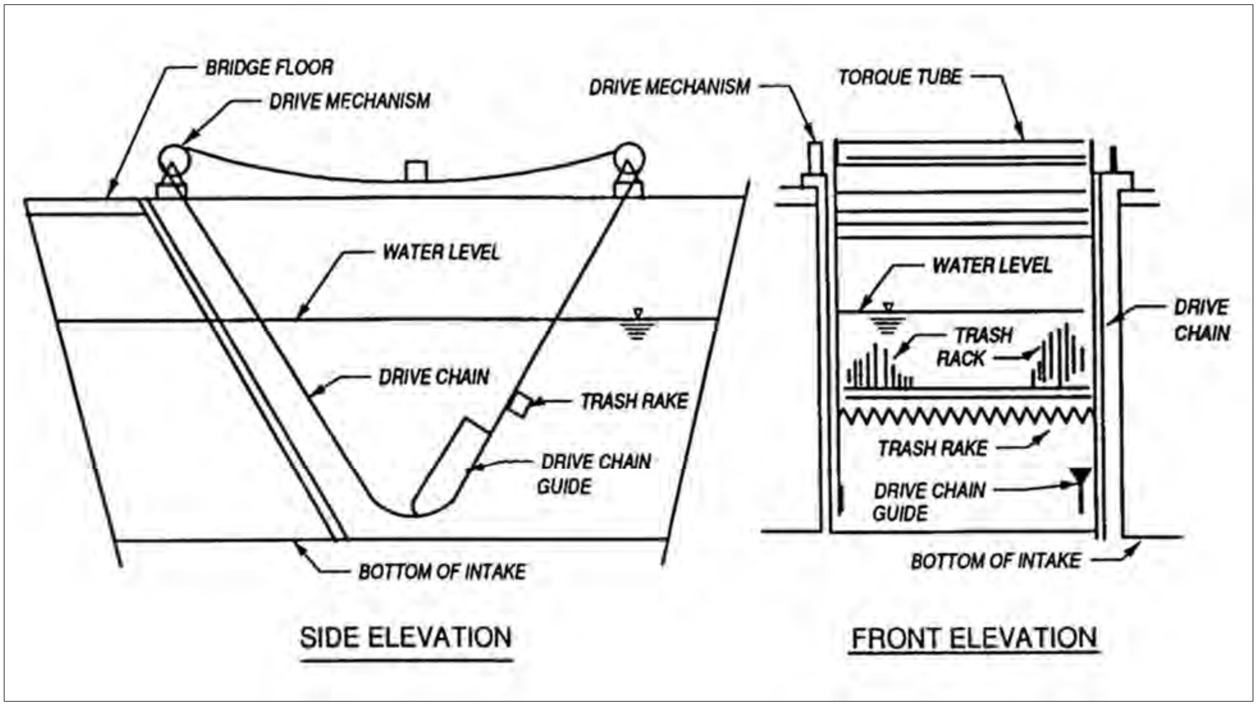

Figure 13.12. Guided Catenary Arrangement

Chapter 14
Miscellaneous Equipment

14.1 Stoplogs. Most closures by stop logs require multiple stop logs, stacked, to reach the level of protection desired. Figure 14.1 shows a typical stop log assembly. Stop log placement usually requires a mobile crane. A mobile crane will typically not be furnished as part of the station construction. Sufficient stop logs should be furnished to allow one pump sump area to be unwatered. Stop logs should be constructed of a material that requires a minimum amount of maintenance. In most cases, aluminum stop logs best satisfy the weight and corrosion requirements. Storage at the station with convenient access should be provided.

Figure 14.1. Stop Log Closure

14.2 Bulkheads. Bulkheads most often consist of a single fabricated steel unit. See Figures 14.2 and 14.3. Bulkheads can be set faster than stoplogs and therefore, should be considered when closure must be achieved quickly. Bulkhead placement will require a larger capacity mobile crane than that required to place stoplogs. See ETL 1110-2-584 for further information regarding the design of stoplogs and bulkheads.

Figure 14.2. Bulkhead Placement

Figure 14.3. Bulkheads placed in front of pump station

14.3 Slide Gates. The terms slide gates and sluice gates are often used interchangeably today. Traditionally, however, sluice gates referred to cast iron gates built as described in AWWA C560. Side wedges typically of bronze are used to help seal the gate to the frame. Slide gates follow the requirements in AWWA C561.

a. Sluice gates and slide gates for pump stations should either be cast iron construction or welded stainless steel construction. Slide gates and sluice gates are classified as either pressure-seating or pressure-unseating type and having either a rising or a non-rising stem. In all cases, slide and sluice gates should be designed to provide positive seating.

b. Slide and sluice gates provide a more positive means of sealing than any other types of closure. In selection of sizes and shapes of gates today, the utilization of manufacturers' standard products should be used in order to avoid necessity for special designs. In general, the use of pressure unseating gates should be avoided unless the stem threads are exposed to fouling or abrasive materials, it would be difficult to maintain the wedges due to continuous submergence, or it would be costly to either bulkhead or cofferdam the upstream side.

c. Rising-stem gates are preferred due to their easy maintenance and the locations of thread engagement outside the corrosive area.

d. Non-rising stems are to be used only if there is insufficient head room for a rising stem. Slide gates are normally limited to a 3.0 meter (10 foot) opening width.

e. Gates used for pumping station service are usually of the flush bottom style. This style gate permits station design without steps in the flow line. All gates should be mounted on an "F" type wall thimble which is cast into the concrete wall. A flange back type gate is recommended since they are the strongest. For sluice gates, the gate frame and slide should be of cast material with all wedges, seats, and fasteners to be constructed of bronze or stainless steel. Slide gate frames should be stainless steel.

f. Cast iron sluice gates are becoming more difficult to procure because of the limited number of foundries. Fabricated stainless steel gates (Figure 14.4) are typically more prevalent and available in both seating and unseating head applications. Where exposed to salt or brackish water, welded stainless steel slide gates should be used. Stainless steel should be material acceptable for saltwater application. See Chapter 15. The gate stems should be made of stainless steel. ANSI/AWWA C560 covers cast-iron sluice gates. ANSI/AWWA C561 covers fabricated stainless steel slide gates.

Figure 14.4. Fabricated Stainless Steel Slide Gate

g. Sump Closure Gate Sizing. The size of gate required is determined using the maximum pumping capacity of the station and the number of pumps. The example below is provided in English units. The velocity through the gates at the maximum capacity should be limited to 0.6 m/s or 2.0 fps to achieve the best flow conditions to the pump when used for sump closure. The maximum capacity of the station can be estimated at 33 percent above the design capacity.

Example (English Units): Station Capacity = 180 cfs
No. of Pumps = 3

$$V = \frac{Q}{A} \qquad \text{(Equation 14.1)}$$

where

V = Velocity through gate = 2.0 fps
Q = Flow through a gate = $\frac{Max.Cap,}{3}$
$Max.Cap.$ =180 x 1.33=240 cfs
$\therefore Q = \frac{240}{3} = 80$ cfs
$A =$ Gate area in ft^2

$2.0 = \frac{80}{A}$, $\therefore A = 40$ ft^2

where

W = Gate opening width in feet
H = Gate opening height in feet

Note: The gate opening height and width are then determined using the area calculated, the sump floor elevation, sump width, and the minimum pumping elevation. The top of the gate opening should not be higher than the minimum pumping elevation. If this is not possible at a particular site, then the top of the gate opening should not be higher than the elevation at which all pumps are operating. For this example use:

$$40 = H \times W \Rightarrow H = 5 \text{ ft and } W = 8 \text{ ft} \quad \text{(Equation 14.2)}$$

h. Gate Operators.

(1) Gate operators may be manual or motorized, but only motorized slide gate operators should be considered for pump stations where electric power is readily available.

(2) Gate Operator Sizing. The size of the gate operator is determined by first calculating the force needed to open the gate with the maximum differential head acting on the gate. This will normally occur when the sump is dry and the maximum expected forebay water elevation is present.

(a) There are three terms used during the selection of a motorized gate operator: run torque, pullout torque, and stall torque. The definition of each of these terms is as follows:

- Pullout torque. This is the torque the operator develops to initially break the seal caused by the wedges on the sluice gate; operators are designed to develop this torque for only a short period of time.

- Run torque. This is the torque the operator develops to move the gate after the wedge seal is broken; operators should be designed to develop this torque continuously.

- Stall torque. This is the torque that is developed by the operator just as the motor stalls out; this is the maximum torque which will be exerted on the gate stem.

(b) Example (English Units): See Figure 14.5:

Gate centerline - El 50.0
Maximum expected forebay water elev. - El 54.0
Gate height - 5.0 ft. Gate width - 8.0 ft.
Operating floor elevation - el. 65.0

$$F_u = 62.4 \times S \times A \times f_u + W_g + W_s \qquad \text{(Equation 14.3)}$$

where

F_u = Maximum required gate unseating force, lbf
S = The distance from gate centerline to maximum forebay water elev., ft.
A = Gate opening are, ft^2
f_u = Friction factor for unseating (bronze seals)
W_G = Weight of the movable disk, lb (standard sluice gate catalog info.)
W_s = Weight of stem, lb (standard sluice gate catalog info.)

For this example (English Units only):

S = El.54.0 - El.50.0 = 4 ft.
A = 5×8 = 40 ft^2
f_u = 0.6
W_G = 4,900 lb
W_s = 396.5 lb
∴ F_u = 62.4×4.0×40.0×0.6+4,900+396.5 = 11,287 lbf

(c) Preliminary hoist and stem size. This force or thrust to unseat the gate is then compared with manufacturers of motorized gate operators' catalog information to determine a preliminary hoist and stem size.

(d) Required torque. The required torque (ft-lb) is determined by multiplying the calculated thrust with the stem factor (provided by manufacturer). For this example the stem factor is 0.0204 with 3 threads per inch.

The resultant torque = 11,287 × 0.0204 = 230.3 ft-lb

(e) Output rotation speed. The required output rotation speed of the operator (in rpm) is then determined. For this example, the desired gate travel speed is approximately 1 foot per minute.

Stem Nut Rotation Speed = (1 ft/min)(12 in/ft)(3 threads/in) = 36 rpm

(f) The torque required of 230.3 ft-lb and speed of 36 rpm is used to select an operator.

(g) The electric data for this operator is then obtained from either the catalog or directly from the manufacturers. This data is used for preparing the electrical design of the station.

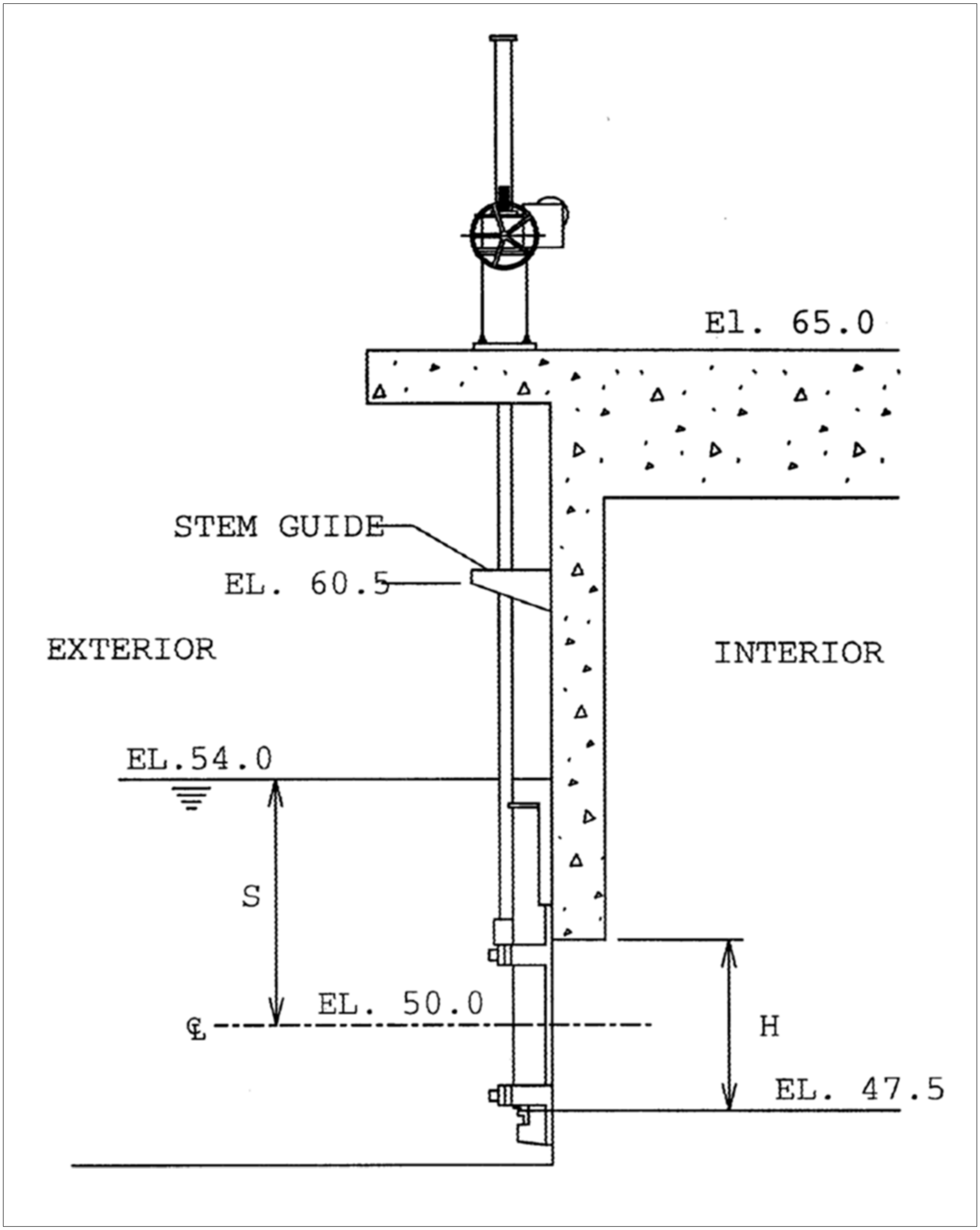

Figure 14.5. Sluice Gate Operator

i. Maximum Loads on Stem. The maximum loads which can be transferred to the stem and the structure are calculated. The design must be such that the stem would fail before any supporting structural failure would occur. The maximum loads are based on 125 percent of the stall torque (taken from published catalog information) of the operator selected.

(1) For this example, the stall torque of the selected operator is 481 ft-lb (this figure should always be verified by the gate operator manufacturer).

Max. Thrust = (Stall Torque × 1.25)/Stem Factor = (481 × 1.25)/0.0204 = 29,473 lbf

(2) The maximum thrust is an upward thrust of 30 kips and a downward thrust of 35 kips (this includes the dead weight of the gate itself).

(3) The required spacing of the stem guides is then determined. The Euler Column Formula is used (English units):

$$F_{CR} = \frac{C^2EA}{\left(\frac{L}{r}\right)^2} \qquad \text{(Equation 14.4)}$$

where

F_{CR} = Maximum thrust, lbf
C = End condition factor
E = Modulus of elasticity, psi
A = Cross-sectional area of the stem, in2
L = Maximum unsupported length of stem, in.
r = Radius of gyration, in.

(4) The L/r ratio must not exceed 200.

(5) For this example (English Units):

C = 2 (for all slide gate computations)
E = 28,000,000 psi (for stainless steel)
A = for threaded portion = 2.14 in^2
for plain portion = 3.14 in^2
r = for threaded portion = 0.41 in.
for plain portion = 0.50 in.

(6) Using these numbers, the maximum unsupported lengths of the stems can be calculated (English units):

$$L = r\sqrt{\frac{C \times E \times A}{F_{CR}}} \qquad \text{(Equation 14.5)}$$

where

Maximum length of threaded stem (LMT) = 82.2 in.
Maximum length of plain stem (LMS) = 121.5 in.

(7) However, at an L/r ratio of 200.

$LMT = 200 \times 0.41 = 82$ in.
$LMS = 200 \times 0.50 = 100$ in.

(8) Since both the L/r ratio < 200 and the Euler's Column Formula criteria have to be met, the criterion resulting in the shortest lengths is used. For this example, the L/r ratio < 200 criterion has resulted in the shortest lengths. Two stem guides are located to meet these calculated lengths. Figure 14.5 shows that one stem guide was placed at elevation 60.5 or 96 inches (8.0 feet) above the top of the gate (this length of stem is solid; therefore, the previously calculated 100 inch maximum length is applied). The other stem guide would be located at the bottom of the gate operator base. This location would result in a length between guides of 54 inches, which is less than the minimum for threaded stem (82 inch).

j. Position limit switches. All motorized gate operators must be equipped with position limit switches in the open and closed positions. In addition, mechanical torque limit switches must be provided. These would provide backup in case the position limit switches fail or if debris jams the gate while opening or closing.

k. If the gate is extra wide or if the ratio of the width to the height is equal to or greater than 2:1, the gates are normally raised and lowered through the use of two stems placed near each side of the gate. Each stem passes through a geared operator. The geared operators are both connected to an electric or hydraulic operator located between the two stems. The loads incurred by raising the gate are equally distributed between the two stems.

14.4 Roller Gates.

a. Roller gates are an alternative closure with a lower required opening and closing force. The tradeoff is that roller gates are more expensive and require more maintenance.

b. The same computations are done for roller gates to size the operators and structural design loads. The force required to open this type of gate is the sum of gate weight, stem weight, seal friction, and roller friction. The seal friction is a result of the deflection of the rubber J-seal attached to the top and sides of the gate.

c. The roller friction is a result of the bearing friction in the roller and the roller-to-rail friction. The amount of seal and roller friction will vary depending on the types of materials used for the roller wheels, roller bearings, rails and seal plates.

d. During the early design phases of a pump station, a roller gate manufacturer should be consulted to assist in determining the design loads, forces, and lifting arrangement.

14.5 Lubrication Systems. The pump lubrication system should be automatic as shown in Figure 14.6 with a control system that provides a pre-lube cycle before the pumps are allowed to start and adjustable period between greasing cycles. Automatic greasing systems should be controlled by a PLC system and include a timer to control the greasing cycle. This has to be coordinated with the pump manufacturer.

a. Manual greasing systems (Figure 14.7) should be considered for use only on pumps such as sump pump and for flood risk management pumps whose capacity is less than 600 liters per second (20 cfs) and where the time of operation is such that daily greasing would not be required. These systems typically will have a hand crank used to grease bearings.

b. The frequency of greasing is based both on the manufacturer's recommendations and how the equipment will be operated. See Chapter 4 for further information regarding pump bearing lubrication.

Figure 14.6. Automatic Lubrication System

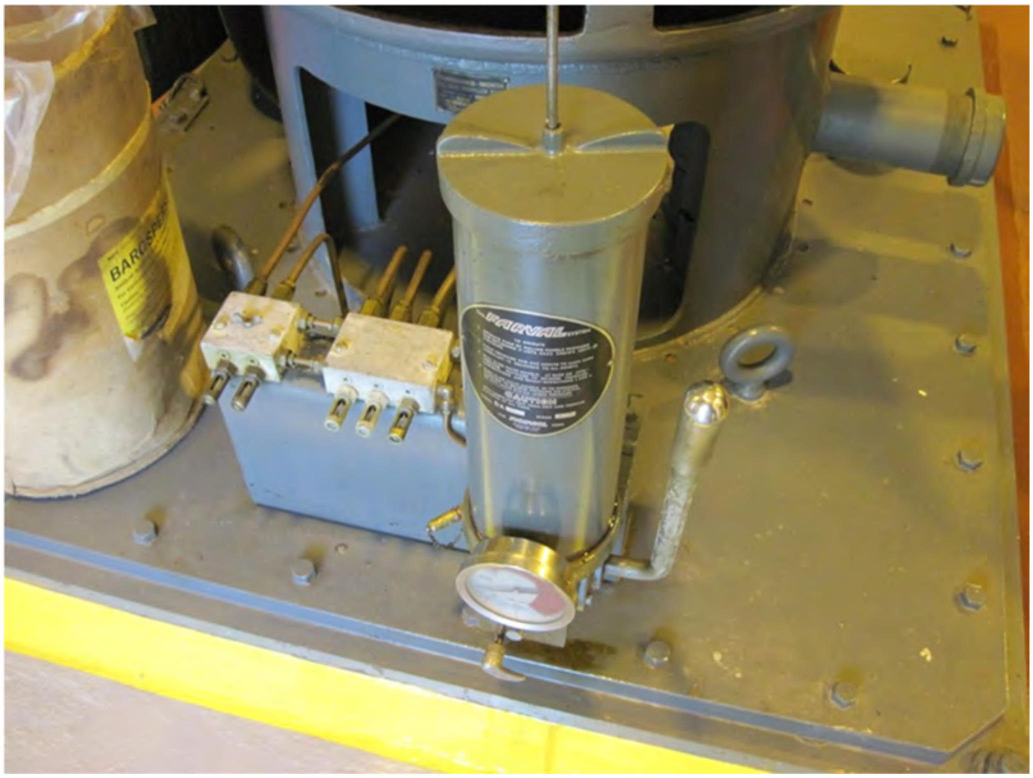

Figure 14.7. Manual Lubrication System

14.6 <u>Ventilation</u>.

a. General. Proper ventilation of pumping stations is an important design consideration and is provided for both safety and heat removal purposes.

b. Ventilation of the pump station should be provided separately for the sump area and the operating areas. All ventilation equipment should be rated for the most appropriate hazard condition based on the site and local codes, per OSHA, 29 CFR 1910.399, NFPA 820 and NFPA 70.

c. The operating period, equipment ratings, duct arrangements, locations of outlets and fresh air inlets, and all other details should be based on accepted principles outlined in publications of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). Specifically, ASHRAE 62.1 can be referenced for applicable ventilation requirements of the operating room.

d. Sump ventilation. Mechanically forced ventilation should be provided for all pump sumps during operating periods to prevent accumulation of gases. This manual does not classify sump areas of the station as a hazardous location per NFPA 820. The designer needs to determine the proper classification of the sump area per site design conditions, type of inflow and local codes. For many flood risk management projects already in service, the sump area is not defined as a hazardous location. Regardless of classification, the sump area should be designated as a confined space per applicable OSHA requirements.

(1) Gravity ventilation of the sump may be adequate if the trash rack is not enclosed; operation of pumping equipment is not required from a platform within the sump; the station is not in an urban area adjacent to a sewer where explosive conditions are known to exist; or the sump is not exposed to sewer gases from any source. The design of the sump area, however, should still be treated as a confined space per OSHA requirements.

(2) For those cases where the hazard of an explosion exists, the ventilation should be designed as discussed in NFPA 820 and NFPA 70 so that the station may be continuously ventilated. The designer must document in the project design report the specific reasons for a hazardous classification. The mechanical ventilation of sumps should be accomplished using motor-driven blowers removing air from the sump while fresh air is ducted into the sump. The blower should be located outside the sump and should be connected to ductwork that takes air from the sump and discharges to the atmosphere outside the station.

(3) The discharge from the blower should be located such that recirculation of fumes into the operating area is minimized. The suction ducts from the blower should run to a point near the sump floor and should be equipped with louvers that allow suction from either the floor or ceiling area of the sump. The louvers should be operable from outside the sump.

(4) If the sumps are separated in such a way that openings are not located at both the top and bottom of the sumps, individual ventilation will be required for each sump. It is a requirement that all sump areas must be ventilated before any personnel enter.

(5) The mechanical ventilation rate should provide a minimum of 15 air changes per hour based on the total volume of an empty sump. This value may need to be increased depending on the classification of the sump area. The fresh air inlet areas should be a minimum of twice the outlet area to prevent high losses. For stations pumping sanitary flows or a mixture thereof, the ventilation system should be in operation continuously when in a pumping mode.

e. Operating area ventilation. The operating area is ventilated to remove any gases and excess heat buildup caused by the operation of the electrical and mechanical equipment.

(1) The system design is based on the amount of air to be removed in order to have an inside temperature not greater than 95° F (35° C).

(2) The design should consider outside maximum temperatures occurring coincident with operation. As a minimum, the ventilation equipment should be designed for at least six air changes per hour to provide ventilation during non-pumping periods. Gravity or mechanical ventilating equipment can be used to satisfy these requirements.

14.7 Comfort Heating and Air Conditioning. A heated space should be provided for operator use during pumping operations. Either an air-conditioned space or ventilated space should also be provided for the operating room.

a. This will depend on the station location, size of station and operator preference. Generally, whether or not cooling is included is dependent on occupancy classification and operator comfort/safety. The designer will need to determine this during the early phases of the pump station design.

b. Sometimes the electrical room can be split from the pump room and air conditioned separately and this can be a consideration. The designer will need to reference and utilize applicable codes including ASHRAE and applicable guide specifications and Unified Facilities Criteria (UFC).

c. Specifically, UFC 3-410-01 Heating, Ventilating, and Air Conditioning Systems can be referenced. The operating room can often be heated and cooled with a small packaged unit for smaller stations. Larger stations will require more complex heating and cooling systems.

d. The entire operating room should be provided with a heating system capable of maintaining a temperature of 55° F (13° C) when outside temperatures are at the normal low temperature for that area. These heaters are provided to permit maintenance operations at any time of the year and are often electric since their operation time will be limited.

14.8 Equipment Protection.

a. Various means have been used to protect equipment, particularly the electrical equipment, of pumping stations from deterioration and general moisture. The methods employed are:

(1) Providing electric heaters within the housings of the motors and switchgear.

(2) Heating the operating room.

(3) Dehumidification of the operating-room area, which includes sealing of the motor room and the application of vapor barrier material to the interior surfaces.

(4) Heating the interior of the motors and switchgear by means of a central heating plant.

(5) Dehumidification of the interior of the motors and switchgear by means of individual dehumidifiers.

b. Operating experience indicates that method (1) above is the most practical and economical for small- and medium-size stations. For the larger stations, using motors rated

1,500 kW (2,000 HP) and above, methods (4) and (5) may be feasible. Dehumidification methods are usually less costly to operate; however, maintenance and replacement costs are such that local users seldom keep the units running after initial failure. The sizing of electric heating elements in system (1) is done by the equipment supplier; however, the ambient conditions should be specified for this equipment.

14.9 Equipment Handling.

a. General. A station crane should be provided, for all but the smallest stations, for handling the major items of equipment. The crane should be sized to lift the heaviest, fully assembled, single piece of equipment.

b. Small stations may be built with removable ceiling hatches so that a mobile crane may be used when work is required. Metal buildings should be designed to allow removing the roof hatches without reducing the building's stability. Load and reach requirements of a mobile crane, for removal of the pumping units, should be furnished with the design of the building. A concrete slab outside of the equipment door should be provided and sized to hold the larger pieces of the disassembled pumping unit and driver.

c. Station cranes. There are several UFGS specifications available on Whole Building Design Guide for cranes (Division 41 Materials Processing and Handling).

(1) Since the service expected of the crane is standby, a Class A type described in the Crane Manufacturers Association of America can be used. Bridge-type cranes are usually used, but a monorail type over the pumping units may be used if that is the only requirement for the crane and it is capable of doing the job.

(2) Monorail cranes with the travel rail located over the equipment should also be considered. When providing a monorail-type crane, there should be sufficient space in the station to place equipment. An alternate would be to continue the rail outside of the station where room would be provided to place equipment.

(3) Cranes of less than 2,722 kilogram (3 ton) lifting capacity may be of the manual type but this has to be coordinated with the station maintenance and operation staff.

(4) Cranes with capacities from 2,722 to 9,072 kilogram (3 to 10 ton) lifting capacity may be equipped with a motorized hoist while still retaining manual travel arrangements.

(5) Cranes over 9,072 kilogram (10 ton) capacity should be of the three-motor type, where all functions of the crane are motorized. Hoist and travel speeds can be kept to a minimum since the crane will be used only for major maintenance.

(6) Cranes over 9,072 kilogram (10 ton) capacity should be equipped with multi-speed type controls with speeds such that "inching" is possible to permit close positioning of the loads.

The high position of the crane hook should be at such an elevation to permit removal of the pump in pieces; however, allowance should be made for use of slings and lifting beams plus some free space. If a hatch is provided in the operating floor, the crane hook should have sufficient travel to reach the sump floor to permit removal of items from the sump.

(7) The crane should have a capacity large enough to lift either the completely assembled motor or pump, but not both at the same time except for submersible pumping units, in which case the entire unit is lifted.

(8) Consideration should be given to removal of equipment from the station when determining the crane travel requirements. It may be necessary to run the crane rails to the outside of the station in order to load the equipment onto hauling equipment rather than provide space inside the station for this equipment. Because most stations are usually located some distance from rail facilities, trucks should be considered for movement of the equipment to or from the station.

(9) Station design may permit the use of chain blocks from I-beams or from arrangements of hooks in the operating room ceiling where the loads are small. Permanently embedded eyes or hooks in the sump may be required for those pump parts that cannot be raised overhead with the station crane. This is usually required only for those pumps that have part of the pump bowl embedded in the sump ceiling.

d. Mobile. The mobile crane should be located within 8 hour travel time to the pumping station. Roads to the station and clearance of utility lines should be confirmed after the mobile crane is sized. If available cranes cannot meet these conditions, then an inside overhead crane must be provided.

14.10 Fire Protection. Fire protection requirements will vary depending on size of station, local codes and level of occupancy. The designer will need to determine all these requirements.

a. Pumping stations are considered Special Purpose Industrial Occupancy as defined in NFPA 101, Chapter 28. The designer should also utilize UFC 3-600-01 Fire Protection Engineering for Facilities as applicable.

b. At a minimum, fire protection should be provided by portable fire extinguishers. Fire protection requirements for diesel driven stations are provided in NFPA 37. The number, size, and type of portable fire extinguisher must be provided as specified in NFPA 10.

14.11 Compressed Air System. Compressed air is used in pump stations generally for engine starting, instruments, controls, or service. Sometimes compressed air is utilized for ice control (see below).

a. The compressed air system should include two air compressors, one of which is redundant. If compressed air is used for engine starting, a receiver tank should be provided for each engine. In addition, an air receiver should be provided for the instrument and service air.

b. Instrument and service air pressure should be reduced by two pressure reducing valves, piped in series for reliability. Instrument air should be further conditioned in through a particulate filter and refrigerated air dryer.

c. Service air outlets should be placed strategically throughout the station as needed. Control air is often used to operate valves and other control devices. Air compressors should be electric powered and for engine starting should be capable of supplying a minimum of 250 pounds per square inch (psi) air to the engine receivers.

d. Each engine receiver should contain enough volume for a minimum of four starts. The air receivers should be isolatable from the starting airline to prevent loss of instrument air in the event of the loss of the starting airline.

e. The compressors should automatically alternate and have “hand-off-auto” control switches at the compressors. Pressure sensors should signal low and high pressure in the control room. Each air receiver tank should have a 6 inch (150mm) access port for inspection, and the tank should be epoxy coated.

14.12 Physical Security. Measures should be taken to protect pump stations from vandalism and unauthorized entry. Security features should include closed circuit television cameras and intrusion alarm switches on all doors and other openings. Cameras should be located at each door and other critical locations. Cameras may also be located at the suction discharge basins. Security features should be coordinated with the owner to ensure compatibility with existing remote monitoring systems and security equipment at the owner’s other facilities.

14.13 Louvers. The designer needs to consider the specific location and application for louvers in pump station buildings. Coastal areas subject to hurricanes will have different design requirements. For locations that may have periodic hurricanes, putting a large opening in the pump station wall may not be acceptable due to compromised structural integrity and the potential for wind-driven rain through a large, louvered opening.

a. Wall louvers should be weather resistant and supplied with bird or insect screens. The material of construction should be aluminum or stainless steel and should be rated for air performance and water penetration described in Air Movement and Control Association 500-D and Air Movement and Control Association 511. Water penetration should be less than one ounce per square foot of free area at a velocity of 800 feet per minute. Where any water penetration is a problem or there is a need to close the opening during periods of non-operation operable louvers or dampers should be provided. Local and state building codes should be followed when selecting louvers.

b. Louvers for Coastal Areas. Wall louvers for coastal areas are required to be additionally resistant to wind, rain, and wind-blown debris. Not all louvers are designed for rain exclusion during a high wind event, and this should be taken under consideration. Louvers in coastal areas must be properly designed to account for wind-driven rain.

(1) Because of susceptibility to hurricanes, Miami-Dade County in Florida has strict building codes that include debris resistance. Louver manufacturers will indicate louvers that are Miami-Dade County approved for high wind load and impact resistance.

(2) Testing for hurricane resistant louvers is covered by Air Movement and Control Association 550. Louver requirements are also provided in the SFWMD guidelines.

14.14 Bubbler Systems. Air bubbler systems may be included for either ice control or level measurement.

a. Bubblers for Ice Control. The formation of ice in pump station intakes and sumps can interfere with pump operation and may also damage equipment. Bubblers using compressed air for ice control are used extensively on locks and other navigation structures and also used at pump stations. They work by bringing warmer water to surface and thus retarding the formation of ice. They also may be used to form a barrier to keep ice from floating into an area.

b. Bubblers and other ice control methods are discussed in EM 1110-2-1612. Also, bubbler systems for navigation structures are discussed in EM 1110-2-2610. Many of the principles discussed in that manual are also applicable to pump stations.

c. Bubblers for level measurement are usually of the air-purged type. The nitrogen gas purged type is usually employed at remote sensing areas where power to run the air compressor of an air-purge system operates by purging air into a channel, sump, etc., through a tube and measuring the back pressure which varies in proportion to the variation in liquid level. A linear variable differential transformer is usually used to convert pressure readings to low voltage or current signals. When used in sufficient number, this system may be less expensive than an equivalent float-actuated system. However, it is more complex and is subject to clogging in highly silt laden waters.

14.15 Other Ice Control Methods. As mentioned above, the formation of ice can interfere with pump or gate operation. Various methods have been used to control the formation of ice at USACE facilities.

a. These include heaters installed under seal plates, embedded electric heat tracing, panel heaters, and systems circulating hot water, oil, or other heat transfer medium. Also, ice can be removed with steam lances or spraying hot water.

b. Another area of research is the application of surface treatments or coatings to reduce ice adhesion. This is discussed along with various types of heaters and applications along example calculations in detail in EM 1110-2-1612. Another document which provides an in-depth discussion of ice control methods is Technical Report REMR-HY-14, Ice Control Techniques for USACE Projects available from the ERDC online library. ERDC's Cold Regions Research Lab is available to provide assistance as requested.

Chapter 15
Materials and Coatings

15.1 General. This chapter includes information used in the selection of materials and coatings for various components in a pumping station. It is not intended to be a restrictive list or an all-inclusive detailing of the solutions available, but instead a set of information to take into account when designing new systems or stations, as well as updating existing pump station components.

a. Many factors exist that will shape the approach taken for materials and coatings. Criticality of the station or subsystem, coupled with initial cost, schedule, and availability of materials will affect the approach taken as much as environmental conditions, and personnel, access, and funding available for periodic maintenance.

b. In addition, materials, coatings, and external protections are presented and should be considered as a collective protection system and not separate elements of a component or system in order to maximize the useful life of a pumping station. How the selected material for a given component or system is protected is as critical as the material itself and should be actively considered as part of the functional life of the component or system. A survey of protection methods that have been used in the same process water should be performed, noting both the successful and unsuccessful results from both users and suppliers.

c. As discussed in Chapter 2, most flood protection projects are built for an overall 50-year life, but the station equipment, due to technical or economical limitations may not be able to obtain a 50-year design life. The materials and coatings utilized for that equipment are an integral part of that design life.

d. Comparison of the cost and complexity of initial material verses total life cycle costs and complexities coatings should be included in design life evaluation. Where possible, the recommended minimum design life of 35 years for a station component should be obtained without the protective coating being included in the evaluation. Use of a coating requiring extensive maintenance action (multiple inspections or reapplications over short life cycle) in order to meet design life should only be employed when all other approaches are technically and economically not feasible.

e. USACE Corrosion Control and Cathodic Protection Systems TCX in Mobile District and ERDC's Construction Engineering Research Laboratory (CERL) are USACE sources for technical recommendations and testing concerning materials and coatings.

f. ANSI/HI 9.1-9.5 Pumps – General Guidelines should be consulted for additional recommendations for materials on the various components for the multiple types of pumps and auxiliary systems.

15.2 Considerations for Material Selection. There are multiple elements to consider when selecting the materials for the main components of a pump station pump. What is successful at one facility may not yield the same results are another facility.

a. Even more complex is that a set of materials will work in one location of a pump station and not in another. In selecting materials for application in a pump station there is not a one size fits all and in order to have longevity and functionality, an assessment must be made in order to make an educated decision on what is to be used. Evaluate the economics in using exotic and expensive materials to justify initial cost versus life expectancy and total life cycle costs including inspection, maintenance and replacement.

b. Flow conditions both maximum as well as fluctuations in velocity can influence a material and coating approach. Some locations have a general constant velocity while with storm surge pump stations there are periods of stagnate environment which can shift to high velocity flows.

c. Medium being conveyed. What is coming in contact with the station components will affect the material and coating approach. This is not only the salinity of the water (fresh water vs brackish vs fully salt water), but also clear water vs high sediment vs larger particulates. Fresh water with high sediment can be a harsh on a coating as clear brackish water.

d. Types for corrosion to be considered. Various types of wear need to be considered including cavitation erosion, erosion corrosion, corrosion fatigue and abrasive wear. Different materials, assembly processes, and overall designs will address each of these at various levels. Some solutions may trade off resistance to one corrosion for a higher susceptibility to another.

e. Galling resistance is where one or both elements coming into contact resist the transfer of material to the other.

(1) Utilizing bronze-based materials is a common method to avoid galling. However, bronze based material are not always a solution due to corrosion, such as in media with higher salinity. In these type of applications stainless steels are more likely to provide the longevity of functional life needed.

(2) However, stainless steel being utilized for two interacting surfaces have a high probability of galling. The variation of surface hardness has been known to reduce the probability of a galling issue, but a lubricating medium may be needed to further aid in galling resistance.

15.3 Material Quality. The life span data of materials is based on the assumption that the material is the chemical and material composition of the specified material.

a. As part of the procurement of the material and components, it is important to obtain and confirm the material quality and processing certification of what is being received. The material sources should be required, as well as material testing. It may be necessary to prohibit certain sources if the application is critical.

b. The government may wish to obtain samples and perform independent testing of the material to confirm adherence to the standards. It is recommended that the contractor have material tested at a 3rd party lab or that a government representative be present during the sampling and testing for any unique or critical materials or components. An example is the material testing of large impellers.

15.4 Passivation. A process that is used with stainless steel, especially on pump impeller hubs is passivation. The designer should consult ASTM A967 / A967M - 13 "Standard Specification for Chemical Passivation Treatments for Stainless Steel Parts".

a. It notes the "Stainless steels are corrosion-resistant by nature, which might suggest that passivating them would be unnecessary. However, stainless steels are not completely impervious to rusting.

b. One common mode of corrosion in corrosion-resistant steels is when small spots on the surface begin to rust because grain boundaries or embedded bits of foreign matter allow water molecules to oxidize some of the iron in those spots despite the alloying chromium.

c. The process of passivation process removes materials that may have been embedded during machining. These discontinuities in the material can be sources of localized corrosion, so their removal will return the stainless steel to condition where the surface is more robust in resistance to corrosion. Passivation does not visually change the material.

15.5 Material Interaction.

a. Evaluation of the materials selected should include an assessment of direct and non-direct interactions with other materials in order to examine potential impacts on longevity and durability. A galvanic corrosion chart should be consulted when determining a set of materials to be used in a system or when trouble shooting a field failure. Dissimilar metals and galvanic corrosion generally fall into 4 groupings that depending on the two materials involved may or may not result in loss of material from one of the two components:

(1) Direct contact non-aqueous.

(2) Direct contract periodically in an aqueous solution or fully submerged. Stagnant exposure and turbulent exposure.

(3) Non-direct contact but periodically in an aqueous solution or fully submerged (Stainless steel creates a region of corrosion for carbon steel elements. Care should be taken with threaded elements, such as nuts and bolts.

(4) Periodic usage of components if dissimilar. Example being impeller with ring.

(5) NOTE: The higher the salinity of the aqueous solution, the more likelihood of galvanic corrosion.

b. When designing a new system or component, an attempt should be made to either reduce or altered the galvanic corrosion potential. An example of reducing the galvanic corrosion potential is to have an interface between a carbon steel pipe and a stainless steel intake filter occur inside the station, instead of submerged. A stainless steel extension pipe can be used to connect with the filter underwater and extend into the station where it can connect with an isolating gasket and the carbon steel pipe. The small increase in material cost for that segment of piping would greatly reduce both the need for periodic inspection but also increase the life span of that system.

c. Environments of high humidity present a condition that is similar to a direct exposure condition, and selection of interacting materials should be chosen assuming this condition.

d. When utilizing materials that have a high galvanic interaction potential, material protections discussed further in the chapter can be employed. However, it is critical that ease of accessibility for both inspection and replacement be considered when developing the design.

15.6 Recommended Applications. Corrosion (Cavitation erosion, erosion corrosion, corrosion fatigue and abrasive wear), casting and machining properties, criticality of the component or system, and the overall cost should be evaluated collectively to determine what materials should be used.

a. As in many applications, it may be justified in one location to use a less costly material such as a bronze impeller while in others a stainless steel impeller should be used. It is recommended to conduct an analysis of process water, and perform a survey of materials coatings that have and have not been successfully when used in the same process water.

b. If there is limited information available on planned or recommended material then performing a drop test coupon in the same water, if possible, is recommended. Obtain recommendations from potential equipment manufacturers with their experience in the same process water, including any lab testing results, information on example locations, points of contact and inspection details.

15.7 Common Materials. Common materials used for elements in a pump station pump include cast iron, bronze, cast steel, manganese bronze, 300 series stainless steel and 400 series stainless steel.

a. The most basic small pump will use a bronze impeller and cast iron case. However, such a material pairing will have corrosion and erosion concerns over time, especially in a high velocity or increased water salinity, or water containing higher amounts of coarse sediment.

b. It is recommended to use 316 stainless steel for salt water, and not 304 stainless steel, which has been known to corrode very fast when exposed to brackish water. 400 series stainless should be considered but generally both base material and machining cost make it less cost effective. However, the application may be to a level of severity that may warrant, from a cost and reliability standpoint the use of a higher cost material.

15.8 Painting and Coatings for Pumps. The UFGS guide specifications (Division 09) on the Whole Building Design Guide provide many applicable specifications in particular 09 90 00 Paints and Coatings. Customers and/or local sponsors over the project should also have input on the types of coatings for the pumping equipment and components. The designer can contact ERDC's CERL for both the latest research on paint coatings, as well as testing coating supplies. In addition, consult EM-1110-2-3400 "PAINTING: NEW CONSTRUCTION AND MAINTENANCE" for additional guidance.

15.9 Cathodic Protection for Pumps. Cathodic Protection Systems (CPS) are used to supplement material selection and coating systems. In many cases it is necessary to have additional active protection due to the environment of operation. They should be considered a part of the overall system and component functional life. The designer should consult EM 1110-2-2704 CATHODIC PROTECTION SYSTEMS FOR CIVIL WORKS STRUCTURES for detailed instructions on the types, use and application of many CPSs. In addition, USACE Corrosion Control and Cathodic Protection Systems TCX in Mobile District is additional source for expertise.

a. Sacrificial CPSs. Sacrificial CPSs are generally material that is added to the system to attached the corrosive elements of the environment and keep the loss of material away from the other system material.

(1) Such items are zinc or aluminum anodes. Any sacrificial CPS needs to be properly designed and monitored. If a system has an inadequate number of anodes placed or they are not properly maintained, then the planned prevention of material loss from the system will most likely not occur and damage to functioning elements of the pumping station may result.

(2) The anodes will not only need to be inspected from time to time but all replaced. The cathodic protection system does have a maintenance cost that should be figured into the life cycle costs when performing the initial determination of materials to be used in a system.

(3) It may be more advantageous in the long-term to use a more expensive material initially to avoid the continuous maintenance of a CPS in order to use a less expensive material in the initial build of the station components. If this type of CPS is used, then there should be a plan for reevaluation of system to examine its effectiveness since condition can shift and its level of impact to maintenance should always be assessed.

b. Impressed current CPSs. These systems, like the sacrificial CPSs are used to keep specific materials from corroding. However, instead of a attracting the elements to a sacrificial material, these systems use an impressed current to repel the elements that lead to corrosion. The type and sizing must be carefully evaluated, maintained, and reassess over time for effectiveness and revision. The initial cost of this system will be more than a sacrificial anode system, but the system is generally more effective at corrosion prevention.

15.10 Color Coding Systems. When determining the coating system for a station component, the color pigments available for that coating should be considered. Any existing or established color coating systems should be determined and use for correlation. Having an established color coating system for components assists with maintenance, especially in areas with limited access and multiple components are arranged near each other. Labeling may not be possible for certain components, especially piping, and the color of the coating can be used to indicate the system. In addition, color layering can be used for ease of inspection.

a. Color Layering.

(1) Different pigment for layers of colors. If there is a layering of contrasting colors in the coating, such as a red layer and a yellow layer, then exposure of the yellow under the red allows for a quick visual evaluation. The thickness of the layers can be set, so that an estimate of the amount of coating loss can also be quickly determined from the visual examination.

(2) Some color systems are limited in pigment pallet. The designer should consult with the Paint Technology Center, located at ERDC's CERL.

b. Piping Color Codes. Each station may have different color codes for elements within the station. All should be examined when establishing new work in the station. The two primary color-coding systems used are "MIL STD 101C Department of Defense Standard Practice - Color Code for Pipelines and For Compressed Gas Cylinders" and ANSI/American Society of Mechanical Engineers A13.1, which OSHA follows.

Chapter 16
Seismic Design

16.1 General. Seismic design requires the input of structural engineers. It is imperative mechanical designers work with structural engineers for any seismic design requirements. As such, this chapter does not provide specific seismic design requirements but rather provides general requirements and provides references to design documents including UFC 3-310-04. The designer should also refer to EM 1110-2-3104.

a. The possibility of seismic activity should be considered, and appropriate forces included in the design of pump stations. Mechanical and electrical items for seismic consideration include pumps, piping, conduit, lighting, etc.

b. In areas where seismic activity must be considered but where seismic design is not warranted by the importance of the pumping plant or by economics, certain defensive design measures can be economically built into the facility. The pumping station can be placed far enough from the protection line to allow the discharge conduits to flex under ground motion without fracturing or shearing. Also, additional flexible couplings may be employed, and pipe bends may be installed at intervals in the discharge lines to allow movement without failure.

c. These measures must be considered early in the pump station layout process as alternatives to seismic design procedures, which could greatly increase first cost. In general, seismic design for mechanical and electrical equipment will follow the requirements in UFC 3-310-04 as applicable.

d. Seismic investigation of the pumping station should follow requirements in ER 1110-2-1806, EARTHQUAKE DESIGN AND EVALUATION FOR CIVIL WORKS PROJECTS. The design of anchorages and support for the mechanical and electrical equipment should be as described in UFC 3-310-04 as applicable. An evaluation for seismic design should be performed during the design phase of the project and will require input of the structural engineer.

(1) The International Building Code, which forms the basis for most building codes enforced by state and local government today, no longer uses seismic zones. Instead, today's building codes use the concept of a seismic design category. The six seismic design categories (A to F) are determined by geographic location, site soil type, and occupancy.

(2) The intent of these building code requirements is to assure that these components will not topple over or fall, potentially injure people during an earthquake, or block building egress after the earthquake.

16.2 Mechanical and Electrical Equipment. Most electrical and mechanical equipment for structures in seismic design categories C, D, E, or F must be anchored and braced to withstand seismic forces specified in Chapter 13 of the American Society of Civil Engineers 7 standard "Minimum Design Loads for Buildings and Other Structures."

a. The International Building Code identifies a limited class of mechanical, electrical, and plumbing systems as “designated seismic systems.” These designated seismic systems comprise that equipment and their supporting utilities that are required to remain functional following a design earthquake in order to protect the safety of building occupants. This includes emergency power and lighting systems, fire suppression systems, and smoke exhaust systems associated with emergency egress paths.

b. The building code limits the types of post-installed anchor bolts (expansion bolts, epoxy anchors) that can be used to provide code-required seismic anchorage of equipment. Such anchors must be qualified by the manufacturer for use, using cyclic loading protocols that duplicate the stresses an anchor would experience in an earthquake. Again, the design of these systems will require input from a structural engineer experienced in seismic design.

16.3 Structural Analysis. The general guidance for seismic design and analysis is found in ER 1110-2-1806.

a. Structural attachment to buildings. The seismic bracing of mechanical components imposes force on structures at the point of attachment. The capacity of structures to withstand this force is the responsibility of the structural engineer. Mechanical and electrical engineers must work closely with structural engineers to establish proper seismic-design and attachment criteria. This entails:

(1) Determining whether seismic bracing for suspended pipes can be attached to the floor above or to structural beams only. In either case, maximum forces should be established.

(2) Coordinating the force applied, the type of concrete, and the characteristics of the concrete, which determine the size and embedment depth of anchor bolts and expansion anchors.

(3) Establishing procedures for testing anchors in the field and coordinating and monitoring that testing.

b. Parameters for seismic bracing and attachment to structures should be established during design, with specific coordination coinciding with the development of construction shop drawings, when all details are known. Most seismic design cannot be coordinated fully during design. Reasons include specification options and contractors’ preferences, such as those concerning:

(1) Pipe material (steel or copper).

(2) The actual weight, center of gravity, and support configuration of equipment.

(3) Duct type (rectangular or round).

(4) The location of pipe and duct supports.

(5) The routing of electrical conduit shown as home runs.

(6) The size and location of any sprinkler system piping.

c. Seismic-restraint guidelines reference many details and tables. Because this data may be difficult for installers to use properly in the field, some seismic restraints are planned in greater detail during the shop-drawing phase. Bracing points of pipes and ducts are identified, seismic-restraint components for each bracing point are selected, and the components for each point are shipped separately.

d. Seismic restraint vs vibration isolation. In seismic restraint, equipment is connected to a structure rigidly. In vibration isolation, it is installed on devices designed to prevent the transfer of vibration to a structure.

(1) This conflict of objectives can be resolved through close coordination among acoustical, structural, and mechanical engineers. For example, on many projects, the same vibration-isolation details, including inertia base, are used for all pumps, whether they are installed on an upper floor with occupied space below or on slab on grade in a remote central plant.

(2) Inertia-base weight is a major factor in seismic-restraint design. Sometimes vibration isolation for pumps installed on slab on grade in a remote central plant can be relaxed. This can reduce the initial cost of both vibration isolation and seismic restraint but must be coordinated with the structural engineer for the project. Vibration isolation should be application specific in its design to reduce complexity and cost.

e. Often, specifications require resilient support of pipes and ducts. Seismic-bracing criteria and details tend to be more elaborate when pipes are supported resiliently. Because of complexity and cost, where possible, resilient support should be limited to short distances.

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Chapter 17
Operation and Maintenance

17.1 General. This section covers O&M requirements for pumping equipment. There is also discussion included in this chapter for shipping and storage requirements for pumping equipment since that can directly impact future maintenance.

a. An adequate O&M manual must be prepared to permit successful operation of the pumping station. The portion of the manual covering the mechanical and electrical equipment is generally prepared by the designers responsible for specifying this equipment.

b. The manual should provide a platform for carry-over of information from the designer to the operating personnel. The manual should be prepared to aid the operating personnel in understanding the equipment and to set the guidelines for maintenance procedures. A manual provides a guide which can carry on beyond personnel changes and verbal instructions.

c. The O&M manual should be complete as possible. In most instances, this manual will be the only information available to operate and maintain the station.

d. The contents are usually divided into three sections, operation, maintenance, and reference. Each section is described below, and some examples are included in Appendix D. General guidelines are included in ER 25-345-1, Systems Operation and Maintenance Documentation. Although ER 25-345-1 is for military construction, it also contains valuable information that pertains to CW projects. The electrical fault protection coordination study, including protective device settings, should be provided with the O&M manual.

e. The construction of a pumping station usually does not permit a final manual to be prepared before it is turned over to the user or operating agency. Because of this, an interim manual should be prepared to benefit the end user when they receive the station.

f. The interim manual should include complete operating instructions and any maintenance instructions prepared to that time. The operating instructions should be prepared early enough so that they may be checked during the preliminary and final testing of the station. The final O&M manual should be available for the user within 3 months of the turnover date of the pumping station.

g. Contract specifications should state that a manufacturer's O&M manual be provided which will include transportation and installation instructions. The manual should be submitted and approved before the pump is transported to the construction site. This is to ensure that the installation requirements are provided and used during installation of the pump into the station. The local sponsor should have a copy of this manual in station in conformance with the Inspection of Completed Works required checklist.

17.2 Operation. The operation portion of the manual is divided into three parts: criteria, constraints, and procedures.

a. The criteria portion describes the operation of the facility that satisfies the project requirements. It deals with the overall operation of the station as opposed to operation of individual pieces of equipment.

b. The constraints section should indicate all conditions that must be considered external to the station so that it can be successfully operated. These items usually consist of control structures away from the station that require certain gate opening and closing operations for the station to perform properly.

c. The procedures part would include detailed operating procedures for each piece of equipment. The detailed equipment operating procedures are provided by the equipment manufacturers. The operations portion of the O&M manual should be coordinated with the hydraulics and hydrology engineers to establish pump operating levels.

17.3 Maintenance. A pumping station maintenance program should consist of inspections, standards, a control system, and lubrication. The available shop drawings on the equipment should be made a part of the manual so that they may be used when performing detailed maintenance or repair work.

a. Inspections. The success of a maintenance program is dependent on adequate inspections. The inspections assure that the equipment receives proper attention and is ready for use.

b. The extent of preventative maintenance inspections includes adjusting, lubricating, repairing, and replacing worn out or defective parts. A guide for the inspection frequencies and tasks for the various items of equipment is usually obtained from manufacturers' recommendations but may need to be adjusted for flood risk management pumping station operating conditions. Any changes to manufacturers' recommendations should be coordinated with the manufacturer to avoid the possibility of voiding warranties.

c. Standards. A balanced criteria maintenance program must be based on defined criteria that establish quality, extent, and quantity of maintenance desired. A quality program requires capable personnel, proper tools, use of quality materials, and a record of meeting program performance. The maintenance recommendations of most equipment manufacturers are usually for continuous operation, which is typically not the case for flood risk management pumping stations. Inspection and maintenance requirements must be keyed to the expected operation of the station.

d. Maintenance Control system. An effective maintenance control system should include comprehensive and accurate basic data, such as equipment records, historical inspection, maintenance, and repair records. Effective scheduling of maintenance work is required to ensure the most effective use of the operating agencies' personnel. The record filing system should consist of:

e. Equipment data file. This file should be indexed by equipment name or title and contain all pertinent data for that specific item of equipment or facility, such as manufacturers' instruction books, operating pressure limits, parts catalogs, manufacturers' drawings, reference field tests, special reports on major repairs, dates of replacements and retirements, and changes in operating procedures.

f. A preventative maintenance file. This file should contain a record of equipment inspections, maintenance data, a record of hours of operation, number of operations, or other significant operating data. Consideration should be given to furnishing the information on a computer database program for large and complex stations.

g. Lubrication. Proper lubrication is an important part of a good maintenance program. Dependable operation and the life expectancy of equipment requiring lubrication are almost entirely dependent on the use of proper lubricants at the right time intervals and in the proper quantities.

(1) All equipment requiring lubrication should be surveyed and appraised for the type of bearings, gears, and service conditions under which the equipment must operate. After these operating conditions are fully analyzed, then it can be determined what characteristics the proper lubricant should have, such as resistance to moisture, temperature range, whether an extreme pressure lubricant is required, and the proper viscosity range.

(2) Some manufacturers recommend only the viscosity of the lubricant while others list the lubricants by trade name. The number of different types should be kept to a minimum.

(3) The frequency of lubrication used is recommended by the manufacturer. The frequency of lubrication may have to be adjusted based on special use or experience. The equipment must be examined in detail when preparing lubrication instructions, so that every grease fitting and oiling location can be indicated in the maintenance instructions.

(4) Manufacturers' information does not always show enough detail to permit accurate preparation of the lubrication instructions. Photographs of the various pieces of equipment showing the locations of all the lubricating points are very useful.

17.4 Reference.

a. The reference section of the O&M manual should contain a listing of all data that are necessary to operate and maintain the station. These data should include all of the shop drawings for the equipment, as-built contract drawings, advertised specifications, and design documentation used in the design of the station.

b. Copies of all reference items except the design data should be furnished to the user as an appendix to the O&M manual. The design data and documentation should be furnished as a separate package.

c. The contract specifications for the equipment should contain the requirement for the contractor to furnish as-built shop drawings of the equipment. Since this reference material is usually voluminous, it is recommended that a file cabinet be furnished as part of the construction of the station so that adequate storage is available at the station.

d. The Levee Inspection Checklist (Interim Policy for Determining Eligibility Status of Flood Risk Management Projects for the Rehabilitation Program Pursuant to Public Law 84-99 dated 21 March 2014 or most recent) should be used for identifying, describing, and rating visual observations of pump stations during formal inspections.

17.5 Periodic Testing. Since flood risk management pumping stations are usually operated on an infrequent basis, trial operation is required between flood events. All equipment should be operated at least every 30 days.

a. It is acceptable to operate the pumping equipment in the dry providing that equipment is designed for dry operation and the water level present is below the bottom of the pump suction bell or umbrella. Wet testing of pumping equipment should occur only if the water present is above the minimum pumping level. These test operations should be included in the maintenance schedule. The duration of the exercise period should be coordinated with the equipment suppliers but should be limited to as short a period as possible.

b. Motor Insulation Testing. Megger testing should be performed as described in Institute of Electrical and Electronic Engineers (IEEE) 43. It is recognized that megger testing capability will vary greatly depending on whether the station is in a rural area or in an urban area. Often larger cities will have maintenance staff capable of megger testing equipment while this capability may not exist for smaller cities. Megger testing of pump motors should be done initially when new to establish a baseline condition. Megger testing should then be done every 2 years after.

c. Pump Operation Testing. In dry conditions this can only be done with pumps that are lubricated by grease or oil. Pumps with water lubricated type bearings should not be tested in the dry condition. Testing can be accomplished in three ways to determine possible pump component problems such a worn guide bearing, bent shafts or damaged impellers:

(1) Visually inspect of the shaft rotating to ensure that there is no wobble with the shaft. If wobbling is noticed this could be a sign of a bent shaft or worn guide bearing (this means that the bearing clearance from the shaft has increased and the guide bearing might be worn outside operational clearance limits set by the pump manufacturer). Guide bearing clearance is determined by the type of lubrication used and the shaft diameter. Consult pump manufacturer or O&M information provided with the pump shop drawings.

(2) Use vibration equipment to measure the velocity of the pump and motor as described in HI 9.6.4, Rotodynamic Pumps for Vibration Measurements and Allowable Values. IRD MECHANALAYSIS, INC., General Machinery Vibration Severity Chart (Figure 17.1) for dry testing is also a good reference.

(3) Velocity measurements can mean worn guide bearings, bent shaft or impeller damage/unbalanced. The velocity measurements during dry operation testing is taken using an analog/digital vibration meter at two locations X and Y.

(4) X is located near the thrust bearing at the top of the motor housing on the water discharge side and Y is located 90 degrees counterclockwise at the same elevation. See Figure 9.6.4.2.3.1 in HI 9.6.4 for vibration sensor locations.

(5) The velocity measurement data should be used to interpret vibration severity. USACE design specifications require that vibration severity must be in the "good" range or better rating which requires that the velocity be 0.0785 in/sec or lower as indicated in Figure 17.1 shown below. If the vibration is greater than this the pump could possibly have worn guide bearings.

(6) During the operation of the pumps in a dry condition, which means that the water levels are below the suction bells, coast-down times can be obtained while watching the rotation of the shaft until it comes to a complete stop.

(7) The times aid in determining if there are possible pump equipment problems. For example, if the coast down times changed drastically from a previous reading, this indicates a possible problem with the pumping equipment.

(8) If coast-down times are shorter or longer than the last inspection/testing, this could be caused by the time of year the testing was accomplished. Colder weather can cause oil/grease to be thicker resulting in more drag and shorter coast down times. The coast down time is the most useful when a pump station has more than one pump of the same size. The coast down times should be very close to each other is there a large gap between times might mean that there could be worn guide bearings.

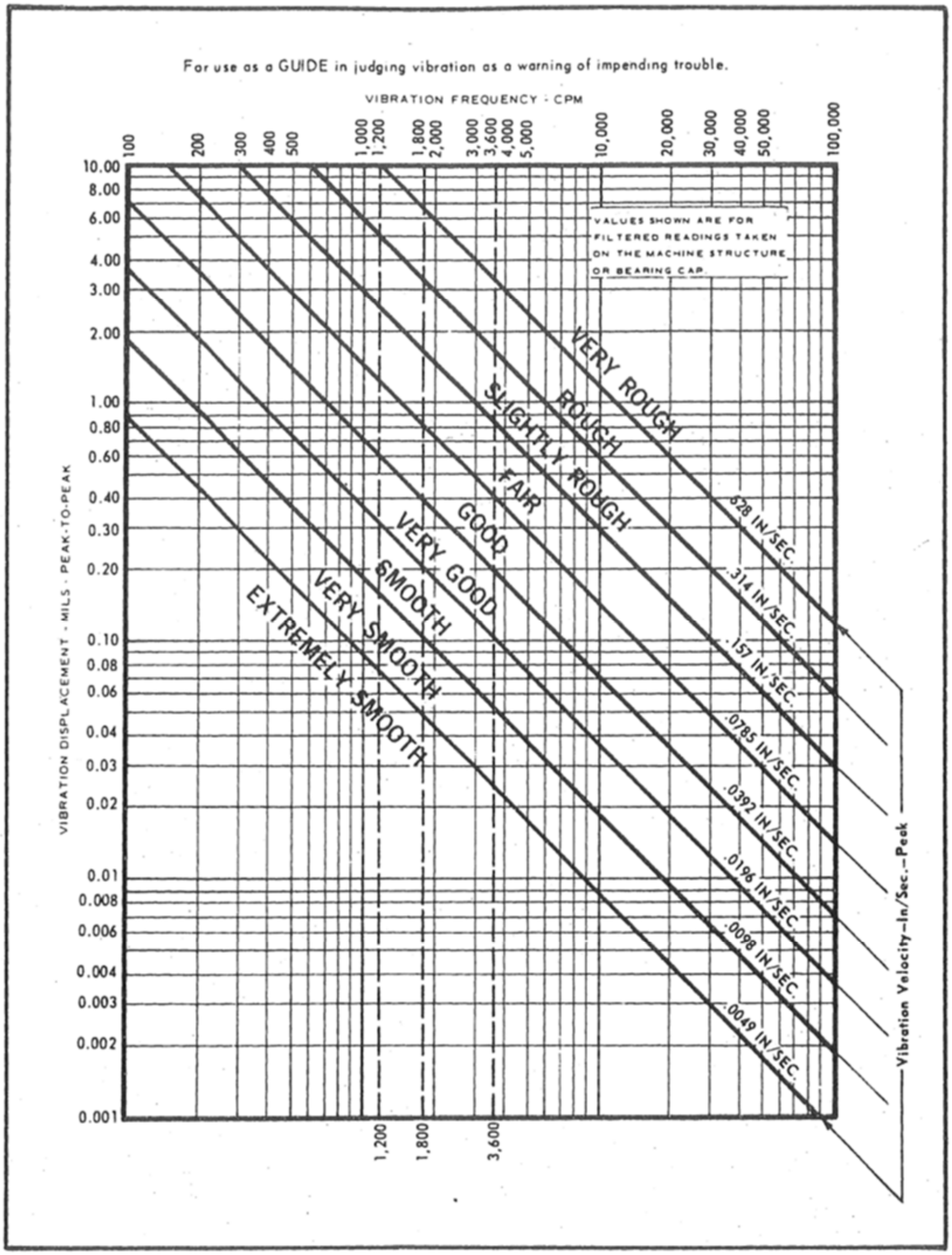


Figure 17.1. General Machinery Vibration Severity Chart courtesy IRD

17.6 Condition Monitoring of Controls. Control units and monitors for bearing temperature RTDs and monitors for both pump and motor bearings on vertical or horizontal type pumps should be inspected and tested for operation. Submersible pumps should be supplied with control units that will indicate bearing failures or leakage detection. Inspect controls and test submersible pumps with a bump test to ensure proper rotation and operation.

17.7 Preparation for Shipment. Before shipment and assembly, the engineer should inspect the painting and components of the pump to ensure they meet contract requirements. If the pump is shipped completed or partially assembled with the shaft installed inside the pump column, the shaft will need to be blocked or supported so that the shaft remains in a stable horizontal position, so that the shaft will not deflect or bend during shipping. The discharge elbow should also be blocked so that it will remain rounded and not become oblong (egg shaped) during shipment.

a. After a pump is assembled in the manufacturer's shop, it should be suitably prepared for the type of shipment the purchaser has specified. This can include blocking of the rotor, when necessary. If the rotor is blocked, this should be identified by weather-resistant tags.

b. As shipped, the equipment should be suitable for at least 6 months of outdoor, uncovered storage from the time of shipment, with no disassembly required at the time of installation and operation except for possible inspection of bearings and seals. If storage for a longer time is required and specified, the manufacturer and purchaser should agree on the preparation and storage procedures and requirements prior to shipment.

c. The pump and driver should be prepared for shipment only after all testing and inspection processes have been completed and the equipment has been released for shipment by the purchaser. If packing was used for testing, it should be removed before shipment. Usually pumps are not disassembled after performance testing. The pump must be completely drained and dried, and all internal parts should be coated with a suitable rust preventative within 4 hours of testing. Alternatively, within 4 hours of testing, the pump and seal chamber should be drained to the extent practical, filled with a water-displacing inhibitor, and drained before shipment.

d. Flanged openings should be provided with covers, usually metal, at least 4.7 mm (3/16 inch) thick and sealed with an elastomeric gasket. Threaded openings should be closed with steel caps or plugs.

e. Any openings that have been prepared for welding in the field should be provided with closures designed to protect against damage to the welding surface as well as the entrance of foreign materials into the equipment.

f. Exposed shafts and shaft couplings should be wrapped with waterproof cloth or paper and sealed with oil-proof adhesive tape. Bearing assemblies should be protected from moisture and dirt (dust). If vapor phase inhibitor crystals in bags are installed to absorb moisture, the location of the bags should be tagged so they will be removed before installation of the equipment in the field.

17.8 Care of Equipment in the Field. The manufacturer should provide the purchaser with the instructions necessary to preserve the integrity of the original storage preparation when the equipment is received at the job site and prior to start-up.

a. All equipment and materials should be stored free from direct ground contact and away from areas subject to collecting water. Indoor storage should be used whenever possible.

b. All carbon and low alloy steel surfaces should be protected from any contact with corrosive environments to prevent rust formation. All items with machined surfaces should be stored to facilitate periodic examination for damage or rust.

c. Storage areas should be kept clean and free from such contaminants as concrete chipping, sanding, and painting. Periodic rotation of equipment shafts should be performed per the equipment manufacturer's instructions for the specific equipment type and preservation methods used. When rotation is performed, determine first that all shipping blocks on rotating components have been removed and that there is adequate lubrication before rotation.

d. Certain preservatives and storage lubricants can affect safety and operating life of the equipment, especially if they react with the process fluid or operating lubricant. The installer should ensure that all preservative and storage lubricants are suitable for the specific application. Preservatives should not be used on surfaces where prohibited by the process or application.

17.9 Maintenance Considerations. Because of the wide variation in pump types, sizes, designs, and materials of construction, this discussion on maintenance is restricted to those types of pumps most commonly encountered.

a. The manufacturer's instruction books must be carefully studied before any attempt is made to service a particular pump. Daily observation of pump operation when operators are on constant duty, hourly and daily inspections should be made and any irregularities in the operation of a pump should be recorded and reported immediately. This applies particularly to changes in sound of a running pump, abrupt changes in bearing temperatures, and seal chamber leakage.

b. A check of pressure gages and of flowmeters (if installed) and vibration should be made routinely during the day. If recording instruments are provided, a daily check should be made to determine whether the current capacity, pressure, power consumption or vibration level indicates that further inspection is required. If these readings are taken electronically trending charts should be produced to allow observation of changes as a function of time. Certain trends may allow for scheduled outages to address deterioration of specific performance values.

17.10 Semi-annual Maintenance Inspection. The following should be done at least every 6 months:

a. For pumps equipped with shaft packing, the free movement of stuffing box glands should be checked, gland bolts should be cleaned and lubricated, and the packing should be inspected to determine whether it requires replacement.

b. The pump and driver alignment should be checked and corrected if necessary.

c. Housings for oil-lubricated bearings should be drained, flushed, and refilled with fresh oil.

d. Grease-lubricated bearings should be checked to see that they contain the correct amount of grease and that it is still of suitable consistency. Verify the pump lubricator is programmed correctly and dispensing proper amount of grease. Verify proper amount of grease is on site.

17.11 Annual Maintenance Inspection and Requirements.

a. A very thorough inspection should be performed once a year. In addition to the semiannual procedure, the following items should be considered. Vibration testing should be taken, reviewed and trended. Readings should be checked to see how they conform the IRD Mechanalysis Chart (Figure 17.1) for dry testing and HI requirements for wet testing (flowing water). If the pump is trending toward unacceptable vibration levels:

(1) The bearings should be removed, cleaned, and examined for flaws and wear, if applicable. This is not typically practical for a vertical column type pump. Typically, this would be horizontal or submersible type pumps.

(2) The bearing housings should be carefully cleaned.

(3) Rolling element bearings should be examined for scratches and wear. Immediately after cleaning, rolling element bearings that are considered acceptable for reinstallation should be coated with oil or grease. Note: If there is any sign of damage, or if the bearings were damaged during removal, they should be replaced with new bearings of the correct size and type per the manufacturer's instruction book.

(4) The assembled rotor or major rotor components, if the rotor is not assembled of shrink-fit components, should be checked for balance prior to reassembly in the pump.

(5) Check grease lines and supports for damage and repair immediately if found.

(6) Check bearing RTD lines and supports if installed for damage and repair immediately if found.

