BASF Corporation

DRAFT
Basis of Design Report
Preliminary 30% Design
Perimeter Barrier Remedy

BASF North Works Site
Wyandotte, Michigan

September 2022

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BASIS OF DESIGN REPORT
PRELIMINARY 30% DESIGN
PERIMETER BARRIER REMEDY

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ACRONYMS AND ABBREVIATIONS

%	percent
µg/L	micrograms per liter
AG	above grade
AOC	area of concern
Arcadis	Arcadis of Michigan, LLC
BASF	BASF Corporation
BFS	blast furnace slag
bgs	below ground surface
BOD	Basis of Design
CCR	Current Conditions Report
cm/sec	centimeters per second
COC	contaminant of concern
Consent Order	1994 Administrative Order on Consent (Docket No. V-W-011-94)
CPT	cone penetrometer test
DBO	distiller blow-off
DTH	down the hole
DUWA	Downriver Utility Wastewater Authority
EBCT	empty bed contact time
EDZ	engineered discharge zone
EGLE	Michigan Department of Environment, Great Lakes, and Energy
F&G	funnel and gate
GAC	granular-activated carbon
GLLA	Great Lakes Legacy Act
gpm	gallons per minute
H&S	health and safety
H:V	horizontal unit to vertical unit
HASP	Health & Safety Plan
HMI	human machine interface
HPT	hydraulic profiling tool
HSU	hydrostratigraphic unit
JSA	job safety analysis
LWD	low water datum

mg/L	milligrams per liter
NAVD88	North American Vertical Datum of 1988
NFPA	National Fire Protection Association
ng/L	nanograms per liter
NPDES	National Pollutant Discharge Elimination System
O&M	operation and maintenance
OSHA	Occupational Safety and Health Administration
P&ID	piping and instrumentation diagram
P&T	pump and treat
PC	Portland cement
PDI	pre-design investigation
PFAS	per- and polyfluoroalkyl substances
PLC	programmable logic controller
POTW	publicly owned treatment works
PPE	personal protective equipment
psi	pounds per square inch
QAPP	Quality Assurance Project Plan
QST	QST Environmental
RCRA	Resource Conservation and Recovery Act of 1976
RD	Remedial Design
RFI	RCRA Facility Investigation
RSSCT	rapid small-scale column test
S.U.	standard units
SCADA	supervisory control and data acquisition
SVOC	semi-volatile organic compound
SWMU	solid waste management unit
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
VE	value engineering
VOC	volatile organic compound
Woodward-Clyde	Woodward-Clyde Group

1 Introduction

On behalf of BASF Corporation (BASF), Arcadis of Michigan, LLC (Arcadis) has prepared this Basis of Design (BOD) Report for a groundwater remedy at the BASF North Works site in Wyandotte, Michigan (the Site). This BOD Report describes the Preliminary (30%) Design of the remedy, which consists of a physical containment barrier and a groundwater collection and treatment system to manage/mitigate off-site migration of groundwater at the downgradient site perimeter. The physical containment barrier will block groundwater from entering the Detroit River. The groundwater collection system is necessary to prevent groundwater elevations from rising when the containment barrier is installed. The groundwater collection system will be operated to lower the groundwater table and further reduce the potential for migration and is comprised of drains, sumps, and a conveyance network that will be constructed to extract site groundwater. Extracted groundwater will be treated before being discharged to the local publicly owned treatment works (POTW).

This document is being submitted as part of a Preliminary 30% Design as requested by the United States Environmental Protection Agency, Region V (USEPA) for a site-wide downgradient perimeter groundwater remedy. The other components of the 30% Design include Preliminary 30% Design Drawings (Appendix A), Design Calculations (Appendix B), Cost Estimate (Appendix C), and Construction Schedule (Appendix D).

This BOD Report was developed consistent with applicable USEPA guidance, including:

- Guidance for Scoping the Remedial Design (USEPA 1995a);
- Remedial Design/Remedial Action Handbook (USEPA 1995b);
- EPA Oversight of Remedial Designs and Remedial Actions Performed by Potentially Responsible Parties, Interim Final (USEPA 1990); and
- Handbook on the Benefits, Costs, and Impacts of Land Cleanup and Reuse (USEPA 2011).

2 Site Description and Background

The Site is located on the west bank of the Detroit River in Wyandotte, Wayne County, Michigan, and occupies approximately 230 acres (Figure 1). The Site is bounded by Perry Place to the north, the Detroit River to the east, James Desana Drive to the south, and Biddle Avenue to the west. The Site is an active industrial property used for manufacturing chemicals and other products. Facility operations and workforce have expanded since issuance of the 1994 Administrative Order on Consent (Docket No. V-W-011-94) (Consent Order) and continue to grow.

At present, approximately 50% of the Site is developed with buildings, paved streets, parking lots, tank farms, and docks. Many of the former site features associated with discontinued processes have been demolished, although concrete surfaces and foundations at or below grade remain. The site boundary with the river is approximately 5,750 feet long and consists of the following shoreline perimeter structures and features:

- A pier structure and a timber Wakefield wall constructed in the early 1900s extends approximately 4,920 feet south from the northern property boundary at Perry Place (Figure 2). The pier structure consists of a soil-covered concrete deck supported on timber piles. The Wakefield wall serves as a bulkhead wall between the upland area and the pier structure and consists of oak sheets with tongue-and-groove joints keyed into the river bottom. The width of the soil-covered concrete deck increases from approximately 3 feet at the northern end of the Site to approximately 34 feet at the southern end of the pier (Arcadis 2019b).

  - An anchored steel sheet pile wall was installed in the 1990s on the river side of the existing- pier structure/Wakefield wall described above (Figure 2). The sheet pile wall extends approximately 3,300 feet south from the northern site boundary (i.e., the northern end of the existing pier structure) and was installed as part of a shoreline stabilization project.
  - A pile-supported concrete dock (South Dock) extends approximately 1,620 feet south from the anchored sheet pile wall to the rip rap-protected portion of the riverbank.
- The riverbank south of the existing pier structure is protected by an approximately 830-foot-long rip rap revetment (Figure 2).

Detailed descriptions of the site physical and hydrogeological settings and distribution of chemicals of concern (COCs) are provided in the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) Report (QST Environmental [QST] 1999) and the RFI Current Conditions Report (CCR) (Woodward-Clyde Group [Woodward-Clyde] 1994).

2.1 Site History

A comprehensive description of the site history is presented in the RCRA RFI Report (QST 1999) and the CCR (Woodward-Clyde 1994). Various industrial operations have been implemented at the Site since the late 1800s, and the RFI Report identified several areas of concern (AOCs) and solid waste management units (SWMUs) requiring corrective measures. Detailed information on each AOC/SWMU is provided in the RFI Report (QST 1999) and the CCR (Woodward-Clyde 1994). In addition, land reclamation activities conducted at the Site have led to the widespread distribution of fill material containing site-related constituents. Constituents present in groundwater as a result of past site-related activities include volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and metals (including mercury). Elevated metals concentrations in groundwater are driven by the site geochemistry (e.g., strongly reducing conditions resulting from the presence of organic matter and elevated pH levels associated with fill material in the subsurface). Due to the extent of groundwater impacts at the Site, BASF proposed to address groundwater as a site-wide AOC, managed at the downgradient site perimeter. USEPA concurred with this approach in its letter to BASF dated August 26, 2016 (USEPA 2016).

2.2 Subsurface Conditions

Subsurface conditions in the upland and near-shore areas of the Site have been investigated extensively. Most recently, geotechnical and hydrogeological preliminary design investigations (PDIs) were performed along the perimeter of the Site (upland and near shore) in 2020 to support the Preliminary 30% Design of the containment barrier. The results of the PDIs are summarized below.

2.2.1 Geotechnical Investigation

Between June 17 and August 5, 2020, 17 geotechnical borings and 17 cone penetrometer test (CPT) explorations were performed in the upland and near shore areas along the proposed barrier alignments in the South Dock area and along the rip rap-protected riverbank south of the South Dock at the approximate locations shown on Figure 3. Four of the geotechnical borings and 14 of the CPT explorations were completed in the river, within 50 feet of the shoreline, using barge-mounted equipment (Figure 3). The findings of this investigation are summarized in the *BASF North Works Geotechnical Data Report* (Arcadis 2021a).

Fill was encountered below the surficial coverings at the Site extending up to 32 feet below ground surface. The fill consists of various types of soil, concrete, crushed stone, gravel, other debris, and distiller blow off (DBO). Concrete slabs are also encountered at some locations below ground surface in the upland area. These fill characteristics influenced the selection of the perimeter barriers as discussed in Section 4.

A very soft, alluvial silt layer was encountered in some of the upland borings with a thickness of 7 to 15 feet. Loose to medium dense lacustrine sand was encountered in the upland areas, either below the alluvial silt or directly below the fill where no alluvial silt was encountered. The sand layer varied in thickness from approximately 5 to 17 feet. The alluvial silt and the lacustrine sand were not encountered in the in-water explorations.

A soft to medium stiff layer of lacustrine clay was encountered ranging in thickness from approximately 25 to 43.5 feet in the upland area and from approximately 15 to 25 feet in the river. The overburden soils overlying the till and bedrock in the upland ranges in total thickness from approximately 62 to 65 feet. In the river, the total thickness of the overburden soils ranges from approximately 39 to 41 feet. The geotechnical properties and thickness of these overburden soils influences the selection of the perimeter barriers as discussed in Section 4.

2.2.2 Hydrogeologic Investigation

A Hydraulic Pre-Design Investigation Report was submitted to document the results of the hydraulic pre-design investigation activities conducted at the Site (Arcadis 2021c). The purpose of the PDI work was to collect the hydraulic data needed to support the Preliminary 30% Design for a perimeter barrier remedy. The conclusions of the Hydraulic PDI were as follows:

- **Transducer evaluation.** Communication was observed between the river and the unconfined aquifer in the rip rap zone on the south end of the shoreline. Communication between the aquifer and the river was not observed in the north portion of the site adjacent to the steel seawall.

  Hydraulic profiling tool (HPT) investigation. A consistent and well-defined depth of basal clay was confirmed along the shoreline, northern, and southern property boundaries. A high-resolution hydraulic conductivity profile was developed using HPT data, which has clearly defined areas of relatively low and high-K zones correlating to zones of lower and higher groundwater discharge, respectively. The hydraulic conductivity profile was used to select areas for pumping tests and to update the numerical groundwater model.
- **Groundwater pumping tests.** Pumping tests were completed at three high-K zones identified during the HPT investigation. The results of the pumping tests confirmed a hydraulic no-flow boundary adjacent to the sea wall and the high-flow boundary associated with the river in the south where the rip-rap is present at the shoreline. The pumping tests better estimated the K at locations were the HPT estimated K was beyond the range of the tool. The higher range of K was used to further calibrate the numerical groundwater model and estimate groundwater discharge.
- **Calibration/update of the groundwater model.** Data gathered from the additional hydraulic testing were used to correlate/update and spatially define the hydraulic conductivity distribution used within the numerical model for the Site. Updates to the model were based on a review of the existing model (Waterloo Hydrogeologic 2002) in conjunction with new and relevant data collected since the original model was developed, including but not limited to data collected during the Hydraulic PDI work. The updated groundwater model (Arcadis 2021b) serves as a design tool estimating flow scenarios for the groundwater collection and abovegrade treatment systems.

3 Perimeter Barrier Remedy Basis

From June 2015 to September 2017, BASF submitted various documents proposing remedy options to manage/mitigate potential off-site migration of groundwater at the downgradient site perimeter to adjacent properties and the Detroit River. Ultimately, on April 24, 2018, USEPA provided a letter to BASF outlining the following key requirements for a downgradient perimeter remedy:

- USEPA requires physical stabilization of the Site and a downgradient perimeter barrier to contain groundwater for treatment prior to off-site discharge.
- Site stabilization, a containment barrier, and on-site groundwater treatment are essential for integrating the RCRA corrective action with the Great Lakes Legacy Act (GLLA) project.
- Any proposed remedy must include plans to address sediment under the overhanging dock and to physically stabilize the Site to prevent erosion of fill from the facility to the river.
- Demolition of the dock and shoreline reconstruction are suggested as an optimal alternative for physical stabilization.

In 2018, BASF and USEPA agreed upon a perimeter barrier remedy, including groundwater extraction and on-site groundwater treatment, to facilitate site stabilization, containment, and treatment as requested by USEPA in its April 24, 2018, letter.

On June 5, 2018, USEPA issued a letter indicating concurrence with BASF’s proposal to submit a work plan for completion of a preliminary 30% design for a site-wide downgradient perimeter groundwater remedy (USEPA 2018). BASF’s proposal is documented in its May 29, 2018, letter to USEPA (BASF 2018). USEPA was acting under the authority of the Consent Order, which requires that BASF perform corrective action at the Site pursuant to RCRA of 1976 as amended by the Hazardous and Solid Waste Amendments of 1984.

3.1 Design Criteria

In lieu of preparing a separate Design Criteria Report (DCR), the components of the DCR summarized in the EPA Handbook (EPA, 1995b) are included in the sections of this BOD report as referenced Table 1.

Table 1. Design Criteria Components

Required Design Component	Report Section
Corrective action objects and performance standards	Sections 3.3 and 3.4
Compliance with pertinent regulatory requirements	Section 3.5
Technical Factors of Importance	Sections 4.1; 4.4; 4.5; 6.2
Volume and type of each medium requiring treatment	Sections 4.3.4.1; 4.3.4.2; 6.2; 7 and Appendix E
Treatment schemes	Sections 6.3; 6.4.2
Waste management and characterization requirements	Section 8
Operation and maintenance (O&M) requirements	Section 14

3.2 Proposed Remedy Description

Once USEPA and BASF agreed upon a path forward a Remedial Design (RD) Work Plan was submitted in May 2019 (Arcadis 2019a) and provided the framework for design of the perimeter barrier remedy. Based on current site conditions, the technical feasibility and cost benefit of an F&G system are not apparent, and the F&G option was not carried forward. A funnel and gate may be considered in the future if site conditions change. This preliminary 30% design therefore includes a physical downgradient perimeter containment barrier with a P&T system.

The remedy will include a combination of subsurface and shoreline barriers, along with a series of groundwater collection drains and an above-grade groundwater treatment system that discharges treated groundwater to the local POTW. The groundwater collection drains will operate to manage groundwater once the containment barrier is installed.

The physical barrier option considered and the basis for barrier selection is detailed in Section 4. The groundwater extraction and conveyance system components of the barrier remedy are described in Section 5, and the above-grade treatment system design is discussed in Section 6.

3.3 Corrective Action Objectives

Corrective action objectives (CAOs) are being developed in coordination with USEPA and the Michigan Department of Environment, Great Lakes, and Energy (EGLE) concurrently with the design. For the purposes of the preliminary 30% design, it is agreed that the CAOs will specify the following:

- The contaminants of concerns
- The exposure route(s) and receptor(s)
- An acceptable contaminate level or range of levels for each exposure route

The CAOs will be developed based on:

- USEPA and EGLE law, policy, and guidance
- Threshold criteria: Protech human health and the environment, achieve media cleanup objectives, control sources
- Conceptual site model
- Current uses and exposures
- Reasonably expected future uses and exposures
- Resource values (ecological, groundwater, etc.)

Details of the CAOs will continue to be developed in collaboration with USEPA and EGLE as the design progresses and will be presented with the final design package.

3.4 Performance Standards

Performance standards are being developed by BASF and USEPA, in consultation with EGLE, concurrently with design development. For the purposes of the preliminary 30% design, it has been agreed upon by BASF, USEPA, and EGLE during monthly meetings that the performance standards, with specific metrics, will address the following key elements:

- Physical containment barrier will contain groundwater and mitigate groundwater from entering the Detroit River. Performance standards will assign appropriate value to the presence of the physical containment barrier.
- The groundwater collection system will prevent groundwater elevations from rising upland of the containment barrier. Performance standards will incorporate a hydraulic gradient component that is protective of the Detroit River in combination with the physical containment barrier.
- Performance standards will be adaptable to future site conditions and manage risk over the lifetime operation of the barrier remedy.

Specific metrics of the performance standards will continue to be developed in collaboration with USEPA and EGLE as the design progresses and will be presented with the final design package. Recommendations of the amount of time needed to reach specific performance metrics after system commissioning will also be included as part of the final design.

3.5 ARARs, Pertinent Codes, and Standards

The Barrier Remedy will be designed in accordance with ARARs, codes, and standards. Potential regulatory requirements, including requirement description and applicability, are listed in Table 2.

Table 2. Regulatory Requirements

Requirement	Description	Applicability	Notes
Resource Conservation and Recovery Act (RCRA; 42 USC, Ch. 82); Hazardous Waste Management (NREPA, 1994 PA 451, as amended, Part 111)	Hazardous waste management requirements	RCRA Corrective Action at Michigan facility; waste generation anticipated	Applicable to the management of generated wastes, including tank storage of extracted groundwater characterized as hazardous
Environmental Remediation (NREPA, 1994 PA 451, as amended, Part 201)	Protects the environment and natural resources of the State of Michigan	RCRA Corrective Action at Michigan facility	Applicable to the development of performance standards for groundwater venting to surface water
Clean Water Act (33 USC, Ch. 26)	Regulations for the discharge of pollutants into waters of the United States	Groundwater vents to a surface water of the United States	Applicable to the development of performance standards for groundwater venting to surface water
Safe Drinking Water Act (42 USC, § 300f et seq.)	Program and performance standards for underground injection programs	Potential for underground injection	Class V Underground Injection Control requirements may be applicable to air sparging systems
Clean Air Act (42 USC, Ch. 85); Air Pollution Control (NREPA, 1994 PA 451, as amended, Part 55)	Protect quality of air and promote public health	Potential for producing air emissions of regulated air pollutants (including particulate emissions)	Emission standards may be applicable
Migratory Bird Treaty Act (16 USC, §§ 703–712)	Protects almost all species of native migratory birds in the United States from unregulated "take"	Potential presence of migratory birds	Measures will be taken to evaluate whether migratory birds are present; project activities will be scheduled to not disturb migratory birds, or depredation permits will be obtained if necessary

Requirement	Description	Applicability	Notes
Endangered Species Act (16 USC, Ch. 35)	Requires that federal agencies ensure that any action authorized, funded, or carried out by an agency is not likely to jeopardize the continued existence of any threatened or endangered species and will not destroy or adversely modify critical habitat	Potential presence of federal-listed species	Work will be conducted in disturbed areas and is not anticipated to affect federal-listed species; however, the United States Fish and Wildlife Service (USFWS) and Michigan Department of Natural Resources (MDNR) will be consulted
Fish and Wildlife Coordination Act (16 USC, Ch. 5A)	Requires that activities avoid adverse effect and minimize potential harm, preserve natural and beneficial values, and/or compensate for impacts to fish, wildlife, and their habitats through restoration	Potential impacts to fish/wildlife habitat	USFWS and the MDNR will be consulted regarding the impacts on fish and wildlife resources and measures to avoid, minimize, and mitigate the impacts
Bald and Golden Eagle Protection Act (16 USC, Ch. 5A)	Provides for the protection of the bald eagle and the golden eagle by prohibiting, except under certain specified conditions, the taking, possession, and commerce of such birds	Potential presence of bald eagle habitat	USFWS will be consulted regarding potential impacts to bald eagles
Coast Guard Notification	The United States Coast Guard is responsible for disseminating information concerning aids to navigation, hazards to navigation, and other items of marine information of interest to mariners on the waters of the United States	Potential in-river work	Appropriate notifications will be provided to the United States Coast Guard District 9 Commander
Soil Erosion and Sediment Control (SESC) Permit (NREPA, 1994 PA 451, as amended, Part 91)	Protects the waters of the State of Michigan and adjacent properties by minimizing erosion and controlling off-site sedimentation	Potential land disturbance within 500 feet of lake or stream (applies to work affecting 1 or more acres)	SESC permit coverage will be obtained as applicable

Design codes and standards deemed applicable to construction of the perimeter barrier remedy include the following:

- The design of buildings will comply with the 2015 Michigan Building Code, as currently adopted by the City of Wyandotte.
- The design of electric utility services and electrically powered installations will comply with the following:
  - Utility standards designated by Wyandotte Municipal Services;
  - 2015 Michigan Electrical Code, as currently adopted by the City of Wyandotte; and
  - 2017 National Electrical Code, as currently adopted by the City of Wyandotte.
- The design of plumbing and mechanical installations will comply with the following:
  - 2015 Michigan Plumbing and Mechanical Code, as currently adopted by the City of Wyandotte.
- Extraction and conveyance equipment will be designed in accordance with applicable codes, standards, and regulations.

4 Perimeter Barriers

Perimeter containment barriers will be constructed along the north, east, and south sides of the property perimeter. For the Preliminary 30% Design, the barrier alignment is further subdivided into the following (Figure 2):

- Northern boundary (approximately 950 feet of planned barrier along Perry Place to the property boundary);
- Northern shoreline (existing 3,300-foot-long sheet pile wall);
- South Dock (approximately 1,700 feet long);
- Rip Rap Area (approximately 850 feet of existing rip rap-covered riverbank between the South Dock and southern site boundary); and
- Southern boundary (approximately 1,450 feet of proposed barrier along the northern edge of Desana Drive).

These sections of the proposed barrier alignment are shown on Figure 2. The planned barrier network consists of approximately 4,950 linear feet of new barrier construction along the northern boundary, the South Dock, the rip rap area, and the southern boundary. The existing sheet pile wall along the northern shoreline will be incorporated into the barrier network. No additional barrier construction is planned for the northern shoreline section.

The following sections describe the barrier options (Section 4.1), provide the rationale for the selection of barrier types for each section of the perimeter alignment (Section 4.2), and present the Preliminary 30% Design of the selected barriers (Section 4.3).

4.1 Barrier Considerations

The barrier types considered as part of the design process include “subsurface barriers” and “shoreline barriers.” Subsurface barriers are barriers that are constructed in upland areas, away from the shoreline, and are completely below the ground surface. Shoreline barriers are defined herein as barrier options directly along the shoreline that are in-water and may be exposed or partially exposed above the ground or sediment surface. All are low permeability and a barrier to groundwater flow.

4.1.1 Subsurface Containment Barriers

Five subsurface barrier types were evaluated for the proposed subsurface portion of the barrier network:

- Ex-Situ Mixed Site Soil-Cement Barrier via Excavator
- Ex-Situ Mixed Borrow Soil-Cement Barrier via Excavator
- Steel sheet piles
- Cement Bentonite Barrier (Self-Hardening Slurry)
- Soil-Cement Barrier via Trencher

Each barrier type is low permeability to mitigate groundwater discharge and requires embedment into the clay layer. Each barrier type includes installation of a groundwater collection and treatment system on the upland side of the barrier. Evaluation criteria included geologic considerations, constructability, overall effectiveness, and cost. Appendix E summarizes the options and evaluation criteria. Following sections provide a brief description of each barrier type.

4.1.1.1 Ex-Situ Mixed Site Soil-Cement Barrier via Excavator

For this barrier type, the subsurface barrier would be constructed using existing site soils blended with the required reagents (e.g., Portland cement [PC], blast furnace slag [BFS]) at dosages based on the results of a bench-scale treatability study (Arcadis 2022a). A slurry wall trench is first excavated utilizing conventional and specialized long stick excavators under an engineered fluid (bentonite slurry) for trench support. A wide bench/platform is constructed along the alignment to control the slurry and for equipment operation. The excavated peat and DBO site soils/materials from the trench excavation would be separated and transported for off-site disposal. Remaining suitable site soils are blended on site with the reagents and placed into the trench as backfill. As the wall construction progresses, the slurry is continually tested, and old slurry replaced or rejuvenated as appropriate. Displaced bentonite slurry is typically mixed with soils scheduled for off-site disposal.

4.1.1.2 Ex-Situ Mixed Borrow Soil-Cement Barrier via Excavator

This alternative is similar in site preparation, construction methodologies, and waste management to the previous option with the exception of using imported soils instead of existing site soils as the wall backfill. The wall is constructed under an engineered fluid utilizing a hydraulic excavator, working on a wide, prepared platform surface. All excavated soils for this alternative are transported for off-site disposal.

4.1.1.3 Steel Sheet Piles

This alternative includes driving interlocking steel sheet piles into the low-permeability clay layer. Prior to pile installation, pre-trenching would be required for removal of debris and obstructions to the extent practicable, followed by backfilling with borrow soil as needed. Prior to sheet pile installation, an interlock sealant would be applied to each sheet pile interlock.

4.1.1.4 Cement Bentonite Barrier (Self-Hardening Slurry)

Cement bentonite walls are constructed similarly to the soil-cement wall options discussed above. A working platform is constructed along the alignment, and the wall trench is excavated under slurry using a hydraulic excavator. The slurry mixture typically consists of cement bentonite, water, and other admixtures, if needed, and is pumped into the trench as excavation proceeds. Soils are excavated through the slurry and transported for off-site disposal. Once the excavation is to full depth, the bottom is scraped for removal of loose soil and the cement bentonite slurry is allowed to harden. No soil (imported or existing) is used as backfill for this option. Controlled mixing of slurry and consistency of slurry materials provide for an effective containment barrier.

The wall is constructed in panels, typically a minimum of 20 feet in length, which are excavated incrementally (every other panel). The panels are overlapped between 12 and 18 inches and sequenced so that the slurry is still removable for developing the tie-in of adjacent panels. This process is repeated until a continuous barrier is formed. The contractor typically prepares an execution plan prior to implementation that addresses the specifics regarding target depths, panel layout and sequencing, and method of documenting that the minimum overlap or tie-in to the previous panel is sufficient.

4.1.1.5 Soil-Cement Barrier Via Trenching

This option involves use of a one-pass trencher for wall construction in lieu of a hydraulic excavator. Because of the potential for obstructions and the unsuitable fill soils along the alignment, the trencher would need to make two passes along the alignment. The first pass would include advancing the trencher from ground surface to the bottom of the fill and peat layers for removal of unsuitable site soils. As the trencher progresses along the wall alignment for this first pass, the trench would be backfilled with imported sand. A supporting excavator would be positioned along the alignment for removal of obstructions where the trencher is limited in this capacity. Then, a second pass with the trencher would be completed for in-situ mixing of the sand backfill, native soils, and required reagents (cement/bentonite). Soils/materials from the first trencher pass would be transported for off-site disposal.

4.1.2 Shoreline Containment Barrier

The shoreline containment barrier consists of a steel bulkhead and a groundwater collection and treatment system on the upland side of the barrier.

4.1.2.1 Steel Bulkhead Barrier

This option involves installation of a steel bulkhead wall along the shoreline, on the outboard side of the existing South Dock structure, to serve as a containment barrier. Interlock sealant would be applied between sheet piles to minimize the potential for seepage.

This type of barrier can also serve as a structural wall that can be designed to support the existing South Dock waterfront structure by tying the wall to anchors placed inland of the existing structure and by placing fill underneath the existing pile-supported concrete deck (i.e., the existing South Dock structure). The installation of the sheet pile would support dredging of sediment near the wall, if the wall is installed first, without destabilizing the dock

Based on Preliminary 30% Design calculations, the bulkhead wall would need to consist of a headwall on the outboard side of the existing dock that is anchored to a deadman structure located behind the headwall in the upland area. The deadman structure could consist of a subsurface steel sheet pile anchor wall, an A-frame anchor structure constructed of H-piles, or similar anchor structure. Tie rods would be installed at regular intervals between the headwall and the anchor structure. The headwall would likely need to consist of a combination wall system. A combination wall is a relatively strong and stiff wall that consists of king piles and intermediate sheet piles. The king piles can consist of large H-piles or pipe piles.

4.2 Development of Containment Barrier

This section describes which subsurface and shoreline barrier types evaluated were selected for each area of the site perimeter to develop two options for the containment barrier system. Preliminary 30% Design drawings showing the proposed location for each barrier selected are included in Appendix A. The proposed types of barriers for the containment barrier system in this Preliminary 30% design are summarized in Table 3.

Table 3. Barrier Remedy

Area	Barrier Type
Northern Perimeter	Subsurface Barrier – Steel Sheet Pile
Northern Shoreline	Shoreline Barrier – Existing Steel Sheet Pile
South Dock	Shoreline Barrier – Steel Bulkhead
Rip Rap Shoreline	Subsurface Barrier – Ex-Situ Mixed Borrow Soil-Cement Wall
Southern Perimeter	Subsurface Barrier – Ex-Situ Mixed Borrow Soil-Cement Wall and Steel Sheet Pile

The basis for selection of each barrier type by area is included in the following sections.

4.2.1 Northern Perimeter

The steel sheet pile is proposed for the subsurface barrier along the northern perimeter of the Site (Figure 4 and Appendix A). It was selected for this area because of the thinning fill layer and the lower potential for encountering obstructions during pile driving. It was also selected for the northern perimeter alignment since this portion is within a public roadway and has the advantage of reduced disruption during installation when compared to the other subsurface barrier options considered. The steel sheet pile barrier will extend along the northern perimeter of the Site, within Perry Place, for approximately 950 feet to the west from the existing northern bulkhead.

4.2.2 Northern Shoreline

An anchored sheet pile wall was installed along the northern shoreline in the 1990s (Figure 4 and Appendix A). A description of this wall is provided in Section 2. The existing wall forms a relatively low-permeability barrier that will become part of the proposed network of containment barriers. While available information indicates the existing the sheet pile interlocks of this wall are not sealed, hydraulic testing completed behind the wall suggests it is a robust barrier to flow (Arcadis 2021c). Section 4.4 includes additional detail on the known construction aspects of this wall and the steps that will be taken to incorporate it into the barrier remedy.

4.2.3 South Dock

An independent steel bulkhead wall will be installed outboard of the South Dock and associated structures in a way that would provide long-term structural support and stability to the South Dock. The steel bulkhead could allow for dredging of contaminated sediments up to the sheet pile bulkhead, if designed accordingly, which could benefit the dredging planned by USEPA.

The Preliminary 30% Design basis is discussed in Section 4.3.3 and 4.3.4, respectively. The steel bulkhead is shown on Figure 4 and in Appendix A.

4.2.4 Rip Rap Shoreline

An ex-situ mixed borrow soil-cement wall will be constructed along the rip rap shoreline (Figure 4 and Appendix A) in conjunction with the steel bulkhead wall along the South Dock. Construction of the wall would be through excavation under slurry with either a conventional excavator or a specialized long stick excavator. This technology was selected due to the thickness of the fill layer in this area and the high potential of encountering obstructions in the fill. The estimated fill thickness is between 20 and 25 feet below grade along the proposed soil-cement wall alignment. Compared to other containment wall technologies considered for the Site, this method of slurry wall construction is more adaptable to addressing and removing obstructions and debris. The soil-cement wall will lie within the limits of the Site, which is also more accommodating to the working platform requirements and aboveground operations that are typically part of this wall technology.

4.2.5 Southern Perimeter

The southern perimeter of the barrier network will consist of a combination of two barrier types, a soil-cement wall and a steel sheet pile wall (Figure 4 and Appendix A).

The ex-situ mixed borrow soil-cement wall will wrap the southeastern corner of the Site and continue from the shoreline barrier to the west for approximately 550 feet. This technology was selected for this portion of the southern perimeter due to the thickness of the fill layer and its alignment relative to the existing fire water impoundment. This method of wall construction, when considering the generation of vibrations, is considered less impactful to adjacent sensitive features. It is also more adaptable to addressing and removing obstructions and debris.

At the western end of the soil-cement wall, the barrier network will transition to a driven steel sheet pile wall and continue westward along the southern perimeter of the Site for approximately 900 feet. Similar to the northern perimeter, the steel sheet pile wall type was selected for the southern perimeter because of the thinning fill layer and lower potential for obstructions. In addition, the southern perimeter alignment is within a public roadway, and this wall type offers the advantage of reduced disruption during installation compared to the other subsurface barrier options.

4.3 Barrier Design

4.3.1 Soil-Cement Wall

A soil-cement wall was selected for portions of the barrier network. This section provides the basis of design of the soil-cement barrier and includes a summary of subsurface conditions, treatability test results, and items specific to the wall properties and alignment. Data gaps that must be filled before subsequent design phases are discussed in Section 10.

4.3.1.1 Bench Test Results

Arcadis performed a bench-scale treatability study in support of the proposed slurry wall design. This treatability study evaluated the efficacy of soil/cement and soil/bentonite mix formulations using both native site soil and a clean borrow soil source. Details of the testing procedures and findings of the study are summarized in the treatability study report (Arcadis 2022a).

The purpose of the bench-scale testing was to optimize one or more mix designs for the slurry wall. The specific performance targets were to achieve mixes that demonstrated the following:

- Unconfined compressive strength values of at least 30 pounds per square inch (psi) at 28 days of curing.
- Hydraulic conductivity values less than 1×10^{-6} cm/sec.

Soil from three geotechnical borings and two visual screening borings was collected from locations along the proposed subsurface barrier alignment, and a groundwater sample was collected from an on-site monitoring well. Mix formulations tested included BFS and Types I/II PC in combination with either native soil or a borrow soil.

Through this bench-scale barrier wall treatability study, Arcadis identified mix formulations that are expected to meet or exceed geotechnical performance goals for a slurry wall using either native soil or a borrow soil replacement strategy. As discussed in the treatability study report, Arcadis concluded that three of the mixes for slurry wall implementation with a 1.5:1 water/cement ratio meet the established performance requirements, discussed below, and are considered viable for full-scale design and construction (Arcadis 2022a). In addition, results of a long-term permeability test indicate that the integrity of a soil/cement mixture will not be negatively impacted by exposure to site groundwater.

4.3.1.2 Material Selection

The treatability testing resulted in development of acceptable mix designs incorporating site soils or using borrow soils from an off-site source. As indicated in the treatability study report, Mix-3 (2.5% PC plus 5% BFS by soil dry mass using site soils) and Mix-9 (2.1% PC plus 4.2% BFS by soil dry mass using borrow soil) achieved unconfined compressive strength in exceedance of the 30-psi target at 7 days of curing and continued to develop compressive strength at all subsequent testing intervals through 56 days of curing (Arcadis 2022a). Both mix formulations resulted in hydraulic conductivity values (at 56 days of curing) that were approximately one order of magnitude lower than the maximum allowable goal of 1.0×10^{-6} cm/sec.

Although an acceptable mix using site soils was developed during the laboratory treatability study, borings in proximity to the proposed alignment encountered significant variability within the fill portion of the soil column, which presents concerns with respect to wall properties and consistency during implementation. The practicality of effectively separating DBO and peat from the appropriate soils for mixing is a concern, and if these materials are not properly separated, there is a greater potential for wall inconsistencies. Based on these concerns, borrow soil is proposed for the slurry wall backfill. The use of borrow soil will provide a more consistent and engineered wall section that meets the performance criteria for the full wall section. If site soil is used for the wall backfill, there is a greater potential for permeability above the target and/or zones of low strength in the wall based on the heterogeneity and overall poor quality of the fill soils (e.g., debris, DBO, peat).

4.3.1.3 Wall Alignment

The proposed limits of the soil-cement wall for the bulkhead option of the barrier network are based on positioning the alignment along the rip rap-protected shoreline at an offset distance that allows for construction of the wall using conventional techniques. Typically, a working platform is constructed along a slurry wall alignment to provide a uniform surface for equipment operation and to aid in control of slurry as the wall is being excavated. The platform is typically 2 to 3 feet in height, 20 to 25 feet in width, and constructed of soil. The alignment of the slurry wall portion along the existing shoreline accounts for this platform width and assumes a minimum distance between the slurry wall centerline and the edge of rip rap to be approximately 25 feet.

As the soil-cement wall alignment extends to the south and west, the alignment then accounts for the existing embankment for the fire water impoundment. This earthen embankment is approximately 11 feet in height and slopes at approximately 4H:1V (4 horizontal units to 1 vertical unit). For protection of the impoundment, the soil-cement wall is positioned approximately 30 feet from its toe. This offset also allows for positioning of the collection trench and conveyance piping between the barrier and the embankment.

4.3.1.4 Wall Properties

The soil-cement wall will be designed to meet the following performance criteria:

- Unconfined compressive strength values of at least 30 psi at 28 days of curing; and
- Hydraulic conductivity values less than 1×10^{-6} cm/sec.

Based on the findings of the treatability study, a design mix that incorporates borrow-source soil with 2.5% PC and 5% BFS will meet the performance criteria and is proposed for construction of the slurry wall. Borrow soil with this proposed reagent dosage will be mixed at the ground surface and placed into the trench via a dozer, front-end loader, excavator, or other approved method proposed by a contractor. Conceptual details of a partial wall profile and a plan detail are shown in Appendix A. A minimum wall width of 2 feet is proposed.

The wall is proposed to be excavated under slurry using a hydraulic excavator or long stick excavator. The soils excavated will be transported off site for disposal, and the wall will be backfilled with the specified design mix. A benefit of this construction method is the ability to confirm the top of the impermeable surface during construction. Quality control criteria will be established for confirming embedment into the clay layer through visual observations as the wall construction progresses. Quality control plans for this type of wall construction typically involve a geotechnical engineer or other qualified person continuously observing the excavation and backfilling process. The soils removed at depth will be examined to confirm that the contractor is sufficiently tagging the clay and embedding the wall into the clay to the required depth. This confirmation of tagging and embedding is typically recorded no less than every 25 feet and as often as every 10 feet. As shown by the barrier details on the Design Drawings (Appendix A), the wall will extend a minimum of 3 feet into the clay layer, which is considered sufficient embedment into an impermeable layer for developing a bottom seal for the barrier. The overall embedment depth as measured from existing grade will range from 13 to 30 feet.