(7) If installed, check cathodic protection anodes, since they may require replacement.

b. For pumps equipped with shaft packing, the packing should be removed and the shaft sleeves-or shaft, if no sleeves are used-should be examined for wear.

c. For pumps equipped with mechanical seals, if the seals were indicating signs of leaking, they should be removed and returned to the seal manufacturer for inspection, possible bench testing, and refurbishment.

d. When coupling halves are disconnected for an alignment check, the vertical shaft movement of a pump with sleeve (journal) bearings should be checked at both ends with packing or seals removed. Any movement exceeding 150% of the original design clearance should be investigated to determine the cause. Endplay allowed by the bearings should also be checked. If it exceeds that recommended by the manufacturer, the cause should be determined and corrected.

e. All auxiliary piping, such as drains, sealing water piping, and cooling water piping, should be checked and flushed, as necessary. Auxiliary coolers should also be flushed and cleaned.

f. Pump equipped with stuffing boxes should be repacked, and the pump and driver should be realigned and reconnected.

g. Auxiliary fuel system components should be checked for proper operation and generator testing conducted. If applicable, verify automatic transfer switches are working correctly to transfer power to the generator and back to utility power.

h. For any diesel drives, verify engine is starting correctly, such as pneumatic starting systems, and verify all instruments are working correctly. Verify no overheating is present and cooling systems are functioning correctly. Verify exhaust system is functioning correctly.

i. Check alignment on any right-angle gear drives.

j. All instruments and flow-metering devices should be recalibrated, whenever feasible, and the pump should be tested to determine whether proper performance is being obtained. If internal repairs are made, the pump should again be tested after completion of the repairs.

17.12 <u>Complete Overhaul</u>. It is difficult to make general rules about the frequency of complete pump overhauls as it depends on the pump service, the pump construction and materials, the liquid handled, and the economic evaluation of overhaul costs versus the cost of power losses resulting from increased clearances or of unscheduled downtime. Some pumps on very severe service may need a complete overhaul monthly, whereas other applications require overhauls only every 2 to 4 years or even less frequently.

a. A pump should not be opened for inspection unless either factual or circumstantial evidence indicates that overhaul is necessary. Factual evidence implies that the pump performance has fallen off significantly or that the noise or driver load indicates trouble. Circumstantial evidence refers to past experience with the pump in question or with similar equipment on similar service.

b. In order to ensure rapid restoration to service in the event of an unexpected overhaul, an adequate store of spare parts should be maintained at all times. The relative complexity of the repairs, the facilities available at the site, and many other factors enter into the decision whether the necessary repairs will be carried out at the installation site or at the pump manufacturer’s plant.

17.13 Spare and Repair Parts. The severity of the service in which the pump is used will determine, to a great extent, the minimum number of spare parts that should be carried in stock at the installation site. Unless prior experience is available, the pump manufacturer should be consulted on this subject. As an insurance against delays, spare parts should be purchased when the pump is purchased. Depending on the contemplated method of overhaul, certain replacement parts may have to be supplied either oversized or undersized instead of the size used in the original unit.

a. American Petroleum Institute Standard 610, 8th edition, provides recommended spare parts as a function of the number of identical pumps installed at a site. It also lists parts usually associated with start-up and with normal maintenance.

b. When ordering spare parts after a pump has been in service, the manufacturer should always be given the pump serial number and size (stamped on the nameplate). This information is essential in identifying the pump exactly and in furnishing repair parts of correct size and material.

17.14 Records of Inspections and Repairs.

a. The working schedule of the semiannual and annual inspections should be entered into a log that tracks individual pump maintenance history. This log should then contain a complete record of all the items requiring attention.

b. This log, usually electronic, should also contain comments and observations on the conditions of the parts to be repaired or replaced, on the rate and appearance of wear, and on the repair methods followed. In many cases, it is advisable to photograph badly worn parts before they are repaired.

c. In all cases, complete records of the cost of maintenance and repairs should be kept for each pump, together with a record of its operating hours. A study of these records will generally reveal whether a change in materials or even construction may be the most economical course of action to improve pump performance, reliability, and life.

17.15 Diagnosis of Pump Problems.

a. Pump operating problems may be either hydraulic or mechanical. In the first category, a pump may fail to deliver liquid, it may deliver an insufficient capacity or develop insufficient pressure, or it may lose its prime after starting.

b. In the second category, it may consume excessive power, or symptoms of mechanical difficulties may develop at the seal chambers or at the bearings, or vibration, noise, or breakage of some pump parts may occur. There is a definite interdependence between some difficulties of both categories.

c. For example, increased wear at the running clearances is typically classified as a mechanical trouble, but it will result in a reduction of the net pump capacity. This is the case without necessarily causing a mechanical breakdown or even excessive vibration. As a result, it is most useful to classify symptoms and causes separately and to list for each symptom a schedule of potential contributory causes. Such a diagnostic analysis is presented in Tables 17.1 through 17.4 courtesy of Pump Handbook, Fourth Edition, McGraw Hill.

Table 17.1 from Pump Handbook McGraw Hill
Check Chart for Centrifugal Pump Problems

Symptoms	Possible Cause of Trouble (each number is defined in Table 17.2)
1. Pump does not deliver liquid	1, 2, 5, 10, 12, 13, 14, 16, 21, 22, 25, 30, 32, 38, 40
2. Insufficient capacity delivered	2, 3, 4, 5, 7, 7a, 10, 11, 12, 13, 14, 15, 16, 17, 18, 21, 23, 24, 25, 31, 32, 40, 41, 44, 43, 63, 64,
3. Insufficient pressure developed	4, 6, 7, 7a, 10, 11, 12, 13, 14, 15, 16, 18, 21, 22, 23, 24, 25, 34, 39, 40, 41, 63, 64,
4. Pump loses prime after starting	2, 4, 6, 7, 7a, 8, 9, 10, 11
5. Pump requires excessive power	20, 22, 23, 24, 26, 32, 33, 34, 35, 39, 40, 41, 44, 45, 61, 69, 70, 71
6. Pump vibrates or is noisy at all flows	2, 16, 37, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 58, 59, 60, 64, 67, 78, 79, 80, 81, 82, 83, 84, 85
7. Pump vibrates or is noisy at low flows	2, 3, 17, 19, 27, 28, 29, 35, 38, 77
8. Pump vibrates or is noisy at high flows	2, 3, 10, 11, 12, 13, 14, 15, 16, 17, 18, 33, 34, 41
9. Shaft oscillates axially	17, 18, 19, 27, 29, 35, 38
10. Impeller vanes are eroded on visible side	3, 12, 13, 14, 15, 17, 41
11. Impeller vanes are eroded on invisible side	12, 17, 19, 29
12. Impeller vanes are eroded at discharge or near center	37
13. Impeller vanes are eroded at discharge near shrouds or at shroud/vane fillets	27, 29
14. Impeller shrouds bowed out or fractured	27, 29
15. Pump overheats and seizes	1, 3, 12, 28, 29, 38, 42, 43, 45, 50 51, 52, 53, 54, 55, 57, 58, 59, 60 61, 62, 77, 78, 78, 82
16. Internal parts are corroded prematurely	66
17. Internal clearances wear too rapidly	3, 28, 29, 45, 50, 51, 52, 53, 54, 55, 57, 59, 61, 62, 66, 77
18. Axially-split casing is cut through wire-drawing	63, 64, 65

19. Internal stationary joints are cut through wire-drawing	53, 63, 64, 65
20. Packed box leaks excessively or packing has short life	8, 9, 45, 55, 57, 68, 69, 70, 71, 72, 73, 74
21. Packed box; sleeve scored	8, 9
22. Mechanical seal leaks excessively	45, 54, 55, 57, 58, 62, 75, 76
23. Mechanical seal, damaged faces, sleeve, bellows	45, 54, 55, 57, 58, 62, 75, 76
24. Bearings have short life	3, 29, 41, 42, 45, 50, 51, 54, 55, 58, 77, 78, 79, 80, 81, 82, 83, 84, 85
25. Coupling fails	45, 50, 51, 54, 67

Table 17.2 from Pump Handbook McGraw Hill
Possible causes of problems

Suction Problems:

1. Pump not primed	10. Inlet of suction pipe insufficiently submerged
2. Pump suction pipe not completely filled with liquid	11. Vortex formation at suction
3. Insufficient available NPSH	12. Pump operated with closed or partially closed suction valve
4. Excessive amount of air or gas in liquid	13. Clogged suction Strainer
5. Air Pocket in suction line	14. Obstruction in suction line
6. Air leaks into suction line	15. Excessive friction losses in suction line
7. Air leaks into pump after through stuffing boxes or through mechanical seal	16. Clogged impeller
7a. Air in source of sealing liquid	17. Suction elbow in plane parallel to the shaft (for double suction pumps)
8. Water seal pipe plugged	18. Two elbows in suction piping at 90 degree to each other, creating swirl and pre-rotation
9. Seal cage improperly	19. Selection of pump too high a suction specific speed

Other Hydraulic Problems

20. Speed of pump too high	32. Total head of system higher than design of pump
21. Speed of pump to low	33. Total head of system lower than design of pump
22. Wrong direction of rotation	34. Running pump too high a flow (for low specific speed pumps)
23. Reverse mounting of double-suction impeller	35. Running pump at too low a flow (for high specific speed pumps)
24. Un-calibrated instruments	36. Leak of stuck check valve
25. Impeller diameter smaller than specified	37. Too Close a gap between impeller vanes and volte tongue or diffuser vanes
26. Impeller diameter larger than specified	38. Parallel operation of pumps suitable for the purpose
27. Impeller selection with abnormally high head coefficient	39. Specific gravity of fluid differs from design conditions
28. Running the pump against a closed discharge valve without opening a by-pass	40. Viscosity of liquid differs from design conditions
29. Operating pump below recommended minimum flow	41. Excessive wear at internal running clearances
30. Static head higher than shut-off head	42. Obstruction in balancing device leak – off line
31. Friction losses in discharge higher than calculated	43. Transients at suction source (imbalance between pressure at surface of liquid and vapor pressure at suction flange)

Mechanical Problems – General

44. Foreign matter in impellers	56. Parts loose on the shaft
45. Misalignment	57. Shaft running off-center because of worn bearings
46. Foundation insufficiently rigid	58. Pump running at or near critical speed
47. Loose foundation bolts	59. Too long a shaft span or too small a shaft diameter
48. Loose pump or motor bolts	60. Resonance between operating speed and natural freque3ncy of foundation, baseplate, or piping
49. Inadequate grouting of baseplate	61. Rotating part rubbing on stationary part
50. Excessive piping forces and moments on pump nozzles	62. Incursion of hard solid particles into running clearances
51. Improperly mounted expansion joints	63. Improper casing gasket material
52. Starting the pump without proper warm-up	64. Inadequate installation of gasket
53. Mounting surfaces of internal fits (at wearing rings, impellers, shaft sleeves, shaft nuts, bearing housings and so on) not perpendicular to shaft axis	65. Inadequate tightening of casing bolts
54. Bent Shaft	66. Pump materials for suitable for liquid handled
55. Rotor out of balance	67. Certain couplings lack lubrication

Mechanical Problems – Sealing Area

68. Shaft of shaft sleeves worn or scored at packing.	73. Dirt and grit in sealing liquid
69. Incorrect type of packing for operating conditions	74. Failure to provide adequate cooling liquid
70. Packing improperly installed	75. Incorrect type of mechanical seal for prevailing conditions
71. Gland too tight, prevents flow of liquid to lubricate packing	76. Mechanical seal improperly installed
72. Excessive clearance at bottom of stuffing box allows packing to be forced into pump interior	

Mechanical Problems – Bearings

77. Excessive radial thrust in in single volute pumps	82. Improper installation of rolling element bearings such as damage during installation, incorrect assembly of stacked bearings, use of unmatched bearings as a pair and so on
78. Excessive axial thrust caused by excessive wear at internal clearances or, if used, failure or excessive wear of balancing drive	83. Dirt getting into bearings
79. Wrong grade of grease or oil	84. Moisture contaminating lubricant
80. Excessive grease or oil in rolling element bearing housings	85. Excessive cooling of water-cooled bearings
81. Lack of lubrication	

Table 17.3 from Pump Handbook McGraw Hill
Diagnosis from appearance of stuffing box packing in centrifugal pumps

Symptom	Cause
Wear on one or two rings next to packing gland; other rings OK	Improper packing installation
Wear on O.D. of packing rings	Packing rings rotating with shaft sleeve or leakage between rings and I.D. of box. Wrong packing size or incorrectly cut rings
Charring or glazing of inner circumference of rings	Excessive heating. Insufficient leakage to lubricate packing or unsuitable packing
I.D. of rings excessively increased or heavily worn on part of inner circumference	Rotation eccentric

Table 17.4 from Pump Handbook McGraw Hill
Vibration symptoms and causes in centrifugal pumps

Vibration frequency	Cause
Several times pump RPM	Bad rolling element bearings
Twice pump RPM	Loose parts on rotor, axial misalignment of coupling, influence of twin-volute when gap is insufficient
Running Speed	Imbalance of rotor, clogged impeller, coupling misaligned or loose
Running Speed time number of impeller vanes	Vane passing syndrome – insufficient gap between impeller vanes and collector vanes. This is also sometimes seen during operating with suction recirculation.
One-half running speed	Oil whirl in bearing
Random low frequency	Internal circulation impeller or cavitation
Random high frequency	Usually resonance
Sub-synchronous frequency at 70% to 90% of running speed	Hydraulic excitation of resonance

Chapter 18
Electrical Design

18.1 Electrical Design Philosophy.

a. General. The first step in any electrical design is to identify the loads associated with the system. These will likely be defined by the mechanical designer and dictated by whether the pumps are diesel or electric motor driven.

b. While a diesel driven pump station may have smaller electrical loads, power is still necessary for lighting, ventilation, and control. A pump station may also be equipped with intake or discharge gates requiring a gate operator. While the electrical data associated with these loads may change based upon the equipment being supplied in the construction contract, a project baseline and product data should be made available from the mechanical designer.

c. Publications.

(1) IEEE Std 141. The IEEE Recommended Practice for Electric Power Distribution for Industrial Plants is part of the Color Book series and is also known as the "Red Book." The IEEE Red Book covers the various topics for electrical design from planning, voltage considerations, fault calculations, grounding, cable systems, harmonics, and more.

(2) IEEE Std 242. The IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems is part of the Color Book series and is also known as the "Buff Book." The IEEE Buff Book deals with the proper selection, application, and coordination of the components that constitute system protection for industrial plants and commercial buildings.

(3) IEEE Std 399. The IEEE Recommend Practice for Industrial and Commercial Power Systems Analysis is part of the Color Book series and is also known as the "Brown Book." The publication can be used as an engineer's reference. The IEEE Brown Book also references power analysis texts that can be used as a resource.

(4) UFC 3-501-01. While much of the "Electrical Engineering" UFC is related more towards building design, some of the content is applicable to a pump station design.

18.2 Electrical Design Considerations.

a. Electric Utility.

(1) General. The size and location of the electric utility determines whether a pump motor can start reliably. Even a large, urban utility can have issues starting a pump if it is located at the end of their distribution system.

(2) Whether the pump station is in an urban or rural area or whether the pump station is a Flood Risk Management or Environmental Management Program project will help define the electrical reliability requirements. The reliability of the electric utility is of greater importance to the Flood Risk Management station versus the Environmental Management Program. A rural Environmental Management Program project may greatly limit the amount of starting current available for an electric pump.

(3) Coordination with the local utility should be performed during the planning phase. If not, the utility should be consulted early in the design process to ensure three-phase power is available in the area and adequately support the additional loads.

(4) Availability. The early coordination with the electric utility identifies whether adequate three phase power is available in the area. The availability of reliable electric power usually dictates whether the station is diesel or electric driven during the planning stage.

(5) The new pump station may require an upgrade to the existing distribution lines or more often the utility must extend the primary distribution system to the pump station location. The primary extension may be overhead or underground distribution lines. Often the establishment of utility service is included with the construction of the pump station requiring the contractor to coordinate with the utility to provide service. If the costs to establish utility service are more significant such as when a long primary extension is needed, a separate contract may be used.

b. Type of Station. Early pump station designs included brick and mortar buildings to house all of the equipment. This included the pumping equipment in addition to the electrical distribution and control equipment.

(1) As noted in Chapter 2, this manual recommends a building over all stations. However, in an effort to reduce overall construction costs, some pump stations now make use of submersible electric pumps eliminating the need for a building.

(2) Electrical equipment is either housed in a modular (prefabricated) building near the structure or simply remains outside with suitably-rated environmental enclosures. Equipment installed outside in environmental enclosures will be more susceptible to vandalism and public safety depending on how the site is secured which would reduce plant reliability and availability. The elimination of the building also eliminates many of the lighting and HVAC loads. Smaller stations can be constructed more cost-effectively using distribution panelboards and separate motor controllers rather than a single large MCC or switchboard.

c. End User. The electrical designer should consider the maintenance capabilities of the end user when designing the power distribution and control systems for the pump station. If the end user of a pump station is a rural levee district, they may not have access to qualified personnel or contractors to operate and maintain the system. Sometimes use of technology and electronics is necessary to provide a cost-effective, reliable, and robust system, but without the right personnel the equipment cannot stay operational.

d. Contract Specification Requirements. The necessary UFGS sections will vary by project. Sections common to pump station designs are identified below. The list below should not be considered complete for all required specifications depending on the project. The list does not identify sections for automatic transfer switches or standby generators. These sections should be included as needed.

(1) Section 25 05 11.00 28, Cybersecurity. This section addresses the cybersecurity requirements for industrial control systems (ICS).

(2) Section 26 00 00.00 20, Basic Electrical Materials and Methods.

(3) Section 26 05 19.10 10, Insulated Wire and Cable. Addresses the requirements for the cross-linked polyethylene insulation systems.

(4) Section 26 24 13, Switchboards. Depending upon the electrical loads and service equipment associated with the pump station, electrical manufacturers may recommend switchboard construction over MCC. Switchboard construction is common for a fused disconnect used as a service entrance.

(5) Section 26 24 16.00 40, Panelboards. The requirements of this section are often incorporated into other sections. Larger pump station designs requiring stand-alone panelboards may necessitate the need for the section. Ensure the requirements for copper bus and bolt-on breakers are clearly identified.

(6) Section 26 24 19.00 40, Motor Control Centers. The requirements for a solid-state starter (soft start) or VFD may need to be added to the section.

(7) Section 26 28 00.00 10, Motor Control Centers, Switchboards and Panelboards.

(8) Section 26 29 23, Variable Frequency Drive Systems Under 600 Volts.

(9) Section 26 28 01.00 10, Coordinated Power System Protection.

(10) Section 33 71 02, Underground Electrical Distribution.

(11) Section 40 95 00, Process Control. Identifies requirements for the PLC system hardware. Level sensors and other field devices should be identified. Part 3 of the specification section should describe how the pump station should operate. This sequence of operation will be used by the Contractor to program the PLC system. The section should require the Contractor to furnish all software applications, including cabling and other accessories, necessary to program the PLC system as part of the construction contract.

e. Contract Drawing (Plans) Requirements.

(1) One-line Diagram. The one-line diagram is the basis of any electrical design. It identifies all of the loads in the system and how they are interconnected. The loads identify information such as motor HP or full load amps. Circuit breakers should identify the frame size and trip settings.

(2) Utility Plan. The utility plan should highlight the location of the utility transformer in relation to the pump station and identify existing overhead or underground primary utility lines, extensions of the primary, and location of the riser pole. The utility plan should identify conduit sizes and routing including manhole/handhole details.

(3) Electrical Plan. The electrical plan shows the location of the utility transformer, metering, and power distribution equipment (MCC, switchboard, panelboards, etc.) within pump station. The plan should identify the routing of the transformer secondary conduits and other raceways in the station. These include pump motor power and control, gate power and control, and lighting.

(4) Riser Diagram. A riser diagram or elevation drawing (Plate 11) shows the layout of the switchboard, switchgear, or MCC. While an elevation of a MCC, switchgear, or switchboard is not critical to the design, it can help the designer ensure the layout meets manufacturer requirements and the equipment fits within the pump station. This fit becomes more critical if the equipment is to be used with a modular building and space is limited.

(5) The riser will identify the overall equipment and vertical section dimensions. The riser diagram can also provide a detail of the pump starter controls. A detail of the pump starter controls can identify the necessary indicating lights, alarm, and bypasses. When laying out the MCC, switchboard, or switchgear, consider locating redundant main breakers at opposite ends of the equipment. This prevents a catastrophic failure of one breaker from damaging the other.

(6) Grounding Plan. Refer to Chapter 25 for pump station grounding requirements.

(7) Starter Schematic(s). The pump motor starter schematic provides details on the equipment being used such as a simple across-the-line contactor or soft-start. The schematic may include float switches to ensure a minimum water level, a timing relay to prevent re-starting of a pump while water is draining from the pump tube, or interlocks with intake or discharge gates.

(8) Vendors are providing instrumentation and protection systems, often with submersible pumps, that should be identified in the schematic and automatically stop the pump in the event of a failure or alarm. If the pump station is equipped with sluice gates (intake, discharge, etc.), a schematic is necessary to identify local and/or remote operation for the gate operator. The gate operator should include a separate 120 V motor heater circuit to allow the main power to be shutoff when the station is not in use.

(9) Control System Schematics. Additional schematic diagrams may not be needed for simple pump controllers that can be identified on the pump schematic, but when the station includes a programmable logic controller, they will be needed to identify the necessary input/output cards. A block diagram may be necessary to illustrate the connections between the PLC processor, remote input/output racks, and user interfaces.

(10) Panelboard Schedule. The schedule identifies the electrical loads and trip ratings for circuit breakers in the panelboard. The schedule is useful for ensuring all loads are accounted for in the electrical system. A distribution panelboard may be used to supply 480 V power to several gate operators or power receptacles. Obviously, a "lighting" panelboard provides power to 120/240/208 V lighting, but it may also include heater circuits for equipment, pump, and gate motors and control system power.

(11) Conduit and Cable Schedules. A conduit schedule is used to identify the type and size of raceways. Revisions to existing pump stations may identify raceways as new or existing. A cable schedule will identify the type and size of cabling. This would include single conductors or multi-conductor cables, insulation type, voltage rating, etc. These schedules may be included in contract specifications as they may be easier to manage in a spreadsheet instead of a drawing.

18.3 Load Studies. The load study confirms whether the designed power system is capable of supplying the various loads. It confirms whether services, feeders, and equipment are sized properly or they are overloaded. The load study is often performed in conjunction with the voltage drop and short-circuit studies with the power study software. For further information on load studies, refer to ANSI/IEEE 399, Power System Analysis.

18.4 Voltage Drop Studies.

a. General. A preliminary voltage drop study for motor start-up as well as for motor-running conditions should be made during the initial design phase. The final study should be made during the approval drawing and data review phase of the project. The voltage drop study must be updated whenever the electrical system is revised. Computer programs are available to calculate the system's voltage dips and currents from motor starting to full load speed. For further information on voltage studies, refer to ANSI/IEEE 141, Recommended Practice for Electric Power Distribution for Industrial Plants and ANSI/IEEE 339, Power System Analysis.

b. Motor start-up. Motor start-up voltage drop depends on the motor inrush current. Depending upon the method of motor start-up, the inrush current ranges from two to six times the motor full-load current. Excessive starting voltage drop can result in problems such as motor stalling, nuisance tripping of undervoltage relays, motor overload devices, and temporary dips in lighting system brightness or restriking of high-intensity discharge lamps. During motor starting, the voltage level at the motor terminals should be maintained at approximately 80 percent of rated voltage or higher as recommended by the motor manufacturer.

c. Motor running. Undervoltage during the motor running condition may produce excessive heating in the motor windings, nuisance tripping of undervoltage relays and motor-overload devices, dim lighting, and reduced output of electric space heating equipment. Approximately 5-percent voltage drop from the transformer secondary terminals to the load terminals is acceptable. Per National Electrical Manufacturers Association (NEMA) MG-1 for medium and large machines, a 10-percent voltage drop is acceptable.

18.5 System Protection and Coordination Studies.

a. General. When a short circuit occurs in the electrical system, overcurrent protective devices such as circuit breakers, fuses, and relays must operate in a predetermined, coordinated manner to protect the faulted portion of the circuit while not affecting the power flow to the rest of the system.

(1) Isolation of faulted section. Isolation of the faulted section protects the electrical system from severe damage. It also results in efficient troubleshooting since the faulted section is downstream of the tripped protective device. Efficient troubleshooting results in the reduction of costly repair time and system downtime.

(2) One-line diagram of electrical system. A one-line drawing of the electrical system is an important element of the protection and coordination study.

b. Procedures. The coordination study is accomplished by overlaying protective device characteristic curves over equipment damage curves. This method is applicable in the range of fault clearing times greater than approximately 0.016 seconds (1 cycle) on a 60-Hz basis. For clearing times faster than this, as is the case for protecting solid state inverters, protection and coordination studies are achieved by comparing let-through energy (I-squared-t) values of current-limiting fuses to withstand energy values of the equipment being protected.

(1) Protection and coordination study. A protection and coordination study may be performed manually or with the aid of computer software. Computer software is available with a device library that contains time-current characteristic curves for many devices and allows for several devices to be plotted on the same time current graph for coordination studies.

(2) Additional information. For further information on protection and coordination studies refer to:

(a) ANSI/IEEE 141, Recommended Practice for Electric Power Distribution for Industrial Plants.

(b) ANSI/IEEE 242, Recommended Practices for Protection and Coordination of Industrial and Commercial Power Systems.

(c) ANSI/IEEE 399, Recommend Practice for Industrial and Commercial Power Systems Analysis.

c. Main disconnecting device. The utility supplying the power to the facility should be consulted regarding the type of protective device it recommends on the load side of the supply line which best coordinates with the source side protective device furnished by the utility.

d. Motors. Protective device characteristics must be coordinated with motor start-up characteristics. The devices must be insensitive enough to allow motors to start up without nuisance tripping caused by the relatively high magnitude of motor start-up current. The devices must be sensitive enough, however, to operate during overload or short-circuit conditions.

e. Transformers. Transformer protection is similar to that of motor protection as discussed above. The protective device must be insensitive to the transformer magnetizing in-rush current, but sensitive enough to operate for a short circuit condition. Note, the new ANSI standard on transformer protection (ANSI/IEEE C57.109) could be used as an alternative to the classic method of transformer protection. Transformer magnetizing inrush should be specified as 8 X full-load current for transformers rated less than 3 Mega Volt Amp (MVA), and 12 X full-load current, otherwise.

f. Cables. Cable protection requires coordinating the protective device characteristics with the short circuit withstand capability of the cable.

g. Specification requirements. The pump station construction specifications should require the contractor to furnish the completed protection and coordination study during the shop drawing approval process. The study should then be reviewed by the designer and returned to the contractor with any appropriate comments. It should be clearly stated in the specifications that it is the contractor’s responsibility to coordinate with his various equipment suppliers to produce a complete and accurate protection and coordination study.

h. The actual preparation of the study should be performed by the equipment manufacturer or an independent consultant. The construction specifications should require the contractor to submit the following items as one complete submittal:

(1) Full-size drawings of protective device characteristic curves.

(2) The motor-starting characteristics in the form of time versus current curves or data points.

(3) Data indicating the short-circuit withstand capability of MCCs, panelboards, switchgear, safety switches, motor starters, and bus bar and interrupting capacities of circuit breakers and fuses.

(4) Transformer impedance data. These data should be submitted in one of three forms: percent IR and percent IX, percent IZ with X/R ratio, or percent IZ with no load and total watt losses.

(5) Completed time-current coordination curves indicating equipment damage curves and device protection characteristics.

(6) A marked-up one-line diagram indicating ratings and trip sizing of all equipment.

(7) Software models used for the coordination study, including any device characteristics for devices not typically found in the software’s device library. It is also encouraged that software available to the local USACE office be used allowing for USACE personal to make future updates as needed.

18.6 Short Circuit Studies.

a. General. Short-circuit calculations are necessary in order to specify equipment withstand ratings and for use in conjunction with the protective device coordination study. Switchgear, MCCs, safety switches, panelboards, motor starters, and bus bar must be capable of withstanding available fault currents. After the available fault current has been calculated at each bus in the electrical network, the available fault current withstand ratings are specified.

(1) Circuit breakers. Circuit breakers must be capable of withstanding the mechanical and thermal stresses caused by the available fault currents. They must be able to remain closed even though tremendous forces are present in such a direction as to try to force the breaker contacts open. The ability of circuit breakers to remain closed is indicated by their momentary ratings. The momentary rating is a function of the circuit breakers interrupting rating, which is the ability to interrupt a fault current without incurring excessive damage to the breaker.

(2) Fuses. Fuses must also be capable of safely interrupting fault current and are rated in terms of interrupting capacity.

(3) Motor starters. Motor starters furnished with motor circuit protectors are available with short-circuit withstand ratings up to 100,000 amperes. Starters furnished with fusible switches are available with withstand ratings up to 200,000 amperes.

b. Procedures. The basic elements of a short-circuit study are the short-circuit calculations and the one-line diagram of the electrical system. For pumping stations, the three-phase bolted fault is usually the only fault condition that is studied. Utility systems line-to-ground faults can possibly range to 125 percent of the three-phase value, but in pumping plants line-to-ground fault currents of greater magnitude than the three-phase value are rare. Line-to-line fault currents are approximately 87 percent of the three-phase fault current. Short circuit studies can include following:

(1) Preliminary short-circuit study. A preliminary short-circuit study should be prepared during the design phase of the project. The final study should be prepared by the pump station construction contractor as described below.

(2) Calculations. The magnitude of the fault currents can be calculated using long-hand methods. However, software is available to reduce preparation time and simplify the task for large complex systems.

(3) Additional information. For further information on short circuit studies refer to:

(a) ANSI/IEEE 141, Recommended Practice for Electric Power Distribution for Industrial Plants.

(b) ANSI/IEEE 242, Recommended Practices for Protection and Coordination of Industrial and Commercial Power Systems.

(c) ANSI/IEEE 399, Recommend Practice for Industrial and Commercial Power Systems Analysis.

c. One-line diagram. Plate 9 in Appendix B indicates the format of the one-line diagram developed as part of the preliminary and final protection and coordination and short-circuit studies. Plate 10 provides a typical one-line diagram for a medium-voltage station.

(1) Standard symbols. Standard symbols for use on the one-line diagram are listed in ANSI Y32.2. Any nonstandard symbols that are used to show special features or equipment should be explained in the drawing legend to make their meaning entirely clear.

(2) Check list. The following is a check list of items that should be included on the study one-line diagram:

(a) Fault current. This is the available three-phase fault current of the utility supply at the pumping station metering point. This information can be presented in amperes, MVA, or as an impedance to the utility infinite bus (impedance in ohms or per unit on a specified base). The designer should also request the utility to provide an estimate of future three-phase fault levels. The estimate provides an indication of utility system changes which may affect the future short-circuit interrupting capability and withstand ratings of installed electrical equipment.

(b) Bus voltage.

(c) Transformers. The diagram should show winding connections, kVA rating, percent impedance, the X/R ratio, neutral grounding, if any, including the neutral ground impedance value, if not solidly grounded.

(d) Power cables. The diagram should show size, length, conductor material, whether single or multi-conductor, and whether the cable is carried in a magnetic or nonmagnetic duct.

(e) Circuit breakers. The diagram should show type by appropriate symbol (for example, molded case or draw-out) and the following ampere ratings: interrupting rating, frame size, thermal trip setting, and magnetic trip setting. It should show also the range of adjustment of the magnetic trip, if adjustable, as well as the recommended setting as determined by a protective device coordination study.

(f) Switches and fuses. The diagram should show type of fuse or switch and the continuous and interrupting rating in amperes.

(g) Motors. The following should be given: HP or kilowatt rating, power factor, synchronous or induction type, mechanical speed (revolutions per minute), and sub-transient reactance. The following additional data are required for synchronous machines: transient reactance, synchronous reactance, and the impedance of any grounding resistor.

(h) Location(s) where power purchased from a utility company is metered.

(i) The following information is required for preparation of the protection and coordination study: locations of potential and current transformers and relays and metering. Show location, quantity, and types of relays by standard IEEE device numbers, such as 51 for overcurrent relays, 67 for directional overcurrent relays. Device numbers are listed in ANSI/IEEE C37.2.

d. Specification requirements. The pump station construction specifications should require the contractor to furnish the final short-circuit study during the shop drawing approval process. The study should then be reviewed by the designer and returned to the contractor with any appropriate comments.

e. It should be clear in the specifications that it is the contractor’s responsibility to coordinate with his various equipment suppliers to produce a complete and accurate short-circuit study. The actual preparation of the study should be performed by the equipment manufacturer or an independent consultant.

f. The specifications must state that the cable sizes, ampere ratings of the protective devices, and the short-circuit withstand ratings of the equipment shown on the one-line diagram are preliminary and that the contractor must furnish a complete and final one-line diagram upon completion of the coordination and protection and short-circuit studies.

18.7 Arc Flash Study.

a. General. Shock and electrocution have long been recognized as risks to those who work with electricity. In recent years, additional emphasis has been placed on the dangers associated with arc flash and arc blast energy. This risk arises, not from the passage of electric current through the body, but from the concentrated energy during an arcing fault.

(1) Arc flash. The release of this energy instantly vaporizes materials such as copper or steel and can produce an extremely bright arc flash. The result could be severe burns to the hands and face.

(2) Arc blast. As opposed to arc flash, which is associated with thermal hazard and burns, arc blast is associated with extreme pressure and rapid pressure buildup. A substance requires a different amount of physical space when it changes state, say from a solid to vaporized particles. When liquid copper evaporates, it expands 67,000 times. This accounts for the expulsion of vaporized droplets of molten metal from an arc, which is propelled up to a distance of 10 ft. The rapid temperature rise causes the air in the arc to expand creating a pressure wave that can produce a sound level of 165dB. The result could be hearing loss and physical trauma.

b. Generators. In order to calculate the incident energy, the available fault current must be known for all connected sources of power, including the standby generator. This allows modeling of the worst-case incident energy based on which power source is connected. The major determining factor in calculating available fault current for generators is the internal impedance. When available, the actual generator impedance is used in the calculations. However, many times, the actual impedance is not available. In this case, industry standard impedance data based on the type and construction of the generator is used, resulting in an estimated available fault current being used for the incident energy calculations.

c. Publications.

(1) ER 385-1-100. USACE published ER-385-1-100, Arc Flash Hazard Program. The regulation requires an arc flash analysis to be performed on all USACE operated industrial facilities, including pumping stations. While most stations are turned over to a local sponsor once construction is completed, performing an arc flash analysis during the design phase may allow a designer to reduce the hazards prior to construction.

(2) Engineering Pamphlet (EP) 385-1-100. The pamphlet EP-385-1-100 serves as an implementation guide for developing an arc flash hazard program, but the content also provides a good overview of arc flash hazards, incident energy and arc flash boundaries, equipment labeling requirements, and personal protective equipment (PPE).

(3) NFPA 70E. NFPA publication 70E, Standard for Electrical Safety in the Workplace, served as a basis for ER 385-1-100.

(4) IEEE Std 1584™. The IEEE Guide for Performing Arc-Flash Hazard Calculations provides details on the analysis process and serves as the basis for the calculation models used in many of the commercial analysis software packages. The guide is applicable for three-phase alternating current (AC) systems from 208 V to 15 kV. Equations have yet to be developed to calculate are flash energy for single-phase AC and direct current (DC) systems.

d. Data Collection. Data collection is often a tedious task when performing an arc flash analysis on an existing system. Not only must the one-line diagrams be verified, but the transformer impedances, the size, type, and length of conductors, and the make and model of the overcurrent protective devices must be collected. On a new system, the designer must select a make and model for the overcurrent protective devices to be used in the power system model and take transformer impedances from product data.

e. Calculations. Arc flash calculations are easily performed as part of a power systems software package. The software uses the coordination and short circuit studies to determine the amount of incident energy released during an electrical fault for each piece of equipment in the power system.

f. The faster the fault is cleared by the upstream overcurrent protective device, the lower the amount of energy that is released. The energy is expressed in calories (cal) per centimeters squared. Energy above 1.2 cal/cm^2 on unprotected skin may cause a 2nd degree burn. The higher the incident energy, the higher the PPE Category needed for protection to limit burns to 2nd degree.

g. PPE Category. The PPE Categories, numbered one through four, are defined in Table 130.7(C)(15(c) of NFPA 70E. The PPE ranges from arc-rated clothing of 4 cal/cm^2 to the bulkier arc flash suit and hood rated for up 40 cal/cm^2. In the 2012 publication of NFPA 70E, PPE Category was referred to as a Hazard Risk Category, which is the term used throughout ER and EP 385-1-100.

h. Hazard Reduction. As stated in paragraph 5-3.c of ER 385-1-100, the PPE Category should not exceed level 2 where feasible. This may necessitate a more robust electronic trip unit or the use of a maintenance switch to modify the trip settings. In a new design, these changes can be easily incorporated prior to contract advertisement and award reducing the need for contract modifications.

18.8 Starting Study.

a. General. The size of the pump motors and the robustness of the power source may dictate the need for a motor starting study. Chapter 9 of IEEE Std 399, IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis provides additional information on the analysis.

b. Large motor inrush currents can create a dip in the bus voltage. The voltage dip can prevent the motor from fully accelerating and starting, but the dip can also cause other motors and equipment in the power system to drop offline. In rural areas with smaller electric utilities, a starting study may be needed to ensure the system is capable of supporting the pump motor(s).

c. The starting study can be a simple voltage drop “snapshot,” a detailed voltage profile, or a transient (speed, torque, and acceleration) motor analysis. IEEE 399 recommends using a motor starting study if the motor HP exceeds approximately 30% of the supply transformer base kVA rating. If using a generator, a starting study is recommended for motor HP of 10-15% of the generator kVA rating.

d. Reduced Voltage Starting. During starting, a motors inrush current is directly proportional to the terminal voltage. A lower motor voltage will require a smaller inrush current reducing the amount of voltage dip.

e. Before the introduction of soft-starts and VFDs, a reduced voltage autotransformer starter was an effective means of starting larger motors. The autotransformer included taps ranging from 50% to 80% on the normal rated voltage. The starting study allowed the designer to select the lowest possible transformer tap to limit inrush, but still allow the motor to start. Because of their lower initial costs, soft-starts and VFDs have replaced reduced voltage autotransformer starters.

f. Soft Start. A soft start will accelerate a pump motor from zero to full speed over several seconds to reduce the starting current. The speed cannot be varied with a soft start. When the motor is at full speed, a shorting contactor may be closed to remove the soft start from the circuit. If the power system can support across-the-line starting, a bypass contactor will allow the starting of the pump motor in the event of a soft start failure.

(1) When a bypass contactor is used, manufacturers often require an isolation contactor to remove power from the soft start input. While use of the bypass contactor can provide a more robust pumping system, additional panel space will be required to house the contactor(s).

(2) The pump motor is protected by the soft start. This includes overload (motor thermal), overcurrent, phase loss, and undervoltage. The soft start can limit the starts per hour and also prevent restarting immediately after stopping (backspin). Soft starts also provide communication options to allow a control system or operator interface to display motor data such as line current.

g. Variable Frequency Drive (VFD). The VFD includes all of the benefits of a soft start and the ability to change the speed of the pump motor. Since the VFD costs more than a soft start, it should only be used when the pump application requires a motor to be run at less than full speed. This may be necessary when the pump station inflows vary greatly or the ponding capacity is small.

(1) At conditions of low inflows, reducing the pump speed will prevent excessive “short” cycling of the pumps. The speed of the pump is often tied to the inlet or sump level, but the minimum speed of the pump must be coordinated with the mechanical designer and the pump curve.

(2) A VFD may also be necessary to limit the starting current based on utility requirements. Large loads may require additional filtering to reduce harmonics being put back into the utility.

Chapter 19
Power Supply

19.1 General.

a. Studies. When the power requirements for the pump station have been tentatively established, the adequacy of the intended source of electric power and any limitations of that source must be ascertained before proceeding with station design. The design investigations should disclose:

(1) Maximum available power.

(2) Capacities and location of existing transmission lines, distribution lines, and substations which may be involved in the supply of power to the pump station.

(3) The optimum system operating voltage and voltage regulation characteristics if necessary.

(4) The power company's reliability, maximum permissible motor in-rush current limitations, and short circuit characteristics.

b. Adequacy. The responsibility for the supply of electric energy required for the operation of the pump station after completion of the project rests with the local sponsor. Any extension of existing power transmission facilities required to make this energy available at the pump station site is a construction feature and the responsibility of the Government.

c. In many instances, it will be necessary for the Government to participate in the preliminary negotiations with the utility supplying power in order to ensure that the completed project will have, at minimum rates, an adequate power supply of the proper characteristics. Where feasible, the contract should be made between the local interests and the utility supplier.

d. However, there will be many cases where it will be more advantageous for the Government to procure both the extension of power facilities and supply of electric service by the local power company. This will need to be coordinated with and procured by the construction contractor as part of the construction contract. In those cases, the Government should enter into such a contract with the understanding by all parties that the costs of energy will be assumed by the local interest upon completion of the project.

e. Power Rates. In view of the type of operation and the public service pump stations render to the community, it has been the practice to request the public utility supplying power to give special rate considerations. These considerations include the waiver of some or all demand and standby charges, and the charging for only the actual energy used. Power rates should be negotiated on the basis of turning over maintenance and repair to the power company for all the power lines and the substation necessary to operate the pump station.

f. Hydrology studies are a good tool to estimate the amount of pump required, the power usage, possible time of day or off-peak pump scenarios when applicable, and the resulting rate structure. Local interests should be invited to participate in the pump usage scenarios and power supply studies.

g. Electric Power System Data Sheet. An electric power system data sheet is included in Appendix E as an example method to organize the information received.

19.2 Power Supply.

a. Construction Required. All facilities and construction necessary to supply the electric power required to operate the pump station should be provided as part of the project. Local power utility companies coordinate, provide, and install all of the labor and equipment necessary to extend their power system(s) to provide a new power service drop for pump stations. The cost of these facilities will be included in the project costs either as part of the construction contract or as a separate contract activity.

b. The construction required may vary from the simple overhead service drop at utilization voltage to extensive installations involving transmission lines, switching, and transformer equipment. The power line should be available at the time that the construction contractor needs temporary power for his use to construct the pump station.

c. Coordination, power costs, and temporary substation costs incurred during construction should be borne by the pump station construction contractor. The construction contract should require the pump station construction contractor to perform coordination with the power utility and to pay all costs incurred by the power company to provide and install equipment for a new power utility service.

d. Note that some power utility companies require partial payment or full payment before the power utility will construct their system and this must be addressed as it is encountered. Refer to ANSI/IEEE C2, "National Electrical Safety Code" regarding power systems greater than 600 Volts.

e. Power for Lighting and Auxiliary Loads. A continuous electric supply for lighting, security system, communications, heating devices, and miscellaneous control or protective devices is required. The power supply for these auxiliary services may be provided by a low voltage step-down lighting and receptacle transformer supplied by the main service. Alternately, the power for lighting and ancillary loads may be supplied by a second, smaller power utility service which is separate from the main power supply which would eliminate the necessity to have continuous energizing of main transformers and switchgear.

f. Emergency Power Supply Facilities. In general, flood protection pump stations should be considered emergency facilities. Other pump station types such as environmental stations typically are not classified as emergency facilities. Equipment and power supply should be selected primarily on the basis of reliability under emergency conditions.

g. The reliability of the power supply needs to be determined by the designer. Dual power service feeders or standby power supply facilities typically will not be provided unless the power supply is considered unreliable.

h. Dual power service feeder refers to a power utility connection in which the pump station is provided with two separate power utility services routed from different directions or different portions of the local power utility. That way if one power service from one route of the power utility loses power, then the other service routed from a different path in the power utility's system still is available to provide power to the pump station.

i. The reliability of the power utility service must be addressed by the electrical designer with the local power company as described in Paragraph 19-4. The project's product delivery team must determine the degree of reliability needed for the pump station, assess the reported reliability, and determine an acceptable level of risk to determine the need for alternate backup power sources for the pump station.

19.3 Station Operating Voltage.

a. Operation and Load Considerations. It is important that the proper operating voltage for the motors be selected if the minimum overall installed cost of equipment is to be realized. Most flood risk management pump stations operate at either 480 or 4,160 Volts.

b. As a general rule-of-thumb, motors of 150 kW (200 HP) and below are usually most economically operated at 480 volts. Above 150 kW (200 HP), 2,300 Volts or 4,000 Volts motors should be considered. Consider and determine the electric pump motor starting methods including full voltage starting, soft start starters, reduced voltage starters, variable voltage drives, and VFDs.

c. The motor starting method will be finally determined upon consultation with the electric power company to acquire the best starting method for the pump motors based on the specific application. Once the station capacity has been determined, the utility should be contacted to determine what utilization voltages are available.

d. Capacitor Banks. Capacitor banks may be installed for pump stations to increase the pump station power system's power factor and improve voltage if necessary. The pump station designer should coordinate with the local power utility company to determine if a capacitor bank is necessary to improve the quality of the power service or if it would otherwise be beneficial for the pump station's electric power system. The power utility company should advise if capacitors will add value to the system and if a capacitor bank is determined to be beneficial, should then work with the pump station designer to determine what capacitor size is most effective to install.

e. Metering and Utility Rates Considerations. The utility rate structure and discounts such as untransformed service credit and time-of-day metering for off-peak time pump hours must also be obtained and analyzed.

(1) Pump station pump operation scenarios may or may not be able to adapt to allow time of day metering or other special utility metering. For example, flood protection pump stations must conduct pump operations whenever the demand occurs regardless of the time of day or month while operation of some environmental management pump stations may allow flexibility to only pump during off-peak hours.

(2) Determination of the most economical operating voltage requires accurate estimation and comparison of the complete electrical installation costs required for each operating voltage considered. Costs which must be considered include line construction, substation installation, power regulators, capacitor banks, electric motors, controls, conduit sizes, cable sizes, and floor space required.

(3) The total connected power load, the load factor, and the demand factor are power load considerations which determine the pump station's service size and have influence on the utility cost rates. Power utility companies typically charge a cost for the electric service availability regardless if the pumps are used.

(4) Some pump station owners have considered disconnecting the electric utility service when pumping is not needed as a method to save costs, but there are many considerations (i.e., reconnection response time, lighting, enclosure heaters, building ventilation, and building heat, etc.) which must be addressed to determine if this idea is a feasible cost saving method.

19.4 Power Supply Reliability and Availability.

a. General.

(1) The first step in assuring an adequate power supply to a pump station is to define the degree of reliability needed. This is not an easy task that results in the assignment of a numerical value. It is, instead, an evaluation of the tolerable power outages versus the additional costs to reduce the probability of outages. Some factors to consider in determining the degree of reliability needed in the power supply are:

(a) The type of property being protected. Is it cropland, industrial buildings, or urban areas?

(b) The consequences if the pump station fails to operate when required. Would an industrial plant be inundated causing immediate damage or could crops planted in a rural area tolerate submergence for a short time? Is ponding available? Would residential areas be flooded? Could there be potential human injury?

(c) The frequency and duration of outages that are acceptable to prevent any of the above.

(d) The time of year flooding is likely to occur. Does that pose any special problems such as overloading total utility capabilities?

(2) Once the designer has established the need of continuity of service, coordination with the utility is necessary to establish a system to meet that need. Several meetings or correspondences may be required to work out final details of the system. Figure E-1 of Appendix E is a flowchart for interfacing with the power company.

b. Reliability.

(1) Power source reliability will be indicated by the number, size, type, and location of generating facilities, and of interconnections with other systems. In this respect, consideration should be given to the short, infrequent periods of operation of the pump station and to the ability of local governments to direct power distribution under emergency conditions.

(2) Discuss this reliability subject with the power utility during coordination of a new pump station power service. Local owner's operation records and the outage history of the supply lines to which connections are contemplated are important aids in determining the extent and nature of construction necessary for reliable supply. Factors affecting the reliability of the supply connection between the power source and the pump station are:

(a) Length, location, and type of construction of the connection.

(b) Location of the point of connection to a different source.

(c) Appropriate switching equipment between the connection and supply circuits.

(3) Consider the following guidance regarding reliability for critical operations power systems and reliability for fire protection power systems from which one can learn more about reliability that may be considered for pump stations:

(a) Note that NFPA 70, "National Electrical Code", Informative Annex F Availability and Reliability for Critical Operations Power Systems; and Development and Implementation of Functional Performance Tests (FPTs) for Critical Operations Power Systems contains additional information regarding availability and reliability. Note also that although this Annex F is informative, it also states that the electrical power industry has historically not used the definitions for reliability which are cited in Annex F.

(b) Refer to UFC 3-550-01, (February 3, 2010 including Change 1, July 1, 2012), Exterior Electrical Power Distribution for additional power system reliability considerations.

(c) Refer to UFC 3-600-01, (8 August 2016 Edition), “Fire Protection Engineering for Facilities”, Paragraph 2-1.31.2 which defines a reliable power source as follows: “Unless otherwise noted, a reliable power source is a power source having forced down time, excluding scheduled repairs, that does not exceed 8 consecutive hours for any one incident within the last 3 years, or more than 24 hours cumulatively over the last 3 years.”

(d) Refer to NFPA 20, (2016 Edition), “Installation of Stationary Pumps for Fire Protection”, Paragraph A.9.3.2 which identifies the following characteristic that a reliable power source should have; “The source power plant has not experienced any shutdowns longer than 10 continuous hours in the year prior to plan submittal.”

c. Availability. Availability could be defined as the long-term average that the electric service is expected to be energized. Outage data, given over a 5-year period, are usually available from the utility. The number of outages and duration of those outages over the 5-year period for the substation which will supply the pump station can be used to calculate the availability.

(1) Distribution System Alternatives. The pump station designer will primarily be concerned with local distribution systems and premises systems when discussing reliability considerations with the utility. Basically, there are two types of distribution systems including radial and network.

(2) A radial system has only one simultaneous path of power flow to the load; a network has more than one simultaneous path of power flow to the load.

(3) A complete listing of the variations of these two broad groups falls outside the scope of this document. In general, the usage of a radial feed should be limited to projects where either the economics or characteristics of the protected property do not justify or require a more expensive network. Not all of the possible network schemes will be available from every utility. Consultation and coordination with the local electric power utility company that will supply power to the pump station project will be necessary to provide the appropriate system for the specific application.

19.5 Alignment and Location and Power Utility Service Entrance. The pump station service entrance equipment and substation equipment should be located and constructed so that it is protected from flood waters.

a. Electric power service distribution poles, transformers, switchgear, and substations should be installed on the protected side of levees or flood walls. The electric power utility poles should be routed so they are physically protected from flooding as best as possible and should enter the project site on the protected side of the project’s levee.

b. Other power service equipment such as transformers, metering equipment, and switchgear should be installed either elevated on poles or on elevated concrete pads if necessary so that the bottom of the equipment is located not less than 18 inches above the highest estimated flood elevation based on guidance from NFPA 70 for electrical equipment installed in marinas. However, an elevation of 24 inches above highest estimated flood elevation is preferable because it will allow additional 6 inches of freeboard protection against wave action during a flood event.

c. This electric power service equipment will be owned and maintained by the electric power utility company for the life of the project so service equipment should also be located to be accessible to the electric utility for maintenance and repair activities.

19.6 Pump Station Distribution Substation.

a. Layout and design. Normally the Government contracts with the local utility to design, construct, operate, and maintain the power supply to the pump station either by separate contract or by procurement which is inclusive in the pump station's project construction contract.

b. In some cases, the electric power utility company will require the Government to provide the transformer pad and on this occasion the transformer pad is made a requirement of the pump station contract constructed by the construction contractor. In such cases, close coordination between the utility, the Government, and the contractor will be necessary to ensure pad sizes, and mounting bolt locations are as required by the utility's transformers or other substation equipment.

c. Generally, close coordination between these parties is necessary whenever providing a new electric power service to ensure all considerations for equipment type, size, location, and proper installation are properly addressed. The service entrance equipment or substation equipment should be located as close to the pump station as possible. Further guidance on rights-of-way, ownership, operation, etc., of the transmission line and substation may be found in TM 5-811-1, "Electric Power Supply and Distribution".

d. Service Transformers. The type of transformer used, i.e., whether single-phase or three-phase, should generally be determined by the availability of replacements from the local power company stock.

(1) The local power company manages their equipment and provides the service equipment based on information provided by the designer as coordinated. Most utilities keep an inventory of replacement transformers of the various sizes necessary to provide quick replacement.

(2) The designer should inquire as to the location of transformer storage and the length of time required to transport and install it in an emergency. All transformers used must be non-Polychlorinated Biphenyls to comply with all Federal, State, and local laws. It is common to employ either a single, three phase transformer or otherwise three single phase transformers connected delta-wye.

(3) It may be available in rural areas to employ three single-phase transformers connected either wye-delta or delta-delta so that, in the event of a transformer failure, they can remain in operation when connected in an open delta configuration. However, this configuration should be used with caution since it prohibits the application of ground fault relaying as well as producing inherent unbalanced voltages which could result in the overloading of motors.

(4) Another, more attractive, option would be the furnishing of a fourth single-phase transformer or a second three-phase transformer as a spare. Utility service transformers should be located so they may be accessed. Service transformers should be located where they are protected from flooding either installed at a higher elevation located above possible flood elevation or located inside reliable flood protection.

(5) Elevated platforms or elevated pads should be provided as required for three phase pad-mounted transformers. Three, single phase service transformers should be mounted on poles at appropriate elevations. Some pole-mounted service transformer assemblies are provided with additional structure features as necessary to support the equipment and provide safe access (e.g., additional pole(s) and mounting platform).

19.7 Power Supply System Characteristics. An interchange of information between the designer and the utility is necessary if the pump station electrical system is to be compatible with the power supply furnished.

a. The designer should obtain the data requested in Appendix E from the local utility supplying power to the proposed pump station. The designer will need to obtain the maximum fault current available from the electric power utility company as well as information concerning the new power service or distribution substation transformer impedance to prepare the short-circuit coordination and arc flash hazard studies indicated in Chapter 18.

b. The designer should transmit pump station loads and motor starting requirements to the local electric power utility company as soon as they become available so that the utility company can prepare an analysis of the impact upon their system. The utility company can then advise the designer of power factor and motor inrush current limitations. After details of the electrical system have been coordinated, the designer should request time-current curves of the substation primary side protective devices so that a coordination study as described in Chapter 18 can be prepared.

19.8 Pump Station Main Disconnecting Equipment. For guidance on selection of the pump station main disconnecting equipment, See Chapter 21.

Chapter 20
Motors

20.1 General.

a. Motor types. Constant-speed motors of either the squirrel-cage induction or synchronous type are the preferred drives for pumps installed in flood-protection pumping stations. Both squirrel-cage and synchronous motors are available in speed ranges and sizes that embrace most requirements.

b. Vertical type motor construction. Usually, the vertical type motor construction is preferred since it requires minimum floor space, which contributes significantly to an economical pumping station layout. The simplicity of the vertical motor construction also contributes to station reliability.

c. Horizontal type motor construction. Horizontal motors with gear drives have been used in some applications, but any first cost advantages must be weighed against increased O&M costs as well as decreased reliability over the life of the project. The gear reducer and its associated auxiliary equipment are additional components that are subject to failure. Comparative costs should include installation and maintenance costs for gear lubricating pumps, cooling water pumps, associated piping, monitoring equipment, etc.

d. Submersible type motor construction. Submersible-type motor construction has become common for significantly sized submersible pumps. A submersible-type motor is provided integrally constructed in a combined pump column with the submersible-type pump installed directly inside the discharge pipe column. The submersible motor construction also requires minimum floor space, which contributes significantly to an economical pumping station layout. The simplicity of the vertical motor construction also contributes to station reliability.

e. Full voltage starting. All motors should be designed for full-voltage starting, even if incoming power limitations indicate that some form of reduced-voltage starting is required and applied. For installations having discharge lines with siphon assist, the power required to establish prime should not exceed the motor rating plus any additional service factors. This is necessary to assure successful operation in case siphon action is not established.

f. Contractual requirements. The contractual requirements for the majority of induction and synchronous motors used in flood-control pumping stations are described in UFGS 26 29 01.00 10, “Electric Motors, 3-Phase Vertical Induction Type” and UFGS 26 29 02.00 10, “Electric Motors, 3-Phase Vertical Synchronous Type”.

20.2 Induction Motors.

a. Squirrel cage. The squirrel-cage induction motor has a stator winding which produces a rotating magnetic field that induces currents in a squirrel-cage rotor.

(1) The squirrel cage consists of a number of metal bars connected at each end to supporting metal rings. Current flow within the squirrel-cage winding produces the torque necessary for rotor rotation.

(2) Squirrel cage induction motors have very simple construction, with no electrical connections to the rotor, and hence they possess a very high degree of reliability. However, the squirrel-cage rotor does not rotate as fast as the revolving magnetic field setup by the stator winding. This difference in speed is called "slip." Because of this inherent feature, squirrel-cage motors are not as efficient as synchronous motors, whose rotors rotate in synchronization with the magnetic field. There are three basic variables that classify motor performance types. These are:

(a) Starting torque.

(b) Starting current.

(c) Slip.

(3) Motors can have high or low starting torques, starting currents, and slip. However, these variables are not produced in every combination. For example, high resistance rotors produce higher values of starting torque than low resistance rotors. But high resistance in the rotor also produces a "high slip" motor. A high slip motor, by definition, has higher slip losses, hence lower efficiency, than an equivalent low slip motor.

b. Pump Applications. Three-phase, squirrel-cage, induction motors are the most common type of electric motor used as drive pumps in the range of pump sizes from 0.746 kW (1 HP) to (375 kW) 500 HP. Note that the other type of induction motor, the wound-rotor motor, is not typically used to drive pumps in CW pump stations.

20.3 Synchronous Motors.

a. Operating principle. The synchronous motor starts and accelerates its load utilizing the induction principles common to a squirrel-cage motor. However, as the rotor approaches synchronous speed (approximately 95 to 97 percent of synchronous speed), a second set of windings located on the rotor is energized with direct current.

b. These field coil windings are responsible for providing the additional torque necessary to "pull" the rotor into synchronism with the revolving magnetic field established by the stator windings. The time at which direct current is applied to the field coil windings is critical and usually takes place when the rotor is revolving at approximately 95 to 97 percent of synchronous speed.

c. Field coil winding excitation. There are several methods commonly employed to achieve field coil winding excitation. Generally, brushless field control is the preferred method of field application. In a brushless motor, solid state technology permits the field control and field excitation systems to be mounted on the rotor. The motor, its exciter, and field control system are a self-contained package.

d. Application and removal of field excitation are automatic and without moving parts. The brushes, commutator collector rings, electromagnetic relay, and field contactor are eliminated. Thus, the extra maintenance and reliability problems usually associated with older brush-type synchronous motors are greatly reduced.

e. Flow-type or propeller-type pumps. Synchronous motors find their application as pump drives in the large capacity, low rpm mixed flow-type or propeller-type pumps.

(1) In general, their usage should be limited to pumps of at least 375 kW (500 HP) and above, and at speeds of 500 rpm and below. Careful attention must be given to available pull-in torque to "pull" the rotor into synchronism with the revolving magnetic field.

(2) At this point, the motor must momentarily over speed the pump past the moving column of water. Knowledge of the pump speed torque curve, voltage drop at the motor terminals, and the ability of the motor field application control to provide the best electrical angle for synchronism must all be considered.

20.4 Submersible Motors.

a. Applications. Submersible motors have been used effectively in pump stations where economy of design is paramount and where submersible pumps are suitable for the pump size and application.

b. The submersible motor is designed, selected, and provided by the submersible pump manufacturer integrally assembled with the submersible pump. The submersible pump and therefore its submersible motor must be rated suitable for use for the application for which it will be installed.

c. For example, where the possibility exists that combustible gases or flammable liquids may be present the pump well (or vault) should be deemed to be classified with the appropriate NFPA 820 and NFPA 70 hazardous location rating. Then the submersible pump, including its integral submersible motor and all electrical equipment designed to be located inside the classified location area must be properly rated for use in the appropriate hazardous location.

d. Additional common electrical features. Thermal sensors should be provided in submersible pump motors to monitor the winding temperature for each stator phase winding. A water leakage sensor should be provided to detect the presence of water in the stator chamber. If the possibility exists that rodents may enter the sump, special protection should be provided to protect the pump cable(s).

e. For example, split-type stainless steel wire mesh can be installed along the length of the submersible pump motor cable to provide physical protection. Also, the submersible pump motor cables should be supported when suspended from the top of the pump discharge column (pump can) using wire mesh cable hangers and hanger hooks. The submersible pump manufacturer likely has typical cable hanger methodology and requirements.

20.5 Common Features. UFGS 26 29 01.00 10 and UFGS 26 29 02.00 10 provide detailed requirements for common motor features such as frames, enclosure type, winding insulation, winding heaters, thermal protection devices, moisture sensing devices, overspeed design, anti-reversing device, and core construction.

20.6 Shaft Type. Motors can be furnished with either a hollow shaft or a solid shaft. Commonly, however, hollow shaft motors are available only up to about 750 kW (1,000 HP). The hollow shaft motor provides a convenient means to adjust the impeller height. Other factors such as station ceiling height and the ability of the crane to remove the longer pump column must be considered in the decision of the type of shaft to employ.

20.7 Starting Current Limitations.

a. General. The electric power utility must be contacted to determine starting restrictions, maximum inrush currents, or voltage dip limits. This is especially critical for motors over 75kW (100 hp).

b. The designer should then perform a Motor Torque and Accelerating Time Study to evaluate the motor starting torque and voltage dip requirement. The selection of a reduced voltage starter must then be based on the electric utility requirements and the motor pump arrangement.

c. UFGS 26 29 01.00 10 and UFGS 26 29 02.00 10 state the manufacturer’s standard is to limit the locked rotor current to 600 percent of rated (full-load) current. However, when utility requirements necessitate, lower inrush current induction motors may be specified not to exceed 500 percent of the rated full-load current. (Note: Starting inrush varies with efficiency; therefore, specifying reduced inrush will result in a somewhat lower efficiency.)

d. The motor manufacturer should be contacted before specifying a reduction of inrush current for a synchronous motor. The designer should consider and compare full voltage starters, reduced voltage starting by autotransformer, reduced voltage starting by soft starter, and use of VFDs when selecting starting methods for pump motors.

e. Reduced-voltage starting by autotransformer. If 500 percent is not acceptable, reduced-voltage starting of the closed-transition autotransformer type may be considered for use, but generally this is not the current method and solid state starters are more common.

f. Autotransformer starters provide three taps giving 50, 65, and 80 percent of full-line voltage. Caution must be exercised in the application of reduced voltage starting, however, since the motor torque is reduced as the square of the impressed voltage, i.e., the 50-percent tap will provide 25-percent starting torque. Connections should be made at the lowest tap that will give the required starting torque. Reactor-type starters should also be given consideration for medium voltage motors.

g. Reduced-voltage starting by soft starter. Another method to limit the starting current is to use a soft starter which is a solid state drive that alters the applied voltage during the starting of the pump motor. The starting characteristic can be programmed specifically for the pump motor it is starting. The reliability, price, availability of qualified maintenance personnel, and space considerations should all be considered carefully before electing to use soft starters.

h. Variable frequency drives. VFDs are also a common method to reduce inrush currents for 460 Volts low voltage applications and for medium voltage motor applications. VFDs are also commonly used for speed control which can be a consideration for flood risk management pumps. The reliability, price, availability of qualified maintenance personnel, and space considerations should all be considered carefully before electing to use VFDs.

20.8 Duty Cycle. Duty specifies the length of time the motor can operate at its rated load safely and indicates whether the motor is rated for continuous duty. Pump motors must be rated for continuous duty.

a. Care should be taken in the selection of the number and size of pumps to avoid excessive duty cycles. Mechanical stresses to the motor bracing and rotor configuration as well as rotor heating are problems with frequently started motors.

b. The number of starts permissible for a Design A and Design B squirrel-cage induction motor should conform to the limitations given in NEMA MG 1, Paragraph 12.54 for small and medium machines.

c. The number of starts permissible for large squirrel-cage induction motors should conform to the limitations given in NEMA MG 1, Paragraph 20.12. The definitions for small, medium, and large machines can be found in NEMA MG 1, Paragraphs 1.3-1.5.

d. Starting limitations for synchronous motors should conform to NEMA MG 1, Paragraph 21.13. The motor manufacturer should be consulted concerning the frequency of starting requirements if other than those prescribed above. Economic comparisons of different pumping configurations should include the reduction in motor life as a function of increased motor starting frequency.

20.9 Starting Torque.

a. General. Most stations use medium or high specific speed propeller-type pumps with starting torques in the range of 20 to 40 percent of full-load torque. The motor must be designed with sufficient torque to start the pump to which it is connected under the maximum conditions specified, but in no case should the starting torque of the motor be less than 60 percent of full load. For a more detailed discussion of torque values, see the particular motor type below.

b. Squirrel cage induction motors. Normally, motors specified in UFGS 26 29 01.00 10 will have normal or low starting torque, low starting current. Each application should be checked to ensure that the motor has sufficient starting torque to accelerate the load over the complete starting cycle. UFGS 26 29 01.00 10 requires that the pump motor have a minimum starting torque of 60 percent of full load. Breakdown torque should not be less than 200 percent of full load unless inrush current is reduced to 500 percent of full load current. If 500 percent is specified, the breakdown torque must be reduced to 150 percent of full load.

c. Synchronous motors. Synchronous motors must usually be specially designed for pumping applications. The load torques and Wk^2, so called "normal" values, on which NEMA MG-1 requirements are based are generally for unloaded starts and are therefore relatively low. Starting and accelerating torque must be sufficient to start the pump and accelerate it against all torque experienced in passing to the pull-in speed under maximum head conditions and with a terminal voltage equal to 90 percent of rated.

d. The minimum design for a loaded pump starting cycle should be: 60-percent starting torque, 100-percent pull-in torque, and 150-percent pull-out torque for 1 minute minimum with a terminal voltage equal to 90 percent of rated. This would produce inrush currents of 550 to 600 percent of full load.

e. Amortisseur windings. Double-cage amortisseur windings may be required to facilitate starting for and stabilize operation of a synchronous type motor by generating the uniformly high torque from starting to pull-in that is required by loaded pump starting. They consist of one set of shallow high resistance bars and one set of deeper low-resistance bars.

f. Measuring motor torque. One torque measuring tool, a Prony brake, is a simple type of dynamometer used to measure the amount of torque produced by a motor to determine its brake horsepower (BHP) rating.

20.10 Locked Rotor Torque. Each pump's structural anchorages must be designed with proper consideration of the pump's locked rotor torque. The electrical designer must coordinate with the mechanical and structural designers as necessary to determine the necessary design considerations and requirements for the pump motor mechanical connections and the structural anchors which must be designed to withstand the applied motor's locked rotor torque.

20.11 Selection.

a. General. The choice between a squirrel-cage induction and synchronous motor is usually determined by first cost, including controls, and wiring. In general, the seasonal operation of flood-control pump stations results in a fairly low annual load factor, which, in turn, diminishes the advantage of the increased efficiency of synchronous motors.

b. A life-cycle cost analysis should be performed that includes first costs, energy costs, and maintenance costs. Another factor that should be considered is the quality of maintenance available since the synchronous motor and controls are more complex than the induction motor. The additional cost of providing power factor correction capacitors to squirrel-cage induction motors, when required, should be included in cost comparisons with synchronous motors. Also, the extra cost to provide torque and load WK^2 values higher than normal for a synchronous motor because of loaded pump starting characteristics must be taken into account.

c. Annual Load Factor (ALF): The ALF can be estimated from data obtained from a period-of-record routing study or from the electric billing history of a similar pumping station. If a period-of-record routing or billing history is used, ALF would be defined as:

$$ALF = We / (Pd \times 8{,}760) \qquad \text{(Equation 20.1)}$$

where

We = total amount of energy consumed during year
Pd = maximum of 12 peak demands occurring during year
8,760= number of hours in a year

20.12 Power Factor Correction.

a. General. Power factor is the ratio of total watts to the total root-mean-square volt-amperes. Utility companies may meter the reactive or out-of-phase component (kVAR) of apparent power (kVA) as well as total energy (KWH). They may charge additionally for higher capacity requirements driven by peak loads and low power factor. A rule of thumb is that about 12 to 14 percent of line loss can be saved by improving the power factor 10 percent.

b. Flood-control pumping stations. In flood-control pumping stations, the power factor for induction motors will vary according to size and rpm. The power factor should be corrected to 92 to 95 percent at full load through the addition of power factor correction capacitors. The power factor correction capacitors are usually located either within or on top of the MCC. The capacitors should be switched in and out of the circuit with the motor. Feasibility, needs, and benefits of using power factor correction capacitors should be discussed with the local electric power utility company during coordination of the pumping station service.

20.13 Noise Level. The DoD considers hazardous noise exposure of personnel as equivalent to 85 decibels or greater A-weighted sound pressure level for 8 hours in any one 24-hour period (MIL-STD-1474E). Also refer to OSHA Regulations Standard 29 CFR 1910.95, Occupational noise exposure. The guide specifications provide requirements to obtain motors that meet this limitation. The designer, however, should evaluate the advantages and disadvantages of providing either the more expensive motors that meet these requirements or a room to isolate the operating personnel from the noise exposure. NEMA MG-1 provides more information on the subject.

20.14 Variable Speed Pump Drives.

a. General. V/S pump drives are not normally required in CW pump stations. Normally, if base flows are anticipated, a smaller C/S vertical or submersible pump is furnished to avoid excessive cycling of larger storm water pump motors.

b. VSDs are more frequently employed in sewage stations where the ability to match flow is more critical. VSDs are also used to start large HP pump motors as a method to limit the starting inrush current. If it has been determined that a variable speed drive is necessary, the designer should determine the most efficient and economical method that meets the needs of the application.

c. Variable frequency drive. Adjustable speed is obtained by converting the fixed-frequency AC line voltage into an adjustable voltage and frequency output that controls the speed of a squirrel-cage motor. A rectifier converts power from 60-Hz AC to DC. An inverter, then, reconverts the DC power back to AC power, which is adjustable in frequency and voltage.

d. The starting speed of large pump motors can be controlled by programming a VFD to ramp the pump motor speed up from start to full speed and thus controlling the inrush current. Drives are available in sizes up to 600 kW (800 HP) with variable frequency operation from 2 to 120 Hz. Inrush currents can be reduced to 50 to 150 percent of rated.

e. VFDs are very efficient and provide a wide range of speed adjustment. Both the electrical and mechanical designers must consider the amount and effects of eddy currents which may be produced by a pump’s VFD inducing currents in the motor shaft which then travel to ground through the pump and pump motor bearings.

f. Coordinate with a pump manufacturer and a VFD manufacturer during design to obtain knowledge about possible VFD-induced shaft currents. Coordinate during construction installation to determine what the actual VFD-induced shaft currents will be and how to protect the bearings as necessary from VFD-produced eddy currents which may be damaging to the pump bearings.

20.15 Electric Motor Enclosure Ratings. An electric motor frame and enclosure must be designed and the type selected for the environment in which it will be applied.

a. The level of environmental protection and method of cooling are defined and standardized by NEMA MG 1. NEMA MG 1 adopted the ingress protection (IP) and insulation contact ratings developed by the International Electrotechnical Commission (IEC) International Standards IEC 60034-5 and IEC 600034-6 for motor enclosure protection and cooling ratings respectively.

b. NEMA MG 1 now simultaneously states the original NEMA MG 1 protection level and the corresponding IP and insulation contact ratings expected for each type of electric motor. Refer to NEMA MG 1, Paragraph 1.25 for descriptions of the standard available classifications for motor protection and cooling.

20.16 Pump Motor Bearings. Pump motors are available with sealed bearings, grease lubricated bearings, oil lubricated bearings, and water-cooled bearings.

a. Normal service temperatures for these types of bearings follow as described in NEMA MG 1, Paragraph 31.1.2. An ambient temperature in the range of −15ºC to 40ºC for machines with grease lubricated bearings, 0ºC to 40ºC for machines with oil lubricated bearings, or, when water cooling is used in the range of 5ºC to 40ºC.

b. See Paragraph 20.14 above regarding considerations of harmful induced shaft currents that may be produced by VFDs and effect(s) on pump motor bearings if not properly addressed.

20.17 Winding Space Heaters. Pump motors may be provided with winding space heaters to prevent condensation in the pump motor when installed in damp or wet locations.

a. The designer should work with the pump motor manufacturer to determine recommended winding space heater wattages for specific motor frame sizes. It is prudent to conduct market research for specific applications.

b. The designer should require the pump motor manufacturer to finally determine the size and type of the winding space heater(s) for each specific pump motor that is actually provided if the designer determines and specifies in the construction contract that winding space heaters are required.

c. Winding space heaters often are connected to the motor controls to energize when the pump motor is de-energized and the winding space heaters de-energize when the pump motor is energized. For example, the winding space heater should be connected to a separate 120 Volt single phase power source that is switched OFF by an auxiliary contact from the pump motor starter when the pump motor starter is energized to run the pump and the auxiliary contact re-closes to switch ON to energize the winding space heater when the pump motor is de-energized.

20.18 Reverse Ratchets. Some pump motors can be provided with an integral anti-reversing ratchet to prohibit the pump from reverse rotation (i.e., running backwards) as the water backflows out of the discharge pipe after the pump motor is turned off, or if power is interrupted or lost, or if the electric motor fails.

a. Another alternative to prevent backflow damage is to allow the pump and motor to backspin, but to also install a backspin timing control relay in the pump controls.

b. The timer is wired to keep the pump locked out so it is unable to be restarted until the backspin is complete when the shaft comes to rest. At this time the timing control relay time period expires and allows the pump to be started again as needed.

20.19 Repair, Refurbishing, and Rebuilding Motors. Electric motors may be refurbished or rebuilt described as follows.

a. Repair and Refurbishment. The electric motor refurbishment process includes replacing the motor bearings, reusing and baking the stator winding, reusing and baking the rotor winding, applying new paint to frame, testing, and new specification data plate. Also included are removal and replacement of motor appurtenances specific to each motor such as winding condensation heaters, thermal sensors, and moisture sensors.

b. Rebuilding and rewinding. The electric motor rebuilding and rewinding process includes the refurbishment process described above except it also includes removal of existing windings and rewinding both the stator winding and rotor winding to original motor winding specifications. Also included are removal and replacement of motor appurtenances specific to each motor such as winding condensation heaters, thermal sensors, and moisture sensors.

c. Electrical Apparatus Service Association, Inc. (EASA) Standard AR100-2015, Recommended Practice for the Repair of Rotating Electrical Apparatus can be consulted regarding comprehensive requirements for refurbishing, rebuilding, rewinding, and testing of electric motors.

20.20 Factory Testing Motors. The designer should carefully consider the following factory motor tests regarding which tests are applicable and required for each specific project. The designer is sometimes questioned during construction phase whether the factory motor tests or some of the factory motor tests are required. The designer may have to carefully consider whether to allow the factory motor tests to be waived.

a. Factory complete tests. Includes the following: Excitation Test; Impedance Test; Performance Test; Speed-Torque Test; Temperature Test; Insulation Resistance-Temperature Test; Cold and Hot Resistance Measurement; Sound Level Test; Vibration Measurement; and Conformance Tests. This list of tests was derived from UFGS SECTION 26 29 01.00 10, Paragraph 2.6.1 which also refers to NEMA MG 1.

b. Factory check tests. Includes the following: Routine Test; Cold Resistance Measurement; Insulation Resistance and Winding Temperature; Conformance Test; and

Vibration Test. This list of tests was derived from UFGS SECTION 26 29 01.00 10, Paragraph 2.6.1 which also refers to NEMA MG 1.

c. New electric pump motors. One motor of each rating type must be given a complete test as defined in Paragraph 20.20.a. The remainder of the motors must be given a check test as defined in Paragraph 20.20.b. Alternately, it may be acceptable if the pump motor manufacturer's factory test results of a complete test of a prototype motor of the same type and size required for the specific project may be acceptable to fulfill the complete test, but each such pump motor must be given a check test.

d. Refurbished electric pump motors. Each motor must be given a check test as defined in Paragraph 20.20.b. Also, refer to EASA Standard AR100-2015.

e. Rebuilt and rewound repaired pump motors. Each motor must be given a complete test as defined in Paragraph 20.20.a. Also, refer to EASA Standard AR100-2015.

20.21 Field Testing Motors.

a. General. The designer should carefully consider the following field motor tests regarding which tests are applicable and required for each specific project. The Contractor should provide an erecting engineer to conduct startup services. The approved erecting engineer must supervise the handling, installation connections, startup and testing of the equipment to ensure that the pumps are installed properly per the manufacturer's instructions and requirements. Construction contractor must prepare and submit test reports of all completed field testing.

b. Megaohm test (a.k.a. Megger Test). The conductor insulation of an installed pump motor's stator winding and pump motor power lead conductors may be tested by using a megohmmeter applying a Megaohm test. The test is applied to cables at 500 Volts and the testing unit measures the resistance between each of the conductor combinations and between each of the conductors and ground in a circuit.

c. The rule of thumb is that the insulation resistance should be infinite, however insulation degrades over time and as it does so the insulation still has integrity if the insulation resistance is greater than 1 Megaohm. An insulation problem exists if the measured insulation resistance is less than 1 Megaohm which is indication that the insulation is breaking down and this problem should be investigated and corrected as soon as possible.

d. Dry pump test (including pump motor). An operational test conducted in the dry when the assembled pump, pump motor, and appurtenances are installed. Each pumping unit should be tested in the dry per the pump manufacturer's instructions to determine whether it has been properly installed. Such tests should be witnessed by the Government as deemed appropriate for the application.

e. Each pump should be at least “jogged” or “bumped” to rotate the shaft if dry operation is not advisable, otherwise each pump should be operated at full rated speed as allowable by its manufacturer and as long as it does not damage the pump. If the dry test reveals a design or installation deficiency or a manufacturing error in pumping unit components, the problem must be corrected by the Contractor.

f. Wet pump test (including pump motor). An operational test conducted when the assembled pump, pump motor, and appurtenances are installed and water is pumped. Each pumping unit must be given an operating test under load for a period as directed by the Government and is typically four (4) hours minimum of operation per pump but could be longer depending on the complexity of the pump station.

g. Each test should be witnessed by the Government. During the tests, the operation of the pumping units must be observed and measurement of noise as described in HI 9.1-9.5. Motor-bearing temperatures, voltage, and current should be recorded for each pump.

h. Measured parameters should be within the pump manufacturers published limits. Vibration measurements should be made at the top of the discharge tube for each pump. Vibration limits should not exceed those recommended by Hydraulics Institute standard, HI 9.6.4. Without additional cost to the Government, the Contractor must make all changes and correct any errors for which the Contractor is responsible. The water elevations should be measured and recorded so that an indication of the pump operating head parameters can be made from the pump curve.

Chapter 21
Power Distribution Equipment

21.1 General. The power distribution equipment for motors used in flood-protection pump stations must be as simple as possible, compact, and reliable. Other types of CW pump stations will have similar considerations.

a. Since the equipment will stand idle for long periods and be subject to wide temperature variations, provisions must be made to prevent condensation within control enclosures.

b. Refer to Appendix B, Plates B.9 to B.19, which identify various pump station electrical power and control diagrams. Also see Chapter 27, "Electrical Equipment Environmental Protection," for recommended protection requirements for electrical equipment. Other resources for electrical design are UFC 3-520-01, “Interior Electrical Systems” (2015) and UFC 3-550-01, “Exterior Electrical Power Distribution” (2016).

21.2 Main Disconnecting Device.

a. General. The main pump station disconnecting device should be located within the pump station as part of the MCC (for low-voltage stations) or the motor controller line-up (for medium-voltage stations). This location provides protection for the equipment and convenience for operations.

b. The main disconnect for the MCC could be a molded case circuit breaker, a power air circuit breaker, or a quick-make, quick-break fusible interrupter switch. Similarly, the medium-voltage motor controller line-ups can utilize high-voltage load interrupter switches or power circuit breakers of the air or vacuum type.

c. The main disconnect may also be an enclosed circuit breaker or an enclosed fused safety switch alternately located separately from the MCC or motor controller line-up if it is more suitable for a specific pump station application. The main disconnect should be rated for use as service entrance equipment.

d. Design decision. The design decision between a fusible interrupter switch and a circuit breaker ultimately depends upon the specific application. In some cases, continuous current requirements or interrupting capacities will dictate. Below 600 volts, circuit breakers and fuses are generally available in all continuous current ratings and interrupter ratings likely to be encountered. Refer to IEEE C37.42 for standard current ratings of high-voltage level (>1000 V) fuse supports and disconnecting switches which are usually limited to maximum standard ratings.

e. Designers must determine the proper maximum short-circuit current interrupting capacity when selecting the sizes of circuit breaker equipment, fuse equipment, and fuses.

Additionally, at this continuous current level, the slow interrupting characteristics of the fuse often presents coordination problems with the utility's overcurrent protective relaying.

f. Additionally, low voltage and medium voltage current-limiting power fuses offer advantages for protecting electrical power systems and equipment including fast current-limiting operation and high interrupting capacity. Current-limiting fuses should be considered for use when coordination is a problem. In any event, the utility should be advised of the choice of main disconnect in order to ensure compliance with their standards and to prevent coordination problems. If a fusible interrupter switch is selected, protection from single phasing should also be provided.

g. Fusible interrupter switch. Some general advantages and disadvantages of a fusible interrupter switch are listed here in Table 20.1:

Table 20.1
Fusible Interrupter Switches

Advantages	Disadvantages
• Simple • Constant characteristics • Low maintenance requirements	• Requires spare fuses • Nonadjustable • Self-destructive

h. Circuit breaker. Some general advantages and disadvantages of a circuit breaker are listed here in Table 20.2:

Table 20.2
Circuit Breakers

Advantages	Disadvantages
• Resettable • Adjustable • Remote control • Simultaneous tripping of all poles	• Higher initial cost • Requires periodic maintenance • Complex construction (at medium voltage)

21.3 Low-Voltage Pump Stations.

a. General. MCCs and low-voltage controllers should comply with NEMA ICS 2, "Industrial Control and Systems Controllers, Contactors and Overload Relays Rated 600 Volts".

b. Maintenance. Every effort should be made to reduce system maintenance and optimize pump station reliability.

c. Motor protection. For further information on motor protection, refer to ANSI/IEEE 242, "Recommended Practices for Protection and Coordination of Industrial and Commercial Power Systems – IEEE Buff Book (2001)".

d. Motor overload protection. Overload protection of the pump motor is provided by thermal overload relays or solid-state overload relays, which are either built into the motor starter itself or wired in series as separate relay unit.

(1) The thermal overload relays contain high-wattage electric heaters, in each phase, which are heated by the passage of motor current. The heat generated either bends a bi-metallic strip or melts a low temperature (eutectic) fusible alloy. The bent bi-metallic strip opens contacts that interrupt the current to the contactor-operating coil. The melted alloy frees a spring-loaded shaft that rotates and breaks contacts in the operating coil circuit.

(2) The bi-metallic relay has two advantages not found in the fusible-alloy type: it can reset itself automatically and can compensate for varying ambient-temperature conditions if the motor is located in a constant temperature and the starter is not. The heaters must be sized to accept the starting current of the motor for the expected starting time without causing the contactor to open.

(3) To achieve this with a variety of connected loads, conventional starters are available with a range of standard heaters, which can be selected according to the application. Always replace the entire set (one heater per phase) of overload heaters when replacing overload heaters to establish reliability on all phase lines so each heater is new and equal in quality.

(4) Solid-state overload relays measure the motor current with current transformers which is processed and converted into an electronic signal that opens (de-energizes) the motor power circuit if the measured current exceeds the overload current trip setting.

e. Undervoltage protection. Undervoltage protection is supplied inherently by the action of the operating coil. An abnormally low supply voltage causes the motor to run well below synchronous speed, drawing a current which, even though not as high as the starting current, quickly overheats the motor. A low supply voltage, however, also means a low current to the holding coil and causes the contactor to drop out and isolate the motor. If more protection from undervoltage is required, an undervoltage relay can be added to the motor controls to provide increased protection.

f. Combination motor controllers. Combination duplex or triplex motor controllers are sometimes provided by the pump manufacturer as part of a pump, motor, controller package. This is often the case for smaller pump stations employing submersible motors. This is a viable option, where applicable, and assures one manufacturer responsibility if problems arise.

21.4 Medium-Voltage Stations.

a. General. The designer must choose between a medium-voltage motor controller (incorporating a magnetic contactor) and an air-magnetic or vacuum circuit breaker. While "metal-clad" switchgear is the highest quality equipment produced by the industry, motor controllers are still preferred. Circuit breakers in metal-clad switchgear are used as motor starters primarily by utilities, where a motor, once started, may run a week or more without stopping. In industry, circuit breakers find their application as main or feeder breakers that are not frequently opened or closed.

(1) Circuit breaker benefits. The benefit of circuit breakers is that although the contact mechanism is not designed for a large number of operations, it is designed to interrupt short-circuit currents of high magnitude and be returned to service immediately.

(2) Cost. Another consideration in the choice between the two is the relative cost. Metal-clad switchgear is approximately three times as expensive as an equivalent line-up of motor controllers. Where required, air or vacuum circuit breakers can be used as mains with transition sections to accommodate the motor controller line-up.

b. Medium-voltage motor controllers. The medium voltage controllers should comply with NEMA ICS 3, "Industrial Control and Systems: Medium Voltage Controllers Rated 2001 to 7200 Volts AC", NEMA ICS 3.1, Guide for the Application, Handling, Storage, Installation, and Maintenance of Medium-Voltage AC Contactors, Controllers, and Control Centers", and UL Standard 347 (Underwriters Laboratories, Inc. Sixth Edition, 2016).

c. Medium voltage controllers may be described as metal-enclosed high-interrupting capacity, draw out, magnetic contactor type starter equipment with manual isolation. Medium-voltage motor controllers are available for reduced-voltage and full-voltage starting of non-reversing squirrel-cage and full-voltage starting of synchronous motors typically used in pump stations.

(1) High-voltage and low-voltage sections. Each motor controller enclosure is divided into a high- and low voltage section. The high-voltage section contains the magnetic contactor and its protective fuses. The low voltage section contains the controls and protective relaying. Contingent upon motor size and relaying requirements, one, two, or three starters can be located in one vertical section. Power for control relays is usually 120 volts but may be applied at a standard control voltage common in the range of 24-240 volts AC/DC.

(2) Fuses. The contactor itself is not capable of interrupting a short circuit and must be protected by silver-sand type current limiting fuses. Fuses are generally mounted on the contactor itself and can be drawn out of the cabinet for replacement by withdrawing the contactor. One limitation of such fuses is that, should a short circuit occur on one phase only, only that fuse will blow, and the motor will continue to operate on the single phase between the remaining two lines.

(3) Current drawn in that phase is twice full-load current and will rapidly overheat the motor. This can be avoided by the addition of suitable relaying, as described later, but, in some cases, the contactor may also incorporate a trip mechanism that is actuated by the blown fuse itself. The trip mechanism causes the contactor to open immediately when the fuse is blown,

isolating the motor. Either protective relaying or a mechanical trip mechanism should be provided.

d. Motor protection. The following gives general guidance for protection of medium-voltage motors. For further information on motor protection, refer to ANSI/IEEE 242, "Recommended Practices for Protection and Coordination of Industrial and Commercial Power Systems – IEEE Buff Book (2001)".

(1) Induction motor protection. It is logical that more extensive protection be considered for larger motors than for smaller motors, since they represent a larger capital investment.

(2) Therefore, minimum recommended protective relaying is divided into two groups: one for motors rated below 375 kW (500 HP), and the other for those rated 375 kW (500 HP) and above.

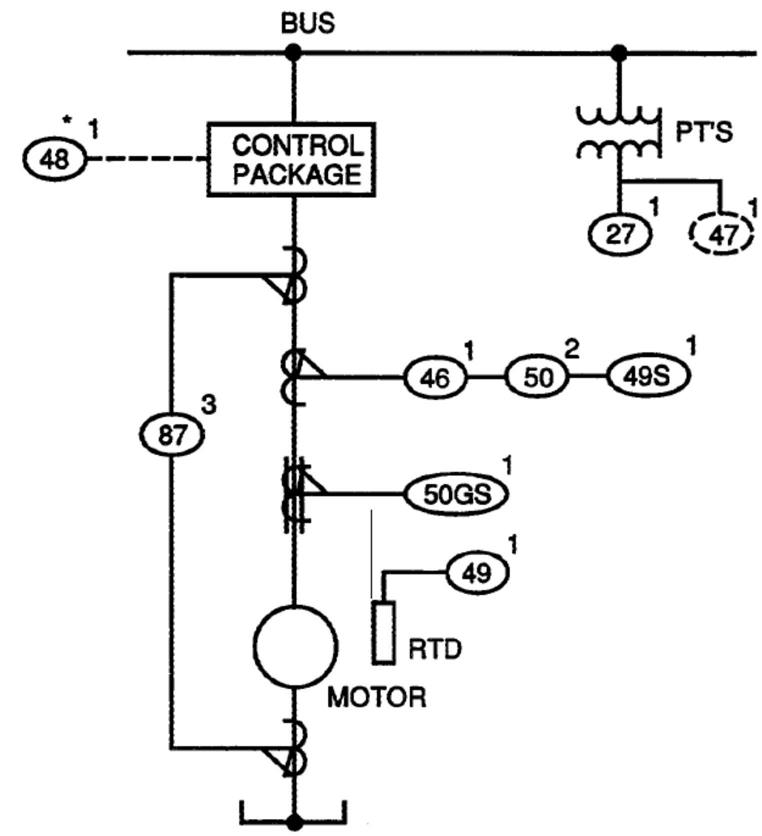
e. Motors below 375 kW (500 HP). Referring to Figure 21.1, for motors rated below 375 kW (500 HP), protection against loss of voltage or low voltage is generally provided by the single-phase time-delay under voltage relay, Device 27.

(1) Where it is desired to secure three-phase under voltage protection, such as when the motor is fed through fuses or from an overhead open line wire, Device 47 would be used in place of Device 27. In addition, Device 47 would provide protection against phase sequence reversal should it occur between the source and the motor's associated switchgear.

(2) The Device 49/50 provides short-circuit, stalled-rotor, and running overload protection; this relay has a thermally operated time-overcurrent characteristic. It is therefore generally to be preferred for this application over an inverse time-overcurrent relay such as the Device 51 relay. The instantaneous device on the Device 49/50 relay is normally set at 1.6 to 2 times locked-rotor current. Sensitive and fast ground-fault protection is provided by the instantaneous ground-sensor equipment.

(3) Device 49 operates from a resistance temperature detector embedded in the machine stator winding. This type of running overload protection is to be preferred over the stator-current-operated device, since it responds to actual motor temperature.

(4) The Device 40S provides protection against stalled rotor conditions. This device is necessary since the resistance-temperature detector used with Device 49 will not respond immediately to fast changes in the stator conductor temperature as would be the case under stalled conditions.



DEV.
27^{Δ} - UNDERVOLTAGE
46 - CURRENT BALANCE (375 KW (500 HP) THRU 2200 KW (3000 HP))
47^{Δ} - 3 PHASE UNDERVOLTAGE & REVERSE PHASE ROTATION
48 - INCOMPLETE SEQUENCE-TIMER FOR WOUND ROTOR MOTORS
ADD 2-DEV. 51
49 - THERMAL
49S - THERMAL (STALLED)
50 - INSTANTANEOUS SHORT CIRCUIT
50GS - INSTANTANEOUS GROUND SENSOR
87 - DIFFERENTIAL (375 KW (500 HP) THRU 2200 KW (3000 HP))

NOTES:
* - INCLUDE IF CONTROL PACKAGE IS REDUCED VOLTAGE START
Δ - OMIT DEV. 27 WHEN DEV. 47 IS INCLUDED.

Figure 21.1. Recommended minimum protection for medium-voltage induction motors (applies to all HP except as noted)

(5) The Device 49S relay includes a special high-drop-out instantaneous-overcurrent unit which is arranged to prevent its time-overcurrent unit from tripping except when the magnitude of stator current is approximately equal to that occurring during stalled conditions.

(6) Device 48, the incomplete sequence timer, would be included where the control package is of the reduced-voltage type. It provides protection for the motor and control package against continued operation at reduced voltage which could result from a control sequence failure. Microprocessor multi-function motor protection relays include capability to provide protection against single-phase operation and provide differential protection for motors of size less than 375 kW (500HP).

(7) Motors rated 375 kW (500 HP) or above. For the larger motors rated 375 kW (500 HP) and above, a discrete current-balance relay, Device 46, is included to provide protection against single-phase operation. Differential protection for larger motors is provided by Device 87. This discrete device provides sensitive and fast protection for phase-to-phase and phase-to-ground faults.

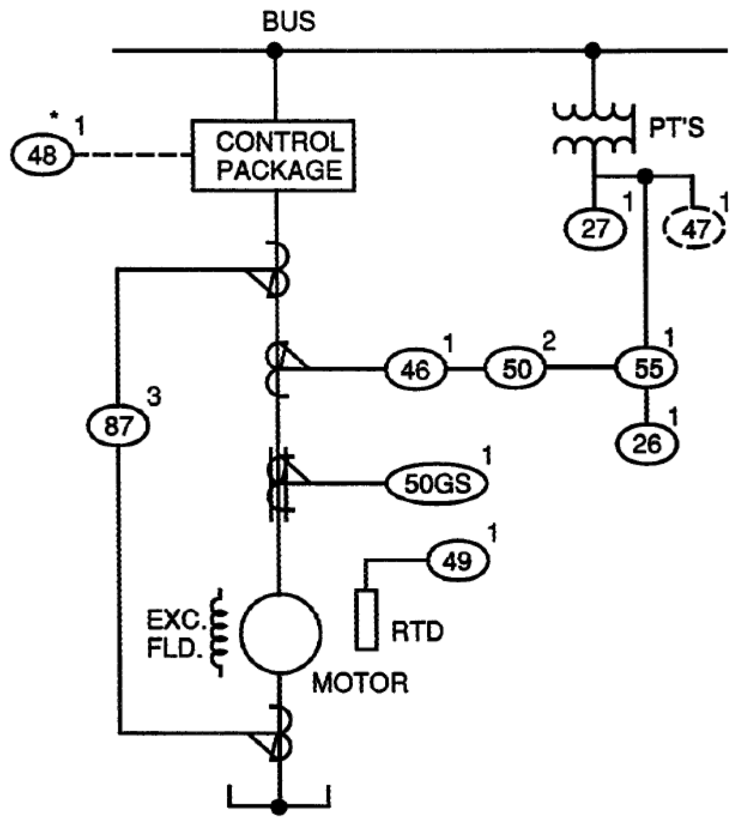
(8) Medium voltage brushless synchronous motor protection. Figure 21.2 covers the recommended minimum protection for brushless synchronous motors.

(9) Device 26 has been included to provide stalled-rotor protection. It is a stator-current operated device. The characteristic and rating of this device is provided by the equipment manufacturer and must be closely coordinated with the starting and operating characteristics of the individual motor being protected.

(10) The power factor relay Device 55 has also been included to protect the motor from operating at sub-synchronous speed with its field applied. This commonly called out-of-step operation will produce oscillations in the motor stator current, causing them to pass through the "lagging" quadrature. The power factor relay is connected to sense this current and will operate when it becomes abnormally lagging. Upon operation, excitation is immediately removed from the motor, allowing it to run as an induction machine. After excitation has been removed, the control is arranged to shut down the motor.

f. Microprocessor-based motor protection systems. Microprocessor-controlled motor protective systems combine control, monitoring, and protection functions in one assembly.

(1) Most protection packages provide complete motor protection for any size motor. The packages usually include motor overload protection, over temperature, instantaneous overcurrent, ground fault, phase loss/phase reversal/phase unbalance (voltage), phase loss and unbalance (current), overvoltage, under voltage, and motor bearing temperature protection.



DEV.
26 - APPARATUS THERMAL DEVICE
27[Δ] - UNDERVOLTAGE
46 - CURRENT BALANCE (375 KW (500 HP) THRU 2200 KW (3000 HP))
47[Δ] - 3 PHASE UNDERVOLTAGE & REVERSE PHASE ROTATION
48 - INCOMPLETE SEQUENCE\-TIMER
49 - THERMAL
49S - THERMAL (STALLED)
50 - INSTANTANEOUS SHORT CIRCUIT
50GS - INSTANTANEOUS GROUND SENSOR
55 - POWER FACTOR RELAY
87 - DIFFERENTIAL (375 KW (500 HP) THRU 2200 KW (3000 HP))
IF 87 IS SELF-BALANCING PRIMARY CURRENT ADD 2 DEV. 51

NOTES:
* - INCLUDE IF CONTROL PACKAGE IS REDUCED VOLTAGE START
Δ - OMIT DEV. 27 WHEN DEV. 47 IS INCLUDED.

Figure 21.2. Recommended minimum protection for medium-voltage brushless synchronous motors (applies to all horsepower except as noted)

(2) The monitoring features include current, voltage, watts, frequency, power factor, and elapsed time. Some units can tabulate the number of starts per programmed unit of time and lock out the starting sequence, preventing inadvertent excessive cycling.

(3) The control features replace discrete relay logic for pre-start, post start, pre-stop, and post stop timing functions and various enabling signals. Programmable logic under the control of the processor performs these functions. The units can be programmed for simple, across-the-line starting or more complex starting sequences such as reduced-voltage autotransformer starting. Also included are adjustable alarm and trip parameters and self-diagnostics including contractor report-back status to enhance system reliability.

(4) In instances where motor conditions exceed the programmed set point values, an alarm and/or trip condition is automatically initiated. One of the advantages to these systems is that there are few options making it less likely that a desired protective feature will be overlooked in the specification process.

(5) Considerations. Microprocessor-controlled protection packages are a viable option when precise and thorough motor protection is required. After the designer has decided upon the minimum required protective features, as described above, an economic comparison should be made between standard methods of relay protection versus the microprocessor-based systems.

(6) Consideration should be given to the microprocessor system's added features such as the built-in logic capabilities, expanded motor protection, and monitoring and alarm functions when making the cost comparison. As with all solid state devices, careful consideration must be given to their operating environment.

(7) The typical operating range of the processor is -20° to 70° centigrade (-4°F to 158°F). However, the operating temperature of the external face of the operator panel is limited to 0° to 55° centigrade (32°F to 131°F). Special coating of the circuit boards is, also, required to provide protection from the extremely humid environment of the typical pumping station. The applications department of the manufacturer should be consulted for each application.

21.5 Enclosure Ratings, Design, and Selection. See Chapter 27: Electrical Equipment Environmental Protection.

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Chapter 22
Control Equipment

22.1 General. The basic premise of a pump station is to start the pumps based on an inlet or sump water level.

a. As the water level continues to rise, additional pumps are started. As the water level drops, the pumps are turned off. A pump will stop at a lower water level than when it is started.

b. A common configuration is lead-lag operation. The “lead” pump starts first and if it cannot keep up with the inflow, a lag pump is started. The system can contain multiple lag pumps. The last pump started is usually the first to turn off. When an “alternator” function is added, the controller changes the lead pump so the run hours are distributed across all of the pumps in the system.

22.2 Methods of Control.

a. Float Control. In the early designs, operation of the pump station was controlled by a float gage as shown in Figure 22.1. Movement of a float in a stilling pipe and a counterweight rotated mercury switches inside the controller. As the switches closed, the pump starter would energize. The float control was usually equipped with the dial gage to indicate the water level.

b. With this method, the same pump was always started as the lead or first pump. Ice and other debris could hinder the operation of the float in the stilling pipe. As other technologies of controlling pump station operation have become more prevalent, the float control has become obsolete. However, it is still sometimes used for back-up operation.

c. Encapsulated Floats. Individual float switches can be used to control the operation of a pump station. The float switch can be used for smaller stations with a single pump and avoid the use of electronics. Figure 22.2 shows the floats installed in the intake structure at the Grassy Lake Pump Station in the Wood River Levee District in Illinois.

Figure 22.1. Float Controller

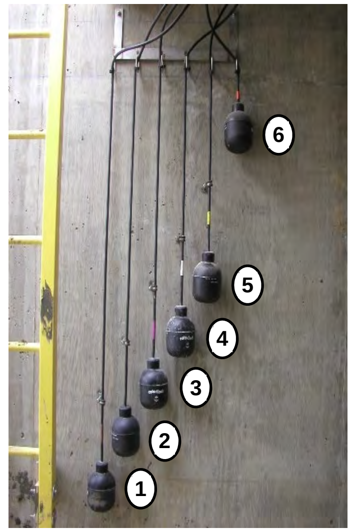

Figure 22.2. Encapsulated Float

The six floats provide: (1) Close the Intake Gate (2) Low Water Pump Cut-Off (3) Pump Stop (4) Open the Intake Gate (5) Pump Start (6) High Water Alarm

d. Pump Controller. A pump controller is a commercial-off-the-shelf (COTS) electronic device used to control the operation of the station.

(1) The dedicated controller uses a level measuring device to monitor the water level and a series of output relays to start and stop pumps or generate alarms. The controller can alternate the lead and lag pumps.

(2) If water conditions change, the pump start and stop elevations can be easily changed by modifying setpoints in the controller. Some controllers may provide communication using a serial connection. The Siemens (formally Milltronics) MutliRanger and HydroRanger models provide examples of pump controllers, but many manufacturers are readily available.

e. Programmable Logic Controller. A PLC system is much more robust than the dedicated Pump Controller and can provide additional functionality.

(1) In addition to the alternator functionality, the PLC can start another pump when one fails. A pressure or ultrasonic level transmitter installed on the station inlet is used to control the operation of the pumps. The system can be programmed to monitor inlet and sump water levels and indicate when raking is required to remove the accumulated debris from the trash rack.

(2) While the PLC system may be more suited to the larger pump station applications, a requirement for a graphical user interface, remote monitoring or operation, may necessitate the use of a PLC on a small pump station.

(3) The PLC system installed in the Ste. Genevieve Pump Station is shown in Figure 22.3. While this installation has the PLC installed in a separate floor-standing enclosure of the modular electrical building, it is often installed in a section of the MCC or switchboard.

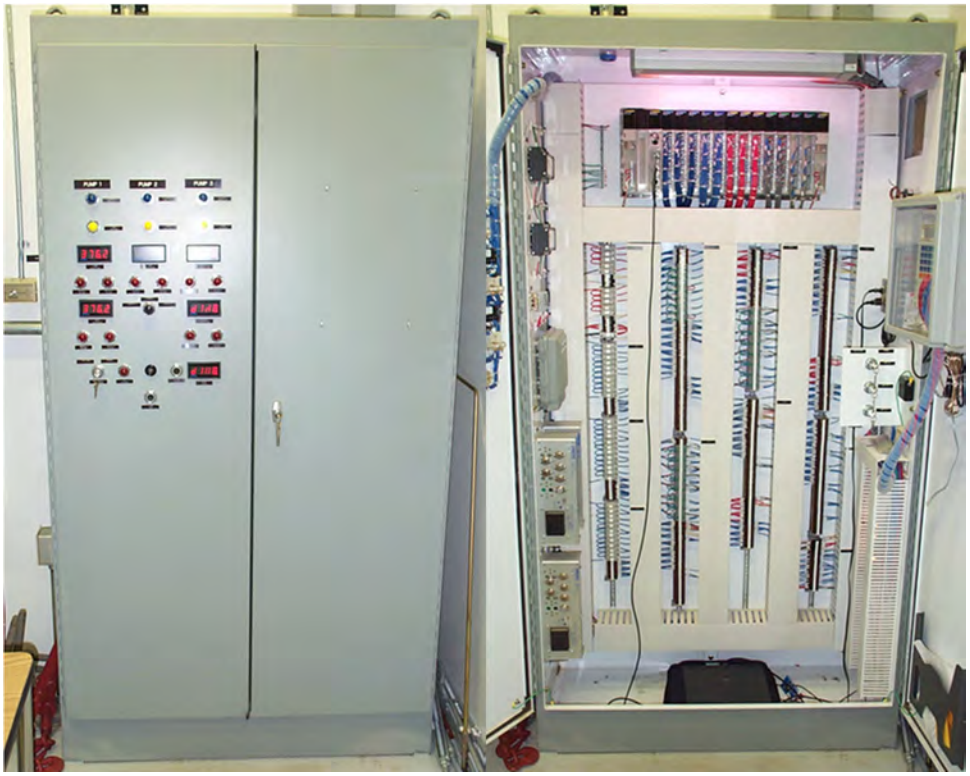

Figure 22.3. PLC System Installed at the Ste. Genevieve Pump Station

22.3 <u>Local Sponsor Requirements</u>. The Electrical Designer should consult with the local sponsor to determine his capabilities and project requirements for the station operation.

a. An important question to answer is whether a sponsor has the means to troubleshoot an electronic control system. City sponsors often have personnel trained in electronics such as with a sewage treatment plant, but a rural sponsor may have to contract with a local electrician.

b. While a sponsor may want a simple control system for the pump station, other requirements may dictate the need for electronics. Remote monitoring of a station by a project sponsor will require the use of some electronics.

22.4 Encapsulated Floats. Encapsulated floats can be used on very simple pump stations when coordinated with the project sponsor.

a. Advantages. Advantages of the encapsulated floats include:

(1) Lowest initial cost.

(2) Being COTS allows easy replacement.

(3) Least complex system making it easier to install, troubleshoot, and maintain.

b. Disadvantages. Disadvantages of the encapsulated floats include:

(1) More difficult to adjust start and stop elevations.

(2) May not be suited to pump stations with multiple pumps.

22.5 Pump Controllers. The functionality of the pump controller is limited by the number of output relays. Some pump controller output relays can be closed at one setpoint (water level) and opened at another lower setpoint. Other less sophisticated pump controllers require a separate output relay to be used for the start and another for the stop. A dedicated pump controller may be used when the pump station is limited to one or two pumps. The requirements of the local sponsor may dictate the use of a PLC system.

a. Advantages. Advantages of the pump controller include:

(1) Lower initial cost.

(2) Being COTS allows easy replacement.

(3) Less complex system making it easier to install, troubleshoot, and maintain.

b. Disadvantages. Disadvantages of the pump controller include:

(1) Functionality is limited to what is designed in by the manufacturer.

(2) Is not modular and cannot be expanded.

(3) May not be robust enough to control complex pump station applications.

22.6 Programmable Logic Controllers. A PLC should be considered for usage when the controls or monitoring requirements of the station become complex. When appropriately applied, this device provides the processing power and flexibility necessary to efficiently control a complicated system.

a. Advantages. Advantages of the programmable controller include:

(1) The flexibility to reprogram or modify the control sequence.

(2) The ability to manipulate, compare, or perform arithmetic functions on data stored at various memory locations.

(3) A high degree of reliability when operated within their ratings.

(4) The ability to accept a wide variety of input and output devices.

(5) The capability to force inputs and outputs "on" or "off" to aid in troubleshooting.

(6) Provide remote connectivity.

b. Disadvantages. Disadvantages of the programmable controller include:

(1) Higher initial cost.

(2) Trained personnel needed to modify or troubleshoot the system.

(3) Cybersecurity requirements must be addressed.

c. Operator interfaces. Operator interfaces can range from simple pushbuttons and indicating lights to a terminal or a personal computer (PC) running human machine interface (HMI) software. The PC offers increased computing power, data logging, and graphics capabilities.

d. Cautions.

(1) Personnel. Some caution should be exercised, however, in applying PLCs and PCs to pump station applications. Most pumping stations are operated and maintained by local interests. The local levee or sewer district may not have the experience or expertise to maintain the PLC system. An evaluation should be made of the availability of qualified repair services and the competency level of the anticipated operating and maintenance personnel.

(2) Environment. Also, while PLCs are rugged devices which can normally be applied to pumping station environments with little concern for exceeding their environmental ratings, the designer should evaluate the need for any special provisions to ensure that the PLC will be operated within its temperature and humidity ratings. If the use of a PC is desired, it should be an industrially hardened version and should be kept in a conditioned environment.

e. Temperature and humidity ratings. Typical ambient operational temperature ratings are 0° to 60° C (32° F to 140° F) and -40° to 85° C (-40° F to 185° F) during storage. Typical humidity ratings are from 5 to 95 percent without condensation. Operation or storage in ambient temperatures exceeding these values is not recommended without special consultation with the manufacturer.

f. Interposing relays. The output contacts of programmable controllers have limited current carrying capacity. Electrical devices which require significant amounts of current for operation, such as large solenoid devices, may require the addition of interposing relays to the system. However, to minimize complexity, the use of interposing relays should be avoided wherever possible.

22.7 Water Level Sensors.

a. General. A variety of sensors are available for use in sensing water levels, including float-actuated mercury switches, float-actuated shaft encoders, bubbler systems, bulb-type floats, etc.

b. The use of float-actuated mercury switches is discouraged due to environmental concerns. A comparison should be made of the particular pumping station requirements in relation to the various level sensor capabilities before deciding upon the system to be employed.

c. It is advisable to provide multiple level sensors in the same location such as the inlet to permit comparison of the returned water level. In more sophisticated stations, it may be desirable to utilize a shaft encoder. With its associated electronic packages, very accurate level comparisons and alarm functions are possible. Also, its output may be convenient for inputting to programmable controllers or computers.

d. The selection of a sophisticated water level sensing system, however, must always be made with consideration of the quality of maintenance and repair services available to the station after construction.

e. Bubbler systems. Bubbler systems when used are usually of the air-purged type. The nitrogen gas purged type is usually employed at remote sensing areas where power to run the air compressor of an air-purged system is difficult to obtain.

(1) The air-purged system operates by purging air into a channel, sump, etc., through a tube and measuring the back pressure which varies in proportion to the variation in liquid level.

(2) A linear variable differential transformer is usually used to convert pressure readings to low voltage or current signals. When used in sufficient number, this system may be cheaper than an equivalent float-actuated system. However, it is more complex and is subject to clogging in highly silt laden waters.

f. Shaft encoders. The transducer should be of the electromagnetic resolver type and nonvolatile. Each shaft position should be a unique output that varies as a function of the angular rotation of the shaft. If power is lost, the correct output should immediately be restored upon restoration of power. Units are available in single or multi-turn construction.

g. Pressure Transducer.

(1) General.

(a) The pressure transducer measures the hydrostatic pressure or the amount of water above it. The pressure exerted on a diaphragm is converted to an analog signal using strain gages. The housing is usually stainless-steel. The diameter of the sensor may range from as small as 25 mm to 127 mm (one inch to five inches) or more. The diaphragm is often protected by a nose cone. The nose cone contains small ports or openings to allow the water to reach the diaphragm. To ensure proper readings, the nose cone must be unscrewed from the transducer periodically to be cleaned. Some transducers utilize a robust diaphragm and do not require the nose cone for protection.

(b) These transducers are suite for a "high-solids" environment and may be a larger diameter. The transducer is vented to account for the atmosphere pressure. The electrical connection of the transducer should be made in a termination housing with a desiccant or a breather bag to prevent moisture from condensing in the vent tube.

(2) Output. The transducer may output 0 to 5 VDC or 4 to 20 mA depending on the model selected. A current output is often used due to its noise immunity while transmitting long distances. A current-output device is often referred to as a "transmitter." The output of pressure transducer must be coordinated with the pump controller input or the PLC analog input cards.

(3) Range. The pressure range of the transducer may be rated by psi or feet of water depending upon the model and manufacturer. A 15 psi transducer can measure 15 x 2.31 feet of water/psi or 34.65 feet of water. The pressure range selected should be large enough to cover the maximum water level, but small enough to ensure the majority of the range is being used.

h. Ultrasonic. An ultrasonic level sensor is a non-contact alternative to pressure transducers avoiding the maintenance associated with silt. The sensor uses sound waves and its reflection from the liquid surface to determine the water level. Ultrasonic is generally more expensive than pressure transducers. The features of the ultrasonic transducers are similar to those of pressure transducers. The manufacturer's installation recommendations must be followed to ensure the sensor will function properly. Mounting the sensor too close to the side wall of the sump or inlet structure can cause interference.

i. Low Water Cutoff. A submersible pump is usually protected by a "low water cutoff." This protects a pump from damage when insufficient water is available in the sump. An encapsulated float usually serves as the cutoff. The motor starter may include a key switch to bypass the float for periodic testing. The key switch should only permit removal of the key when the switch in in the open position. The float is shown in the detail of Figure 22.4.

j. Stilling Well. A pipe is often used as the stilling well. For the pressure transducer, the stilling well provides physical protection of the sensor. For the non-contact sensor, such as ultrasonic, the stilling pipe promotes a calmer and cleaner surface for measurement.

(1) The stilling pipe will also isolate disturbances from inflow points or other obstacles. The stilling well can be made from galvanized steel or polyvinyl chloride (PVC) pipe.

(2) With an inlet or outlet structure, the stilling well should be tucked into a vertical blockout in the side of the structure to limit the possibility of damage even further. Schedule 80 PVC pipe was used in the detail of Figure 22.4. PVC was chosen to eliminate the corrosion associated with steel pipe even when galvanized.

(3) The details provide for the installation of two transducers in the same stilling pipe, but the Contractor supplied transducers in excess of four inches in diameter. This necessitated installing the inlet transducers in separate pipes on opposite sided on the inlet structure.

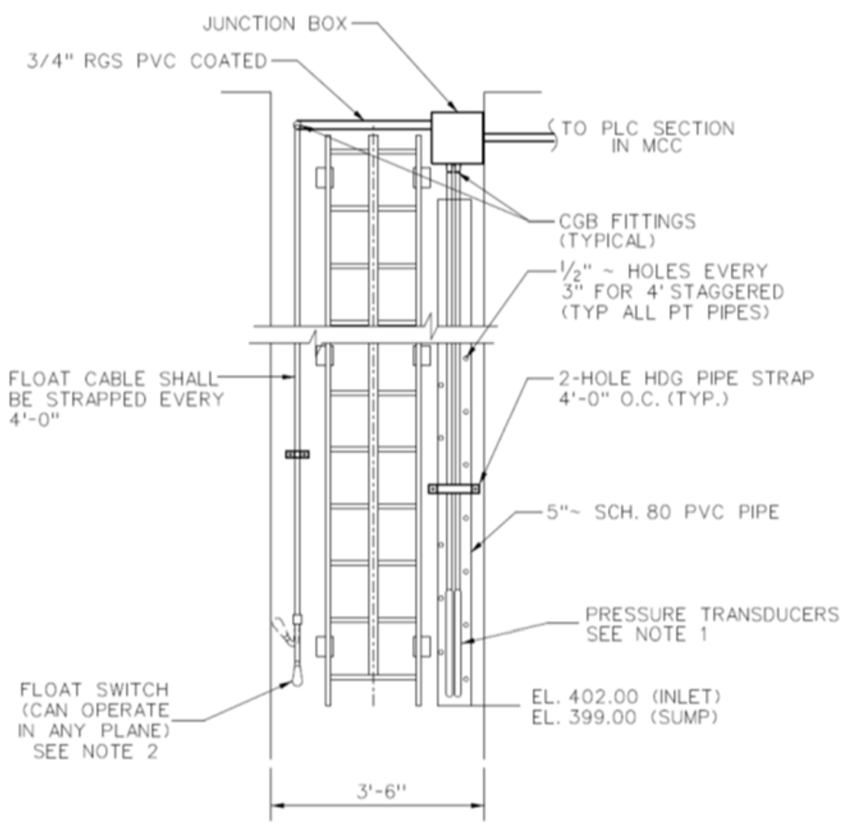

Figure 22.4. Level Sensor Stilling Pipe

k. Environmental Considerations. Level sensors should be installed to protect them from damage by the environment such as drift and other debris as well as vandalism.

22.8 Elapsed Time Meters and Alternators. To ensure even wear on pumping units as well as reducing the frequency of motor starting, it is recommended that elapsed time meters and alternators (where pumps are started automatically) be installed to provide a record of pump usage.

22.9 Timing Relays. Several timing relays are commonly employed in pump control circuits. If siphon breakers are required, an on-delay timer can be used. An on-delay timer delays the closing of the siphon breaker solenoids until the siphon system is fully primed. This feature reduces motor HP requirements to establish prime. The other is an off-delay timer which prevents the motor from being restarted until any reverse spinning of the pump has stopped.

22.10 Miscellaneous Circuits. The miscellaneous small power circuits commonly required in installations for the control transformers, potential transformers, lighting transformers, and control power should either be protected by standard circuit breakers or fuses of adequate rating.

22.11 Programming the PLC System.

a. General. The process control guide specification defines the role of a System Integrator (SI). The SI is tasked with taking the various pieces of hardware and software, often from different manufacturers, and integrating them together into a complete and working control system.

(1) The SI will be responsible for developing the PLC programming logic necessary to implement the functionality defined in the pump station sequence of operation. The SI should structure the logic into functional sections often by the type of equipment being controlled, but the section could be a defined function of the station.

(2) The process control specifications must clearly define how the station is supposed to operate so it can be programmed by the integrator. The following are examples of functionality that may be included in the contract requirements.

b. Sluice Gate Control. When sluice gates are installed at the pump inlet, the gates will be programmed to open based on the inlet water elevation.

(1) A timer function should be used to ensure the inlet level is steady and prevent the cycling of a gate because the inlet signal is fluctuating. The inlet gates should be open prior to the pump starting.

(2) The sluice gate will close at different elevation lower than the pump stop elevation. An alarm should be generated if a gate does not reach its end position (detected by the limit switch PLC inputs) in a certain amount of time. The sluice gate installed as part of an integrated gatewell will close based on an outlet elevation of the river or creek. A float switch may be installed to close the gate in the event of an outlet sensor failure.

c. Level Control. The PLC logic will start the lead and lag pumps based on the inlet water elevation. The automatic operation of the pumps should ensure the inlet water level sensors have not failed.

(1) Again, a timer function should be used to limit the impact of the inlet signal fluctuating. The pump stops at an inlet elevation lower than the start. The “alternator” logic must define which of the installed pumps starts as the lead, the second, third, etc.

(2) The SI may implement this logic in a separate section. The logic may cycle the lead pump through each of the installed pumps to evenly distribute the run hours or reach a percentage of the runtime established for each pump.

(3) The logic should require that the starter is in the AUTO mode and the pump has not failed to operate. If a lead pump fails, the logic should automatically start the lag pump and not wait for the next start elevation. This is an advantage of the PLC system over the dedicated pump controller. A dedicated pump controller does not determine when a pump has failed and has to wait until the inlet level reaches the lap pump start elevation.

d. Pump Operation. This section will be duplicated for each installed pump. The logic will start the pump when commanded by the “Level Control” section. The logic should verify that the starter is in the automatic mode, the inlet sluice gate is open, a gatewell sluice gate is closed, the low water cutoff float is closed, and the sump level transducers have not failed. The logic should stop a pump in the event a failure is detected. This may be from a failure to start or an alarm condition associated with starter (thermal overload, Reduced Voltage Soft Start (RVSS), VFD) or pump monitor.

e. Runtime. While most pump starters will be equipped with an elapsed time meter, the PLC system can use an auxiliary contact from the starter, contactor, RVSS, VFD, etc.to calculate a runtime. By doing this in the PLC, a remote operator can monitor the pump operation during a high-water event. The runtime should be stored in non-volatile memory and allow the manual input of a value from the elapsed time meter in the event the value is lost in memory.

f. Water Level Sensing. The water level sensing may consist of sensors located in the inlet, sumps, and discharge. The logic will scale the analog input values to the feet of water measured by the sensor. An offset is often added to the scaled measurement to make it an elevation. Each input should be checked to ensure it is in range and compared against another sensor. When sensors at the same location differ by 152 mm (6 inches) or more, they are considered failed.

g. Alarms. An integrator may program all alarms in a common section or include it with the other logic for the equipment. Alarm conditions to consider are:

(1) Gate Failure.

(2) Pump Start Failure.

(3) Pump Failure.

(4) Station Power Failure.

(5) Power Supply or Uninterruptible Power Supply Failure.

(6) Water Level Sensor Failure.

(7) High Inlet Water Level.

(8) Pumping Required.

(9) Trash Raking Required (difference between inlet/sump).

h. Telemetry. The PLC will communicate to other devices such as a reduced voltage soft start, VFD, or power monitor to collect device data. Information is stored in a data file, registers, etc. that can be accessed by the operator interface terminal (OIT) or HMI. Cybersecurity for the ICS must be addressed as outlined in Chapter 23.

22.12 Monitor and Status Modules for Submersible Pumps. The module monitors several areas of a submersible pump to detect problems and prevent extensive damage to the pump and/or submersible motor.

a. The module provides leakage detection inside the stator housing of the motor and monitoring of motor and bearing temperatures. The module includes a relay contact to stop a pump upon detection of a problem and one to indicate each alarm condition.

b. The Monitor and Status (MAS) module is associated with Flygt's submersible pumps. The MAS in the successor to the Control and Status module. When a MAS module (Figure 22.5) or an equivalent from another manufacturer (Figure 22.6) is specified, it should be integrated with the pump's motor starter and the station's control system.

Figure 22.5. Flygt MAS Unit

Figure 22.6. Separate Pump Protection

22.13 Sluice Gate Interlocks. Sluice or slide gates may be used at the pump station inlet to reduce siltation of the sump or as a means to provide gravity drain operation. Pump motor starters should be integrated with the sluice gate limit switches to ensure the inlet gates are open and the gravity drain gates are closed.

22.14 Fuel Monitoring Controls.

a. General. In a diesel-driven pump station, a fuel transfer system may be necessary for movement of fuel from bulk storage tanks to day tanks located at each pump.

b. Monitoring. The monitoring of the fuel level in each system may be comprised of discrete inputs indicating a low or high fuel level through a float switch or an analog input providing a value in gallons from a level sensor.

(1) Instrumentation is required for each day and bulk fuel tank. The fuel monitoring system may include independent sensors or integrate with sensors already installed as part of the engine and day tank control system.

(2) Most engine control systems monitor the available fuel and provide a warning alarm at a low fuel level. This is considered a “low” alarm. As the fuel level continues to drop, a shutdown alarm is generated, and the engine is stopped to prevent damage. The shutdown may be considered a “low-low” alarm.

c. Transfer. Fuel pumps provide the transfer of fuel from bulk storage to the engine’s day tank. Upon low fuel indication by means of a float switch in the day tank, a solenoid valve is opened at the inlet to the day tank, a solenoid valve is opened at the outlet of the bulk storage tank, and the transfer pump is started.

(1) When a high fuel level is reached at the day tank, the pump is shut off and the inlet and outlet solenoid valves are closed.

(2) A second "high-high" level indication is provided on the day tank as a backup to shut off the transfer pump in the event the high-level indication is faulted.

(3) The transfer system may include flow meters to verify the movement of fuel. Revenue meters may be required on the inlet of the bulk storage tanks to verify fuel deliveries.

d. Filtering. Depending upon the complexity of the fuel system, an auxiliary pump and filter system may be provided. Often this is an off-the-shelf system with a small pump to transfer fuel from the tank, pass it through a filter to remove water and other contaminants, and return it to the tank for smaller tanks. For large-scale diesel stations, this may be performed using separate fuel filter pumps and filters. Pressure sensors may be installed at the inlet and outlet of the filter to determine when the filter must be changed. The filtering is programmed to occur once a week, month, etc. and must run long enough to ensure the entire fuel tank is filtered.

22.15 Control Rooms and Consoles. In larger pumping stations, the complexity of the pumping system and the trend toward reducing the number of operating personnel will usually require the formation of a centralized monitoring and control room.

a. Controls, alarms, and devices to indicate system status should be grouped on a control console so that one operator can conveniently initiate control sequences and observe the system response.

b. Care should be taken to include a monitoring capability for all essential pumping system parameters. Some alarms that may be required include motor and pump bearing temperatures, motor winding temperature, motor trip and lockout relays, motor or gear cooling water failure, excessive pump discharge piping pressures or flow rates, lubrication system failures, abnormal water levels, trash rake malfunction, etc. A graphic display is an effective means of grouping alarm and status information.

c. Motor Control Center Integration. The smaller size of most pump stations does not dictate the need for separate control rooms and dedicated consoles. The controls necessary for station operation can be integrated with the MCC. Figure 22.7 shows the MCC for a 4.3 m^3 per second (155 cfs) pump station in the St. Louis District.

Figure 22.7. Pump Station MCC Integration
Main Circuit Breaker (2) Generator Circuit Breaker (key-interlocked) (3) Pump RVSS (4) Power Meter (5) Distribution Panelboard (6) Lighting Panelboard (7) PLC Section

(1) General. The MCC lineup includes three RVSSs for a submersible pump and the programmable logic controller section. The MCC may use across-the-line starters for small HP pumps. A distribution panelboard provides feeder breakers for the sluice gates. An integral lighting transformer and panelboard not only sources the interior and exterior lighting but powers the strip heaters and PLC section installed in the MCC.

(2) Starter Controls. The pump controls are shown in Figure 22.8. These controls are typical whether the station is manually operated or controlled by a pump controller or PLC. The pushbuttons are functional when the selector switch is in the HAND position. Note that the START pushbutton is fully shrouded while the STOP pushbutton is not shrouded. The keypad for the RVSS is mounted in the door of the pump starter. This is useful to provide error or fault information to the station operator without opening the starter door. The keypad may allow reset of the RVSS for some error or fault conditions.

Figure 22.8. Pump Starter Controls

(3) Communication. The RVSS and power meter support the Modbus® serial communication protocol. An Ethernet converter allows the PLC processor to collect data from both devices and store it in memory. The PLC memory is then accessed by the operator interface. While the operator interface could access the devices directly, using the PLC to poll data is often easier as it can adjust for data types and different memory maps.

d. Operator Interface. An OIT providing a resistive touchscreen is a cost-effective means to provide access to the functionality of the PLC system. An advantage of an OIT over a hardwired console is the flexibility to provide new or additional functionality with a few software changes.

e. The OIT must provide either serial and/or Ethernet communications to access the data in the PLC processor. The OIT may run an embedded operating system such as Windows Embedded Compact or Linux.

f. The manufacturer often provides the software necessary to develop the graphic screens with the purchase of the hardware. The functionality of the HMI is limited to the features provided by the programming software. OITs range from 4, 7, and 10 inches in size, but will vary by manufacturer. The OIT must be programmed by a System Integrator to provide the various operating screens needed for the pumps station application. A 7” screen by Maple Systems is pictured in Figure 22.9. The OIT is mounted in the door of the PLC section of the MCC.

g. Monitoring PLC. A Nanoline™ PLC by Phoenix Contact is used to provide text message alerts for alarm conditions in the pump station.

(1) The PLC uses discrete and analog inputs with a Code Division Multiple Access (CDMA) modem to provide alerts to users stored in a phone book.

(2) The terminal shown mounted in the door mimics the messages sent via text. Authorized users may be permitted to send a text to the PLC where it will respond with the analog input level.

(3) The discrete inputs are used to alert operators of pump and power failures and high-water alarms. As wireless providers change their networks from 3G and 4G to 5G, modem technologies may become obsolete. Ensure any technology designed into a monitoring system is supported by the local wireless providers.

h. Water Level Sensing Indicating Light. A separate indicating light is used to warn a station operator of the warning level failure, since an inlet failure will prevent the entire station from operating automatically. A failure of the sump transducers will only affect the single pump.

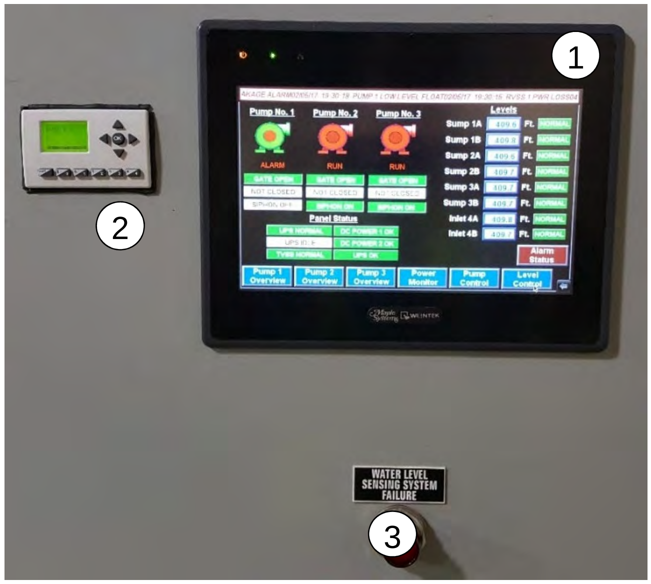

Figure 22.9. Operator Interface Terminal
(1) Operator Interface Terminal (2) Monitoring PLC
(3) Water Level Sensing Indicating Light

i. OIT Screen Requirements. A robust interface provides the operator insight into the PLC application and permits them to determine what is wrong without having to access the PLC programming software. The following figures are merely provided as examples. Most System Integrators have an OIT application that gets recycled from job to job. The contract specifications should identify required screens and provide a verbal description. It is recommended to require at least a Station Overview, Water Level, and Water Level Calibration screens.

j. Station Overview. The overview screen for the station is shown in Figure 22.10. It indicates the run state of each pump and siphon breaker and the position of the intake sluice gates. The blue buttons at the bottom of the screen switch to the different screens programmed in the OIT.

Figure 22.10. Operator Terminal: Pump Station Overview

k. Pump Overview. A dedicated screen is provided for each stormwater pump as shown Figure 22.11. It provides more status and details on each of the pump and sluice gate alarms.

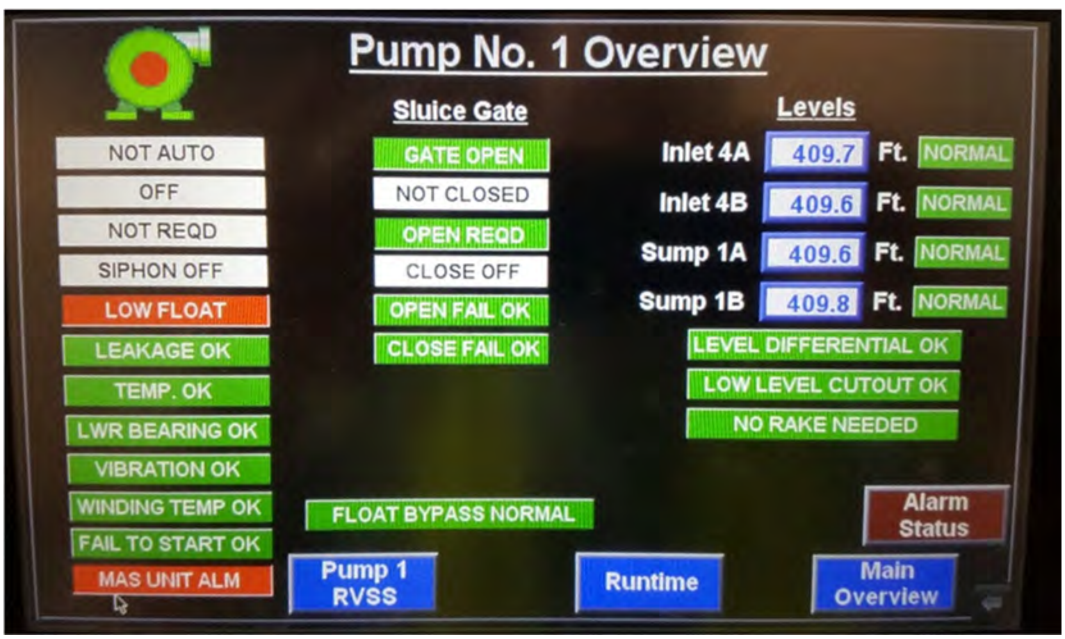

Figure 22.11. Operator Terminal: Pump Overview

l. Pump Starter Overview. Detailed status of the reduced voltage soft start is shown in Figure 22.12. It provides details of each fault or alarm condition for the RVSS which may be easier to determine than a code or abbreviated message shown on the keypad at the starter. The motor voltage and current can be read from the RVSS rather than providing an analog meter and selector switch at each starter.

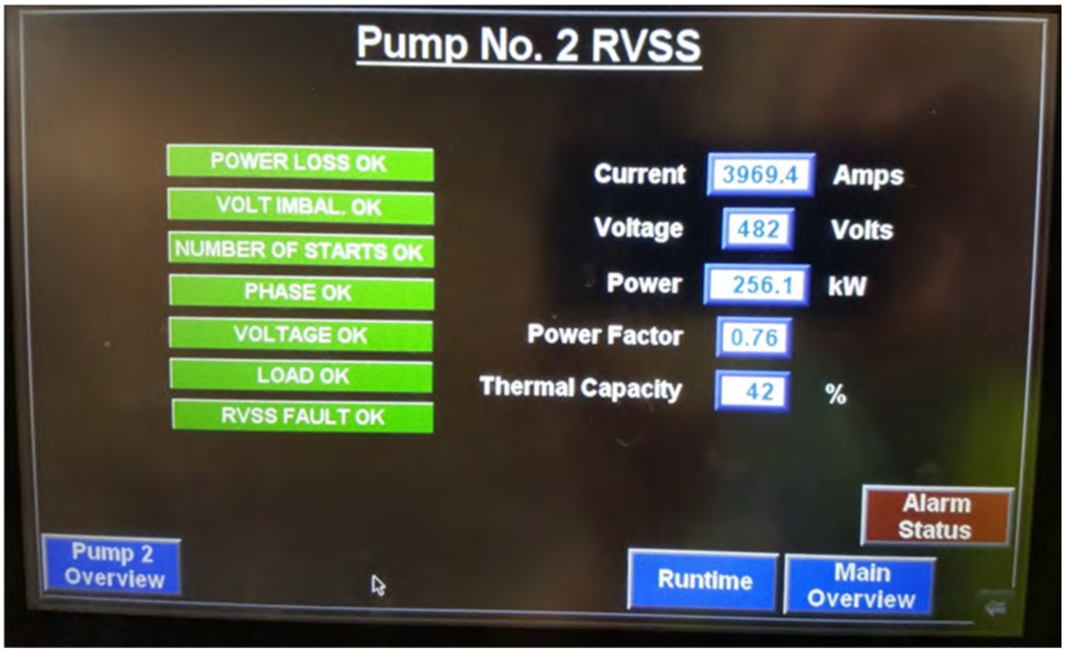

Figure 22.12. Operator Terminal: Pump Starter Overview

m. Pump Starting Sequence. The screen in Figure 22.13 is used to identify which pump will start first, second, and third. It also indicates how many pumps are needed based on the inlet water level (yellow “required” block).

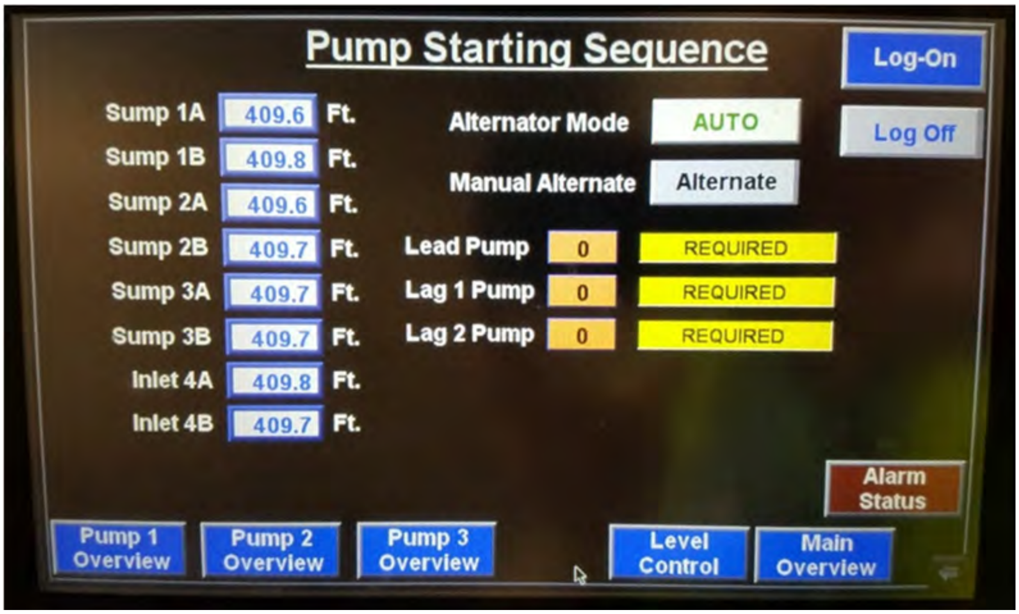

Figure 22.13. Operator Terminal: Pump Starting Sequence

n. Pump Start Elevations. The system integrator will initialize all of the start/stop and open/close elevations in the PLC program. The Water Level Control screen shown in Figure 22.14 will allow an operator to modify the elevation. The operator must log on and any changes made by the operator will not be permanently stored in the PLC program.

Figure 22.14. Operator Terminal: Pump Start/Stop Elevations

o. Water Level Calibration. An operator can modify the offset value associated with each water level sensor to ensure both sensors display the same value (Figure 22.15). This screen permits calibration without having to use the PLC programming software to adjust the offset elevations.

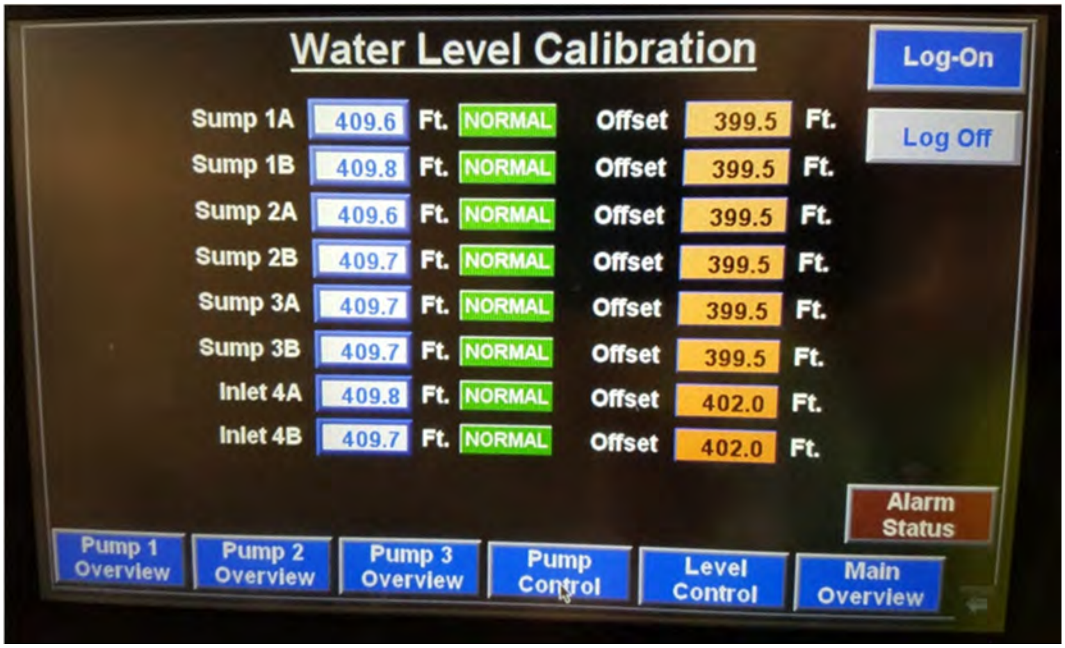

Figure 22.15. Operator Terminal: Water Level Calibration

p. MCC Power Monitor. The data typically associated with a power monitor or meter is shown in Figure 22.16. The use of the OIT permits the display of all of the data on one screen rather than toggling through several menus on the smaller power monitor display.

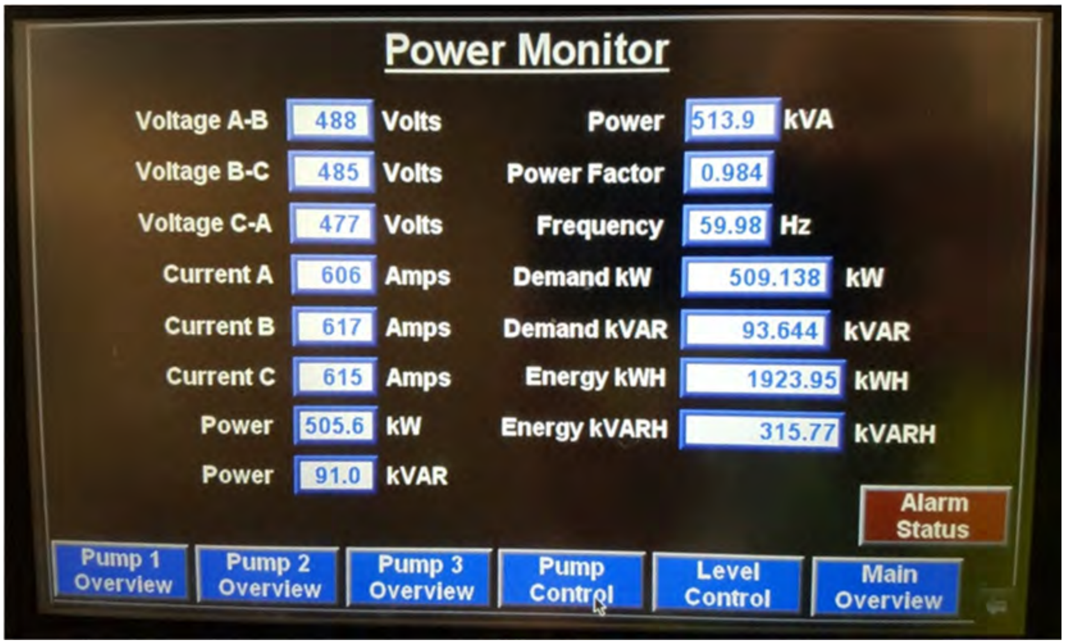

Figure 22.16. Operator Terminal: MCC Power Monitor

q. Alarm Summary. An alarm summary screen as shown in Figure 22.17 can provide the date and time associated with an alarm entry. The station operator will have to periodically update the clock in the OIT to maintain accuracy.