Because of the shallow groundwater level at the Site, the top of the soil-cement wall must be above the frost depth to remain an effective containment barrier. Typically, the tops of soil-cement walls do not extend above the frost depth due to impacts from the freeze-thaw action and the potential for development of cracks through the wall. It is common to require removal of the soil-cement to the frost depth and backfill with select soil to grade. Given the shallow groundwater at the Site, removal of soil-cement may not be an option and other methods for addressing freeze-thaw impacts to the barrier need to be developed.

As part of the final design of the soil-cement barrier, the potential for freeze-thaw damage of the soil-cement wall will be assessed. This assessment may include the following options:

- Testing the proposed mix design for frost resiliency and pending results, adjusting the reagent dosage to optimize the mix against freeze-thaw impacts. Soil-cement removal for this option would extend to approximately 12 inches below grade, or as needed for restoration surfaces.
- Replacing the upper 4 feet of soil-cement (i.e., estimated frost depth) with clay or flowable fill. This option requires proper sequencing to ensure that a sufficient bond is formed between the soil-cement wall and overlying material so as not to promote a preferential path. Wall removal within 7 days of construction is recommended for placement of clay or flowable fill.
- Installing a hanging wall to a depth of 5 feet below grade. This option would not require removal of the soil-cement wall. As the slurry trench is backfilled, a liner would be positioned along the side of the trench extending from grade to approximately 5 feet. The liner would be supported by the backfill and serve as a second barrier should cracks develop in the soil-cement wall from freeze-thaw actions. This option has been incorporated into the soil-cement wall details shown on the Design Drawings.

4.3.2 Subsurface Sheet Pile Walls

As discussed previously, the limits of the soil-cement wall were established based on considering a combination of fill material thickness, potential for deep obstructions, vibration impacts, and minimization of disruption to public roadways. The remaining segments of the subsurface barrier are proposed to be driven, steel sheet piling. This section provides the basis of design of the steel sheet piling and includes a summary of subsurface conditions and items specific to the wall properties and alignment. Data gaps that must be filled before subsequent design phases are discussed in Section 10.

4.3.2.1 Material Selection

The sheet pile section material will be selected based on drivability through the subsurface, potential for encountering obstructions/debris at depth, corrosion potential, and type of interlock joint. The hydraulic conductivity for this wall type will meet the criteria established from the site groundwater model of 1×10^{-6} cm/sec and, when considering the application of a sealant at each interlock joint, is expected to range between 1×10^{-6} and 1×10^{-7} cm/sec.

For this Preliminary 30% Design, a Z-shaped pile is assumed. This pile type is common and widely available in the United States. The interlocks for this pile shape are the Larssen type, and each joint will be sealed with a hydrophilic sealant. Given the currently available subsurface information along the alignment, pile sections are expected to range from an NZ-20 to NZ-22.

4.3.2.2 Wall Alignment

The alignments of sheet pile segments of the barrier are shown on the Design Drawings (Appendix A). For the northern perimeter, the sheet pile alignment is in Perry Place, generally positioned within the southern portion of the roadway. A watertight connection to the existing bulkhead is required at its eastern end. The wall length is approximately 950 feet.

The southern alignment of the proposed sheet pile wall extends from the western end of the soil-cement wall and continues along James Desana Drive for approximately 900 feet. The majority of the wall will be positioned along the northern edge of the roadway.

Both the northern and southern alignments will intersect existing public utilities. Approximate locations of the utility crossings are shown on the Design Drawings for the northern sheet pile alignment (Appendix A). Utility information for the southern alignment is limited and will be obtained during future phases of design. Each utility crossing will be addressed with the utility owners. Options for addressing utilities could include requiring temporary bypass systems or incorporating another wall technology (e.g., jet grouting) to maintain the barrier properties.

4.3.2.3 Pile Depths

The steel sheet piles will be driven into the clay layer to provide a bottom seal for the barrier. Similar to the soil-cement wall, a minimum of a 3-foot embedment into the clay layer is proposed for the sheet piles and is considered sufficient embedment for an effective vertical seal along the wall alignment. Based on currently available subsurface information, the pile depths for the northern alignment of the sheet pile wall will vary from approximately 16 feet below proposed grade at the western end to 25 feet at the connection to the existing sheet pile bulkhead. For the southern alignment, the pile depths will range from approximately 10 to 28 feet below proposed grade. The tops of sheet piles will be above groundwater surface but also at a sufficient depth (approximately 12 inches) below grade for placement of restoration materials.

Prior to pile driving, the alignment of the sheet pile wall will be pre-trenched through the fill layer or to a maximum depth of 10 to 12 feet below grade, dependent on trench stability. If deeper obstructions are found during pre-construction work, they will be removed prior to wall installation during pre-trenching activities. Excavated materials from the pre-trenching activities will be staged and loaded for off-site disposal.

Unlike for the soil-cement wall, visual confirmation of embedment into the clay layer for each sheet pile is not possible. Additional investigations along the alignment will be conducted to obtain greater certainty of the clay profile for each alignment and to allow for greater efficiency in the required pile lengths.

4.3.3 Steel Bulkhead Design at South Dock

The steel bulkhead provides stability to the existing historical structures on the shoreline, does not change the footprint of the Site, and is a “tried and true” approach for a groundwater barrier along a surface water body.

In addition to design information, this section provides background information, the rationale for the wall type selection, and discussions of construction methods, constructability, and sequencing the steel sheet pile bulkhead with a steel sheet pile anchor wall at the South Dock. Alternative design elements for the bulkhead to be evaluated as part of the final design are also introduced. Data gaps that must be filled before subsequent design phases are discussed in Section 10.

4.3.3.1 Background

This section provides a brief description of background information relevant to the steel bulkhead design including the existing structures along the South Dock, information about planned dredging in the Detroit River adjacent to the Site, and subsurface conditions.

4.3.3.1.1 Existing Structures Along South Dock

The existing South Dock structure consists of a soil-covered concrete deck supported on timber piles. Previous design drawings are available for some of the waterfront structures and are included in the RCRA RFI Response (Arcadis 2017). A 1939 drawing of an outfall structure shows a cross section through the concrete deck at the South Dock (Drawing 92/9, titled “Alterations to Dock for Main Sewer Outfall,” dated October 10, 1939, Michigan Alkali Company, Engineering Department; note that portions of the drawing are barely legible).

In addition to the pier structure, there is a Wakefield wall (a tongue-and-groove timber sheet pile bulkhead) between the concrete deck and the upland area. Based on drawings for similar structures located north of the South Dock, it is assumed that lateral support for the Wakefield wall is provided by steel tie rods connected to timber piles that were driven into the ground in the upland area. At the locations to the north, there are two rows of timber piles that are used as anchors, one approximately 30 feet behind the Wakefield wall and another row approximately 50 feet behind the Wakefield wall (Arcadis 2017).

4.3.3.1.2 Upper Trenton Channel Dredging Project

A sediment remediation project that involves dredging in the UTC including along North Works adjacent to the South Dock is currently being developed by BASF and other non-federal partners in collaboration with USEPA (CH2M HILL, Inc. 2019). The current dredge prism design along the South Dock includes a 10-foot offset from the face of the pier structure and a 3H:1V (3 horizontal units to 1 vertical unit) downward dredge slope away from the shoreline.

Although not currently incorporated in the UTC project dredge prism design, for this Preliminary 30% Design it is assumed that dredging can be performed to an elevation of 540 feet NAVD88 up to the new bulkhead, after installation of the bulkhead. This assumption is included in the Preliminary 30% Design to evaluate the feasibility of a bulkhead wall that would allow sediment removal next to the wall. Note that this assumption may change in later stages of the design.

4.3.3.1.3 Subsurface Conditions

Detailed information regarding subsurface conditions and physical characteristics of the geologic units in the alignment of at steel bulkhead wall are provided in the Geotechnical Data Report for the Site (Arcadis 2021a).

The subsurface soils predominantly consist of relatively loose and soft soils over bedrock. During the 2020 subsurface investigation, the till was encountered at elevations between approximately 514 feet and 519 feet NAVD88. Based on the borings drilled in 2020, the top-of-bedrock elevation varies between approximately 509 feet and 516 feet NAVD88.

The combination of soft soils over relatively shallow bedrock provides a challenge in terms of achieving passive resistance for the bulkhead wall. The necessary amount of passive resistance to prevent the toe of a wall from “kicking out” (i.e., excessive movement to the point of wall failure) is typically achieved by increasing sheet pile embedment depth into the subsurface materials. The shallow bedrock makes this difficult because it is not possible to drive sheet piles into relatively competent bedrock requiring the design to incorporate constructable methods of embedding components of the wall into bedrock.

4.3.3.2 Bulkhead Wall Preliminary Design

This section provides descriptions of the bulkhead structural components, the design criteria and assumptions, and the results of calculations performed for the Preliminary 30% Design the steel bulkhead wall.

4.3.3.2.1 Bulkhead Structural Components

The steel bulkhead structure will consist of an anchored steel sheet pile wall. A typical cross section through the wall system is provided in Appendix A. For the Preliminary 30% Design, the bulkhead system consists of a headwall on the outboard side (river side) of the existing South Dock waterfront structure and a parallel anchor wall in the upland area behind the South Dock. To achieve sufficient structural capacity, the headwall will likely need to be constructed using a combination wall system consisting of steel king piles with intermediate sheet piles. The structural requirements are provided in Section 4.3.3.3. The king piles can consist of H-piles or pipe piles. A wall system consisting of interlocking steel pipe piles may also be considered.

Combination walls and interlocking pipe pile systems are readily available from steel suppliers and generally provide higher capacities and wall stiffnesses than regular sheet pile walls without king piles. These systems also are often more efficient in terms of the ratio of steel weight (which largely determines the cost of the steel) and the structural capacity (and stiffness) of the wall. However, combination walls are generally more expensive than regular sheet pile walls in terms of installation costs because of overall lower production rates during installation.

For the Preliminary 30% Design, it was assumed that the headwall will be anchored to a continuous subsurface, steel sheet pile anchor wall through steel tie rods. Anchors will be needed because of the significant lateral loads that will be imposed on the headwall. The anchors will provide lateral support for the headwall, reduce structural demand on the headwall, and limit wall deflections. The tie rods will be installed at regular intervals, perpendicular to the headwall and anchor wall alignments (i.e., approximately perpendicular to the river). During final design, the anchor wall alignment will be reviewed, and adjustments incorporated to the anchor wall as needed to facilitate groundwater recovery in the collection trench. These adjustments could include incorporation of weep holes in the sheet pile, staggering segments of the anchor wall (i.e., a discontinuous anchor wall), or an A-frame anchor as described in Section 4.3.3.4.3.

Walers will be used to transfer loads from the tie rods to the anchor wall and will likely consist of two parallel steel channel sections that will be installed near the top of the anchor wall. At the connection point between the tie rod and headwall wall, a waler may not be needed and the tie rod may be connected directly to each king pile spaced at the bulkhead wall system width (i.e., the center-to-center spacing of the king piles). Note that design of connections and walers is not included in the Preliminary 30% Design and will be included in the final design.

Because of the limited available embedment depth into subsurface soils (Section 4.3.1.5), it was assumed for the Preliminary 30% Design that the steel king piles and intermittent sheet piles will be driven to the top of bedrock. It was also assumed that shear pins (also referred to as rock bolts) will be installed to connect the bottom of the headwall to the bedrock and provide sufficient resistance to prevent the toe of the wall from "kicking out" (i.e., experiencing excessive movement to the point of failure). Shear pins are typically approximately 8 feet long and installed through steel casing that is welded to the sheet piles and/or king piles before pile installation. The pins consist of high-strength steel and are typically up to approximately 3.5 inches in diameter. Half of the shear pin length (approximately 4 feet) is typically embedded in the bedrock through drilling. Other potential options for providing passive resistance and preventing a failure scenario are discussed under Section 4.3.3.4.

4.3.3.2.2 Design Criteria and Assumptions

The bulkhead wall will be designed to form a low-permeability containment barrier to mitigate the flow of groundwater toward the Detroit River. In addition, the wall will be designed to withstand structural loads, including lateral earth pressures, hydrostatic pressures, and a temporary surcharge load.

The Preliminary 30% Design calculations for the headwall and anchor loads were performed in general accordance with the United States Army Corps of Engineers (USACE) guidance document titled "Design of Sheet Pile Walls" (USACE 1994). The analysis methodology and assumptions are provided with the bulkhead wall calculations in Appendix B. The assumptions in Appendix B include the following:

- Design cross section showing the assumed geometry and soil and bedrock stratigraphy;
- Factors of safety;
- Design loads, including temporary surcharge load and hydrostatic loads; and
- Design soil parameters.

To reduce seepage through the sheet pile interlocks, a sealant will be applied to the interlocks prior to installation of the sheet piles and king piles. Additionally, the use of Larssen-type sheet pile interlocks and connectors (or similar) will be specified to avoid the use of ball-and-socket interlocks. Larssen interlocks provide a tighter connection than ball-and-socket interlocks and are therefore less prone to seepage through the interlocks.

4.3.3.2.3 Results of the Preliminary 30% Design Calculations

The Preliminary 30% Design calculations are provided in Appendix B. For this level of design, calculations were performed to determine preliminary requirements for the headwall only. The purpose of the calculations was to determine the following:

- Structural demand on the headwall;
- Wall type: regular sheet pile wall or combination wall (i.e., king piles and intermediate sheet pile or similar system);
- Required embedment/need for shear pins; and
- Anchor load.
- The minimum structural requirements for the Preliminary 30% Design are summarized in Table 4. The calculations will be refined further as part of the final design and will likely include additional analysis methods, as outlined in Appendix B. Requirements for the anchor wall will also be established during the next design phase and may include requirements for the alternative structural components described in Section 4.3.3.4 (e.g., A-frame anchor instead of anchor wall).

As discussed in Appendix B, the calculations indicate that, because of the relatively shallow bedrock at the Site, there is insufficient available embedment depth in the clay unit and glacial till to achieve the factors of safety needed for wall stability. Therefore, it is assumed that shear pins will be required to achieve sufficient resistance against rotational failure (i.e., kickout of the headwall toe).

Table 4. Summary of Minimum Bulkhead Structural Requirements for Preliminary 30% Design

Structural Component	Description/Parameter	Type/Value
Steel Headwall	Wall Type	Combination wall (steel king piles with intermediate steel sheet piles)
	Steel Grade	ASTM A 572 Grade 50
	Minimum Section Modulus (in.^{3}/ft)	163.3
	Top-of-Wall Elevation (feet NAVD88)	578.0
	King Pile Length (feet)	Approximately 62 to 69 feet (installation to top of competent bedrock; shear pins required)
	Intermediate Sheet Pile Length (feet)	Approximately 61 to 63 feet (driven 1 foot in glacial till)
Steel Anchor Wall	Wall Type	Sheet pile
	Steel Grade	ASTM A 572 Grade 50
	Minimum Section Modulus (in.^{3}/ft)	77.0
	Top-of-Wall Elevation (feet NAVD88)	576 (2 feet bgs)
	Sheet Pile Length (feet)	40
Steel Tie Rods	Design Capacity (kips/foot)	29.21
	Tie Rod Length (feet)	105

Notes:
Structural requirements for walers have not been determined.
in.^{3}/ft = cubic inches per foot
kips = kilo pounds

4.3.3.3 Construction Methods and Constructability Considerations

This section describes the construction methods, constructability considerations, and anticipated construction sequence for the steel bulkhead along the South Dock. A Construction Quality Assurance Plan will be included with the Pre-final Design (95%) that describes quality assurance controls to monitor and verify that the steel bulkhead wall is installed per specification requirements. The Construction Quality Assurance Plan will also include contingency measures for field adjustments to meet the specification requirements. The use of construction quality monitoring results to adapt the construction methods and/or the construction monitoring methods may be needed to achieve installation of the steel bulkhead wall.

4.3.3.3.1 Sheet Pile and Combination Wall Construction

Sheet piles and king piles will likely be driven into the subsurface soils using a vibratory hammer. A crane will be required to lift the piles in position for driving. Driving the piles through the relatively loose and soft native subsurface soils is anticipated to be relatively easy and smooth. Based on the stiffness of the glacial till, a vibratory hammer is anticipated to be able to drive the king piles and sheet piles of the combination wall system to the top of bedrock. However, an impact hammer may be used to drive the piles through the glacial till to the top of the bedrock, if necessary.

Difficult conditions may be encountered during pile driving for the anchor wall in the upland fill soils, which contain various types of debris, including concrete debris and even slabs. The contractor will be prepared to remove subsurface obstructions. To the extent possible, the contractor will locate and remove debris and other obstructions prior to pile driving. Based on experience during the subsurface investigation, subsurface obstructions are more prevalent in the upland fill soils. CPTs conducted in the upland areas frequently encountered debris and difficult conditions in the fill materials. The CPT probe generally encountered less resistance and fewer obstructions along the river bottom.

Combination walls are typically installed using a heavy, prefabricated template to ensure that king piles are installed plumb and at the right spacing. After the king piles are installed using the template, the intermediate sheet pile pairs are installed between the king piles, forming a continuous steel wall.

Although the bulkhead wall can be installed from the river side using deck barges, it may also be possible to position a crane on the upland side for pile installation. Because of the condition of the South Dock, it may not be possible to position the crane on the dock. Instead, the crane would likely be positioned on the upland side of the concrete deck. Based on a maximum deck width of approximately 34 feet, the crane should be within reach of the headwall alignment at that distance.

A sealant will be applied to the sheet pile interlocks prior to sheet pile installation. Various interlock sealants are commercially available and are routinely applied by contractors or fabricators.

4.3.3.3.2 Shear Pin Installation

Shear pins may be needed at every king pile location and potentially at the intermediate sheet pile pairs. The technology is described in an ArcelorMittal guidance document (ArcelorMittal 2018). Embedment of the king piles into the bedrock (referred to as rock socketing) may also be considered at later stages of design (Section 4.3.3.4.1).

For the shear pin installation, steel casing will be welded to the king piles and/or sheet piles. Welding is typically performed at an off-site location prior to delivery of the pilings to the Site. The diameter of the casing is slightly larger than the diameter of the shear pins. After installation of the piles, the contractor will use drilling equipment, similar to equipment used for drilling of geotechnical borings, to drill through the casing and into the bedrock below the tip of the king piles and/or sheet piles. The drill cuttings will then be removed from the hole and grout will be tremied to the bottom. Immediately after grouting, the shear pin will be pushed or hammered through the casing to the bottom of the hole. Because of the condition of the existing South Dock structure, and the need for the drill rig to be directly above the headwall and casing, shear pin installation is expected to be performed using barge-mounted equipment.

4.3.3.3.3 Anchor System Components

Once the headwall and anchor wall are in place, walers will be installed on the walls for load transfer from the tie rods to the walls. A waler may not be required for the connection to the bulkhead wall. However, this detail will be addressed as part of the final design. Waler installation will involve some welding and bolting.

The tie rods will be installed at a relatively shallow depth below the ground surface, within the soil cover on top of the concrete deck of the existing South Dock. This installation will require excavating trenches between the headwall and anchor wall. The river side edge of the existing concrete deck consists of a “concrete kneewall” that retains the soil on the concrete deck. The contractor will need to cut notches into the concrete kneewall to allow penetration of the tie rod through the concrete bulkhead.

For the Preliminary 30% Design, it is assumed that the tie rod headwall connection will be near the top of the headwall (approximate elevation of 576 feet NAVD88) to keep the tie rods above the concrete deck and the connection points above the river water surface elevation to avoid underwater welding. At the anchor wall, the connection point will likely be lower (approximate elevation of 574 feet NAVD88) to keep the top of the anchor wall at least 2 feet bgs.

4.3.3.3.4 Backfill Placement

Because the concrete deck of the existing South Dock structure would remain in place, backfill to fill the void behind the new bulkhead wall, underneath the concrete deck, must be placed either through a tremie pipe hydraulically or using gravity. Access points need to be created through the concrete deck by first removing some of the soil on the deck to expose the concrete and then cutting holes into the concrete.

Placement of fill will likely induce consolidation settlement in the underlying clay unit. As a result, the fill surface will move away from the concrete deck above over time. Therefore, filling the gap completely during initial backfilling will not be beneficial; the concrete deck will still be supported by the timber piles. Settlement monitoring of the fill surface should be performed to assess the progress of consolidation in the clay unit. Pore pressure monitoring equipment may also be installed in the clay unit, through an opening in the concrete deck, to monitor consolidation.

Once consolidation settlement is complete or nearly complete, which could take several years, the gap between the fill and the concrete will be closed by pumping flowable, cementitious grout into the gap. To reduce the amount of grout that might enter the void space of the backfill material, the backfill material will be selected such that the fill is progressively finer (i.e., relatively coarse aggregate near the bottom and finer materials such as sand near the top of the fill).

While it may not be possible to completely close the gap between the fill surface and the concrete, it may not be necessary to do so. Over time, the existing deck might develop cracks as the timber piles deteriorate, and some minor ground settlement may occur above the concrete deck. This scenario would then be treated as part of maintenance, which may include regrading of the surface. This scenario is not considered a safety concern because the new bulkhead structure will be designed to carry the full weight of the backfill and the old concrete deck.

4.3.3.3.5 Existing Subsurface Structures and Stability of Existing South Dock

There are various existing structures that will either stay in place or will need to be removed during bulkhead construction. Data gaps regarding the locations of existing subsurface structures that need to be filled before the next design phase are discussed in Section 10. The need for maintaining the anchoring for the existing Wakefield wall during construction must be assessed further. The anchor wall (or alternative anchor structure such as an A-frame anchor as described in Section 4.3.3.4.3) for the new bulkhead may need to be located behind the existing timber piles used for anchoring of the Wakefield wall. An anchor wall would likely need to be located approximately 100 feet or more behind the existing timber piles in any case to avoid overlapping the active soil wedge behind the headwall and the passive soil wedge in front of the anchor wall. An A-frame structure could potentially be placed closer to the headwall, although stability of the Wakefield wall may need to be maintained during construction of the new anchored bulkhead structure until the gap behind the bulkhead is backfilled. Installation of new tie rods for the bulkhead will require cutting notches into the concrete kneewall along the face of the existing South Dock structure.

4.3.3.4 Alternative Design Elements and Construction Methods

The anchored wall design presented above is generally considered feasible. Certain aspects of the design will be evaluated further during subsequent phases of the design, including technologies to improve constructability and approaches to lower the structural demand on the wall system. The alternative technologies and approaches are described below.

4.3.3.4.1 Rock Socketing of King Piles

As an alternative to the shear pins described in Section 4.3.3.3.2, the king piles within the headwall can be embedded into the bedrock. This is referred to as rock socketing, which will require the use of down-the-hole drilling (DTH) either within a casing or within a pipe pile (i.e., pipe pile installed as king pile).

For the installation of H-piles as king piles, a casing would be driven through the sediment and soil to the top of bedrock first. Then, a DTH drill is inserted into the casing to remove the soil inside the casing and then drilled several feet into the underlying bedrock. A king pile can then be inserted and grout placed via a tremie pipe to the top of bedrock. Following grouting, the casing would be removed and the next king pile can be installed in the same fashion.

Technology exists to install pipe piles into rock without the use of a casing. Mincon makes DTH drills that allow advancing pipe piles into rock directly without installing casing first. However, this technology may not be widely available in the United States at this time.

4.3.3.4.2 Reinforced Concrete Anchor Wall Installed as Slurry Wall

As described previously, the upland fill soils contain debris that will likely make driving sheet pile relatively difficult. An alternative to a sheet pile wall as the anchor wall is a reinforced concrete wall installed as a slurry wall. A trench is excavated under slurry to prevent collapse of the trench, a rebar cage is inserted into the trench, and the trench is then backfilled with structural concrete. The advantage over a sheet pile wall is that debris can be removed during trench excavation. Note that the construction process is similar to the process used for the subsurface barrier. However, the anchor wall will serve as a structural wall, not a subsurface barrier.

4.3.3.4.3 A-Frame Batter Pile Structure for Anchoring

An alternative to an anchor wall is an A-frame batter pile structure. The batter piles would consist of steel H-piles driven to refusal in the bedrock. The piles are driven at an angle (at a batter) to increase lateral resistance of the structure. Several batter piles are typically tied together near the ground surface by a reinforced concrete block or continuous beam. The tie rods from the bulkhead wall are later connected to the concrete block or beam. A potential advantage of an A-frame over a sheet pile anchor wall is that it can be easier to install H-piles through debris than to install sheet pile in the same material. However, predrilling some of the piles may be needed in case of heavy resistance during pile driving.

4.3.3.4.4 Lightweight Fill as Backfill Behind the Bulkhead Wall

A fill material with a unit weight that is significantly less than that of aggregates or soil could potentially reduce structural demand and sheet pile lengths. There are lightweight aggregates and lightweight controlled low-strength materials (“flowable fills”) that may be suitable for filling behind the bulkhead wall, under water.

4.3.3.4.5 No-Dredge Alternative

The design described in Section 4.3.3 includes accommodating dredging directly adjacent to the bulkhead wall to allow for the removal of contaminated sediments. Removal of the sediments will reduce passive resistance, which results in higher structural demand on the wall and longer required sheet piles. The benefits of implementing the planned dredge offset from the waterfront structure will be evaluated further as part of the final design.

4.3.3.4.6 Buttressing to Increase Passive Resistance

If the sediments in front of the headwall are removed to the depth described in Section 4.3.3.1.2, placing a sand and gravel buttress in front of the wall is expected to reduce the structural demand and the required wall embedment depth. Buttressing in combination with using lightweight fill could potentially reduce the required wall embedment depth enough to prevent the need for installation of shear pins.

4.4 Existing Sheet Pile Wall

The existing bulkhead extends approximately 3,300 feet north of the South Dock. It was constructed in the mid-1990s and consists of interlocking steel AZ-13 sheet piles that are approximately 40 to 45 feet deep and embedded into the clay layer. This bulkhead is offset approximately 2 feet on the river side of the original wooden bulkhead and concrete seawall when present. Its anchorage system extends 30 to 70 feet upland of the bulkhead. Historical drawings do no indicate that the interlock joints were sealed or that corrosion protection measures (i.e., coatings, cathodic protection) were applied to the piles. However, hydraulic testing and groundwater modeling completed as part of the pre-design investigation concluded that this bulkhead is an effective barrier to groundwater flow (Arcadis 2021c). The groundwater model is discussed further in Section 5.1.1.

In May 2018, Arcadis conducted a visual inspection of the shoreline structures at the Site, including the existing bulkhead north of the South Dock. The visible portions of the piling above the water surface were inspected. General findings from this inspection concluded that the existing bulkhead was in good, stable condition. The existing sheet piles appeared to be in proper alignment with no signs of rotation or other failures. The visible portions of the sheet pile wall and its components (pile caps, waler, tie rods) also appeared to be in good condition with no significant signs of corrosion or steel section loss.

Arcadis performed a desktop evaluation of the estimated corrosion rates for the existing bulkhead in support of this BOD Report. The purpose of the evaluation was to assess the anticipated lifespan of the existing sheet piles from a steel thickness loss aspect. Thickness loss rates were determined using Eurocode 3 – Design of Steel Structures – Part 5: Piling (European Committee for Standardization 2007), which provides loss rates based on environmental conditions typical of industrial sites. The existing sheet pile wall is approximately 30 years old. The estimated corrosion loss over 30 years is approximately 0.05 inches or 15% of the pile's original thickness of 0.375 inches. Longer timeframes of 60 to 80 years result in expected corrosion losses of 0.10 to 0.15 inches or approximately 25 to 40% of the original pile thickness.

Although, from a containment barrier aspect, the estimated corrosion losses would not compromise the steel wall's ability to be an adequate barrier to groundwater flow, the structural capacity of the steel section and the potential for the bulkhead's failure from excessive rotation or bending could be of concern. For those piles where corrosion losses do progress during the pile lifespan, the expected failures would be localized areas of bulging or cracking/splitting of the sheet pile section. An effective monitoring and maintenance program can optimize the lifespan of the existing bulkhead by identifying and addressing these types of failures on a case-by-case basis. Monitoring and maintenance requirements will be in place for the existing bulkhead as discussed in Section 12.

Based on groundwater model findings and results of the 2018 inspection, an additional visual inspection of the bulkhead will be conducted to identify and address any areas noted in the inspection as deficient or in need of repair from a containment barrier perspective. The inspection will focus on those areas of soil and/or water seepage identified in 2018 and include observations of pile conditions above and below the water surface. The ground surface behind the bulkhead will also be inspected for signs of soil loss, such as localized depressions, pavement cracking, and utility displacement. Specific repair measures will be developed after the visual inspection is completed and included as part of the final design. Repair measures might include welding steel plates over former outfalls and/or sealing around existing outfalls.

4.5 Barrier Intersections

Construction of the barrier system will require design of appropriate transition zones from one barrier type to the next. These transition zones will be designed so that the intersections of the barrier types are properly overlapped or sealed and provides a continuous barrier along the downgradient perimeter of the Site.

There are four intersections along the network. The northernmost connection is common to both barrier network options and is between the existing steel bulkhead and the subsurface sheet pile barrier wall. For this intersection, it is proposed to seal the two walls through a series of jet grout columns extending from grade to a minimum embedment of 3 feet into the clay layer. Another option for this intersection involves directly connecting the sheet pile into the interlock of the existing bulkhead sheet piling. This option requires further investigation of the sheet pile configuration of the existing bulkhead.

For the South Dock area, piles will be connected with the existing bulkhead at the dock's northern end and with the soil-cement barrier at the dock's southern end. Approaches for connecting the bulkhead piles to the existing piles will be similar to the options discussed above for the northernmost barrier connection.

At the connection to the soil-cement barrier, a transition zone will be designed between the steel sheet pile of the bulkhead and the soil-cement wall. At the southern end of the soil-cement barrier, a similar transition between wall types will occur at the soil-cement wall and the subsurface steel sheeting intersection along James Desana Drive. For both of these intersections, the design will consider the following methods for sealing:

- Series of jet grout columns at the intersection of the two wall types; and
- Extension of the steel sheet piling approximately 10 feet into the alignment of the soil-cement wall. At each end, a cement-bentonite wall (instead of the soil-cement wall) would be installed, and the piles driven to depth in this zone.

5 Groundwater Extraction and Conveyance System

The BOD for the groundwater extraction and conveyance system is described in this section. The layout of the drainage and conveyance network is shown on Figure 4. Piping and instrumentation diagrams (P&IDs) are provided with the Design Drawings (Appendix A).

5.1 Extraction Trench Network

5.1.1 Summary of Groundwater Modeling Results

To support the Preliminary 30% Design of the barrier remedy, the numerical groundwater flow model of the localized groundwater flow system at the Site (Waterloo Hydrogeologic 2002) was updated. Updates were based on a review of the existing model in conjunction with new and relevant data collected since the original model was developed, including but not limited to data collected during the Hydraulic PDI work (Arcadis 2021c). Model updates included recent water level data, boundary conditions, hydraulic conductivity distribution, applied recharge, and the model grid. In addition to the model design changes, recent versions of the modeling software were used. The objective of the effort to update the groundwater flow model was to simulate localized groundwater dynamics at the

Site to support the design of the barrier remedy. The model updates were summarized in the Groundwater Modeling Report (Arcadis 2021b).

The model was calibrated by systematically adjusting the model boundary conditions and input parameters to obtain as close a match as possible between observed and simulated water levels. The model was calibrated using 84 groundwater level measurements collected in March 2021 from locations distributed throughout the Site. The model was also validated using 77 groundwater level measurements collected in March 2019 from locations distributed throughout the Site. Based on both quantitative (e.g., calibration statistics) and qualitative (e.g., groundwater flow directions) data, the groundwater flow model was determined to be well calibrated. A sensitivity analysis was performed to improve the model calibration and to assess the uncertainty associated with the model.

The updated calibrated model was used to simulate a low-permeability downgradient perimeter barrier located 950 feet along the northern property boundary, located along the entire eastern boundary, and located 1,340 feet along the southern boundary. A non-continuous drain was simulated behind the barrier to estimate an expected drain rate that would meet performance objectives for the Site. The overall drain rate was modeled to be approximately 45.5 gallons per minute (gpm) using an average recharge of 3.5 inches per year.

The calibrated groundwater flow model was also used to assess the sensitivity of the remedial design to different recharge and river/drain elevations. The Detroit River elevation was varied between 569 ft IGLD 85 and 574.39 ft IGLD 85, representing the anticipated low river elevation for the Detroit River and the average March 2021 stage, respectively. The recharge rate used in the model was varied between 3.5 and 7 in/yr, representing the calibrated recharge rate over the model domain and two times the calibrated recharge rate, respectively. The drain elevation was varied between 0 ft and 5.39 ft less than the Detroit River elevation. The resulting drain rate ranged between 42 and 77.7 gpm.

The drain rates presented this report are not an estimate of groundwater discharge to the Detroit River under current conditions (i.e. no perimeter barrier).

5.1.2 Initial Design

To adequately capture groundwater flux and prevent flooding of the Site behind the barrier, a passive perimeter groundwater drainage system is proposed for the Site. Vertical wells and horizontal wells were evaluated as options for collecting groundwater behind the perimeter barriers. For vertical wells, the highly heterogeneous nature of the site soils would likely result in varying capture zones that would be difficult to predict in localized areas. Use of vertical wells for groundwater capture would also require significantly more pumping equipment and therefore significantly more maintenance. With horizontal wells, it is difficult to control drawdown and capture across the length of a horizontal well screen in heterogenous soils. In addition, the inability to design and install a filter pack around the screen of a horizontal well would likely result in fine sediment entering the wells and the associated conveyance and groundwater treatment system. The presences of these solids would lead to management and operation and maintenance (O&M) issues. Vertical wells may be utilized to supplement passive drains, as needed, and/or in cases where passive drains cannot be installed due to subsurface obstructions.

Based on results of the updated groundwater model, the HPT investigation, and groundwater pumping tests, the drainage network will consist of eight collection drains capturing groundwater on the northern, eastern, and southern boundaries of the Site. The drain alignment is presented in the Preliminary 30% Design Drawings (Appendix A).

Drain lengths and locations required to hydraulically capture groundwater flux were established based on groundwater model simulations. Design elements considered to identify the drain type included ease of installation, ease of operation, and long-term operation, maintenance, and monitoring requirements. Design parameters for the collection drains are presented in Table 5.

Table 5. Groundwater Modeling Drain Rates at Drain Locations

Drain ID	Boundary Location	Length (feet)	Drain Rate (gpm)
1	North	400	6.4
2	East	220	4.7
3	East	715	8.6
4	East	170	1.3
5	East	2,045	12.1
6	East	95	7.3
7	East	875	5.1
8	South	115	

The collection drainage network will consist of perforated pipe installed at a targeted depth interval of approximately 569 feet above mean sea level, consistent with 20-year historical river low-flow levels. Drainage trenches will be backfilled with a high-permeability material (i.e., pea stone) to promote maximum drainage. To monitor groundwater levels and support the evaluation of drainage efficiency, a series of piezometers will be installed within and adjacent to the drains. Groundwater will drain into the perforated pipe and will flow by gravity into sumps, where the groundwater will be pumped through a conveyance network to a treatment system.

5.2 Conveyance Network

5.2.1 Sump Network

Groundwater captured in the collection drains will flow by gravity into a sump network. The sump locations are presented on the Preliminary 30% Design Drawings (Appendix A). Thirteen sumps will be placed at intervals of approximately 500 feet along each segment of the collection drainage network. Each sump will be equipped with a primary pump and a redundant pump, both with variable frequency drives, pressure transducers to monitor water levels, valves, and a level transducer. Additionally, level switches (floats) will act as equipment safety devices in the event the level transducer fails. Each pump will be sized to operate at the maximum flow rate for the sump as determined by anticipated drainage flow rates.

5.2.2 Conveyance Piping

Groundwater collected at the sumps will be pumped through a network of below-grade conveyance piping to a treatment system. The lateral piping from each sump will connect to a singular header pipe that runs to the treatment system as depicted on the Preliminary 30% Design Drawings (Appendix A). To mitigate potential flooding risks from unexpected conveyance issues (line breaks, fouling, etc.), a network of redundant lateral piping from the sumps to a redundant header pipe will also be installed. The conveyance network will be constructed with buried high-density polyethylene and above-grade carbon steel piping. Pipe sizing was determined using total dynamic head calculations, which account for static head and head loss or frictional loss (e.g., pipe lengths, fittings, instrumentation) for the conveyance line within the conveyance network. Conveyance line hydraulic calculations are included in Appendix B.

To mitigate freezing risk, conveyance piping will be buried below the frost line. Pipe fouling within the conveyance network will be mitigated by installing cleanouts placed at intervals of approximately 500 feet. The piping will be cleaned as part of scheduled routine maintenance or when the conveyance network demonstrates increasing pressure or decreased flow as a result of blockages.

6 Above-Grade Treatment System

The BOD for the above-grade (AG) treatment system is described in this section. P&IDs and a drawing depicting the general arrangement of the treatment building are included in the Preliminary 30% Design Drawings (Appendix A).

6.1 Treatability Study

In March 2022, an AG treatment treatability study was initiated to support the design of the AG treatment system using groundwater collected from monitoring wells throughout the Site. The treatability study included the following main components:

- Site groundwater sampling – Groundwater samples for analysis of key constituents were collected from select perimeter monitoring wells (i.e., those located in the zones of highest hydraulic conductivity). These data, along with existing analytical data, were used to evaluate the range of potential influent water quality for bench-scale testing.
- Treatability test groundwater collection – Groundwater used for bench-scale testing was collected from select perimeter monitoring wells. Water from these wells was blended to represent reasonably anticipated influent water quality for a full-scale AG treatment system.
- Laboratory treatability testing – Bench-scale testing included the following: pH neutralization (via acid addition), chemical-physical treatment (using coagulant and flocculant), sludge dewatering, and implementation of a granular-activated carbon (GAC) rapid small-scale column test (RSSCT).

An evaluation of the results of the treatability study provided the basis for the design of each major process unit (Arcadis 2022b). Groundwater characteristics of the Site and treatability study results are discussed in the following sections.

6.2 Influent Characteristics

Influent groundwater chemical characteristics and anticipated flow rates were evaluated to inform system design. Treated groundwater will be discharged to the local POTW, and as such influent chemical characteristics were compared to predicted local POTW criteria. Anticipated flow rates were utilized to understand mass loading and needed system capacity.

6.2.1 Influent Flow Rates

The treatment system will be designed to process a maximum flow rate of 100 gpm. Based on the groundwater modeling calculations and pre-design field investigations, anticipated operational flow rates will be approximately 50 gpm based on an average recharge rate of 3.5 inches per year. The design flow rate of 100 gpm is based on a reasonable worse-case recharge rate of 7.0 inches per year, which would increase the flow rate to 75 gpm, and an applied 33% contingency. The increased flow rate will provide a safety factor for significant precipitation recharge and aid in site drainage. In addition, a means of additional on-site storage such as a retention pond or temporary tank storage will be considered in the Pre-final design (95%) to handle unanticipated temporary influent flow surges.

6.2.2 Influent Chemical Characteristics

On November 11, 2021, and December 16, 2021, Arcadis collected samples from 10 monitoring wells at the perimeter of the Site based on the results of perimeter groundwater monitoring and hydraulic testing as described in the pre-design investigation report (Arcadis 2021c). The monitoring wells sampled are located in zones with the highest hydraulic conductivity and therefore are expected to drive the treatment system influent water quality on a mass flux basis. To ensure the water quality characteristics of the groundwater samples were representative of anticipated influent contaminant of concern (COC) concentrations, the groundwater samples were blended to best replicate the predicted influent flow concentrations of a full-scale P&T system (e.g., higher percentage of water from areas with higher expected groundwater flux). The primary COCs based on local POTW limits are mercury, VOCs, SVOCs, and per- and polyfluoroalkyl substances (PFAS). The analytical results for the COCs detected and general chemistry in the blended groundwater samples are presented in Table 6.

Table 6. Influent Groundwater Characteristics

SVOCs	**Concentration (µg/L)**
1,4-Dioxane	1.1 J
2,4-Dimethylphenol	0.76 J
2-Methylnaphthalene	0.89
2-Methylphenol	0.92 J
3-Metylhpenol, 4-Methylphenol	22
Carbazole	1.0
Naphthalene	8.5
Phenol	43
VOCs	**Concentration (µg/L)**
1,1-Dichloroethane	2.1
1,2-Dichloropropane	1.1
Acetone	25
Ethylbenzene	1.1
m&p-Xylenes	2.3
o-Xylene	2.1
Toluene	2.4
Inorganics	**Concentration (mg/L)**
pH (standard units)	12.4
Alkalinity	930
Total Suspended Solids	114
Total Dissolved Solids	5300
Total Organic Carbon	29
Total Mercury	0.00052
Total Mercury (Low Level)	0.00058
PFAS	**Concentration (ng/L)**
Perfluorohexane sulfonic acid (PFHxS)	33
Perfluorohexanoic acid (PFHxA)	9.6
Perfluorooctane sulfonic acid (PFOS)	68
Perfluorooctanoic acid (PFOA)	12
Perfluoropentoanoic acid (PFPeA)	9.4

Notes:
J = estimated value
µg/L = micrograms per liter
mg/L = milligrams per liter

6.3 Major Unit Processes

Eight major components comprise the AG treatment system. These components were determined and designed based on treatability study findings (Arcadis 2022b). Influent water is first sent to an equalization tank to dampen variable flow rates. Neutralization is then completed to reduce the pH and prepare the influent water for metals precipitation via coagulation, flocculation, and clarification. Following metals precipitation, process water is then fed to a pump-out tank to facilitate transfer to bag filter, GAC, and ion exchange units to address SVOCs, VOCs, and PFAS. Further detail is provided in the following sections and in the Preliminary 30% Design Drawings included in Appendix A.

6.3.1 Influent Equalization

An influent equalization tank will receive untreated groundwater from the extraction sump network. The equalization tank will be designed to control and dampen variable flow rates into and out of the unit process. The influent equalization tank will be sized to allow groundwater extraction to continue during routine anticipated maintenance. During normal operation, the tank will operate to maintain a hydraulic residence time of at least 20 minutes. Transfer pumps with a variable frequency drive will be used to facilitate transfer of influent equalization tank water to the rest of the system within the design flow rates. The influent equalization tank parameters are summarized in Table 7.

Table 7. Influent Equalization Tank Design Parameters

Design Parameter	Value
Treated Equalization Detention Time (minutes)	20
Target Equalization Tank Volume (gallons)	20,000
Equalization Height (feet)	16
Calculated Equalization Tank Diameter (feet)	15
Equalization Tank Freeboard (feet)	1
Operating Equalization Tank Volume (gallons)	20,000

Tank level will be maintained using control loops to communicate with associated pumps, flow meters, and automated valves. Control loop setpoints will be established for continuous operation, and alarm conditions will be defined that interlock the process equipment as a safety measure to protect equipment and prevent a release.

As noted, a means of additional on-site storage for influent equalization purposes such as a retention pond or temporary tank storage will be considered in the Pre-final design (95%) to handle unanticipated temporary influent flow surges.

6.3.2 pH Neutralization

The treatability study (Arcadis 2022b) included a pH neutralization test to determine the acid dosage needed to reduce the groundwater pH level. A circumneutral pH is necessary to efficiently remove metals by coagulation and flocculation treatment, prevent fouling of downstream piping and equipment, and ensure discharge is in compliance with the maximum POTW limit of 9.0 standard units (S.U.). The pH level in the blended influent water used for the treatability study measured at approximately 12.4 S.U. The blended influent water was titrated with sulfuric acid to determine the volume of acid needed to neutralize the pH level. Sulfuric acid was selected for pH adjustment due to its effectiveness in pH neutralization with similar groundwater chemistry. The design parameters based on the influent water quality and pH neutralization test are presented in Table 8.

Table 8. pH Neutralization Design Parameters

Design Parameter	Value
Process Flow Rate (gpm)	100
Initial pH (S.U.)	12.4
Target pH (S.U.)	9.0
Total Alkalinity (prior to pH adjustment) (mg/L)	930
Sulfuric Acid Dosage for pH 9 s.u. (mg/L)	1,900

Sulfuric acid will be delivered in bulk and fed from a 7,000-gallon operational capacity tank using a metering pump. The acid dose initially will be set according to the bench-scale test results and adjusted by the operator as needed during startup and operation, maintenance, and monitoring of the system. The metering pump feed rate will be paced to accommodate the system flow rate.

6.3.3 Precipitation, Coagulation, and Flocculation

The pH-neutralized process stream will be treated with organosulfide metal precipitant (i.e., MetClear) to precipitate solids and thereby reduce mercury concentrations to less than 200 nanograms per liter (ng/L) per the POTW discharge limitation. The blended influent was bench tested at various pH conditions and MetClear doses to determine the optimal MetClear dose to precipitate dissolved mercury into solid form. Using a 20-mg/L MetClear dosage at a pH-adjusted value of 9.0, the test demonstrated a significant decrease in total and dissolved mercury concentrations, visible indication of mercury precipitation, and gravity settling of precipitates after 30 minutes.

Following MetClear treatment, coagulation and flocculation treatment will be implemented to remove the precipitated mercury from the process stream. The treatability study tested varying doses of coagulants and flocculants to determine the optimal combinations to remove mercury. The blended groundwater, sampled with total mercury concentration range of 480 ng/L to 620 ng/L, was used for jar test screening. As presented in the treatability study report (Arcadis 2022b), all test conditions or combinations of doses and coagulant/flocculant solutions met performance objectives. The total and dissolved mercury concentrations decreased to 23 ng/L and 1.4 ng/L following coagulation and flocculation treatment, below the local POTW permit limit of 200 ng/L. The recommended chemical additions and doses are indicated in Table 9.

Table 9. Proposed Metal Precipitant Chemicals and Doses

Chemical	Stock Solution	Dose
Metals Precipitant	MetClear MR2405 (100%)	20 mg/L
Coagulant	Ferric Iron KlairAid IC1251	10 mg/L
Cationic Flocculant	Polyfloc AE1703	3 mg/L

Following pH neutralization, the metals precipitant will be metered into the process stream while it is gravity fed into a rapid mixing chamber. The coagulant will be metered into the rapid mix tank and mixed for approximately 1.1 minutes at 100 gpm. Following coagulant mixing, process water will be gravity fed into the slow mix flocculation tank. The flocculation tank will be sized to provide approximately 3.2 minutes of retention time at 100 gpm. Retention time is based on equipment specifications for a clarifier at the 100-gpm design point.

6.3.4 Clarification

Process flow will continue from the flocculation tank by gravity into the inclined plate clarifier. The clarifier will be designed with an industry standard loading rate for metals precipitation of not more than 0.25 gpm/square foot to allow the flocculant to settle. From the clarifier, process water will flow by gravity into a transfer tank for feeding the filtration system. Solids will be removed periodically from the bottom of the clarifier using a pneumatic-diaphragm pump and transferred into a sludge holding tank. The design parameters for the clarifier are presented in Table 10.

Table 10. Clarifier Design Parameters

Design Parameter	**Value**
Clarifier Solids (%)	1.5
Total Pretreatment Tank Volume (gallons)	426
Flash Mix Tank Volume (gallons)	110
Clarifier Overall Height (feet)	12.3
Clarifier Overall Length (feet)	11.3
Clarifier Overall Width (feet)	6.4

6.3.5 Pump-Out Tank and Bag Filtration

Clarifier effluent will be gravity fed to a pump-out tank. Transfer pumps will convey process flow to bag filters to remove suspended sediment and large particles. Bag filtration will increase the longevity of media in the GAC unit by reducing the solids loading. The filtration process will start with a 5-micron bag filter and be adjusted based on observed conditions during startup. The bag filters will be provided on a dual filter skid and automatically switch from one housing to the other based on pressure drop setpoints or have the option of running in parallel. Bags will be changed by the operator on site, as needed. The pump-out tank design parameters are presented in Table 11.

Table 11. Pump-Out Tank Design Parameters

Design Parameter	**Value**
Process Flow Rate (gpm)	100
Total Pump-Out Tank Volume (gallons)	2,000
Tank Overall Height (feet)	6.9
Tank Overall Diameter (feet)	7.5

6.3.6 Liquid-Phase Granular-Activated Carbon

The GAC unit process will support the removal of total organic carbon, PFAS, SVOCs, VOCs, and additional particulate solids. An RSSCT was conducted to determine the effectiveness of SVOC and VOC removal with GAC. The blended influent groundwater collected from the Site used for the RSSCT was pretreated with sulfuric acid to neutralize pH to 9 S.U. and mixed with the recommended chemicals to remove mercury (i.e., 20 mg/L of MetClear, 10 mg/L of KlarAid IC1251, and 3 mg/L of Polyfloc AE1703). A Calgon DSR-C reactivated carbon was used for the RSSCT with two columns each of which had a 20-minute empty bed contact time (EBCT). The RSSCT was used to establish that the selected GAC is capable of treating VOCs and SVOCs to below POTW limits. An existing on-site GAC system was used to determine a target EBCT for the AG treatment system. Hydraulics were then used to establish the parameters for the GAC unit process design. At the maximum flow rate of 100 gpm, four GAC vessels will be operated as two trains of two vessels. During normal anticipated operation of 50 gpm, one train will be operational. The unit process will automatically switch between both operational modes based on the influent flow rate and have the capability to alternate lead-lag operation in each treatment train. The GAC unit process parameters are listed in Table 12.

Table 12. Liquid-Phase Granular-Activated Carbon Design Parameters

Design Parameter	Value
Design Flow Rate (gpm)	100
Design Hydraulic Loading (gpm/square feet)	2
Design EBCT (minutes)	20
No. of Vessels in Series	2
No. of Vessels in Parallel	4
Maximum Flow Per Vessel (gpm)	50
Calculated Vessel Area Required (square feet)	177
Calculated Vessel Diameter Required (feet)	7.5
Selected Vessel Diameter (feet)	6
Calculated Vessel Area (square feet)	28
Actual Hydraulic Loading (gpm/square feet)	3.5
Minimum GAC Volume, Per Vessel (cubic feet)	135
Selected GAC Volume, Per Vessel (cubic feet)	180
GAC Specific Gravity (grams/cubic centimeter)	0.54
Vessel Height (feet)	9.9
Minimum GAC Bed Height (inches)	72
Minimum GAC Bed Height (feet)	6
GAC, Per Vessel (pounds)	5,000
Actual EBCT, Per Vessel (minutes)	30

6.3.7 Ion Exchange Resin

An ion-exchange resin will be used for the removal of PFAS following GAC treatment. Similar to the GAC process, the resin units will be configured in series with a valve tree to enable alternating lead-lag operation. The vessels will be equipped with a differential pressure indicator for each stage to monitor pressure drop across the system. A sample port will be provided between vessels to check for COC breakthrough. Purolite PFA694 pilot testing data collected for another on-site groundwater treatment system were used to determine the resin unit process design. Pilot data showed successful PFAS treatment to non-detectable levels with influent concentration levels up to 2,500 ng/L utilizing a 3-minute EBCT. Elevated total dissolved solids primarily due to chloride and sulfate are present in the influent water used for the treatability study. These general chemistry characteristics were not noted in the pilot testing completed but are known to potentially interfere with PFAS treatment via resin. Further analysis, including potential field pilot testing, to determine if additional pretreatment processes are warranted will be completed during the final design. Resin vessel parameters for the Preliminary 30% Design are based on the 2-minute EBCT at maximum design flowrate and 4-minute EBCT at nominal flows and hydraulic loading between 6 and 18 gpm/ft2. Design parameters are provided in Table 13.

Table 13. Ion Exchange Design Parameters

Design Parameter	Value
Design Flow Rate (gpm)	100
Design EBCT Per Vessel (minutes)	2
No. of Vessels in Series	2
No. of Vessels in Parallel	0
Maximum Flow Per Vessel (gpm)	100
Calculated Vessel Area Required (square feet)	1.32
Calculated Vessel Diameter Required (feet)	2.7
Minimum Ion Exchange Volume, Per Vessel (cubic feet)	27
Vessel Height (feet)	5

6.3.8 Discharge

Effluent samples will be collected regularly for analysis to confirm the treatment system is meeting POTW discharge limitations. Bulk flow will be metered using a magnetic meter and will be discharged to the POTW via sanitary sewer lines. A tie-in to the existing line will be installed and equipped with check and isolation valves to prevent backflow from the site sanitary connection.

6.4 Ancillary Processes

6.4.1 System Pumps

Pump and motor sizes were determined using supporting hydraulic calculations for all unit processes as presented in Appendix B. Total dynamic head calculations to determine pump size and type include length of conveyance, anticipated process flow rates, conveyance pipe diameter, conveyance material, material compatibility, discharge elevation, and head loss through respective unit processes. The preliminary pump and motor parameters are presented in Table 14.

Table 14. Pump Design Parameters

Pump ID	Number of Pumps	Description	Pump Type	Design Flow Rate (gpm)	Head (feet)	Horsepower
P-0XX	8	Collection Sump Pump	Submersible	3.5 to 6.0	80 to 88	1
P-0XX	16	Collection Sump Pump	Submersible	12.8 to 17.2	80 to 122	2
P-100/101	2	Transfer Pump	Centrifugal	100	11	3
P-200/201	2	Transfer Pump	Centrifugal	100	195	10
P-40X	7	Dosing Pump	Diaphragm	0.15 to 2.0	134 (maximum)	-
P-50X	5	Sludge Wasting Pump	Diaphragm	15	15	-
P-505	1	Sump Pump	Submersible	30	22	0.5

6.4.2 Solids Management

Solids from the influent equalization tank and clarifier will be removed periodically during operation. Sludge removal will be a manual process from the equalization tank and an automatic process from the clarifier. Solids or sludge transfer intervals will be determined and optimized during initial operation to ensure adequate removal of total suspended solids. The collected sludge will be stored in a holding tank prior to dewatering. To dewater the sludge, a thickening agent will be added and the sludge will pass through a filter press prior to being stored in a disposal container. The treatability study included an assessment of solids from each process, including sludge volume generated, and solids content was recorded (Arcadis 2022b). A Toxicity Characteristic Leaching Procedure analysis was performed on the sludge to evaluate the potential waste characteristics. The treatability study results indicated very little sludge generation. To be conservative, reference design standards were used to establish the parameters for the solids management process design as listed in Table 15.

Table 15. Solids Management Design Parameters

Design Parameter	Value
Holding Tank Influent Flow Rate (gallons/day)	1,826
Retention Time (days)	5
Holding Tank Sludge (wet) (pounds/day)	15,420
Holding Tank Solids (dry) (pounds/day)	204
Holding Tank Solids (%)	2
Hold Tank Decant Volume (gallons/day)	626
Filter Press Sludge (wet) (pounds/day)	10,196
Filter Press Solids (dry) (pounds/day)	204
Cake Solids (%)	35
Cake Density (pounds/cubic feet)	75
Minimum Filter Press Size (cubic feet)	19
Cycles per week	3
Dewatered Sludge (wet) pounds/day	583
Filtrate (gallons/day)	1,153

6.4.3 Tank Mixing

The coagulant tank and flocculation tank will be equipped with a mixing component (rapid vertical mixing unit, picket fence vertical mixing unit, etc.) to distribute chemical additions and promote aggregation of dissolved and suspended particles in the process stream. Rapid mixing will occur in the coagulation tank, while slow mixing will occur in the flocculation tank. Aggregation of particulate will facilitate efficient flocculation formation to promote settling in the inclined plate clarifier.

6.4.4 Compressed Air

A compressor will be sized based on treatment system air demand and future expansion capacity. The compressor will be coupled with a refrigerated air dryer and filters to mitigate the risk of damaging air-driven sludge pumps. The compressor will operate at less than a 40% uptime to reduce equipment wear, reduce noise, and protect the system from overheating caused by high ambient temperatures.

6.4.5 Instrumentation and Controls

The treatment system will include a programmable logic controller (PLC) based supervisory control and data acquisition (SCADA) system. The SCADA system will provide monitoring, control, alarming, and data collection. Flow and pump control at the perimeter drains will be programmed for automatic operation with the ability to operate manually when necessary. Treatment system process pumps and instrumentation will be monitored and controlled by the SCADA system. A human machine interface (HMI) will be used to operate equipment and display SCADA information.

Alarm interlocks based on the monitored process variables will be programmed into the PLC to enable an automatic shutdown of process pumps and equipment. Examples of alarm conditions requiring shutdown include low/high discharge flow, high discharge pressure, low/high tank levels, and motor overloads. Critical alarm conditions (e.g., leak detection) will shut down the entire system, requiring operator review of the alarm and a determination as to whether to restart the system. An interlock table describing process alarm conditions and associated process responses will be provided with the final design.

6.4.6 Fire Protection

All required federal, state, National Fire Protection Association (NFPA), and Occupational Safety and Health Administration (OSHA) fire protection standards will be implemented and followed based on the design, construction, and operation of the proposed barrier and AG treatment system.

6.4.7 Utilities

All required federal, state, local, and OSHA utility codes and standards will be implemented and followed based on the design, construction, and operation of the proposed barrier and AG treatment system.

6.4.8 Secondary Containment

The treatment system will be constructed with secondary containment to reduce the risk of a process stream and chemical release. All secondary containment will be designed to contain 120% of the capacity of the largest volume tank in the contained area. Secondary containment for treatment chemicals will be isolated from general plant containment.

6.4.9 Hazardous Area Classification

The proposed design will include an evaluation of hazardous area classifications to ensure process safety for all personnel involved in the construction and operation of the proposed barrier and AG treatment system.

7 Waste Management and Characterization

The following waste streams will be subject to characterization in accordance with local, state, and federal regulations prior to transportation and off-site disposal during construction of the perimeter containment barrier and groundwater collection and conveyance system:

- Excavation and shoreline spoils, including subsurface concrete and debris,
- Excess soil-cement slurry,
- Groundwater generated during dewatering, and
- Packaging for materials and equipment.

Soil and/or sediment generated from trenching and subgrade wall installation will be pre-characterized for waste disposal in accordance with applicable regulations prior to construction activities. All soils will be disposed of at a licensed waste facility. Groundwater generated during dewatering will either be characterized prior to construction activities for disposal or to confirm it can be treated through the abovegrade treatment system (if available). Non-impacted packaging for materials and equipment will be disposed of with general refuse.

The following waste streams will be generated during the operation of the groundwater treatment system:

- Sludge cake from clarification
- Bag filters from filtration
- Spent GAC from GAC treatment
- Spent IX resin from IX treatment

Waste streams associated with operation of the groundwater treatment system will be characterized for waste disposal and disposed of at a licensed waste facility.

8 Health and Safety Plan

A project-specific health and safety plan (HASP) will be developed for the construction and operation of the proposed remedy at the Site. The HASP will describe the health and safety commitment of all office and field employees, contractors, and site visitors. The HASP will be structured to contain information regarding emergency points of contact and details of the hospital route. The HASP will be supplemented by appropriate Job Safety Analyses (JSAs) for all safety-critical tasks conducted on the Site. It is expected that these JSAs will be modified in the field by the personnel conducting the tasks to integrate real-time conditions and hazards at the time of the task. Safety Data Sheets will be available for all materials managed on the Site during construction and operation of the proposed remedy.

All tasks performed under the project HASP will follow the BASF Health and Safety Standards of Procedure. All project personnel will be required to sign the certification page included at the end of the HASP acknowledging that they have read, understand, and will abide by the plan. Any supplemental contractor HASP that addresses specific hazards for tasks conducted by the subcontractor will be stored with the project-specific HASP.

8.1 Health and Safety Considerations

During construction and operation of the proposed remedy, H&S protocols will be developed, implemented, and enforced to provide for the safety of project team members and visitors to the Site. Examples of H&S considerations during construction and operation of the barrier remedy include the following:

- Potential hazards during construction activity conducted in the Detroit River or any water body;
- Potential hazards during excavation and shoring activities (i.e., cave-ins);
- Potential to encounter below- and above-grade utilities;
- Heavy equipment operation risks;
- Fall protection;
- Confined spaces;
- Potential to encounter impacted vapors, soil, and/or groundwater; and
- Handling of chemicals associated with construction and the treatment system process.

8.2 Site Safety

All personnel working on the project are responsible for completing tasks safely and have the responsibility to stop the work of a coworker or contractor if working conditions or behaviors are deemed unsafe. All BASF and OSHA-required general safety equipment, including personal protective equipment (PPE) standards, will be identified and followed by all personnel involved in the construction and operation of the proposed barriers, conveyance network, and AG treatment system. All staff and subcontractors are required to complete a safe work permit prior to the start of each workday, describing the tasks performed at the start of the day with an evaluation of hazards and mitigations for those hazards. Prior to initiation of site activities, all staff and contractors are required to take BASF site-specific safety and site-awareness training.

8.3 Safety in Design

During the final design phase, a comprehensive program, documentation, and review tool will be applied to identify potential hazards and provide guidance for best practices associated with system fail safes, remedy construction, O&M, and regulatory codes. The hazard analysis will systematically identify potential concerns and provide a hazard rating related to the process unit design. The analysis will outline engineering and administrative controls that can mitigate the identified hazards.

9 Future Design Considerations

A draft list of Final Barrier Remedy Design Drawings is provided in Appendix F. Following final design and during remedy operation, optimization of the barrier system will be considered to meet the established corrective action objectives. The perimeter containment barrier, extraction network, conveyance network, and treatment system design will allow for potential adaptive management, optimization, and/or expansion to potentially improve upon the effectiveness of the proposed barrier remedy to meet the performance objectives. Potential areas of expansion include the following:

- Enhancement of barriers to mitigate the risk of extracting and treating river water;
- Addition or removal of sumps and/or vertical extraction wells to improve or optimize hydraulic control to meet performance standards;
- Treatment system expansion or contraction optimize the process stream capacity based on the potential of increased or decreased influent flow rates; and
- Addition or removal of transfer pumps, carbon vessels, and tank freeboard to optimize treatment.

10 Data Gaps

During this Preliminary (30%) Design phase of the project, data gaps were identified for elements of the remedy that must be addressed prior to completing the next design phase (95% and 100%). This section summarizes the additional information and/or assessment activities necessary to address the data gaps.

10.1 Subsurface

The following assessment will be performed regarding the subsurface barriers and extraction/conveyance networks:

- Presence and locations of utilities along proposed excavation areas. Locations of these utilities and subsurface structures will be evaluated in coordination with Wyandotte Municipal Services, BASF, and other parties (as appropriate);
- Geophysical surveys of the barrier and extraction/conveyance trench network alignments to identify subgrade obstructions;
- Geophysics and/or additional soil borings, if necessary, along the alignment of the barrier to further define the top of the clay layer;
- Presence and locations of utilities along the proposed barrier and extraction/conveyance trench network alignments. Locations of these utilities and subsurface structures will be evaluated in coordination with Wyandotte Municipal Services, BASF, and other parties (as appropriate);
- Geotechnical assessment and/or investigation (as appropriate) for foundation design of the abovegrade treatment system building; and
- Additional evaluations of the soil-cement design mix to address potential freeze-thaw issues and compositional changes to PC.

10.2 New Bulkhead

The following additional information will be collected regarding the existing South Dock structures:

- Soil thickness on concrete deck;
- Top-of-concrete elevation for the soil-covered deck and the concrete bulkhead at the face of the dock;
- Concrete deck thickness;
- Approximate locations of tie rods and timber piles that provide lateral support to the Wakefield wall; and
- Geophysics for constructability of the anchor wall.

No drawings appear to exist that show the South Dock structures in detail. To obtain the information listed above, may be necessary to excavate test pits at various locations to expose the existing structures and take measurements. It may also be necessary to cut holes into the existing concrete deck to measure its thickness.

10.3 Above-Grade System

The following assessment activities will be performed regarding the AG system:

- Field pilot test to investigate ion-exchange PFAS treatment interferences:
  - Total organic carbon; and
  - Total dissolved solids (particularly sulfate and chloride).
- Evaluation and addition of ion-exchange pretreatment technologies, if warranted.

11 Permit Plan

The following is a summary of the preliminary list of required permits prior to or during construction:

- **National Pollutant Discharge Elimination System (NPDES).** A Construction General Permit will be submitted for approval prior to the start of construction. The permit will include a developed Stormwater Pollution Prevention Plan, a Notice of Intent submittal, and a list of required inspections to verify compliance with the permit.
- **EGLE/USACE**. A Joint Permit Application will be submitted to cover requirements derived from state and federal rules and regulations for construction activities within and near the Detroit River. A summary of the site background, a project description, and site plans will be submitted in the application for review and approval.
- **Downriver Utility Wastewater Authority (DUWA)**. Discharging treated groundwater into a DUWA sewage collection system tributary requires an approved Wastewater Discharge Permit. A permit application will be submitted a minimum of 90 days prior to the proposed discharge for evaluation and approval. An alternative to a new permit would be a modification to the existing Wastewater Discharge Permit obtained by BASF. A request to modify the existing permit would be submitted to DUWA for approval.
- **Wayne County**. A Soil Erosion and Sedimentation Control Permit is required for earthwork within 500 feet of a water of the state.
- **City of Wyandotte**. Construction of a new building may require approved building, electrical, plumbing, mechanical, and utility permits from the Engineering and Building Department.
- **Air Permitting**. Air permitting requirements for construction associated with diesel operated equipment and/or generators will be assessed and completed, if applicable. At this time, the design does not include active air discharges; however, any air emissions identified prior to construction and system operation will be evaluated and addressed in the Pre-final (95%) and Final (100%) Design.
- **Spill Control**. All liquids included in treatment system design and operation will be evaluated to determine spill control requirements. Any tanks or drums containing flammable, combustible, or corrosive liquid will be subject to containment standards set by federal, state, OHSA, and NFPA code.

Additional activities to be completed prior to or during construction include the following:

- Access agreements with adjacent property owners for installation of sheet pile along Perry Place and James Desana Drive;
- Institutional controls will be obtained from the property owner (i.e., City of Wyandotte, or private party) to restrict excavation into the off-site sheet pile; and
- Notice to Mariners.

12 Operation, Monitoring, and Maintenance Requirements

An O&M manual for the barrier remedy will be submitted with the pre-final (95%) design package. The O&M manual will address routine inspections of remedy components (e.g., below-water inspections of barriers and bulkhead, ground surface grades and features behind bulkhead); O&M of the extraction and treatment systems including management of waste streams; collection of performance monitoring data for active remedy components (extraction and treatment systems); and compliance monitoring. The O&M manual will present the procedures for O&M activities, sampling and monitoring, and implementation of contingency measures associated with the barrier remedy.

For the pre-final/final design phase submittal of the proposed barrier, extraction and conveyance network, and AG treatment system, a draft O&M manual including schedules and procedures will be submitted for approval.

13 Remedial Design Management

This section describes the proposed approach to carry out the design and implement the remedial strategy. An outline of technical specifications required to complete the barrier remedy is provided in Appendix G. The pre-final design (95%) will present an outline of technical specifications for the selected barrier remedy and will include each element of the remedy (i.e., barrier, extraction, and treatment systems).

As the barrier, extraction/conveyance network, and treatment system design progresses, the design elements will continue to be evaluated in an effort to reduce overall costs. Opportunities for value engineering (VE) include the following:

- Evaluation of cost versus function to identify high-cost design elements that may be candidates for a formal VE study;
- Consideration of material/equipment factors including capital cost, complexity, high-volume, critical materials, difficulty of use in construction, high O&M costs, required specialized skills to construct, and potential for materials and methods to become obsolete;
- Evaluation of proprietary technology requiring trained personnel to operate;
- Allowance of substituted equipment that meets the design specifications at a reduced cost;
- Use of industry established design technology;
- Use of pre-designed skids or equipment packages;
- Allowance in schedule and/or budget for VE redesign activities; and
- Recommendation supporting or rejecting the need for a full-scale VE study.

13.1 Design and Construction Schedule

A preliminary design and construction schedule is presented in Appendix D.

13.2 Construction Approach

13.2.1 Cost Estimates

A preliminary cost estimate to construct the containment barriers, extraction/conveyance network, and AG treatment system based on the proposed Preliminary 30% Design is between $34 million and $74 million. The preliminary cost estimate is presented in Appendix C. Appendix C also includes a preliminary bill of materials for the treatment system.

13.2.2 Procurement Methods and Contracting Strategy

Contractors for construction, startup, and operation, maintenance, and monitoring of the barrier remedy will be selected in conformance with BASF purchasing and procurement requirements, and considering factors such as cost, qualifications, and health and safety (H&S). The current contracting strategy is design-bid-build. Under this approach, the design would be reviewed and approved by USEPA at the final design phase. The design-bid-build approach allows bidding from multiple contractors on well-defined work that can be implemented using standard construction methods (i.e., significant design modifications or constructability issues are not anticipated). If warranted (e.g., due to need for an expedited schedule), alternate contracting strategies, such as design-build or sole-source procurement, may be adopted for certain remedial components. Under the design-build approach, contractor procurement and construction elements can be initiated during the design. In this case, USEPA would not review a final design before construction; therefore, a design review process would need to be developed and agreed upon with USEPA to allow adequate time for agency review and approval of the field design and construction submittals.

A Construction/Corrective Action Implementation Work Plan and O&M manual will be submitted as part of the pre-final (95%)/final (100%) design. The Construction/Corrective Action Implementation Work Plan will present the strategy and procedures for construction and startup of the barrier remedy, including the overall management strategy, site management plan, H&S considerations, construction quality assurance procedures, and procedures/sequencing for construction of the remedial components, and will address contractor, labor, and equipment availability concerns. A Construction Quality Assurance Plan will be included in the Construction/Corrective Action Implementation Work Plan.

13.2.3 Construction Sequence

The construction sequence of the steel bulkhead barrier, extraction network, conveyance network, and AG treatment system is generally that the abovegrade treatment system and groundwater extraction and conveyance systems will be completed prior to the completion of the perimeter barriers. This sequence is important so that the groundwater can be managed before the perimeter barriers are completed to avoid flooding of the Site. Therefore, the general construction sequencing for the steel bulkhead barrier is expected to be as follows:

- Treatment building construction.
- Installation of treatment system equipment (tanks, pumps, mixers, etc.).
- Installation of treatment system piping.
- Conveyance network trenching and pipe installation.
- Extraction network sump and collection drain trenching and installation.
- Preparation of soil staging and mixing area to support off-site removal of excavated materials and mixing of imported materials with reagents for ex situ borrow soil cement barrier construction.
- Debris removal along the headwall and anchor wall alignments where subsurface obstructions are known exist.
- Pre-trenching and debris removal along the alignment, followed by backfilling with borrow soil, ahead of the proposed northern and southern perimeter sheet pile wall installation.
- Debris removal along the barrier alignment where subsurface obstructions are known to exist in the rip rap shoreline for the proposed soil-cement barrier. Backfilling of pre-trench to grade.
- Construction of working platform along wall alignment in the rip rap shoreline area.
- Preparation of the South Dock area for installation of tie rods and placement of backfill under the existing dock, including concrete cutting along the concrete bulkhead at the face of the wharf and creation of access holes through the existing concrete deck.
- Off-site fabrication/installation of casing for shear pin installation (shear pin installation method is described separately).
- Application of sheet pile interlock sealant (may be performed off site by steel supplier or fabricator) for the bulkhead and sheet pile walls.

- Installation/driving of bulkhead wall, anchor walls, and subgrade sheet pile walls to specified depths.
- Installation of shear pins along the toe of the headwall.
- Installation of walers and structural connection elements.
- Installation of tie rods, including soil removal/trenching along tie rod alignments.
- Installation of a cast-in-place concrete cap along the top of the bulkhead wall.
- Backfilling with aggregate fill material behind the new bulkhead wall and under the existing concrete deck.
- Installation/driving of sheet piles to specified depths.
- Removal of the top of the sheet pile to a maximum of 12 inches below final grade.
- Backfilling over the sheet pile with fill and surface restoration materials as appropriate.
- Installation of soil-cement barrier via excavation under slurry and backfilling of the trench with mixed imported soils.
- Off-site disposal of excavated soils from the soil-cement barrier trench.
- Complete surface restoration along the soil-cement barrier alignment as appropriate.
- Dredging in front of the new bulkhead wall (separate project/contract).

13.3 Phasing Alternatives

The remedial design phase has included field/laboratory work to support the Preliminary 30% Design, major elements of the Preliminary 30% Design submittal, and components leading to the final design. To accelerate the project objective, phasing alternatives will be considered and evaluated to meet or fast-track the remedial strategy approach and scheduling. The construction sequence alternatives may be implemented to mitigate the risk of delays or improve scheduling timelines. BASF will have monthly check-in meetings with USEPA to discuss work completed since the last meeting and the schedule for upcoming work. Any actionable feedback requiring phasing alternatives will be implemented accordingly.

13.4 Roles and Responsibilities

The responsibilities and authority of organizations and key personnel involved in the RD process are summarized in Table 16.

Table 16. Project Roles and Responsibilities

Name	Title	Organization
Mr. Michael Gerdenich	Expert, Remediation Senior Specialist	BASF
Ms. Jacelyn Saling, PE	Project Manger	Arcadis
Ms. Andrea Krevinghaus, PE	Engineer of Record	Arcadis
Mr. Carsten Becker, PE	Engineer of Record	Arcadis
Molly Finn	Project Manger	USEPA
Jacob Runge	Project Manger	EGLE

13.5 Sample and Data Collection Methodology and Quality Assurance

Sampling and analytical activities conducted have followed quality assurance/quality control procedures as detailed in the RFI Quality Assurance Project Plan (Environmental Science & Engineering, Inc. 1996) and its subsequent revisions and addenda (Arcadis 2008), collectively referred to as the existing Quality Assurance Project Plan (QAPP). A QAPP supplement was prepared to address laboratory activities proposed in the RD Work Plan that extend beyond the scope of the existing QAPP (Arcadis 2018).