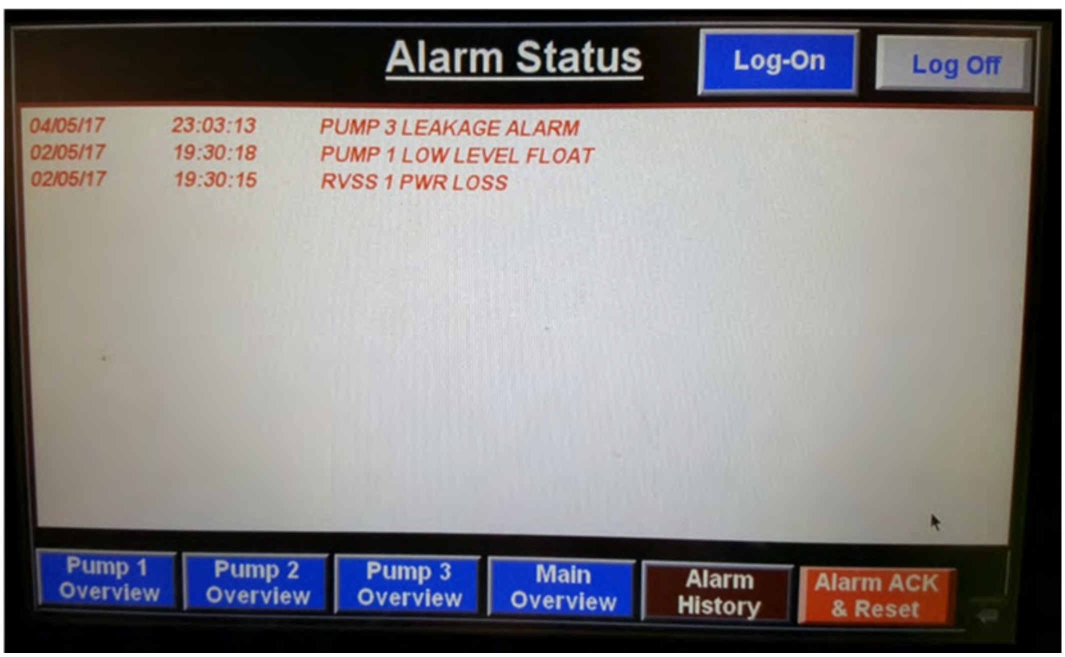

Figure 22.17. Operator Terminal: Alarm Summary

r. Human Machine Interface. A HMI is a software package designed to run on a PC. The HMI provides for the development of a graphical user interface similar to that of the OIT. An HMI is used for larger more complex stations when equipment data would be difficult to fit in a small 7” OIT screen. The HMI may also be used when a remote operator or monitoring function is needed.

(1) Hardware. A PC is needed to execute the HMI software. Hardware requirements for the PC will be defined by the HMI software developer. The type of PC necessary will be governed by the environment in which it is installed.

(2) A standard desktop PC may be used when installed in a separate control room or electrical building. These areas must be environmentally controlled. PC manufacturers have bridged the gap between the limited functionality of OITs and the more robust HMI software packages with the development of panel-mounted, flat PCs providing an industrial-rated touchscreen. If the user interface is needed on the pump station operating floor adjacent to equipment such as diesel engines, gear boxes, etc., an industrial PC will be required.

(3) The industrial PC is constructed to operate in areas that are susceptible to higher operating temperatures and dust. IPCs will provide a robust power supply and constructed to provide replacement of individual parts. Given the 3 to 5-year life of a PC, replacement will add to the life-cycle costs of the user interface. When IPCs are required, the cost will be even more significant.

(4) Software. HMI software packages are available from many different manufacturers/ developers. The HMI software manufacturer may be different than that of the PLC system. As with the OIT, a System Integrator must develop the screens needed for the pump station as part of an HMI application. The cost of the software is dependent upon the number of nodes being monitored and whether the license permits development or is only runtime. A “developer” license allows changes to be made to the application.

(5) HMI Overview. An overview from the HMI application developed for the Ste. Genevieve, Missouri Pump Station is shown in Figure 22.18. The HMI was not provided during construction of the pump station. It was added after station testing when it became apparent that the operator needed more insight into the PLC system than what was provided by the indicating lights and LED display mounted on the front of the PLC enclosure shown on Figure 22.3.

(6) The screen summarizes all of the pertinent information in regard to pump and station status in a single screen. The alarm and event summary allow operators to scroll the events and determine the pump starts, stops, and failures with the pump station.

s. HMI Pump Status. Status information for each stormwater pump is shown Figure 22.19. The “PMCM” is a Pump Monitoring and Control Module. This was the generic name in the contract documents for the Flygt CAS™ module installed in the motor starter. The “DMPR” is a Digital Motor Protection Relay. The DMPR monitored phase-loss, phase reversal, undervoltage, etc. with respect to the motor starter. The alarm summaries were filtered to provide separate windows for start/stops and failures making a search easier for the station operator.

t. A key switch located in the PLC enclosure allowed a pump to be placed in normal or maintenance operating modes. Figure 22.20 shows Pump 3 in maintenance mode. Placing a pump in maintenance mode meant it was out of service and eliminated alarms being sent to the autodialer.

u. HMI Pump Station Set Points. Figure 22.21 illustrates all of the set points defined for the station operation. Two sets of pump start/stop elevations were programmed into the PLC. These were dependent upon the river elevation. A higher river elevation resulted in higher inlet (ponding) levels to reduce the gradient and reduce seepage through the levee. The set points include a peak power start and stop time.

v. The PLC was programmed to avoid pumping during the peak power window that resulted in a significant demand charge. A high-water alarm would alert an operator to the need for pumping during the peak power window. Using limit switch inputs from the sluice gates, the PLC would determine whether the station was in gravity flow operation. During gravity flow operation, the station would permit a higher differential between the inlet and sump water levels indicating the need to cleaning the trash rack.

w. HMI Water Level Sensing. Figure 22.22 provides the water levels for all pressure transducers installed at the pump station. The alarm summary is filtered to only show alarms associated with the water level sensing system.

x. HMI Autodialer. The pump station was equipped with an autodialer. The autodialer used an analog phone line to call numbers from an internal phonebook when an alarm input was activated. A short recording would be played indicating which alarm was active. If a call was not answered, the autodialer proceeded to the next number in the phonebook.

(1) When an individual receiving the call entered an acknowledgement code, the autodialer would stop calling further entries in the phonebook until the alarm persisted for a defined amount of time.

(2) The alarms instrumented by the autodialer are shown in Figure 22.23. Most of the autodialer alarm inputs were outputs of the PLC system based on the state of the pump or motor starters, but a few were based on circuit breaker, control relay, and float switch contacts. While autodialers are still commercially available, the functionality can be performed more cost-effectively with other technologies.

(3) This includes the short messaging system (SMS/text) of paragraph 22.16.b.(2). A machine-to-machine data plan is generally cheaper than maintaining an analog phone line, but adequate cellular coverage is required. This could be difficult in rural locations.

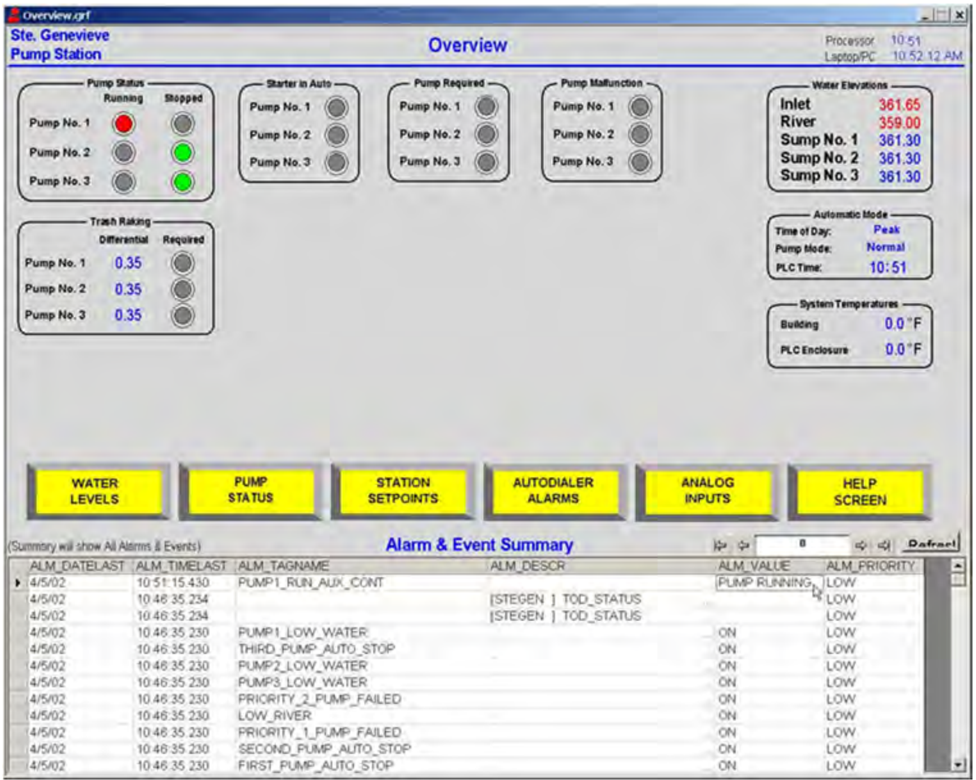

Figure 22.18. HMI Overview Screen

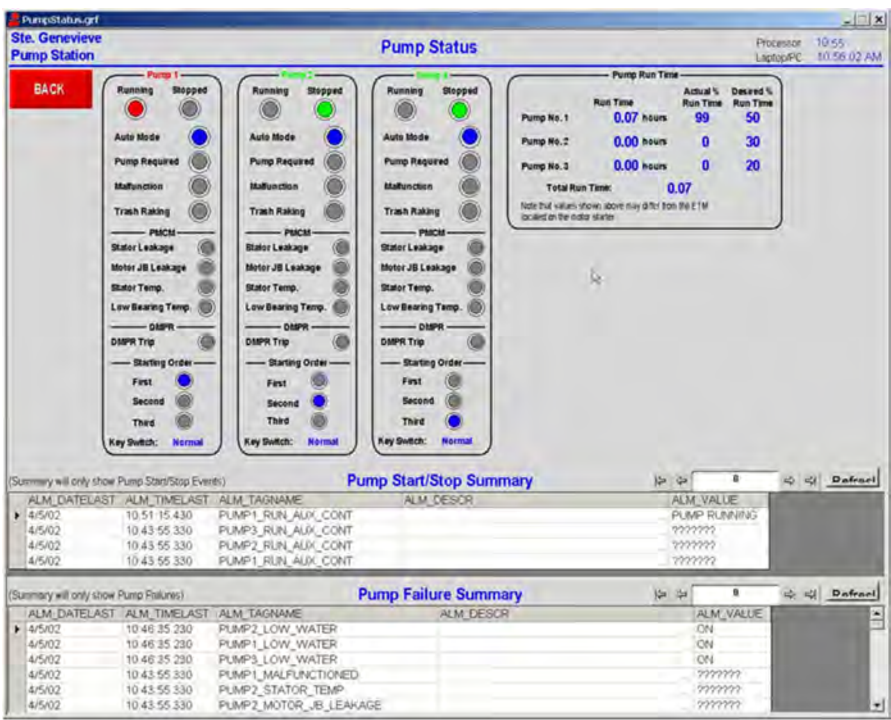

Figure 22.19. HMI Pump Status Screen

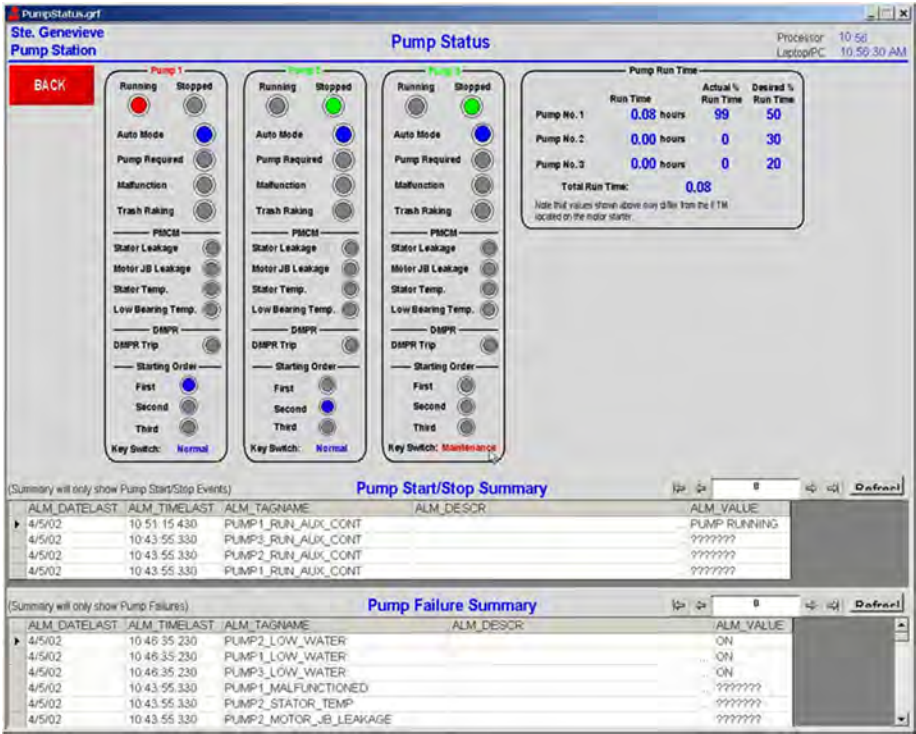

Figure 22.20. HMI Pump Station Screen

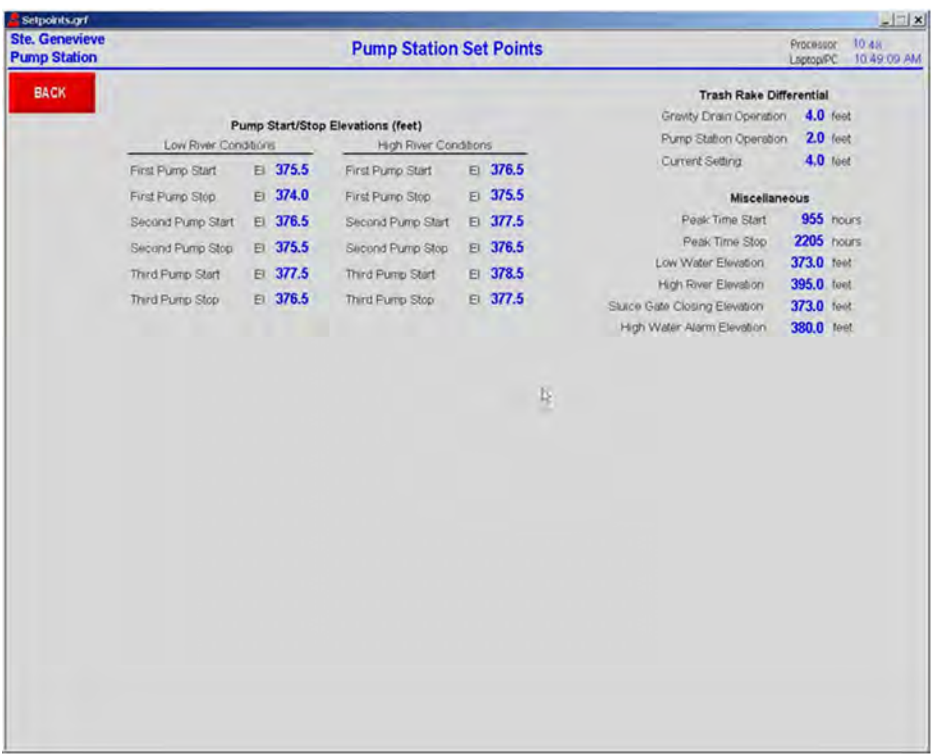

Figure 22.21. HMI Pump Station Set Points

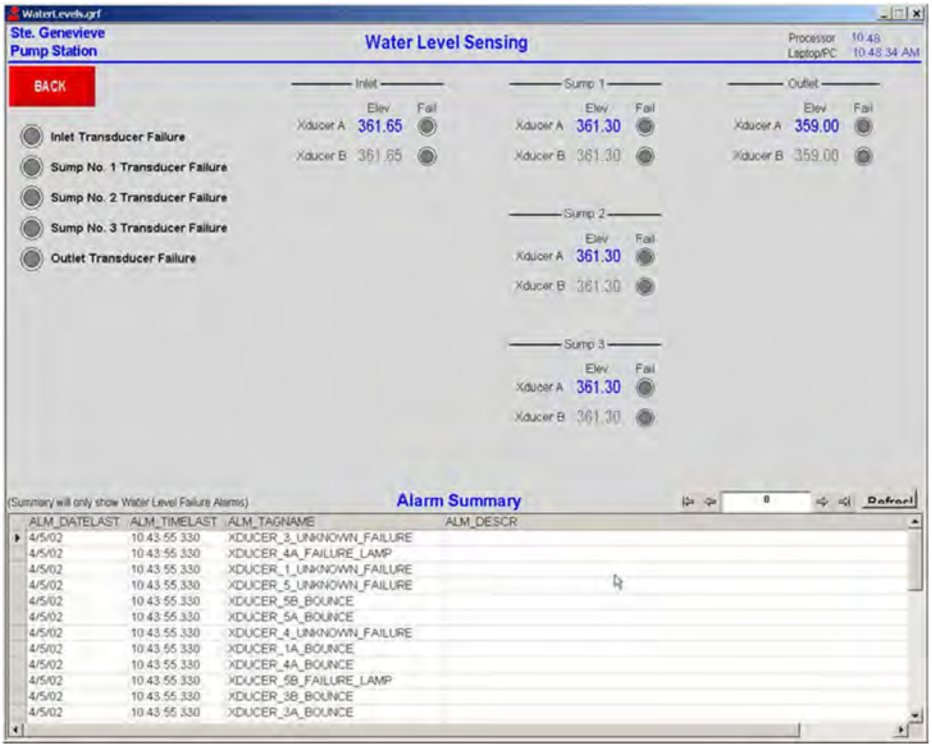

Figure 22.22. HMI Water Level Sensing

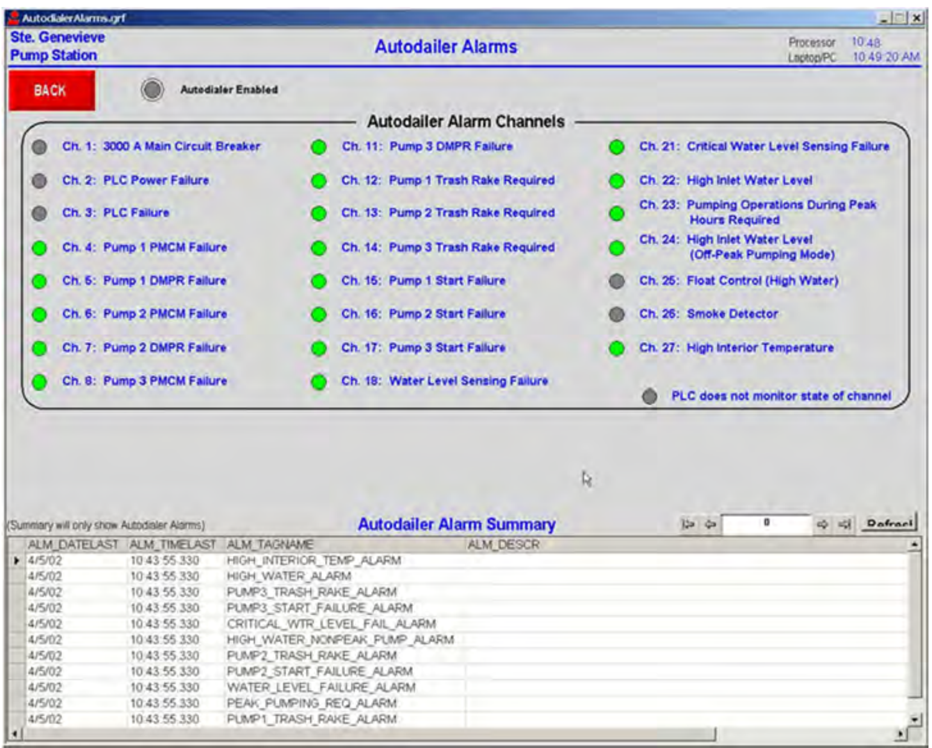

Figure 22.23. HMI Autodialer Alarms

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Chapter 23
Cybersecurity and Communication Systems

23.1 General. An advantage of using a PLC system to operate and manage a pump station is the ability to provide remote monitoring and/or operation of the facility using Ethernet or other communication technology.

a. "Remote" does not necessarily refer to monitoring from a physically separate or disconnected site. It may refer to an adjacent spillway, lock & dam, or administration building on the USACE project.

b. When using communication or information technology, a risk of cyber-attack exists that could permit damage to equipment and harm infrastructure or the public. The risk must be assessed and if too high, it must be mitigated to an acceptable level.

c. Mitigation may require additional technologies or changes to the system architecture increasing the design or construction costs if performed too late in the lifecycle. Cybersecurity of any system should be addressed early in the design process.

23.2 Publications. The concept and requirements of information assurance have evolved through several processes through the years.

a. Engineer Regulation (ER) 25-1-113, USACE Critical Infrastructure Cybersecurity Mandatory Center of Expertise, 31 January 2019.

b. ECB 2018-11, Control System Cybersecurity Coordination Requirement, 9 August 2018.

c. Department of Defense Instruction (DoDI) 8500.01, Cybersecurity, 14 March 2014.

d. Army Regulation 25-2, Army Cybersecurity, 4 April 2019.

e. DoDI 8510.01, Risk Management Framework (RMF) for DoD Information Technology, 12 March 2014.

f. National Institute of Standards and Technology (NIST) Special Publication (SP) 800-37 Rev. 1, Guide for Applying the Risk Management Framework to Federal Information Systems: a Security Life Cycle Approach, 5 June 2014.

g. NIST SP 800-37 Rev. 2, Risk Management Framework for Information Systems and Organizations: A System Life Cycle Approach for Security and Privacy, December 2018.

h. NIST SP 800-53 Rev. 5, Security and Privacy Controls for Information Systems and Organizations, August 2017.

i. NIST SP 800-60 Volume II Revision 1, Appendices to Guide for Mapping Types of Information and Information Systems to Security Categories, August 2008.

j. UFC 4-010-06, Cybersecurity of Facility-related Control Systems, 18 January 2017.

23.3 Centers of Expertise. When it relates to cybersecurity, USACE has established two centers of expertise (CX). While the CXs work with Headquarters to establish, refine, and enforce the USACE cybersecurity policy, they are available as a resource.

a. Control Systems Cybersecurity Mandatory Center of Expertise. The Control System Cybersecurity Mandatory Center of Expertise is located in the Engineering and Support Center in Huntsville. The TCX leverages ICS cybersecurity technical expertise from across the USACE to ensure USACE delivers cyber secure facilities to its military customers. Its focus is on facility-related control systems.

b. USACE Critical Infrastructure Cybersecurity Mandatory Center of Expertise.

(1) The USACE Critical Infrastructure Cybersecurity Mandatory Center of Expertise (UCIC-MCX) was established in the Little Rock District to secure CW structures.

(2) These include hydropower plants, lock and dams, and pump stations. The UCIC-MCX is led by the National Information Assurance Manager. The UCIC-MCX must "Ensure all CW are logically and physically secure" and "Ensure all CW control systems are assessed and authorized as described in current DoD and Department of the Army regulations."

(3) The CX should be contacted when designing new CW control systems and prior to engaging any other outside entities in regards to cybersecurity. The requirements for the UCIC-MCX and how ICS are secured are defined in ER 25-1-113.

(4) Regional Information System Security Manager. The UCIC has appointed a Regional Information System Security Manager for each USACE Division. They are the primary point of contact to the MCX when beginning a new project.

23.4 Cybersecurity.

a. General. For DoD, a key component of the cybersecurity program is the use of the RMF as required by DoDI 8510.01. The end-goal of RMF is to authorize a system to operate after a system has been assessed and its risk evaluated and mitigated if necessary. It is often assumed that control systems that are not connected to a network or the internet do not require RMF authorization. This is incorrect as all USACE-operated and maintained control systems must be authorized using RMF. The UCIC-MCX must be consulted as they have the responsibility to ensure the system is secure and can help navigate the RMF process.

b. Risk Management Framework. The RMF outlined in NIST SP 800-37 Rev. 2 provides a disciplined and structured process that combines information system security and risk management activities into the system development life cycle and authorizes their use within DoD.

c. The RMF changes the traditional focus of certification and accreditation as a static, procedural activity to a more dynamic approach that provides the capability to more effectively manage information system-related security risks in diverse environments of complex and sophisticated cyber threats and ever-increasing system vulnerabilities. The seven-step process includes:

(1) Prepare to execute the RMF from an organization- and a system-level perspective by establishing a context and priorities for managing security and privacy risk.

(2) Categorize the information system and the information processed, stored, and transmitted by that system based on an impact analysis.

(3) Select an initial set of baseline security controls for the information system based on the security categorization; tailoring and supplementing the security control baseline as needed based on an organizational assessment of risk and local conditions.

(4) Implement the security controls and describe how the controls are employed within the information system and its environment of operation.

(5) Assess the security controls using appropriate assessment procedures to determine the extent to which the controls are implemented correctly, operating as intended, and producing the desired outcome with respect to meeting the security requirements for the system.

(6) Authorize information system operation based on a determination of the risk to organizational operations and assets, individuals, other organizations, and the Nation resulting from the operation of the information system and the decision that this risk is acceptable.

(7) Monitor the security controls in the information system on an ongoing basis including assessing control effectiveness, documenting changes to the system or its environment of operation, conducting security impact analyses of the associated changes, and reporting the security state of the system to designated organizational officials.

d. This document will discuss the steps of the RMF process as the pump station functional requirements and design will affect the outcome of these steps.

(1) RMF Step 1: Prepare. Owners must identify personnel capable of executing the RMF. Personnel must have the necessary certifications for their roles.

(2) RMF Step 2: Categorize. The architecture complexity of the control system will dictate some of the requirements of the RMF process.

e. Impact Levels. As part of categorizing a system, an impact level (low, moderate, or high) is identified for the security objectives of Confidentiality, Integrity, and Availability.

(1) Confidentiality is defined as preserving authorized restrictions on information access and disclosure, including means for protecting personal privacy and proprietary information [44 USC § 3542].

(2) Integrity is guarding against improper information modification or destruction and includes ensuring information non-repudiation and authenticity [44 USC § 3542].

(3) Availability is ensuring timely and reliable access to and use of information [44 USC § 3542].

f. The results of the impact analysis help tailor the security controls to be implemented in the system. For CW Flood Risk Management projects, the UCIC-MCX has identified initial provisional impact levels of low-moderate-moderate for confidentiality, integrity, and availability, respectively. The impact levels may be adjusted higher or lower based on the requirements or risks of the system. The UCIC-MCX must be consulted to determine the impact levels for a particular system and develop a baseline for approval.

g. Operational Technology (OT). The UCIC-MCX studied the OT systems (defined as platform information technology (PIT) in DoDI 8500.01) deployed throughout USACE as it gathered data from Operational Order 2014-17. The MCX defined four main architecture types. The MCX must confirm the architecture type.

(1) OT Product. An OT Product (formerly PIT Product) is a small ICS consisting of a single PLC and an operator interface. The operator interface is using an embedded operating system, but only serial communications are used.

(2) OT Subsystem. The OT Subsystem (formerly PIT Subsystem) is comprised of one or more PLCs and a PC-based HMI. Devices are interconnected using an Ethernet network, a routable protocol. The system cannot provide remote access and it cannot include a routable connection to any external networks (outside the physical boundary).

(3) OT System Closed Restricted. An OT Closed Restrict System is a subsystem that is networked to another government-owned system within an identified boundary under the control of a single authority and security policy. The systems may be structured by physical proximity or by function, independent of location. A system is using encrypted virtual private network tunnels between sites to another government-owned or operated subsystem. The system cannot include any routable connections outside the authorization boundary.

(4) OT System Restricted Interconnected. An OT Restricted Interconnected System, formerly known as a PIT System Restricted Interconnected, is an OT subsystem or an OT system that has interconnection capabilities with any external network. This interconnection is typically used for the transfer of data from one system to another government-owned, government-operated control system.

(5) It is important to note that the architecture type is called “Restricted Interconnected” because the networking infrastructure is extremely limited in scope. Most frequently, these interconnections are meant for a single-directional data push and cannot reach out to the DoD Information Network.

h. RMF Step 3: Security Controls. From the RMF Knowledge Service (https://rmfks.osd.mil), security controls are the safeguards/countermeasures prescribed for information systems or organizations that are designed to protect the confidentiality, integrity, and availability of information that is processed, stored, and transmitted by those systems/organizations and satisfy a set of defined security requirements.

(1) Security controls serve as a common management language for establishing cybersecurity needs. The security controls establish a common dialogue among information owners, PMs, outsourced service providers, enclave managers, assessing and authorizing authorities, and information system security engineers.

(2) They aid in the negotiation and allocation of cybersecurity requirements and capabilities, enable traceability to specific cybersecurity solutions, and provide a consistent reference for certification activities and findings.

(3) The NIST SP 800-53 set of security controls is organized into 18 subject families, indicating the major subject or focus areas to which an individual security control is assigned. The areas range from Access Control, Contingency Planning, and Personnel Security. NIST SP 80-53 identifies all of the security control families.

i. Customization. The set of security controls to be evaluated for a control system is defined by the impact levels assigned to confidentiality, integrity, and availability during the categorization process. These impact levels and security controls can also be augmented or modified based on the functional requirements or risks inherent in the control system. The UCIC-MCX must be used to identify the security controls for the system.

j. RMF Steps 5 and 6: Assess and Authorize. As step 5 of RMF process suggests, the security configuration of a control system must be assessed. In RMF this is performed by a Security Control Assessor (SCA).

(1) The SCA analyzes the system and generates a report of their findings to be used by an Authorizing Official. The Authorizing Official must evaluate the risks to the control system and its vulnerabilities and determine whether it can be Authorized to Operate.

(2) An Authorized to Operate is valid for three years at which time the system must be re-assessed and authorized. The UCIC has identified three types of assessment: Assess Only, Organizational Assess and Authorize, and Army Assess and Authorize. The UCIC-MCX will determine which assessment is required based on the system architecture, but other factors may affect their decision.

(3) Assess Only. For the smaller pump station applications that can be classified as an OT Product, an assessment of the system can be performed by the UCIC-MCX and will not require authorization. This will greatly reduce the cost of the RMF and cybersecurity process. An example would be a small pump station of one or two pumps controlled by a PLC. The PLC is only wired to pushbutton inputs to operate the station.

k. Organizational Assess and Authorize. All OT Systems and some OT Subsystems will require an assessment and authorization.

(1) The assessment must be performed by an SCA, but they can be part of the organization (USACE). The approval chain for the assessment remains in USACE. This type of an assessor is an SCA-O and is completed by the UCIC-MCX as they are organizational representative.

(2) Most of the UCIC-MCX activities as part of this process are funded by Headquarters reducing the cost to the District for RMF. If the UCIC-MCX is engaged in implementing the security controls (RMF Step 4), their costs must be charged to the project. Due to complexities in the system, the UCIC may still require a third-party assessor.

l. Army Assess and Authorize. The larger and more complex OT Systems must be assessed by the Army.

(1) This assessor is a Security Control Assessor-Validator (SCA-V) and is typically an independent third-party from the system and the owner's organization. SCA-V capabilities can be provided by the Information Security Engineering Command and USACE's ERDC – Information Technology Lab.

(2) The use of a SCA-V may come at a significant cost to the project as they must prepare for an assessment, make a site visit to inspect and assess the system, and develop documentation of their findings. Costs may range from $30k-$60k for an assessment that must be completed every three years. The approval chain for the assessment is also at the higher Army level.

m. RMF Lifecycle. As the seventh step of the RMF process suggests, RMF is a continuous process. System Owners must constantly monitor their systems and determine the impact of changes to the system and the environment. Documentation and annual reviews must be updated accordingly.

23.5 Remote Monitoring and Operation.

a. General. The term “remote” refers to monitoring or controlling the pump station physically separate from the pumps. Requirements for remote operation of pump stations must follow the requirements in ER 1110-2-1156, Chapter 20. Some examples of remote monitoring of pump stations are indicated below in Paragraphs 23.5 b and 23.5 c. These examples are provided as a reference only for the designer.

(1) Remote operation could be from a control room inside the pump station or an operation center located miles away.

(2) A majority of federal projects are independent, single pump stations constructed by USACE and turned over to a sponsor such as a municipality or levee district. A remote monitoring and operation capability is rarely included in these projects and must be funded and implemented by the sponsor. Some pump station projects may be a component of a larger water management or protection system and therefore require monitoring as part of the initial design.

b. Hurricane Protection System. The Hurricane Protection System in the New Orleans District includes several pump stations on the outfall canals. The pump stations are monitored from the District’s Emergency Operation Center. While the pump stations are physically separated from each other, fiber optic cable installed as part of the project provides a dedicated communication path between the facilities.

c. SFWMD. The SFWMD is remotely monitoring and operating a large number of structures including pump stations.

(1) The District has a central control center in West Palm Beach, Florida connected to a microwave backbone system which connects to individual pump stations (usually by point-to-point microwave, but occasionally by fiber optic cable).

(2) Firewalls are used to partition the network at the pump station/tower. The pump stations have two Ethernet networks: 1) industrial Ethernet network for SCADA and 2) an enterprise network for email and other functions.

(3) The SCADA network includes a Station Control Center SCC with dual PLCs (for reliability) and each engine driven pump has a PLC. The Station Control Center collects all general station input/output including fuel tank monitoring, trash rakes, fire alarm, security alarm, backup generator, automatic transfer switch (ATS), stilling wells, and all electric driven pumps.

(4) All PLCs have battery backup. The microwave system/ information technology network has a 48V DC battery system and also a separate generator and ATS.

(5) There is a camera system connected to the network which provides upstream, downstream, interior, and other camera views for remote operation and security monitoring. The pump stations also have an exterior horn/strobe to provide warning of operation.

(6) SFWMD operates their electric pumps remotely but like to have operators at the station for operating engine driven pumps. The pump stations, command center, and microwave tower infrastructure are designed for 186 mph wind loading to survive a major hurricane.

23.6 Connectivity. Connectivity between the pump station and the other facility is necessary to implement remote monitoring or operation. The following technologies may be used in the system.

a. Radio. Spread-spectrum radios can be used to provide connectivity between a pump station and an adjacent structure. The technology often requires line-of-sight transmission and is used for shorter distances. Manufacturers should be consulted when considering a radio connection as they can provide test equipment to evaluate its feasibility. Wireless transmissions must be encrypted using DoD approved cryptography.

b. Fiber Optic Cable. Single-mode and multi-mode fiber optic cabling may be used to establish an Ethernet connection between locations. Industrial Ethernet switches with fiber optic ports should be managed switches to meet cybersecurity requirements. Defense Information Systems Agency maintains an approved products list at https://aplits.disa.mil. Industrial switches on the approved products list are limited, but approved products should be used when feasible.

c. Leased Line. For locations without existing connectivity, a dedicated connection can be leased for a monthly cost. The costs are based on the physical distance between the locations and the bandwidth or speed required. T1 circuits typically provide a transmission of 1.544 Mbps and may be adequate for HMI data, but the use of video may require additional bandwidth. T3 and T4 lines may also be available for lease in some locations across the country.

d. Microwave. A microwave radio link can be more cost-effective than leased lines and trenched fiber optic cable. It avoids the trenching and installation costs of fiber optic cable and the monthly recurring costs of leased lines. The microwave link can also prove more reliable than land-based technologies. The microwave link can be established faster than a cable connection, but transmission or “link” distances may be limited. Licensed and unlicensed bands are available between 2 and 42GHz. The microwave link must be properly designed to ensure topographic and atmospheric conditions do not interfere with the propagation of the radio signal.

e. Corporate Network. Most USACE facilities have a connection to the corporate network, CorpsNet. While a designer might be able to leverage existing bandwidth, Army Corps of Engineers Information Technology requires a “SCADA Security Stack” between any ICS and CorpsNet. The security stack will be configured and managed by Army Corps of Engineers Information Technology, but it could have a significant first-cost and its maintenance and upkeep must be considered in the system lifecycle. CorpsNet should only be used as a last resort and its use must be coordinated with the UCIC.

Chapter 24
Pump Station Wiring

24.1 General. The reliability of the entire electrical installation will be only as good as that of the wiring by which the various items of power supply, power distribution, control, and utilization equipment are interconnected. Selection of proper materials and methods of construction for the wiring system are therefore a matter of prime importance. The following basic principles and components should be observed in design of pump station wiring systems.

24.2 Conduit. For the mechanical protection of wiring and for the safety of operating personnel, all pump station wiring should be enclosed.

a. Rigid galvanized steel conduit is the most commonly used material for raceways and is suitable for all locations where wiring is required within a pump station. If it is necessary to run conduits exposed below the operating floor, consideration should be given to PVC coated rigid galvanized steel or PVC conduit.

b. Designers should note that aluminum and stainless steel conduits are also available, but would be used only in very special applications which most pump stations will not require. All ferrous conduit fittings should be zinc coated or otherwise suitably plated to resist corrosion due to moisture and fumes common to pumping stations. In large stations where extensive cabling is required, the usage of cable trays should be considered. If conduits are to be embedded, the use of nonmetallic conduits should be considered.

24.3 Flexible Conduit. Liquidtight™ flexible metal conduit is recommended for use in pump stations to make final connection of rigid metal conduit to load equipment that vibrates. Liquidtight™ flexible metal conduit provides excellent protection for conductors and is recommended instead of regular flexible metal conduit because of the wet, damp, and moist environment typical of pump stations.

24.4 Low Voltage Conductors. Wire and cable for pump stations should be furnished with moisture- and heat-resisting insulation.

a. Conductors must be rated not less than 600 Volts, 90° C of copper or aluminum wires. Conductors should be mostly designed to be copper, although aluminum conductors may be used if the installation is addressed properly and associated equipment is properly rated for aluminum conductors.

b. Details of cable construction and insulation can be found in UFGS 26 05 19.10 10, Insulated Wire and Cable. Sizes of conductors should be designed per NFPA 70, National Electrical Code for motor feeders and branch circuits.

24.5 Low Voltage Conductor Splices.

a. General. The most common causes of trouble in completed wiring installations are imperfect splices and terminations of conductors that permit entrance of moisture under protective sheaths. The procedures to be followed in terminating conductors should be made a part of the installation contract specifications. The best policy is that no splicing of circuits of 480 volts or greater should be allowed in the contract specifications. This important detail of electrical construction should receive proper consideration by both designers and field inspectors.

b. Design considerations. There may be projects where the length of an electrical cable requires installation of cable joints to extend from source to load or to make final connections to the load equipment.

(1) Cable lengths are available in specific lengths on cable reels to allow shipping and handling. Single conductor cables and multiple conductor cables must be spliced with a high integrity cable splice that does not allow entrance of moisture into the splice in an application that has long run(s) of cable.

(2) Additionally, there are circumstances when the designer must consider if areas of the pump station and surrounding area may become flooded and in this special circumstance ensure that cable terminations and splices are all installed above the highest possible flood elevation to keep cables from piping water to the equipment they serve. There are no commercially available splices or splice kits that are rated or warranted for prolonged submersion in water.

c. Splice connectors. The designer must select connectors and materials rated for the conductors being spliced. Connectors must be typically rated 600 Volt, 90° C, and should be compression type connectors applied with a correctly sized swaging tool.

d. Splice tape and resin splice kits. The designer should be aware that splice tape and industrial cable splice kits are available to use when conductor splices are necessary. A resin splice kit is comprised of a normal connector wrapped with splice tape which is then placed in a composite splice mold. A resin compound from the kit is poured into and hardens inside the mold encapsulating the splice. This splice can be physically long and wide depending on the size of the single or multiple conductor being spliced.

e. Pre-formed heat-shrink breakout cable boots. Designers should consider for some applications that a heat shrink type breakout boot for three- and four-conductor multiple conductor cables are available to install to terminate a cable jacket. This is a special boot for each application and should be researched for availability.

f. Heat shrink and cold shrink tubes. This product has become common and if installed properly can provide a good seal for a conductor joint or to repair a damaged cable jacket.

g. Splice location. If it is deemed that a conductor splice is necessary then ensure that if the splice fails, exposed to moisture, or is submerged in water that the water in the cable does not flow down to the load equipment. Firstly, ensure that conductor joints are elevated as high as possible to ensure that they cannot flood. Secondly, ensure that if water penetrates the conductor joint that the infiltrated water cannot travel by gravity to the load equipment by installing the splice at lower elevation than the load equipment or by creating an air trap so that water cannot rise past the air trap.

24.6 Conductor Terminals. All electrical systems require that the conductor terminals be rated to accept the cables being terminated on them. A cable's ampacity per NFPA 70, Table 310-16 is dependent on the temperature rating of the terminal (i.e., 60° C, 75° C, or 90° C).

a. The designer must select conductors with the ampacity based on the ampacity of the actual equipment being provided, but there is a rule of thumb available that allows the design to be conservative with the correct ampacity.

b. That is, when terminal ratings are uncertain, then design ampacity for conductor size 1 American Wire Gage (AWG) or less to have ampacity rated at 60° C and design ampacity for conductor size 1/0 AWG or greater to have ampacity rated at 75° C on industry standard terminals for those conductor sizes. The full ampacity of a conductor rated at 90° C can only be applied if and only if the designer knows the applied terminals of the equipment being installed are rated 90° C.

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Chapter 25
Pump Station and Equipment Grounding

25.1 General. Following are the recommended practices for system and equipment grounding in pump stations. However, special applications may require variations to the recommended practices. A thorough discussion of grounding principles can be found in IEEE 142, Recommended Practices for Grounding of Industrial and Commercial Power Systems (IEEE Green Book). Installations should also comply with the applicable provisions of Article 250 – Grounding of the National Electric Code (NFPA-70). A typical grounding plan is shown on Plate 21 in Appendix B.

25.2 Pump Station and Equipment Grounding.

a. General. An effective grounding system is an essential part of a pump station electrical system. Grounding must be installed to comply with NFPA 70.

(1) In general, 19 mm (3/4 inch) diameter by 3 m (10 feet) long copper-clad steel ground rods should be driven at the corners of the structure and exothermically welded to a ground ring (a.k.a. a ground loop or a counterpoise) routed completely around the periphery of the pump station. Standard grounding electrodes are commonly available in 3 m (10 feet) lengths. Longer ground rods are achieved by using threaded, sectional ground rods connected to acquire extra length rod depths.

(2) The ground ring should be installed a minimum of 457 mm (18 inches) outside the building wall and a minimum of 762 mm (30 inches) below the finished grade as described in NFPA 70 requirements.

(3) Irreversible-compression type grounding connectors may be considered in lieu of exothermic connections when installed with the proper hydraulic compression tool to provide the correct circumferential pressure.

(4) Note that either exothermic-welded type or irreversible compression type grounding connections are required for underground connections and either Underwriters Laboratories (UL) approved split-bolt type or bolt/screw type grounding connections are required for above ground connections.

(5) Split bolt or set bolt/screw type grounding connectors should not be used for underground connections because they may become loose, unreliable, and cannot be inspected in their underground location.

(6) Electrical materials and equipment must be rated for use as grounding equipment suitable for each specific application. Dissimilar metals must not be installed adjacent to each other without redress to corrosion.

(7) The resistance to ground for a facility grounding system should be as low resistance as possible. Designers should try to achieve resistance to ground of 10 ohms, preferably 5 ohms or less, for pump stations that contain critical system(s) or critical in nature as defined by ANSI/TIA-607-C. Otherwise, the resistance to ground must not exceed 25 ohms per NFPA 70 for pump stations that do not contain systems that are critical in nature.

(8) In rocky ground where driven rods are impractical, it is sometimes more economical and desirable to use a grid system with cable spacing of approximately 3 m (10 feet) being common. The cables should be placed 152 mm (6 inches) to 304 mm (12 inches) deep and encased in concrete.

(9) The grounding system must be installed in compliance with NFPA 70, National Electrical Code. It is important to bond all metal equipment and significant metal structures to the pump station's equipment grounding system.

(10) Grounding systems at old pump stations should be inspected periodically, in a similar manner as other electrical systems. Grounding systems intended to be rehabilitated should be replaced with new equipment. New and rehabilitated grounding systems should be provided, commensurate with the grounding needs of other electrical systems installed at the facility, including grounding equipment for the power distribution system, the pump control system, the SCADA system, the communication system, the closed-circuit television system, surge protection equipment, and lightning protection system as applicable.

(11) All grounding electrodes for all systems must be bonded together. Refer to NFPA 70, UL 467, IEEE 142, and ANSI/TIA-607-C for more information regarding electrical grounding and bonding.

b. Ground bus. The ground ring may act as the ground bus to which all grounding conductors bond or otherwise a common bonding copper ground busbar may be provided inside the pump station to centrally manage and bond all of the grounding conductors.

(1) A copper ground busbar may be integral to the service switchgear, service panelboard, the MCC, or provided as a separate, dedicated copper grounding busbar determined by the amount of space required to manage the grounding conductors.

(2) Grounding conductors should be bonded to the sump floor reinforcement bars, grounding electrodes, metal enclosures, significant metal structures, any steel columns of the structure, and metallic underground water piping where present. Mechanically bond the ground ring to the copper ground busbar.

c. Grounding conductors. Grounding conductors must be copper (aluminum is not acceptable). At least four grounding conductors should be routed from the ground bus or grid and exothermically welded or irreversible compression type connected to a ground loop embedded in the operating floor.

d. All connections to either the ground loop or ground bus should be by either exothermic-welded type or irreversible compression type grounding connections for underground connections. Grounding connections should be by either Underwriter Laboratory (UL) approved split-bolt type or bolt/screw type grounding connections for above ground connections.

e. Sizing of ground bus and ground ring conductors. Sizing of ground bus and ground ring conductors should be made per the applicable requirements of the National Electrical Code (NFPA-70). The grounding conductors should not be smaller than 2/0 AWG conductor to provide mechanical strength. However, it may be desirable to exceed these values where exceptional precaution is required or where extremely high ground-fault currents are expected.

f. Frames and enclosures. The frames of stationary or permanently located motors, and the frames and enclosures of static equipment such as transformers should be grounded by direct connection.

(1) Direct connection should be to the operating floor ground ring or grounding bus bar through an equipment grounding conductor equal in size to the largest conductor in the line connected to the equipment, but in general not less than No. 6 AWG should be connected to the equipment through the use of a clamp-type connector.

(2) The designer must choose a method to route and extend grounding conductors to bond to equipment frames and enclosures and may consider requiring grounding conductor pigtail penetrations that extend out of the concrete, requiring grounding inserts to bond to frames, requiring surface-routed grounding conductors connected to a grounding busbar, or a combinations of these methods.

g. Switchgear. To provide a convenient method of grounding switchgear, a ground bus should be provided as part of the equipment.

(1) For metal-clad switchgear, ANSI/IEEE C37.20.2 requires the ground bus to carry the rated short-time withstand current of the switchgear for two seconds.

(2) For low-voltage, metal-enclosed switchgear, ANSI/IEEE C37.20.1 requires the ground bus to carry the rated short-time withstand current of the switchgear for 0.5 second. The switchgear ground bus should, in turn, be connected to the ground ring or a centralized grounding busbar by grounding conductors having a current-carrying capacity equal to that of the switchgear ground bus.

h. All electrically operated equipment. Additionally, an equipment grounding conductor must be provided for each circuit per NFPA 70, Article 250.120 and it must be properly sized per NFPA 70, Article 250.122.

i. Other noncurrent carrying metal. All other noncurrent carrying metal such as ladders, fences, fuel storage tanks, etc., must be connected to either the ground bus or operating floor ground loop. All neutral conductors of grounded power supplies must be solidly grounded to the pump station ground system.

j. Utility power. The utility furnishing power to the station should be contacted to determine if any interconnections are required between the pump station ground grid and the substation ground grid.

25.3 System Grounding.

a. General. The basic reasons for system grounding are the following:

(1) To limit the difference of electric potential between all uninsulated conducting objects in a local area. This provides a safer installation for pump station operators and maintenance activities.

(2) To provide for isolation of faulted equipment and circuits when a fault occurs which allows quicker reaction times by overcurrent devices to clear faults to better protect pump station operators and equipment.

(3) To limit overvoltage appearing on the system under various conditions.

b. Low-voltage systems. It is recommended that pump stations with electrical systems of 1,000 volts and below be solidly grounded.

(1) Solid grounding is the least expensive way to detect and selectively isolate ground fault through the usage of fast-acting ground-fault relaying. However, use of a solidly grounded low voltage distribution system increases the probability of damage from arcing ground faults.

(2) The driving voltage of these systems tends to sustain arcs rather than clear them through the standard phase overcurrent protective devices. High impedances associated with the arc may limit fault current to levels too low for detection by conventional overcurrent protective devices. For this reason, sensitive ground-fault relaying should be provided on the feeders and the main of all solidly grounded systems.

(3) Ungrounded operation of low-voltage systems is not recommended because of the potential overvoltage problems.

c. Medium-voltage systems. Modern power systems in this range of voltages are usually low resistance grounded to limit the damage due to ground faults in the windings of rotating machines and yet permit sufficient fault current for the detection and selective isolation of individually faulted circuits. The lowest ground-fault current (highest resistance) consistent with adequate ground relay sensitivity should be used. High-resistance grounding is not recommended for medium-voltage systems.

25.4 Lightning Protection. Lightning protection should be provided for pump stations.

a. Each pump station should be assessed to determine how much lightning protection is required. It is recommended that a budget maximum cost be determined for the lightning protection system cost because it is possible to design for protection beyond the lightning protection basic design needs.

b. Design the lightning protection system plan, materials, and installation per NFPA 780, Standard for the Installation of Lighting Protection System (2017) and UL 96A. Ensure that the basic lightning protection system requirements are adhered to.

c. Lightning protection system components must comply with UL 96. The USACE designer must prepare a biddable lightning protection plan and properly edit UFGS SECTION 26 41 00 specifically for each design project.

d. The UFGS SECTION 26 41 00 supports and ensures final correctness of the lightning protection design and proper materials by requiring third party design and approval of the lighting protection system by a qualified lightning protection designer.

e. Similarly, UFGS SECTION 26 41 00 requires and ensures that only a qualified lightning protection system installer provides the equipment and properly constructs the lightning system.

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Chapter 26
Surge Protection

26.1 General.

a. Lightning-induced voltage surges. Pump stations are particularly vulnerable to lightning-induced voltage surges on incoming power lines, since it is characteristic of their operation to be in use during thunderstorms. Therefore, special care should be taken to reduce the magnitude of these voltage surges to avoid major damage to the electrical equipment contained within. A relatively small investment can greatly reduce the voltage stresses imposed on rotating machinery and switchgear by lightning-induced surges.

b. Power supply transient voltage surges. Power surges on the power service grid may cause surges which exceed insulation ratings and can damage equipment either catastrophically. Additionally, pump station may be subject to low amplitude surges which occur frequently that may shorten or negatively impact the pump equipment life or require more frequent repairs.

c. Protective equipment. There are two transient elements of a voltage surge that require different protective equipment.

(1) The protection of the major insulation to ground is accomplished by a surge arrester which limits the amplitude or reflections of the applied impulse waves within the motor windings.

(2) The protection of turn insulation by reducing the steepness of wave fronts applied to or reflected within the motor windings is accomplished by protective capacitors.

(3) Medium voltage surge arrestors, medium voltage surge protection, medium voltage motor surge protection (MSP), and low voltage surge protection devices (SPD) are used to protect equipment from overvoltage surges. SPDs were formerly known as transient voltage surge suppressors, but the terminology has changed.

26.2 Medium-Voltage Motors. Medium-voltage motor surge arrestors and special surge capacitors assembled in a pre-packaged assembly is called a MSP.

a. MSP should be used to protect medium voltage motors as coordinated with the pump manufacturer. The pump manufacturer should be consulted for the particular application.

b. A MSP protects both the main insulation and the turn insulation of the protected pump motor. To obtain the most reliable protection of the motor's major and turn insulation systems, a specific assembly of arresters and capacitors should be installed as close as possible to the motor terminals. The arresters should be valve-type, Station-Class designed for rotating machine protection. The capacitors should be of the non-Polychlorinated Biphenyls type. The leads from the phase conductor to the capacitor and from the capacitor to ground should be as short as possible.

c. If solid state motor controllers or VFDs are used, the addition of capacitors at the motor terminals may not be recommended. Chopped-wave equipment such as VFDs or other SCR controlled motor starters can generate surges and harmonics. The capacitors can contribute to the problem by increasing resonance effects.

26.3 Low-Voltage Motors. Motors of 600 volts and below have relatively higher dielectric strength than medium-voltage machines.

a. Normally, when higher speed motors of this voltage class are connected through a transformer protected by Station-Class arresters on the primary side, no additional protection is warranted. However, due to the more expensive slower speed motors employed in pump stations, plus the critical nature of these motors, the minimal additional cost of lightning protection is justified.

b. Low voltage pump stations should be provided with a SPD at the service entrance or at the service entrance equipment panelboard, switchboard, or MCC. The station surge protectors should be provided to protect each phase to ground and the neutral to ground as applicable. SPDs provide protection from overload surges so additional motor protection must be provided by motor circuit protectors short-circuit protection, overload protection, and as deemed applicable, ground fault circuit interruption protection.

26.4 Substation. The power utility company should be requested to supply valve-type Station-Class surge arresters on the primary side of the pump station substation transformer. The power utility company will provide equipment that they deem suitable.

26.5 Pump Station Electronic Equipment. Electronic equipment in pump stations such as pump controllers, liquid level sensor and control equipment, remote monitoring equipment, security equipment, and closed-circuit television equipment are susceptible to damage caused by lightning surges as well as other power surges. This electronic equipment should be provided with properly sized and properly applied SPDs. Uninterruptible power supplies or power conditioners may be required for some projects depending on the specific application needs as coordinated with the system manufacturers.

Chapter 27
Electrical Equipment Environmental Protection

27.1 General. Pump station interior environments differ in different regions, however typically the interior of pump stations are humid and damp.

a. The equipment inside pump stations has to be properly designed for the environment applied. Pump station exterior equipment also experiences extreme weather. This is in the form of heat, cold, humidity, fog, rain, driven rain, electrical thunderstorms, hail, sleet, freezing rain, ice, snow, high velocity winds, blowing dirt and debris, tornadic winds, and hurricane force winds). Other issues include periodic and potential flooding, birds and bird nests, and insects (bees, mud-daubers), spider webs, and insect nests.

b. Atmospheres at pump stations can be fresh water or be brackish. Fresh water pump stations require corrosion resistant electrical equipment materials such as hot-dipped galvanized or stainless steel equipment.

c. Saltwater pump stations exposed to brackish water and brackish atmosphere require higher-integrity corrosion resistant electrical equipment materials such as stainless steel or aluminum equipment.

d. Additionally, since some pump station electrical equipment may stand idle for long periods of time, special attention must be given to corrosion protection due to inactivity. UFGS 26 29 01.00 10 (“Electric Motors, 3-Phase Vertical Induction Type”) and UFGS 26 29 02.00 10 (“Electric Motors, 3-Phase Vertical Synchronous Type”) provide recommended corrosion-protection requirements for induction and synchronous motors, respectively.

e. The standard manufacturer’s treatments of the medium-voltage motor controller line-ups and MCCs consist generally of one undercoat of a phosphatizing rust inhibitor followed by one finish coat applied to both internal and external surfaces.

f. In many stations where humidity is especially high or other conditions merit special consideration, two undercoats of the rust-inhibiting primer should be specified. In addition, all major items of electrical equipment including motors, control centers, controller line-ups, control consoles, wall-mounted combination starters, gate operator controllers, trash rake controllers, etc., should be equipped with space heaters sized per the manufacturer’s recommendations to prevent condensation.

g. Heaters in motors and controllers should be interlocked with the motor starters to ensure they are de-energized when the equipment is in operation. Heaters are generally fed separately from the pump station lighting panelboard as a separate power source to the equipment, and as such pose a shock safety hazard.

h. Therefore, all items of equipment containing space heaters should be clearly marked indicating the power source of the space heater power, so the space heater is also turned off for safe maintenance service access and activities. These heaters will require 120 VAC, single-phase service year-round.

27.2 Formulas. Standard formulas used to estimate the output ratings of equipment heaters to give a temperature rise above ambient are as follows (English units):

$$Ph = 0.6 \times A \times \Delta T \qquad \text{(Equation 27.1)}$$

where:

Ph = panel heater output rating (watts)
A = panel external surface area (square feet)
ΔT = designed temperature rise above ambient
(Degrees Fahrenheit)

For motor-winding heaters giving a 10° Fahrenheit rise above ambient,

$$Ph = D \times L / 2.52 \qquad \text{(Equation 27.2)}$$

where

Ph = motor winding heater output rating (watts)
D = end bell diameter (inches)
= "2D" (frame dimension from NEMA MG1)
L = motor length (inches)
= "2F + 2BA" (frame dimensions from NEMA MG1)

27.3 Enclosure Ratings, Design, and Selection.

a. General. All electrical enclosures must be designed to be suitable for the environment in which they are installed. The typically damp, wet, and harsh conditions must be considered when selecting the correct electrical enclosure material and level of environmental protection. Lessons learned and general considerations follow:

(1) Painted steel enclosures with pre-punched knockouts have been noticed to corrode more quickly around the knockout punches. It is difficult to stop the corrosion process on electrical enclosures once it has begun. If an enclosure is rusting then the rust should be ground or brushed off until bare metal is exposed leaving no rust and then a new paint coat or cold-galvanizing finish may be applied.

(2) Electrical conduits routed from either underground or outside the pump station, an exterior atmosphere to inside the pump station, an interior atmosphere should be sealed inside

the conduit after conductors are installed with either electrician's putty or expanding foam to keep moisture from entering the electrical equipment and condensing.

(3) It is recommended to allow all electrical enclosures to drain and breathe to help prevent moisture condensation. Maintain an enclosure rating when installing drains and breathers (i.e., install NEMA 4X drains in NEMA 4X enclosures).

(4) Avoid installing conduit penetrations into top of outdoor electrical enclosures to help prevent water entry from the top side. Water will penetrate the enclosure by following the conduit threads.

(5) Install grounding, insulated-throat conduit hubs in outdoor enclosures at conduit penetrations to provide good integrity conduit terminations and water-resistant penetrations.

(6) Provide hinged doors on electrical enclosures installed in ladder access locations where handling an unfastened enclosure door is inconvenient and unsafe.

(7) Provide insect screens when fixed louvered vents are used. The insect screens require periodic cleaning maintenance but require less maintenance than electrical equipment inundated with insects.

b. Indoor enclosures. The interior of a pump station is typically protected from direct application of the elements, but the atmosphere inside a pump station is typically very humid and damp so that electrical enclosures should be corrosion resistant and either have a continuous paint finish, have a hot-dipped galvanized steel finish, or be fabricated from stainless steel.

(1) Non-metallic enclosures are typically not used in pump stations.

(2) If used, they should be corrosion-resistant but the designer must consider possible physical impact from adjacent work activities that may damage a nonmetallic enclosure, but which may not damage a metallic enclosure.

(3) Consider using NEMA 3, NEMA 3R, or NEMA 4X stainless steel enclosures.

c. Outdoor enclosures. The exterior of a pump station is typically exposed to most of the harsh environment conditions listed above.

(1) The electrical enclosures must be protected from direct exposure to these environmental elements. Electrical enclosures should be corrosion resistant and either have a hot-dipped galvanized steel finish or be fabricated from stainless steel.

(2) Painted steel enclosures subjected to hail or blowing debris which can scratch their paint coat may lead to failure of the enclosure finish and early corrosion.

(3) Non-metallic enclosures are corrosion resistant and otherwise may be suitable for use outdoors of a pump stations, but the designer must consider potential damage from physical impact from adjacent work activities, ultraviolet light, and freeze/thaw temperature cycles. NEMA 4X stainless steel enclosures are recommended for use outdoors at pump stations.

(4) NEMA 4X stainless steel enclosures should be provided outdoors of pump stations installed in brackish water atmosphere and salt-water environments. Non-metallic enclosures are typically not used outdoors at pump stations.

d. Hazardous location enclosures. Pump station electrical installations must comply with NFPA 820 and NFPA 70. NFPA 820 and NFPA 70 defines hazardous (classified) locations and requires electrical equipment enclosures to be rated for the hazardous location to which they will be applied. An electrical enclosure may have multiple hazardous (classified) locations ratings and may also be rated for the environment in which it will be installed (e.g., outdoors rated for blowing rain). Electrical enclosures must be rated for not less than the rating of the hazardous (classified) location to which they are applied.

e. Industry standards. The following industry standards define the level of protection ratings of electrical enclosures used to determine the proper enclosure for each specific environment application:

(1) NEMA 250: Enclosures for Electrical Equipment (1000 Volts Maximum).

(2) UL 50: Enclosures for Electrical Equipment – Non-Environmental Considerations.

(3) UL 50E: Enclosures for Electrical Equipment – Environmental Considerations.

(4) IEC 60529: Degrees of Protection Provided by Enclosures (IP Code).

Chapter 28
Station Service Electrical Systems

28.1 Auxiliary Power Distribution.

a. Low-voltage pump stations. In low-voltage pump stations, the auxiliary loads of 480 volts and below are most conveniently distributed by means of a power panelboard either mounted in a vertical section of the MCC or in a strategic location along a pump station wall.

(1) The power panelboard should be fed from a circuit breaker located in the MCC. A separate auxiliary power service or lighting power service may be required to obtain the optimum rate schedule from the utility. That is, the separate auxiliary or lighting power service may be connected and operated continuously where the 480 Volts, 3-phase power service may either be disconnected until needed to operate the pumps or when pumps are only used seasonally or periodically.

(2) These power utilizations and connections may offer an opportunity to get utility cost savings. Pump station connection and operation alternatives must be discussed with the local electric power utility company.

b. Medium-voltage pump stations. In medium-voltage pump stations, packaged unit substations are available that conveniently incorporate a high-voltage load interrupter switch, a 4160/480-volt transformer section, and a power panel section.

(1) It is not necessary to provide a main breaker on the power panel since the high-voltage interrupter switch provides a disconnecting means. Three phase voltmeters should be provided to monitor the 480-volt service. A separate auxiliary or lighting power service may be required to obtain the optimum rate schedule from the utility.

(2) That is, the separate auxiliary or lighting power service may be connected and operated continuously where the medium-voltage power service may either be disconnected until needed to operate the pumps or when pumps are only used seasonally or periodically. These power utilizations and connections may offer an opportunity to get utility cost savings. Pump station connection and operation alternatives must be discussed with the local electric power utility company.

28.2 Lighting System. In general, 208/120-volts, three-phase, five-wire (L1-L2-L3-N-G) grounded systems are recommended for lighting loads.

a. Light fixture, receptacle, and general small load circuits will typically be 20 Amperes, 120 Volts, single pole. Two pole and three phase circuits applied when needed. The pump station power service system should be designed to anticipate load growth.

b. Anticipated load growth will depend on a number of factors, including the size and location of the pump station. A minimum of 20-percent spare power circuit capacity should be provided for future expansion.

c. Operating floor light fixtures, floodlights, and other light fixtures that may be used for considerable periods of time should usually be of the Light Emitting Diode (LED) type. Fluorescent and high-intensity discharge light fixtures were the recent standard type of light source, but LED technology has immerged as the more efficient, more economical, and better light color source solution for both interior and exterior lighting and is replacing fluorescent and high-intensity discharge technology. Refer to Illuminating Engineering Society of North America, "The Lighting Handbook Reference & Application", Tenth Edition.

d. The following are typical minimum recommended average foot-candle levels for various pumping station areas derived from The Lighting Handbook for equal or similar areas. Additionally, Illuminating Engineering Society RP-8, is a useful reference regarding the recommendation for roadway lighting also included in Table 28.1 below. Another lighting design resource is UFC 3-530-01, "Interior and Exterior Lighting System and Controls" (2016). The designer is responsible for making final determinations of applications, tasks, and illumination criteria.

Table 28.1
Typical minimum recommended average foot-candle levels for various pumping station areas

Location	LUX	(Foot-Candles)
Operating Floor	300	30
Control Room	300-500	30-50
Lavatory	200	20
Sump Catwalk	200	20
Forebay	50	5
Entrance Door	10	1
Roadway	10	1

28.3 Emergency Egress Lighting and Illuminated Exit Signs. Emergency egress light fixtures and illuminated exit signs are not required by the NFPA 101, Life Safety Code.

a. This is because a pump station building does not fit standard requirements for standard buildings and has normal human occupancy for which emergency egress lights and illuminated exit signs are not required. For example, a pump station may be so small that the operator will always be able to find the single exit door during an emergency.

b. The end user or designer may ultimately require this emergency lighting and illuminated exit sign equipment to be installed as a matter of providing life safety features regardless if it is required by code.

28.4 General Purpose, Lighting, and Receptacle Panelboard. The pump station alternatives to provide power to the general pump station circuits is to either provide a 480/208/120 Volts general transformer or to provide a separate 208/120 Volts electric power utility service that provide "house power" for the general electrical loads required for the pump station.

28.5 Auxiliary Equipment Loads. Pump station electrical loads that although may not be applicable or needed at every pump station, should be considered and must be coordinated with the design team.

a. These include but not limited to the following ancillary equipment loads: overhead crane; overhead rollup vehicle doors; exhaust fans; motorized louver operators; unit space heaters.

b. Other equipment loads include air compressors; water pumps; oil reservoir heaters; pump station pump control panel(s); battery chargers; syphon and syphon break controls; auto water level monitor, indication, and controls; bubbler system compressor and controls; condensation heaters; fuel transfer pumps and controllers; sump pumps and controllers; hot water heater; self-contained sewage treatment unit; interior lights; exterior lights; special user-defined receptacles; and general convenience receptacles.

28.6 Receptacles.

a. 120 Volts convenience receptacles. Provide 20 Amp, 120 Volt convenience receptacles throughout the pump station.

(1) Generally, 120 Volt convenience receptacles should be duplex, ground fault circuit interrupter (GFCI) to protect personnel from ground fault. The pump station has a concrete floor which provides a good, solid ground fault circuit path from a receptacle through a human operator to the floor that must be protected against by use of GFCI receptacles similar and as analogous to GFCI required by NFPA for garages.

(2) GFCI circuit breakers are available to serve several standard duplex on one circuit, but experience is that operators prefer each receptacle to be GFCI to have convenience of reset right at the location they are working. Ensure that the receptacles have properly sized conductors so that the receptacles farthest from the panelboard do not experience excessive voltage drop (refer to NFPA 70 for voltage drop considerations).

b. Special receptacles. The designer should coordinate with the pump station user what other types of special receptacles may be needed such as, for example, a 240 Volt, 2-pole, 30 Ampere receptacle necessary to power a plug and cord connected electric welder or a portable air compressor. Consideration and coordination will identify these special receptacles if they are needed. Coordination should also include how many special receptacles are needed and at what location(s) they will be used.

c.   Portable standby generator connection receptacle. This receptacle is only needed if the pump station is designed to be powered with a portable generator in which case the pump station electrical power distribution system will require a properly sized electrically-operated manual transfer switch, a properly sized receptacle located in the appropriate location to run the generator set, and properly sized conductors and conduits from the generator set receptacle to the transfer switch.

Chapter 29
Station Service Diesel Generator

29.1 General. The necessity for a diesel generator should be evaluated on a project-by-project basis. The designer is required to evaluate the available electrical service and its reliability and redundancy. A risk-based decision should also be done as described in ECB 2019-15.

a. The designer should also refer to EM 1110-2-2610 for a further discussion of electrical power systems. The designer should determine if alternate power is needed for pumping operations and/or to keep the life support and control systems operational.

b. The geographic location of the pump station is also a factor as an alternate source of power may be more critical to coastal areas impacted by hurricanes. Stations located in the Midwest often have access to a reliable electric service, but rural locations may experience more outages.

29.2 Generator Ratings. Generator set manufacturers follow ISO 8528-1 (2018) regarding the generator set ratings.

a. Continuous Power. Per ISO 8528-1, "Continuous power is defined as being the maximum power which the generating set is capable of delivering continuously while supplying a constant electrical load when operated for an unlimited number of hours per year under the agreed operating conditions with the maintenance intervals and procedures being carried out as prescribed by the manufacturer." Note that this definition requires a "constant" load and cannot provide any overload capability.

b. Prime Power (PRP). Per ISO 8528-1, "Prime power is defined as being the maximum power which a generating set is capable of delivering continuously while supplying a variable electrical load when operated for an unlimited number of hours per year under the agreed operating conditions with the maintenance intervals and procedures being carried out as prescribed by the manufacturer."

(1) The permissible average power output over 24 hours of operation must not exceed 70% of the PRP unless otherwise agreed by the engine manufacturer. The PRP rating is lower than the emergency standby power rating.

(2) A prime-rated generator generally has an overload capability and can support a varying load. Manufacturers can provide higher permissible average power output ratings. Prime ratings should be used when an electric utility is not available or unreliable and when the generator is the primary source of power.

c. Emergency Standby Power. Per ISO 8528-1, "Emergency standby power is defined as the maximum power available during a variable electrical power sequence, under the stated operating conditions, for which a generating set is capable of delivering in the event of a utility power outage or under test conditions for up to 200 h of operation per year with the maintenance intervals and procedures being carried out as prescribed by the manufacturers." The permissible average power output over 24 hours of operation must not exceed 70% of the emergency standby power unless otherwise agreed by the engine manufacturer. A standby rating should be used when the generator is providing service during short periods while a utility is unavailable.