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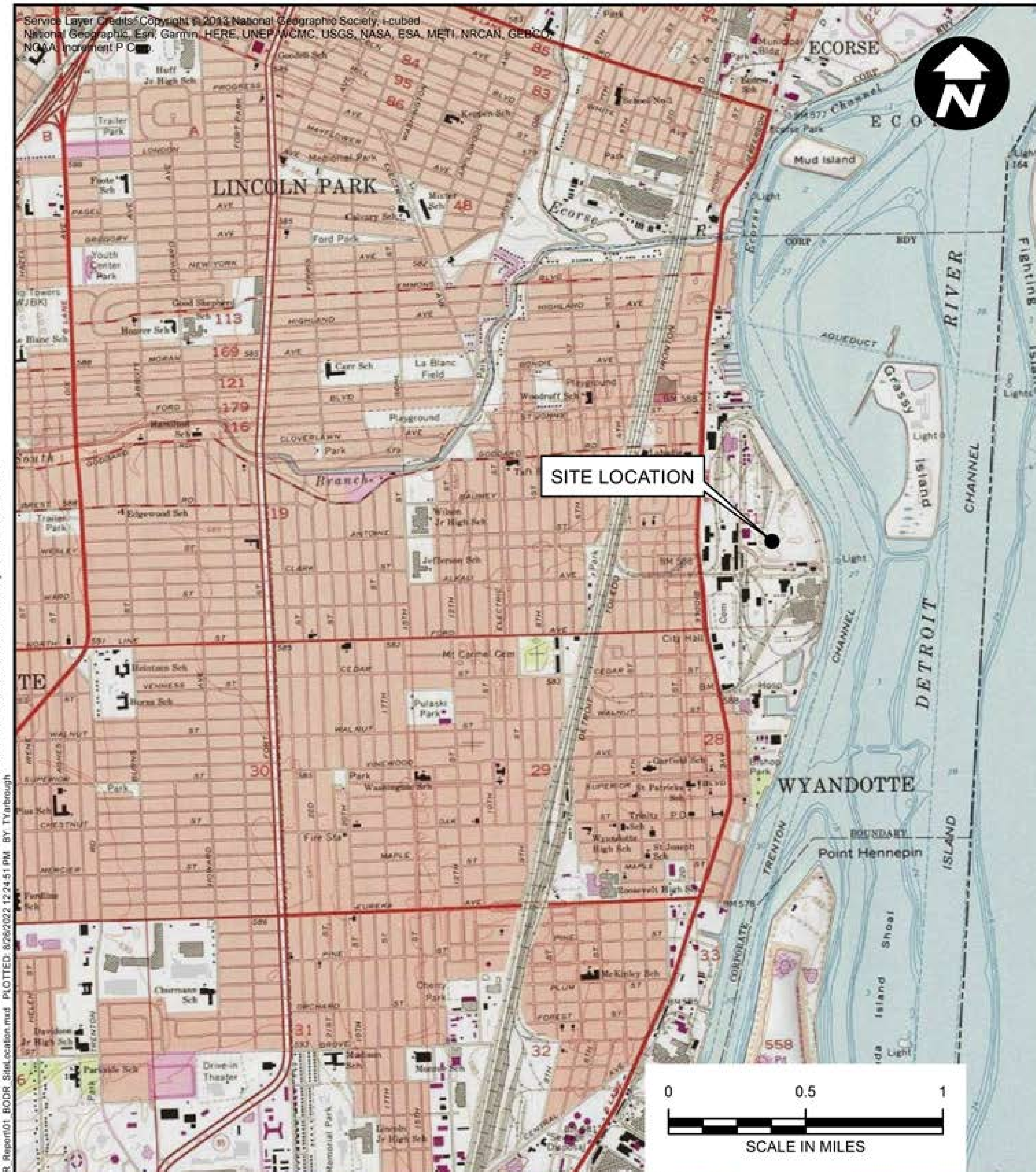
Figures



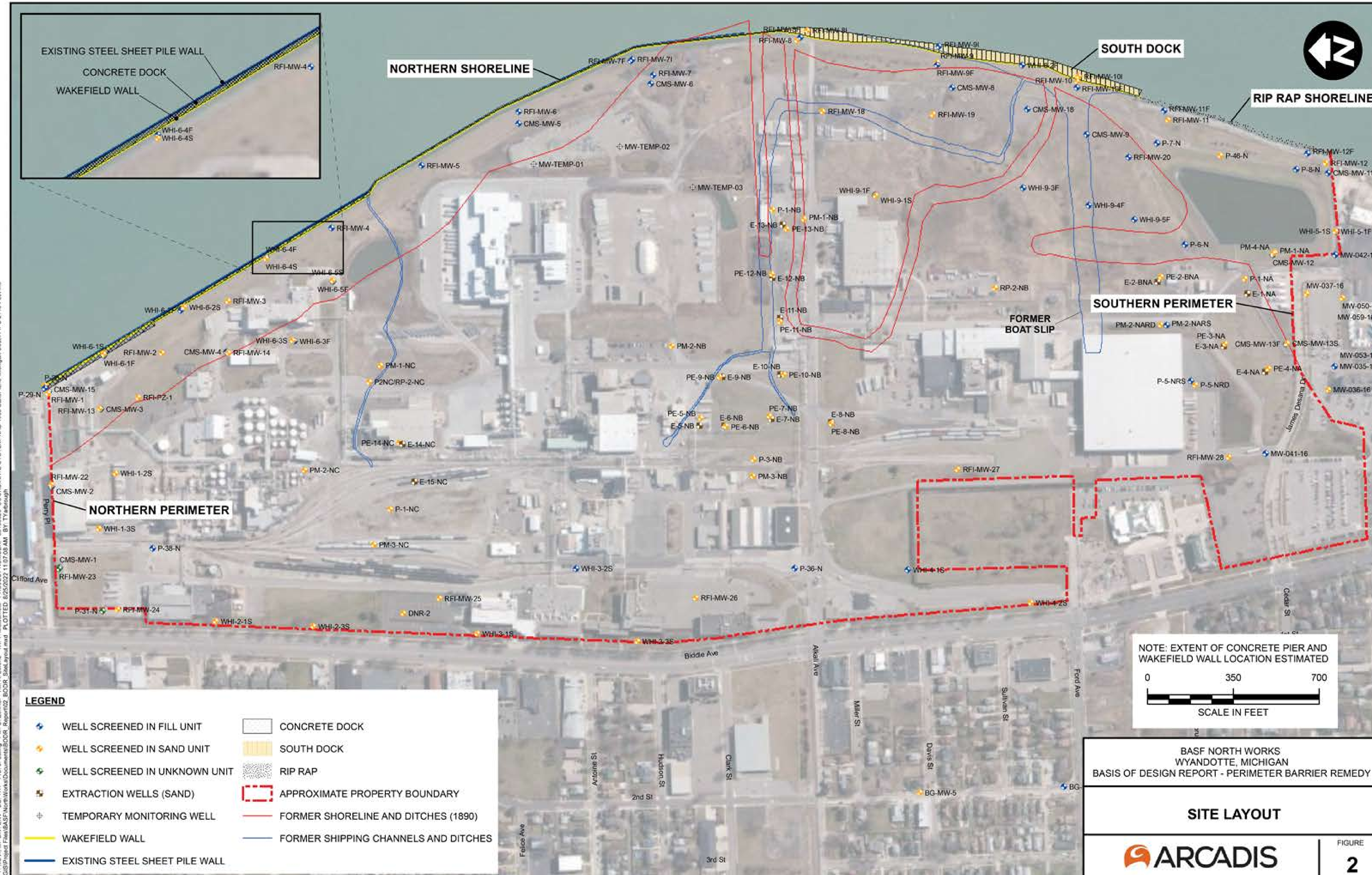
BASF NORTH WORKS
WYANDOTTE, MICHIGAN
BASIS OF DESIGN REPORT - PERIMETER BARRIER REMEDY

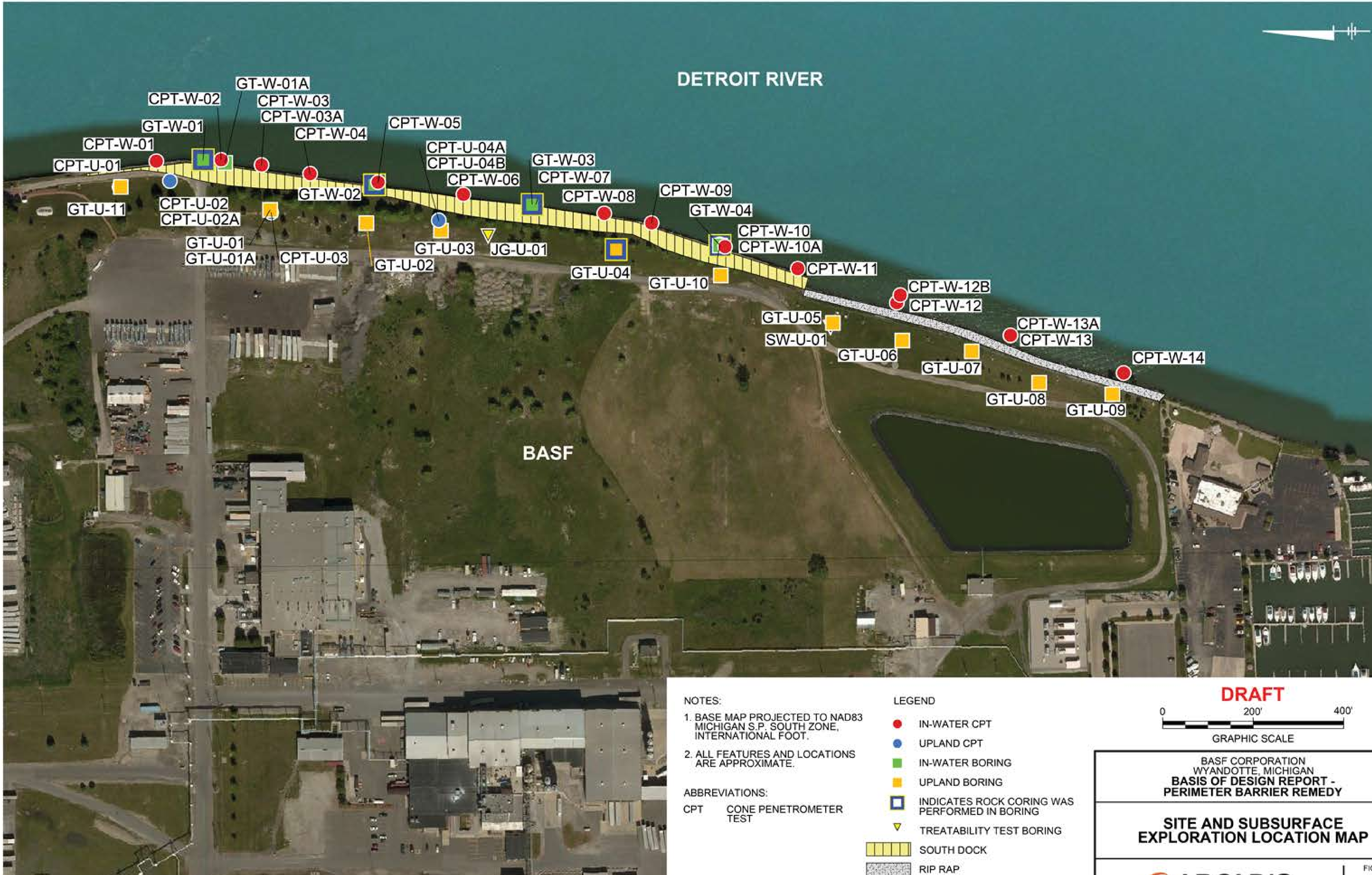
SITE LOCATION MAP

ARCADIS

FIGURE
1

CITY: NOVI, MI DIV: ENV DB: TRY PIC: J. Saling PM: G. Zellmer TM: A. Lorenz TR: T. Matsumoto PROJECT NUMBER: 30133323 COORDINATE SYSTEM: NAD 1983 StatePlane Michigan South FIPS 2113 Feet
D:\GIS\Project Files\BASF\NorthWorks\Documents\BODR_Report\01_BODR_SiteLocation.mxd PLOTTED: 8/26/2022 12:24:51 PM BY: TYarbrough


EXISTING STEEL SHEET PILE WALL
CONCRETE DOCK
WAKEFIELD WALL
NORTHERN SHORELINE
SOUTH DOCK
RIP RAP SHORELINE
SOUTHERN PERIMETER
FORMER BOAT SLIP
NORTHERN PERIMETER
Biddle Ave
Alkali Ave
Ford Ave
Clifford Ave
Perry Pl
James Desana Dr
Cedar St
NOTE: EXTENT OF CONCRETE PIER AND WAKEFIELD WALL LOCATION ESTIMATED
0
350
700
SCALE IN FEET
LEGEND
WELL SCREENED IN FILL UNIT
WELL SCREENED IN SAND UNIT
WELL SCREENED IN UNKNOWN UNIT
EXTRACTION WELLS (SAND)
TEMPORARY MONITORING WELL
WAKEFIELD WALL
EXISTING STEEL SHEET PILE WALL
CONCRETE DOCK
SOUTH DOCK
RIP RAP
APPROXIMATE PROPERTY BOUNDARY
FORMER SHORELINE AND DITCHES (1890)
FORMER SHIPPING CHANNELS AND DITCHES
BASF NORTH WORKS
WYANDOTTE, MICHIGAN
BASIS OF DESIGN REPORT - PERIMETER BARRIER REMEDY
SITE LAYOUT
ARCADIS
FIGURE
2



NOTES:

1. BASE MAP PROJECTED TO NAD83 MICHIGAN S.P. SOUTH ZONE, INTERNATIONAL FOOT.
2. ALL FEATURES AND LOCATIONS ARE APPROXIMATE.

ABBREVIATIONS:

CPT CONE PENETROMETER TEST

LEGEND

- IN-WATER CPT
- UPLAND CPT
- IN-WATER BORING
- UPLAND BORING
- INDICATES ROCK CORING WAS PERFORMED IN BORING
- TREATABILITY TEST BORING
- SOUTH DOCK
- RIP RAP

DRAFT

0 200' 400'

GRAPHIC SCALE

BASF CORPORATION
WYANDOTTE, MICHIGAN
BASIS OF DESIGN REPORT - PERIMETER BARRIER REMEDY

SITE AND SUBSURFACE EXPLORATION LOCATION MAP

ARCADIS

FIGURE
3

NOTES:

1. BASE MAP PROJECTED TO NAD83 MICHIGAN S.P. SOUTH ZONE, FEET.
2. AERIAL IMAGE PROVIDED BY BING
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LEGEND:

- APPROXIMATE SITE BOUNDARY
- PROPOSED SOIL-CEMENT BARRIER
- PROPOSED SHEET PILE WALL
- EXISTING STEEL SHEET PILE WALL
- WAKEFIELD WALL
- PROPOSED STEEL BULKHEAD
- PROPOSED CONVEYANCE PIPING
- PROPOSED COLLECTION DRAIN
- PROPOSED TREATMENT BUILDING
- PROPOSED SUMP LOCATION

0 400' 800'
GRAPHIC SCALE

BASF CORPORATION
WYANDOTTE, MICHIGAN
BASIS OF DESIGN REPORT - PERIMETER BARRIER REMEDY

BARRIER REMEDY LAYOUT

ARCADIS

FIGURE
4

CITY: NOVI, MI DIV: ENV DB: G.STEINBERGER PIC: J. SALING PM: G. ZELLMER TM: A. LORENZ TR: T. MATSUMOTO PROJECT NUMBER:30133323 Coordinate System: NAD 1983 StatePlane Michigan South FIPS 2113 Feet
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PM BY: STEINBERGER, GEORGE
XREFS: IMAGES: PROJECTNAME: —
BW-BODR-X-TITLE

Appendix A

Preliminary 30% Design Drawings

PRELIMINARY 30% DESIGN DRAWINGS FOR

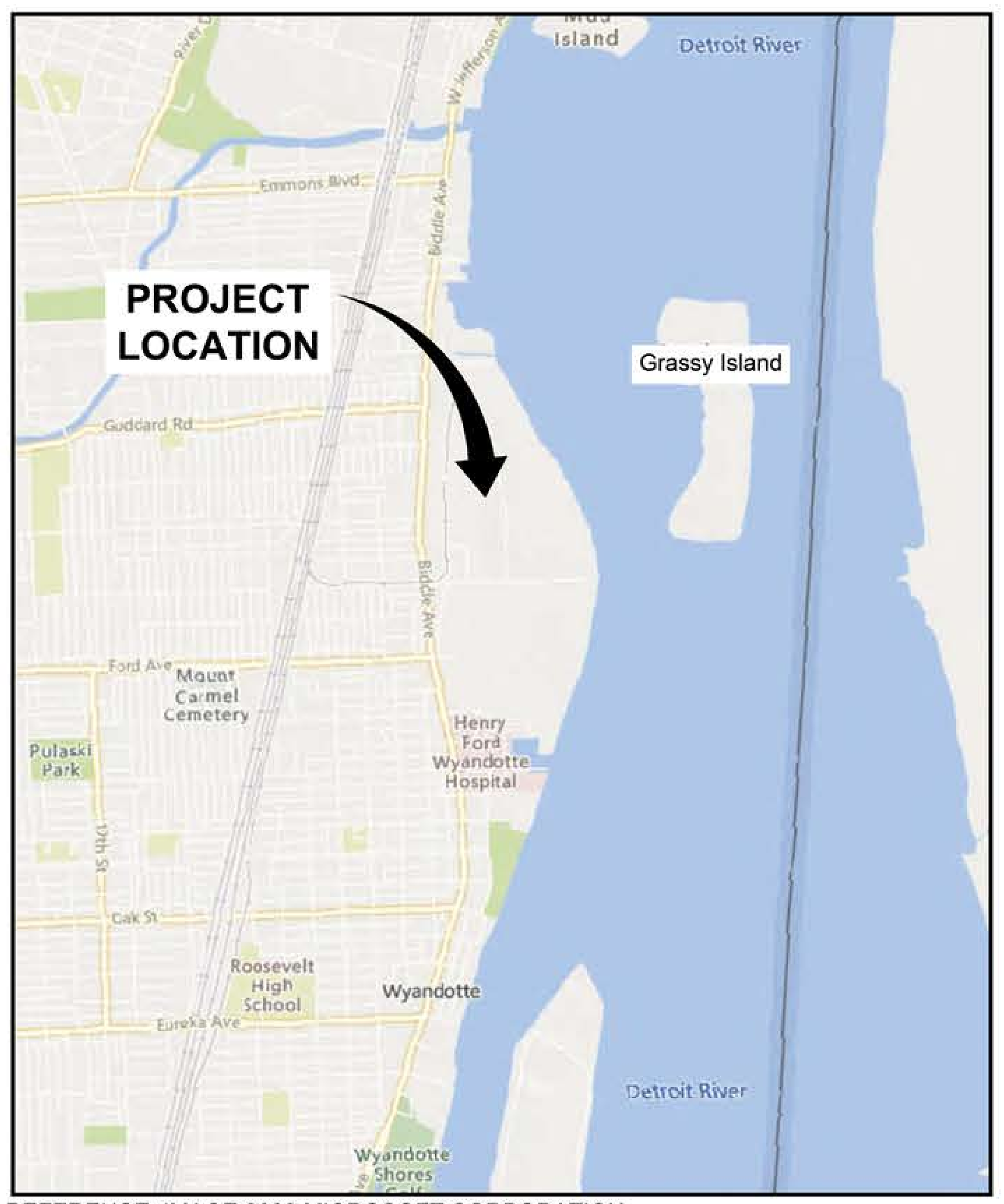
PERIMETER BARRIER REMEDY

DRAFT

KEY CONTACTS:

OWNER:
BASF
1609 BIDDLE AVENUE
WYANDOTTE, MI 48192
CONTACT: MICHAEL GERDENICH
TELEPHONE: (734) 324-6298

ENGINEER:
ARCADIS OF MICHIGAN, LLC
28550 CABOT DRIVE
SUITE 500
NOVI, MI 48377
CONTACT: ANDREA KREVINGHAUS, PE
TELEPHONE: (248) 994-2282



REFERENCE: IMAGE 2022 MICROSOFT CORPORATION

LOCATION MAP

0 2000' 4000'
GRAPHIC SCALE

SITE ADDRESS:
1609 BIDDLE AVENUE
WYANDOTTE, MI 48192

DATE ISSUED

SEPTEMBER 2022

INDEX TO DRAWINGS

CIVIL

PROCESS

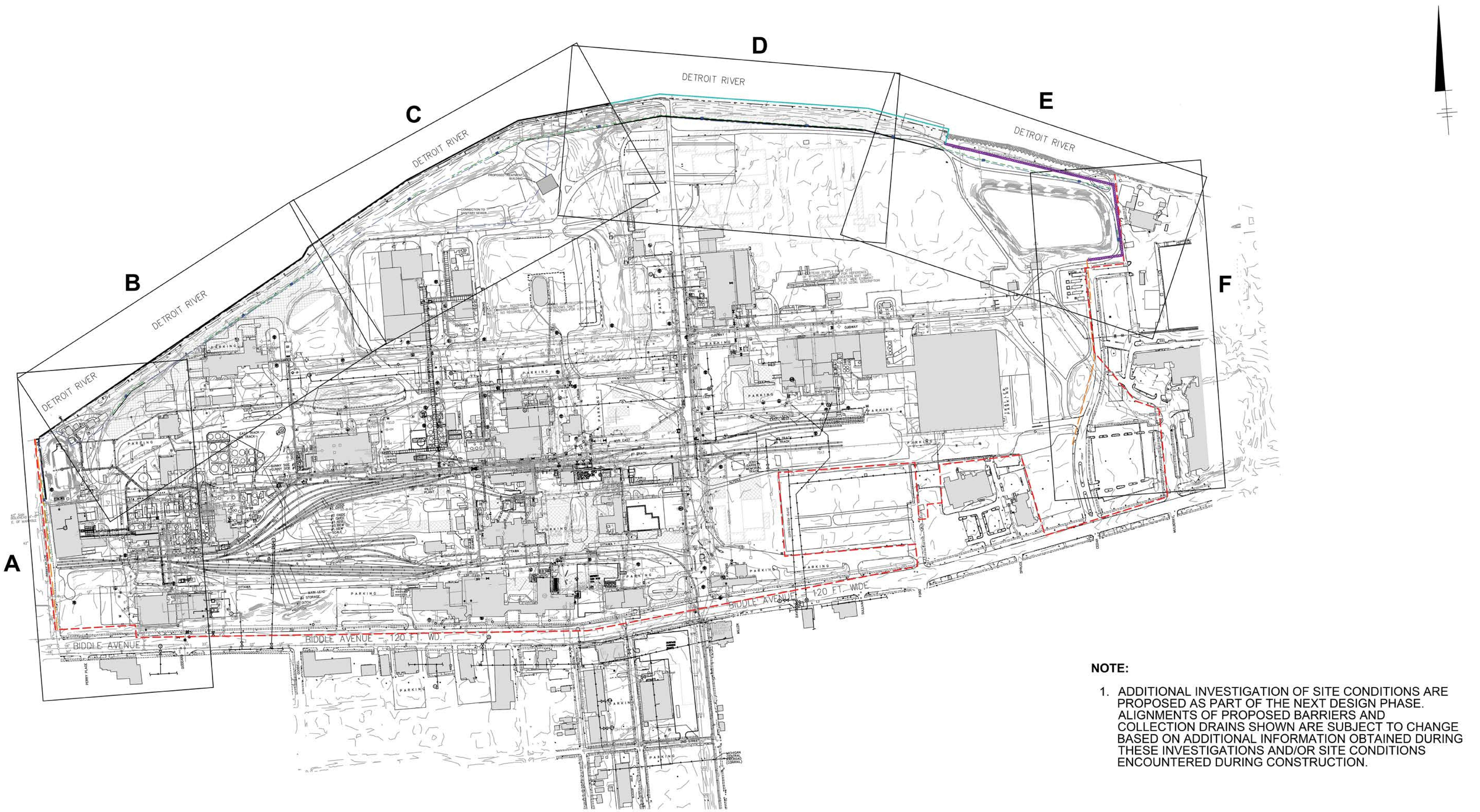
MECHANICAL

BASF NORTH WORKS
WYANDOTTE, MICHIGAN
ARCADIS PROJECT NO. 30133323

ARCADIS

ARCADIS OF MICHIGAN, LLC

BASF
The Chemical Company



NOTE:

1. ADDITIONAL INVESTIGATION OF SITE CONDITIONS ARE PROPOSED AS PART OF THE NEXT DESIGN PHASE. ALIGNMENTS OF PROPOSED BARRIERS AND COLLECTION DRAINS SHOWN ARE SUBJECT TO CHANGE BASED ON ADDITIONAL INFORMATION OBTAINED DURING THESE INVESTIGATIONS AND/OR SITE CONDITIONS ENCOUNTERED DURING CONSTRUCTION.

0 500' 1000'

GRAPHIC SCALE

LEGEND:

- PROPOSED SOIL-CEMENT BARRIER
- APPROXIMATE SITE BOUNDARY
- PROPOSED SHEET PILE WALL
- PROPOSED STEEL BULKHEAD
- PROPOSED ANCHOR WALL AND TIERODS
- PROPOSED SUMP
- PROPOSED CONVEYANCE PIPING
- PROPOSED COLLECTION DRAIN
- FENCE
- WATER BOUNDARY
- SIDEWALK
- EXISTING SHEET PILE WALL
- EXISTING WAKEFIELD WALL
- EXISTING BUILDING
- CONFIRMED FORMER BUILDING FOUNDATIONS
- FORMER BUILDING FOUNDATIONS
- RIP RAP
- 586 EXISTING CONTOUR
- EXISTING GAS LINE
- EXISTING FIRE WATER HIGH PRESSURE LINE
- EXISTING POWER AND LIGHTING SYSTEM
- EXISTING STORM SEWER LINE
- EXISTING SANITARY SEWER LINE
- EXISTING SITE AIR SYSTEM LINE
- MATCH PLAN
- EXISTING NITROGEN SYSTEM LINE
- EXISTING STEAM SYSTEM LINE
- EXISTING RIVER WATER LINE
- EXISTING WATER LINE
- EXISTING TELEPHONE LINE
- FIRE HYDRANT
- GATE VALVE W/VALVE BOX
- GATE VALVE
- CATCH BASIN / STORM DRAIN
- LIGHT POLE
- SIGN

DRAFT

REV	DATE	BY	APPROVED	DESCRIPTION	REV	DATE	BY	APPROVED	DESCRIPTION
0	09/06/22	GEC	AK	PRELIMINARY DESIGN (30%)					

ORIGINATION	BY	DATE	PROJECT INFORMATION	
DRAWN	GEC		I.O. NO.	
DESIGN	AL		PROJ NO.	
CHECKED	MG		ARCADIS PROJ NO.	30133323
APPROVAL	BY	DATE	SITE INFORMATION	
			SITE	
			PLANT	
			SYSTEM	
			BLDG. NO.	

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OVERALL SITE PLAN

PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

DRAWING NUMBER	REV
0154-WYN-SITE-C-101	0
SITE / LOCATION / TYPE / NUMBER	

LEGEND:

- PROPOSED SOIL-CEMENT BARRIER
- APPROXIMATE SITE BOUNDARY
- PROPOSED SHEET PILE WALL
- PROPOSED STEEL BULKHEAD
- PROPOSED ANCHOR WALL AND TIERODS
- PROPOSED SUMP
- PROPOSED CONVEYANCE PIPING
- PROPOSED COLLECTION DRAIN
- FENCE
- WATER BOUNDARY
- SIDEWALK
- EXISTING SHEET PILE WALL
- EXISTING WAKEFIELD WALL
- EXISTING BUILDING
- CONFIRMED FORMER BUILDING FOUNDATIONS
- FORMER BUILDING FOUNDATIONS
- RIP RAP
- 586 EXISTING CONTOUR
- EXISTING GAS LINE
- EXISTING FIRE WATER HIGH PRESSURE LINE
- EXISTING POWER AND LIGHTING SYSTEM
- EXISTING STORM SEWER LINE
- EXISTING SANITARY SEWER LINE
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- EXISTING WATER LINE
- EXISTING TELEPHONE LINE
- FIRE HYDRANT
- GATE VALVE W/VALVE BOX
- GATE VALVE
- CATCH BASIN / STORM DRAIN
- LIGHT POLE
- SIGN

DRAFT

0 100' 200'

GRAPHIC SCALE

REV	DATE	BY	APPROVED	DESCRIPTION	REV	DATE	BY	APPROVED	DESCRIPTION
0	09/06/22	GEC	AK	PRELIMINARY DESIGN (30%)					

ORIGINATION	BY	DATE	PROJECT INFORMATION	
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CHECKED	MG		ARCADIS PROJ NO.	30133323
APPROVAL	BY	DATE	SITE INFORMATION	
			SITE	
			PLANT	
			SYSTEM	
			BLDG. NO.	

ARCADIS
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AREA A
PROPOSED NORTHERN PERIMETER SHEET PILE BARRIER AND COLLECTION DRAIN ALIGNMENT
PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

DRAWING NUMBER	REV
0154-WYN-B30-C-102	0
SITE / LOCATION / TYPE / NUMBER	

LEGEND:

PROPOSED SOIL-CEMENT BARRIER	EXISTING BUILDING
APPROXIMATE SITE BOUNDARY	CONFIRMED FORMER BUILDING FOUNDATIONS
PROPOSED SHEET PILE WALL	FORMER BUILDING FOUNDATIONS
PROPOSED STEEL BULKHEAD	RIP RAP
PROPOSED ANCHOR WALL AND TIERODS	586 EXISTING CONTOUR
PROPOSED SUMP	EXISTING GAS LINE
PROPOSED CONVEYANCE PIPING	EXISTING FIRE WATER HIGH PRESSURE LINE
PROPOSED COLLECTION DRAIN	EXISTING POWER AND LIGHTING SYSTEM
FENCE	EXISTING STORM SEWER LINE
WATER BOUNDARY	EXISTING SANITARY SEWER LINE
SIDEWALK	EXISTING SITE AIR SYSTEM LINE
EXISTING SHEET PILE WALL	MATCH PLAN
EXISTING WAKEFIELD WALL	

EXISTING NITROGEN SYSTEM LINE
EXISTING STEAM SYSTEM LINE
EXISTING RIVER WATER LINE
EXISTING WATER LINE
EXISTING TELEPHONE LINE
FIRE HYDRANT
GATE VALVE W/VALVE BOX
GATE VALVE
CATCH BASIN / STORM DRAIN
LIGHT POLE
SIGN

DRAFT

0 100' 200'
GRAPHIC SCALE

REV	DATE	BY	APPROVED	DESCRIPTION	REV	DATE	BY	APPROVED	DESCRIPTION
0	09/06/22	GEC	AK	PRELIMINARY DESIGN (30%)					

ORIGINATION	BY	DATE	PROJECT INFORMATION	
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DESIGN	AL		PROJ NO.	
CHECKED	MG		ARCADIS PROJ NO.	30133323
APPROVAL	BY	DATE	SITE INFORMATION	
			SITE	
			PLANT	
			SYSTEM	
			BLDG. NO.	

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AREA B
PROPOSED COLLECTION DRAIN ALIGNMENT
PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

DRAWING NUMBER	REV
0154-WYN-E6N-C-103	0
SITE / LOCATION / TYPE / NUMBER	

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8/29/2022 11:21 AM BY: THORWATH, CHANDRAKANTH

LEGEND:

PROPOSED SOIL-CEMENT BARRIER	EXISTING BUILDING
APPROXIMATE SITE BOUNDARY	CONFIRMED FORMER BUILDING FOUNDATIONS
PROPOSED SHEET PILE WALL	FORMER BUILDING FOUNDATIONS
PROPOSED STEEL BULKHEAD	RIP RAP
PROPOSED ANCHOR WALL AND TIERODS	EXISTING CONTOUR (586)
PROPOSED SUMP	EXISTING GAS LINE
PROPOSED CONVEYANCE PIPING	EXISTING FIRE WATER HIGH PRESSURE LINE
PROPOSED COLLECTION DRAIN	EXISTING POWER AND LIGHTING SYSTEM
FENCE	EXISTING STORM SEWER LINE
WATER BOUNDARY	EXISTING SANITARY SEWER LINE
SIDEWALK	EXISTING SITE AIR SYSTEM LINE
EXISTING SHEET PILE WALL	MATCH PLAN
EXISTING WAKEFIELD WALL	

EXISTING NITROGEN SYSTEM LINE
EXISTING STEAM SYSTEM LINE
EXISTING RIVER WATER LINE
EXISTING WATER LINE
EXISTING TELEPHONE LINE
FIRE HYDRANT
GATE VALVE W/VALVE BOX
GATE VALVE
CATCH BASIN / STORM DRAIN
LIGHT POLE
SIGN

DRAFT

0 100' 200'

GRAPHIC SCALE

REV	DATE	BY	APPROVED	DESCRIPTION
0	09/06/22	GEC	AK	PRELIMINARY DESIGN (30%)

ORIGINATION	BY	DATE	PROJECT INFORMATION	
DRAWN	GEC		I.O. NO.	
DESIGN	AL		PROJ NO.	
CHECKED	MG		ARCADIS PROJ NO.	30133323
APPROVAL	BY	DATE	SITE INFORMATION	
			SITE	
			PLANT	
			SYSTEM	
			BLDG. NO.	

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AREA C
PROPOSED COLLECTION DRAIN ALIGNMENT
PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

DRAWING NUMBER	REV
0154-WYN-D15N-C-104	0
SITE / LOCATION / TYPE / NUMBER	

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PLOTTED: 8/29/2022 11:22 AM BY: THORWATH, CHANDRAKANTH

NOTE: SEALED CONNECTION DETAIL TO BE DETERMINED DURING NEXT PHASE BASED ON EXISTING WALL CONSTRUCTION AND ADVANCEMENT OF BARRIER DESIGN.

LEGEND:

- PROPOSED SOIL-CEMENT BARRIER
- APPROXIMATE SITE BOUNDARY
- PROPOSED SHEET PILE WALL
- PROPOSED STEEL BULKHEAD
- PROPOSED ANCHOR WALL AND TIERODS
- PROPOSED SUMP
- PROPOSED CONVEYANCE PIPING
- PROPOSED COLLECTION DRAIN
- FENCE
- WATER BOUNDARY
- SIDEWALK
- EXISTING SHEET PILE WALL
- EXISTING WAKEFIELD WALL
- EXISTING BUILDING
- CONFIRMED FORMER BUILDING FOUNDATIONS
- FORMER BUILDING FOUNDATIONS
- RIP RAP
- 586 EXISTING CONTOUR
- EXISTING GAS LINE
- EXISTING FIRE WATER HIGH PRESSURE LINE
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- EXISTING RIVER WATER LINE
- EXISTING WATER LINE
- EXISTING TELEPHONE LINE
- FIRE HYDRANT
- GATE VALVE W/VALVE BOX
- GATE VALVE
- CATCH BASIN / STORM DRAIN
- LIGHT POLE
- SIGN

0 150' 300'
GRAPHIC SCALE

DRAFT

REV	DATE	BY	APPROVED	DESCRIPTION
0	09/06/22	GEC	AK	PRELIMINARY DESIGN (30%)

ORIGINATION	BY	DATE	PROJECT INFORMATION	
DRAWN	GEC		I.O. NO.	
DESIGN	AL		PROJ NO.	
CHECKED	MG		ARCADIS PROJ NO.	30133323
APPROVAL	BY	DATE	SITE INFORMATION	
			SITE	
			PLANT	
			SYSTEM	
			BLDG. NO.	

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AREA D
PROPOSED BULKHEAD
AND COLLECTION DRAIN ALIGNMENT
PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

DRAWING NUMBER	REV
0154-WYN-E5N-C-105	0
SITE / LOCATION / TYPE / NUMBER	

NOTE: SEALED CONNECTION DETAIL TO BE DETERMINED DURING NEXT PHASE BASED ON EXISTING WALL CONSTRUCTION AND ADVANCEMENT OF BARRIER DESIGN.

LEGEND:

- PROPOSED SOIL-CEMENT BARRIER
- APPROXIMATE SITE BOUNDARY
- PROPOSED SHEET PILE WALL
- PROPOSED STEEL BULKHEAD
- PROPOSED ANCHOR WALL AND TIERODS
- PROPOSED SUMP
- PROPOSED CONVEYANCE PIPING
- PROPOSED COLLECTION DRAIN
- FENCE
- WATER BOUNDARY
- SIDEWALK
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- EXISTING WAKEFIELD WALL
- EXISTING BUILDING
- CONFIRMED FORMER BUILDING FOUNDATIONS
- FORMER BUILDING FOUNDATIONS
- RIP RAP
- 586 EXISTING CONTOUR
- EXISTING GAS LINE
- HPFW EXISTING FIRE WATER HIGH PRESSURE LINE
- EXISTING POWER AND LIGHTING SYSTEM
- EXISTING STORM SEWER LINE
- EXISTING SANITARY SEWER LINE
- EXISTING SITE AIR SYSTEM LINE
- MATCH PLAN
- N EXISTING NITROGEN SYSTEM LINE
- ST EXISTING STEAM SYSTEM LINE
- RW EXISTING RIVER WATER LINE
- W EXISTING WATER LINE
- T EXISTING TELEPHONE LINE
- FIRE HYDRANT
- GATE VALVE W/VALVE BOX
- GATE VALVE
- CATCH BASIN / STORM DRAIN
- LIGHT POLE
- SIGN

0 100' 200'
GRAPHIC SCALE

DRAFT

REV	DATE	BY	APPROVED	DESCRIPTION	REV	DATE	BY	APPROVED	DESCRIPTION
0	09/06/22	GEC	AK	PRELIMINARY DESIGN (30%)					

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DESIGN	AL		PROJ NO.	
CHECKED	MG		ARCADIS PROJ NO.	30133323
APPROVAL	BY	DATE	SITE INFORMATION	
			SITE	
			PLANT	
			SYSTEM	
			BLDG. NO.	

ARCADIS
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AREA E
PROPOSED BULKHEAD, SOIL-CEMENT BARRIER AND COLLECTION DRAIN ALIGNMENT
PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

DRAWING NUMBER	REV
0154-WYN-D15S-C-106	0
SITE / LOCATION / TYPE / NUMBER	

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CITY: SYRACUSE, NY DIV/GROUP: IM/DV DB: L.POSENAUER PM/TM: D.WEEKS LYR:(Opt)ON=*;OFF=*REF*
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NOTE: SEALED CONNECTION DETAIL TO BE DETERMINED DURING NEXT PHASE BASED ON EXISTING WALL CONSTRUCTION AND ADVANCEMENT OF BARRIER DESIGN.

LEGEND:

- PROPOSED SOIL-CEMENT BARRIER
- APPROXIMATE SITE BOUNDARY
- PROPOSED SHEET PILE WALL
- PROPOSED STEEL BULKHEAD
- PROPOSED ANCHOR WALL AND TIERODS
- PROPOSED SUMP
- PROPOSED CONVEYANCE PIPING
- PROPOSED COLLECTION DRAIN
- FENCE
- WATER BOUNDARY
- SIDEWALK
- EXISTING SHEET PILE WALL
- EXISTING WAKEFIELD WALL
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- GATE VALVE
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- LIGHT POLE
- SIGN

DRAFT

0 100' 200'
GRAPHIC SCALE

REV	DATE	BY	APPROVED	DESCRIPTION	REV	DATE	BY	APPROVED	DESCRIPTION
0	09/06/22	GEC	AK	PRELIMINARY DESIGN (30%)					

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CHECKED	MG		ARCADIS PROJ NO.	30133323
APPROVAL	BY	DATE	SITE INFORMATION	
			SITE	
			PLANT	
			SYSTEM	
			BLDG. NO.	

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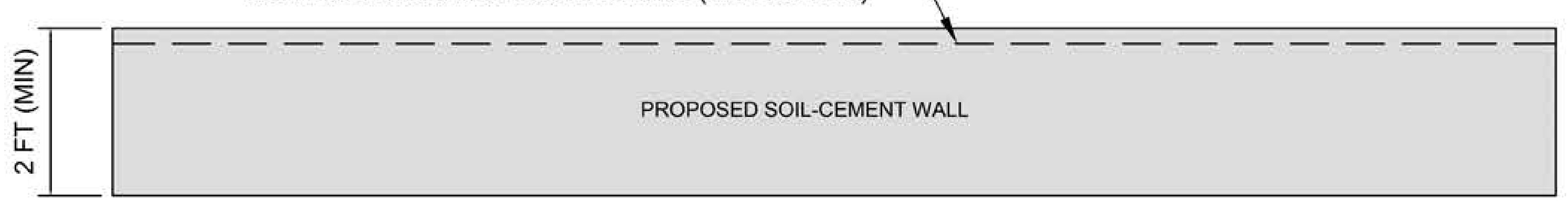
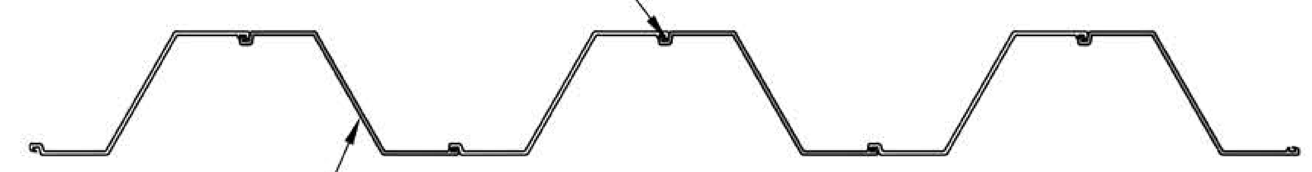
AREA F
PROPOSED SOUTHERN PERIMETER SHEET PILE BARRIER AND COLLECTION DRAIN ALIGNMENT
PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

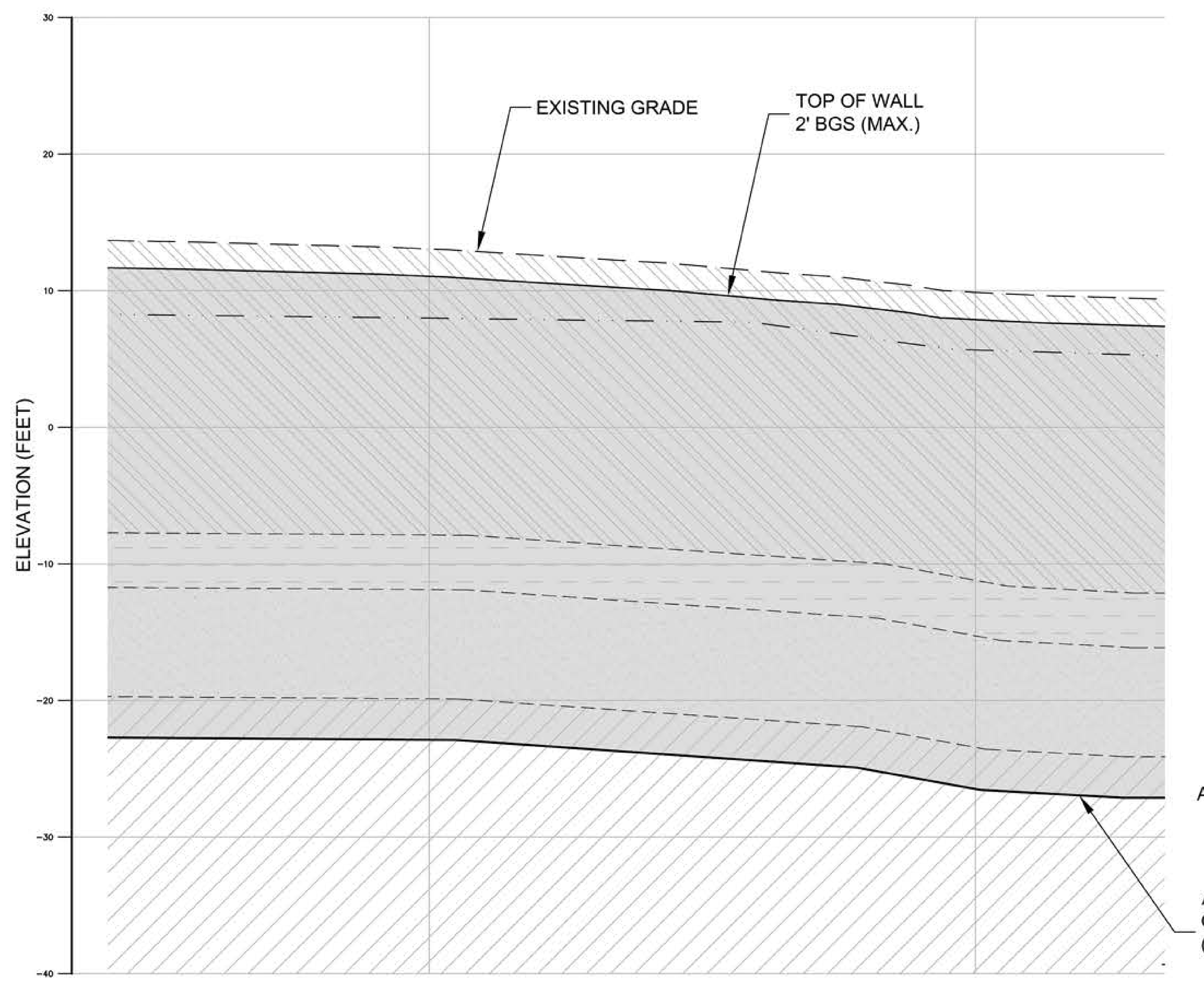
DRAWING NUMBER	REV
0154-WYN-C15S-C-107	0
SITE / LOCATION / TYPE / NUMBER	



PLAN DETAIL
NOT TO SCALE



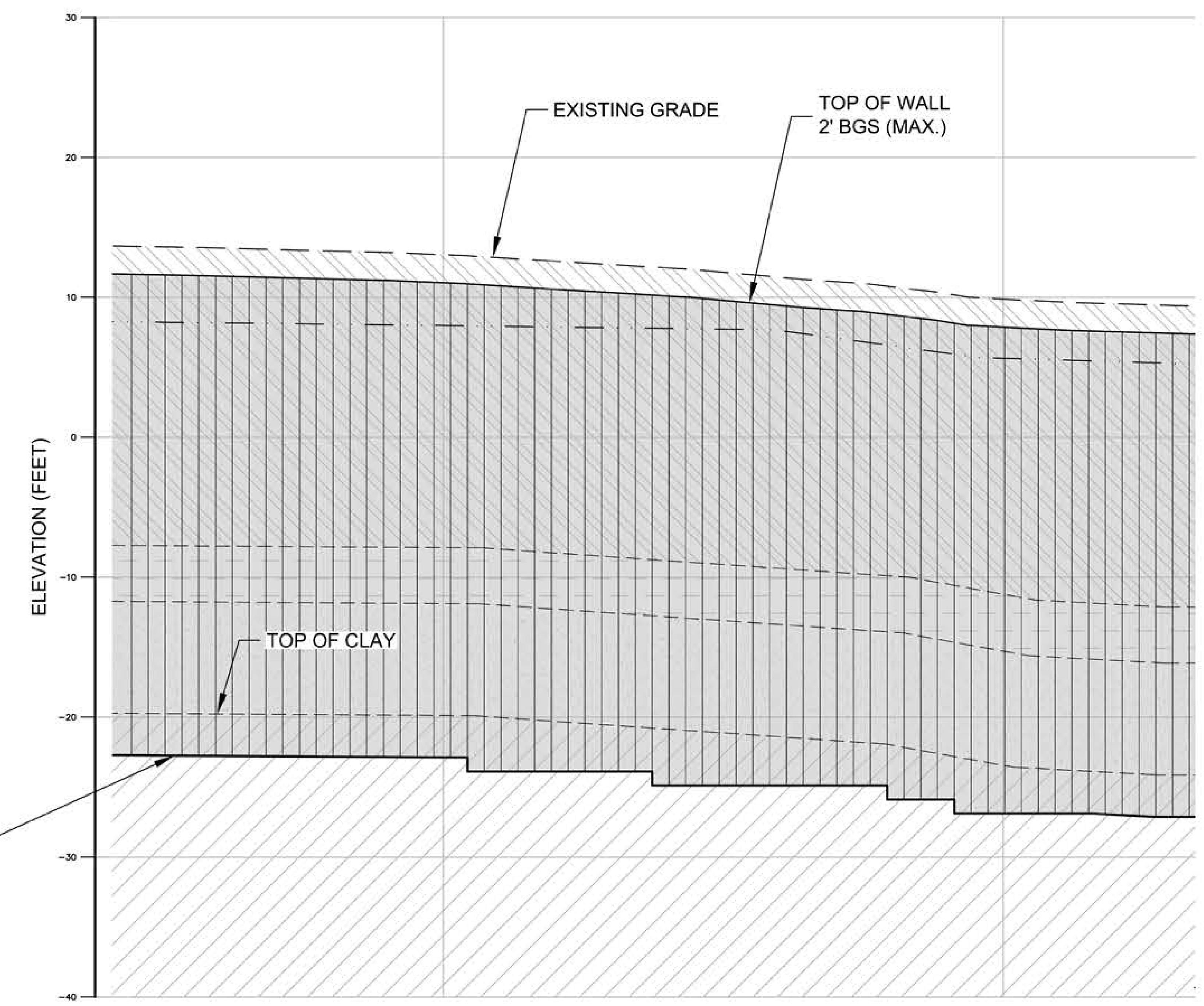
PLAN DETAIL
NOT TO SCALE



PARTIAL WALL PROFILE
NOT TO SCALE

SOIL-CEMENT BARRIER WALL

APPROXIMATE BOTTOM OF SHEETING (SEE NOTE 2)



PARTIAL WALL PROFILE
NOT TO SCALE

SHEET PILE BARRIER WALL

LEGEND:

- SOIL-CEMENT WALL
- SHEET PILE WALL
- FILL
- SAND
- PEAT
- CLAY
- APPROXIMATE GROUNDWATER LEVEL
- EXISTING GRADE
- TOP OF WALL

NOTES:

1. SOIL TYPES AND SUBSURFACE CONTACTS SHOWN ARE FOR SCHEMATIC PURPOSES ONLY TO SUPPORT THIS PRELIMINARY DESIGN. ACTUAL SUBSURFACE CONDITIONS ENCOUNTERED DURING THE WORK WILL VARY FROM THOSE SHOWN.
2. BARRIER WALLS SHALL KEY INTO THE CLAY LAYER BY A MINIMUM OF 3 FEET.
3. A VERTICAL HDPE LINER POSITIONED ALONG EDGE OF TRENCH IS ONE OPTION UNDER CONSIDERATION FOR ADDRESSING POTENTIAL FREEZE-THAW IMPACTS TO THE SOIL-CEMENT WALL. ADDITIONAL ALTERNATIVES FOR FROST RESILIENCY WILL BE DEVELOPED AND EVALUATED AS THE WALL DESIGN PROGRESSES AND FINAL SELECTION WILL BE SPECIFIED IN THE FINAL DESIGN PACKAGE.

DRAFT

REV	DATE	BY	APPROVED	DESCRIPTION
0	09/06/22	GEC	AK	PRELIMINARY DESIGN (30%)

ORIGINATION	BY	DATE	PROJECT INFORMATION	
DRAWN	GEC		I.O. NO.	
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CHECKED	MG		ARCADIS PROJ NO.	30133323
APPROVAL	BY	DATE	SITE INFORMATION	
			SITE	
			PLANT	
			SYSTEM	
			BLDG. NO.	

ARCADIS
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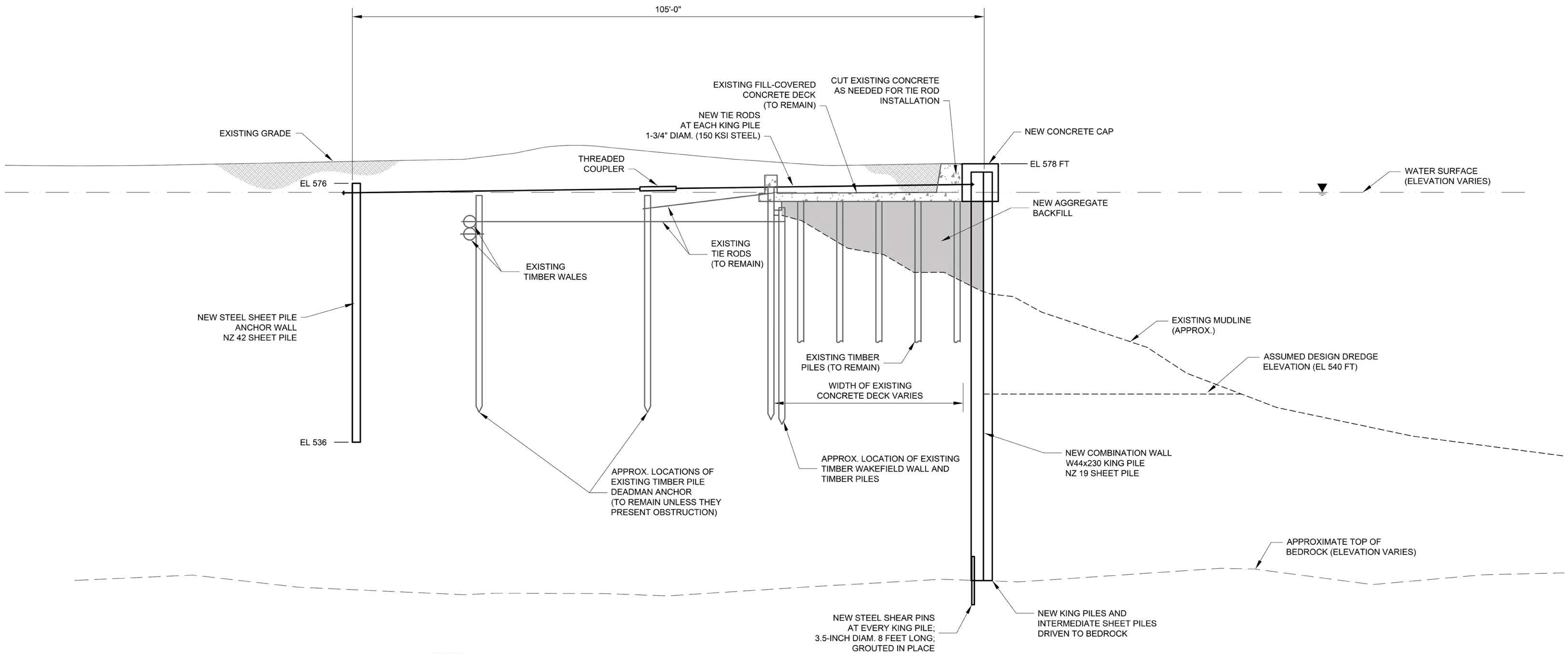
SUBSURFACE BARRIER DETAILS
SOIL-CEMENT AND SHEET PILE

PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

DRAWING NUMBER	REV
0154-WYN-SITE-C-301	0
SITE / LOCATION / TYPE / NUMBER	



NOTES:

1. THE LOCATIONS OF THE EXISTING STRUCTURES SHOWN IN THE CROSS SECTION ARE APPROXIMATE AND BASED ON HISTORICAL DRAWINGS FROM NEARBY AREAS. THE ACTUAL LOCATIONS OF THESE STRUCTURES MAY VARY AND MAY BE DIFFERENT AT THE LOCATION OF THE PROPOSED ANCHORED BULKHEAD. THE ACTUAL LOCATIONS OF THE EXISTING STRUCTURES WILL BE DETERMINED BY THE ENGINEER BEFORE COMPLETION OF THE DESIGN OF THE PROPOSED BULKHEAD.

2. THE ASSUMED DREDGE ELEVATION IS THE ASSUMED ELEVATION FOR THE 30% DESIGN OF THE BULKHEAD STRUCTURE. IT IS GENERALLY BASED ON PLANNED DREDGE ELEVATIONS FOR THE UPPER TRENTON CHANNEL DREDGING PLANNED BY THE USEPA. IT SHOULD BE NOTED, HOWEVER, THAT DREDGING MAY BE DEEPER IN SOME AREAS OF THE RIVER AND THE DREDGE ELEVATION ALONG A NEW BULKHEAD WILL NEED TO BE ESTABLISHED BASED ON INPUT FROM THE UPPER TRENTON CHANNEL PROJECT TEAM DURING SUBSEQUENT STAGES OF DESIGN.

ABBREVIATIONS:
EL = ELEVATION

0 4' 8' 16'

REV	DATE	BY	APPROVED	DESCRIPTION	REV	DATE	BY	APPROVED	DESCRIPTION
0	09/06/22	GEC	AK	PRELIMINARY DESIGN (30%)					

ORIGINATION	BY	DATE	PROJECT INFORMATION	
DRAWN	GEC		I.O. NO.	
DESIGN	SM / CB		PROJ NO.	
CHECKED	CB		ARCADIS PROJ NO.	30133323
APPROVAL	BY	DATE	SITE INFORMATION	
			SITE	
			PLANT	
			SYSTEM	
			BLDG. NO.	

ARCADIS
ARCADIS U.S., INC.

BASF
The Chemical Company

BULKHEAD CROSS SECTION

PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

DRAWING NUMBER	REV
0154-WYN-SITE-C-302	0
SITE / LOCATION / TYPE / NUMBER	

DRAFT

INSTRUMENT IDENTIFICATION LEGEND

	FIRST LETTER		SUCCEEDING LETTERS		
	MEASURED OR INITIATING VARIABLE,	MODIFIER	READOUT OR PASSIVE FUNCTION	OUTPUT FUNCTION	MODIFIER
A	ANALYSIS		ALARM		
B	BURNER FLAME		NOT USED	NOT USED	NOT USED
C	CONDUCTIVITY (ELECTRICAL)			CONTROL	CLOSED
D	DENSITY (MASS) OR SPECIFIC GRAVITY	DIFFERENTIAL			
E	VOLTAGE (EMF)		PRIMARY ELEMENT		
F	FLOW RATE	RATIO (FRACTION)			
G	INTRUSION		GLASS GAGE (UNCALIBRATED)		
H	HAND (MANUALLY INITIATED)				HIGH
I	CURRENT (ELECTRICAL)		INDICATE		
J	POWER	SCAN			
K	TIME OR TIME SCHEDULE			CONTROL STATION	
L	LEVEL		LIGHT (PILOT)		LOW
M	MOISTURE OR HUMIDITY				MIDDLE OR INTERMEDIATE
N	SEQUENCE, STRATEGY		NOT USED	NOT USED	NOT USED
O	NOT USED		ORIFICE (RESTRICTION)		OPEN
P	PRESSURE OR VACUUM		POINT (TEST CONNECTION)	PULSE	
Q	QUANTITY	INTEGRATE OR TOTALIZE			
R	RADIOACTIVITY				
S	SPEED, FREQUENCY	SAFETY		SWITCH	
T	TEMPERATURE			TRANSMIT	
U	MULTIVARIABLE		MULTIFUNCTION	MULTIFUNCTION	MULTIFUNCTION
V	VIBRATION			VALVE, DAMPER OR LOUVER	
W	WEIGHT OR FORCE		WELL	UNCLASSIFIED	UNCLASSIFIED
X	UNCLASSIFIED	X AXIS	UNCLASSIFIED	RELAY OR COMPUTE	
Y	EVENT STATUS	Y AXIS			
Z	POSITION			DRIVE, ACTUATE OR UNCLASSIFIED FINAL CONTROL ELEMENT	

ABBREVIATIONS

CU FT CUBIC FEET
GAC GRANULAR ACTIVATED CARBON
GAL GALLON
GPM GALLONS PER MINUTE
IX ION EXCHANGE
NA NOT ANALYZED
ND NON-DETECT
pHC pH CONTROL
YD YARD

PANEL DEVICE SYMBOLS

HS H/O/A — HAND SWITCH (MANUAL SELECTOR)
FUNCTION SUBSCRIPT

PB H/O/A — PUSHBUTTON
FUNCTION SUBSCRIPT

FUNCTION SUBSCRIPTS FOR HAND SWITCH AND PUSHBUTTON CONTROLS:

ESTOP E-STOP
F/O/R FORWARD-OFF-REVERSE
F/O/JR FORWARD-OFF-JOG REVERSE
H/O/A HAND-OFF-AUTO
H/O/R HAND-OFF-REMOTE
H/O/SBY HAND-OFF-STANDBY
L/O/R LOCAL-OFF-REMOTE
M/A MANUAL-AUTO
M/O/A MANUAL-OFF-AUTO
O/C OPEN-CLOSE
O/O ON-OFF
O/S/C OPEN-STOP-CLOSE
RS RESET
R/L REMOTE-LOCAL
R/O RUN-OFF
SC SPEED CONTROL POTENTIOMETER
SCR SILICON CRYSTAL RECTIFIER
S/S START-STOP
S/SLO START-STOP WITH LOCKOUT

IL AF — INDICATING LIGHT UNIT
G-GREEN (RUN,START,OPEN)
R-RED (OFF,STOP,CLOSED)
W-WHITE (POWER ON)
A-AMBER (ALARM CONDITION)
F-FLASHES ON ELECTRIC OR MECHANICAL MALFUNCTION

1 — INTERLOCK
1 = NOTE NUMBER

ELECTRONIC HORN

A — STROBE LIGHT
A - AMBER
W - WHITE
R - RED
B - BLUE

VFD — VARIABLE FREQUENCY DRIVE

MCC — MOTOR CONTROL CENTER

PIPING MATERIAL CLASS

BIOP BIOPRENE TUBING
C1 CARBON STEEL
DI DUCTILE IRON
CPVC CHLORINATED PVC
FRP FIBERGLASS REINFORCED PLASTIC
HDPE HIGH-DENSITY POLYETHYLENE
HDPE2 HIGH-DENSITY POLYETHYLENE (DOUBLE WALL)
PTFE TEFLON TUBING WITH 316 L + ANTISTATIC SHEATH STAINLESS STEEL BRAIDED SHEATH
PEX CROSS LINKED POLYETHYLENE
PVC POLYVINYL CHLORIDE
PVCT POLYVINYL CHLORIDE TUBING
PP2 POLYPROPYLENE (DOUBLE WALL)
C2 COPPER

SERVICE DESIGNATIONS

CO2 CARBON DIOXIDE GAS
CO2L CARBON DIOXIDE LIQUID
CW CITY WATER
DR DRAIN
OF OVERFLOW
PW PROCESS WASTE
SAMP SAMPLE
SAN SANITARY SEWER
SH SODIUM HYDROXIDE
STW STORM WATER
VT VENT
WW GENERAL WASTE WATER
N2 NITROGEN GAS
CA CHEMICAL ADDITIVE
PA PLANT AIR

INSULATION AND TRACING

INSULATION
AS ANTI-SWEAT
CC COLD CONSERVATION
HC HEAT CONSERVATION
PP PERSONAL PROTECTION
VJ VACUUM JACKET

TRACING
ET ELECTRICAL
GT GLYCOL
ST STEAM

BASE INSTRUMENTATION SYMBOLS

XXX ### — FIELD I/O POINT FOR SHARED VIDEO DISPLAY
XXX ### — SOFT I/O POINT FOR SHARED VIDEO DISPLAY (BROKEN LINE)
CS # — SOFTWARE INTERLOCKS/LOGIC FUNCTION, PRIMARY LOCATION.
CS # — SOFTWARE INTERLOCKS/LOGIC FUNCTION, SECONDARY LOCATION.
FY ### — INSTRUMENT ON REAR OF PANEL (BROKEN LINE). ACTIVATES AND DEACTIVATES CONTROL AND/OR ALARM SWITCHES AT PRESET SIGNAL VALUES.
Δ DIFFERENCE
> HIGH SELECTOR
< LOW SELECTOR
P/I PNEUMATIC/CURRENT CONVERTER
I/I CURRENT/CURRENT CONVERTER (REPEATER)
Σ SUMMATION
AV AVERAGE
% RATIO

XXX INSTRUMENT IDENTIFICATION. (SEE THIS SHEET FOR INSTRUMENT IDENTIFICATION LEGEND AND NUMBERING SYSTEM)
LOOP NUMBER.
CONTROL STRATEGY NUMBER IN SPECIFICATION
INPUT (DISCRETE)
OUTPUT (DISCRETE)
INPUT (ANALOG)
OUTPUT (ANALOG)
XXX ### — FIELD INSTRUMENT. POWER SUPPLY REQUIRED LOCALLY WHERE SHOWN.

XXX ### — INSTRUMENT ON PANEL.
HSS ### — SAFETY PULL CORD
ZS ### — BELT ALIGNMENT SWITCH
FR ### AR ### — FR & AR TWO FUNCTIONS AS PART OF ONE UNIT (CIRCLES TOUCH).
AIT ### — SUPERSCRIPTS (X) FOR ANALYTIC DEVICES:
CH4-METHANE
Cl2-CHLORINE
COMB-COMBUSTIBLES
DO-DISSOLVED OXYGEN
FeCl3-FERRIC CHLORIDE
H2S-HYDROGEN SULFIDE
H3PO4-PHOSPHORIC ACID
H2SO4-SULFURIC ACID
Na2S2O5-SODIUM BISULFITE

ORIFICE FLOW ELEMENT
VENTURI FLOW ELEMENT
FLUME
M — MAGNETIC FLOW ELEMENT
LE XXXX — ULTRASONIC OR RADAR ELEMENT

INTERCONNECTING LINES WITH DOT INDICATES ROUTING OF THE SAME SIGNAL.
INTERCONNECTING LINES WITHOUT DOT INDICATES ROUTING OF MORE THAN ONE SIGNAL.
IAS INSTRUMENT AIR SUPPLY
120V 120V AC POWER SUPPLY
480V 480V AC POWER SUPPLY
24V 24V DC POWER SUPPLY

LINE IDENTIFICATION

X"-C1-WW-HC-ET
PIPE SIZE
PIPE MATERIAL
SERVICE DESIGNATION
INSULATION
TRACING

VALVE & GATE IDENTIFICATION

AA-BB-001
SERVICE DESIGNATION
EQUIPMENT SERVED
SEQUENCE NUMBER

EQUIPMENT NUMBER IDENTIFICATION

AAABBBB
EQUIPMENT LETTER DESIGNATION
EQUIPMENT SEQUENCE NUMBER

A AGITATOR
CST CHEMICAL STORAGE TANK
DS DUPLEX STRAINER
EQT EQUALIZATION TANK
MN MIXING NOZZLE
NT NEUTRALIZATION TANK
P-CF PUMP-CHEMICAL FEED
P-RC PUMP-RECIRCULATION
P-TR PUMP-TRANSFER
SG SLIDE GATE
SU SUMP TANK
WWL WET WELL

SIGNAL TYPE ABBREVIATIONS

ANG ANALOG
CNT CONTROLNET
DCT DRY CONTACT
DNT DEVICENET
ENT ETHERNET
FLB FOUNDATION FIELDBUS
MOD MODBUS

OPERATION TYPE ABBREVIATIONS

OC OPEN/CLOSE
MD MODULATING

DRAFT

REV	DATE	BY	APPROVED	DESCRIPTION	REV	DATE	BY	APPROVED	DESCRIPTION
0	09/06/22	GEC	AK	PRELIMINARY DESIGN (30%)					

ORIGINATION	BY	DATE	PROJECT INFORMATION	
DRAWN	GEC		I.O. NO.	
DESIGN	MS		PROJ NO.	
CHECKED	RD		ARCADIS PROJ NO.	30133323
APPROVAL	BY	DATE	SITE INFORMATION	
			SITE	
			PLANT	
			SYSTEM	
			BLDG. NO.	

ARCADIS
ARCADIS U.S., INC.
BASF
The Chemical Company

PIPING AND INSTRUMENTATION DIAGRAM
LEGEND, SYMBOLS, AND ABBREVIATIONS
SHEET 1
PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

DRAWING NUMBER	REV
0154-WYN-E5N-I-001	0
SITE / LOCATION / TYPE / NUMBER	

PIPING AND MISCELLANEOUS SYMBOLS

- SC — SAMPLE CONNECTION
- OR — STRAINER (Y-TYPE)
- QUICK DISCONNECT
- BELLOWS/EXP. JOINT
- FLEX HOSE
- FLEX HOSE W/ PERMANENT FIXED END AND QUICK DISCONNECT END
- FLEXIBLE HOSE W/ QUICK DISCONNECT END
- PP — INSULATION FOR PERSONNEL PROTECTION
- AS — INSULATION FOR ANTI-SWEAT
- INSULATION
- INSULATION BREAK
- E — ELECTRIC TRACED
- S — STEAM TRACED
- ORIFICE PLATE
- M — FLOW METER
- MM — MASS METER
- T — STEAM TRAP
- DIAPHRAGM SEAL
- LIGHT AND SIGHT GLASS
- F — IN LINE FILTER
- SIGHT GLASS, SG
- SIGHT GLASS, SG
- REDUCER
- UNION
- CONCENTRIC REDUCER
- VACUUM BREAKER USING SWING CHECK VALVE
- SANITARY CONNECTION (TRI-CLAMP)
- SPRAYBALL OR SPRAY NOZZLE (INSIDE VESSEL)
- FRL — (F) FILTER/(R) REGULATOR/(L) LUBRICATOR WITH PRESSURE INDICATOR
- PSE (RUPTURE DISK)
- PSV (EMERGENCY RELIEF VALVE)
- VB — VACUUM BREAKER (AUTO)
- BFP — BACKFLOW PREVENTER
- VE — VENT VALVE (AUTO)
- CV — PRESSURE/VACUUM CONSERVATION VENT
- CVF — PRESSURE/VACUUM CONSERVATION VENT WITH FLAME ARRESTOR
- PROXIMITY SWITCH
- FLOAT — FLOAT

PIPELINE SERVICES–UTILITIES

IDENTIFICATION BOX ON P&ID
SERVICE ABBREVIATION
SERVICE

11	CWS	COOLING WATER SUPPLY	30	N	NITROGEN
12	CWR	COOLING WATER RETURN	31		
13	DW	WATER–DEMINERALIZED	32	V	TO ATMOSHPHERE
14	KW	WATER–COAGULATED	33		TO FLARE
15	PW	WATER–POTABLE	34		
16	FW	WATER–FIRE PROTECTION	35		SEWER–SANITARY
17	CHS	CHILLED WATER SUPPLY	36	DP	SEWER–PROCESS
18	CHR	CHILLED WATER RETURN	37	SW	SEWER–STORM
19	SH	STEAM–HIGH PRESSURE	38	D	TO GRADE
20	SM	STEAM–MEDIUM PRESSURE	39		SAMPLE CONNECTION
21	SL	STEAM–LOW PRESSURE	40		SAMPLE WITH COOLER
22	SLL	STEAM–LOW LOW PRESSURE	41		
23			42		HOSE CONNECTION
24	CM	CONDENSATE–MEDIUM PRESSURE	43		DRAIN CONNECTION
25	CL	CONDENSATE–LOW PRESSURE	44		VENT CONNECTION
26			45		PURGE CONNECTION
27	PA	AIR–PLANT	46		GAS DETECTOR
28	IA	AIR–INSTRUMENT	47		
29	NG	NATURAL GAS	48	CA	CAUSTIC

49

50

INSTRUMENTATION AND EQUIPMENT SYMBOLS

AGITATOR	BASKET STRAINER	CALIBRATION UNIT	CENTRIFUGAL BLOWER	ROTAMETER	DENOTES SPEC. CHANGE	DENOTES AREA CHANGE	SLIDE GATE	PNEUMATIC CYLINDER ACTUATOR (SINGLE OR DOUBLE ACTING)	
DUPLEX STRAINER	EDUCTOR	ELECTRICAL QUICK DISCONNECT	FILTER	HEAT EXCHANGER	OVERFLOW POT	HORIZONTAL PRESSURE VESSEL	HOSE BARB	PNEUMATIC DIAPHRAGM ACTUATOR (SPRING OPPOSED OR SINGLE OR DOUBLE ACTING)	
LOBE PUMP	PERISTALTIC PUMP	VACUUM PUMP	DIAPHRAGM PUMP	SUBMERSIBLE PUMP	CHEMICAL DOSING PUMP	PULSATION DAMPENER	MOTORIZED ACTUATOR	VALVE POSITIONER PNEUMATIC DIAPHRAGM ACTUATOR (WITH VALVE POSITIONER)	
SOLENOID ACTUATOR	STEAM TRAP	STRAINER	TANK DRAIN	TANK LIGHT	TANK VENT	TWO WAY ACTUATOR	PROGRESSIVE CAVITY PUMP	CENTRIFUGAL PUMP	
VERTICAL PRESSURE VESSEL	WEIR GATE	MOTOR	SCREW PUMP	GEAR PUMP	ISO LOOP	PORTABLE DRUM PUMP	US ULTRASONIC TRANSMITTER	STATIC MIXER	

PROCESS SYMBOLS, VALVES AND MISCELLANEOUS

ANGLE BODY RELIEF VALVE	ANGLE VALVE	BALANCE VALVE	NORMALLY OPEN BALL VALVE	NORMALLY CLOSED BALL VALVE	GAS CYLINDER	BUTTERFLY VALVE	CONCENTRIC REDUCER	REGULATING SIDE BACK PRESSURE OR PRESSURE REGULATING VALVE
DIAPHRAGM VALVE	DIVERTER VALVE	DRY QUICK DISCONNECT	ECCENTRIC REDUCER	FLANGED CONNECTIONS WELDED OR SCREWED	FLOW ARROW	FOUR-WAY VALVE	GATE VALVE / KNIFE GATE VALVE	NOZZLE
MANUAL DISPENSE	NEEDLE VALVE	PIPE END WITH CAP	SILENT CHECK VALVE	ORIFICE PLATE	PIPE BREAK CONTINUATION MARKER	SWING CHECK VALVE	PIPE ENDED WITH BLIND FLANGE	PLUG VALVE
SLOPE	BALL CHECK VALVE	S TWO WAY SOLENOID VALVE	THREE-WAY VALVE	VALVE POSITIONER AUTO FLOW CONTROL VALVE (WITH MANUAL OVERIDE FOR HAND OPERATION)	INSIDE BUILDING	FA FLAME ARRESTOR	LINE DRAIN	DUCK BILL CHECK VALVE
WATER LEVEL	DIFFUSER	DRAIN	LOCK	FLOAT SWITCH	HOSE BIB	PIPE END WITH PLUG	CAPPED CAM LOCK FITTING	CLEANOUT
FOOT VALVE								

INTER DRAWING CONNECTORS

WW — 001 DRAWING NO. — TO OR FROM XXX — PIPING SERVICE — PROCESS CONNECTOR — ORIGIN OR DESTINATION FLOW CONNECTOR NUMBER

WW — 001 DRAWING NO. — TO OR FROM XXX — PIPING SERVICE — INSTRUMENT CONNECTOR — ORIGIN OR DESTINATION FLOW CONNECTOR NUMBER

LINE SYMBOLS

- PRIMARY PROCESS LINE
- AUXILIARY PROCESS LINE
- EXISTING PROCESS LINE
- INSTRUMENT AIR
- ELECTRICAL SIGNAL
- SKID BOUNDARY PACKAGED EQUIPMENT
- SOFTWARE OR DATA LINE
- HYDRAULIC SIGNAL

GENERAL NOTES

1. COORDINATE WORK WITH OTHER DRAWINGS AND DISCIPLINES.
2. THE SYMBOLS SHOWN ON THIS SHEET ARE STANDARD DESIGNATIONS. NOT ALL SYMBOLS ARE APPLICABLE TO THE INCLUDED DIAGRAMS AND INSTRUMENT TAG NUMBERING SYSTEM.
3. NOT ALL PIPING, FITTINGS, AND TANK DETAILS ARE SHOWN. REFER TO PROCESS DRAWINGS FOR ACTUAL DETAILS.
4. VALVES ARE SHOWN AS NORMALLY OPEN. NORMALLY CLOSED VALVES HAVE SOLID FILL.