29.3 Engine-Driven Stations.

a. General. In stations utilizing engine-driven pumps, it may be more economical to furnish a diesel generator unit to provide station auxiliary power requirements (if three-phase is required) than to provide a separate service from a local utility. However, a single-phase service to meet minimal heating and lighting needs may still be necessary. Engines often require block or other heaters to start reliably and will require a constant electric service. Economic comparisons should be made to determine the most cost-effective method of supplying auxiliary power. The unit should be rated for PRP service, not for standby.

b. Life Support and Control Systems. Severe weather conditions, such as a hurricane, and the need to ensure operation of the pumps often results in the selection of engine-driven equipment. In these applications, backup power may be needed to keep control and communication systems functional. These systems should include an uninterruptible power supply to keep them energized until the transition to generator power has been made. Life support systems may include safe house power, lighting, and HVAC systems.

29.4 Electrically Operated Stations. Electric pumps will require a larger alternate power system. Due to the inrush currents associated with motor starting, the generator must be sized to accommodate the current running loads and the starting loads ("starting kVA"). While reduced voltage starting can lower motor inrush currents, the solid-state devices cannot handle a voltage dip greater than 15%. Many generator manufacturers provide software tools to help with sizing to ensure sufficient starting kVA and limit voltage drop.

29.5 Generator Connections.

a. Manual Transfer Switches. A manual transfer switch must be operated by the station operator. It also requires the station operator to start the diesel generator and verify the output voltage prior to the transfer. A manual transfer switch should only be used when the station operator will not be exposed to weather and other hazards during operation.

b. Automatic Transfer Switches. An ATS does not require operator intervention. The ATS constantly monitors the utility for undervoltage, phase loss, etc.

(1) When a condition occurs, the ATS will command the starting of the generator and switch to the unit when the output voltage is reached. An ATS can be configured to return automatically to the utility when it is available or to wait to return until commanded by an operator. The ATS is often configured to periodically exercise the generator.

(2) The ATS may serve as the service disconnect if it is service entrance-rated, but it is recommended to provide a means of disconnecting the utility ahead of the ATS. This will make repair work on the ATS easier.

c. Generator Circuit Breaker. For pump stations where a diesel generator is not included in the project, a key-interlocked circuit breaker should be included in the power distribution equipment.

(1) The extra breaker allows quick integration of a temporary generator into the power system. The key interlock highlighted in Figure 29.1 ensures that the generator circuit breaker can only be closed when the main (utility) breaker is in the open position.

(2) It is recommended to provide a generator connection point outside of the station to allow quick connection of a rental generator. A pad-mounted enclosure is shown in Figure 29.2 although a wall-mount enclosure can be provided as well.

(3) The connection point eliminates temporarily routing conductors throw doorways of the pump station or electrical building. Figure 29.3 shows the field connections to the generator made using standard cable and lugs inside the enclosure.

(4) Field connections to the generator can also be made using standard cam-lock cables that can be rented with the generator. The connection enclosure should be located adjacent to an area that can support a trailer-mount generator.

(5) Coordination with the civil designer is necessary to ensure that vehicle access to the station supports the trailering, delivery, and parking of a generator. The requirements for a generator should also be coordinated with the geotechnical designer to ensure that vibration and other loads associated with a trailer-mounted generator do not affect the integrity of the levee.

Figure 29.1. Generator Circuit Breaker

Figure 29.2. Generator Connection Enclosure

Figure 29.3. Generator Connection Enclosure Field connections

29.6 Closure Gates. Electrically operated closure gates should be capable of operating from an alternate source of power if the utility is not reliable. A permanently installed generator will require periodic testing and maintenance. The electrical designer should consider the use of a truck-mounted generator to operate the closure gate. In either solution, the electrical system should permit the quick connection and transfer to generator power.

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Appendix A
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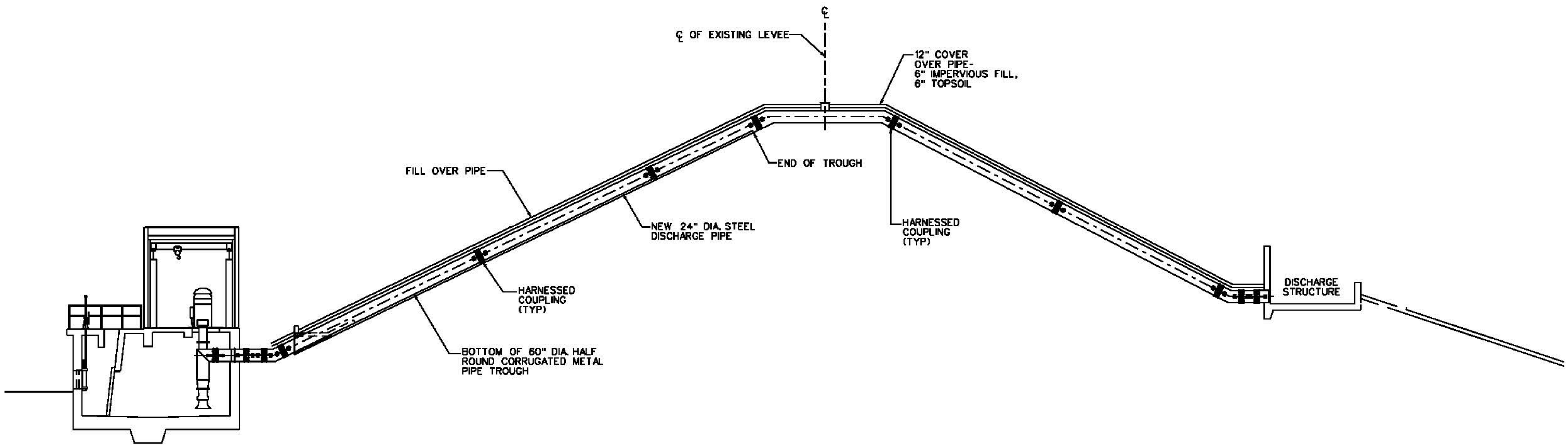


Figure B.1. Pump Station with over the Protection with Discharge Chamber

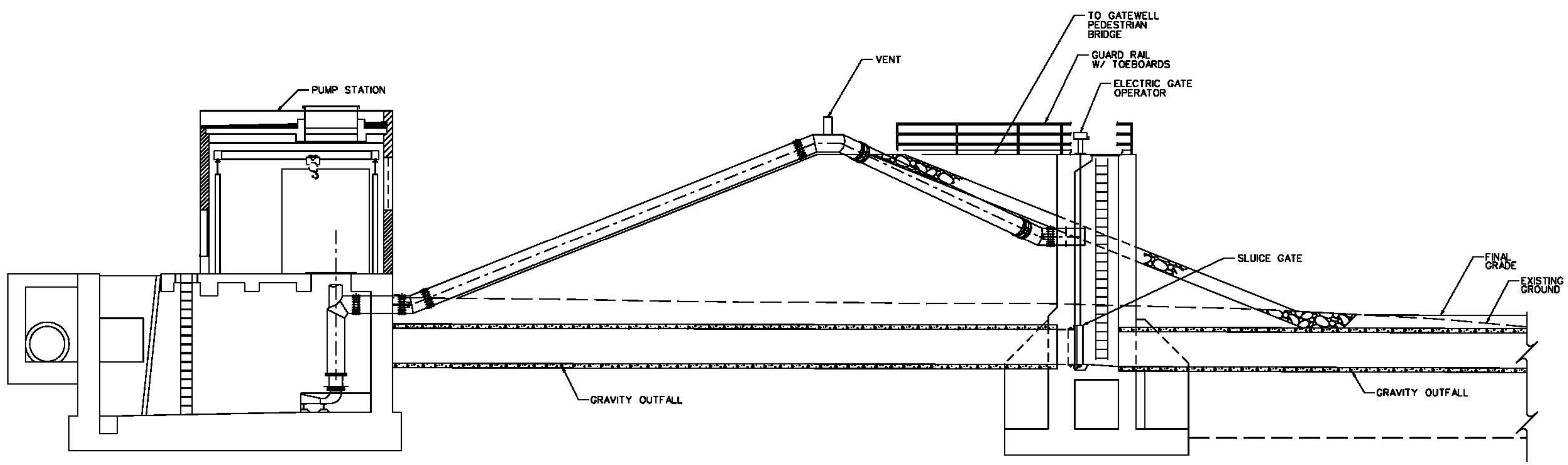


Figure B.2. Pump Station with over the Protection with Discharge Gatewell

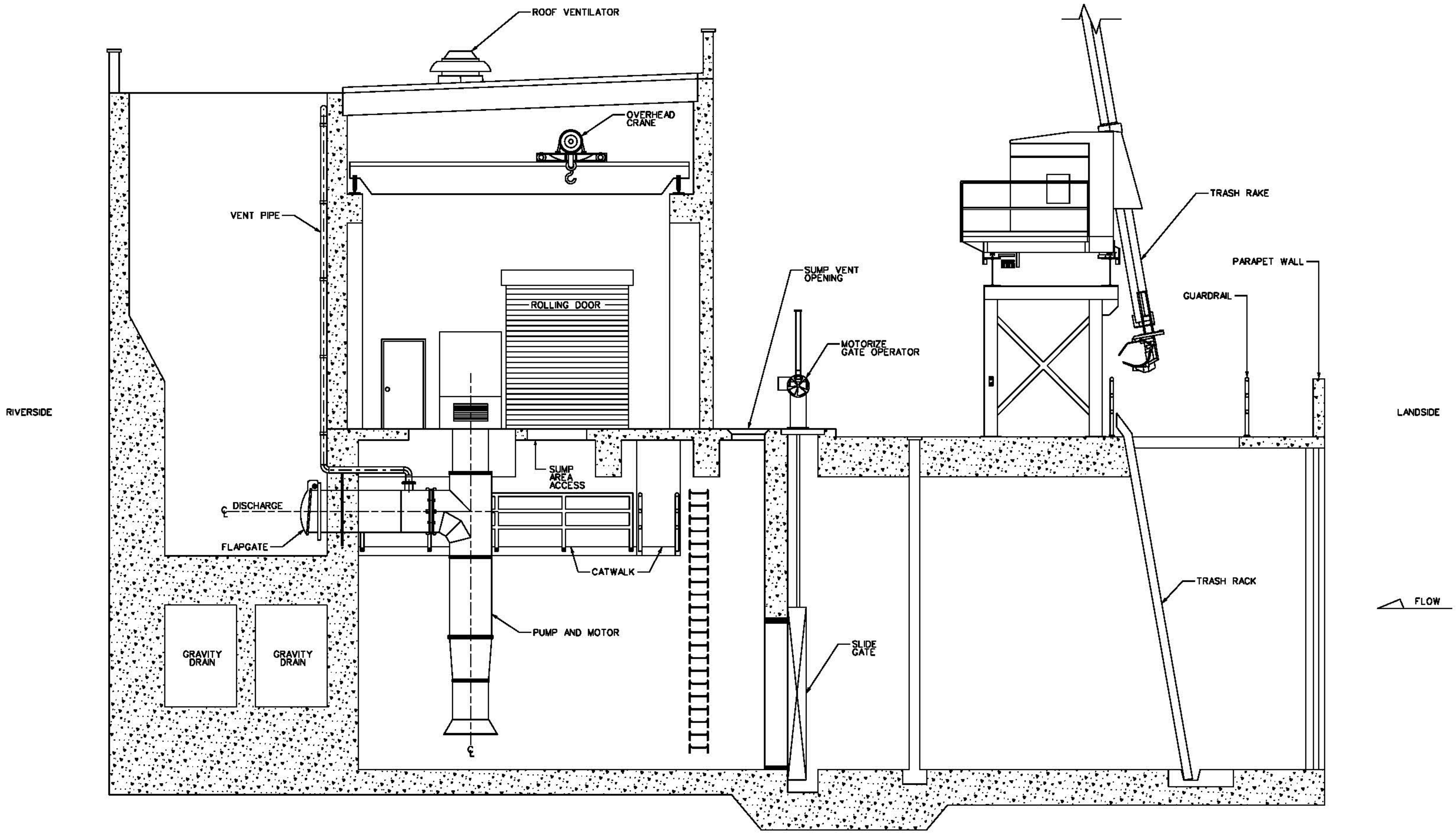


Figure B.3. Discharge Chamber Pump Station (Floodwall)

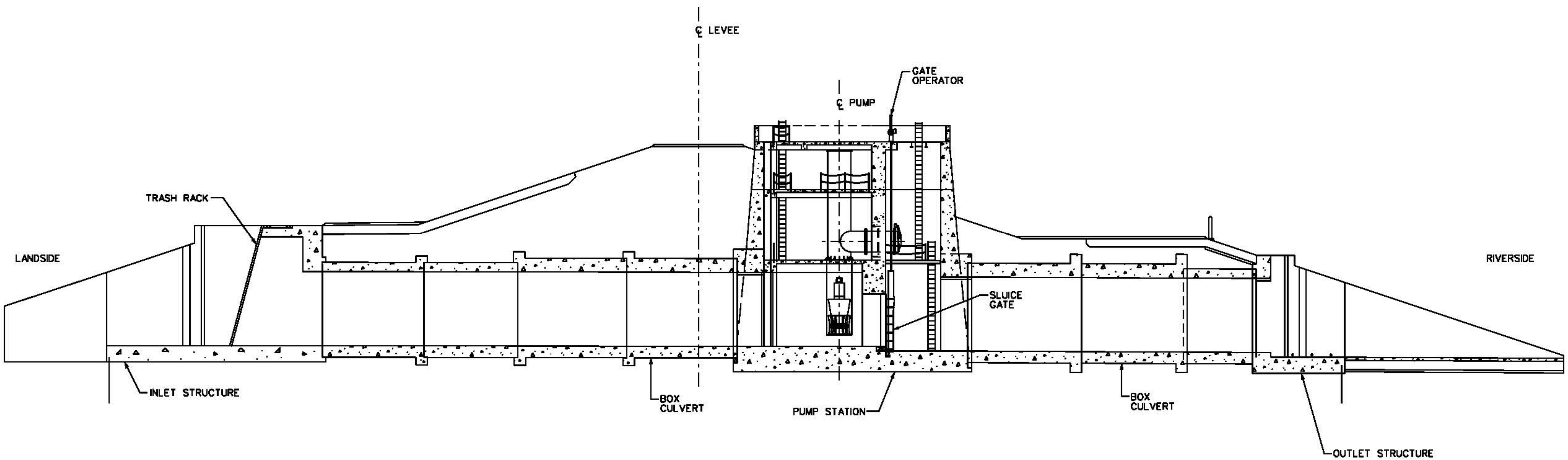


Figure B.4. Combined Gatewell/Pump Stations using Submersible Pumps

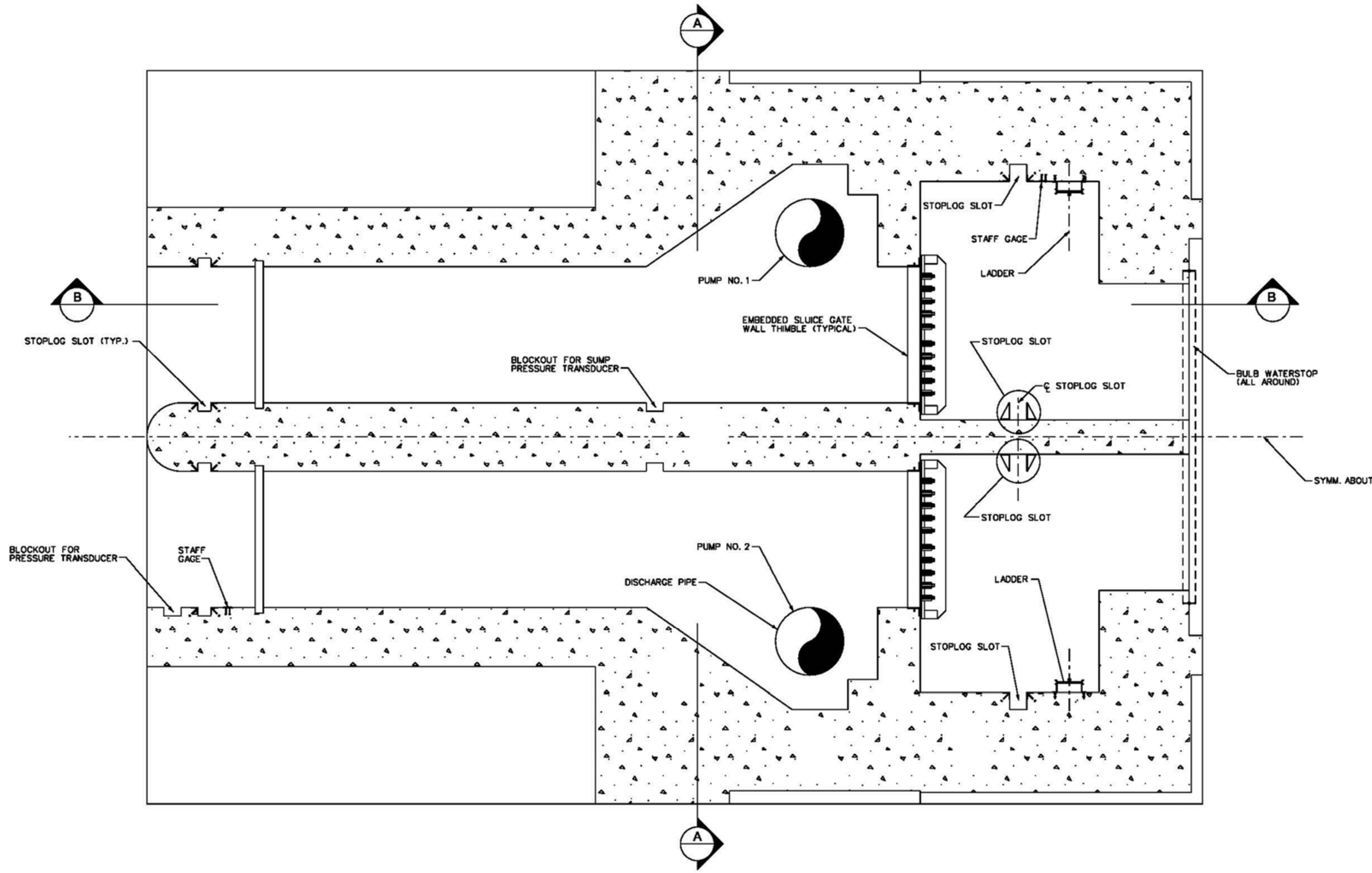


Figure B.5. Combined Gatewell/Pump Station Plan View

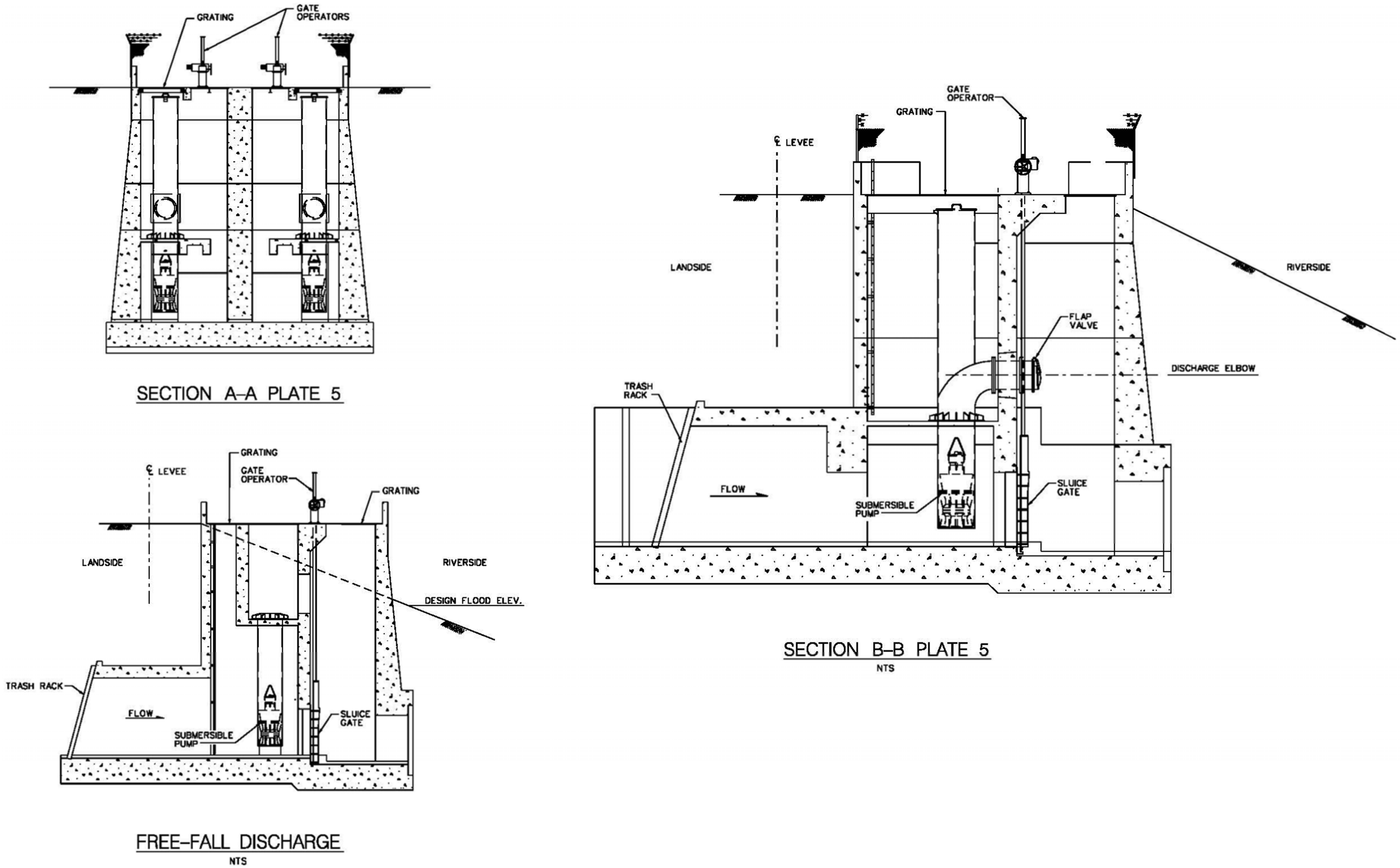


Figure B.6. Combined Gatewell/Pump Station Profiles

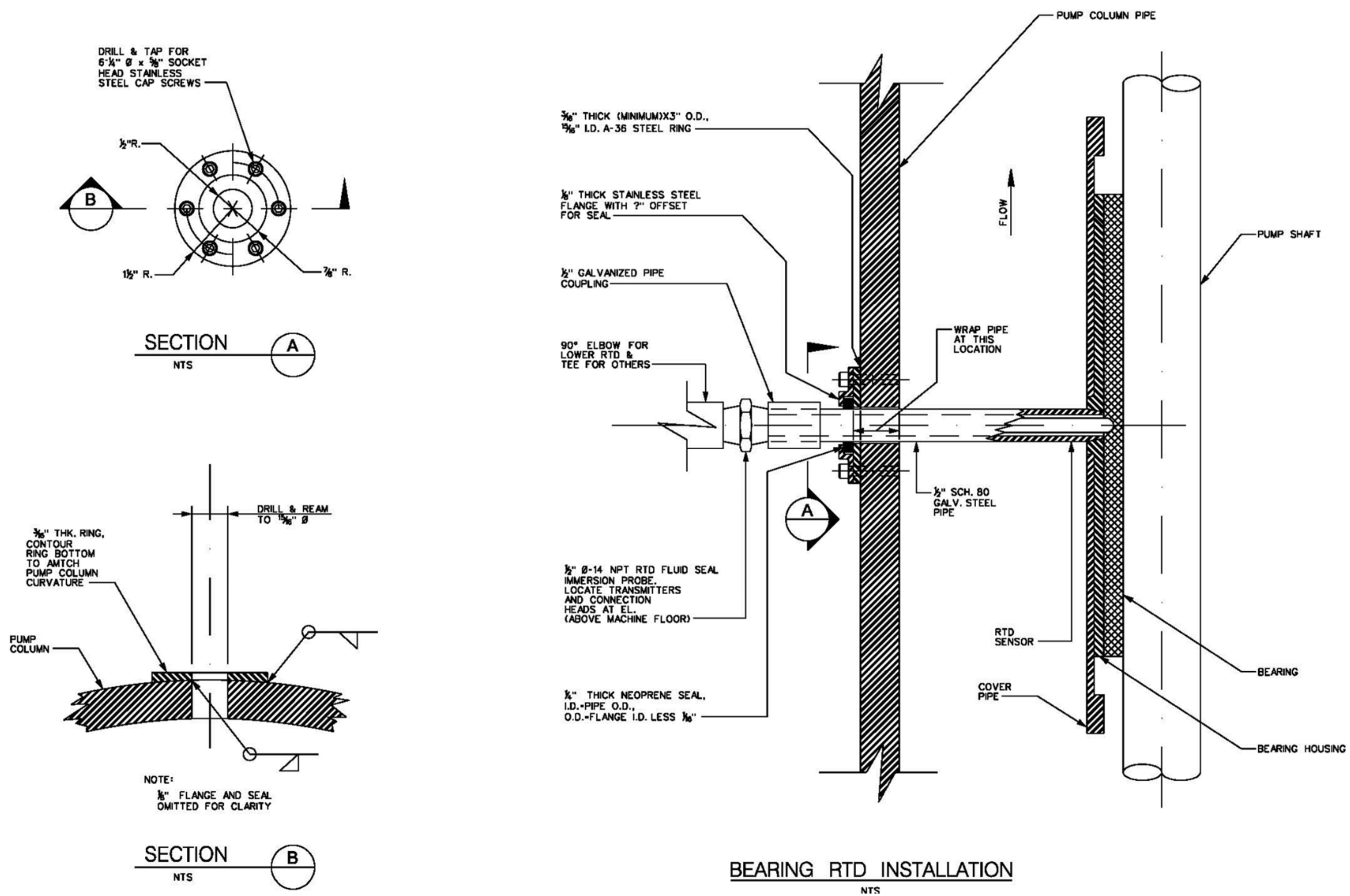


Figure B.7. RTD Installation for Vertical Wet Pit Pumps

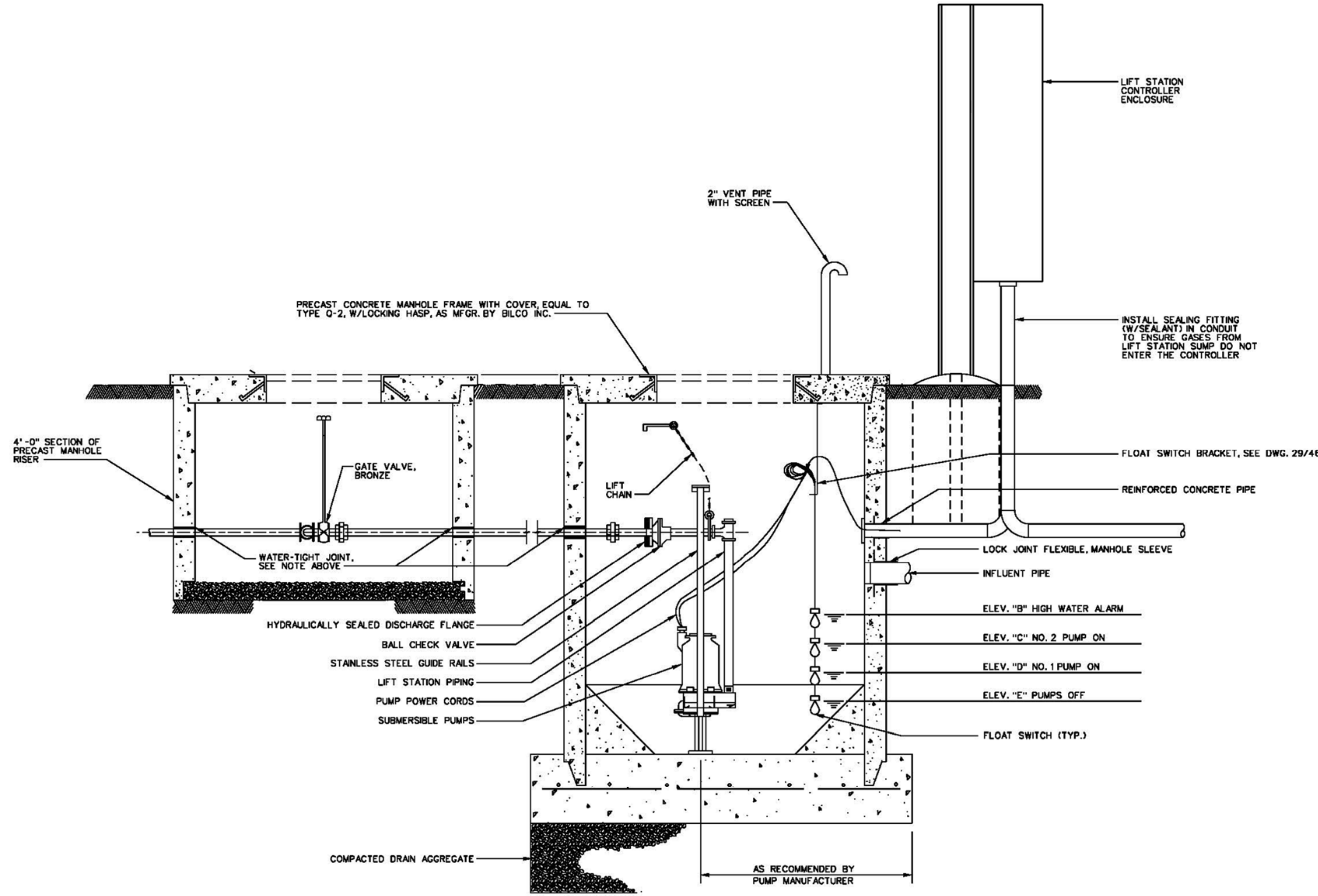


Figure B.8. Submersible Lift Station

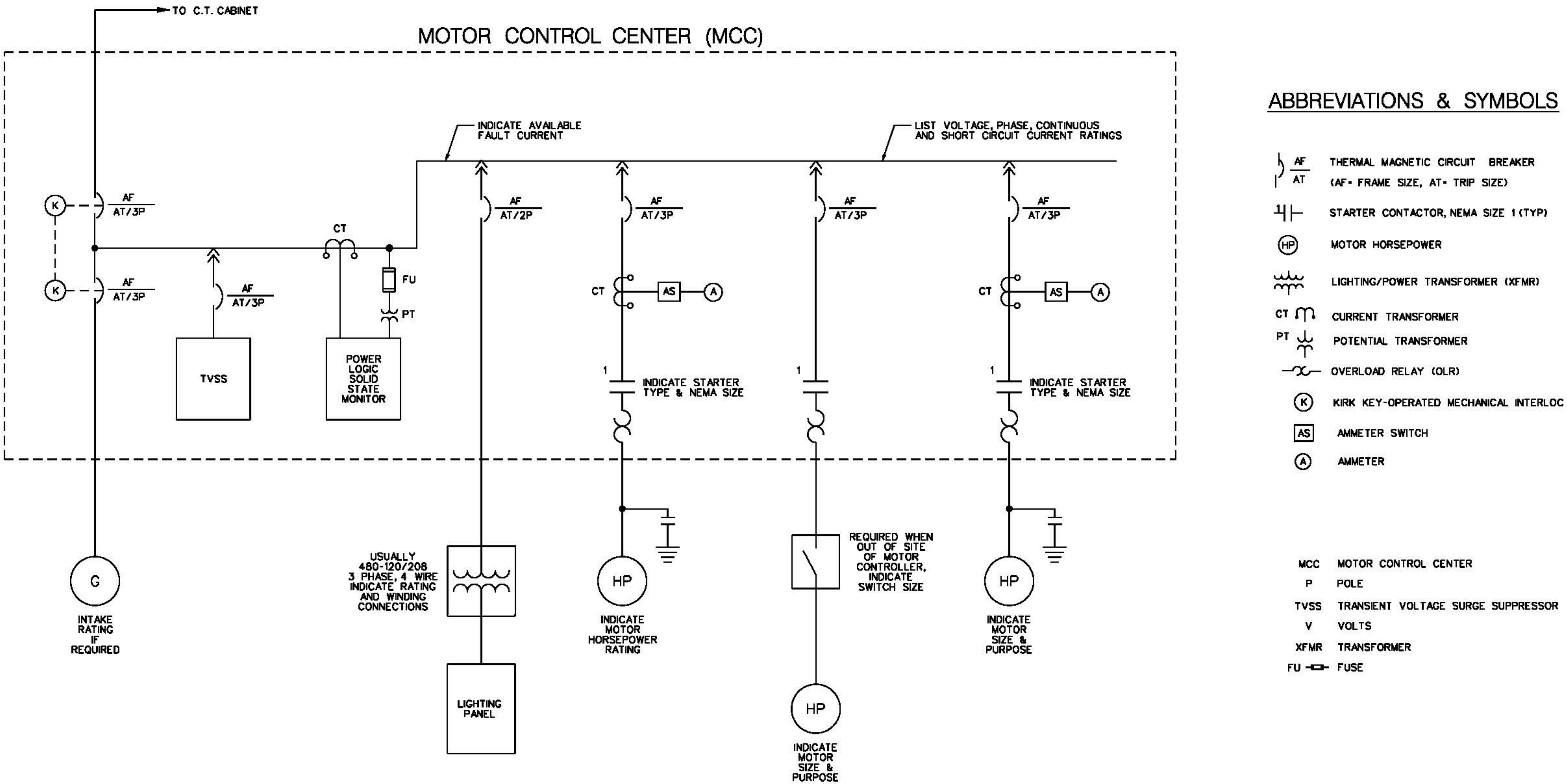


Figure B.9. Pumping Station Typical Low Voltage Station One-Line

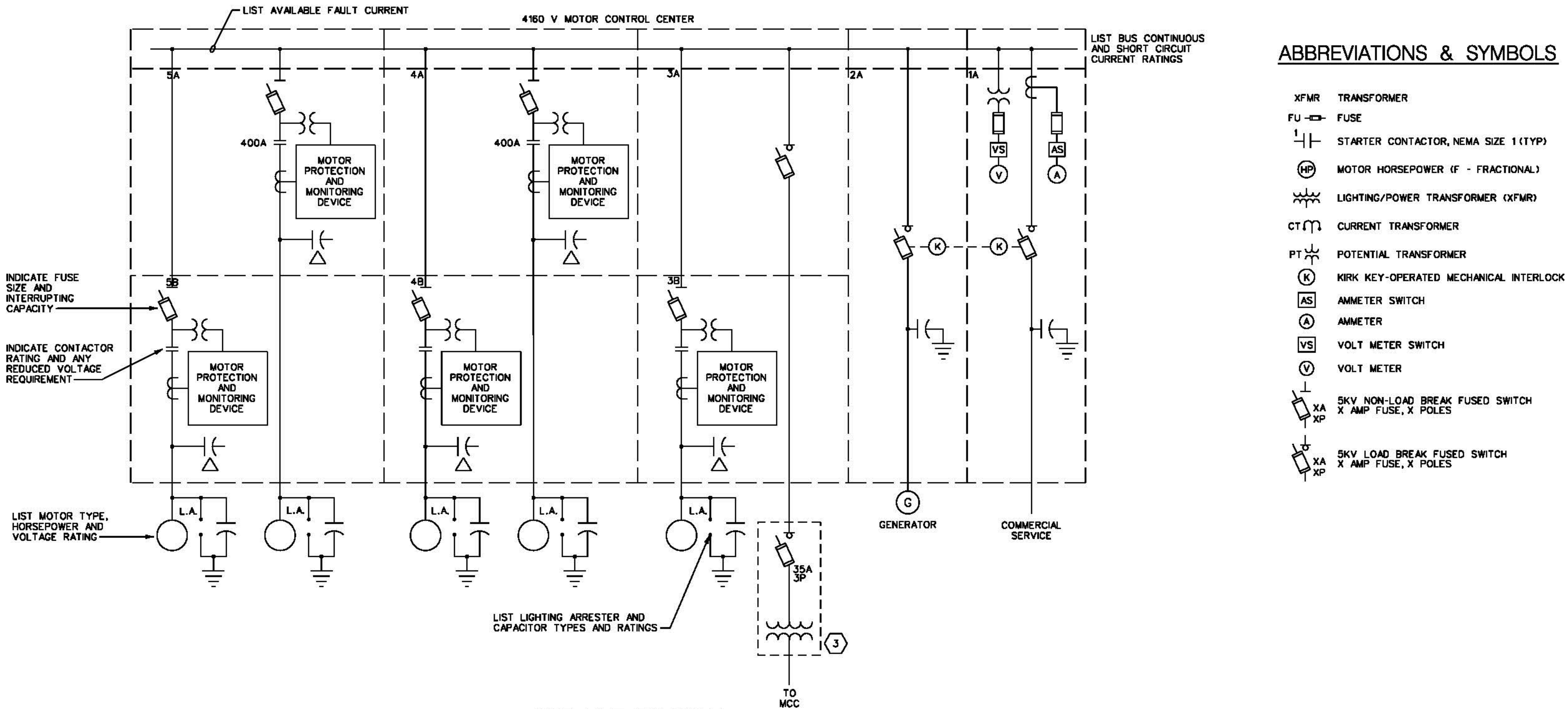


Figure B.10. Pumping Station Typical Medium Voltage Station One-Line

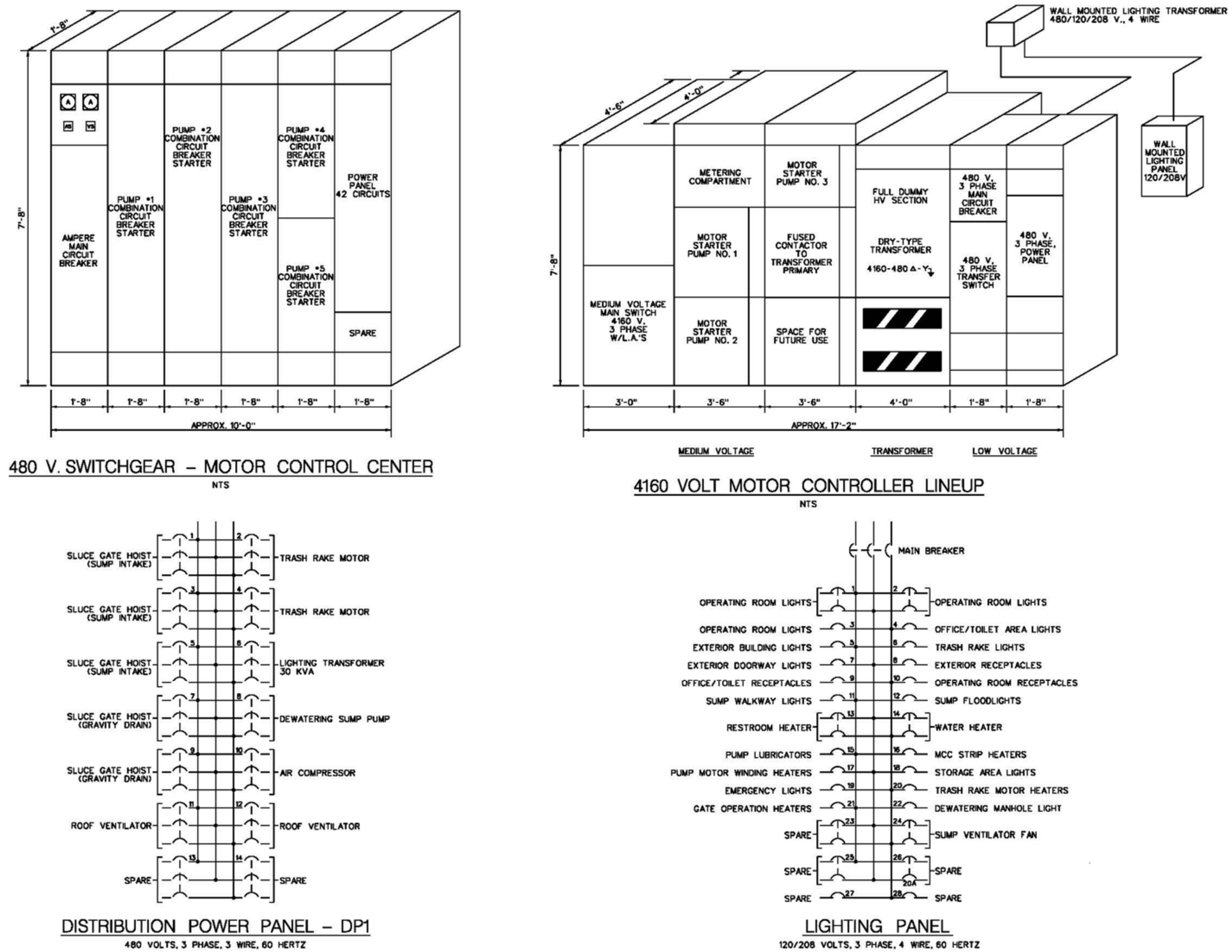
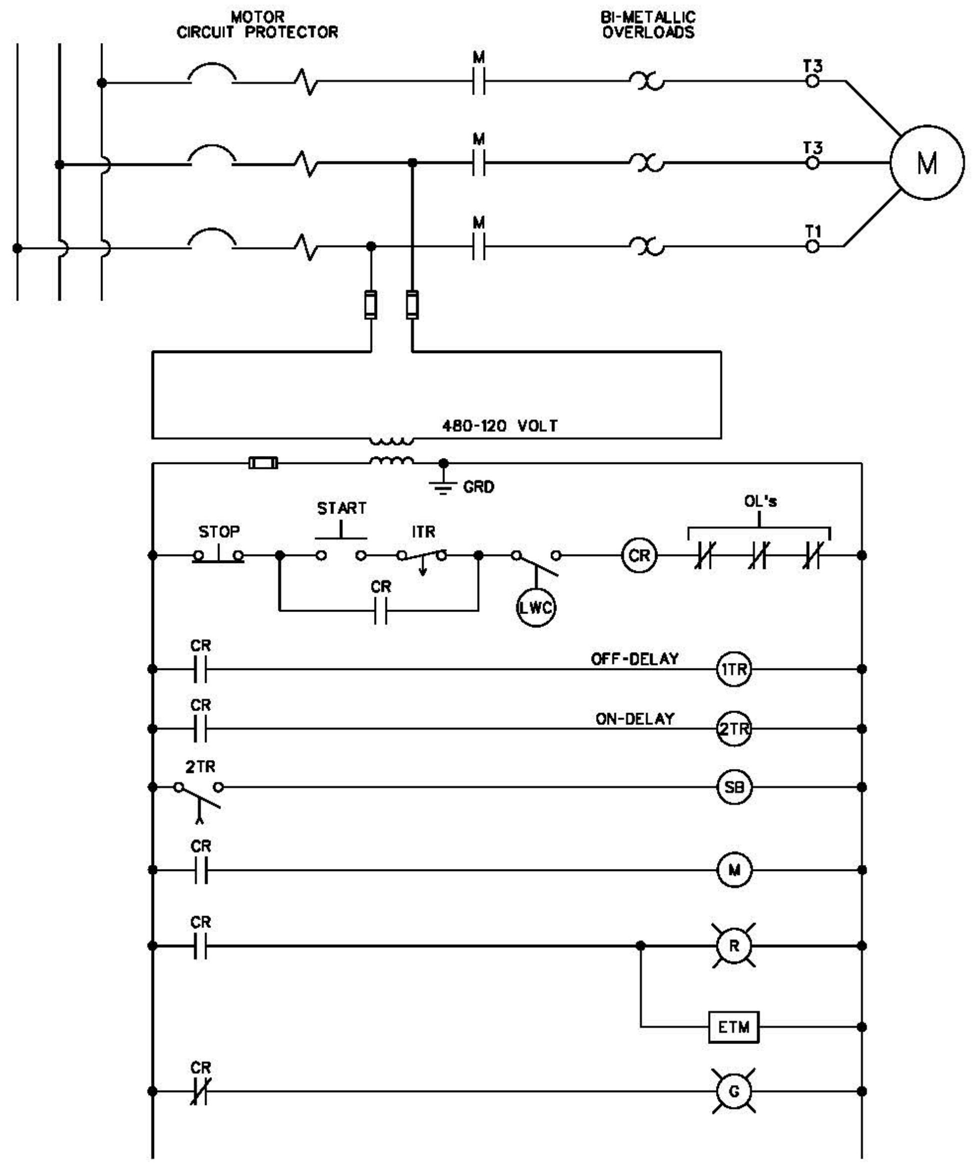
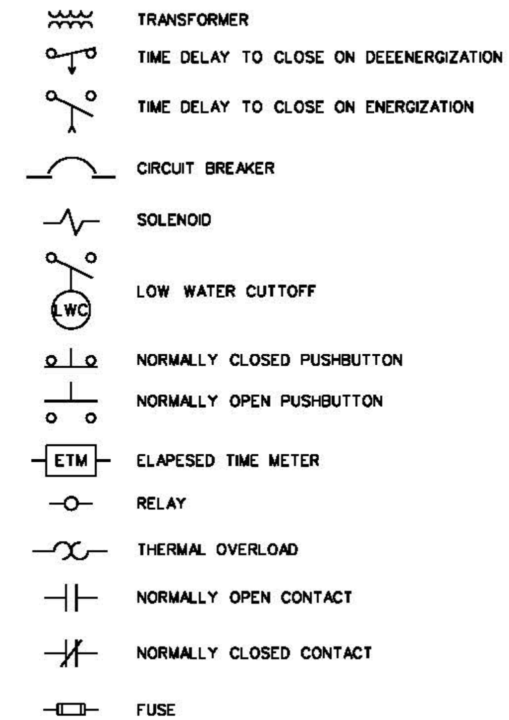


Figure B.11. Pumping Station Typical Controller Lineup and Power & Lighting Panel Layouts



FULL VOLTAGE NON–REVERSING
CIRCUIT BREAKER TYPE

SYMBOLS:



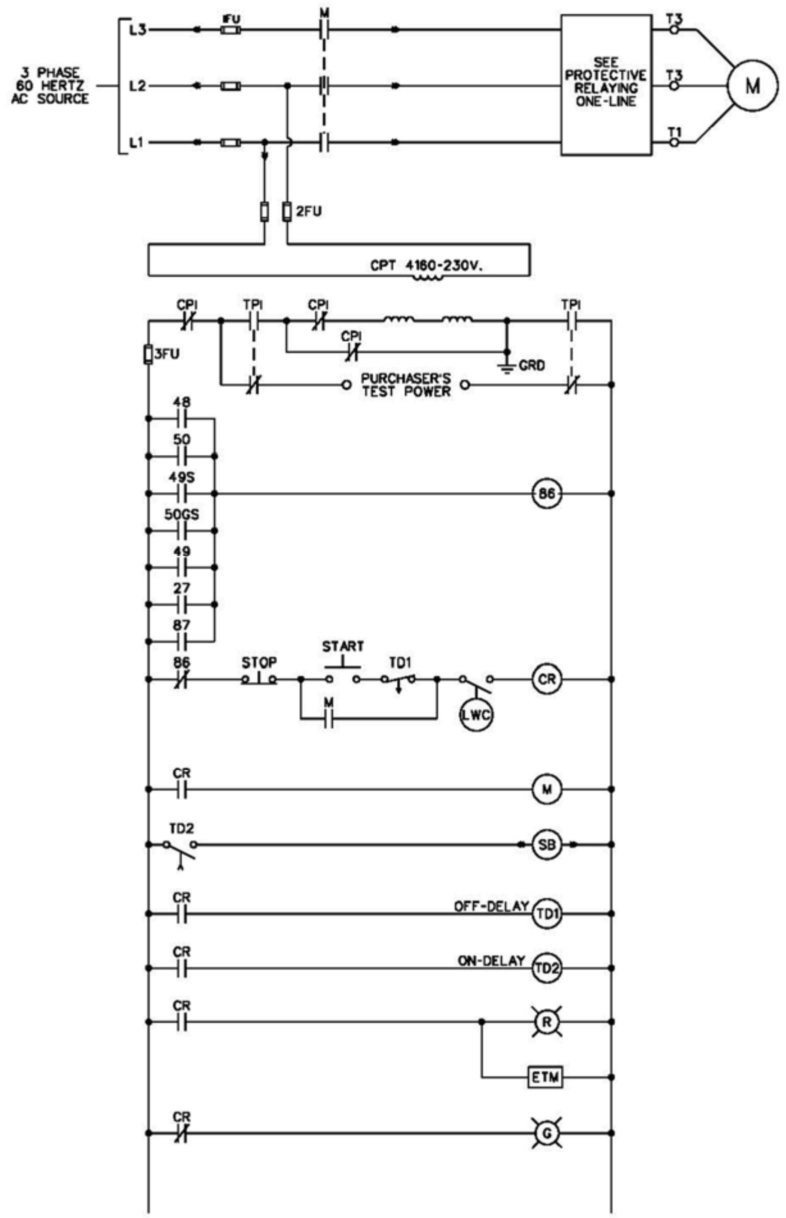
NOMENCLATURE:

AT	AUTOTRANSFORMER
15.25	STARTING CONTACTORS
GRD,GND	GROUND
M	RUN CONTACTOR
MOT	MOTOR
T1,T2,T3	OUTGOING TERMINALS ON STARTER OR MOTOR
SB	SIPHON BREAKER
EMT	ELAPSED TIME METER
CR	CONTROL RELAY
TR	TIMING RELAY
1TR	TIME DELAY RELAY (PREVENTS REENERGIZATION DURING BACKSPINNING)
2TR	TIME DELAY RELAY (DELAYS CLOSING OF SIPHON BRAKER UNTIL SIPHON IS MADE)

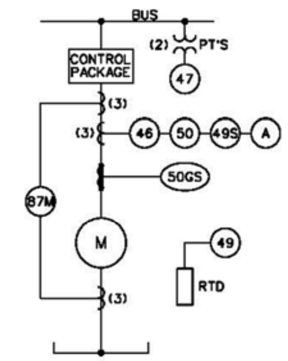
NOTE:

1. CONTROL SCHEMATIC SHOWN IS FOR OVER THE LEVEE TYPE DISCHARGE PIPING THAT REQUIRE SIPHON BREAKERS IN DISCHARGE LINES FOR DISCHARGE CHAMBER TYPE STATIONS, DELETE RELAY TD2 AND SIPHON BREAKER RELAY SB

Figure B.12. Pumping Station Typical Low Voltage Motor Control Schematic



TYPICAL INDUCTION – MOTOR CONTROL
FULL-VOLTAGE NON-REVERSING RELAY LOGIC



TYPICAL ONE-LINE PROTECTIVE RELAYING
FULL-VOLTAGE NON-REVERSING INDUCTION MOTOR

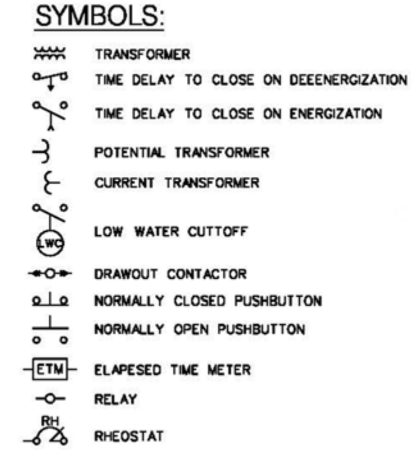
NOMENCLATURE:

CPI	CONTROL POWER INTERLOCK	TD1	TIME DELAY RELAY (PREVENTS REENERGIZATION DURING BACKSPINNING)
1,2,3, CT	CURRENT TRANSFORMER		
1,2,3, FU	FUSE	TD2	TIME DELAY RELAY (DELAYS CLOSING OF SIPHON BREAKER UNTIL SIPHON IS MADE)
GRD	GROUND		
M	LINE CONTACTOR	ETM	ELAPSED TIME METER
MOT	MOTOR	CR	CONTROL RELAY
CPT	CONTROL POWER TRANSFORMER	S	STARTING CONTACTOR
TPI	TEST POWER INTERLOCK	R	RUN CONTRACTOR
L1,L2,L3	INCOMING TERMINALS	N	NEUTRAL
T1,T2,T3	OUTGOING TERMINALS	TR	TIMING RELAY FOR REDUCED VOLTAGE
A	AMMETER	2TR	TRANSITION TIMER
SB	SIPHON BREAKER		

DEVICE NUMBERS:

26	APPARATUS THERMAL DEVICE
27	UNDERVOLTAGE
46	CURRENT BALLANCE
48	INCOMPLETE SEQUENCE TIMER REDUCED VOLTAGE STARTING
49	THERMAL
49S	THERMAL (STALLED)
50	INSTANTANEOUS SHORT CIRCUIT
50GS	INSTANTANEOUS GROUND SENSOR
55	POWER FACTOR PULLOUT
86	MOTOR TRIP AND LOCKOUT
87M	MOTOR DIFFERENTIAL

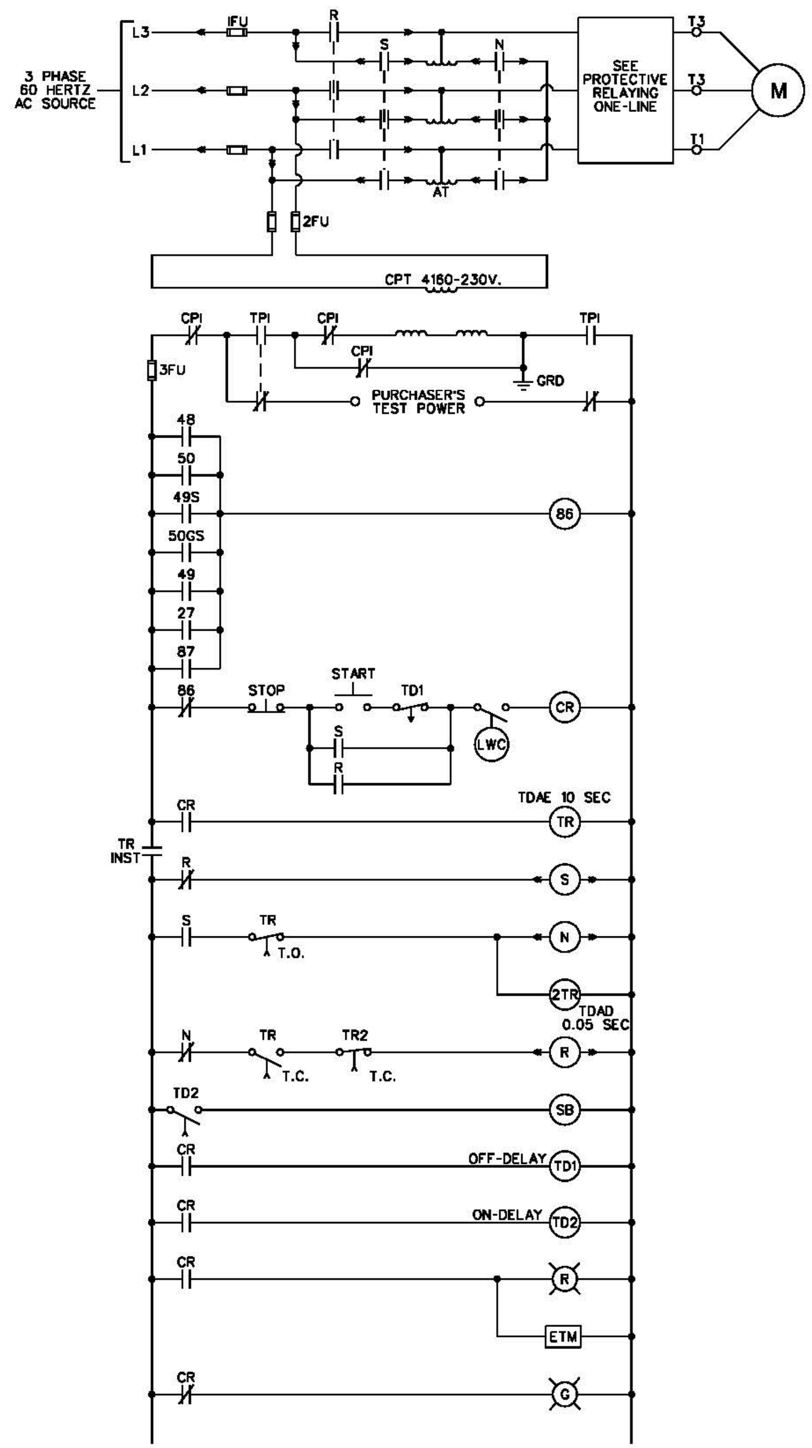
SYMBOLS:



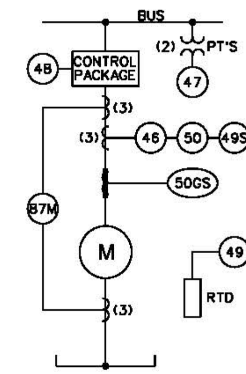
NOTE:

1. CONTROL SCHEMATIC SHOWN IS FOR OVER THE LEVEE TYPE DISCHARGE PIPING THAT REQUIRE SIPHON BREAKERS IN DISCHARGE LINES FOR DISCHARGE CHAMBER TYPE STATIONS, DELETE RELAY TD2 AND SIPHON BREAKER RELAY SB

Figure B.13. Pumping Station Typical Medium Voltage Full-Voltage Induction Non-Reversing Control Schematic Relay Logic



TYPICAL INDUCTION - MOTOR CONTROL
AUTOTRANSFORMER REDUCED-VOLTAGE NON-REVERSING RELAY LOGIC



TYPICAL ONE-LINE PROTECTIVE RELAYING
REDUCED-VOLTAGE NON-REVERSING INDUCTION MOTOR

NOMENCLATURE:

CPI	CONTROL POWER INTERLOCK	TD1	TIME DELAY RELAY (PREVENTS REENERGIZATION DURING BACKSPINNING)
1,2,3, CT	CURRENT TRANSFORMER		
1,2,3, FU	FUSE	TD2	TIME DELAY RELAY (DELAYS CLOSING OF SIPHON BREAKER UNTIL SIPHON IS MADE)
GRD	GROUND		
M	LINE CONTACTOR	ETM	ELAPSED TIME METER
MOT	MOTOR	CR	CONTROL RELAY
CPT	CONTROL POWER TRANSFORMER	S	STARTING CONTACTOR
TPI	TEST POWER INTERLOCK	R	RUN CONTRACTOR
L1,L2,L3	INCOMING TERMINALS	N	NEUTRAL
T1,T2,T3	OUTGOING TERMINALS	TR	TIMING RELAY FOR REDUCED VOLTAGE
A	AMMETER	2TR	TRANSITION TIMER
SB	SIPHON BREAKER		

DEVICE NUMBERS:

26	APPARATUS THERMAL DEVICE
27	UNDERVOLTAGE
46	CURRENT BALLANCE
48	INCOMPLETE SEQUENCE TIMER REDUCED VOLTAGE STARTING
49	THERMAL
49S	THERMAL (STALLED)
50	INSTANTANEOUS SHORT CIRCUIT
50GS	INSTANTANEOUS GROUND SENSOR
55	POWER FACTOR PULLOUT
86	MOTOR TRIP AND LOCKOUT
87W	MOTOR DIFFERENTIAL

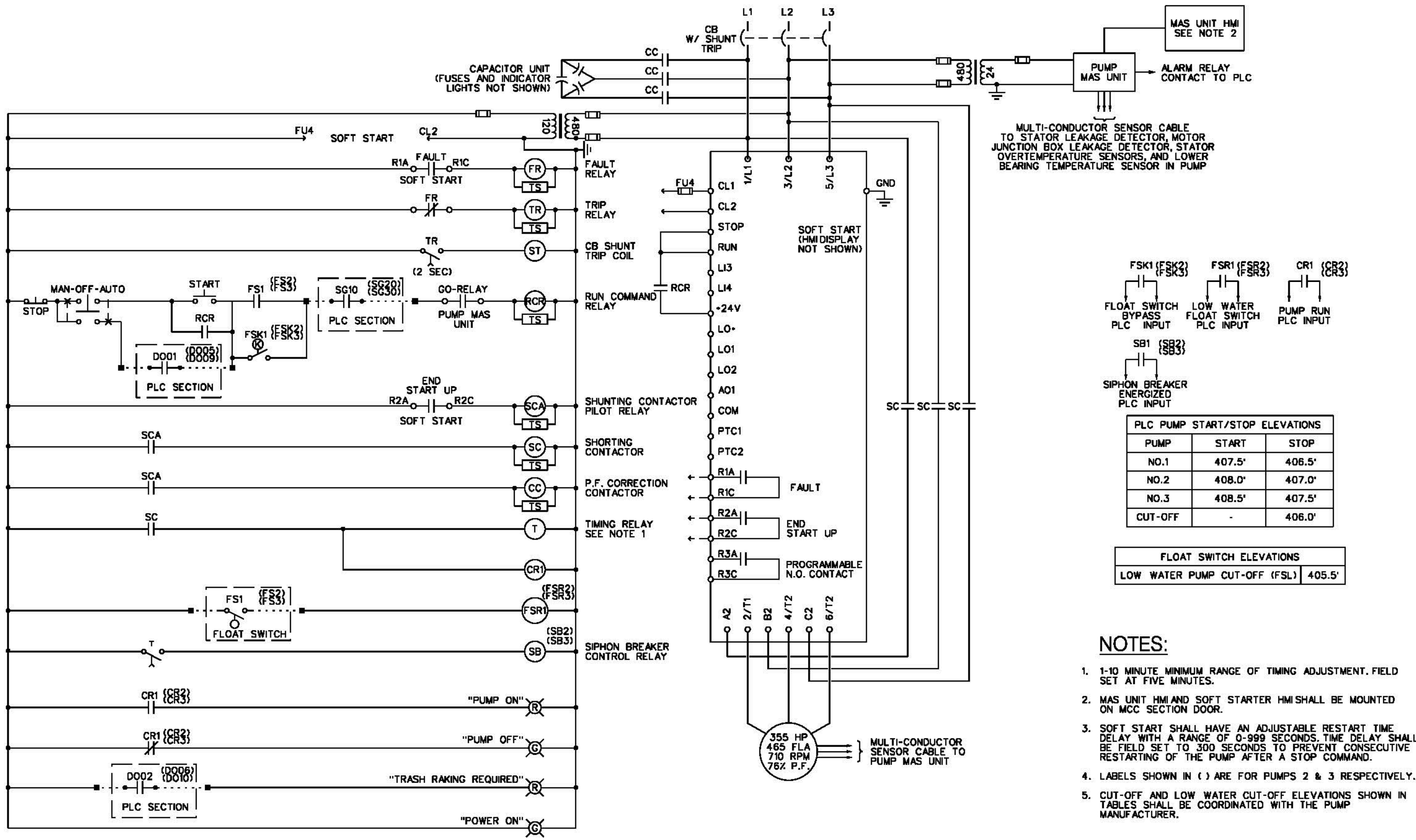
SYMBOLS:

TRANSFORMER
NCTC TIME DELAY TO CLOSE ON DEEENERGIZATION
NCTC TIME DELAY TO CLOSE ON ENERGIZATION
POTENTIAL TRANSFORMER
CURRENT TRANSFORMER
LWC LOW WATER CUTTOFF
DRAWOUT CONTACTOR
NORMALLY CLOSED MOMENTARY PUSHBUTTON
NORMALLY OPEN MOMENTARY PUSHBUTTON
ETM ELAPESED TIME METER
RELAY
RH RHEOSTAT

NOTE:

1. CONTROL SCHEMATIC SHOWN IS FOR OVER THE LEVEE TYPE DISCHARGE PIPING THAT REQUIRE SIPHON BREAKERS IN DISCHARGE LINES FOR DISCHARGE CHAMBER TYPE STATIONS, DELETE RELAY TD2 AND SIPHON BREAKER RELAY SB

Figure B.14. Pumping Station Typical Medium Voltage Reduced-Volt. Induction Non-Reversing Control Schematic Relay Logic



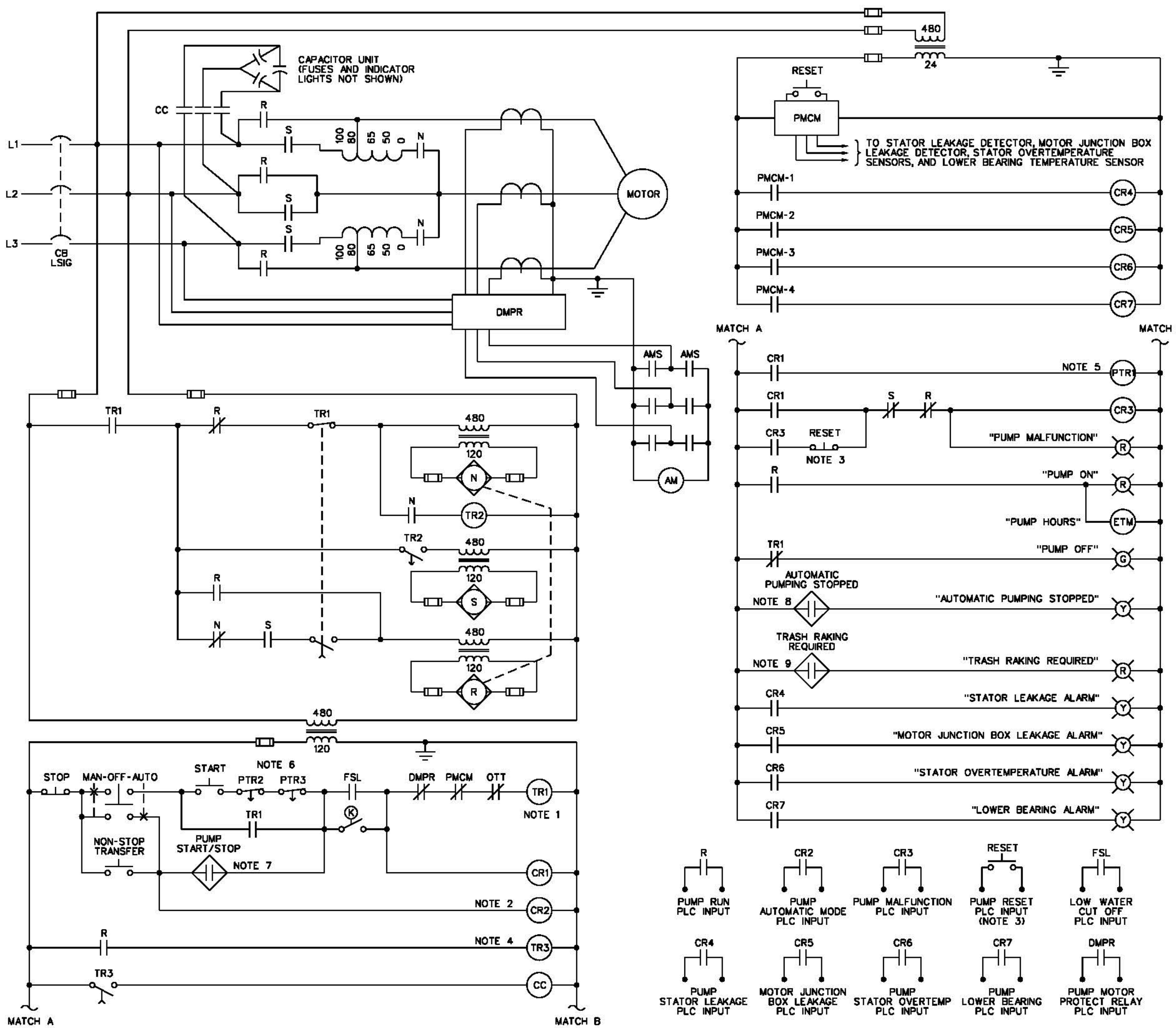
PLC PUMP START/STOP ELEVATIONS		
PUMP	START	STOP
NO.1	407.5'	406.5'
NO.2	408.0'	407.0'
NO.3	408.5'	407.5'
CUT-OFF	-	406.0'

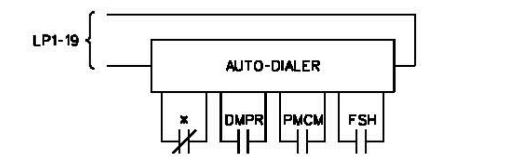
FLOAT SWITCH ELEVATIONS	
LOW WATER PUMP CUT-OFF (FSL)	405.5'

NOTES:

1. 1-10 MINUTE MINIMUM RANGE OF TIMING ADJUSTMENT. FIELD SET AT FIVE MINUTES.
2. MAS UNIT HMI AND SOFT STARTER HMI SHALL BE MOUNTED ON MCC SECTION DOOR.
3. SOFT START SHALL HAVE AN ADJUSTABLE RESTART TIME DELAY WITH A RANGE OF 0-999 SECONDS. TIME DELAY SHALL BE FIELD SET TO 300 SECONDS TO PREVENT CONSECUTIVE RESTARTING OF THE PUMP AFTER A STOP COMMAND.
4. LABELS SHOWN IN ( ) ARE FOR PUMPS 2 & 3 RESPECTIVELY.
5. CUT-OFF AND LOW WATER CUT-OFF ELEVATIONS SHOWN IN TABLES SHALL BE COORDINATED WITH THE PUMP MANUFACTURER.