DRAFT

REV	DATE	BY	APPROVED	DESCRIPTION	REV	DATE	BY	APPROVED	DESCRIPTION
0	09/06/22	GEC	AK	PRELIMINARY DESIGN (30%)					

ORIGINATION	BY	DATE	PROJECT INFORMATION	
DRAWN	GEC		I.O. NO.	
DESIGN	MS		PROJ NO.	
CHECKED	RD		ARCADIS PROJ NO.	30133323
APPROVAL	BY	DATE	SITE INFORMATION	
			SITE	
			PLANT	
			SYSTEM	
			BLDG. NO.	

ARCADIS U.S., INC.

BASF The Chemical Company

PIPING AND INSTRUMENTATION DIAGRAM
LEGEND, SYMBOLS, AND ABBREVIATIONS
SHEET 2
PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

DRAWING NUMBER: 0154-WYN-E5N-I-002 — REV 0

SITE | LOCATION | TYPE | NUMBER

REV	DATE	BY	APPROVED	DESCRIPTION
0	09/06/22	GEC	AK	PRELIMINARY DESIGN (30%)

ORIGINATION	BY	DATE	PROJECT INFORMATION	
DRAWN	GEC		I.O. NO.	
DESIGN	MS		PROJ NO.	
CHECKED	RD		ARCADIS PROJ NO.	30133323
APPROVAL	BY	DATE	SITE INFORMATION	
			SITE	
			PLANT	
			SYSTEM	
			BLDG. NO.	

ARCADIS
ARCADIS U.S., INC.

BASF
The Chemical Company

PROCESS FLOW DIAGRAM

PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

DRAWING NUMBER	REV
0154-WYN-E5N-I-101	0
SITE / LOCATION / TYPE / NUMBER	

DRAFT

CITY: SYRACUSE, NY DIV/GROUP: IM/DV DB: L.POSENAUER PM/TM: D.WEEKS LYR:(Opt)ON=*;OFF=*REF*
C:\Users\di01012\ACCDocs\Arcadis\AUS-30005248-BASF North Works\Project Files\01 - WIP\Process\DWG\GWTS-DESIGN-101-PFD.dwg LAYOUT: 0154-WYN-E5N-I-101 SAVED: 8/22/2022 3:12 PM ACADVER: 24.2S (LMS TECH) PAGESETUP: ---- PLOTSTYLETABLE: ---- PLOTTED: 8/29/2022 10:38 AM
BY: THORWATH, CHANDRAKANTH

Stream		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Description	Units	Groundwater	pH Neutralization Tank Effluent	MetClear Addition Effluent	Flocculation Tank Effluent	Clarifier Effluent	GAC Effluent	IX Effluent	Clarifier Sludge	Settled Sludge	Filter Press Influent	Sludge Cake	EQ Tank Sludge	Sludge Decant	Filter Press Decant	Sulfuric Acid	MetClear	Coagulant	Flocculant	Sludge Thickening Agent
Instantaneous Vol. Flow	gpm	100	101	101	101	101	100	100	0.59	0.83	0.83	0.04	0.68	0.44	0.80	0.1751	0.0018	0.0007	0.0003	0.00007
Volumetric Flow	MGD	0.144	0.145	0.145	0.145	0.145	0.144	0.144	0.001	0.0012	0.0012	0.0001	0.0010	0.0006	0.0011	0.0003	0.000003	0.000001	0.0000	0.0000001
Mass Flow	lb/hr	50,257	--	--	--	50,632	50,335	50,335	300	425	425	24	342	218	401	123	1.00	0.50	0.15	0.08
General Parameters																				
Density	kg/L	1.004	--	--	--	1.004	1.004	1.004	1.014	1.019	1.019	1.349	1.004	1.004	1.004	1.40	1.14	1.40	1.20	1.20
Pressure	psi	atm	atm	atm	atm	atm	42	18	4	atm	4	atm	4	atm	atm	13	10	10	11	10
General Water Quality																				
pH	S.U.	11.70	9.00	NA	NA	8.91	8.91	8.91	NA	NA	NA	NA	NA	8.91	8.91	<1	11.10	--	4.00	4.00
Alkalinity	mg/L as $CaCO_3$	930	NA	NA	NA	63.0	NA	NA	NA	NA	NA	NA	NA	63.0	63.0	--	--	--	--	--
Hardness	mg/L as $CaCO_3$	2,200	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	--	--	--	--	--
TSS	mg/L	114	79.8	NA	NA	22.8	NA	NA	15,000	20,000	NA	350,000	5,000	22.8	22.8	--	--	--	--	--
TDS	mg/L	5,300	NA	NA	NA	5,500	NA	NA	NA	NA	NA	NA	NA	5,500	5,500	--	--	--	--	--
COD	mg/L	220	NA	NA	NA	220	NA	NA	NA	NA	NA	NA	NA	220	220	--	--	--	--	--
BOD	mg/L	40.0	NA	NA	NA	34	NA	NA	NA	NA	NA	NA	NA	34.0	34.0	--	--	--	--	--
TOC	mg/L	29.0	NA	NA	NA	26	ND	ND	NA	NA	NA	NA	NA	26.0	26.0	--	--	--	--	--
Anions																				
Chloride	mg/L	2,400	NA	NA	NA	4,100	NA	NA	NA	NA	NA	NA	NA	4,100	4,100	--	--	1,700	--	--
Sulfate	mg/L	150	NA	NA	NA	1,100	NA	NA	NA	NA	NA	NA	NA	1,100	1,100	950	--	--	--	--
Cations																				
Calcium	mg/L	870	NA	NA	NA	880	NA	NA	NA	NA	NA	NA	NA	880	880	--	--	--	--	--
Magnesium	mg/L	7.2	NA	NA	NA	5.6	NA	NA	NA	NA	NA	NA	NA	5.60	5.60	--	--	--	--	--
Potassium	mg/L	58.0	NA	NA	NA	60.0	NA	NA	NA	NA	NA	NA	NA	60.0	60.0	--	--	--	--	--
Sodium	mg/L	1,100	NA	NA	NA	1,100	NA	NA	NA	NA	NA	NA	NA	1,100	1,100	--	--	--	--	--
Metals																				
Mercury	mg/L	0.00058	NA	0.00042	0.000023	0.000001	NA	NA	NA	0.07	0.07	1.61	NA	0.00	0.00	--	--	--	--	--
Organics																				
VOCs	mg/L	0.036	NA	NA	NA	0.231	0.102	ND	NA	NA	NA	NA	NA	0.23	0.23	--	--	--	--	--
SVOCs	mg/L	0.075	NA	NA	NA	0.068	0.000	ND	NA	NA	NA	NA	NA	0.07	0.07	--	--	--	--	--
PFAS																				
PFHxS	ng/L	33	NA	NA	NA	37.0	37.0	ND	NA	NA	NA	NA	NA	37.0	37.0	--	--	--	--	--
PFHxA	ng/L	10	NA	NA	NA	8.5	8.5	ND	NA	NA	NA	NA	NA	8.5	8.5	--	--	--	--	--
PFOS	ng/L	68	NA	NA	NA	64.0	64.0	ND	NA	NA	NA	NA	NA	64.0	64.0	--	--	--	--	--
PFOA	ng/L	12	NA	NA	NA	13.0	13.0	ND	NA	NA	NA	NA	NA	13.0	13.0	--	--	--	--	--
PFPeA	ng/L	9	NA	NA	NA	6.2	6.2	ND	NA	NA	NA	NA	NA	6.2	6.2	--	--	--	--	--
Chemical Additives																				
Concentration in Stream	ppm	--	1,900	20	10/3	--	--	--	--	--	3	--	--	--	--	400,000	1,000,000	1,000,000	2,500	2,500
Additive to Stream			Sulfuric Acid	MetClear	Coagulant/Flocculant															
Inputs																				
Potable Water	%	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	95.5	95.5

NOTES:

1. DATA FOR STREAMS 1 THROUGH 6 BASED ON GROUNDWATER TREATABILITY STUDY.
2. FOR DESIGN PURPOSES IT IS ASSUMED NO PFAS TREATMENT WILL OCCUR DURING GAC TREATMENT.
3. CONCENTRATIONS IN DECANT FROM SLUDGE TANK AND FILTER PRESS ASSUMED TO BE EQUIVALENT TO CLARIFIER EFFLUENT.
4. CHEMICAL DATA FOR STREAMS 15 TO 19 BASED ON SAFETY DATA SHEETS.
5. ASSUME 30% OF SOLIDS SETTLE OUT IN EQUALIZATION TANK.
6. ASSUME FLOCCULENT AND SLUDGE THICKENER STOCKS ARE 0.25% SOLUTION AND ARE MADE DOWN TO A 0.05% SOLUTION PRIOR TO INJECTION.
7. SYSTEM PRESSURES ARE ESTIMATES, SUBJECT TO CHANGE BASED ON FINAL EQUIPMENT SELECTION AND CONFIGURATION.
8. DECANT INPUTS TO THE BUILDING SUMP AND RETURNED TO THE EQUALIZATION TANK ARE ASSUMED TO BE NEGLIGIBLE.
9. IX AND GAC EFFLUENT pH ASSUMED TO BE EQUAL TO CLARIFIER EFFLUENT.
10. GAC EFFLUENT TOTAL VOCS ELEVATED DUE TO TREATABILITY STUDY CONDITIONS NOT EXPECTED TO BE PRESENT IN THE FULL SCALE DESIGN.

DRAFT

REV	DATE	BY	APPROVED	DESCRIPTION
0	09/06/22	GEC	AK	PRELIMINARY DESIGN (30%)

ORIGINATION	BY	DATE	PROJECT INFORMATION
DRAWN	GEC		I.O. NO.
DESIGN	MS		PROJ NO.
CHECKED	RD		ARCADIS PROJ NO. 30133323
APPROVAL	BY	DATE	SITE INFORMATION
			SITE
			PLANT
			SYSTEM
			BLDG. NO.

ARCADIS
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PROCESS FLOW DIAGRAM
MASS BALANCE

PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

DRAWING NUMBER: 0154-WYN-E5N-I-102 | REV: 0

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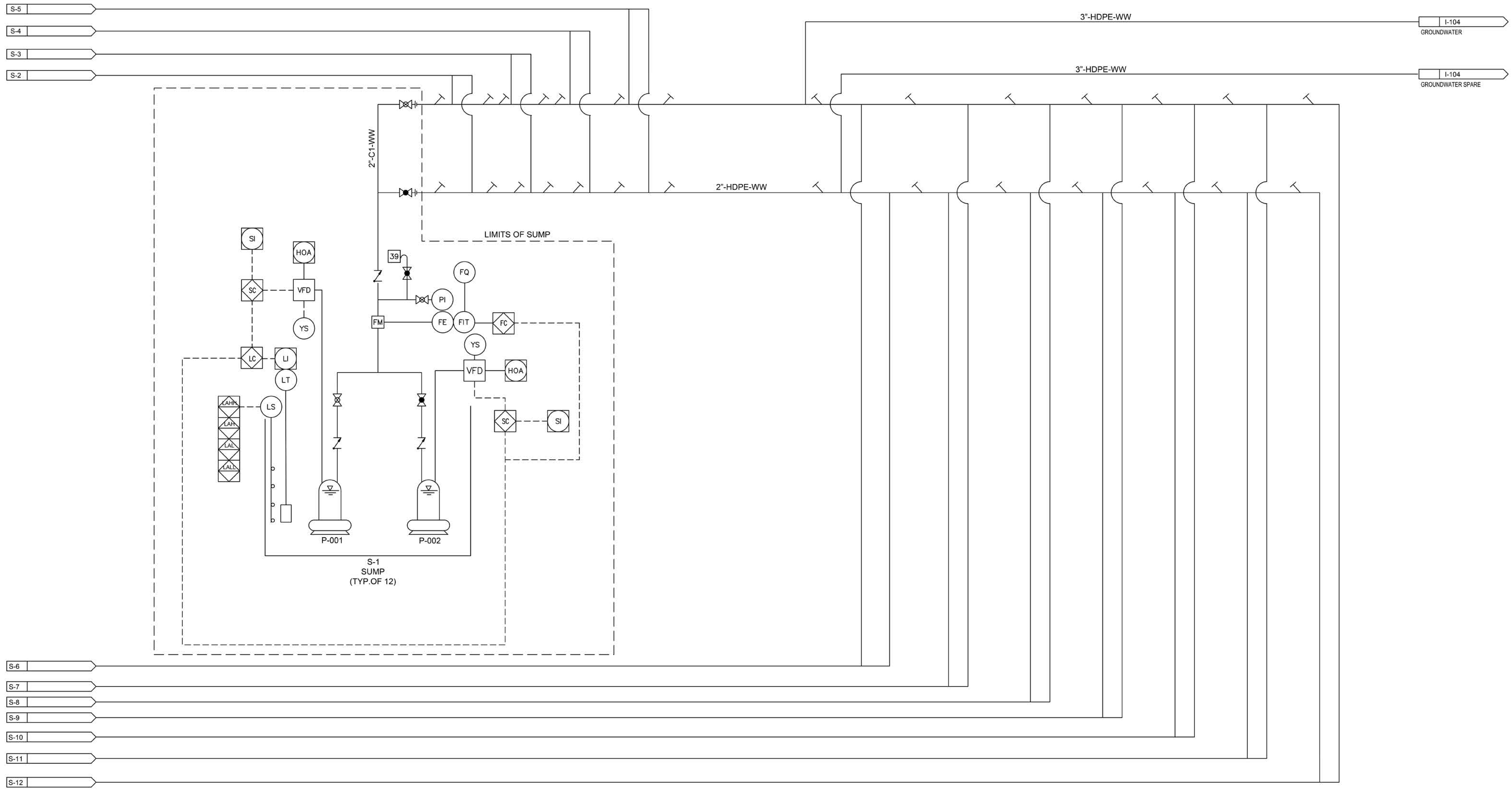

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PIPING AND INSTRUMENTATION DIAGRAM
SUMP PUMPING FLOW HEADERS

PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

DRAWING NUMBER	REV
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PIPING AND INSTRUMENTATION DIAGRAM
CHEMICAL INJECTION AND CLARIFICATION

PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

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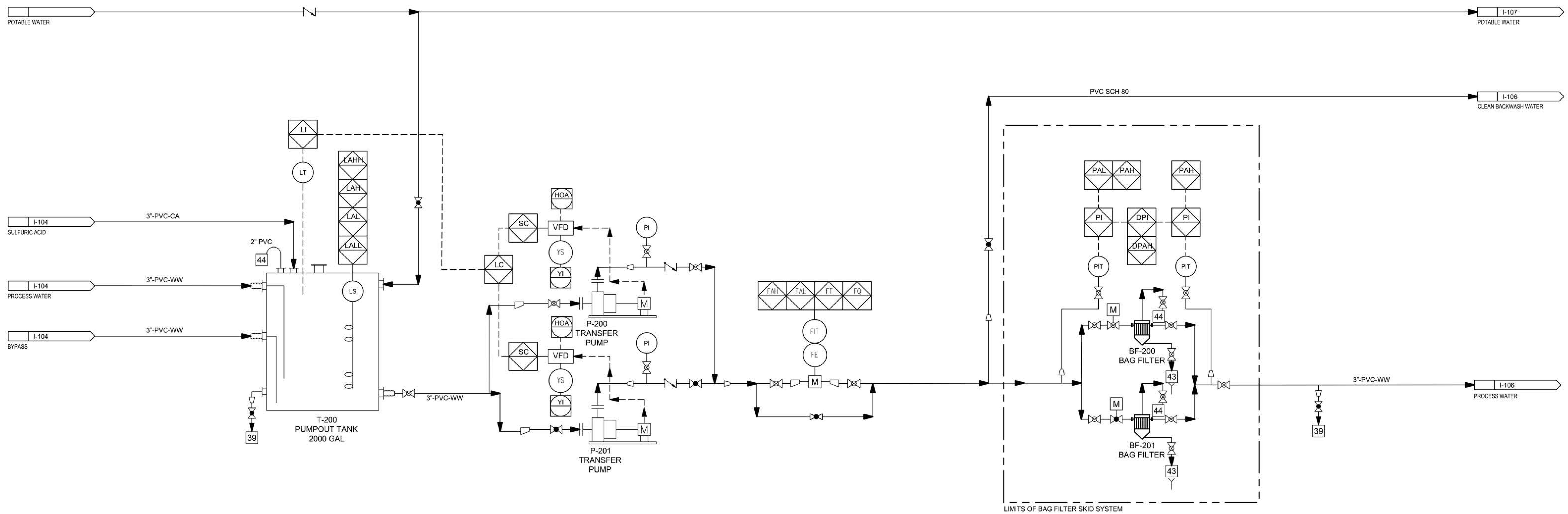

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PIPING AND INSTRUMENTATION DIAGRAM FILTRATION FEED AND BAG FILTERS

PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

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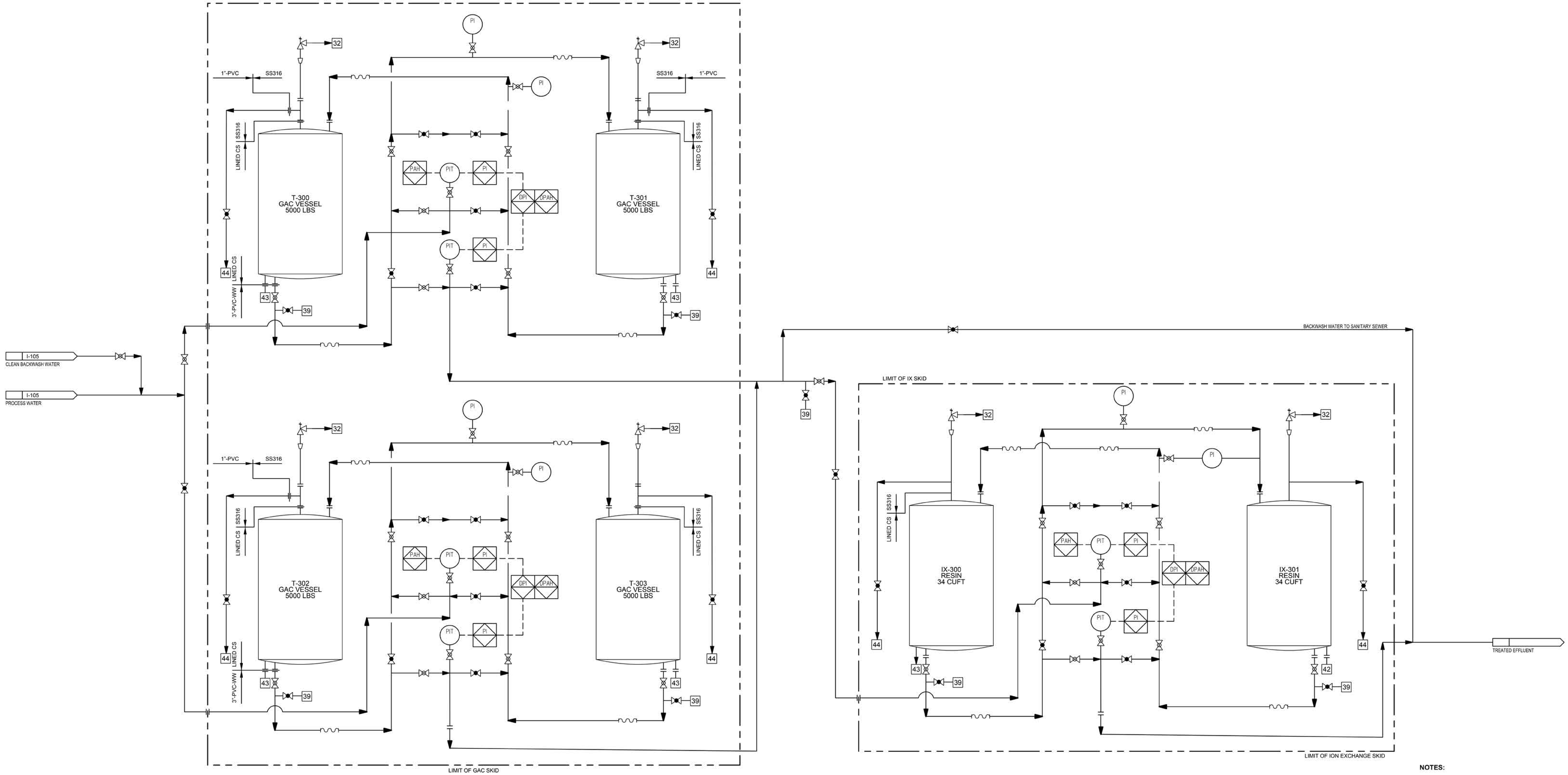

NOTES:

1. FLEX HOSE TO BE TRANSPARENT.
2. PROCESS WATER TO UTILIZE ALL FOUR GAC VESSELS FOR FLOWRATES ABOVE 50 GPM.

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PIPING AND INSTRUMENTATION DIAGRAM
GAC VESSELS AND SYSTEM DISCHARGE

PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

DRAWING NUMBER	REV
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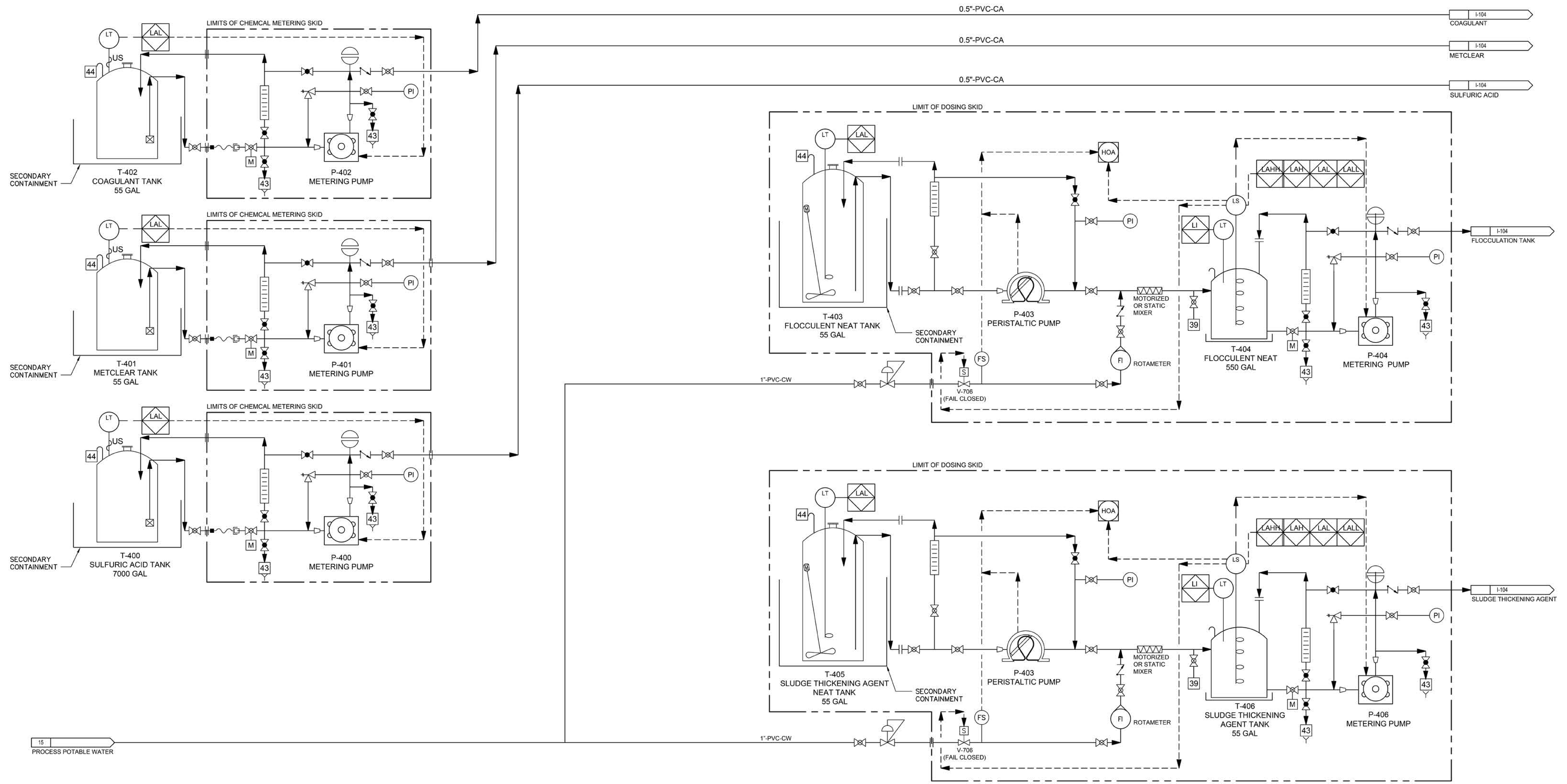

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PIPING AND INSTRUMENTATION DIAGRAM
CHEMICAL FEED

PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

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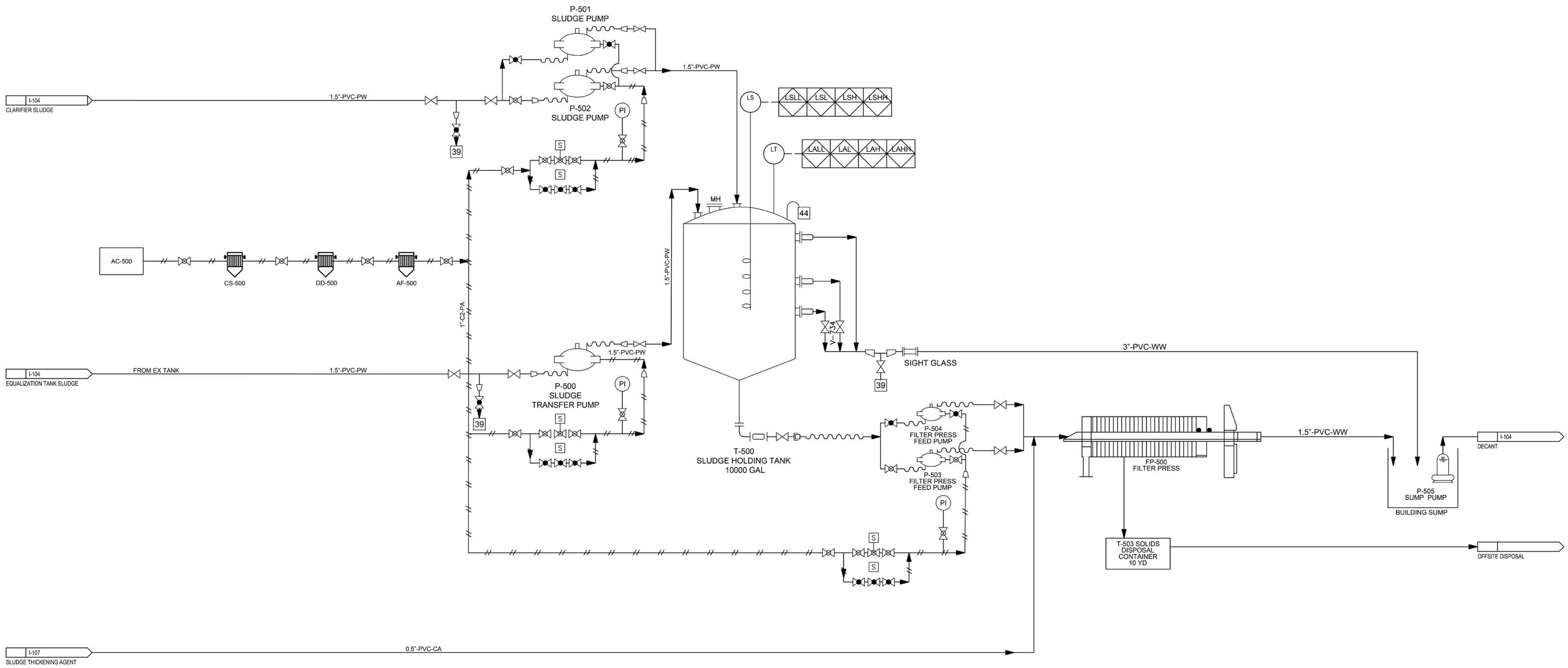

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PIPING AND INSTRUMENTATION DIAGRAM
SOLIDS REMOVAL

PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

DRAWING NUMBER	REV
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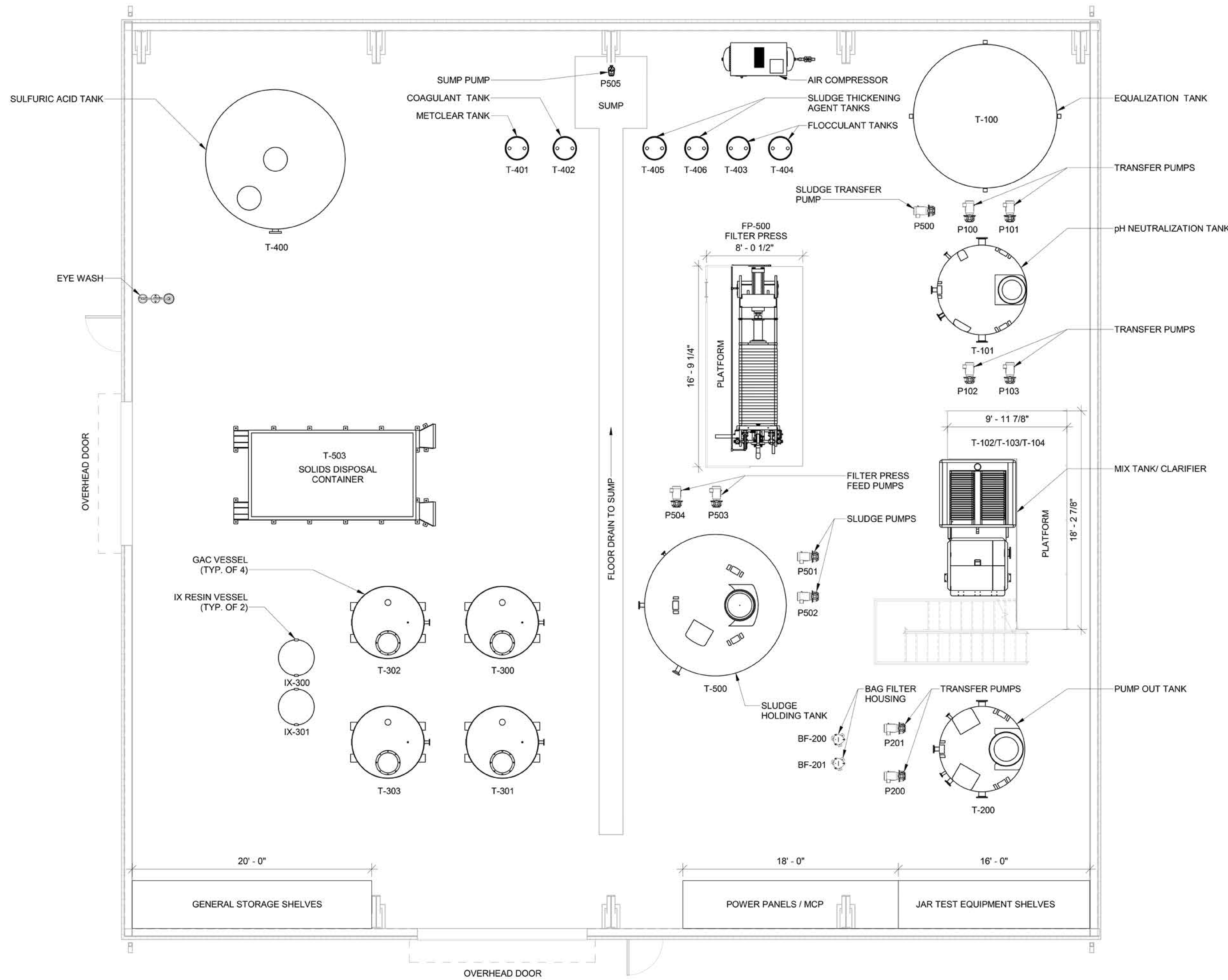

EQUIPMENT LAYOUT

SCALE: 3/16" = 1'-0"

0' 4' 8' 12'

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MECHANICAL PLAN

PERIMETER BARRIER REMEDY
WYANDOTTE, MICHIGAN

DRAWING NUMBER: 0154-WYN-E5N-M-101 | REV: 0

SITE | LOCATION | TYPE | NUMBER

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Appendix B

Design Calculations

DRAFT PRELIMINARY

CALCULATIONS

Subject:	Sheet Pile Design Calculations for New Anchored Bulkhead (Preliminary 30% Design)		
Project:	BASF North Works, Wyandotte, Michigan		
Client:	BASF	**Project No.:**	30005248
Prepared by:	Carsten Becker	**Date:**	5/9/2022
Checked by:	Liz Pitman	**Date:**	7/8/2022

OBJECTIVE

The calculations provided herein were performed for the Preliminary 30% Design of a new anchored bulkhead wall along the South Dock at the BASF North Works site in Wyandotte, Michigan. These calculations focus on determining the structural requirements for the headwall, headwall embedment requirements, and anchor forces for the preliminary design of the new anchored bulkhead. Other design components needed for the anchored bulkhead will be provided elsewhere or in subsequent stages of design. Calculation methods used and assumptions made for the Preliminary 30% Design may be adjusted during subsequent stages of design as the design evolves further toward final design. The Preliminary 30% Design calculations are geared toward evaluating feasibility and providing input for estimating construction costs.

BACKGROUND

The proposed anchored bulkhead wall will be installed on the riverside of an existing pier structure along the South Dock. The existing pier structure consists of a concrete deck supported on timber piles. The concrete deck of the existing structure is overlain by several feet of soil. The existing structure is in poor condition and, for the purpose of this design, it is assumed that the timber piles will deteriorate to the point where they will no longer support the concrete deck and overlying soils. Following construction of the proposed bulkhead, the void behind the bulkhead wall and underneath the existing concrete deck will be filled using aggregate fill materials, which will eventually transfer the weight from the concrete deck and overlying soil to the new bulkhead. For the Preliminary 30% Design calculations, the existing structure was not modeled, which is a conservative assumption, as it would currently serve as a relieving platform that reduces the load on the new bulkhead. It is further assumed that dredging to be performed in the river for a separate USEPA-led remediation project will extend to the new bulkhead wall. The assumed dredge elevation along the wall is provided in the Assumptions section below.

Subsurface Conditions and Associated Challenges

The subsurface conditions at the Site, along with physical characteristics of the geologic units are provided in the geotechnical data report for the Site (Arcadis 2021). The subsurface soils predominantly consist of relatively loose and soft soils over bedrock. A relatively thin layer of stiff to very stiff glacial till overlies the bedrock. During the 2020 subsurface investigation, the till was encountered at elevations between approximately 514 feet and 519 feet NAVD88. Bedrock was encountered at relatively shallow depths. Based on the borings drilled in 2020, the top-of-bedrock elevation varies between approximately elevation 509 feet and 516 feet NAVD88.

The combination of soft soils over relatively shallow bedrock provides a challenge in terms of achieving passive resistance for the bulkhead wall. The necessary amount of passive resistance to prevent the toe of the wall from “kicking out” (i.e., excessive movement to the point of wall failure) is typically achieved by increasing sheet pile embedment into the subsurface materials. The shallow bedrock makes this difficult because it is not possible to drive sheet piles into relatively competent bedrock.

For the Preliminary 30% Design calculations, the bedrock was not modeled in the calculations. Instead, the glacial till that overlies the bedrock was extended down beyond the bedrock surface to provide thick layer for pile embedment. It was then assumed that if the calculation results indicate that penetration into bedrock is needed, it may be necessary to embed the wall in the bedrock or drive the piles to the top of the bedrock and then install shear pins to connect the toe of the sheet pile wall to the bedrock. This construction method is described in the main text of the 30% basis of design report.

Groundwater Conditions

During the 2020 subsurface investigation and based on recent monitoring well data, groundwater along the South Dock is at approximately elevation 575 feet IGLD85 (approximately 575.3 feet NAVD88).

It should be noted that, once the barrier walls have been installed and the groundwater treatment system is operating, the groundwater table on the upland side of the bulkhead wall will be controlled by the treatment system.

The assumed groundwater elevations for Preliminary 30% Design are provided in the Assumptions section below.

River Water Surface Elevations

Based on data from the National Oceanic and Atmospheric Administration (NOAA) for NOAA Station 9044030 in Wyandotte, Michigan, the river water levels have varied widely over the years, with a historic monthly low level of 567.7 feet IGLD85 (International Great Lakes Datum of 1985) (568 feet NAVD88 [North American Vertical Datum of 1988]) in March of 1964 and monthly high of 577.0 feet IGLD85 (577.3 feet NAVD88) in June 1973. Over the last 30 years, the average water surface elevation was at approximately 573.3 feet IGLD85 (573.6 feet NAVD 88). The assumed river water surface elevations for Preliminary 30% Design are provided in the Assumptions section below.

ANALYSIS METHODOLOGIES AND GENERAL ASSUMPTIONS

Method of Analysis

For the Preliminary 30% Design calculations, the public domain computer program ProSheet (ArcelorMittal 2012) was used to perform the sheet pile wall analyses. ProSheet uses the Blum theory to calculate embedment depths, wall deflections, forces, and bending moments using earth pressure theory. Calculations were performed using both, drained and undrained soil shear strength parameters.

Simplifying assumptions regarding the soil stratigraphy were made for this preliminary stage of design to allow use of earth pressure theory (i.e., earth pressure coefficients; refer to Earth Pressure Calculations section below); soil layers were assumed to be horizontal layers and the backfill under the pier structure was not modeled as a separate soil unit. For the Preliminary 30% Design, these are appropriate assumptions, assuming the backfill has higher strength than the site soils and similar unit weight.

For the Preliminary 30% Design, the bedrock was omitted from the model. This approach yielded the required embedment without bedrock. Where the calculations indicated that penetration into bedrock was needed, it was assumed it will be necessary to drive the sheet pile to the top of the bedrock and then install shear pins to connect the toe of the sheet pile wall to the bedrock.

It is anticipated that additional modeling using more sophisticated methods (e.g., p-y, finite element, or similar methods) will be performed during later stages of design to assess the options discussed in the BODR main text, including the use of lightweight backfill and placement of a buttress in front of the bulkhead wall to provide lateral resistance. The more sophisticated methods should also allow a more realistic assessment of the performance of the structure in terms of deflections and ground deformations.

Earth Pressure Calculations

Active and passive earth pressures were used for the design of the enclosure walls. The computer program ProSheet computes Caquot-Kerisel earth pressures based on shear strength and wall friction assumptions (Caquot and Kerisel 1958).

Earth pressures for drained conditions were calculated by multiplying the effective vertical stress of the soil by the appropriate earth pressure coefficient. For drained analyses, the soil's angle of internal friction and an appropriate wall friction angle were used to calculate the earth pressure coefficients. Soil parameters used for design are provided further below in these calculations.

Earth pressures for undrained analyses were calculated as follows:

Active: $\sigma_a = \sigma'_v - 2s_u$

Passive: $\sigma_p = \sigma'_v + 2s_u$

Where:

σ_a = active lateral earth pressure

σ_p = passive lateral earth pressure

σ'_v = effective vertical stress

s_u = undrained shear strength

Using the above equation for calculation of the active earth pressure, the active pressure could become negative at low effective vertical stresses. Where this occurred, the active pressure was assumed to be equal to zero. Undrained shear strength and unit weights used for the soils are provided further below in these calculations.

Calculations of Design Soil Shear Strength for Passive Earth Pressures

For calculation of embedment depths required for wall stability, a factor of safety was applied to the soil strength used for calculation of passive earth pressures. No factors of safety were applied to active earth pressures. Design shear strength parameters used for calculation of passive earth pressures were calculated as follows:

Undrained Strength: $s_{u,design} = \frac{s_u}{FS_p}$

Drained Strength: $\tan \phi_{design} = \frac{\tan \phi}{FS_p}$

Where:

ϕ = angle of internal friction (drained strength parameter)

FS_p = factor of safety applied to soil strength prior to calculation of passive earth pressures

Factors of Safety

Using guidelines provided in Design of Sheet Pile Walls (USACE 1994), factors of safety for calculation of wall embedment depths were selected based on the loading case, type of loading, and type of soil. The walls were designed using usual, unusual, and extreme loading cases per USACE design procedures (USACE 1994). These loading cases correlate with the likelihood of the load occurring. More severe and less likely loading cases are generally assigned smaller factors of safety than less severe loading cases that occur regularly under normal operating conditions. The factors of safety recommended in the USACE guidelines are provided in Table 1.

Table 1. Factors of Safety (FS_p) for Calculation of Wall Embedment Depths (Applied to Passive Pressure)

Loading Case	Fine-Grained Soils	Free-Draining Soils
Usual	2.0 (Q-Case) 1.5 (S-Case)	1.5 (S-Case)
Unusual	1.75 (Q-Case) 1.25 (S-Case)	1.25 (S-Case)
Extreme	1.5 (Q-Case) 1.1 (S-Case)	1.1 (S-Case)

Notes:
FS_p = factor of safety applied to soil strength prior to calculation of passive earth pressures
Q-case = “quick” load application/undrained anaysis; factor of safety used with undrained shear strength parameters
S-case = “slow” load application/drained analysis; factor of safety used with drained shear strength parameters

In the calculations presented herein, the Q-case factors of safety were not used as shown in Table 1 and were therefore not applied per the USACE guidelines. A more conservative approach was used because the USACE guidelines do not address the stress path dependence of the undrained shear strength.

Undrained shear strength is often measured in an unconsolidated undrained triaxial compressive shear strength test. This test simulates conditions that are similar to those in the active zone behind a retaining wall. A triaxial extension test would be more suitable for the conditions in the passive zone, in front of the sheet pile wall. In this zone, the undrained shear strength is equal to approximately one half of the strength under triaxial compression (Terzaghi, Peck, and Mesri 1996). Accordingly, the undrained shear strengths on the passive side for the calculations presented herein were taken as approximately one half of the undrained strength in triaxial compression.

Using these reduced strengths with the Q-case factors of safety in Table 1 would results in overly conservative wall embedment depths. Instead, the S-case factors of safety were used for the Q-case, which results in equivalent Q-case factors of safety of 3, 2.5, and 2.2 for the usual, unusual, and extreme cases, respectively, indicating an overall more conservative approach than what is recommended in the 1994 USACE guidance.

Forces and Moments for Structural Design

To avoid compounding factors of safety, the structural components (i.e., the sheet pile sections) were designed using a factor of safety of 1 on the soil strengths to calculate the forces and moments with the factor of safety applied to the structural steel strength. To calculate required embedment depths, the analyses were then repeated, applying the appropriate factor of safety on the passive earth pressure side.

Allowable Stresses for Steel Sheet Piling

Allowable stresses for steel for usual loading conditions were calculated per USACE design procedures (USACE 1994) as follows:

$f_b = 0.5\ f_y$ (combined bending and axial load)

$f_v = 0.33\ f_y$ (shear)

For the unusual loading conditions, the allowable stress equations were increased 33% above that for usual loading conditions:

$f_b = 1.33\ (0.5\ f_y) = 0.67\ f_y$

For the extreme loading conditions, the allowable stress equations were increased 75% above that for usual loading conditions:

$f_b = 1.75\ (0.5\ f_y) = 0.875\ f_y$

Where:

f_b = combined bending and axial load

f_v = shear stress

f_y = yield stress of the steel

Specifications for Structural Steel

The selected steel grade for sheet piles is American Society for Testing and Materials A572 – Grade 50. This grade is a standard grade.

Wall Deflection Limitations

No wall deflection limitations were used for the Preliminary 30% Design. The performance of the wall was strictly based on achieving stability and structural integrity. Wall performance in terms of deflections and ground deformations will be assessed during later stages of design using more sophisticated methods (refer to Method of Analysis section above).

ASSUMPTIONS

Design Cross Section

The design cross section used for the Preliminary 30% Design calculations is shown on Figure 1. Figure 1 shows the assumed geometry for the bulkhead wall and subsurface stratigraphy. Note that the backfill behind the proposed bulkhead wall was not modeled. Instead, the existing site soils were extended laterally to the bulkhead wall (refer to Method of Analysis section).

Soil Parameters

Engineering properties of the geologic units were estimated based on in-situ test and laboratory test data in conjunction with engineering judgment as well as guidance provided in textbooks and design manuals (e.g., Terzaghi, Peck, and Mesri 1996 and USACE 1994). The soil parameters that were used in the calculations are provided in Table 2.

Table 2. Design Soil Parameters

Geologic Unit	γ (pcf)	γ' (pcf)	ϕ' (°)	c' (psf)	δ (°)	s_u (psf)
Existing Fill	120	57.6	28	0	14	----
Very Soft Silt (Alluvium)	110	47.6	25	0	8	300
Loose to Medium Dense Sand (Lacustrine)	125	62.6	32	0	16	----
Soft Silty Clay (Lacustrine) – Active Side	110	47.6	27	0	9	700
Soft Silty Clay (Lacustrine) – Passive Side	110	47.6	27	0	9	300
Glacial Till – Active Side	135	72.6	28	500	12	2,000
Glacial Till – Passive Side	135	72.6	28	500	12	1,000
Bedrock [a]	---	---	---	---	----	----

Footnotes:
[a] The bedrock was not modeled in ProSheet. Instead, the glacial till was extended down beyond the bedrock surface to provide a thick layer for pile embedment. Calculated sheet pile lengths that exceeded the length available between the top of the wall and the top of bedrock indicate that the wall either needs to be bolted to the underlying rock or embedded into the rock (refer to Method of Analysis section).

Symbols:
γ = total unit weight
γ' = submerged unit weight
ϕ' = effective friction angle (drained shear strength)
° = degrees
c' = effective cohesion (drained shear strength)
δ = wall interface friction angle
s_u = undrained shear strength

Initialisms:
psf = pounds per square foot
pcf = pounds per cubic foot

Surcharge Load

To represent temporary live loads due to access by vehicles and light construction or maintenance equipment during the lifetime of the bulkhead structure, a uniform surcharge load of 250 pounds per square foot (psf) was applied in all of the loading cases.

Hydrostatic Loads

In addition to lateral earth pressures and surcharge loads, hydrostatic loads were used for the 30% headwall design with increasing water level differentials for usual, unusual, and extreme loading cases. The hydrostatic load assumptions are provided in Table 3. Additional information regarding the ground water conditions and river water surface elevations at the Site is provided in the Background section above.

Engineering judgment was used to select appropriate elevations for each of the loading cases. For the Preliminary 30% Design, the groundwater treatment system was assumed to keep the groundwater level slightly below the river water surface elevation to maintain an inward groundwater gradient. This scenario is reflected in the “usual loading case”. For the usual case, it was assumed that there is no water level differential and the net hydrostatic pressure on the wall will be zero. The unusual and extreme loading cases reflect two levels of treatment system malfunction with relatively high assumed groundwater levels and low assumed river water levels.

Table 3. Hydrostatic Load Assumptions

Loading Case	Groundwater Surface Elevation (feet NAVD88)	River Water Surface Elevation (feet NAVD88)	Water Level Differential (feet)
Usual	574.5	574.5	0
Unusual	575.0	571	4
Extreme	577.0	570.0	7

CALCULATION RESULTS

Calculations were performed for three drained and three undrained load cases. The ProSheet calculations are provided in Attachment 1. Table 4 provides a summary of the results for the six cases, in terms of the minimum required sheet pile length, calculated anchor force, maximum moment in the wall, and the required section modulus for the wall. The critical values are bolted in the table.

Based on the required section modulus, a combination wall consisting of king piles with intermediate sheet piles will be required. The king piles can consist of H-piles or pipe piles. The minimum required sheet pile length exceeds the length available between the top of the wall and the top of bedrock, which varies between approximately 62 and 69 feet, based on the borings drilled near the alignment of the headwall. Therefore, it will be necessary to either connect the toe of the wall to the bedrock using rock bolts or to embed the king piles into the bedrock through rock socketing.

Table 4. Calculation Results

Analysis Type	Load Case	Minimum Required Sheet Pile Length (ft)	Anchor Force (kips/ft)	Maximum Moment (ft-kips/ft)	Required Section Modulus (in.^{3}/ft)
Drained	Usual	62.2	12.7	162.8	78.1
	Unusual	62.7	18.5	254.2	91.0
	Extreme	62.5	21.9	316.0	86.7
Undrained	Usual	70.1	20.4	339.2	162.8
	Unusual	71.7	27.1	**466.9**	**167.3**
	Extreme	**71.8**	**30.0**	524.8	143.9

Units:
in. = inch/inches
ft = foot/feet
kips = kilo pounds force

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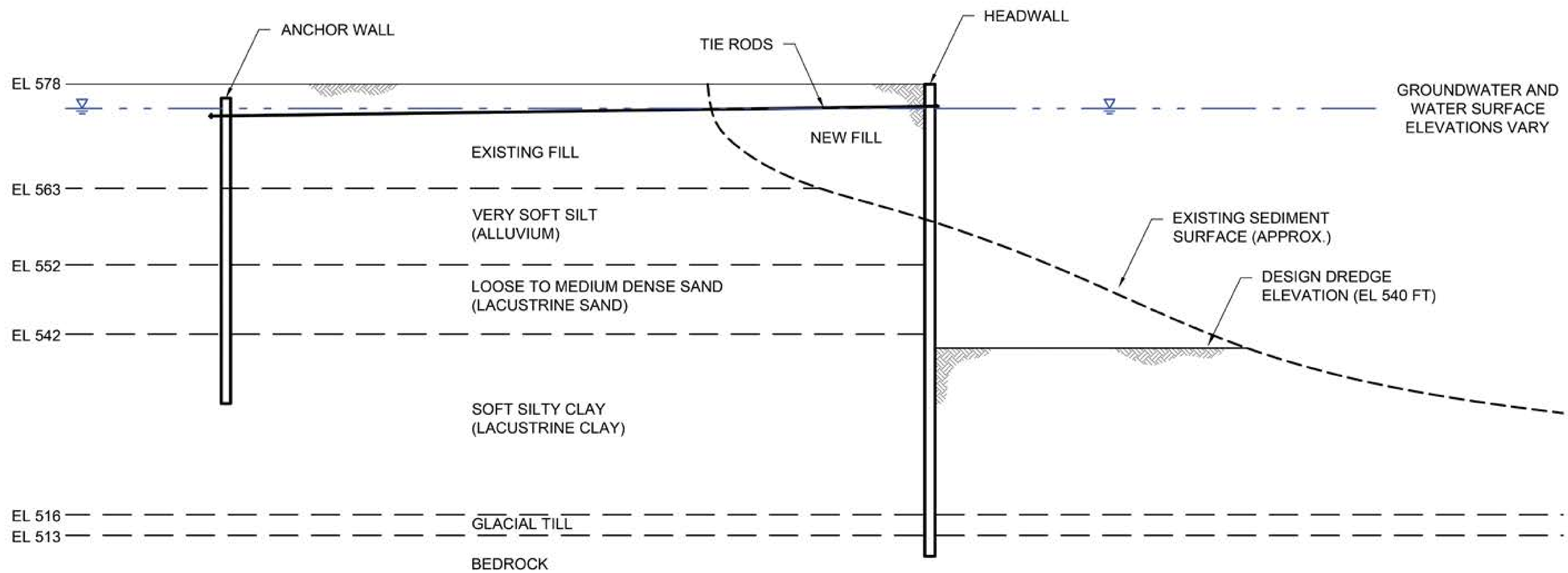


NOTES:

1. THIS FIGURE SHOWS THE SUBSURFACE STRATIGRAPHY ASSUMED FOR THE 30% DESIGN OF THE BULKHEAD WALL.
2. REFER TO THE CALCULATIONS SHEET REGARDING LOAD ASSUMPTIONS, INCLUDING GROUNDWATER LEVELS AND RIVER WATER SURFACE ELEVATIONS.
3. THE NEW FILL WAS NOT MODELED IN THE SHEET PILE CALCULATIONS.
4. THE BEDROCK WAS NOT MODELED (REFER TO CALCULATIONS SHEET FOR DETAILS).
5. REFER TO THE CALCULATIONS SHEET FOR ADDITIONAL INFORMATION.

BASF CORPORATION
WYANDOTTE, MICHIGAN
BASIS OF DESIGN REPORT (PRELIMINARY 30% DESIGN)
SHEET PILE WALL CALCULATIONS

DESIGN CROSS SECTION
(PRELIMINARY 30% DESIGN)

ARCADIS

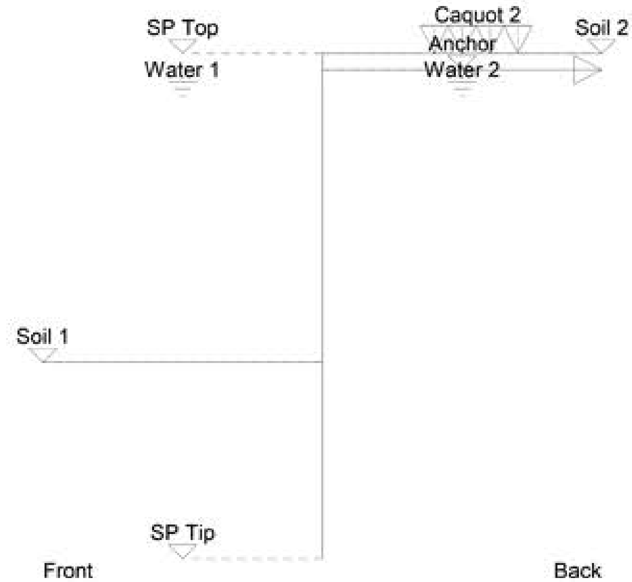
FIGURE
1

Sheet Pile Design According to Blum-Method

Project Name:	BASF North Works - Bulkhead Wall
Date:	6/10/2022
Author:	Arcadis
Company:	Arcadis
Comment:	Drained / Usual / Embedment

Geodata

	Unit
Sheet Pile Top Level [ft]	0.000
Sheet Pile Tip Level [ft]	62.164
Soil Level in Front [ft]	38.000
Soil Level behind [ft]	0.000
Anchorlevel [ft]	2.000
Water Level in Front [ft]	3.500
Water Level behind [ft]	3.500
Soil Surface Inclination in Front [Deg]	0.000
Soil Surface Inclination behind [Deg]	0.000
Caquot Surcharge in Front [kip/ft2]	0.000
Caquot Surcharge behind [kip/ft2]	0.250
Anchor Inclination [Deg]	0.000
Earth Support	Free



Soil Layers

Layers in Front

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	62.000	0.110	0.048	2.262	18.800	-6.000	0.000
Layer 2	114.000	0.135	0.073	2.433	19.500	-8.000	0.333

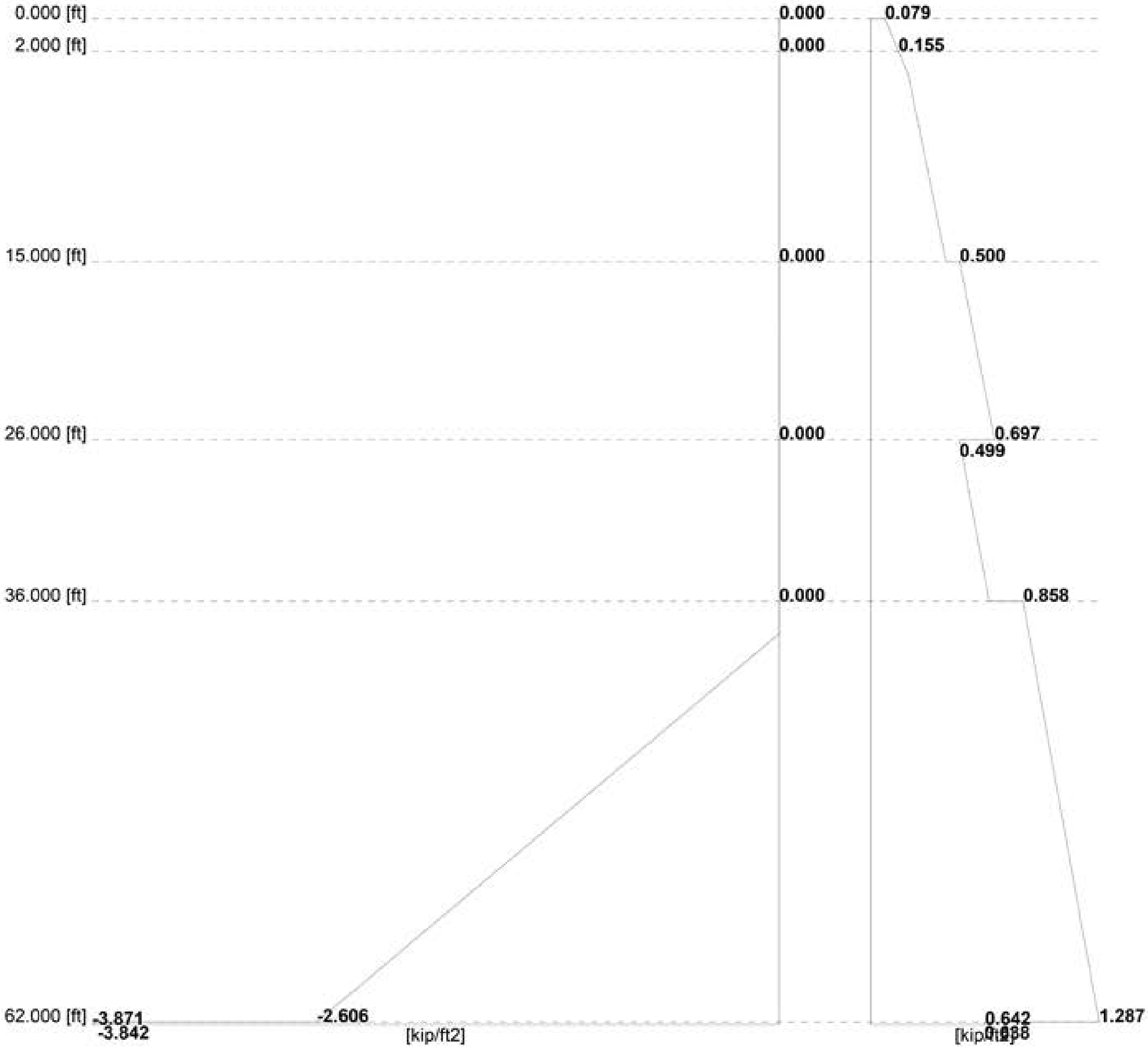
Layers behind

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	15.000	0.120	0.058	0.317	28.000	14.000	0.000
Layer 2	26.000	0.110	0.048	0.374	25.000	8.000	0.000
Layer 3	36.000	0.125	0.063	0.267	32.000	16.000	0.000
Layer 4	62.000	0.110	0.048	0.344	27.000	9.000	0.000
Layer 5	114.000	0.135	0.073	0.322	28.000	12.000	0.500

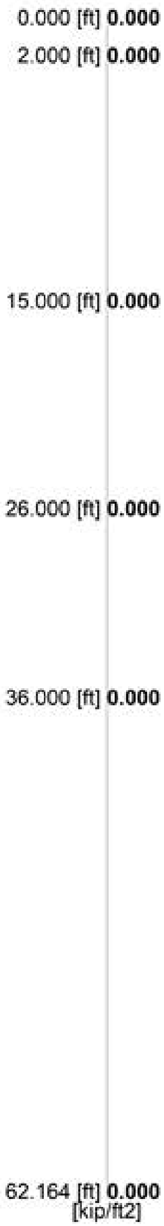
Pile Check

		Depth [ft]
Name	AZ18	
Inertia [in4/ft]	250.439	
Modulus [in3/ft]	33.480	
Area [in2/ft]	7.106	
Mass [lbs/ft2]	24.189	
Steel Grade [lb/in2]	50000.000	
Minimal Moment [kipft/ft]	-202.014	29.281
Maxmimal Moment [kipft/ft]	0.209	2.000
Normal Forces at Max. Moment [kip/ft]	2.459	29.281
Normal Forces at Min. Moment [kip/ft]	0.058	2.000
Deflection at Min. Moment [ft]	-1.332	29.281
Deflection at Max. Moment [ft]	0.000	2.000
Min. Stress at Min. Moment [lb/in2]	-73231.430	29.281
Max. Stress at Min. Moment [lb/in2]	73923.523	29.281
Min. Stress at Max. Moment [lb/in2]	-66.688	2.000
Max. Stress at Max. Moment [lb/in2]	83.134	2.000
Safety < Req. Safety = 2.000	0.676	
Sheet Pile Top Level [ft]	0.000	
Sheet Pile Tip Level [ft]	62.164	
Sheet Pile Length [ft]	62.164	
Included OverLength [ft]	0.000	
Vertical Equilibrium [kip/ft]	4.697	
Anchor Force (horiz.) [kip/ft]	-12.661	

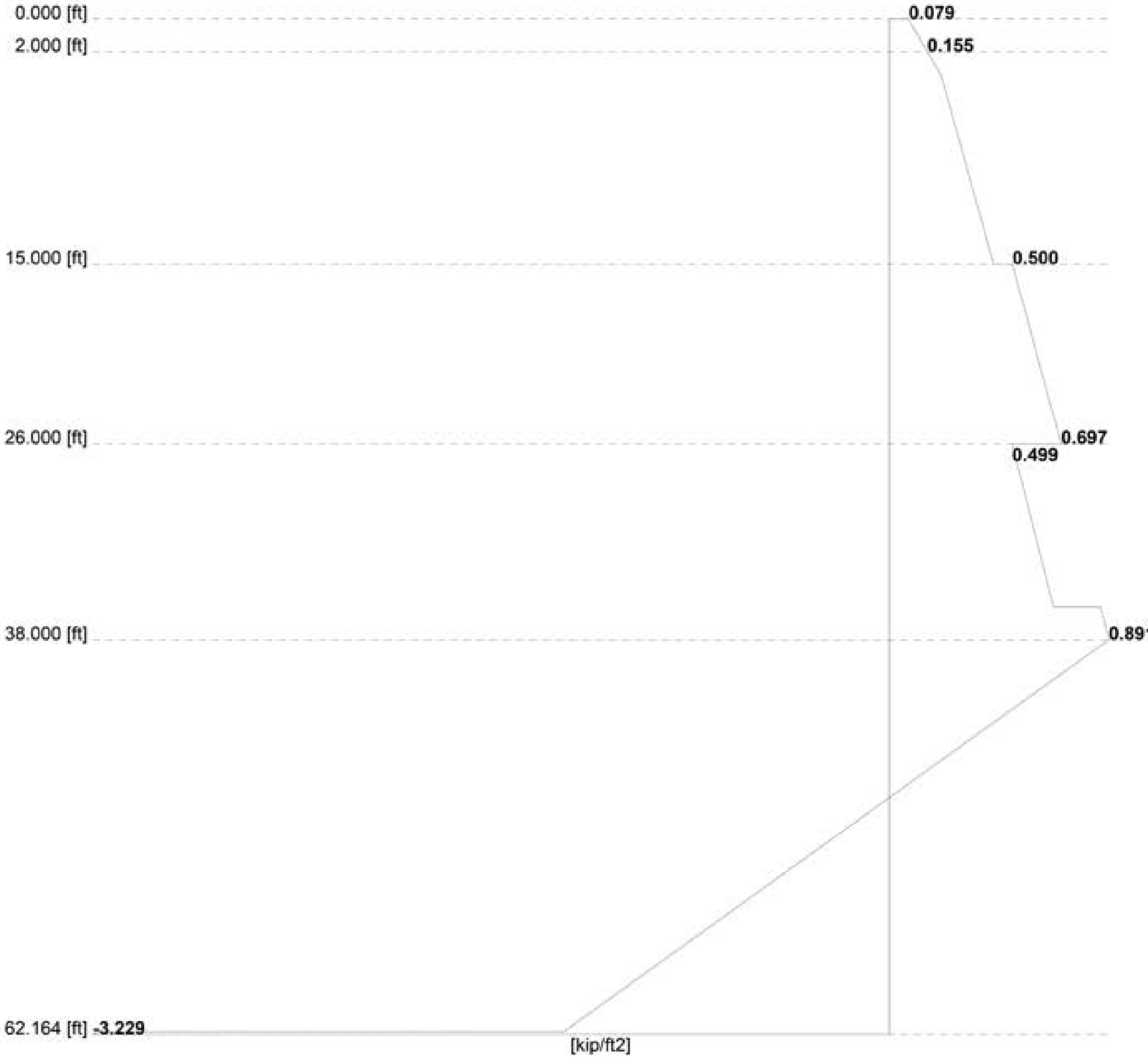
Earth Pressure Diagram



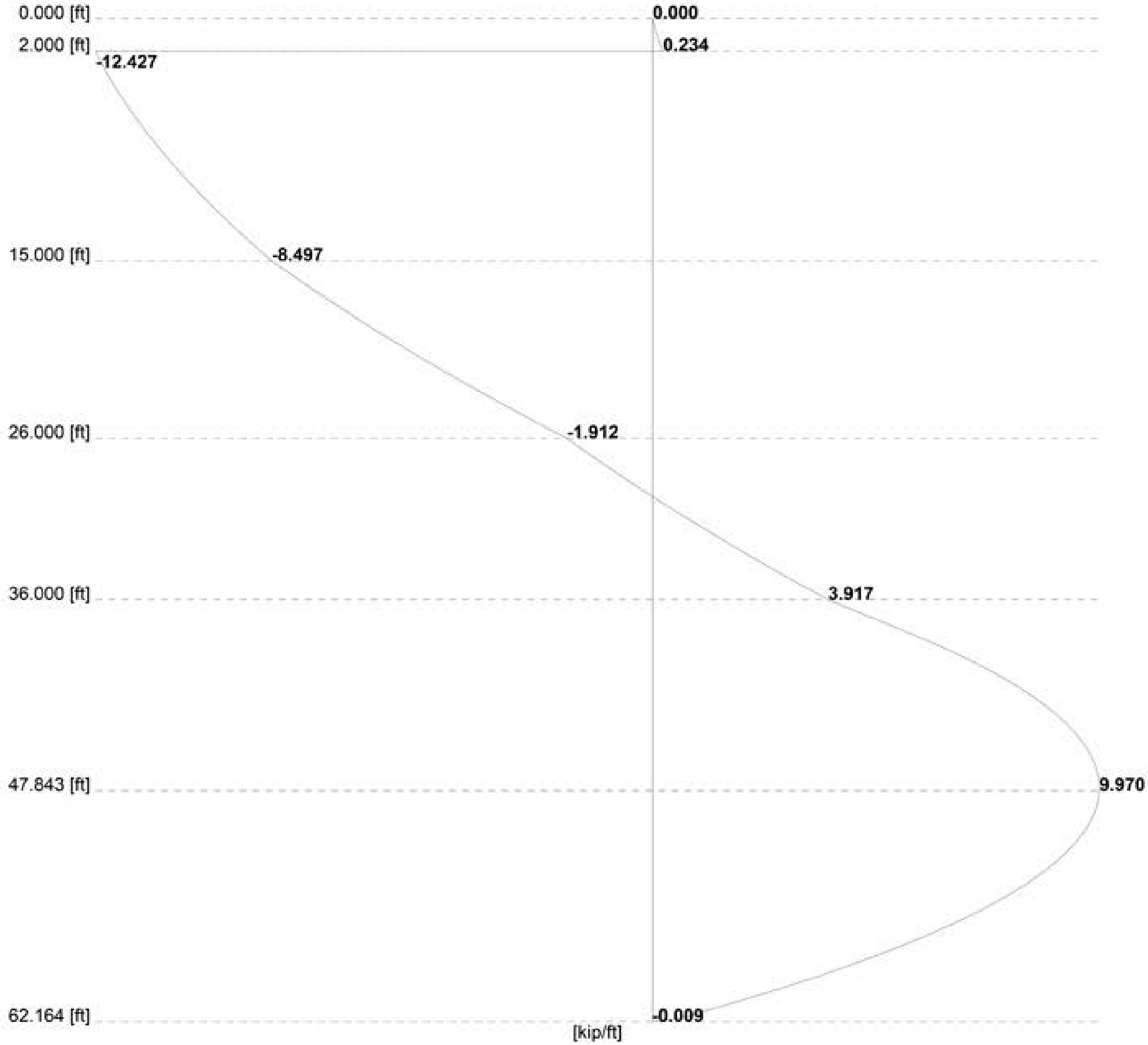
Water Pressure Diagram



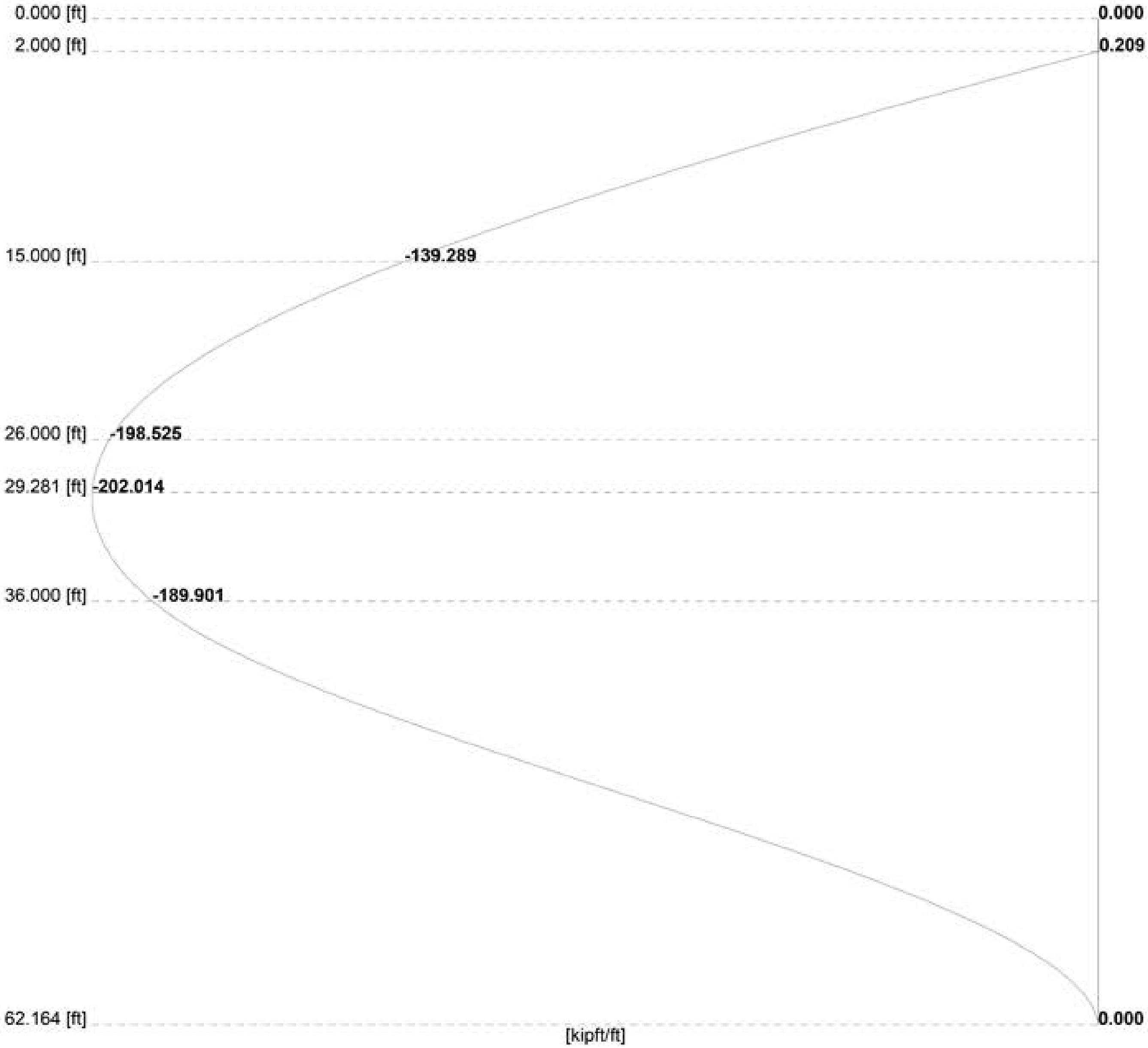
Total Pressure Diagram



Cross Force Diagram



Moment Diagram

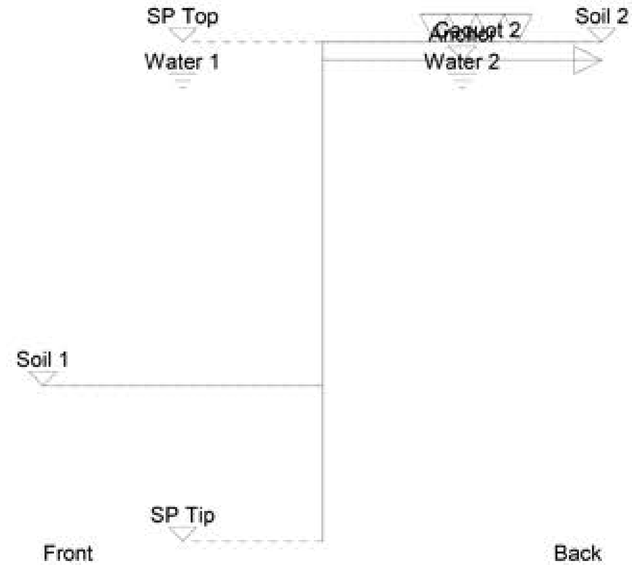


Sheet Pile Design According to Blum-Method

Project Name:	BASF North Works - Bulkhead Wall
Date:	6/10/2022
Author:	Arcadis
Company:	Arcadis
Comment:	Drained / Usual / Structural Demand