Figure B.15. Pumping Station Pump Soft-Start Control Schematic





* MAIN BREAKER AUXILIARY CONTACT
NOTE: NOT ALL AUTO-DIALER INPUTS ARE SHOWN

PUMP START/STOP ELEVATIONS (PLC ONLY)				
PUMP PRIORITY	NORMAL		HIGH LEVEL	
	START	STOP	START	STOP
1ST	374.0	373.0	376.5	375.5
2ND	375.0	374.0	377.5	376.5
3RD	376.0	375.0	378.5	377.5

LOW WATER PUMP CUT-OFF (FSL)	372.5
SLUICE GATE CLOSING STAGE	373.0
INTERIOR HIGH WATER ALARM (PLC)	380.0
HIGH WATER WARNING (FSH)	381.0
HIGH RIVER LEVEL CONDITION	395.0

NOTES:

1. 1-10 SECOND MINIMUM RANGE OF TIMING ADJUSTMENT. FIELD SET AT TWO SECONDS.
2. USED TO LET PLC KNOW WHEN AUTOMATIC MODE IS SELECTED. USED TO PREVENT RESTARTS WHEN MANUAL STOP IS USED. IF AUTOMATIC MODE IS SELECTED, THE RUN (R) CONTACTOR DROPS OUT, BUT THE WATER LEVEL CALLS FOR THE PUMP TO RUN, THE PLC WILL PREVENT RESTART OF THE PUMP.
3. MULTI-POLE RESET BUTTON RE-ENABLES AUTOMATIC STARTING AFTER STOP BUTTON IS PRESSED AND BREAKS MALFUNCTION SEAL-IN.
4. 2-20 SECOND MINIMUM RANGE OF TIMING ADJUSTMENT. FIELD SET AT 15 SECONDS FOR PFCC SWITCHING DELAY.
5. 2-20 SECOND MINIMUM RANGE OF TIMING ADJUSTMENT. FIELD SET AT 10 SECONDS FOR PUMP START INTERLOCKING.
6. NORMALLY CLOSED, TIMED CLOSED CONTACTS FROM OTHER TWO PUMP STARTERS. TIMED CONTACTS FOR PUMP STARTERS 2 AND 3 SHOWN. NUMBER OF STARTS ALLOWED PER TIME PERIOD PROVIDED BY PMCM.
7. PLC CONTACT TO START OR STOP PUMP AUTOMATICALLY AND DERIVED FROM LADDER LOGIC BASED ON WATER LEVELS SHOWN ON THIS SHEET AND TIME OF DAY.
8. PLC CONTACT TO SIGNAL AUTOMATIC PUMPING HAS STOPPED AND DERIVED FROM LADDER LOGIC. USED TO INDICATE THAT A RESET IS REQUIRED TO RESTART AUTOMATIC PUMPING.
9. PLC CONTACT TO SIGNAL THAT TRASH RACK IS CLOGGED AND DERIVED FROM LADDER LOGIC BASED ON WATER LEVEL DIFFERENCE BETWEEN PUMP BAY AND TRASH RACK.
10. REFERENCE PLC WIRING DIAGRAMS FOR STARTER DEVICE INPUTS TO PLC. REF DWG. E-14 FOR PMCM AND DMPR DEVICE INPUTS TO PLC.

Figure B.16. Pumping Station Typical Low Voltage Auto Transformer Motor Control Schematic

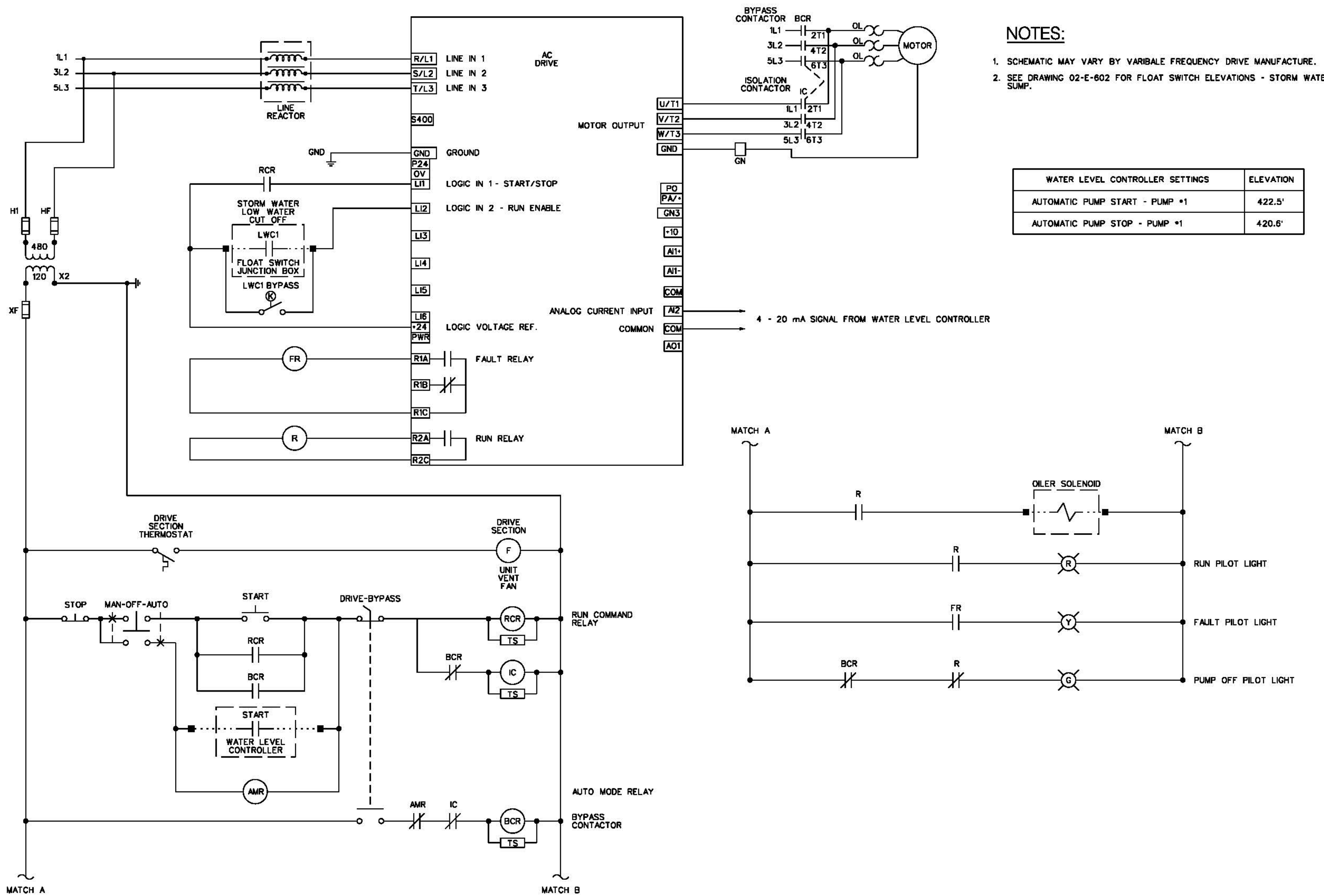
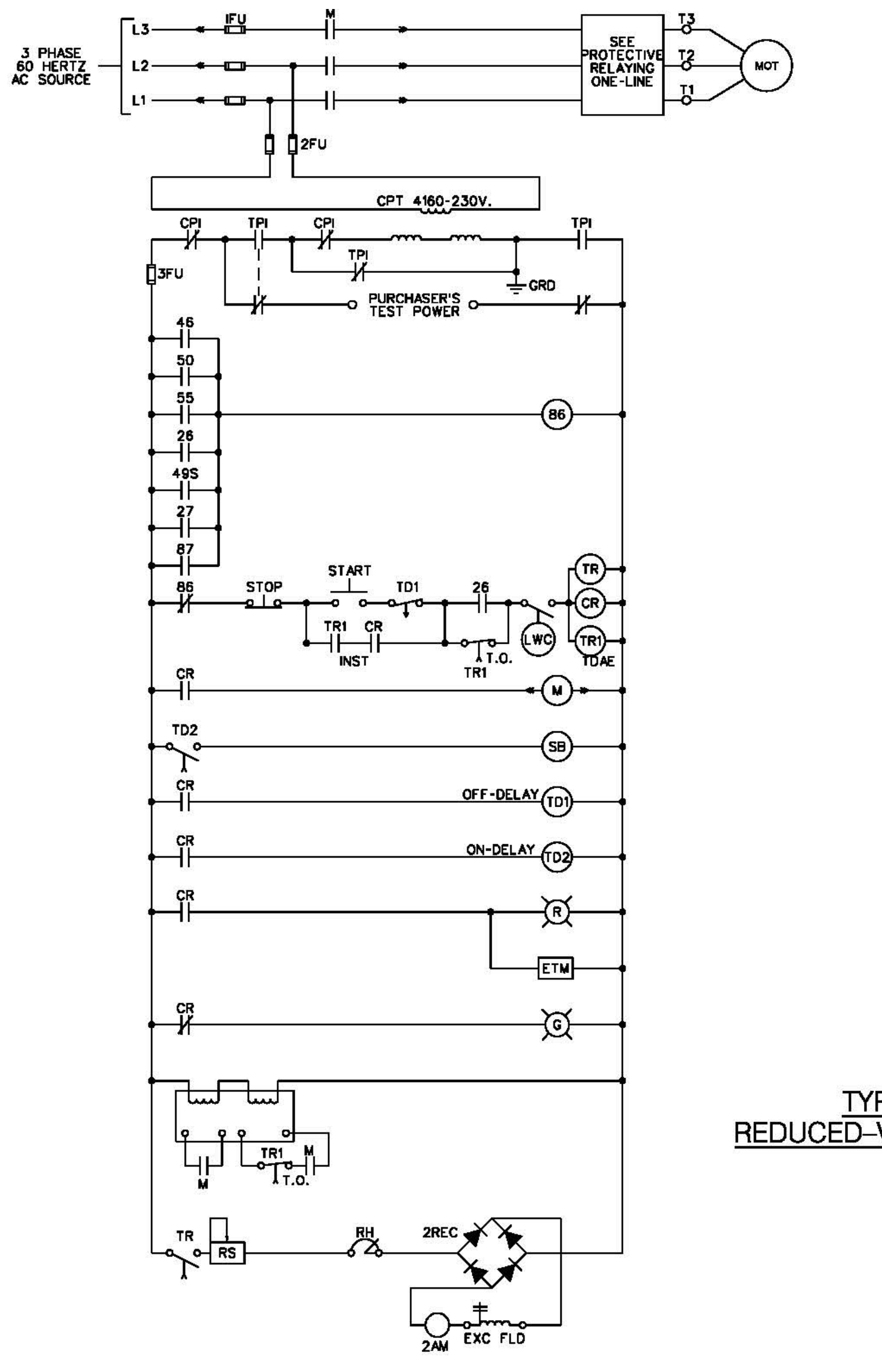


Figure B.17. Pumping Station Starter Schematic



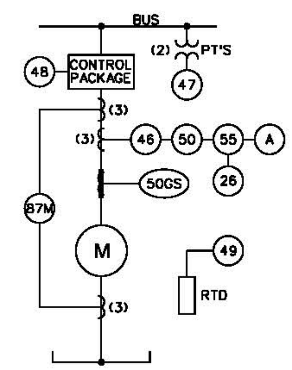
TYPICAL INDUCTION – MOTOR CONTROL
AUTOTRANSFORMER REDUCED–VOLTAGE NON–REVERSING RELAY LOGIC

DEVICE NUMBERS:

26	APPARATUS THERMAL DEVICE
27	UNDERVOLTAGE
46	CURRENT BALLANCE
48	INCOMPLETE SEQUENCE TIMER REDUCED VOLTAGE STARTING
49	THERMAL
49S	THERMAL (STALLED)
50	INSTANTANEOUS SHORT CIRCUIT
50GS	INSTANTANEOUS GROUND SENSOR
55	POWER FACTOR PULLOUT
86	MOTOR TRIP AND LOCKOUT
87W	MOTOR DIFFERENTIAL

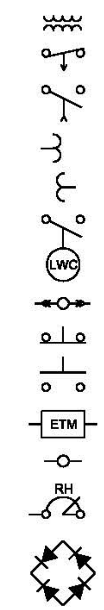
NOMENCLATURE:

CPI	CONTROL POWER INTERLOCK
1,2,3, CT	CURRENT TRANSFORMER
1,2,3, FU	FUSE
GRD	GROUND
M	LINE CONTACTOR
MOT	MOTOR
CPT	CONTROL POWER TRANSFORMER
TPI	TEST POWER INTERLOCK
L1,L2,L3	INCOMING TERMINALS
T1,T2,T3	OUTGOING TERMINALS
A	AMMETER
SB	SIPHON BREAKER
TD1	TIME DELAY RELAY (PREVENTS REENERGIZATION DURING BACKSPINNING)
TD2	TIME DELAY RELAY (DELAYS CLOSING OF SIPHON BREAKER UNTIL SIPHON IS MADE)
ETM	ELAPSED TIME METER
CR	CONTROL RELAY
2AM	Dc AMMETER
EXC FLD	EXCITER FIELD
RH	EXCITER FIELD RHEOSTAT
TR	FIELD - APPLYING TIMER
TR1	PULLOUT PROTECTION APPLYING TIMER



TYPICAL ONE–LINE PROTECTIVE RELAYING
REDUCED–VOLTAGE NON–REVERSING INDUCTION MOTOR

SYMBOLS:



TRANSFORMER
TIME DELAY TO CLOSE ON DEEENERGIZATION
TIME DELAY TO CLOSE ON ENERGIZATION
POTENTIAL TRANSFORMER
CURRENT TRANSFORMER
LOW WATER CUTTOFF
DRAWOUT CONTACTOR
NORMALLY CLOSED PUSHBUTTON
NORMALLY OPEN PUSHBUTTON
ELAPESED TIME METER
RELAY
RHEOSTAT
RECTIFIER

NOTE:

1. CONTROL SCHEMATIC SHOWN IS FOR OVER THE LEVEE TYPE DISCHARGE PIPING THAT REQUIRE SIPHON BREAKERS IN DISCHARGE LINES. FOR DISCHARGE CHAMBER TYPE STATIONS, DELETE RELAY TD2 AND SIPHON BREAKER RELAY SB

Figure B.18. Pumping Station Typ Med. Volt. Full-Volt. Brushless Synchronous Non-Reversing Control Schematic Relay Logic

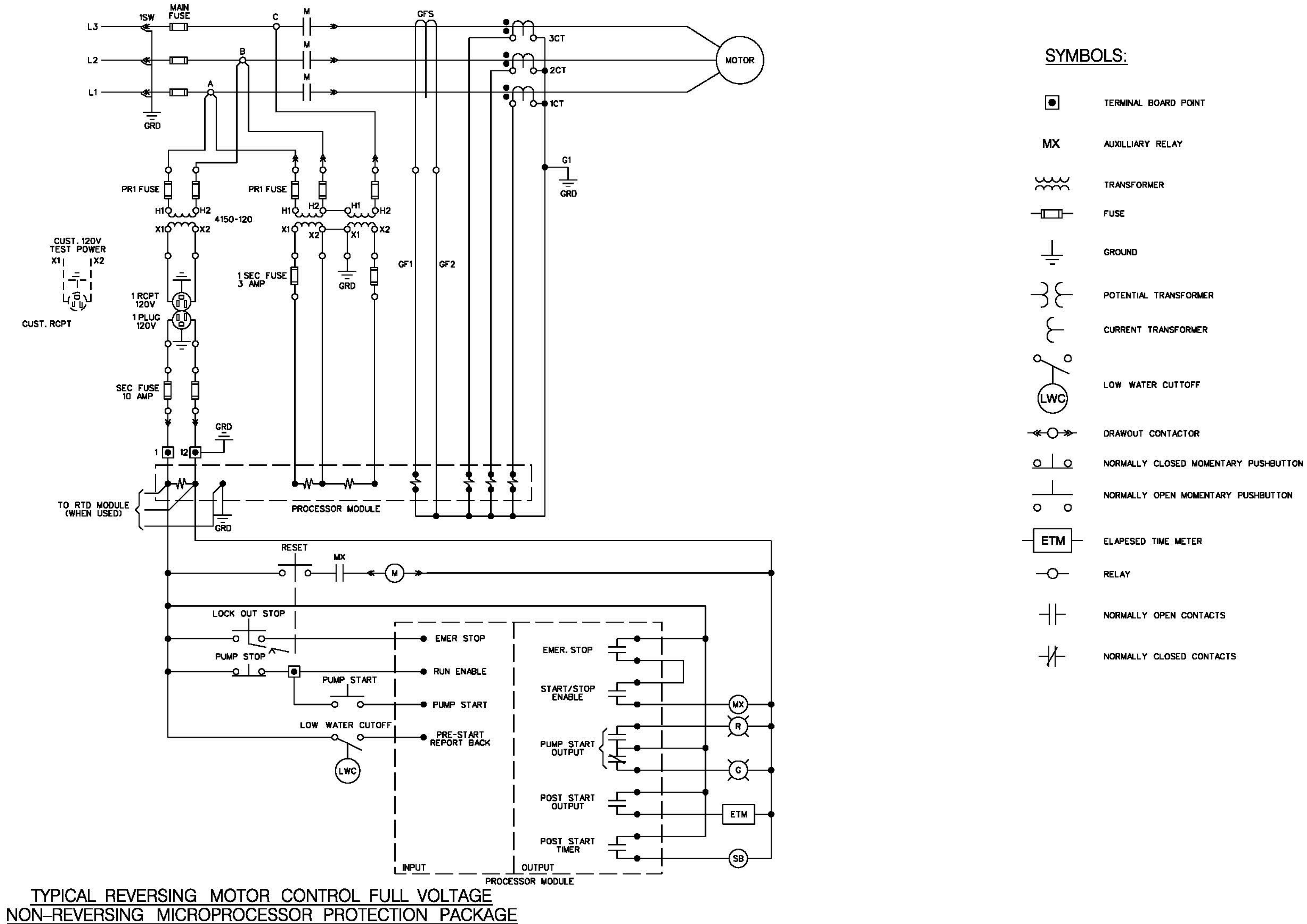


Figure B.19. Pumping Station Typ Med-Volt, Full-Volt, Induction Non-Rev, Control Schematic Microprocessor Based Protective Logic

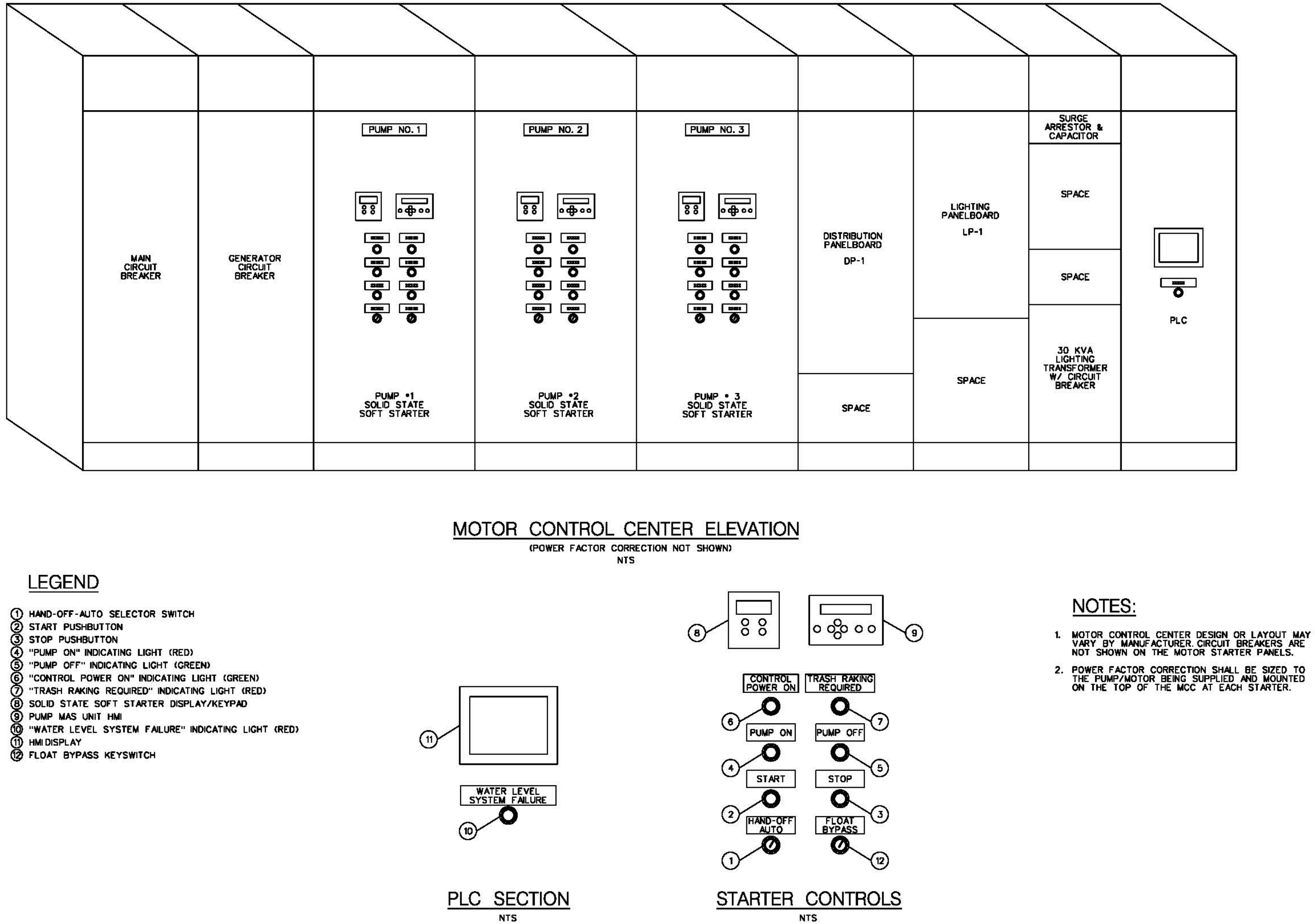
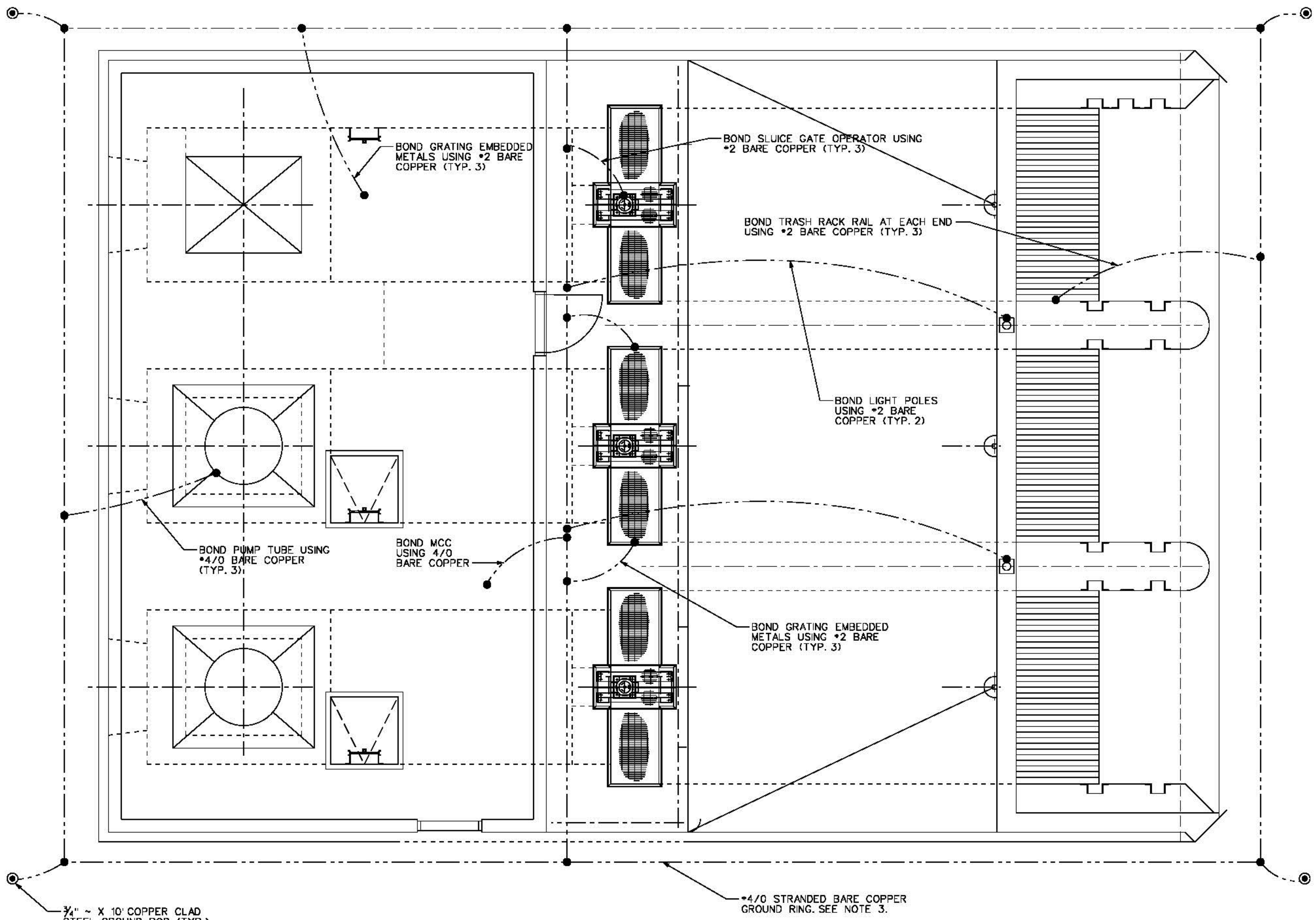


Figure B.20. Pumping Station Typical Motor Control Console



NOTES:

1. ALL GROUND RODS SHALL BE INSTALLED IN SOIL A MINIMUM OF 10 FT. OUTSIDE THE PUMP STATION PERIMETER.
2. CONNECT GROUNDS TO ALL BUILDING AND STRUCTURAL STEEL, FENCING, AND EMBEDDED METALS EQUIPMENT.
3. GROUND RING SURROUNDING STRUCTURES SHALL BE INSTALLED A MINIMUM OF 18" OUTSIDE THE STRUCTURE WALLS AND A MINIMUM OF 30" BELOW FINISHED GRADE.
4. BONDS SHALL BE MADE ACROSS EACH TRASH RAKE RAIL SECTION USING •2 BARE COPPER. BOND CONNECTIONS SHALL BE MOLDED EXOTHERMIC FUSION WELD.
5. CONTRACTOR SHALL INSTALL AND CONNECT ALL GROUNDING SYSTEMS IN ACCORDANCE WITH THE LATEST VERSION OF NFPA 70, NATIONAL ELECTRIC CODE.
6. THE CONTRACTOR SHALL HAVE A CERTIFIED LIGHTNING PROTECTION INSTALLER EXAMINE THE SITE AND RECOMMEND A LAYOUT FOR THE LIGHTNING PROTECTION SYSTEM FOR THE PUMP STATION BUILDING, LIGHT POLES, ETC.

Figure B.21. Pumping Station Typical Grounding Plan

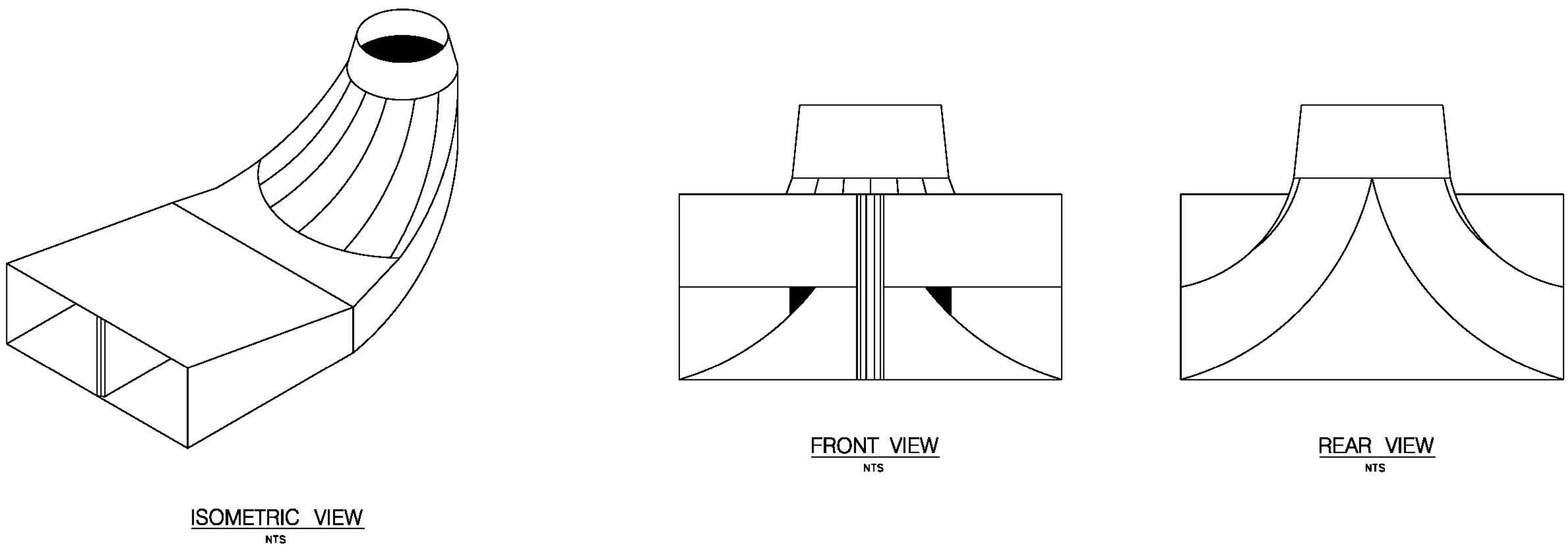
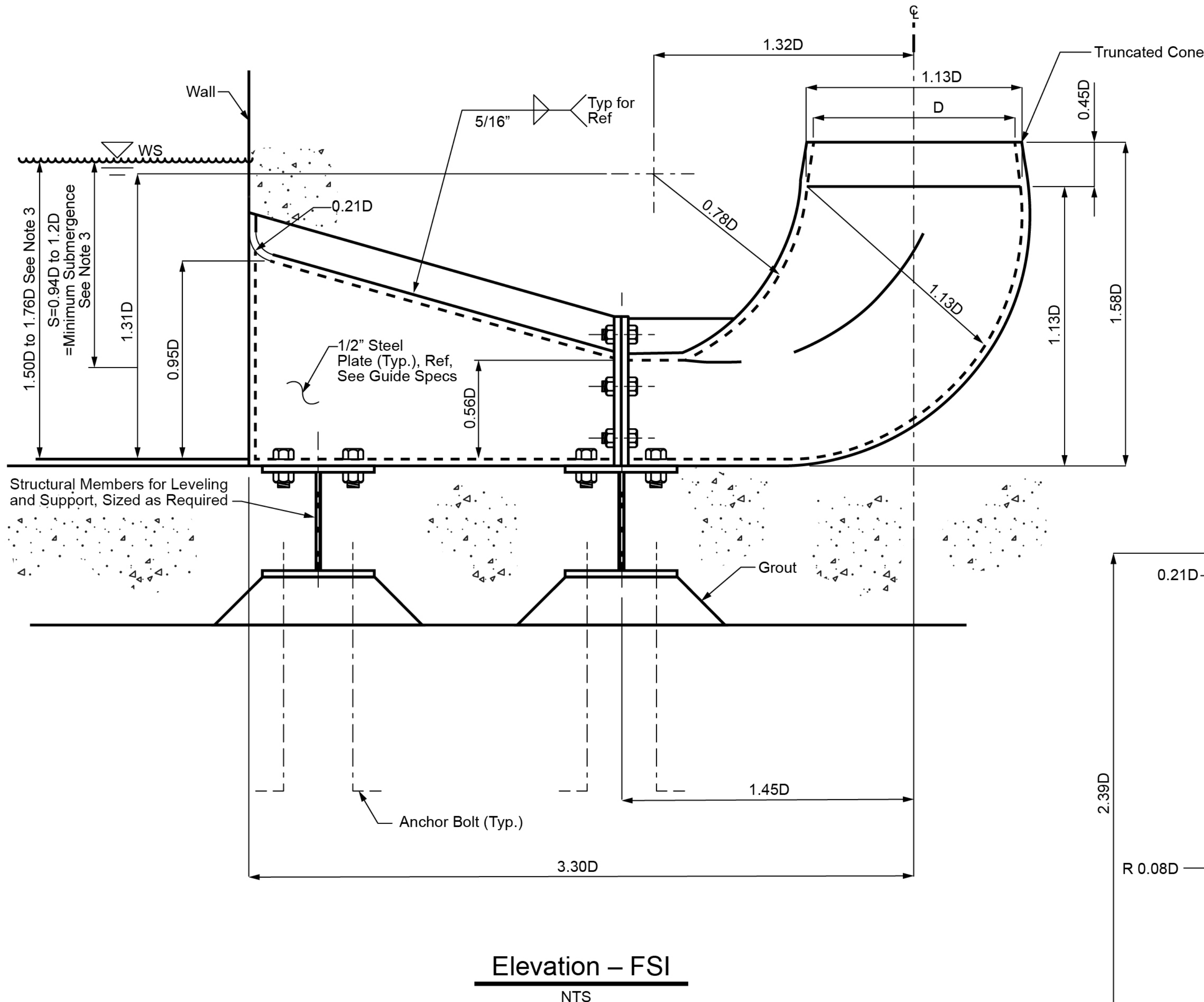


Figure B.22. Typical FSI

Notes:

1. FSI shown as a 2-piece fabrication with bolted connection.
2. Typical support system shown as reference only.
3. Previous submergence was 0.94D as defined from the minimum water surface level to the lowest roof elevation of the FSI, and previous dimension from the water surface to the floor of the FSI was 1.43D. However, experience has shown that performance will improve using the higher numbers shown, especially at higher velocities.



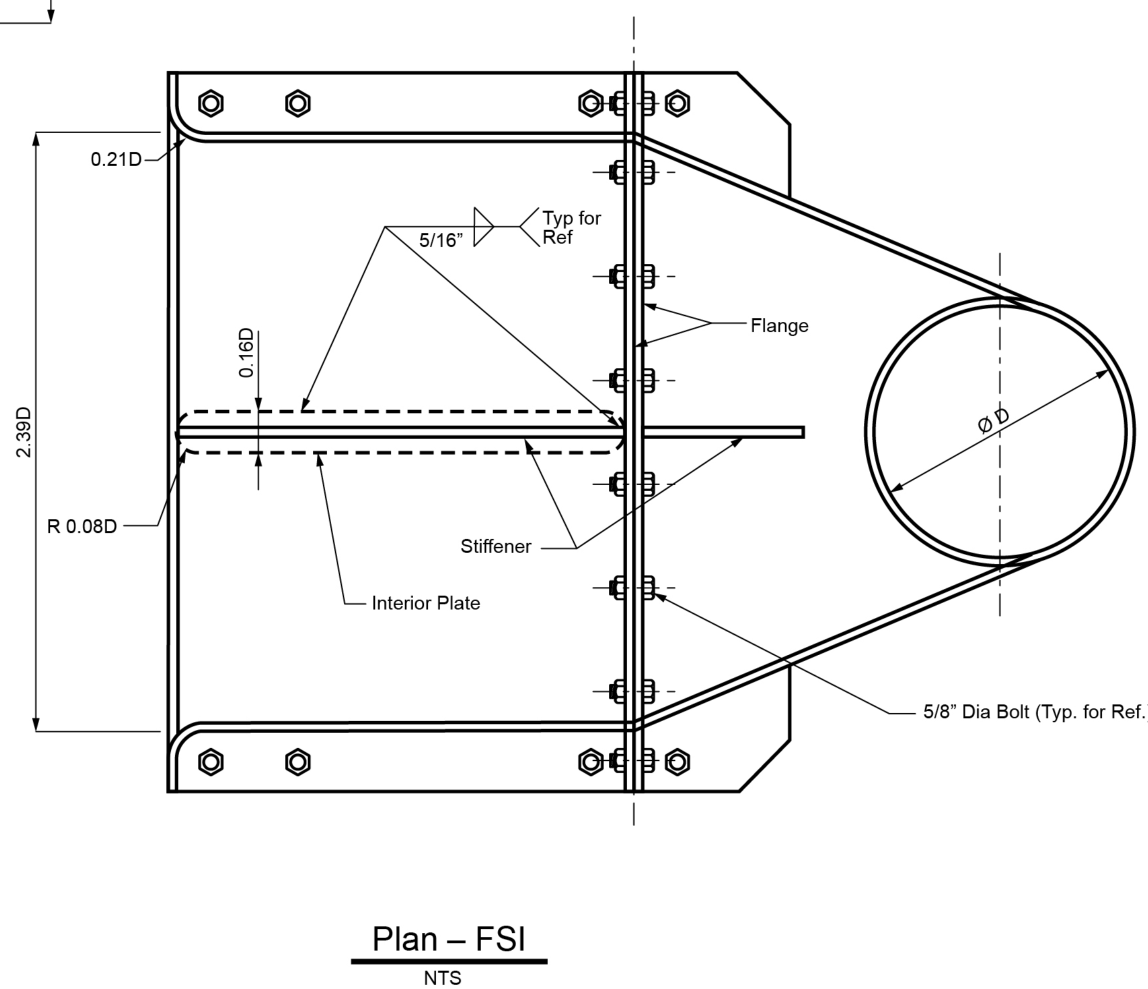
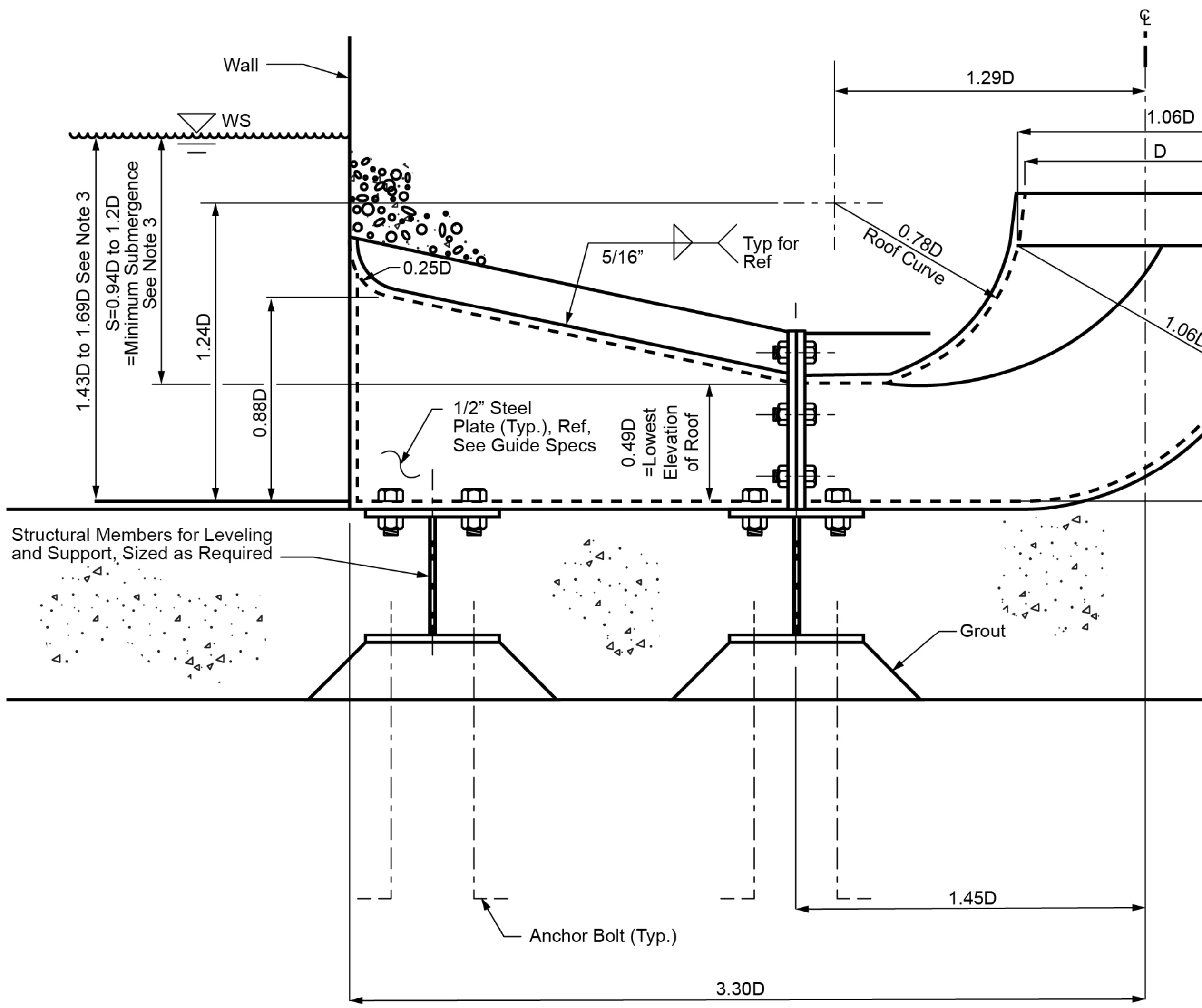
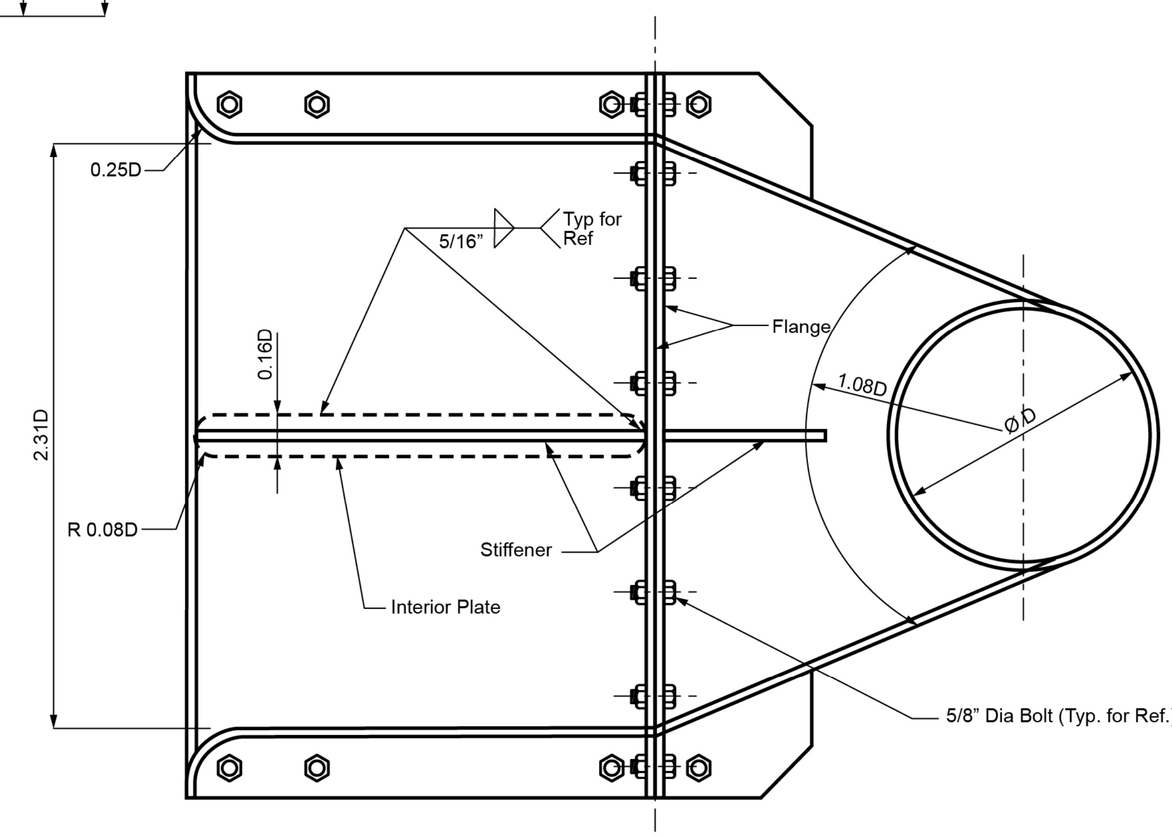


Figure B.23. FSI Type 1 Design



Elevation – FSI

NTS



Plan – FSI

NTS

Notes:

1. FSI shown as a 2-piece fabrication with bolted connection.
2. Typical support system shown as reference only.
3. Previous submergence was 0.94D as defined from the minimum water surface level to the lowest roof elevation of the FSI, and previous dimension from the water surface to the floor of the FSI was 1.43D. However, experience has shown that performance will improve using the higher numbers shown, especially at higher velocities.

Figure B.24. FSI Type 10 Design

Appendix C
Head Loss Calculation, Pump Selection, and Head Curve Development

C.1. General.

a. Purpose. This appendix provides methods for determining the head losses occurring in a pump station and for determining the size of a pump to meet certain pumping requirements. It also provides dimensions for the sump and station layout once the pump is selected. Certain information must be available before the pump selection can be started. This information includes the pumping requirements as determined from hydrology data, number of pumping units, and discharge arrangement as described in Chapters 2, 3, 4, 5, 6, 7, and 8.

b. Procedure. This appendix is divided into three major sections, head loss methods and formulas, selection of vertical wet pit pumps, and selection of vertical submersible propeller pumps. Sample calculations are used to aid in understanding the selection procedures. Figure C.1 indicates the operating range of the various type pumps used in pumping stations. This chart indicates which pumps should be investigated during the alternative study phase.

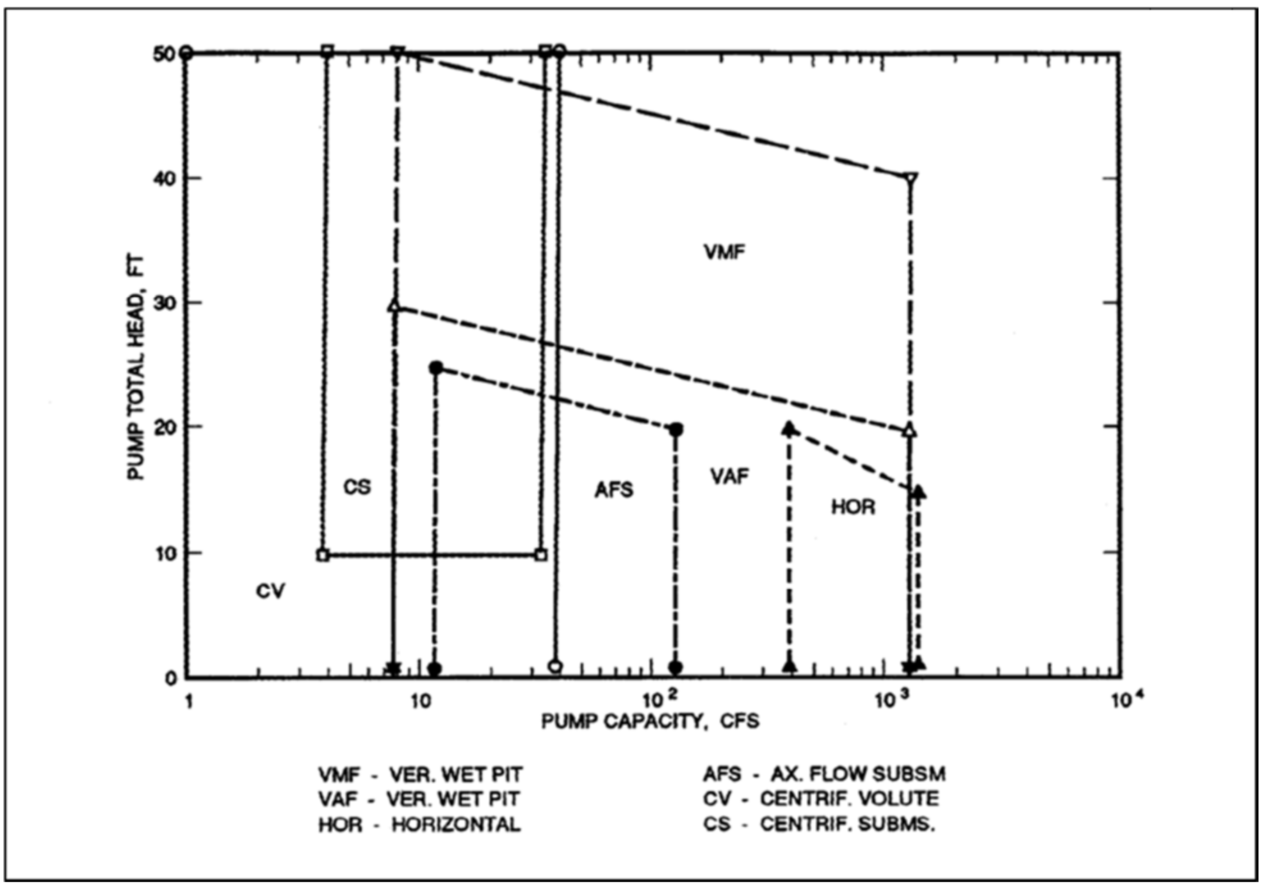


Figure C.1. Operating Range of Typical Pumps

c. Model Tests. For stations with complex discharge configurations and which are over 1,000 cfs total capacity as discussed in Chapter 6, consideration should be given to performing a model test to confirm the losses. This is particularly important when the low head determines the size of the pump driver and the losses are greater than 15 percent of the total head. All losses should be determined for the maximum flow rate expected to occur for that pumping condition.

C.2. Head Loss Methods and Formulas.

a. Internal Pipe Losses.

(1) Friction Losses. The Darcy-Weisbach formula can be used to determine friction losses in circular pipes. This formula is preferable to other formulas since it takes into consideration all the variable conditions. For water temperatures above 60°F and using the friction factors found in typical USACE discharge pipe systems, the following formula (in the form of Hazen and Williams) applies:

$$h_f = 0.0366V^{1.83}/D_{pipe}^{1.17}$$

Where
h_f = frictional resistance, ft of fluid per 100-ft length
V = velocity, fps

(2) Bend Losses. Bends are usually constructed either by fabrication of mitered cut straight pieces welded together or of cast or forged construction. Friction factor "K" can usually be obtained from various charts and tables. The I.D. of the pipe in used to locate the correct friction factor "K." The loss for the bend is found by multiplying the "K" value by the velocity head occurring in that section of pipe.

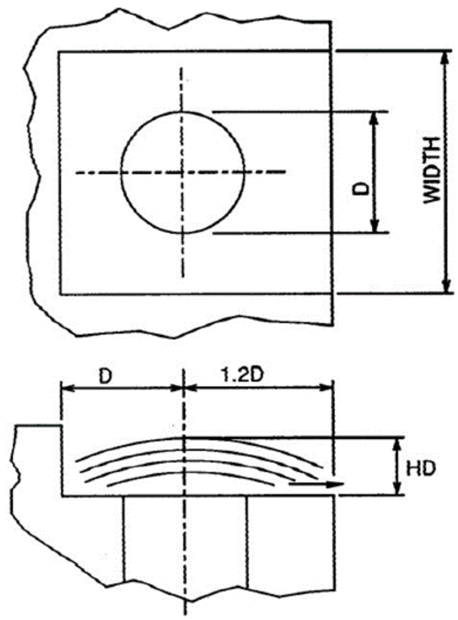
(3) Entrance, exit, and other losses. Other losses occur when a section of piping changes in diameter. These changes in size can be from something less than one pipe diameter to an infinitely greater diameter, such as a discharge into a pool or lake where the velocity downstream of the pipe is zero.

(4) Various charts and tables are available for determining the appropriate friction factor "K" for the various fittings, increasers, and reducers. Figure C.2 shows the various water surfaces for open discharges from vertical tubes such as used with submersible pump installations. When using this chart, the velocity head would not be added into the system losses since this loss is expended in obtaining the height of water above the vertical pipe exit. It is also seen from the chart that the elevation of the water is also dependent on the discharge bay dimensions.

$HD_{ft} = 0.0001(m)(Q) + b$

Where m = Value from table
Q = Pump capacity in GPM
b = Value from table
HD = Water height above floor in feet

WIDTHS = 1.5D, 2.0D, 2.5D & 3.0D
D = TUBE DIAMETER



TUBE DIA. in. nom.	DISCHARGE WIDTH - VALUES OF m AND b								TUBE DIA. mm.
	1.5 D		2.0 D		2.5 D		3.0 D		
	m	b	m	b	m	b	m	b	
28	1.65	0.33	1.24	0.25	1.36	0.13	1.24	0.07	700
32	1.36	0.33	1.24	0.23	1.03	0.13	1.03	0.07	800
40	0.83	0.39	0.89	0.30	0.91	0.16	0.78	0.07	1000
48	0.68	0.62	0.68	0.43	0.52	0.26	0.52	0.07	1200
56	0.52	0.72	0.52	0.82	0.52	0.30	0.39	0.16	1400
64	0.41	0.82	0.41	0.66	0.41	0.33	0.41	0.16	1600

Figure C.2. Open Tube Losses

b. External Losses.

(1) General. The capacity used to determine the external head losses is usually calculated on the basis of total station capacity. An exception to this would be the loss through a single gate opening on an individual pump sump.

(2) Discharge Chamber Losses. The head loss in a discharge chamber usually is caused by a constriction in area at its exit. This restriction is usually the stop log slots used for dewatering the chamber for repair of a flap gate during high discharge stages.

(3) A critical depth condition (Figure C.3) can occur at this location if the water level downstream of this point is at a lower elevation. The discharge chamber critical depth is determined using the formula shown in the example. This formula applies when a free discharge exists beyond the stop log slot at the exit of the discharge chamber.

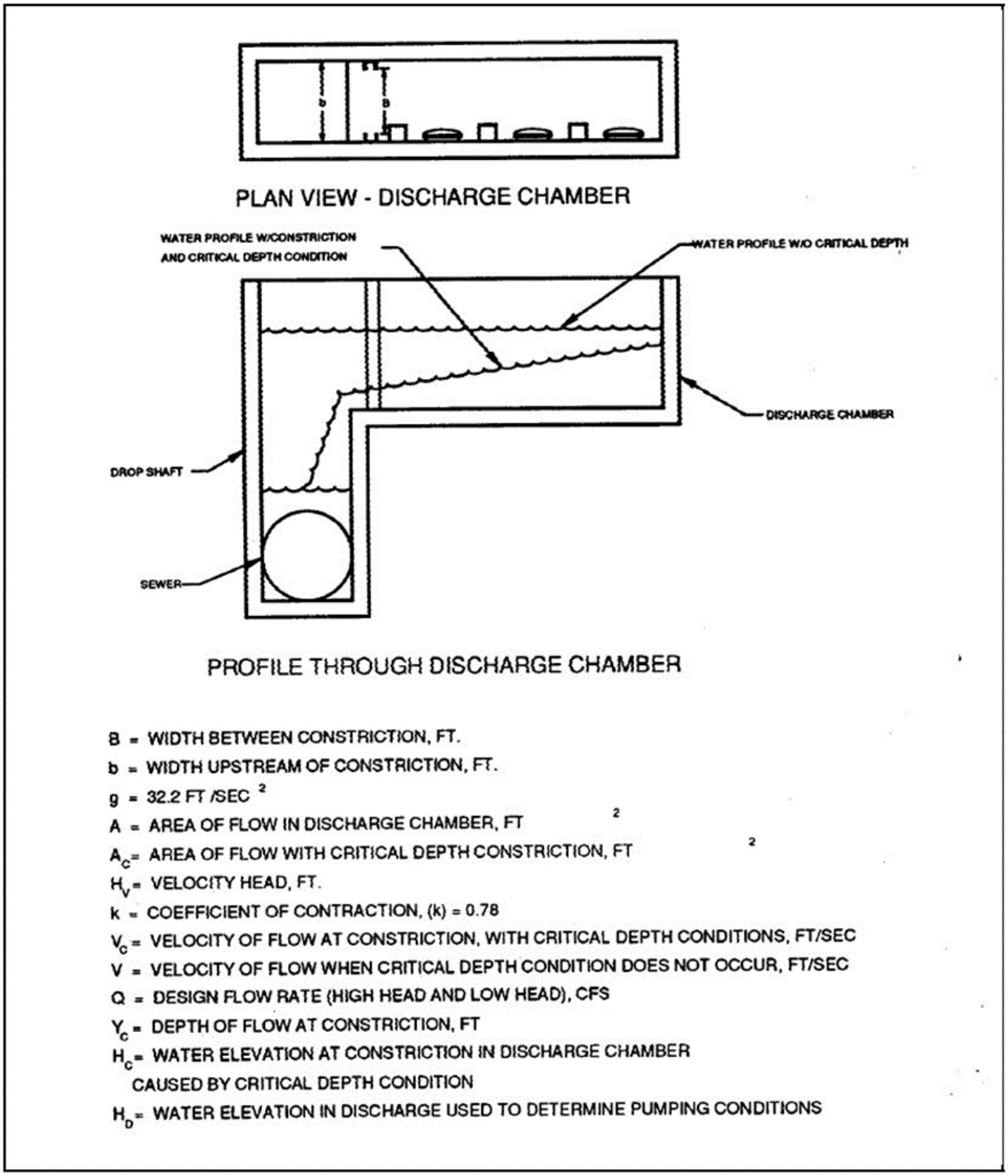


Figure C.3. Discharge Chamber Critical Depth

(4) In order to obtain flow in the discharge chamber, a head of water is required at the opposite end of the chamber. This head of water is added to the water elevation caused by either the critical depth condition at the stop log slots, or the downstream water elevation, whichever is

greater. The head of water is equal to the velocity head occurring with the depth of water at the stop log slots.

(5) An example of calculation of the critical depth and the resulting discharge chamber depth is shown below. It can be seen that the real head on a pump may be greater because of the artificial head created by the losses in the discharge chamber.

(6) It is required to determine which is greatest, the water level in the discharge chamber created by the restriction or the center-line elevation of the flap gates. The center-line elevation of the flap gate is used determine the low static head whenever it is higher than the water level, in the discharge chamber, occurring for that pumped flow rate. The slope of the water surface in the chamber will be greatest at the opposite end from the constriction, and usually not at the exact location of all the discharge flap gates.

(7) For purposes of head determination, it is assumed that the greatest water level occurring in the discharge chamber will be effective for all the pump discharges.

C.3. Discharge Chamber Critical Depth Example.

a. The determination of total head on the pump requires determination of water elevation in the discharge chamber. Three different head conditions are considered:

(1) During pump operation back-up water does not exceed the center of the flap gate.

(2) Water elevation in drop shaft next to discharge chamber is below elevation of the critical depth water level. Elevation of water back-up is above the center of the flap gate.

(3) Water elevation in drop shaft is higher than water elevation due to critical depth condition.

b. The following is a typical computation to determine total head for discharge chamber type pump station in English units. The computations are based on the layout shown in Figure C.3.

Given Conditions:

$B = 4.5$ ft.

$b = 5.0$ ft.

$Q_L = 177$ cfs

$Q_H = 93.4$ cfs

$k = 0.78$

(1) Discharge chamber floor elevation at constriction = 413.0

(2) Drop shaft water elevation due to sewer losses beyond drop shaft with 177 cfs flowing = 417.0

(3) Drop shaft water elevation with 93.4 cfs flowing = 431.0

(4) Elevation of flap gate centerline = 416.75

Computations for water levels as a result of critical depth:

Step 1. Determine ratio of width at constriction to channel width upstream.

Ratio = B/b = 4.0 ft./5.0 ft. = 0.9

Step 2. Determine Y_C (Depth of flow at constriction) – see Figure C.3

$$Y_C = (\frac{Q^2}{k^2 \times b^2 \times g})^{1/3}$$

$$Y_C = (\frac{177^2}{(0.78)^2(5.0)^2(32.2)^2})^{1/3} = 3.9 \text{ ft}$$

Step 3. Determine velocity of flow at the constriction.

$$V_C = (Y_C \times g)^{1/2} = 11.2 \text{ ft/sec}$$

Step 4. Determine critical area of flow at the constriction.

$$A_C = \frac{Q_L}{V_C} = \frac{177 \text{ cfs}}{11.2 \text{ ft/sec}} = 15.8 \text{ ft/sec}$$

Step 5. Determine the velocity head based on the velocity occurring at the constriction.

$$H_V = \frac{Y_C}{2} = \frac{3.9 \text{ ft}}{2} = 1.95 \text{ ft}$$

Step 6. Determine the maximum elevation of water in the discharge chamber at constriction with critical depth condition.

$$H_C = \text{Elev. of discharge chamber floor } + 1.5Y_C$$

$$H_C = 413.0 + 1.5(3.9 \text{ ft}) = 418.8$$

Step 7. Water elevation in drop shaft with low river elevation and flow rate of 177 cfs is 417.0.

Step 8. Determine water elevation in discharge chamber with constriction of flow.

H_C = Floor elevation at constriction + depth of flow at constriction + velocity head based on flow at constriction

$$= 413.0 + Y_C + \frac{Y_C}{2}$$

$$= 413.0 + 3.9 + 1.95$$

$$= 418.8$$

Step 9. This elevation (418.8) is greater than the water level in the drop shaft (417.0), therefore it is used to determine head loss if it is higher than the centerline of the flap gate.

Step 10. When the elevation of water in the drop shaft is greater than the water elevation as a result of a critical depth condition at the constriction, the water level in the discharge chamber is only dependent on the drop shaft water elevation and the resultant velocity head.

The discharge chamber water elevation would equal the drop shaft water elevation + the velocity head.

Water elevation in drop shaft = 431.0

Velocity at constriction, V_C

V_C = Flow rate (cfs)/(Drop shaft elev. – Floor elev.)(B ft)

= 93.4/(431.0 – 413.0)(4.5)

= 1.15 ft/sec

Velocity Head = $(V_C)^2/2g$

= $(1.15)^2/(2)(32.2)$

= 0.02 ft => Negligible

Therefore, Elevation 431.0 would be used for head computations.

C.4. Trash Rack Losses. Head loss through the trash racks should be less than 152 mm (6 inches) for a properly designed rack that is raked regularly. A head loss value of 152 mm (6 inches) should be used when determining the trash rack portion of the total external losses. It is possible to exceed this value when the rack becomes partially clogged with debris; therefore, the structure design of the rack should be designed per EM 1110-2-3104. In unusual cases where the design of the rack is such that for a clean rack the losses would be greater than 152 mm (6 inches), the calculated loss plus a 152 mm (6 inch) margin should be used for the head loss.

C.5. Gate Opening Losses. The head loss through gate openings is assumed to be equal to the velocity head that occurs for the gate opening. If multiple gate openings occur in the water path to the pumps, then a loss would occur at each gate opening and be additive.

C.6. Pump Selection Process.

a. Vertical wet pit pumps. The selection process uses the model and affinity laws to obtain the performance of a prototype pump from the various supplied model pump performance data. Model performance data can be obtained from pump manufacturers, existing pumping stations, or from other Districts. The following general steps are used in the selection process:

(1) Determine pump operating conditions using the furnished hydrology and station/discharge arrangement.

(2) Determine prototype pump performance from model performance.

b. Submersible pumps. The selection process makes use of typical catalog curves of head-capacity and NPSHR. The various curves allow direct selection of pumps after the system design conditions are known.

c. Information sources. The following is a list of information needed to perform the selection process and where it may be found:

(1) Number of Pumps: Chapters 2 and 4.

(2) Pump Discharge Configuration: Chapter 8.

(3) Hydrology Data: Project Hydrology Report.

d. Appendix results. The application of the methods illustrated in this appendix will allow the user to determine the following pump and station parameters.

(1) Maximum design head.

(2) Design heads at rated pumping station capacity.

(3) Capacity requirements other than those required by the hydrology requirements, such as capacity required for siphon priming.

(4) Type of pump.

(5) Estimated pump physical size.

(6) Power required at the design points.

(7) Pump speed.

(8) Station NPSHA and pump NPSHR.

(9) Sump dimensions.

C.7. Vertical Wet Pit Pump Selection Sample Problem.

a. Design data and requirements.

(1) Pump conditions.

(a) The starting point for all pump selection is the hydrology requirements for the station site. The following is assumed given conditions for each pump:

(b) Required from hydrology report (English Units):

- QH = Flow rate at maximum differential head (design flood)
  = 29,000 gpm @ river elevation EL. 339.0 and sump EL. 317.0
- QL = Flow rate at minimum differential head (low head)
  = 34,000 gpm @ river EL. 314.0 and sump EL. 314.0

(2) Station arrangement. Station general arrangement and discharge system are determined as presented in this manual. Table C.1 provides an overall summary.

(3) For this example, a discharge over the protection with siphon assist was assumed (Figure C.4). A static head diagram (Figure C.5) should now be constructed. The top of the discharge pipe is obtained by sizing the pipe diameter based on an approximate maximum velocity in the pipe of 12 fps (using the greatest flow requirement) and adding the diameter to the invert elevation. The invert elevation is usually set equal to the top of the protection on either side of the station so that backflow will not occur with any river level to the top of the protection.

(4) Size discharge pipe.

$$V_{pipe} = \frac{Q_{max}}{A_{pipe}}$$

$$Q_{max} = 34{,}000\ gpm = 75\ cfs$$

$$A_{pipe} = \frac{\pi D_{pipe}^2}{4}$$

$$V_{pipe} = 12\ fps$$

$$D_{pipe} = \sqrt{\frac{4Q_{max}}{\pi V_{pipe}}} = \sqrt{\frac{4(75)}{\pi(12)}} = 2.82\ feet\ (\sim 34\ inches)$$

Use standard sized pipe, the next larger standard size pipe = 36 inches nominal (35.25 inches I.D.)

For this first calculation, use the following wall thickness (English units):

1/4 inch, 12 to 20 inch diameter of pipe

3/8 inch, 24 to 42 inch diameter of pipe

1/2 inch, 48 inch and over *

* (larger pipe sizes may require thickness greater than 1/2 inch for support considerations)

A diagram of the typical over the levee discharge pipe system is shown in Figure C.4.

Table C.1
Example Pump Station Design Data Summary – English units

Pumping Condition	Low Head Condition	Design Flood Condition	Priming Condition
Sump EL*	314.0	317.0	314.0
Impeller EL**	311.0	311.0	311.0
h_{se} – ft	+3.0	+6.0	+3.0
h_{vpa} (80°F) – ft.	1.2	1.2	1.2
h_p – ft.	33.9	33.9	33.9
NPSHA – ft.	35.7	38.7	35.7

* For this condition, use the lowest water that will occur for majority of the pumping; however, all operating water levels should be examined to determine of limiting suction operation will occur. Stop pump level should generally be the lowest sum level
** The impeller eye (entrance) is set to provide the submergence listed below, depending on the station operating hours per year

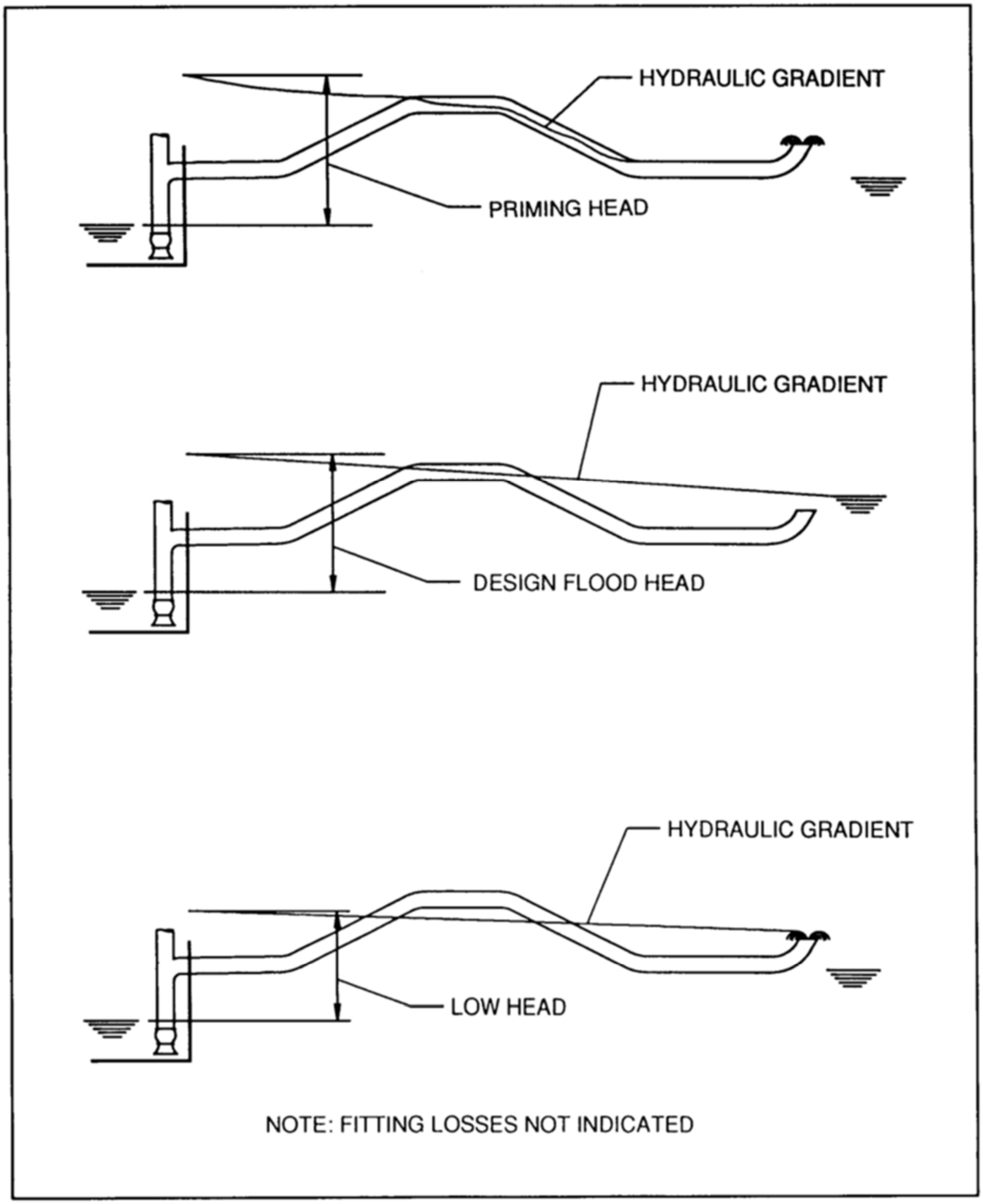


Figure C.4. Discharge Pipe System

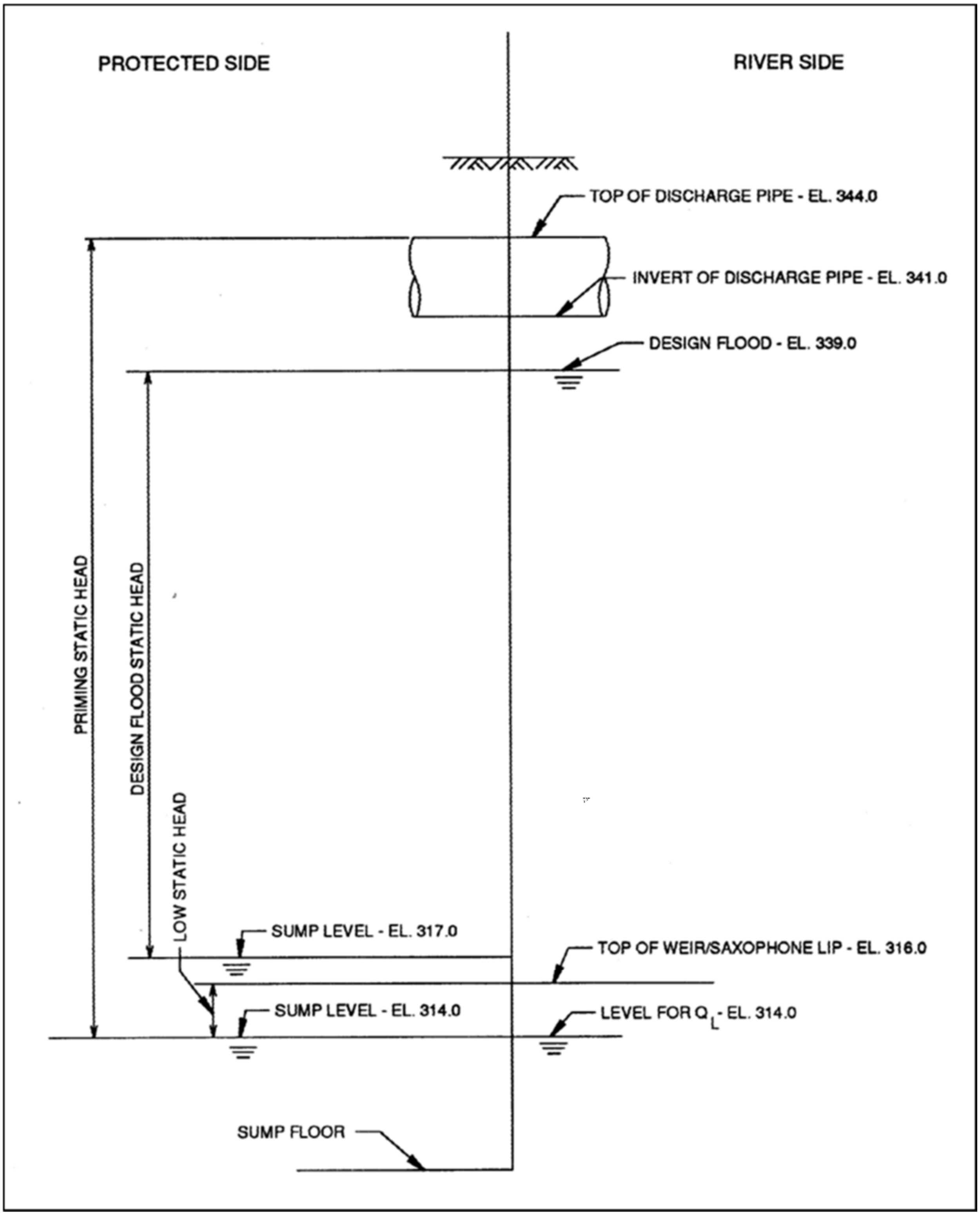


Figure C.5. Construct the Static Head Diagram

(5) Priming condition.

(a) Since the selected discharge system will use a siphon assist, another condition, priming, must be determined. The first step is to determine the required priming flow rate Q_{prime}. The computation is based on the flow required to obtain an average velocity in the discharge pipe at its highest point of 7 fps.

(b) The value of 7 fps will provide a prime for discharge pipe systems with diameters of 54 inches and less having no extra bends other than those necessary at the bottom and top of the levee. For discharge systems with larger diameters or unusual flow lines, consider using the critical depth of flow elevation occurring in the pipe instead of top of pipe. Methods used to calculate the critical depth in a circular pipe are shown in the Handbook of Hydraulics (King and Brater 1996).

$$Q = VA$$
$$Q_{prime} = A_{pipe} * V_{prime} = 6.77 * 7$$
$$= 47.39\ cfs\ or\ \sim 21{,}300\ gpm$$

(c) The priming static head (as shown previously above in Figure C.5) is equal to the difference between the top of the discharge pipe at its highest point and the lowest pump sump level used for starting the pumps. Highest point in discharge pipe at top of protection = elevation of protection + diameter of pipe = 341.0 + 3.0 = 344.0.

(d) Priming static head = 344.0 - 314.0 = 30 ft.

(6) Siphon condition. With a siphon assist system, it is required that the siphon recovery is not greater than 28 feet. The value of 28 feet is used to prevent possible water vaporization and siphon priming problems.

(a) An up-turned saxophone discharge pipe or a weir is used to limit the recovery to 28 feet and seal the end of the pipe. When one of these means is used, the low head must be checked based on the saxophone or weir elevations.

(b) If, at the pumping mode, the lowest water level on the discharge side provides for a recovery less than 28 feet, then a saxophone discharge or weir is not required. The discharge end of the pipe should be submerged when a separate vacuum priming system is provided to prime the pump. The computation is as follows:

Siphon recovery = top of pipe elevation - lowest river elevation for pumping

= 344.0 - 314.0

= 30 ft (2 ft over 28 ft)

Therefore, some means must be used to limit recovery to 28 feet.

El top of weir/lip = el top of pipe - 28 ft

= 344.0 - 28

= 316.0

This elevation will be used in determination of the low static head.

(7) Suction requirements. The other part of the pump conditions is the pump suction requirements. This is specified as NPSHA for the various pumping conditions. See Chapters 4 and 5 for further discussion of NPSHA and NPSHR. It is computed as follows:

$NPSHA = h_{sa} – h_{vpa}$

where

$h_{sa} = h_p + h_{se} – h_f$

or for pumps with suction head:

$NPSHA = h_p + h_{se} – h_f – h_{vpa}$

where

h_{sa} = total suction head in absolute feet

h_{vpa} = vapor pressure of water at given temperature

h_p = absolute pressure on water surface, for open sump = atmospheric pressure in feet

h_{se} = static water level above (+) or below (-) impeller eye datum

h_f = friction and entrance (0 for pumps with bellmouths in wet sumps)

(8) Submergence requirements. The submergence must be for the lowest pumping level at the station where the pumps will be operating for periods of time greater than 2 hours. See Table C.2. Operation below these submergence levels is permitted as long as the operation time is less than 2 hours. In no case will any operation occur with water levels below the impeller eye or datum. Assume for this example that the operation time will be over 300 hours per year; therefore, the impeller elevation is 3 feet below lowest sump elevation for any pumping condition to assure a flooded impeller.

Table C.2
Minimum Submergence Base on Operating Hours

Total Estimated Annual Operating Hours Per Year	Minimum Submergence in Feet*
0 to 99	1.0
100 to 299	2.0
300 and over	3.0

*Minimum submergence over impeller eye or above NPSHR level, whichever is greater

(9) Total system head. The next step is to compute the total system head curves for each condition. The total system curves will include all the losses plus the static head for that condition. For the purposes of pump selection, the total system curves will be constructed to include the losses in the pump beyond the pump bowl. This will permit the subsequent pump selection to be done on the basis of bowl heads.

(10) Bowl head is considered the head produced by a pump if it were measured immediately after the discharge vanes. Bowl heads, therefore, do not include any losses in the transition piece and elbow of the pump which is supplied with the pump. The bowl head permits the user to use any type of discharge system beyond the pump bowl.

(11) For this example, there would be three system curves: design flood, low head, and priming. It should be noted that any system total head curves used for procurement of pumping equipment would only include system losses which would be external to the pump equipment being furnished by the pump manufacturer.

(12) Generally, the pump manufacturer would subtract the column pipe and discharge elbow losses from the bowl performance, thereby producing a performance curve referenced to the discharge point of the equipment being supplied. For this design, the pipe lengths are as follows:

(a) Priming – 175 ft., operating – 250 ft.

(b) The total system head required by the pump to deliver the minimum and the maximum flow rates required should be calculated and tabulated as shown in Table C.3. The total system head should include the discharge loss, pipe and elbow losses, and static head. The next step is to use this table and develop system head (pump bowl) loss curves as shown on Figure C.6.

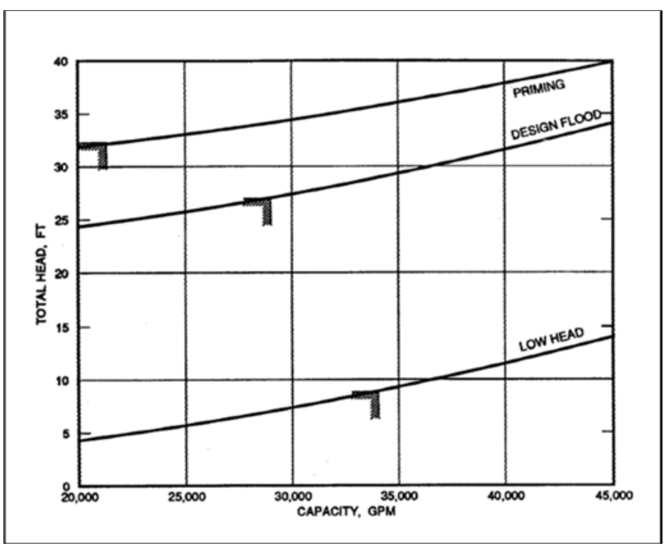


Figure C.6. System Head (Pump Bowl) Loss Curve

Table C.3
Total System Head

Total System Head

Q gpm	$\frac{V^2}{2g}$ ft	$H_{F/100}$ ft	$H_{F/250}$ ft	Other Pump K=0.4 ft	Losses Bends K=1.2 ft	Total[1] Loss ft	Low[3] Total Head ft	Design[4] Flood Total Head ft
Low Head and Design Flood Conditions								
20,000	0.67	0.25	0.62	0.27	0.81	2.37	4.37	24.37
25,000	1.05	0.38	0.95	0.42	1.26	3.68	5.68	25.68
30,000	1.51	0.54	1.35	0.61	1.82	5.29	7.29	27.29
35,000	2.06	0.72	1.81	0.82	2.47	7.17	9.17	29.17
40,000	2.69	0.94	2.35	1.08	3.23	9.35	11.35	31.35
45,000	3.41	1.18	2.95	1.36	4.09	11.81	13.81	33.81

Q gpm	$\frac{V^2}{2g}$ ft	$H_{F/100}$ ft	$H_{F/175}$ ft	Other Pump K=0.4 ft	Losses Bends K=0.8 ft	Total[2] Loss ft	Priming[3] Total Head ft
Priming Head Condition							
20,000	0.67	0.25	0.43	0.27	0.54	1.91	31.91
25,000	1.05	0.38	0.66	0.42	0.84	2.97	32.97
30,000	1.51	0.54	0.95	0.61	1.21	4.28	34.28
35,000	2.06	0.72	1.27	0.82	1.65	5.80	35.80
40,000	2.69	0.94	1.65	1.08	2.15	7.57	37.57
45,000	3.41	1.18	2.07	1.36	2.72	9.56	39.56

Examples (For Q = 20,000 gpm):
[1] Total Loss(Low Head/Design Flood) = 0.62+0.4(0.67)+1.2(0.67)+0.67 = 2.37 ft.
[2] Total Loss(Priming) = 0.43+(0.4)(0.67)+(0.8)(0.67)+0.67 = 1.91 ft.
Priming Static = 344 - 314 = 30 ft. Low Static = 316 - 314 = 2.0 ft.
Design Flood Static = 339.0 - 317.0 = 22.0 ft.
[3] Low T. H. = 2.37+2.0 = 4.37 ft. Priming T. H. = 1.91+30.0 = 31.91 ft.
[4] Design Flood T. H. = 2.37 + 22.0 = 24.37 ft.

C.8. Pump Selection.

a. Formulas used. The method of pump selection consists of computing the performance of a larger prototype pump from the performance of a model pump or a small prototype pump. The following relationships are used for these computations. All relationships are based on pump bowl performance.

$$d_p = d_m \sqrt[4]{\frac{H_m}{H_p}} \sqrt{\frac{Q_p}{Q_m}}$$

$$Q_p = Q_m \frac{N_p}{N_M} \left(\frac{d_p}{d_m}\right)^3$$

$$H_p = H_m \left(\frac{d_p}{d_m}\right)^2 \left(\frac{N_p}{N_m}\right)^2$$

$$H_{sp} = H_{sm} \left(\frac{d_p}{d_m}\right)^2 \left(\frac{N_p}{N_m}\right)^2$$

$$BHP_p = BHP_m \left(\frac{d_p}{d_m}\right)^5 \left(\frac{N_p}{N_m}\right)^3$$

where

d_p = Impeller exit diameter of prototype pump
d_m = Impeller exit diameter of model pump
Q_p = Capacity of prototype pump
Q_m = Capacity of model pump
H_m = Head of model pump
H_p = Head of prototype pump
N_p = Rotative speed of prototype pump
N_m = Rotative speed of model pump
H_{sp} = Required suction head of prototype pump
H_{sm} = Required suction head of model pump
BHP_p = Brake horsepower of prototype pump
BHP_m = Brake horsepower of model pump

b. General. The performance of a prototype pump can be determined by the use of the above equations applied to the model pump performance. As can be seen from the above formula, the two variables are impeller diameter and rotative speed. The selection of these two factors should be to obtain a prototype unit which has the smallest impeller diameter and the highest rotative speed, while still meeting all of the performance requirements of head, capacity, and NPSHA. The impeller diameter is shown on each model pump curve.

c. For mixed-flow type pumps, the maximum impeller diameter is indicated on the curves. On mixed flow pumps, it is possible to reduce the impeller diameter by up to 5 percent, thereby changing the performance of the pump from that shown on the curves for full diameter performance. Blade pitches are taken into account and shown as different model pump curves.

d. Calculation method. The actual calculations of the prototype pump performance is best done by trial and error. A personal computer using a spreadsheet type program or engineering math software simplifies and speeds these calculations and the pump selection. CECW-CE or HDC can furnish information of various Districts where different programs are available to perform these computations. The designer can also work with the pump manufacturer.

e. Sample calculations. The following is an example of computations used to select a prototype pump. It is usually best to start with a model pump that has a head range near that of the required condition points. As a first try, use model curve MF-1 (Figure C.7) and calculate prototype performance. A mixed-flow impeller was tried because highest head requirement was over 20 feet. The selected prototype impeller is usually smaller than the discharge pipe diameter. The maximum prototype pump speed can be estimated by applying the following formula based on suction specific speed (S).

$$S = \frac{N_p\sqrt{Q_p}}{NPSHA_p^{0.75}}$$

For this sample problem, use a value of S = 8,000.

$$N_p = \frac{8{,}000(NPSHA)^{0.75}}{\sqrt{Q}}$$

Where:

$N_p = \text{Rotative speed of the pump, RPM}$
$NPSHA_p = \text{Calculated for the lowest head pumping condition, ft.}$
$Q_p = \text{Flow rate for the lowsest head pumping condition, gpm}$

Therefore:

$$N_p = \frac{(8{,}000)(35.70)^{0.75}}{\sqrt{34{,}000}} = 634 \text{ rpm}$$

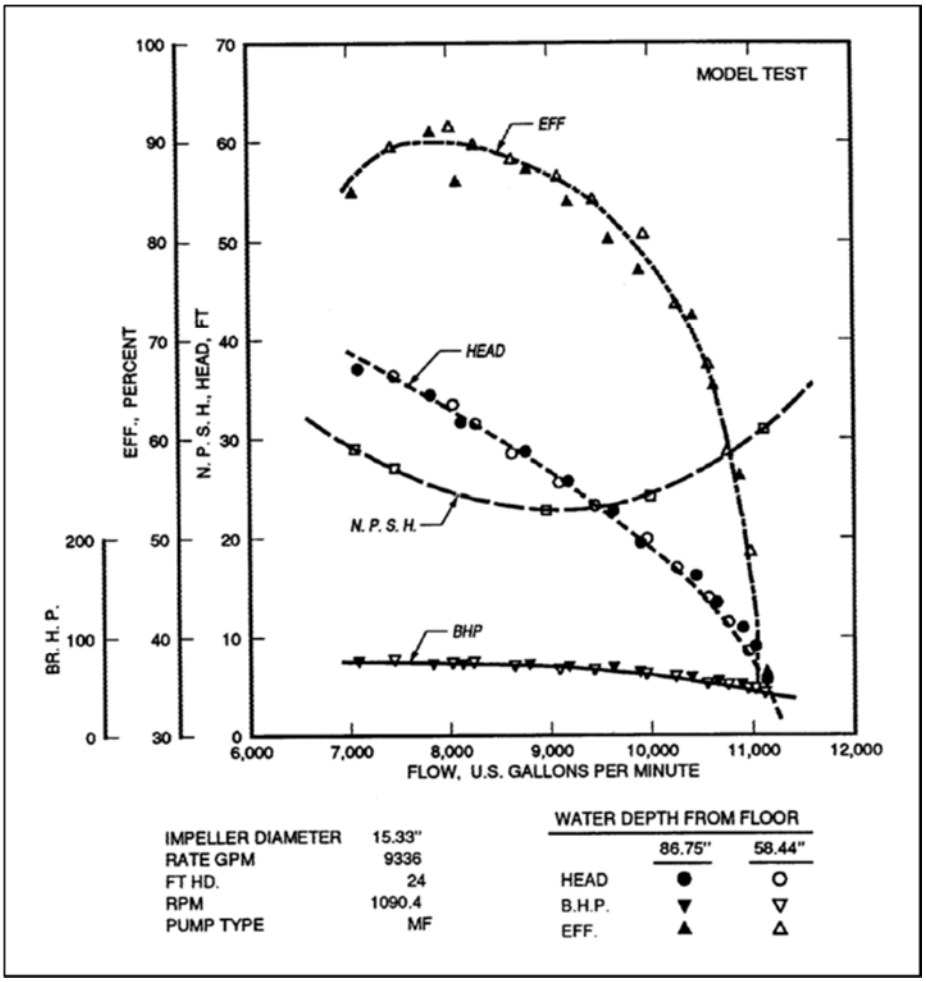


Figure C.7. Pump Model Curve MF-1

f. The pump speed should not in general exceed this calculated rotative speed. The speed used must also meet the restrictions of the pump driver. If using an electric motor that is directly connected to the pump, then the synchronous speed of the motor must be considered. When using an induction motor, the full-load speed can be estimated to be 97 percent of the synchronous speed. The synchronous speed can be calculated using the following formula for electricity with a frequency of 60 cycles.

$$\mathrm{N_p} = \frac{7200}{\#\text{ of motor poles (i.e., } 0, 12, 14 \ldots.)}$$

Motor speed = 7200/12 or 7200/10

= 600 rpm, or 720 rpm

g. Since 720 rpm is over the calculated maximum of 634 rpm, the lower synchronous speed of 600 rpm is used. Assuming an induction motor is to be used, the running speed when operating at full load is estimated to be 97 percent of 600 rpm or 582 rpm. Try Model MF-1. Table C.4 below provides the model performance based on the curves and then compared to calculated prototype performance. Based on the Pump Model Curve MF-1 (See Figure C.7 again above), calculate the diameter of the prototype impeller using the model law (constant specific speed and equal heads).

$$d_p = d_m \sqrt{\frac{Q_p}{Q_m}}$$

Where:

$$d_p = 15.22 \sqrt{\frac{29{,}000}{8{,}900}} = 27.7 \text{ inches}$$

d_m (from model curve MF − 1) = 15.33 inches
$Q_p = Q_h$ (design flood) = 29,000 gpm at 27 feet TDH
Q_m (from model curve MF − 1) = 8,900 gpm at 27 feet TDH

Develop prototype performance curve based on model curve MF-1 and verify that design conditions have been met (Figure C.8).

$$Q_p = Q_m \left(\frac{d_p}{d_m}\right)^3 \left(\frac{N_p}{N_m}\right)$$

$$BHP_p = BHP_m \left(\frac{d_p}{d_m}\right)^5 \left(\frac{N_p}{N_m}\right)^3$$

Where:

$$Q_p = Q_m(1.81)^3(0.534) = Q_m(3.17)$$

$$\frac{d_p}{d_m} = \frac{27.7}{15.33} = 1.81$$

$$\frac{N_p}{N_m} = \frac{582}{1{,}090.4} = 0.534$$

$$BHP_p = BHM_m(1.81)^5(0.534)^3 = BHP_m(2.96)$$

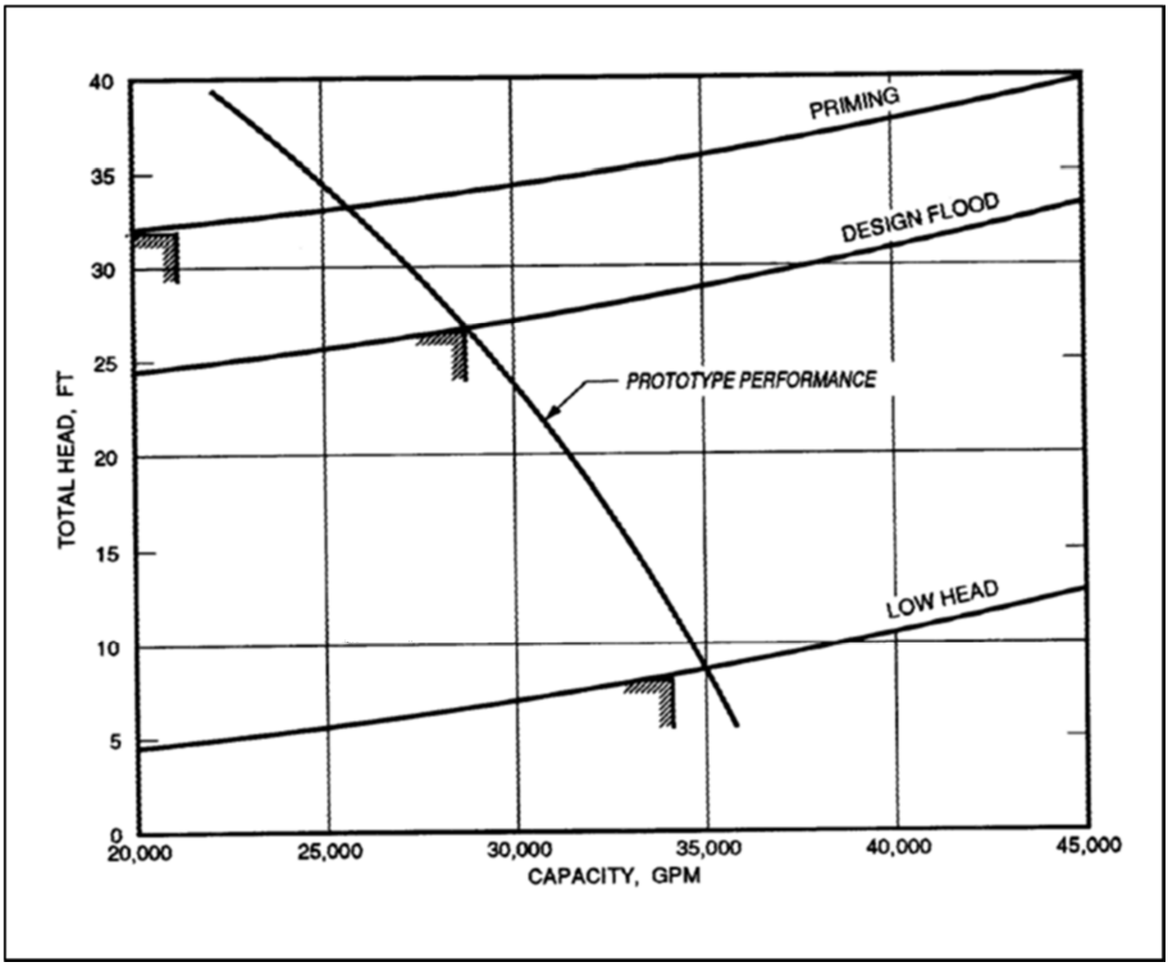


Figure C.8. Prototype Performance Curve Superimposed on the System Head Curves (Pump Bowl) Pump MF-1

Table C.4
Model and Prototype Performance

From curve MF-1, model pump performance			Calculated Prototype Pump Performance		
Q_m	H_m	BHP_m	Q_p	H_p	BHP_p
7,000	38.8	75	22,200	38.8	222
8,000	33.2	73	25,400	33.2	216
9,000	26.9	70	28,530	26.9	207
10,000	19.0	60	31,700	19.0	178
11,000	7.2	45	34,900	7.2	133

h. The results of the first prototype pump computation are plotted on the system head loss curves. Results show that a pump with a 704 mm (27.7 inch) impeller rotating at 582 rpm will satisfy the design requirements.

i. Next, other model pumps and different prototype speeds would have been tried to find other prototype pumps that will meet the requirements. An average prototype pump size could then be calculated. All station layout dimensions would be based on the corresponding standard size pump. The NPSH required by the prototype or model is then checked against the NPSH available. Cavitation curve MF-1 (Figure C.9) confirms that there is adequate submergence.

C.9. Pump Dimensions.

a. General. Determine the dimensions for all the model pumps selected. Since the sump dimensions and elevations used depend on the pump dimensions, some means must be used to determine the dimensions to use for the station layout from the range of pumps selected. The selection of dimensions to allow the maximum number of pumps to meet the guidelines is given below.

b. Bell diameter.

The bell diameter = D

Average D, (D_A) = sum of bell diameter for all selected pumps divided by number of selected pumps.

Largest bell diameter (D_{LARGE}), but not larger than 1.2 times D_A

Smallest bell diameter (D_{SMALL}), but not less than 0.9 times D_A

Sump $width_1$ = 2 times D_{LARGE}

Sump $width_2$ = 2.5 times D_{SMALL}

Sump width is the larger of sump $width_1$ or $width_2$

D = 1/2 of the sump width from the above step.

c. Impeller elevation. The impeller eye (entrance) is set to provide the submergence indicated above in the paragraph on pump conditions. In this example, the impeller was set at elevation 311.0. The bottom of the bell and sump floor elevation are set as follows:

(1) Bottom of pump bell = impeller eye elevation minus 1/2 D

(2) Floor of sump = bottom of bell elevation minus 1/2 D

d. Minimum pump height. The minimum distance from the floor of the sump to the centerline of the pump discharge must be determined to establish a minimum floor elevation. The dimension from the floor of the sump to the bell inlet is determined above.

e. The distance between the centerline of the discharge to the suction bell inlet should be provided by pump manufacturers offering the type and size of pump indicated by the prototype. This pump dimension will vary from one manufacturer to another. The maximum distance found should be used to determine the minimum operating floor. Other considerations such as local flooding due to power outage and surrounding ground elevations may require a higher operating floor elevation.

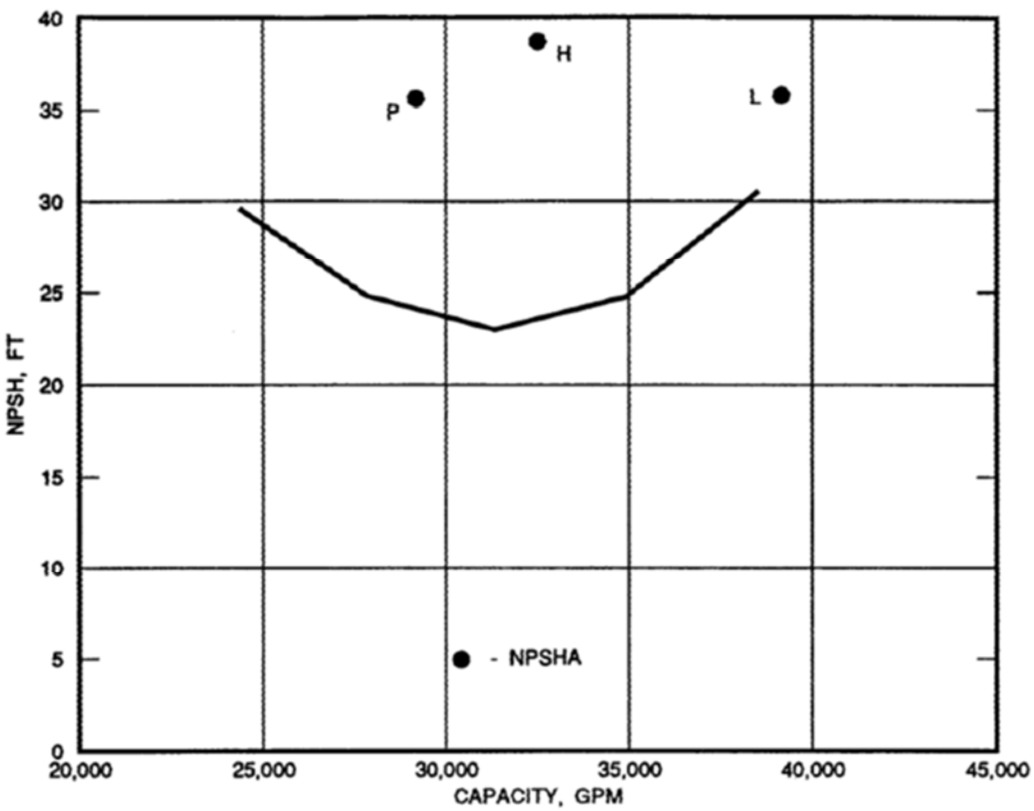


Figure C.9. Cavitation Curve MF-1

C.10. Station Layout.

a. Pump dimensions. For stations with up to three equal sized pumps having capacities not greater than 5.66 m^3/s (200 cfs), and with straight inflow, in front of the station, the dimensions indicated in Figure C.10 may be used. The flow to the station should occur in a straight symmetrical channel with a length equal to or greater than five times the station width (W in Figure C.10).

b. The invert of the channel in front of the station should not contain any slopes greater than 10°. The submergence indicated in Figure C.10 is the depth of water suggested to prevent harmful vortices. In most cases, the water depth will be greater due to the cavitation allowance listed above. If there are any unique inflow conditions or problems, the designer should contact

USACE ERDC Hydraulic Laboratory to determine alternative layouts to correct or compensate for the problems.

c. Considerations for station layout.

(1) Space inside of the station is provided to set one pump driver and disassemble one pump using the overhead crane.

(2) Space in front, side and back of electrical equipment is provided as required by the electrical code requirements.

(3) Space is provided to remove any pumping unit without disassembly of another unit or electrical gear.

(4) Space is provided for an office and sanitary facilities for any station that will be manned.

(5) Space is provided for spare parts and maintenance equipment to be stored at the station.

(6) Location of electrical gear is coordinated with service entrance.

(7) Exit and equipment door are provided and properly located.

(8) Straight approach to pump sump is provided.

(9) Any sump closure gate is neck down at least 4D from the pumps.

(10) Access is provided to trash rack platform for trash removal by truck.

(11) Sufficient room is provided to position a truck for equipment removal.

(12) Minimum slope is provided in ditch flow line beyond the front of the trash rack.

(13) Incoming overhead power lines do not present a hazard to operation and maintenance of the station.

C.11. Pump Manufacture's Selection. Pump manufacture's selection. Using the preliminary layout, correct any system head curves such as change in low head due to different elbow elevation. Check the pump selections using the new system requirements and refine layout as necessary. It is also best at this time to request pump selections from the pump manufacturers using the requirements and sump layout above. This will confirm the pump selections. Figure C.11 is an example of the information to be furnished and requested from the pump manufacturer.

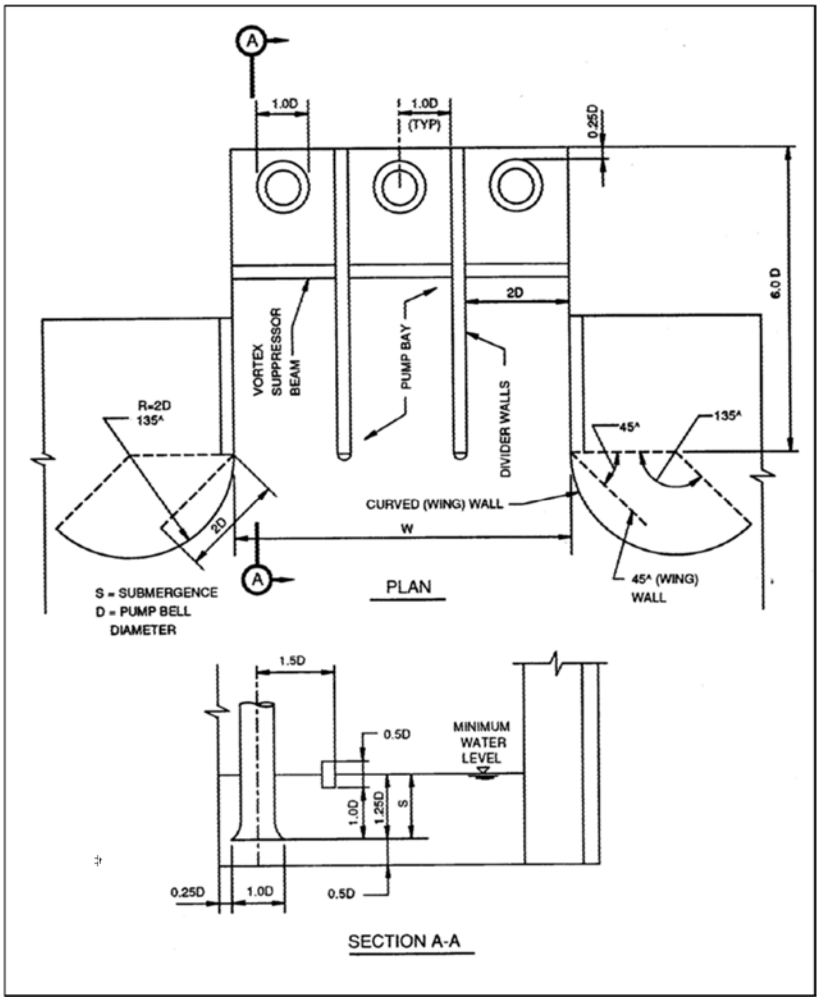


Figure C.10. Vertical Pump Sump Dimensions

C.12. <u>Submersible Propeller Pump Selection</u>.

a. Design data and requirements.

(1) Pump conditions. The sample calculations are based on a pumping station with a through-the-protection discharge, pumping into a discharge chamber. The following is the assumed conditions for each pump (English units).

(2) Required from hydrology report:

Q_H = The flow rate at maximum differential head

= 27,000 gpm @ river el 339.0 and sump el 321.0

= 1,715 L/S

Q_L = The flow rate at minimum differential head

= 33,000 gpm @ river el 322.0 and sump el 319.0

= 2,095 L/S

Pump stop elevation - 315.0
Pump start elevation - 318.0
Normal pumping elevation - 316.0
(Level at which the majority of pump operation will occur)

(a) Submersible propeller pumps typically are constructed in such a manner that the pitch angle of the propeller blades can be changed; therefore, the selection method used is different from that used with fixed blade pumps.

(b) The selection procedure used for submersible pumps will be to compute the system requirements, and then select a pump from available performance curves. After the initial selection is made, then the system requirements can be corrected if necessary due to a more accurate discharge tube sizing and the pump selection confirmed or changed. In addition to the selection based on pump head and capacity requirements, the pump selected must also be checked to ensure that its suction requirements are satisfied by those provided by the station layout.

(c) The pumping system is composed of a discharge/support tube in which the submersible pumping unit is located. In this example, the tube would be fitted with an elbow section and a horizontal pipe terminating with a flap gate. For submersible pump installations of this type, the discharge line invert should be well above the motor to hold the elbow losses to a minimum but low enough to keep the static head reasonable.

(d) The first estimate of the tube diameter can be based on the size required using a 6.5-fps velocity and the greatest required capacity. After calculating a diameter based on these conditions, the nearest size tube diameter as shown on Table C.5 must be used for the preliminary calculations. For the example problem, the calculated discharge is 45.4 inches.

(e) The nearest standard tube diameter of 48 inches is used. The bottom of the tube can be set using the minimum tube submergence required. These submergence requirements are provided by the submersible pump manufacturer and are based on annual operating hours and pump tube design. For this example, 3.0-ft minimum submergence is required.

Elevation bottom of the tube = 315.0 - 3.0 = 312.0

PUMP MANUFACTURER'S DATA SHEET

Information furnished:

Name of station
Type of driver and operating voltage if electric
Type of pump
System head curves, using losses external to the pump, showing required condition points
Pump setting elevation
Sump layout
Number of pumping units to be installed

Information requested from the pump manufacturer:

Pump model/type number
Pump size - discharge, bell and impeller diameter
Pump diameter below impeller where a formed suction intake would attach
Pump operating speed
Pump setting elevation including;
    Elevation of bell
    Elevation of impeller
    Height of the motor above baseplate elevation
    Length of pump elbow of discharge flange dimensions
    Minimum distance from impeller elevation to centerline of elbow
    Elevation of attachment of a formed suction intake
Estimated pump weight
Estimated motor weight
Estimated pump cost
Estimated motor cost
Pump performance curve showing head, horsepower, efficiency, and NPSHR plotted against capacity

For large pumps over 54-inch size, additional information such as the WR^2 of both the pump and motor along with starting torque curves would also be requested.

Figure C.11. Pump Manufacturer's Data Sheet

Table C.5
Submersible Pump Dimensions and Motor Data

Pump Number	Discharge Tube Diameter Inches	Pump Speed RPM	Height of Pump/Motor Inches	Max Weight Pump Motor Pounds	Motor kW Rating
AF-S-1	40	705	97	7,350	236
AF-S-2	48	590	135	12,200	355

(f) The bottom of the tube elevation may need to be lowered later to satisfy the sump velocity criteria as indicated in Figure C.12; however, this will not affect the pump selection.

(g) The minimum invert elevation must be above the top of the motor. With the bottom of the tube set at el 312.0, the minimum elevation of the elbow invert can be determined by adding the pump/motor height indicated on Table C.5 to the bottom tube elevation.

Minimum invert elevation of elbow = 312.0 + 135 inches = 323.25

(h) This elevation will be used since it is above the river elevation for the low head condition. The horizontal discharge pipe connected to the tube is sized based on the flow velocity of 12 fps at maximum capacity. The calculated horizontal discharge pipe size is approximately 33.5 inches; use nominal 36 inch pipe.

(i) A static head diagram is constructed (Figure C.13) using the given hydrology information and preliminary information determined above on the pump tube and the discharge piping. The floor elevation is set 1/2 tube diameter below the bottom of the tube.

(j) This first static head diagram will be used to make a preliminary pump selection. In most cases, at least one or more static head diagrams will need to be prepared after the preliminary pump selection is made to allow the pumping unit dimensions to agree with the static head diagram. The pump selection process would follow the steps below:

1		2		3		4		5
Prepare Static Head Diagram	→	Prepare System Head Curves	→	Make Preliminary Pump Selection	→	Check Pump NPSHR	→	Repeat Steps 1-4 If Necessary

C.13. System Head. The next step is to compute the system head curves (Table C.7). The system head curves include all of the losses plus the static head for that condition (Figure C.14). The system loss curves include all the losses beyond the pump motor, since losses below this point are included in the given pump curves. A loss of K = 0.7 is used for the losses in the pump column and elbow. The other losses in this example are considered to be equal to the velocity head. Next, calculate the NPSHA for the various pumping conditions. Refer back to the previous example problem for the definition of terms.

Table C.6
Pumping Conditions against Low and High Head Conditions

Pumping Condition	Low Head Condition	High Head Condition
Sump Water El*	316.0	316.0
Bottom of Tube**	312.0	312.0
h_{se} *** - ft.	+4.0	+4.0
h_{vpa} (80°F) – ft.	1.2	1.2
h_p – ft.	33.9	33.9
NPSHA – ft.	36.7	36.7
NPSHA – m	11.2	11.2

* For this condition, use the lowest water level that will occur for the majority of the pumping; however, all operating water levels should be examined to determine if potential damaging operation will occur. For this example, it has been assumed this elevation to be 1 foot above the pump stop elevation.
** The NPSHR curves are referenced to the bottom of the tube location rather than the impeller entrance or eye.
*** 4 feet is the submergence above the bottom of the tube.

$$\mathrm{NPSHA} = \mathrm{h_p} + \mathrm{h_{se}} - \mathrm{h_f} - \mathrm{h_{vpa}}$$

C.14. Pump Selection.

a. General. Using the pump curves AS-F-1 and AS-F-2 (Figures C.15 and C.16) and the required condition points from the system head loss curves, a preliminary pump selection can be made.

b. The pump performance head-capacity curves are shown for the various blade angles that are available for that pump. A single blade angle that satisfies all design conditions should be used. Changing blade angles during flood events should not be considered because of the need to remove the pumping unit and thereby taking it out of operation.

c. These pumps have the motors directly attached to the pumping unit. The motors' ratings are shown in kilowatts, which is the input power to the pump shaft. The dashed lines running diagonally from upper left to the lower right show the motor sizes available. Any design condition below these dashed lines may use the motor rating indicated for that line. The information furnished in this manual can be used for the preliminary layout of submersible type pumping stations; however, information should be requested from all manufacturers for the design documentation report.

For the example pump conditions the selected pump would have the following sump dimensions:

D = 48 in., a = 36 in., b = 96 in., c = 24 in., L = 16 ft.

S = submergence over bottom of tube

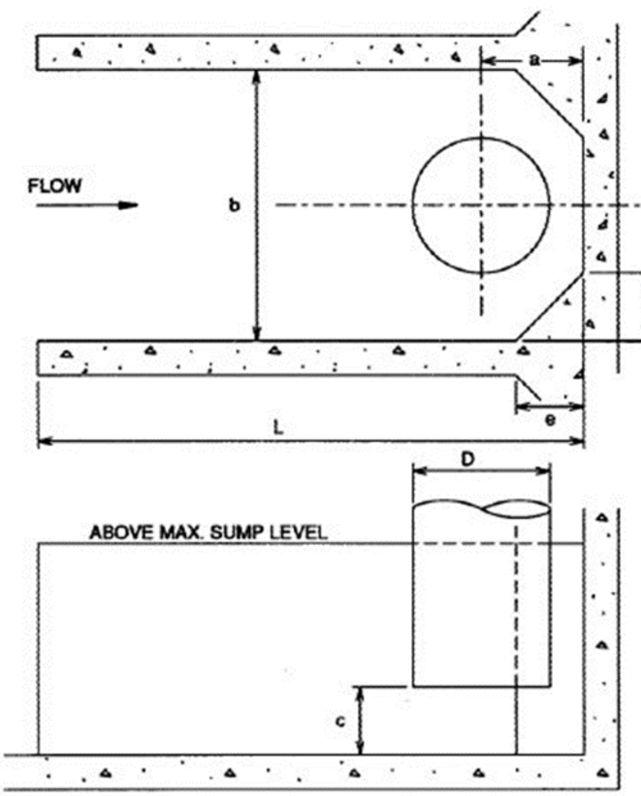
V = Q/A and if V = 1.2 fps, then A = Q/1.2 also A = 2D x (S+.5D)

then S $= (Q \;/\, 2.4D_{cond}) - .5D_{cfs}$ and S = 5.66 ft. ft ft

Bottom of tube = Pump stop level minus submergence

= 315.0 - 5.66 ft. = El. 309.34 instead of El. 312.0

Submersible Pump Sump Layout



TUBE DIA.	DIM.
a	0.75D
b	2.0D
c	0.5D
e	0.5D
L	4D Min.

COURTESY OF FLYGT CORPORATION

Figure C.12. Typical Submersible Pump Sump Layout

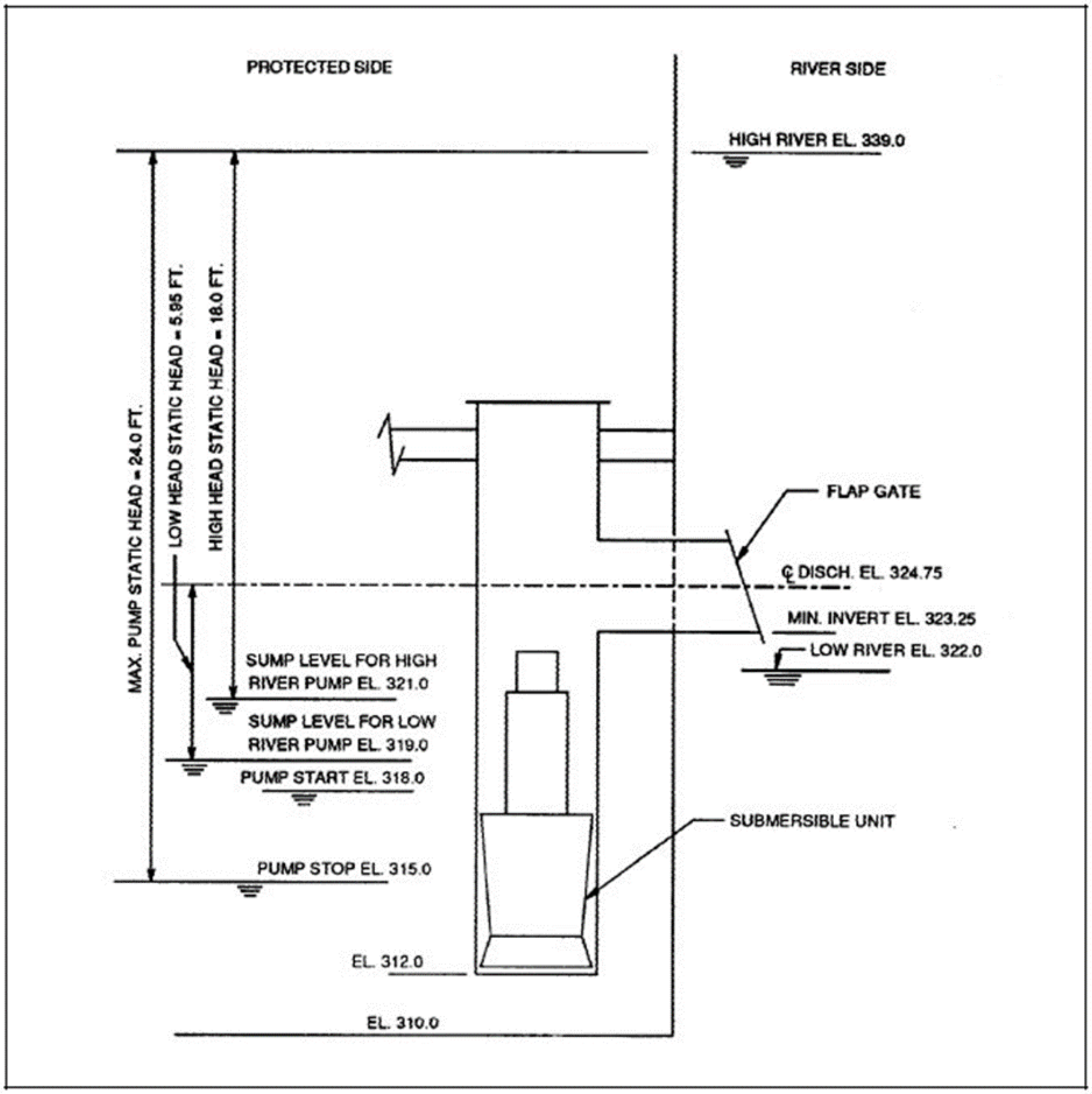


Figure C.13. Static Head Diagram

Table C.7
System Head Calculations – English units

Q gpm	$V^2/2g$ ft	Pump & Elbow K=0.7 ft	Total Losses ft	Total Head Low Hd ft	m	Total Head High Hd ft	m	Max. Head ft
20,000	0.22	0.15	0.37	6.3	1.93	18.4	5.61	24.4
25,000	0.28	0.19	0.47	6.4	1.96	18.5	5.63	24.5
30,000	0.33	0.23	0.56	6.5	1.98	18.6	5.66	24.6
35,000	0.39	0.27	0.66	6.6	2.02	18.7	5.69	24.7
40,000	0.44	0.31	0.75	6.7	2.04	18.8	5.72	24.8
45,000	0.50	0.35	0.85	6.8	2.07	18.9	5.75	24.9
50,000	0.55	0.38	0.95	6.9	2.10	19.0	5.78	25.0

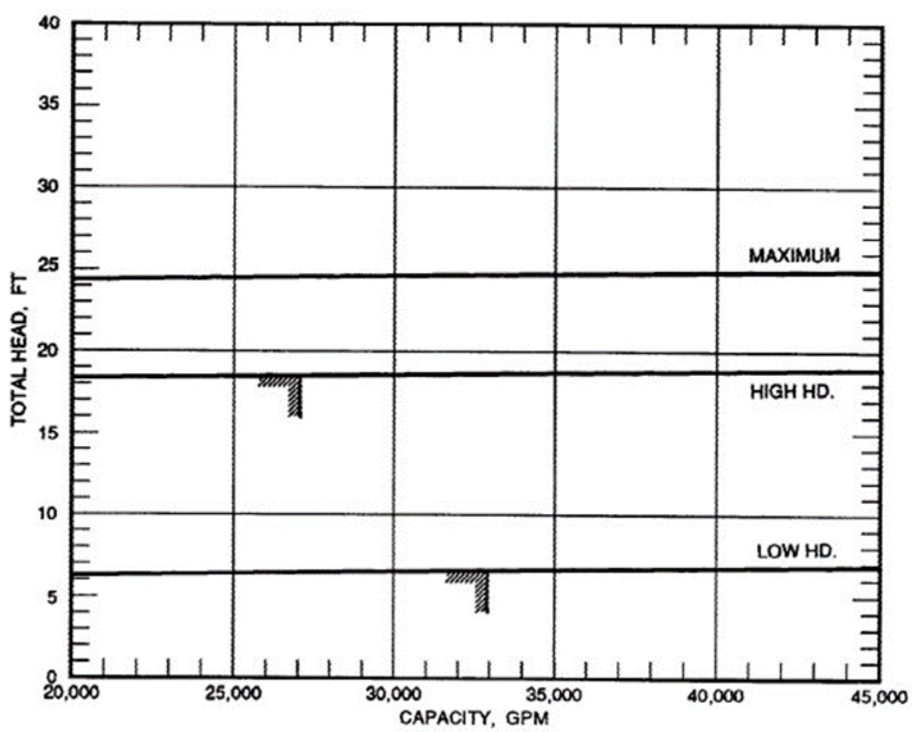


Figure C.14. System Head Loss Curves

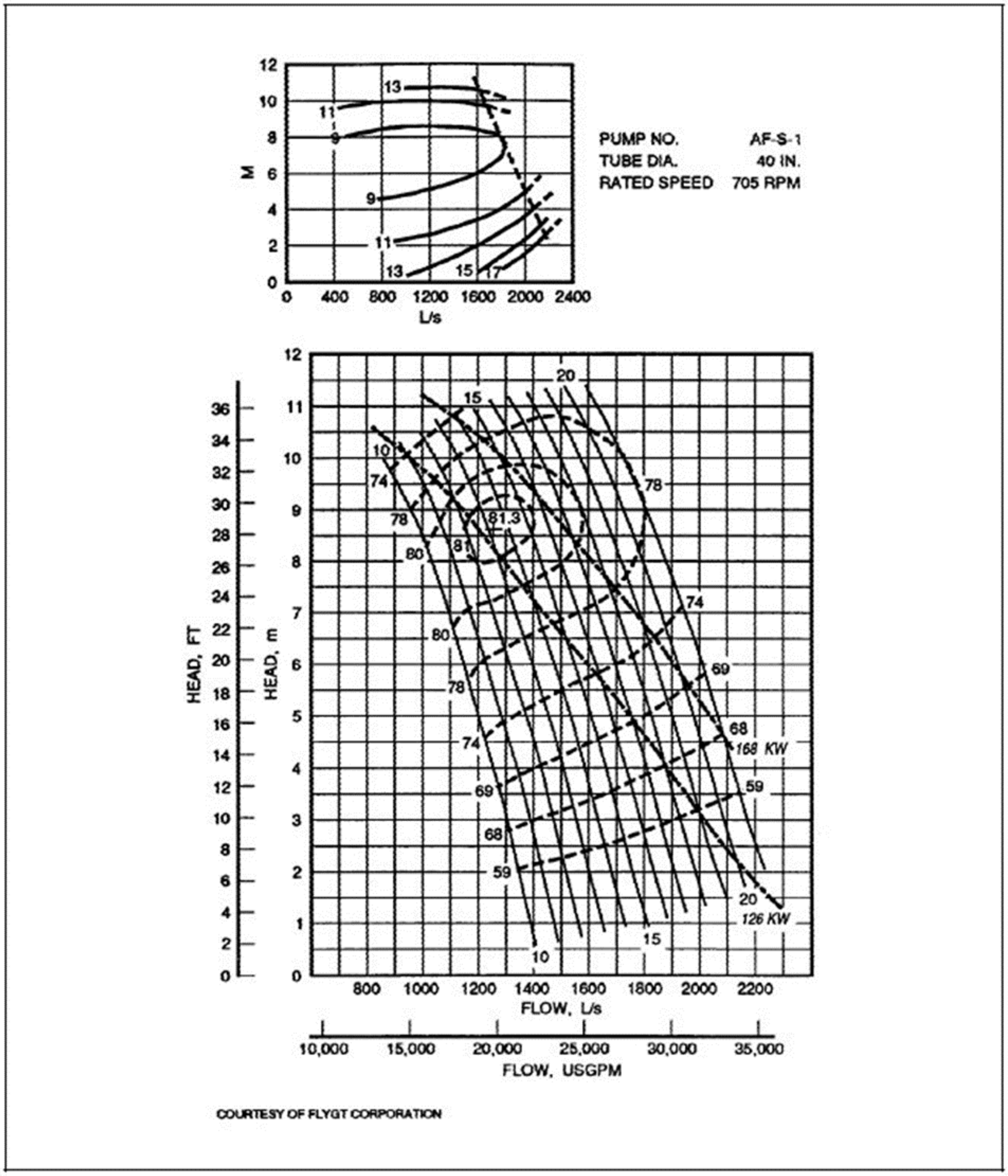


Figure C.15. Submersible Pump Curve AF-S-1

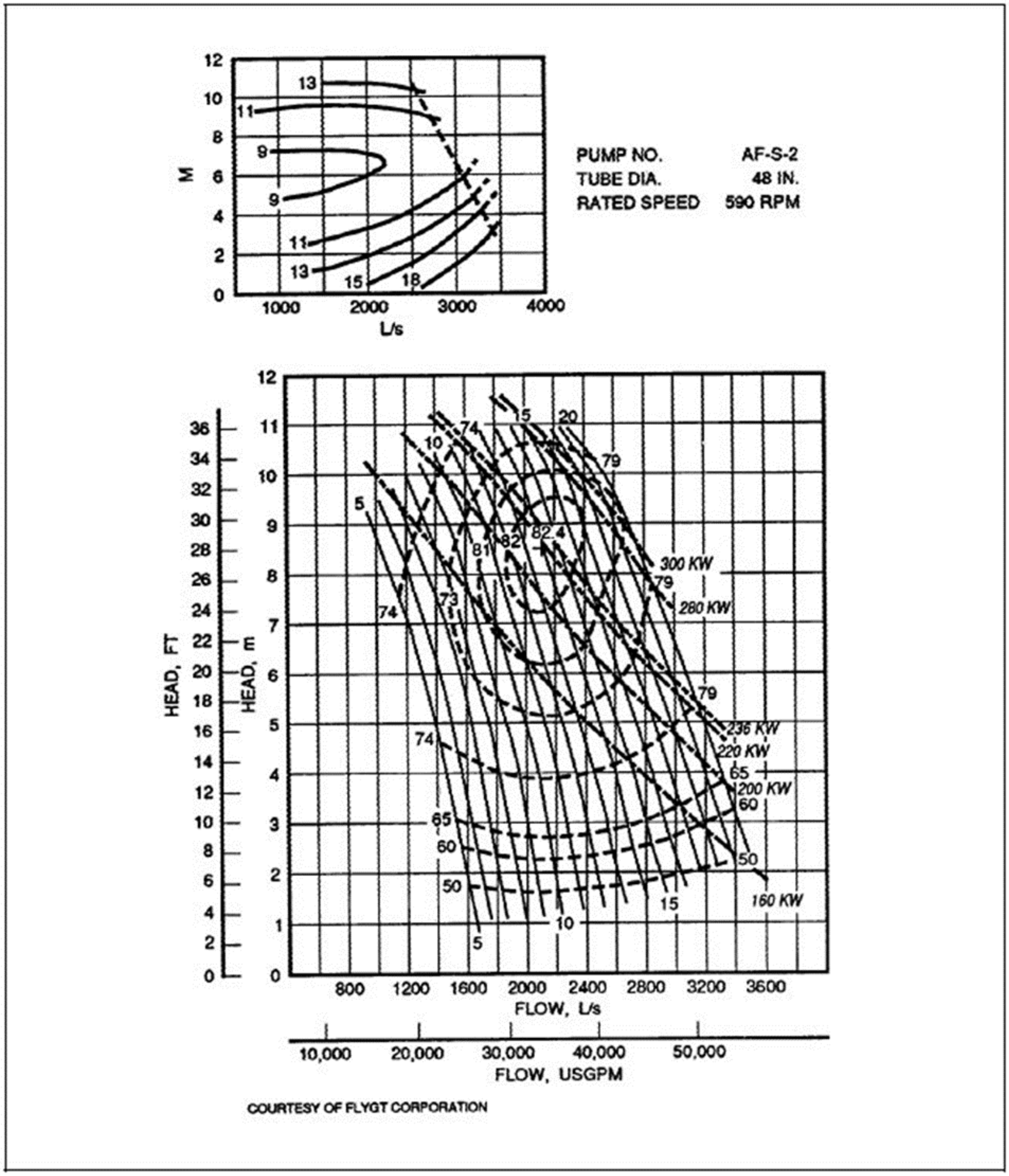


Figure C.16. Submersible Pump Curve AF-S-2

d. Selection procedure. Review of the pump curves indicates that an AF-S-1 size pump operating at a speed of 705 rpm and set at a blade angle of 20 degrees will satisfy the head-capacity design conditions.

(a) The next step is to check the suction requirements of the pump. This is done by plotting the head-capacity curve for the blade angle chosen above on the NPSHR curve for that pump. The plotted head-capacity curve crosses the various NPSHR curves for that pump indicating the required suction head for different pumping requirements.

(b) The curve shown above indicates that the preliminary AF-S-1 pump selection requires a greater submergence than is available; therefore, another pump must be tried or greater submergence provided. Unless the additional submergence required is less than 0.3 m or 0.6 m (1 or 2 feet), it is usually less expensive to provide a larger, slower speed pump than provide a deeper station. A cost comparison can be made to more accurately compare a deeper sump station with that station requiring a larger area because of increased pump size.

(c) The next choice would then be the next larger size pump operating at its highest available speed and meeting all the required design conditions. This would be the AF-S-2 size pumping unit operating at 590 rpm. The 10 degree blade angle satisfies the design conditions and the suction requirements.

(d) Since the selected size pump of AF-S-2 has the same size tube as that first selected, the static head diagram and system head curves are correct.

(e) The NPSH requirements for the pump are determined by plotting the selected blade angle head-capacity curve on the cavitation curve. Where this head-capacity curve crosses the NPSHR lines indicates the NPSHR values for the pump.

C.15. Station Layout. Using the listed discharge tube diameter (Table C.5), the sump can be sized according to Figure C.12. Check the pump selections using the new system requirements and refine the layout as necessary. The sump layout is now complete, and the remainder of the station layout can now be done. It is also best at this time to request pump selections from the pump manufacturers using the requirements and sump layout above. This will confirm the pump selections and permits adequate bidding competition. The following are considerations for station layout:

a. Sump velocities. The average velocity in each pump sump in front of the pump for continuous operation should not be greater than 0.37 meter per second (1.2 fps). For intermittent operation (less than 200 hours per year), the average velocity may be increased to 0.49 meter per second (1.6 fps).

b. To obtain these velocities, the sump depth is varied while the sump width is kept equal to two tube diameters. These maximum velocities are maintained to diminish the formation of vortices in the sump. The water levels obtained by application of these velocities may not be high enough to satisfy the pump's NPSHR. The NPSHR takes precedent, and the resultant submergence will be greater than that necessary to prevent vortices.

c. Superstructure. A structure should be provided to house the motor starters, switchgear, and engine generator, if provided, and office space for operating personnel.

d. Hoist. A method for removing the pumping units should be provided. Any inspection or repair work to the pumping unit is done with the unit removed from the tube. Inspection which requires the removal of the pumping unit are required at least annually to check the integrity of the pump/motor seal system. A monorail hoist capable of lifting the entire pumping unit should be provided. If the maintenance organization has a truck crane of sufficient capacity to raise the pumping unit or such a crane would be readily available on an emergency basis, then a permanent hoist would not be required.

C.16. Formed Suction Intakes.

a. General. The formed suction intake (FSI) is used on pumps to improve flow to the impeller of vertical pumps. The FSI can be used on almost any pumping application. It is, however, recommended when adverse flow conditions occur upstream. Plates B.23 and B.24 in Appendix B show typical Type 1 and Type 10 FSI, respectively. ETL 1110-2-327, Geometry Limitations for the Forced Suction Intake, provides additional information. Also, additional FSI information can be found in Chapter 7 and HI 9.8. The FSI can be used on small pumps; however, the small openings could clog or silt in during nonoperational periods.

b. FSI size determination. FSI is connected directly to the suction flange below the impeller. This diameter, d, will determine the size of the FSI. The selection of the pump will be the same as that used for the vertical wet pit pump except for the additional suction loss.

c. Whereas the conventional vertical pump with a bell uses a suction loss of zero, the pump equipped with an FSI should use a loss coefficient of $K = 0.15$. After the pump has been selected, it is necessary to determine the suction flange connection I.D., d. For axial flow pumps, d will be the same diameter as that determined for the impeller.

d. For mixed flow impellers, d can be estimated to be 0.85 of the impeller diameter d. After d has been determined, the rest of the dimensions of the FSI can be found by applying the ratios indicated in Plate 23 or 24 in Appendix B. In a typical pump selection, the suction diameter will vary with different pump manufacturers. To permit maximum biddability, the FSI must be sized to allow sufficient manufacturers to bid.

e. FSI connection. For vertical wet pit pumps which are suspended from the operating floor, the connection between the FSI and the pump is determined by the pump manufacturer after the pump manufacturer performs a dynamic analysis of the pumping unit to determine the critical speeds of the pump. It is recommended that the FSI be formed or cast integral with the sump concrete.

Appendix D
Operation and Maintenance Manual Example for Pump Stations Including Gates

PUMPING STATIONS

1. Pumping Station No. ___.

(Pump Station Name or Location) is located near what road or intersection. Describe the discharge arrangement from the station including discharge piping size/s. Provide the amount of drainage area of approximately ____ acres serves as a storage pool. Number of pumps in station and design discharge capacity ____ gpm. Describe how the pumps are started manually and stopped automatically.

2. Maintenance. The regulations state the following pertinent requirements for maintenance for the pumping stations:

a. Pumping stations must be inspected by the Superintendent at intervals not to exceed 30 days during flood seasons and 90 days during off-flood seasons to insure that all equipment is in order for instant use. At regular intervals, proper measures must be taken to provide for cleaning station, buildings, and equipment, repainting as necessary, and lubricating all machinery. Adequate supplies of lubricants for all types of machines, fuel for gasoline or diesel-powered equipment, and flashlights or lanterns for emergency lighting must be kept on hand at all times. Telephone service must be maintained at pumping stations.

b. All equipment, including switchgear, transformers, motors, pumps, valves, and gates must be trial-operated and checked at least once every 90 days. Megger tests of all insulation must be made whenever wiring has been subjected to undue dampness and otherwise at intervals not to exceed 1 year. A record should be kept showing the results of such tests. Wiring disclosed to be in an unsatisfactory condition by such tests should be brought to a satisfactory condition or must be promptly replaced.

c. Diesel and gasoline engines should be started at such intervals and allowed to run for such length of time as may be necessary to insure their serviceability in time of emergency. Only skilled electricians and mechanics should be employed on tests and repairs. Operating personnel removed for the station for repair or replacement should be returned as soon as practicable and should be trial-operated after reinstallation. Repairs requiring removal of equipment from the station should be made during off-flood seasons insofar as practicable.

3. Readiness.

Regular inspections, tests, and maintenance of the pumping stations should be accomplished as directed herein to provide a reasonable indication of the readiness of the pumping facilities for uninterrupted operation, and to reduce the possibility of failure of vital electrical and mechanical equipment during critical flood periods. The thoroughness and care with which the inspector does his work will determine the reliability of the equipment. Inspectors should be familiar with the manufacturer's instructions in both the function and adjustment of various devices. In order to insure thorough inspection, the checklists for inspection of pumping stations should be used.

(NOTE: Insurance against breakdown of equipment in the pumping station is available through insurance companies. Such insurance provides for inspection of pumping station and equipment at regular intervals by the company.)

4. Manufacturer's Instructions.

The general instructions herein cover the normal operation and maintenance of the pumping equipment. The operators should also be familiar with the equipment manufacturer's drawings, literature, and instructions in case more detailed information may be required for maintenance and operation. In case of major operating difficulties or repairs of a particular item of equipment, the manufacturer should be consulted.

5. Pumping Stations.

The pumping stations should be properly maintained. The doors, metal, and wood parts should be adequately protected with paint to prevent corrosion or rotting. All hardware should be well oiled or greased for ease of movement and to prevent corrosion. Any cracks or leaks that may develop in the walls, roof, or floor, allowing water to leak or seep into the structure, should be sealed with waterproofing material. The lighting system should be maintained in good working order and all defective lamps should be replaced promptly. The station should be kept free of fire hazards, locked when not in use, and made inaccessible to trespassers at all times. One complete set of keys is located in the office of the Superintendent.

5.1. Grounds and Access Roads.

The roads leading to the pumping station, grounds around the station, and ponding area should be maintained in good condition at all times. Drainage and surface repairs should receive immediate attention when conditions requiring remedial measures arise. This will insure access for heavy rolling equipment at any time and under all weather conditions.

5.2. Crane and Chain Hoists.

The pumping stations are equipped with hand-operated crane and chain hoists of sufficient capacity to handle the heaviest pump or motor in the stations. When it becomes necessary to remove the pumps for repairs, the motors should be hoisted separately from the pumps. No attempt should be made to handle the motor, base plate, and pump together. The crane and hoist should be inspected at regular quarterly inspection. Parts should be adequately protected with paint and oiled or greased for free movement.

5.3. "Megger" Tests.

"Megger" readings, as called for by the regulations, should be taken at the times of regular quarterly times as when wiring has been subjected to undue dampness or excessive dirt conditions. "Megger" tests, properly recorded, show a continuous graphic picture of the condition of the insulation. A study of this picture may make it possible to detect approaching trouble before a breakdown occurs.

a. Insulation Resistance – Temperature Curves – Above 1,000 Volts. Minimum safe values conform to the requirements of the NFPA 70.

b. When the corrected values of insulation resistance are plotted against time, any trend of the readings can be accurately observed. This knowledge is important, as the gradual deteriorating effect of an insulation can be observed and corrective measures taken. The values to be entered on the Insulation Resistance Report, for the motor windings, should be corrected values.

c. Insulation Resistance-Temperature; Below 1,000 Volts. It is recommended that a series of megger readings be made on each piece of equipment at various temperature and humidity conditions, to establish an adjusted "base" for interpretation of future readings. This should be done while the equipment is relatively new.

d. When future resistance readings are made, they should be compared to the base data. If the readings are made, they should be compared to the base data. If the reading at any time is less than 50 percent of the base value, further checks should be made. If the low value appears to be the result of excessive moisture and/or dirt, the insulation should be cleaned and dried.

e. If the readings continue to drop over a period of time, indicating a breakdown of insulating material, major repair is indicated and should be undertaken as soon as possible. General practice is to consider equipment unsafe for operation when insulation resistance is less than 1 megohm per 1,000 volts of apparatus rating, but never less than 1megohm. When necessity for equipment use outweighs possible damage to equipment, it may be used in unsafe range with extreme precaution.

f. Taking "Megger" Readings. The Megger Insulation Tester is a compact lightweight instrument that tells at a glance just what the resistance of the insulation is. All that is required for operation is to connect one of the test leads to the terminal of the machine or wiring to be checked and the other test lead to ground. Then, upon turning the crank, the resistance of the insulation is shown on the direct-reading scale.

g. Drying Windings. Dampness of the windings may be indicated by low insulation resistance. An unsafe low resistance due to this condition will require that the insulation be dried out. It is recommended that drying of winding be accomplished through the application of external heat. External heat should be applied under a canvas cover, properly vented. Heating should not go beyond 85 degrees C. (185 degrees F.), as water might be boiled in the insulation. Keep a check on the temperature.

h. Portable strip heaters or special infrared-ray lamps may be used for this purpose. When damp insulation is being dried, the resistance will generally fall rapidly as the temperature is raised to a drying value. After falling to the minimum for a given temperature, the resistance will rise as moisture is expelled from the insulation. The motor can be placed in service as soon as the resistance measurement rises to the minimum value herein and the remainder of the drying will be accomplished by the heat generated through the operation of the motor.

i. Should low resistance readings be obtained regularly at similar yearly periods, it may be advisable to operate electric space heaters in the pumping stations at these times or to increase the capacity of dehumidification. This will prevent deterioration of the insulation and prolong its useful life.

5.4. Dehumidification.

a. The relative humidity should be checked during each quarterly inspection or more often if desirable. When entering the station for the purpose of obtaining the relative humidity, it is important that the door be closed as quickly as possible and that it be kept closed while psychrometer readings are being taken. The reading obtained by the use of the psychrometer should be treated as follows:

(1) Check the relative humidity obtained against the value set on the humidistat. Reset or recalibrate humidistat if necessary.

(2) Write the building temperature on the “megger” report card in the space provided.

(3) Write the relative humidity on the “megger” report card in the space provided.

6. Electrical Equipment.

All electrical equipment, including transformers, and all component parts of the power supply, the switchgear, circuit breakers, automatic controls, cutouts, insulators, switches, meters, etc., should be checked at the regular quarterly inspections to assure that these facilities are in satisfactory operating condition and ready for service. The float control equipment is described below. The transformers, circuit breakers, and other component parts of the switchgear should be maintained and serviced as prescribed by the manufacturer. Pumping station operators should not adjust any station equipment during inspections and trial operations. Switchgear should be kept in condition, including cleaning by component maintenance personnel. Equipment should be adjusted or serviced only by skilled mechanics. In cleaning circuit breakers, relay contacts and control switches, silvered surfaces should not be sandpapered. All electrical equipment, particularly the switchgear, should be kept as dry as possible. It is recommended that arrangements be made with the power company for the inspection of the electrical equipment and transformers and that data pertaining to these items be added to the inspection reports.

6.1. Pumps and Motors.

Pumps and motors should be maintained and serviced per the manufacturer’s instructions furnished the city. The pumps and motors should be trial operated and parts inspected as outlined under the operating instructions in this section of the manual.

6.2. Control Equipment.

Describe the types of controls and the equipment used for operation of the pumps. Example is manually started and automatically stopped or fully automatic in operation. Automatic starting and stopping of pumps is accomplished through electric transducers or float control equipment. This equipment should be checked at regular intervals to insure successful automatic pumping control.

7. Repairs.

Replacements or repairs of the equipment described herein as determined by the inspections and tests are to be affected by trained personnel without undue delay. In taking remedial measures during periods of imminent high water, repairmen should bear in mind that use of the station may be required at any time, and therefore, repairs or replacements should be accomplished with the utmost speed without sacrificing quality of workmanship.

8. Trial Tests.

Each item of pumping equipment should be trial operated for a period of at least 5 minutes as required herein. It is suggested that, in these trials, the motors be run consecutively and not concurrently. Procedures for operation during testing will be essentially similar to those described herein for normal station operation. During these trial runs, the inspector should search for danger signals that will give warning of possible failure of equipment.

9. Air Relief Valves.

Pump discharge lines are often equipped with check valves located at the maximum elevation of each line on the riverside of the levee crown. Their function is to remove automatically any air trapped in the line during pumping operations. These valves should be inspected at the regular quarterly inspections to be sure that they are in satisfactory operating condition. The discs, in particular, should not be worn and should operate freely.

10. Inspection and Trial Operation.

Pumping stations should be inspected at intervals not to exceed 30 days during the flood season and 90 days during off-flood season. Such inspections should be made at the * beginning of the months of December to May, inclusive, and in July and October. In addition, all equipment, including switchgear, transformers, motors, pumps, valves, and gates should be trial-operated and checked at least once every 90 days. Such trial operations should be made at the beginning of the months of October, January, April, and July. Sample checklist and log forms for use in making inspections and trial operations of pumping stations are shown in the appendix. The checklist forms contain an inventory of tools and spare parts necessary for the operation and maintenance of the stations. Missing parts and tools should be replaced as quickly as possible. Any irregularities should be noted thereon.

The regulations provide that:

"Competent operators should be on duty at pumping stations whenever it appears that necessity for pump operations is imminent. The operator should thoroughly inspect, trial operate, and place in readiness all station equipment. The operator should be familiar with the equipment manufacturer's instructions and drawings with the "Operating Instructions" for each station. The equipment should be operated per the above-mentioned "Operating Instructions" and care should be exercised that proper lubrication is being supplied all equipment, and that no overheating, undue vibration or noise is occurring. Immediately upon final recession of floodwaters, the pumping station should be thoroughly cleaned, pump house sumps flushed, and equipment thoroughly inspected, oiled and greased. A record or log of pumping station operation should be kept for each station, a copy of which must be furnished the District Engineer following each flood."

10.1. Operating Instructions.

Pumping station operating instructions for each pumping station is included in this manual. A larger copy has been mounted and placed in applicable pump station where it will readily be available. The operating diagram shows a layout of equipment, identification of control equipment, operating instructions, and pumping schedule. The flood stage at which each pump should be prepared to go into operation is shown on the pertinent pumping station operation diagram and also on the general plan.

10.2. Operation Log.

The operator of each pumping station should keep a complete log of operations for the entire period over which pumping station requirements are carried out, i.e., from the time of notification of the operator to report for duty to closing down and locking the pumping stations. The log of operation should include readings at 1-hour intervals, a record of all operational and maintenance duties performed, and the exact time of starting and automatic or manual stopping for each pump.

11. River Location of Pump Station ____River – Rate of Rise – Pumping Station Operations.

It is imperative to allow ample time to prepare the pumping stations for operation for such time when pumping will be required. Due consideration must be given to the rate of rise of the river. Consideration must also be given to possible delays in operation due to inexperienced help and other contingencies. It is advisable to prepare the pumping stations at least 24 hours in advance of any anticipated operation in order that sufficient time will be available for any required minor repairs. The pumping stations should be inspected, the transmission line and substation energized, the pumps lubricated, trial operated, and made ready for operation at the pumping elevations as follows:

TABLE D.1
ORDER OF PUMP STATION OPERATIONS

Pump Station	River Elev.	River Stage

12. Pumping Station Preparation.

When National Weather Service predictions indicate that the river will attain stages at which pumping may be required, competent operating personnel should be on hand at each pumping station in ample time to prepare the pumping stations and to trial-operate the equipment for pumping operations. The extent of pumping station operations will be dependent upon the local rainfall during high river stages. Operators should keep each station in operation or in constant readiness until the river has receded to the maximum pumping elevation for the respective pumping station and predictions indicate that another increase in river stage is not anticipated from the current flood.

12.1. Sump Preparation.

Prior to admitting water to the sump, the sump should be inspected and cleaned of any debris which might be drawn into the pumps and damage them. Each station has been provided with a trash rack rake. As the debris collects on the trash rack during pumping operations, it should be removed with the rake so as not to diminish the intake capacity nor damage the pumps. Personnel should not be permitted to enter the sump until precautions have been taken against danger from toxic and explosive gases and a possible deficiency of oxygen.

12.2. Instructions in Starting Motors.

a. General.

(1) Prior to energizing any pumping station, check the control panels and make sure that all switches are in the "OFF" position. Also, that the airbreak switch on the substation tower is open.

(2) Notify power company (24 hours in advance) and request energizing of the pumping stations.

(3) Make sure that pumps are free to rotate, that impellers are up and no foreign matter has lodged in the pump to cause damage. Preliminary oiling by hand oil pump will always be necessary before operation of the pumps. Oil should be forced to all bearings until a slight increase in turning effort is noticed.

(4) All motors and their corresponding controls have the same number.

(5) Always allow motors to attain their full speed before stopping them.

(6) All circuit breakers may be tripped to stop the motors by giving the operating handle a sharp twist in a counter-clockwise direction.

(7) The ammeters should be energized at all times during operation. Any sharp rise in current consumption to a motor indicates an increase in load. The unit should be stopped immediately and investigated to determine the cause. It is advisable to apply extra oil to the bearings in this case in order to prevent the possibility of a bearing freezing. The full load current rating of each motor should be checked against the value read at the ammeter for that motor. Readings more than about 10 percent above the rated full load will indicate the unit is operating under an overload.

b. Pumping Station _____.

(1) Read the "general" instructions above.

(2) To close the airbreak switch on the substation tower, unlock it and, when closing it, replace the pin to hold the switch in the closed position.

(3) Energize the lighting transformer by turning the switch marked "LIGHTING TRANSFORMER" on the control panel one-quarter turn clockwise. The lights in the station may then be controlled from the lighting panel just inside the door. The line voltage should be _.

(4) For dry operation of the pump, it will be necessary while running to hold in the button marked "RELAY RESET." These buttons are located at about the center of the upper right cell of the control panel.

(5) Hold in the button for the desired motor to be started, then pull sharply the handle of the corresponding circuit breaker in a clockwise direction. The motor should start immediately. To stop the motor in dry conditions, release the button.

(6) When there is water in the station sump and it is over the electrode, it is necessary only to close the circuit breaker to the motor being started. The motors may be stopped by either pressing the button located at the bottom of the upper right cell marked “STOP” or by tripping the circuit breaker at the control handle.

12.3 Protective Devices.

Pump motors are protected against undervoltage overload and short circuit. Protection is obtained by undervoltage release and dual thermal-magnetic overcurrent tripping device built into the breakers. The undervoltage release and the dual thermal-magnetic tripping device are automatically reset. Should a breaker trip, determine and correct the cause then restart the pump motor by rotating the circuit breaker handle rapidly and smoothly one-quarter turn in a clockwise direction until it locks into place.

12.4. Pump Operation Precautions.

The pumps should not be operated unnecessarily when the water surface in the sump is below the minimum sump elevation shown on the operation diagrams and above the bottom of the suction bowl. Exceptions may be made during periods when the pumping equipment is being tested in expectation of high water, and then only for short periods of time. The continued operation of the pumps when the impellers are submerged but with the water surface below minimum design sump elevation may result in excessive vibration and also in cavitation of the pump impellers and bowls. Unless the water surface is above minimum sump elevation, pump tests during routine inspections should be made preferably when the water surface is below the bottom of the suction bell.

12.5. Lubrication.

All axial pump lower bearings and sump pump bearings are grease lubricated. Prior to placing the pumps into operation, the following precautions should be observed.

a. Thoroughly lubricate all pump bearings and check oil levels in motors.

b. Rotate the pump shaft by hand to be sure it does not bind.

c. Operate the manual control.

13. Electric Service.

When a pump station is to be placed in operation, the power company should be notified 24 hours in advance to allow its employees to close the necessary cut-out switches for energizing the transmission line. The power company should also furnish a qualified individual to be present when each station is energized in case of short circuit or some other electrical difficulty. The substation is energized by closing the air-break disconnect switch at the substation after the transmission line has been energized.

14. Automatic Stop Control.

Automatic stopping of pumps at minimum pumping elevations is accomplished through the float switch/PLC equipment. In the event that pump motors fail to stop automatically at minimum pumping elevation, they should be stopped manually either by returning the selector switch to the "OFF" position, or by rotating the circuit breaker handle in a counter-clockwise direction until it "trips."

15. Closing Down Pumping Stations.

a. When the floodwaters have finally receded and it has been decided to close down the pumping station, turn all switches to the "OFF" positions and notify the power company to de-energize the substations. The pumping stations and sumps should be thoroughly cleaned and the equipment completely inspected, oiled, and greased.

b. After each flood period and at periodic inspections, all parts of the pumps should be checked. The pump bowls should be inspected for cracks, pitting, or other damage. The impellers should be examined for possible damage, pitting, or looseness on the shaft, etc. The bearings and grease lines should receive close examination for possible damage by floating debris, vibration, or excessive strain.

c. A log of pumping station operation should be furnished the District Engineer following each flood. It is advisable that a log of operations be also submitted for all trial operations of each pumping station in order to be certain that all inspections and operations are carried out and that a complete record of the operations is available for future reference.

16. Safety Equipment and Precautions.

Safety equipment such as guardrails, precautionary signs, fire extinguishers, etc., have been incorporated into the stations. Principal safety precautions are:

a. A guardrail has been provided around the trash rake platform. It should be inspected periodically for corrosion and anchor bolt security.

b. A permanent galvanized steel ladder provided in the sump with a grab bar in the wall above. It should be inspected periodically for corrosion and anchor bolt security. If there is any doubt about ladder or anchorage conditions, a portable ladder should be used until repairs can be made.

c. The hinged ladder access hatch through the raking platform should be kept closed when the station is operating. Hinges should be inspected and greased periodically. During maintenance work or inspection when the sump must be entered, horses or other protective warning devices should be placed around opening.

d. Fused disconnect switches on the substation primary and an unfused disconnect switch inside the pump station structure on the substation secondary are provided to isolate the pump station electrical systems. Safe operation requires the following:

(1) A power company representative should be present each time substation is energized (fused disconnect closed). Before energizing substation primary, be sure that unfused disconnect on substation secondary is open. It is desirable that company representative remains until secondary disconnect is closed and it is ascertained that all electrical circuits are in operating condition.

(2) Be sure that all motor starter switches are in “OFF” position before closing the unfused disconnect switch and never open it when pumps are running. It is not constructed to handle opening or closing under load.

(3) Use fuse pullers when replacing fuses.

e. Secondary circuits of ammeter current transformers should be complete at all times to prevent induction of excessively high voltage in these circuits. Before removing meters or meter switches for servicing, be sure to short-circuit the transformer secondary.

f. Paint, grease, and oil should be kept in closed containers. Oily rags should be removed from the station. Station should be swept out and aired daily while in operation.

g. Dangerous Gases and/or Oxygen Deficiencies. Manholes sumps, and other confined area with no positive ventilation should be recognized as potentially dangerous due to possible presence of enclosed spaces such as manholes, sumps, etc., a positive procedure to eliminate or control the hazards should be established.

(1) Hazards considered should include toxic material and vapors, flammable materials and vapors, asphyxiating, corrosive, or radioactive material, and lack of oxygen.

(2) Enclosed spaces should be tested for contaminants and periodic check tests should be made to assure an acceptable atmospheric condition.

(3) Adequate mechanical exhaust ventilation should be provided.

(4) Protective clothing and respiratory protection should not be used as a substitute for cleaning and ventilating of spaces.

(5) No one should enter an enclosed space containing a flammable atmosphere or one which, because of oxygen deficiency or contamination, may be immediately harmful to life in case of failure of the respiratory equipment.

(6) Persons working in confined or enclosed spaces should have a safety harness and lifeline with an attendant if the atmosphere has oxygen deficiency or contamination sufficient to require respiratory protection. The attendant must be assigned no other duties. A signal system should be established.

h. Warning and Safety Signs. See that adequate warning and safety signs are properly placed near energized or other hazardous equipment and that the signs are maintained in good condition.

i. Carbon Dioxide Fire Extinguisher. Fire extinguishers should be inspected and maintained as required by EM 385-1-1 and by the National Fire Protection Association. A carbon dioxide type fire extinguisher has been provided for use on electrical and oil type fires which might occur in the station. Due to a large amount of electrical service should be disconnected (either to the affected equipment for a small fire or at the substation for larger fires) before using fire extinguisher.

17. Maintenance Schedule

	INSPECTION FREQUENCY
Visual inspection for proper location and condition Check seals.	Monthly (Operational)
Weigh units and recharge any unit weighing less than 90 percent of normal weight.	Semiannually
Fire extinguishers should be returned to the manufacturer or to an approved fire equipment company for hydrostatic cylinder test.	5 years

PREVENTIVE MAINTENANCE

1. General.

a. Purpose. This section of the manual is intended as a guide for the personnel responsible for operation and maintenance of pumping station and other equipment used in the flood protective system. It outlines basic maintenance procedures that are in general practice in stations of this nature in order to guide the operating personnel in systematically detecting and correcting incipient defects before they occur or develop into major failures. It is not intended that instructions contained herein are to take the place of the manufacturers' instructions on maintenance but to be a compilation of general procedure advocated by manufacturers and found necessary through experience.

Although some manufacturer's instruction books have been furnished the City, the Superintendent must procure and maintain for reference a manufacturers' instruction file on all equipment installed. In cases of variance herein from the manufacturers' instructions the latter should be followed.

b. Basic Equipment Care. Preventive maintenance is the systematic inspection and servicing required to keep equipment in continuous service or ready for service. It includes proper care, use, operation, inspection of equipment, cleaning and lubrication. The following paragraphs describe the basic operations making up preventive maintenance.

c. Inspection. Regularly scheduled inspections are necessary to detect and correct mechanical and electrical defects or conditions which prevent efficient operation. The thoroughness and care with which the inspector performs his work may make more frequent inspection than prescribed in the manual unnecessary, while on the other hand, hasty and haphazard inspection will eventually result in trouble even if performed often. Inspections and repairs should be entrusted only to a competent person.

The inspector should have, at least, a general understanding of the electrical and mechanical characteristics of the apparatus being inspected, and sufficient information concerning its correct operating performance to enable him to know whether adjustments and repairs are necessary. The inspector should have access to, or provide himself with, such instruction books (manufacturers' and other publications) pertaining to the apparatus requiring inspection as may be necessary for the satisfactory performance of his duties. Attention should be given to the following items at all inspections.

d. Sound and Appearance. Motors and pumps of different sizes have their own characteristic operating sound when in operation under various conditions. An operator, after a time, will become accustomed to this sound and should immediately investigate any noticeable change from this normal sound. Cleanliness increases the efficiency and life of apparatus.

e. Cleanliness. Moisture, dirt, dust, cobwebs, bugs, or oil causes deterioration and corrosion of mechanical and electrical equipment. Unnecessary oil on surfaces always collects dirt. Cleaning and painting is a most important element needed in preventive maintenance and life of apparatus.

f. Heat. Conditions which cause excessive heat in operating equipment must be eliminated. Since excessive heat cannot always be determined by touch, thermometers should be used for measuring temperature.

g. Condition of Parts. Adjustment or replacement of defective parts is a requirement of every preventive maintenance schedule. Disassembling equipment at regularly scheduled intervals by a factory representative, or a mechanic of equal skill on the equipment being checked, may be necessary for complete inspection.

h. Testing and Adjustment. Testing for proper operation is important. Testing procedures may show that equipment is out of adjustment and not capable of full efficient performance. Trouble may then be located and corrected before a breakdown results.

2. Record Keeping.

a. Records. Preventive maintenance programs are effective only if careful, accurate, and complete records are kept of all work done. In no other way can the Superintendent insure that all personnel are carrying out their individual responsibilities and that all equipment is being properly inspected and maintained.

b. Frequency of Inspection. It is recommended that the manufacturer be consulted as to the physical features of the equipment that should be inspected and the required frequency of the inspection. The instructions set forth in the preceding sections of the manual give the minimum frequencies of inspection for the various features of the works. In no case should inspections be made at a rate less than the frequency prescribed therein.

c. Inspection Records. The check list forms provided have been prepared with due reference to past experience on similar projects although they are not considered as complete as they might be for a thoroughly effective maintenance program. They should serve however, until the Superintendent has had the opportunity to study the installed equipment, manufacturers' recommendations and local conditions and establish a program of inspection particularly applicable to the local project.

d. It is suggested that for an effective preventive maintenance program a record system be set up by the City covering inspection and service for each piece of equipment as described hereinafter. Usually these systems are set up on cards with the inspection schedule on one side and the service performance record on the other. The inspection side sets up the schedule and shows, 1) the equipment and description, 2) the various parts of the equipment to be inspected, 3) the work to be done (lubrication, adjustment, operation, cleaning, etc.), 4) the frequency of inspection, and 5) the date or dates when the inspections should be made. The reverse or service side should record 1) the date of actual service, 2) the part of the equipment on which the maintenance has been performed, 3) by whom performed, 4) type of repairs, if any, required, and 5) the date and by whom the repairs were made.

3. Power Failure.

Power failures during an emergency may be a cause of considerable damage to areas dependent on pumping stations for protection. In order to prevent or hold damage to a minimum, the Superintendent should prepare a list of actions, in their order of importance, to be followed in case of sudden power interruption. This list should be posted prominently in each station.

4. Spare Parts.

a. Availability. In order to be assured of operation of the station equipment when required, it may be necessary to carry a stock of certain parts or know where such parts may be obtained quickly and the time required to procure them. The Superintendent should obtain a parts list with their order number from the manufacturer so that any part may be obtained in an emergency without harmful delay.

b. Parts on Hand. A sufficient number of all sizes of fuses should be kept on hand at all times since these are more apt to need replacement than any other part. The necessity for having other parts on hand may be judged better after consulting with the manufacturers.

5. Care of Functional Structures.

a. General. Pumping stations and flood protection structures, such as gate wells, walls, etc., require periodic inspection as prescribed by Regulations. Pumping station sumps, that contain seepage, should be emptied for such inspections. Masonry structures should be checked for spalling, porosity, cracks and breaks in expansion-joint seals. Flood structural appurtenances such as parts of gate closures, added station fixtures, etc., should be checked for rot, warping, and checking. In particular, flood installations in the pumping station sumps should be checked for possibilities of loosening and entering or clogging the pump intake.

b. Masonry Structures. No large masonry repair job should be undertaken without prior approval of the District Engineer.

(1) Spalling. When spalling is allowed to continue, progressively greater damage is caused to the structure. It should, therefore, be repaired as follows:

(a) Repair concrete surfaces with shallow spalling with special cements such as Cameo, Rugged wear, Standard, or similar materials, which permit carrying the patch to a feather edge.

(b) Patch deeply spalled or porous concrete with ordinary cement, using approximately the same mix as the original concrete. Avoid rich grouts as they cause shrinking.

(c) Keep checked concrete from spalling by sealing the surface with bituminous asphalt, or synthetic resin base paint, suitable for contact with water, making due allowance in the selection for finished appearance.

(2) Cracks. Cracks also lead to more serious damage, especially when structures are exposed to heavy freezing. Therefore, it is important that all cracks be repaired immediately on discovery. Cracks may readily be repaired with the special cements listed above. Where water is flowing from the crack, use special quick-setting mortars or alternately pump sodium silicate and calcium chloride solutions into the crack. (For information on the latter method write to The Philadelphia Quartz Company, Philadelphia, Pennsylvania.)

c. Wood Structures. Wood does not deteriorate under water, but wood used elsewhere may rot quickly unless it is coated with creosote, paint, or other preservative, as may be required, depending on its use and location.

6. Painting.

Periodic painting is required of the parts of pumping stations, storage vaults, closure materials, and other structures that require this type of protection in order to protect metal parts from corrosive action of water and other elements. Frequency of painting varies, depending on type of paint used, method of application, and condition of wear. Always paint metal surfaces before corrosion becomes so severe that equipment is damaged. Prepare metal surfaces by sandblasting, if practical, or by cleaning them thoroughly with sandpaper and wire brush. Only specially prepared paints should be used on damp surfaces that will be encountered in the protection works. Corrosion-preventive compounds may be used in moist or wet places and in gate wells where paint would not last.

7. Valve and Gate Maintenance.

a. General.

Since conditions may not arise with sufficient frequency to require operation of the various gates and valves it is essential that these valves and gates be given several complete cycles of operation at the regularly scheduled quarterly inspections to prevent them from sticking or becoming difficult to operate. If flowage conditions make complete closing of sluice gates impractical, they should be operated to as complete a closure as possible. Check for corrosion of threaded stems and keep steel stems coated with grease to prevent corrosion.

b. Gate Valves.

(1) Should leakage occur around the stem, packing may have to be replaced. These valves can be repacked without removing them from service. Open the valve wide to draw the stem collar of a non-rising stem-valve tightly against the bonnet; or on a rising stem-valve the stem base is tightly drawn against the bonnet bushing, preventing excessive leakage when packing, or the entire stuffing box is removed. Remove all the old packing from the stuffing box. Clean the valve stem of all adhering particles and polish with fine emery cloth. Replace with new packing and assemble the valve.

(2) Repairing Gate Valves. Where the gate valve seats leak they may be refaced using the method described below.

(a) Remove bonnet. Clean and examine gates and body. If too much metal has been corroded, repairs may be impossible or impractical.

(b) Remove stem from bonnet. If stem is scored or pitted, polish lightly with fine emery cloth.

(c) Remove old packing and clean stuffing box. Clean all other parts, removing all dirt and scale.

(d) Remove and discard old gasket. Replace with one of proper quality and size.

(e) Set each gate in a vise with face level. Wrap a piece of fine emery cloth around a flat tool and rub or lap the entire bearing surface to a smooth, even finish. Remove as little of the metal as possible.

(f) Remove any cuts and scratches found on body rings by lapping. Rub ring surfaces all around with small emery block. Work carefully and watch progress closely. Avoid removing too much metal as this may cause the gates to seat too low. Make both gates seat at the same depth.

(g) When seating surfaces appear to be properly lapped in, coat the faces of the gates with Prussian blue and lower them into the body to check the bearing. When a continuous contact has been obtained, the valve is tight and ready for reassembling. Clean parts.

(h) To assemble, insert stem in bonnet, install new packing, assemble other parts, attach gates to stem and place assembly in body. Raise the gates to prevent contact with the seats. Tighten the bonnet joint. Test repaired valve.

c. Globe Valves. Globe valves are used on the city water supply lines serving some of the pumping stations. These are of small size and maintenance or repair is generally limited to the replacement of the washer and refacing the seat. Repairs can be made along the same lines as outlined under gate valves above.

d. Check Valves. Check valves must be in good operable condition at all times during high water periods. It is recommended that these valves be opened for inspection just before the flood season and the operations as are described below are performed.

(1) Remove bolted cover and observe conditions of disc and seat ring.

(2) Remove and discard old gasket. Replace with one of the proper quality and size. Suitable gaskets may be cut from 1.5 mm (1/16 inch) asbestos sheeting.

(3) If seat ring or disc is scarred, unscrew side plug, withdraw hanger pin, and remove disc and hanger assembly.

(4) If disc and seat ring needs resurfacing, remove hanger nut to separate disc from hanger assembly and unscrew seat ring from body of valve. If too much metal has been corroded, replace disc or seat ring as necessary.

(5) If re-grindable, dress with a fine file and lap with fine emery cloth wrapped around a flat tool or use an emery block. Remove as little metal as possible.

(6) When surfaces appear to be lapped in, coat the seating surfaces with Prussian blue and check bearing area. When a good continuous contact has been made, the valve may be reassembled.

(7) Check hanger pin wear since disc must be accurately positioned on seat to prevent leakage. Replace pin if worn.

(8) Clean interior of valve body, removing dirt and scale. In reassembling, coat hanger pin with a thin film of lubricant.

e. Automatic Flap Gates. Automatic flap gate operation is similar to that of check valves. Gates are generally of cast iron or cast steel. These gates require very little attention other than cleaning and lubrication.

(1) Lubrication. At regular intervals the hinged parts should be lubricated with grease. Some hinges are provided with fittings, or with opening, whereby they may be lubricated by use of a grease gun. In other cases it may be necessary to unbolt the pins and remove the links in order to apply grease to the bushings. Disassemble only one side at a time and provide a table support for the flap while the pins are removed.

(2) Just before the flood season, and more often if necessary, clean all the parts with a wire brush, removing all dirt and scale.

(3) Wire-brush the bearing surfaces of the flap and seat for continuous contact. If flaps and seat rings do not line up properly, check bushings or hinge pins for excess wear and replace if necessary.

(4) Paint all steel parts with the proper type of corrosion-resistant paint.

f. Sluice Gates. Sluice gate principle of closure is somewhat similar to that of the gate valve.

(1) Just before the flood season clean all the parts with a wire brush removing all dirt and scale. Clean the wedges and the slides thoroughly. Paint all the steel parts with a suitable corrosion resistant paint.

(2) Remove all hardened grease and replace it with proper grade and type grease. Examine the grease box in two-speed flood stands especially for hardened grease and repack when necessary. Grease the slides and wedges of the gates thoroughly to facilitate ease of operation. Use non-hardening grease.

(3) Check and adjust the wedges so that, when the gate is in a closed position, each wedge will apply uniform pressure against the gate and cause the gate to bear against all points on the gate seat. Proper wedge adjustment must be particularly provided for sluice gates installed for unseating pressures.

8. Lubrication.

a. General. Lubrication is an important part of preventive maintenance. The types of equipment and the conditions under which they operate make proper and regular lubrication practices extremely important. Proper lubrication prevents metal to metal contact, eliminates wear, and reduces corrosion. Improper lubrication causes damage to wearing surfaces, increases maintenance costs and power consumption, and results in insulation failure. Contaminants in lubricants assist in the ultimate failure of equipment.

b. Selection of Lubricant. Lubrication instructions given herein include recommended types and intervals for certain equipment. However, these are to be considered only as guides and may require modification. The manufacturer's instructions, or the manufacturer, should be consulted and the advice of oil companies sought to determine the types of lubricants to be used on all equipment. Lubricated mechanisms generate heat which reduces the viscosity of the lubricant. Knowledge of temperatures to be encountered is necessary to enable the oil companies to correctly determine whether the proper grades of lubricants are being used. The maximum temperatures at the points of lubrication should be determined with the aid of a thermometer when the equipment has been operated under load for any length of time.

c. Precautions. It is axiomatic that efficient lubrication is a matter of using good lubricants, properly selected, in the correct quantity, and at the right intervals. Neglect or omission, of any of these factors means accelerated breakdown. Too much lubricant causes antifriction bearings (ball and roller) to heat through increased friction and may damage them as well as the grease seals. Pump sleeve bearings cannot be over-lubricated, but too much lubricant is wasteful. Over-lubrication of motors may result in leaks and cause damage to windings and insulation. Records show that in installations where proper lubricating procedure and frequency of application were not per manufacturer's instructions a great majority of motor or pump failures were caused by over-lubrication. Always keep machinery wiped clean of oil. Investigate and correct oil leaks. Oil should be changed whenever there is any sign of contamination, stickiness or gumming.

d. Condensation. It may seem proper that as long as the correct amount of oil or grease is in a bearing and no noise or heat is noticeable that the machine would operate indefinitely. This however, is not true as the pumping stations are usually damp and condensation is present. Should the lubricating film break down, the presence of moisture would probably lead to corrosion of the metal surface.

e. Deterioration. The principal deteriorating elements in lubricants are dirt, water, oxygen, and excessive heat. If these are controlled, lubricant deterioration between lubrication periods is less likely. Guard against dust, grit, and abrasives getting into containers used for storing lubricants. Wipe spouts and lips clean before using container; wipe fittings clean before filling with lubricant.

9. Bearings.

a. Flushing. When the pump or motor is disassembled it is advisable to flush the bearings with warm thin oil or flushing oil, under pressure. When clean, the bearings should be repacked with proper lubricant and replaced.

b. Grease Lubricated Bearings. Grease lubricated bearings require very little attention. They should be freshly lubricated after long shutdown periods before starting the pumps, and every six hours of operation. Every 1,000 hours of operation, or at three year intervals the old grease should be removed and replaced. Remove the drain plugs, and fill the bearings until fresh grease runs out of the drain plug. Rotate the motor by hand to free bearing. Run the pump for about five minutes. Remove excess grease from the overflow sump and replace the drain plug.

c. Bearing Temperature. Bearing temperatures should be checked if there is any indication that they are overheating or are not running smoothly when the bearing house is felt. After a pump has been in operation long enough for the bearings to be normal temperatures, the bearing temperature should be checked with a thermometer and not by hand. Should the bearing attain temperatures in excess of 90 degrees C. (195 degrees F.), the operating conditions should be investigated. If anti-friction bearings are running hot, check for too much lubricant and remove the excess. If sleeve bearings are hot, check for need of lubricant. If proper lubrication does not correct the condition, disassemble and inspect the bearing. Check the alignment of the pump and motor if the high temperature should continue.

10. Packing. Packing is a close-fitting bearing and, as in the case other bearings, requires adequate lubrication, especially if the packing is contact with a rotating shift.

a. Type. Use the kind of packing recommended by the equipment or packing manufacturer for each packing application. The kind generally used is the braided type. The metallic type may score rotating shafts if improperly used.

b. Packing Care. Observe the following precautions in using packing and caring for packing glands.

(1) Keep follower bolts clean. When the follower bolts are not clean, it may not be possible to ascertain the amount of gland pressure that is being applied. Keep bolts well oiled.

(2) Dry packing causes excessive friction between shaft and packing. Proper lubrication will prolong the life of the packing.

(3) Undue leakage can usually be stopped by tightening the stuffing-box nuts in order to force the packing gland against the packing. A slight water leakage at the packing is desirable.

c. Replacing Packing. When it is necessary to replace packing, use the following procedure for woven or braided packing. If the manufacturer should recommend another type, follow the manufacturer's instructions.

(1) Remove all used packing with a packing removal tool. Clean the inside of the stuffing box and gland. Clean the surface of the shaft. Clean and oil follower bolts so they work easily.

(2) Dip each ring in oil, or lubricate packing while inserting it, and push it into bottom of box. All packings have some lubricants in them. Packing with about 35% lubrication should be selected. Packing must be lubricated; improper or insufficient lubrication can result in heating and shaft scoring. Tamp the packing into position with a packing gland. Out the ends square, not beveled. Stagger the ring splits.

(3) When the box is half full, draw rings up snug by tightening packing sleeves and gland. Rings of woven or braided packing needs not be compressed individually. Repeat operation and pack remainder of box. Draw up snug by tightening all packing nuts uniformly. Tighten gland bolts, one flat at a time. When gland is snug, back off gland until finger-tight. Glands should never be pulled down with a wrench except to affect proper seating when new packing is installed. Never use more packing than is absolutely necessary to keep the pump from leaking.

(4) Packing on a shaft should not be allowed to run excessively hot. Packing expands with heat so that a box that is little more than finger-tight when cold will generally smoke when

equipment is started. As the packing wears in, tighten as necessary. Allow enough time between each turn for the pressure to be transmitted through the packing. Packing that is too tight will cause a braking effect on the pump shaft and overload the motor.

(5) When repacking stuffing boxes, be sure all used packing has been removed and the shaft or shaft sleeve has not been damaged. Sometimes a number of the used rings may be replaced in the box, but usually replacement with new packing is recommended. Never repack a pump by renewing only the last three or four rings.

d. Grease-Sealed Packing Gland. Where grease is used as a packing gland seal, sufficient grease should be maintained in the packing box during operation to prevent undue leakage. Grease cups, where provided, should be kept filled.

e. Leather-Sealed Packing Gland. Leather discs are used as packing gland seals in some instances. The packing and leather discs are generally kept lubricated by oil from an oil reservoir or automatic feed. The leather discs may need replacement when undue leakage during operation occur at the packing glands.

f. Leather-Seals. Where the shaft and its sleeve bearings are placed in a hollow tube that serves as an oil well, the bottom of the tube above the impeller bearings is generally sealed off to retain the oil by means of a leather disc and threaded gland. This leather disc should be inspected at regular intervals for possible oil leakage. Whenever the pumps are assembled after inspection or repair, these leather discs are generally renewed.

11. Electrical System. Where electrical equipment is to be handled, or where contact is possible during inspection, the equipment must be de-energized and effectively grounded. Grounding harness should be applied where applicable.

a. Switchgear Equipment. A test check and inspection should be made of switchgear equipment at all regular inspections. A thorough general check and inspection should be made at least once every year. Switchgear equipment includes all component parts of the switchboard itself and all auxiliary equipment. Equipment consist of switchboard panels, instruments and meters, control switches, indicating lamps, wiring and insulation, bus bars, drawout devices, switches, relays, and circuit breakers. Circuit breakers and transformers are discussed elsewhere in this section.

(1) The switchboard and component parts should be cleaned regularly. This should be done preferably with a vacuum cleaner having an insulated nozzle. Check the general condition of all parts. See that all covers are in place and in good condition, that there are no broken parts and no loose or missing screws and nuts. Metal-enclosed switchgear should be opened at intervals and all internal parts inspected for surface cleanliness. Any accumulated dust should be removed and all insulators carefully cleaned. These precautions are especially necessary if the equipment is located where metallic dust, cement dust, fine powder dust, salt spray, or acid fumes are present in the vicinity.

(2) Instruments and meters should be examined to see that all are in good condition, are registering properly, and have no broken or cracked glass, or damaged cases. Voltmeters, ammeters, and watt hour meters should be tested and calibrated if necessary.

(3) The operation of control and instrument switches should be checked, and the contacts of all switches inspected. Damaged parts should be repaired or replaced. The inspection should also include the operation of the controlled device.

(4) All indicating lamps should be examined, weak or burned out lamps replaced. The operation test of controlled devices should include checking of the proper indication by the lamps of the “open position” (green light) and “closed position” (red light).

(5) Bus bars and connections should be examined. If they appear to be overheating, the cause of overheating should be found and corrected. If due to poor or loose connections (loose bolts and nuts in the bolted joints), these should be tightened. Where joints are badly overheated, it may be advisable to dismount them, clean the surfaces and reassemble them, making sure that all nuts are properly tightened. Should oxidation recur at any electrical joint after having been cleaned of oxide formation, it is advisable to cover such parts with a protective coating of a non-corrosive lubricant (Vaseline, slushing compound, or the like). “Cup grease or other grease which hardens on exposure to air, should not be used.

b. Motors. The motors are of the squirrel-cage induction type and will demand special attention in order to keep in condition for efficient operation. Due to being located in a damp atmosphere and because of infrequent operation, they require particular care so that moisture will not prevent or impede their operation or affect the life of the insulation. Should the insulation resistance value fall below that specified in this manual the motors might be “burned out” if operated.

c. A regularly scheduled test of motor winding insulation will be essential, the frequency being dependent on the degree of dampness of the atmosphere in the pumping station and on the necessity for operating the pumps. A regular system of inspection will tend to make motor operation, when needed, a practical certainty. In order to facilitate locating the cause of forced shut-downs of pump motors, it is advisable to keep records of all troubles and cures of chronic cases.

d. The most dependable motor service with a longer period of motor life can be provided by adhering to the following rules: (1) Keep the motor clean and dry; (2) Keep it properly lubricated; (3) Keep a regular inspection schedule; (4) At all times know the condition of the apparatus; (5) Correct any indication of weakness before the motor fails; (6) Motor repairs should be made only by a component technician.

(1) When windings need cleaning, use suction or mild blowing.

(2) Motor distress warning will often be given by unusual noises caused by metal – to – metal contact or in the odor from scorching insulation varnish. Pump and motor shaft misalignment can be a contributory cause to motor drag or excessive vibration. When the latter is noted the rotor should be turned by hand in order to locate possible misalignment or rubbing.

(3) Rotors. Rotors may give trouble due to open circuits or high resistance points between the end rings and rotor bars. Symptoms of such conditions are slowing down under load, and reduced starting torque. Fractures at the point of connection to the end ring or at the point where the bar leaves the laminations. Such conditions can usually be detected by looking for evidence of heating at the end ring connections, particularly noticeable when shutting down after operating under load. Since considerable technique is required for the repairs of this nature it is recommended that the manufacturer be consulted before attempting repairs.

(4) Air Gap. Check the air gap dimension between the rotor and the stator for concentricity of the air gap. This will give an indication of wearing condition in the bearings. An occasional check will insure against a worn bearing that permits the rotor to rub the laminations.

(5) Even a very slight rubbing will generate sufficient heat to destroy the stator winding insulation. Four measurements should be taken at approximately 90 degrees apart at each end of the rotor. Revolving air gap measurements may be made by taking the measurements at one reference point on the rotor and then revolving the rotor to measure four points on the stator. Stationary air gap measurements may be made by measuring four points on the rotor from one point on the stator.

(6) All measurements should be recorded. A comparison of new measurements with those previously recorded will permit the early detection of bearing wear. These measurements should always be taken just before disassembling and again upon assembling the motor, for comparison purposes.

(7) Stator Windings. Check the cable connections for tightness. Dust and dirt are usually contributing factors to stator troubles. Some forms of dust are highly conductive and contribute materially to insulation breakdown. The effect of dust on the motor temperature through restriction of ventilation is another reason for keeping the machine clean.

(8) The windings, and the motor in general, should be blown out periodically with dry compressed air applied at a reasonably low pressure in order not to damage the insulation. One of the worst enemies of motor insulation is moisture, mold or water standing in the motor. Check the insulation surfaces for cracks and other evidence of need for repair or coating of the insulating materials. The useful life of the motor depends largely upon the condition of its insulation.

(9) Insulation Tests. A check of the insulation resistance will determine the necessity for drying out the windings before the motor may be safely operated. Tests should be performed

to determine the condition of the stator windings as well as switchgear insulation with regard to moisture.

(10) Operating the motor with too low a resistance may “burn out” the motor. The resistance may be readily measured by use of megohmeter-generally referred to as a “megger” which is a self-contained instrument which gives a direct reading of insulation resistance.

(11) In obtaining “megger” readings follow the instructions furnished with the instrument. Insulation resistance will decrease with increase in temperature of the apparatus (cold motor). Factors that affect “megger” readings are dirt, air temperatures, the weather, humidity, and whether tests are made while the apparatus is hot or cold.

(12) The periods of the year most critical can be determined from “megger” readings obtained for each motor under varying weather conditions so that the results of future periodic tests may be properly interpreted. It is important to obtain sufficient readings when the apparatus is cold so that comparison may be made when it is desired to start a motor.

(13) A low insulation resistance, resulting from exposure to moist air does not necessarily mean that the insulation is not suitable for operation, particularly if the insulation resistance, as shown be reference to periodic test data, is reasonably high. It is believed that the general practice of considering motors unsafe for operation when the insulation resistance is less than one megohm per 1000 volts of apparatus rating should be adhered to until sufficient readings obtained over a period of time may indicate otherwise.

(14) If the “megger” tests indicate that the insulation resistance is gradually dropping, adequate steps should be taken as soon as practicable, to correct the conditions causing the lowering of the resistance. If the cause is moisture the insulation should be dried out. The method to be employed and the rapidity with which this should be done is dependent on the necessity for operating the pumps.

(15) Drying Windings. Dampness of the windings may be indicated by low insulation resistance. An unsafe low resistance due to this condition will require that the insulation be dried out. It is recommended that drying of winding be accomplished through the application of external heat. External heat should be applied under a canvas cover, properly vented. Heating should not go beyond 85 degrees C. (185 degrees F.), as water might be boiled in the insulation. Keep a check on the temperature.

(16) Portable strip heaters or special infrared-ray lamps may be used for this purpose. When damp insulation is being dried, the resistance will generally fall rapidly as the temperature is raised to a drying value. After falling to the minimum for a given temperature, the resistance will rise as moisture is expelled from the insulation. The motor can be placed in service as soon as the resistance measurement rises to the minimum value indicated herein and the remainder of the drying will be accomplished by the heat generated through the operation of the motor.

(17) Should low resistance readings be obtained regularly at similar yearly periods, it is advisable to operate space heaters in the pumping stations at these times. This will prevent deterioration of the insulation and prolong its useful life.

e. Lighting System. Maintenance of the lighting system in good condition is an important factor in preventing accidents. Lighting reflectors should be kept clean and lamps replaced when burned out. All wiring should be maintained free of conditions conducive to damage or faulty operation of the system.

f. Transformers. As compared with most electric apparatus, transformers require relatively little attention. The extent of the inspection and maintenance required is governed by the importance of instantaneously available and continuous service, operating conditions, such as ambient temperature, unusually dirty atmosphere, and heavy fogs. In flood protection project installation, availability of immediate and continuous service is of utmost importance and a greater degree of attention is justified than would ordinarily be given where life and property were not endangered by a power failure. Transformers mounted in the open and exposed to the atmosphere are provided with weatherproof casings.

(1) Temperature. If there is any doubt as to whether the operating temperature of a transformer is within safe limits, a check with a temperature gage should be made. Where a well is not provided for this purpose, tank temperature may be obtained by carefully attaching temperature gage at top of tank, below oil level. A factor of 5 degrees Centigrade (9 degrees Fahrenheit) should be added to the tank temperature to get approximate oil temperature in tank. Test temperatures should only be taken when transformers are operating at full load. Temperatures of oil immersed, self-cooled transformers should not be permitted to exceed 95 degrees C. (203 degrees F.) nor should they be operated long at temperatures above 90 degrees C. (194 degrees F.).

(2) Oil Level and Leakage. Keep oil at level required by the manufacturer. If low, inspect all valves and tank for leaks and make necessary repairs immediately. When adding oil to electrical equipment, use same type and grade as is then being used (and as recommended by the manufacturer).

(3) If, due to high operating temperatures, or for any other reason, the condition of the oil is open to suspension, samples should be drawn and tested. At least every 5 years, the oil should be given a dielectric test and, if satisfactory, may be filtered and re-used. If excessive sludge is present, it is an indication that operating conditions are not satisfactory.

g. Fused Disconnect Switches. Fused disconnect switches are installed on the incoming power transmission lines at the transformers and are used to protect the transformers from excessive overload. They are of the knife-switch variety and carry cartridge-type fuses.

(1) Operation. The disconnect switches are used to open the live lines when the pumping station is out of operation; otherwise current will be consumed by the transformers.

The disconnect switches should only be operated when the switches in the pumping station are in the open position. The pole top switches should be operated with the hot-line pole hooks provided for this purpose. These pole hooks are located in the pumping stations.

(2) Care. These switches require very little maintenance. They should be inspected at the time the transformers are inspected. Inspection consists of examining the contact, insulators, mountings and operating mechanism. The contact surfaces should be cleaned when necessary. This may be done by opening and closing the switch several times in succession. In replacing fuses, use the size and type that will furnish adequate protection for the transformer. Be sure that the surfaces of insulators are clean. This is especially necessary when the switches are located where cement or metallic dust, salt spray, or acid fumes are prevalent. Such conditions may cause flashovers or current flows across the insulator.

h. Circuit Breakers. Circuit breakers perform the double purpose of a switching and protective device for the pump motors. They are intended to open the circuit should the current exceed a predetermined rate through these safety devices. The breakers must be given proper care and maintenance. Quite often trouble is forestalled by tightening a wire or switch, replacing spring cotter pins, readjusting and cleaning contacts, keeping latches free of corrosion, etc., when regular periodic inspections are made. The contacts are held closed by means of a holding latch. Overload protection is provided by means of overload relays or overload release devices which release the holding catch and allow the contacts to open. The frequency of complete inspection depends a great deal on local conditions, but, in general, a complete inspection should be made at least once a year, preferably just before the flood season. An inspection should always be made immediately when it is determined that the circuit breaker has been opened by a severe short circuit. Inspections should only be made by a qualified electrician.

(1) Since operating conditions are such that the breakers are kept in the open position for long periods of time, they should be opened and closed several times in succession at the regular inspections. This will aid in keeping all parts in working order.

(2) All adjustments should be made to comply with the requirements of the manufacturer and construction specifications.

(3) Air Circuit Breakers. Air circuit breakers have been installed as controls for the operation of pump motors. Ventilation of breaker cabinets should be maintained by keeping the cabinets free from obstructions.

(4) Examine the main current –carrying contacts, checking for proper alignment and especially the amount of “wipe” in closing and opening. Contacts should be free from dust and dirt accumulation, and should be clean and bright. Check the condition of the arcing contacts (which open after and close before the main current-carrying contacts). If they are badly pitted or burned, it may be necessary to dress or replace them. Surfaces (except silver) that may have become pitted or rough may be smoothed with a clean fine file or No. 00 sandpaper. Do not use emery cloth.

(5) One of the best ways to check contact impression is to close the contacts on a piece of thin tissue paper and a thin carbon paper, with carbon next to the tissue. When the breaker is closed and opened, it is a simple matter to determine the amount of impression made on the paper. Good impressions will show 75 percent or more of the length of each bar on the contacts.

(6) Check the cable connections to see that cable terminal connectors are not overheating, and that all joints in connections are intact and in good conditions.

(7) See that all nuts and bolts are in place and tight; that no pins or cotter pins have worked out of place; and that all cotter pins have sufficient spread to hold them in. All moving parts should be free from binds, and the mechanism should be in good working order. Circuit breaker mechanisms require little lubrication. A general recommendation is to wipe off all excess oil with a clean rag. This should be done at the regular inspection periods.

(8) Check the tripping device and the trip latches to see that the parts move freely, and that the armature of each trip device has sufficient travel to assure a positive blow that will release the breaker latch. Check the calibration setting to make sure that proper protection is obtainable without undue tripping. Measure the length of the breaker stroke and the opening and closing speed to see that they comply with the manufacturer’s specification. Adjustments, if necessary, should only be made by a skilled electrician.

(9) Check the control switch and the closing relay to see that they are functioning properly; check proper operation of indicating lamps, replacing those that are burned out.

(10) Observe conditions while the breakers are carrying their full-load current to make sure that they are not overheating, and that connecting conductors are not feeding heat into the breakers.

(11) Switches. All switches should be thoroughly cleaned periodically by wiping with a clean cloth to prevent accumulation of dust. Avoid touching the contacts with the fingers. Disconnecting switches should never be opened or closed unless the circuit is open at some other point.

(12) See that the blades make good contact. The condition of contact can be checked by attempting to insert a 0.05 mm (0.002) inch feeler gage between the blade and the contact at all accessible points. If the gage can be inserted, adjustment should be made.

(13) Some switches are provided with silver to silver contacts. These contacts do no tarnish, like copper, but they should be wiped clean occasionally. Never grind or sand the surfaces of silvered contacts. The contact surfaces of copper switches frequently need cleaning to remove oxide. This can be done by opening and closing the switch several times in succession. Do not attempt to grind the blades with powdered emery or other abrasives. Such practice inevitably results in poor contact and overheating.

(14) Check contact pressure, and when contact clips, whose efficiency depends upon tension of the spring, are used, make sure that these spring clips have not been annealed by overheating.

(15) In “safety enclosed switches” make sure that the operating handle and mechanism are in good working order, that the cover and interlock are in good condition and that the enclosure ground connection is intact.

(16) Fuses. The contacts on fuses (indoor and outdoor) should be kept clean and tight.

(17) Insulators. Inspect insulators for cleanliness, especially insulated surfaces on which switches are mounted.

(18) Insulating Oil. Dielectric tests and visual inspection of the insulating oil of the oil circuit breakers should be made at the quarterly inspection and after short circuits. If the oil shows signs of moisture, carbonization or dirt, remove the oil, filter and retest it before replacing it in service. At least once a year remove all the oil and thoroughly clean the tanks, tank liners, lift rods terminal bushings, etc.

(19) Do not operate oil circuit breakers excessively electrically when the oil tank is removed.

i. Reversing Magnetic Contactors. Reversing magnetic contactors have been installed in the switchgear cabinets for the control of the sluice gate motors. They serve the purpose of a switching and protective device for these motors. The contacts and other operating mechanisms should be inspected and maintained as described elsewhere in this section.

j. Relays. The primary function of protective relays, which cause the circuit breakers to operate, is to protect the expensive motors. Keeping these relays in proper working condition, therefore, is extremely important. A thorough general check of all relays should be made at least once a year. Since many of these relays are of the precision type they should be examined, tested and repaired by a relay technician. The following precautions must be taken (a) See that the contacts align properly and that they are clean and bright. If they are dirty, or slightly tarnished, they should be cleaned as described elsewhere for contact surface. (b) The moving parts of the relay should not be impeded by accumulation of dirt or dust. If the movement of the parts is sluggish or impeded because of a damaged jewel bearing, the latter should be replaced. (c) No lubrication of relays is usually required during service.

k. Insulation. A dielectric test should be made of all insulated wiring and coils of the switchgear as well as the motor windings. The purpose of dielectric tests is to determine whether insulation will withstand voltage stresses occurring during normal or assumed abnormal conditions of operation. “Megger” readings for switchboard insulation should be taken at the times when they are made for motor winding insulation.

l. Bushings and Insulators. Bushings at transformer installations ordinarily require little, if any, attention. Maintenance is ordinarily limited to cleaning. The frequency of this operation depends on the prevalence of cement or metallic dust, salt spray or acid fumes in the atmosphere.

(1) Examine housing for chipping, shattering, cracks, or other damage, and for loose bolts on assembly or mounting hardware. Dirt deposits under moist conditions tend to form a conductive coating and should be cleaned off to prevent flashover. Check visually for cracked or broken porcelain. The porcelain transformer bushings should be tested with special testing equipment.

(2) Clean bushings and insulators as required by local conditions.

m. Grounds. Ground resistance to all equipment should be tested occasionally. See that transformer tank, outdoor switch gear housing, operating levers, lighting arresters, and metal fencing (around ground level substation) are properly connected to grounds. Ground resistance should not exceed 15 ohms for driven grounds. Test for accidental grounds on ungrounded equipment. Grounds can best be tested with equipment similar to that used by the Power Company.

(1) Cable and Wire. Periodic inspection of cable and wire is the best method of preventing failure. Such inspection should be made for poor thermal conditions and potential danger spots. Exterior wiring should be noted for tension between anchor points which might be off-standard. Wires which are too slack or too tight should be adjusted to proper tension. If cables appear to be carrying excessive temperature, determine the cable temperature by attaching a suitable thermometer to the cable surface.

(2) Check with the Power Company for the proper temperature for cable size and amperage load. Overheating can be caused by overloads or the presence of external sources of heat and will dry and harden the insulation. This in turn either increases the dielectric losses or produces cracks in the insulation and thus hastens ultimate failure. Oil on rubber insulated cables will cause swelling and softening of rubber.

12. Pumping Equipment. The pumps installed in the stations are either vertical centrifugal or the axial flow type depending on the capacity of the unit. Their dependability when operation is imminent is of major importance. Pumping equipment operates with little trouble if it receives proper preventive care. Too little attention is paid to the necessity for completely dismantling pumps at regular intervals. This may eventually result in failure during a critical flood period. Loose shaft joints and shaft-enclosing pipe joints, bearing wear, corrosive and erosive action, metal chipping and fractures, and the like are extremely difficult to detect by external visual inspection.

a. In order to facilitate inspections requiring disassembly, local operating agency should utilize the service handbooks supplied with this manual and should procure replacements, when needed, from the manufacturer or from other reliable sources for complete detailed disassembly instructions for all types of pumps installed.

b. The necessity for having instructions for this nature cannot be fully appreciated until a flood emergency arises combined with damaged pumps that cannot be placed in service until repairs are made. Replacement or repair of some part that may appear to be a simple matter may resolve itself into a prolonged operation due to the lack of knowledge on proper procedure in dismantling and assembling the pump.

c. This is well illustrated by an incident that occurred during a flood emergency in which two full days were spent in removing the tension nut from a pump because the proper procedure for removal of the nut was not known before.

d. Should pump failures occur or undue wear of parts be observed, the mere replacement of the affected parts is not considered adequate toward a program of good preventive maintenance. The determination of the cause of such failures or damage and its correction are considered as essential as the repair of the pump in order to guard against identical future failures.

e. Pumps and Motor Alignment. Check the alignment of the pump and motor when bearings run hot or when excessive vibration occurs. If misalignment should recur frequently, inspect the entire piping system. Unbolt the piping at the suction and discharge nozzles of the pump to see if it springs away, indicating a strain on the casing. Check all the pump and piping supports for soundness and effective support of the load. Shim the units as needed.

f. Bowls, Water Passage and Impeller. Look for pitting, wear and corrosion on bowls, water passages, and impeller. Corrosive water affects performance and dependability of pump. If pitting occurs only in the lower sections of the pump (bowl and impeller) cavitation may be taking place.

g. Cavitation. Cavitation may result from operating the pump when the level of the water in the sump is too low. Cavitation causes severe pitting and characteristic spongy appearance in the metal. It generally affects the entrance portion of the impeller, though it may also occur in the casing. Pumps may be operated for the dry test runs when the sump water is below the intake of the suction bell.

h. Power Consumption. An indication of either electrical or mechanical difficulties may be determined by comparing ammeter and voltmeter readings for each motor during no load test run with past records for similar conditions. A noticeable increase in the ammeter reading with a normal voltage indicates an undesirable condition, which should be traced. Under full load the current demand should not exceed that shown on the data plate of the motor.

i. Disassembling and Inspecting Pump. The frequency of completely disassembling the pump for a thorough inspection will be dependent on local conditions. It is cautioned that such inspections should not be deferred for long periods as costly breakdowns may result at a most critical time. These inspections should be made under experienced supervision and the manufacturer's instructions followed closely. CAUTION: No one should be permitted to enter the pump chamber to make inspections or repairs until it has been ascertained that the chamber is free from harmful gases and, also, unless an assistant is posted on the pump floor.

EQUIPMENT FAILURE DIAGNOSIS

1. General. This section of the manual is intended as a guide in determining the causes and effects of pump and motor difficulties encountered during station operations. Outlined herein are basic hints on the diagnosis of certain pump and motor ailments that are characteristic of a great majority of pump starting and operating difficulties. Following this procedure may enable one to locate the source of trouble in many cases.

2. Very Little or No Water Being Discharged.

   a. Lack of Prime.
      1. See that suction pipe and impeller casing are completely filled with water. Water level in sump should be above minimum pumping elevation.

   b. Motor speed too low.
      1. Check whether motor is receiving full voltage. Test voltage on all phases.
      2. Open on high resistance point in rotor circuit.

   c. Packing where used too tight.
      1. Release gland pressure. Tighten reasonably.

   d. Discharge head too high.
      1. Gate valves should be wide open.
      2. Check valves and flap gates should operate freely.

   e. Suction lift too high.
      1. Sump water level too low.
      2. Obstruction at suction bell of pump.

   f. Clogged inlet
      1. Trash Rack may be clogged and does not permit sufficient flow. Keep rack raked clean.

   g. Impellers improperly adjusted.
      1. Rubbing on top and bottom.

   h. Impeller wrapped in debris.

1. On vertical centrifugal pumps – shut valves on suction and discharge lines, open hand holes and clean impeller and inside of casing.

2. On axial-flow pumps – clean impeller from pump intake entrance.

3. If the sump cannot be unwatered, it may be necessary to use portable pump.

i. Wrong direction of rotation.

1. This may occur when the wiring has been disconnected from the motor and is reconnected improperly.

3. Not Enough Water Being Discharged.

a. Air leaks in stuffing boxes, casing or flanged joints.

1. Due to the nature of most of the installations, this can only develop after the sump has been pumped down and there is negative auction head. These air leaks will generally show up as water leaks when the sump water elevation is at or above minimum pumping elevation.

2. There should be a very slight leakage from the stuffing boxes while the pumps are operating and discharging water. If there is none, adjust packing gland. If there is still no flow new packing probably is needed.

3. Leaks at joints may require tightening of bolts or new gaskets.

b. Defective impeller.

1. Replace the impeller if worn, damaged, or the blade sections are badly eroded.

2. Incorrect size impeller installed.

c. Incorrect axial adjustment of impeller or rotating element.

d. Suction inlet not immersed deeply enough.

1. Pumping below minimum pumping elevation. Swirling eddies at pump intake indicates air is being sucked into the line, causing severe pounding.

2. Shut off pumps at some higher elevation.

3. Inspect automatic pump controls for adjustment.

e. Check for conditions listed under paragraph 12-02.

4. Pump Starts, Loses Suction and Stops.

a. Incomplete priming.

1. Free pump, piping and valves of all air.

b. Leaky suction line.

1. See paragraph 12-03a.

c Gases in water being pumped.
   1. Causes creating condition should be remedied.

5. Pump Requires Too Much Power.
   a. Lubricating oil being used is too heavy.

   b. Specific gravity of storm water is too high.
      1. Considerable quantity of sand being carried by water.

   c. Vibration.

   d. Misalignment.

   e. Stuffing boxes too tight. Release gland pressure, tighten reasonably.

   f. Impellers improperly adjusted.
      1. Rubbing on top or bottom.

6. Pump Vibrates.

   a. Worn bearings.

   b. Pump not resting securely on supports in sump or on base plate.

   c. Motor or pump out of balance.

   d. Air or gas in water.

   e. Motor shaft not lined up with pump shaft.

   f. Impeller out of balance due to foreign material.

7. Excessive Wear.

   a. Improper lubrication.

   b. Sand in water being pumped.

   c. Vibration.

   d. Misalignment.
      1. May be due to crossed threads on pump shaft.

8. Reverse Flow through Pump – Current Off.

   a. Siphon action taking place.
      1. Check valve or flap gate will not close. Debris holding flag gate open.
      2. Break siphon by one of the following means:
         (a) Close gate valve at pump.
         (b) Open siphon breaker gate valve at top of levee.

9. Motor Will Not Start.

   a. Power not connected.
      1. Check power to controls and controls to motor.
      2. Check clip contacts.

   b. Faulty (open) fuses.
      1. Test fuses.

   c. Low voltage.
      1. Check voltage with meter.

   d. Protection devices holding circuit open.
      1. Overload, short circuit, or undervoltage relay tripped.
      2. Determine and correct cause.

   e. Defective starting or controlling equipment.
      1. Check with manufacturer's information and adjustments.

   f. Loose terminal-lead connection.
      1. Tighten connections.

   g. Pump locked.
      1. Try turning motor and pump shaft with wrench.
      2. If the shaft will not turn, disconnect motor from pump.
      3. If motor starts satisfactorily, check pump.

   h. Open or short circuit in stator windings.
   i. Bearings frozen to shaft.
      1. Free bearings or replace.

10. Motor Noisy.

   a. Motor running single phase.
      1. Stop motor, then try to start it. It will not start on single phase.
      2. Check for "open" in one of the lines or circuits.

3. Check primary fuses.

b. Vibration.
1. Pump may be unbalanced.
2. Remove motor from load.
3. Check for foreign matter caught on rotor.

c. Air gap not uniform. (Magnetic noise).
1. Check the rotor and if necessary replace bearings.

d. Noisy ball bearings.
1. Check for thrust on proper bearing.
2. Check lubrication. Replace bearing if rusted or pitted.

e. Loose rotor on shaft.
1. Disassemble and investigate cause.

f. Rotor rubbing on stator.
1. Check registers, center the rotor.
2. Replace bearings if necessary.

g. Objects caught between fan and end shields.
1. Disassemble motor and clean it. Foreign material around motor should be removed.

h. Motor loose on foundation.
1. Tighten hold down bolts. Motor and pump unit may possibly have to be realigned with connecting piping.

i. Coupling loose (on vertical centrifugal pumps).
1. Insert feeler gage at four places in coupling joint before pulling up bolts to check alignment. Tighten coupling bolts securely.

11. Motor temperature too high.
a. Overload. May be due to mechanical pump defects.
1. Motor stalled by “frozen” pump (tight bearing or packing).
2. Measure motor loading with ammeter.

b. Electrical load unbalance.
1. Check for voltage unbalance or single phasing. Check for “open” in one of the lines or circuits.
2. Fuse blown, faulty control, etc.

c. Restricted ventilation.

1. Clean air passages.

d. Incorrect voltage.

1. Check voltage under full load.

e. Stator winding shorted or grounded.

1. Check with proper instruments

12. Bearings Heat Up.

a. Bent shaft.

b. Too much lubricant.

1. Remove relief plug and let motor run. If excess lubricants does not run out, flush and relubricate.

c. Wrong grade of lubricant.

1. Follow manufacturer's recommendations.

d. Insufficient lubricant.

1. Fill with proper quantity.

e. Foreign material in lubricant.

1. Flush bearings thoroughly, relubricate.

f. Bearings misaligned.

1. Align motor and pump and check bearing-housing assembly. See that races are exactly 90 degrees with shaft.

g. Bearing damaged (corrosion, etc.)

1. Replace bearings.

INSPECTION CHECK LIST
FLOOD PROTECTION WORKS
SUMMARY OF PUMPING PLANTS

1. Date of last report:____
2. Date of this report:____
3. Dates of Inspections since last report:_______________________________
4. Dates of pump operations since last report:___________________________
5. Dates of operation logs since last report:_____________________________

3. Pumping plant:
  a. Pump Station No. or Name _______________________________________
  b. Pump Station No. or Name _______________________________________
  c. Pump Station No. or Name _______________________________________

4. Unusual occurrences or remarks concerning trial operations and inspections during period covered by this report:____
____
____

5. Has the key operating personnel been changed? (If changes have been made submit revised list):____

6. This inspection revealed the following necessary repairs (Explain and/or include rough plan of anticipated repairs):____
____
____

7. Specific date when local operating agency will perform the above repairs:____________
____

8. Remarks and explanations:____
____

9. No of additional sheets:____

Signed:___________________________

Superintendent of Flood Protection Works
City, State

INSPECTION CHECK LIST
FLOOD PROTECTION WORKS
PUMPING PLANTS
Sheet 1 of 3

1. Access road and parking areas:____

2. Substation, power lines:____

3. Pumping plant:

    a. Doors, locks:____
    b. Floors, walls, roof:____
    c. Sumps:____
    d. Sump pump:____
    e. Pump Pipe Couplings:____
    f. Ladders, stairs, guard rails:____
    g. Paint:____
    h. Ventilators:____
    i. Dehumidifier:_(Clean Filter)____
    j. Fire Extinguisher:____
    k. Operation Diagrams:____
    l. Operation Log Forms Available:_______________________________________

4. Fire hazards:____

5. Gratings, manhole covers:____

6. Discharge pipes:____

7. Gate valves:____

8. Air vents:____

9. Flap gates:____

10. Trash racks:____

11. Trash rake:____

12. Wiring System:

    a. Lamps, switches:____
    b. Conduit, wire and cable receptacles:____________________________________

INSPECTION CHECK LIST
PUMPING PLANTS (CONT'D)
Sheet 2 of 3

13. Lubrication system:
    a. Motor and Pump No. 1, general:____
    b. Motor and Pump No. 2, general:____

____
____
____
____

14. Switchgear:
    a. Control breaker, motor breakers Nos. 1 & 2:______________________________
    b. Control panel and protective devices:_____________________________________
    c. Main disconnect switch:____

15. Soft Starters:
    a. Control breaker:____
    b. Control panel and protective devices:_____________________________________

16. Pumps:
    a. Pump No. l, general:____
        (1) Bowl ____
        (2) Impeller ____
        (3) Bearings:____
        (4) Coast Down Times ____
    b. Pump No. 2, general:____
        (1) Bowl ____
        (2) Impeller ____
        (3) Bearings:____
        (4) Coast Down Times ____

INSPECTION CHECK LIST
PUMPING PLANTS (CONT'D)
Sheet 3 of 3

17. Tools:

No.	Required Size Description
1	16 oz Grease Gun (Delo EP NLGI1)
1	Stuffing Box Wrench
2	30″ Pipe Wrench
2	12″ Adjustable Wrench
1	12″ Screwdriver
1	7/8″ Cold Chisel
2	6 ft. Wrecking Bar
2	30″ Chain Wrench
1	1 Pd. Ball Pein Hammer
1	4 Pd. Sledge Hammer
1	10″ Adjustable Grip Pliers

18. Spare Parts:____

19. Equipment or parts in need of repair or replacement:____________________

20. Moisture conditions in plant:________________________________

21. Weather conditions and temperature:____________________________

22. Date of pump operation (trial and flood) since last inspection:_______________

23. Were pumps operated during this inspection:________________________

24. Remarks and explanations:_________________________________

25. Date of last inspection:___________________________________

26. Date of this inspection:__________________________________

Signed:__________________________

Superintendent of Flood Protection Works
City, State

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Appendix E
Electrical Power Data Request

ELECTRIC POWER SYSTEM DATA SHEET

PROJECT: ______________________________
LOCATION: ______________________________

POWER COMPANY: ______________________________
MAIL ADDRESS: ______________________________
STREET: ______________________________
CITY/ST/ZIP: ______________________________

ATTN: ______________________________
TITLE: ______________________________
PHONE: ______________________________

POWER COMPANY SOURCE DATA

1. NEAREST_SUBSTATION_FROM_WHICH_THE_PROJECT_WILL_BE SUPPLIED:

a. SUBSTATION NAME AND LOCATION:
____

b. PRIMARY AND SECONDARY VOLTAGES:
____

c. POSITIVE SEQUENCE SOURCE RESISTANCE: ______________________________

d. POSITIVE SEQUENCE SOURCE REACTANCE:
____

or

c. THREE-PHASE FAULT MVA AND X/R:
____

d. IF IN PER UNIT, BASE MVA AND KV:
____

e. EXPECTED VOLTAGE SPREAD AT SUBSTATION:
____

2. POWERLINE FROM NEAREST SUBSTATION TO PROJECT MAIN TRANSFORMER:

a. LINE VOLTAGE/PHASES/WIRES: ___________________________________

b. POSITIVE SEQUENCE RESISTANCE: ________________________________

c. POSITIVE SEQUENCE REACTANCE: ________________________________

d. IF IN PER UNIT, BASE MVA AND KV: ____________________________

3. PROJECT MAIN TRANSFORMER:

a. POSITIVE SEQUENCE RESISTANCE: ________________________________

b. POSITIVE SEQUENCE REACTANCE: ________________________________

c. RATED KVA AND SECONDARY VOLTAGE/PHASES/WIRES: ________________

d. TAP VOLTAGES: ____

e. PRIMARY CONNECTION: DELTA, UNGROUNDED or ____________________

f. SECONDARY CONNECTION: WYE, SOLIDLY GROUNDED or ______________

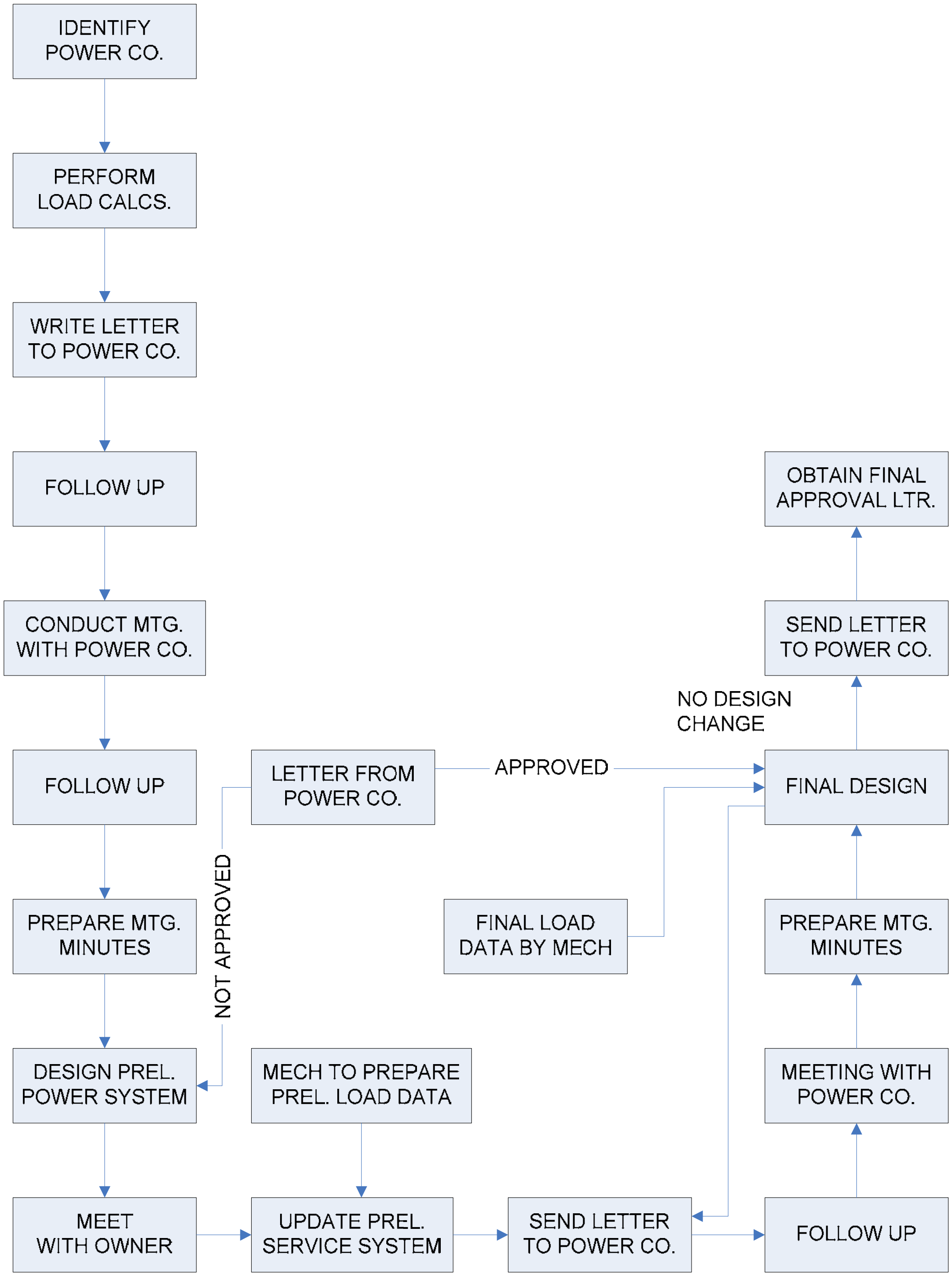

Figure E.1. Electric power company interfacing flowchart