Geodata

	Unit
Sheet Pile Top Level [ft]	0.000
Sheet Pile Tip Level [ft]	55.225
Soil Level in Front [ft]	38.000
Soil Level behind [ft]	0.000
Anchorlevel [ft]	2.000
Water Level in Front [ft]	3.500
Water Level behind [ft]	3.500
Soil Surface Inclination in Front [Deg]	0.000
Soil Surface Inclination behind [Deg]	0.000
Caquot Surcharge in Front [kip/ft2]	0.000
Caquot Surcharge behind [kip/ft2]	0.250
Anchor Inclination [Deg]	0.000
Earth Support	Free



Soil Layers

Layers in Front

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	62.000	0.110	0.048	3.498	27.000	-9.000	0.000
Layer 2	114.000	0.135	0.073	3.997	28.000	-12.000	0.500

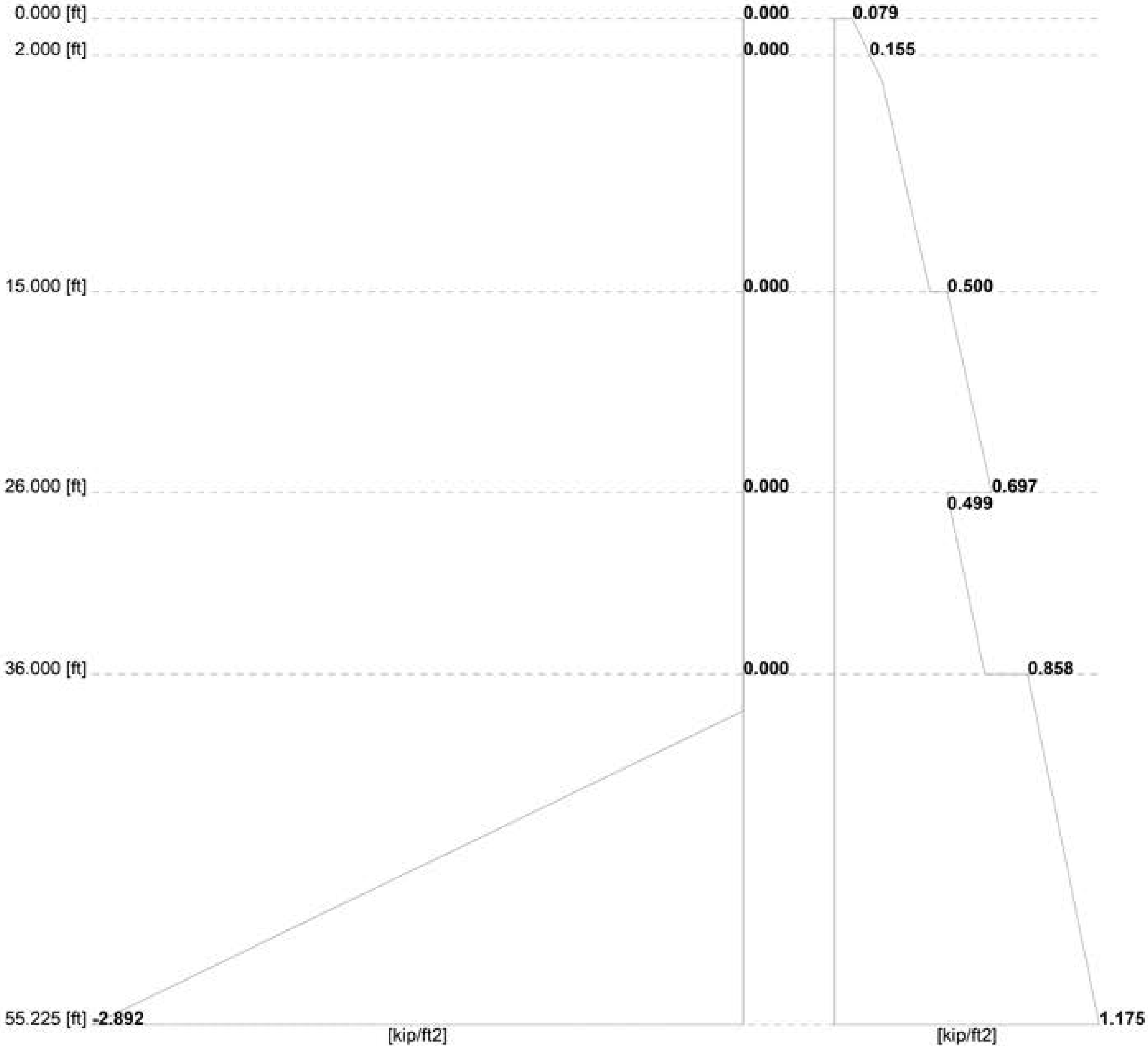
Layers behind

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	15.000	0.120	0.058	0.317	28.000	14.000	0.000
Layer 2	26.000	0.110	0.048	0.374	25.000	8.000	0.000
Layer 3	36.000	0.125	0.063	0.267	32.000	16.000	0.000
Layer 4	62.000	0.110	0.048	0.344	27.000	9.000	0.000
Layer 5	114.000	0.135	0.073	0.322	28.000	12.000	0.500

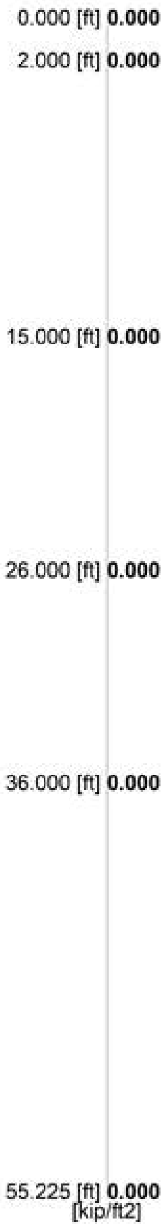
Pile Check

		Depth [ft]
Name	AZ18	
Inertia [in4/ft]	250.439	
Modulus [in3/ft]	33.480	
Area [in2/ft]	7.106	
Mass [lbs/ft2]	24.189	
Steel Grade [lb/in2]	51468.883	
Minimal Moment [kipft/ft]	-162.807	26.820
Maxmimal Moment [kipft/ft]	0.209	2.000
Normal Forces at Max. Moment [kip/ft]	2.083	26.820
Normal Forces at Min. Moment [kip/ft]	0.058	2.000
Deflection at Min. Moment [ft]	-0.853	26.820
Deflection at Max. Moment [ft]	0.000	2.000
Min. Stress at Min. Moment [lb/in2]	-58695.098	26.820
Max. Stress at Min. Moment [lb/in2]	59281.301	26.820
Min. Stress at Max. Moment [lb/in2]	-66.688	2.000
Max. Stress at Max. Moment [lb/in2]	83.134	2.000
Safety < Req. Safety = 2.000	0.868	
Sheet Pile Top Level [ft]	0.000	
Sheet Pile Tip Level [ft]	55.225	
Sheet Pile Length [ft]	55.225	
Included OverLength [ft]	0.000	
Vertical Equilibrium [kip/ft]	2.784	
Anchor Force (horiz.) [kip/ft]	-11.166	

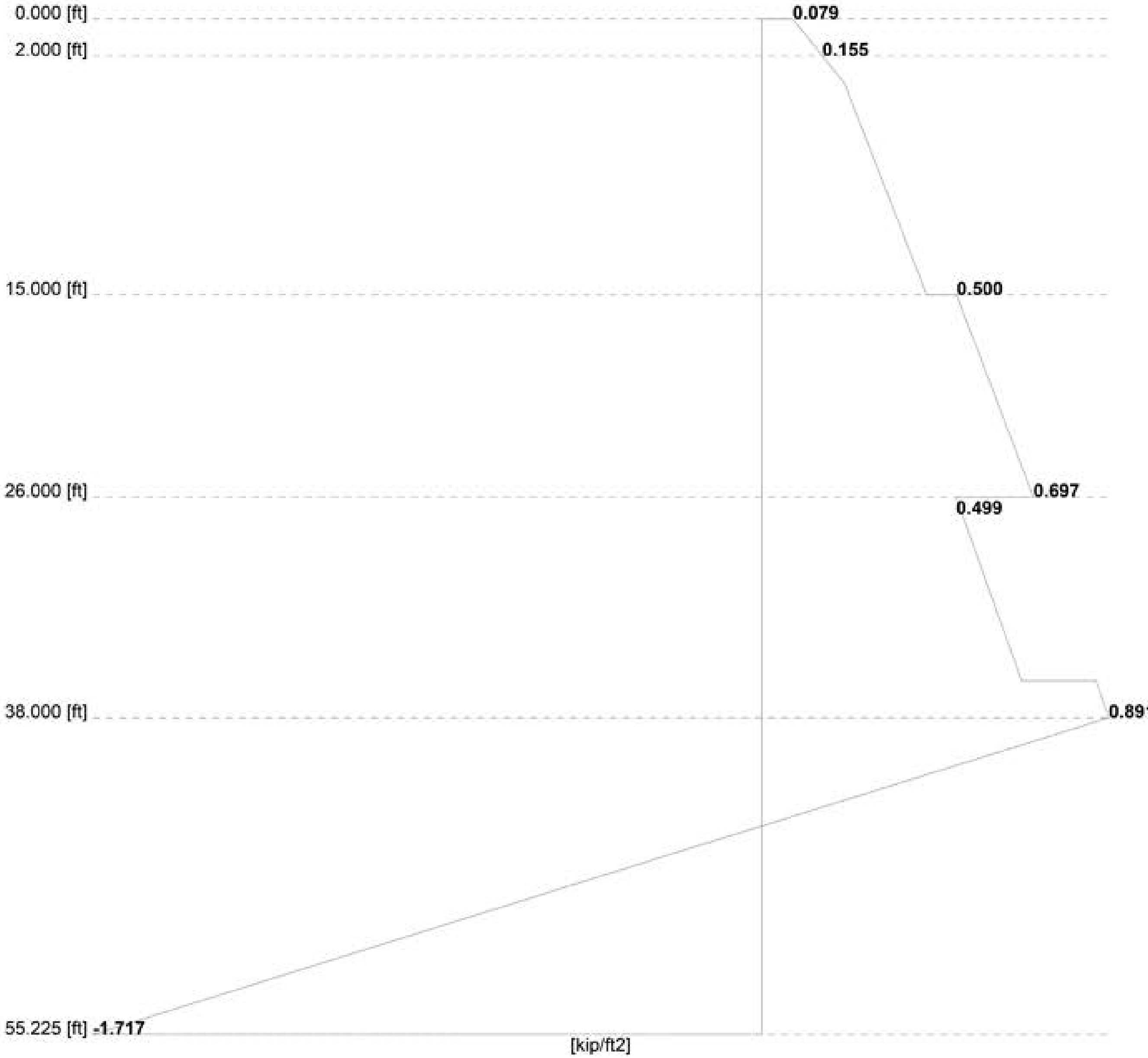
Earth Pressure Diagram



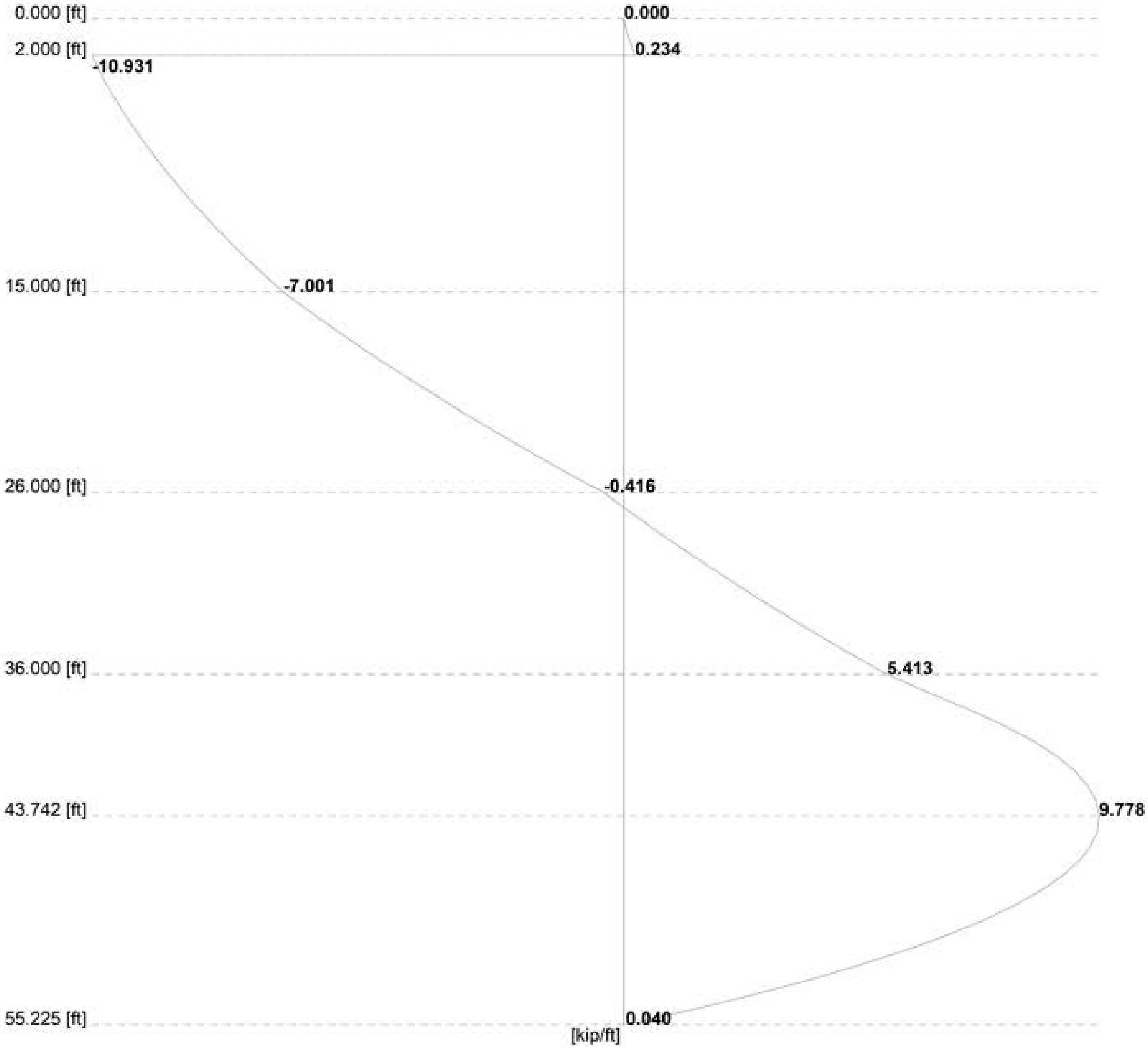
Water Pressure Diagram



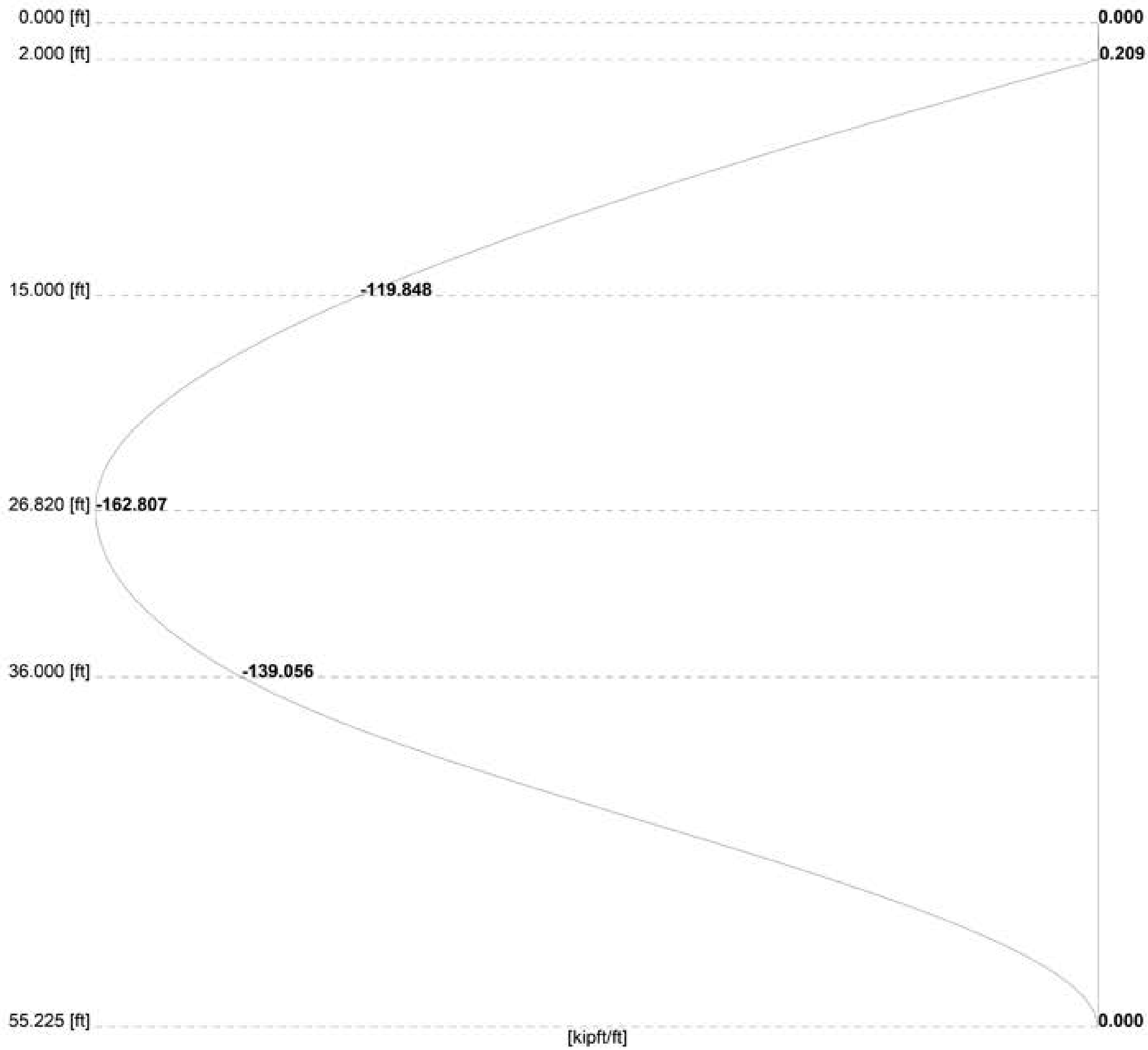
Total Pressure Diagram



Cross Force Diagram



Moment Diagram

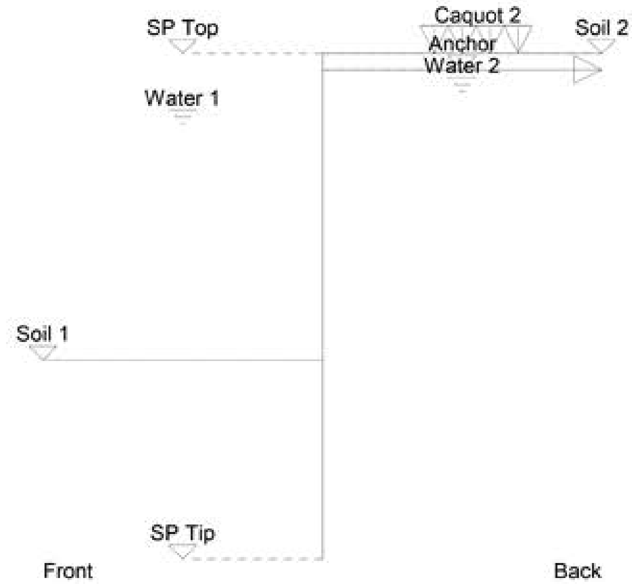


Sheet Pile Design According to Blum-Method

Project Name:	BASF North Works - Bulkhead Wall
Date:	6/10/2022
Author:	Arcadis
Company:	Arcadis
Comment:	Drained / Unusual / Embedment

Geodata

	Unit
Sheet Pile Top Level [ft]	0.000
Sheet Pile Tip Level [ft]	62.689
Soil Level in Front [ft]	38.000
Soil Level behind [ft]	0.000
Anchorlevel [ft]	2.000
Water Level in Front [ft]	7.000
Water Level behind [ft]	3.000
Soil Surface Inclination in Front [Deg]	0.000
Soil Surface Inclination behind [Deg]	0.000
Caquot Surcharge in Front [kip/ft2]	0.000
Caquot Surcharge behind [kip/ft2]	0.250
Anchor Inclination [Deg]	0.000
Earth Support	Free



Soil Layers

Layers in Front

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	62.000	0.110	0.048	2.687	22.200	-7.200	0.000
Layer 2	114.000	0.135	0.073	2.953	23.000	-9.600	0.400

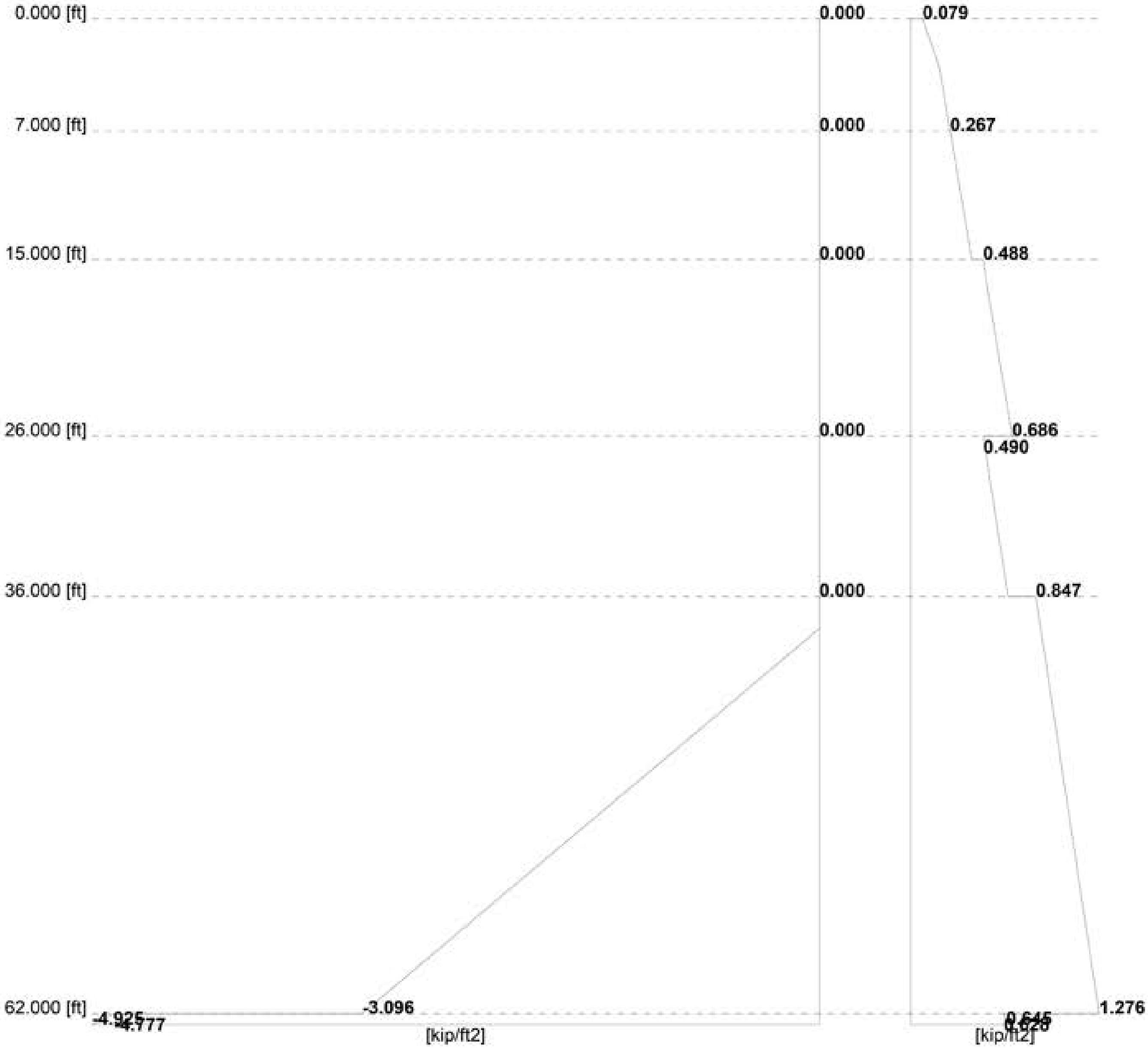
Layers behind

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	15.000	0.120	0.058	0.317	28.000	14.000	0.000
Layer 2	26.000	0.110	0.048	0.374	25.000	8.000	0.000
Layer 3	36.000	0.125	0.063	0.267	32.000	16.000	0.000
Layer 4	62.000	0.110	0.048	0.344	27.000	9.000	0.000
Layer 5	114.000	0.135	0.073	0.322	28.000	12.000	0.500

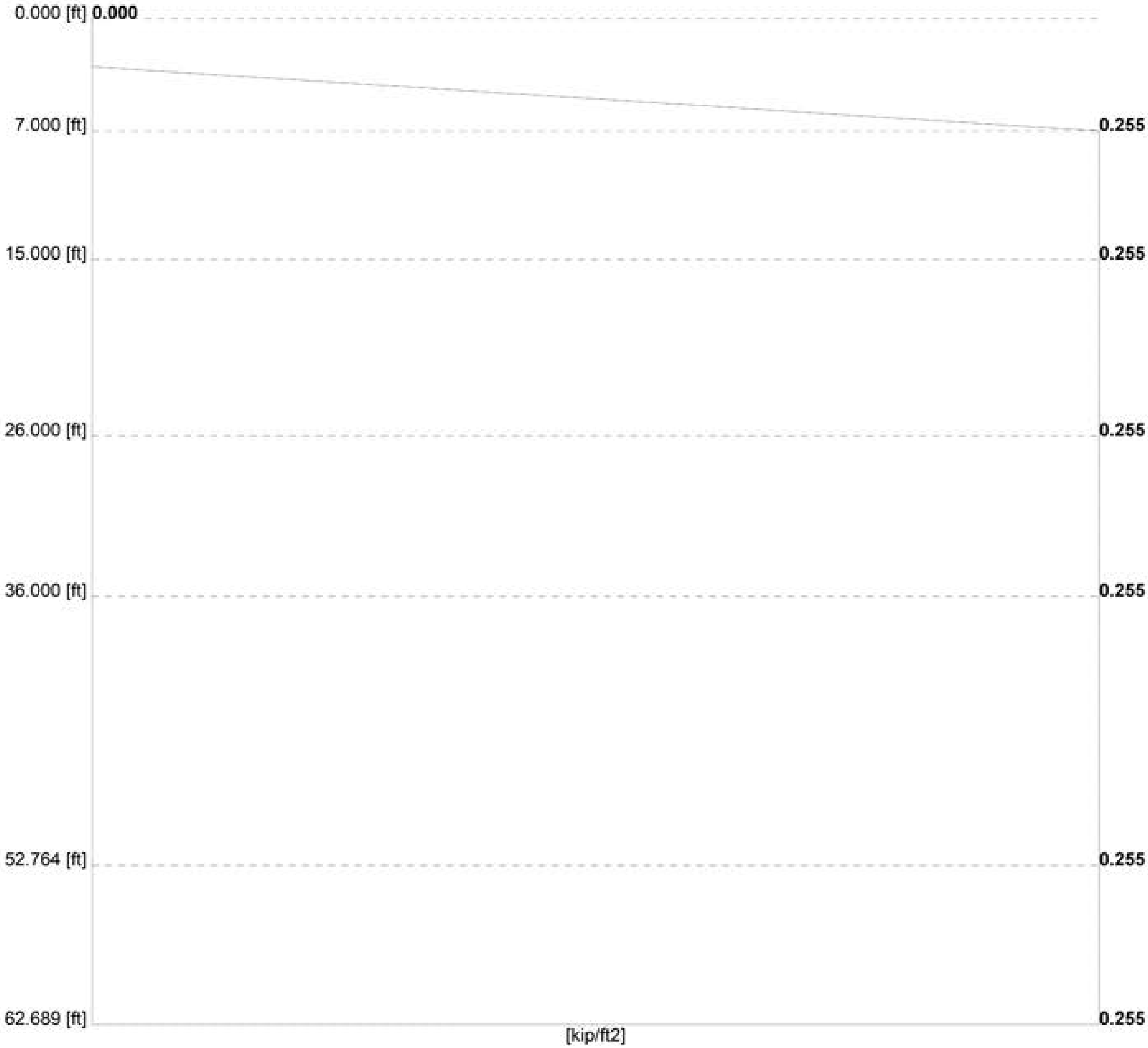
Pile Check

		Depth [ft]
Name	AZ18	
Inertia [in4/ft]	250.439	
Modulus [in3/ft]	33.480	
Area [in2/ft]	7.106	
Mass [lbs/ft2]	24.189	
Steel Grade [lb/in2]	51468.883	
Minimal Moment [kipft/ft]	-289.428	29.281
Maxmimal Moment [kipft/ft]	0.209	2.000
Normal Forces at Max. Moment [kip/ft]	2.404	29.281
Normal Forces at Min. Moment [kip/ft]	0.058	2.000
Deflection at Min. Moment [ft]	-1.944	29.281
Deflection at Max. Moment [ft]	0.000	2.000
Min. Stress at Min. Moment [lb/in2]	-105070.758	29.281
Max. Stress at Min. Moment [lb/in2]	105747.508	29.281
Min. Stress at Max. Moment [lb/in2]	-66.688	2.000
Max. Stress at Max. Moment [lb/in2]	83.134	2.000
Safety < Req. Safety = 2.000	0.487	
Sheet Pile Top Level [ft]	0.000	
Sheet Pile Tip Level [ft]	62.689	
Sheet Pile Length [ft]	62.689	
Included OverLength [ft]	0.000	
Vertical Equilibrium [kip/ft]	2.774	
Anchor Force (horiz.) [kip/ft]	-18.494	

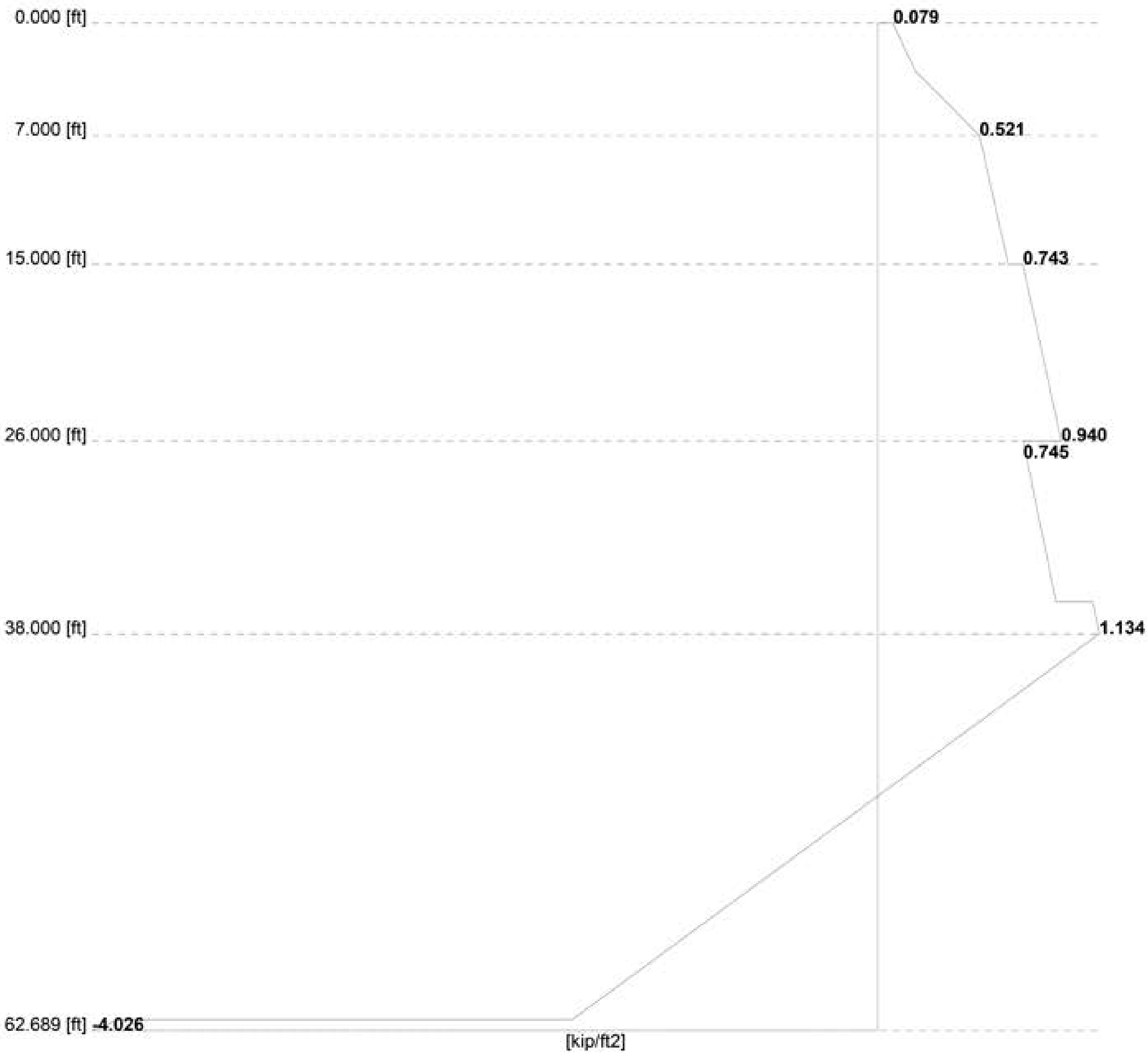
Earth Pressure Diagram



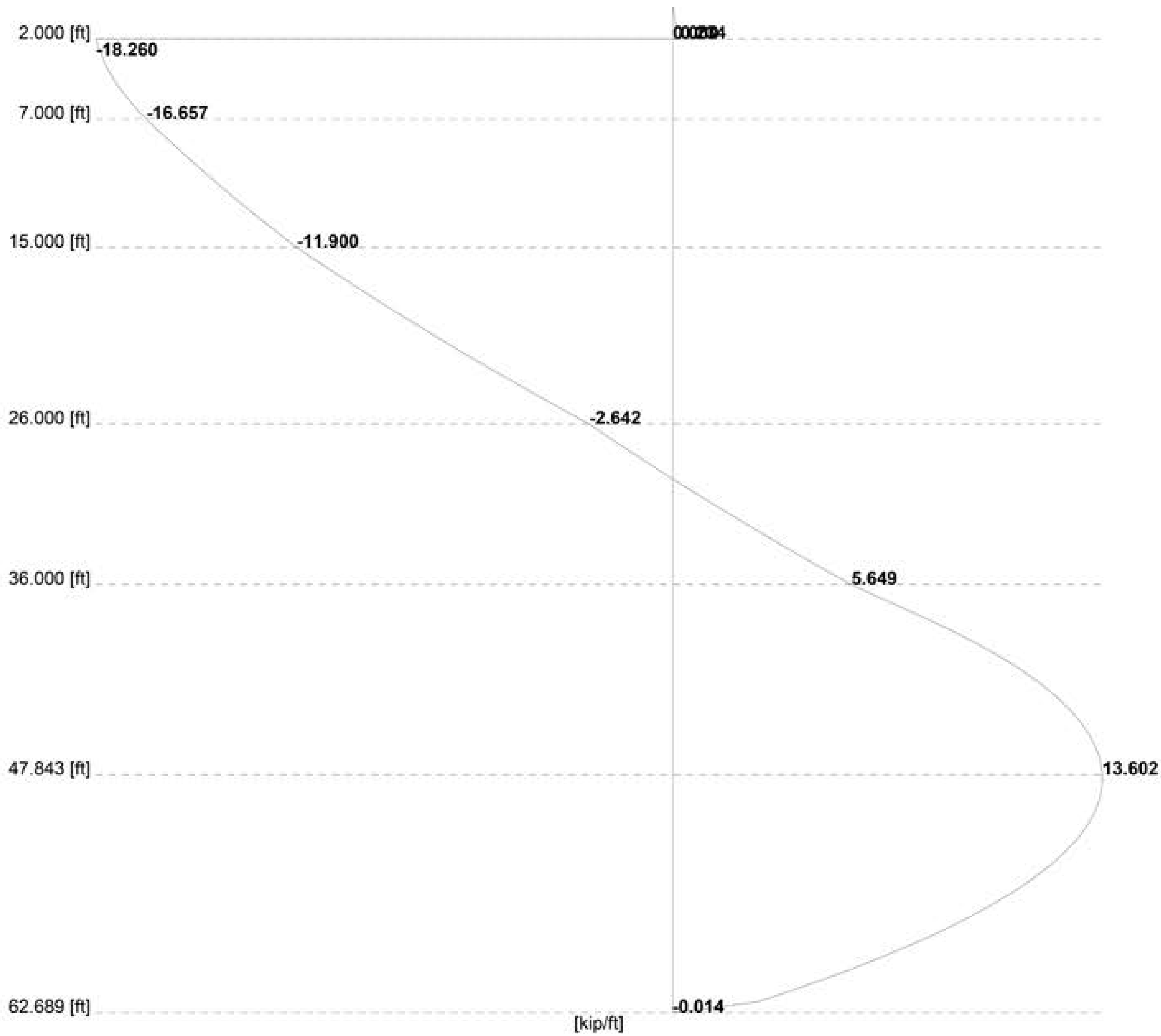
Water Pressure Diagram



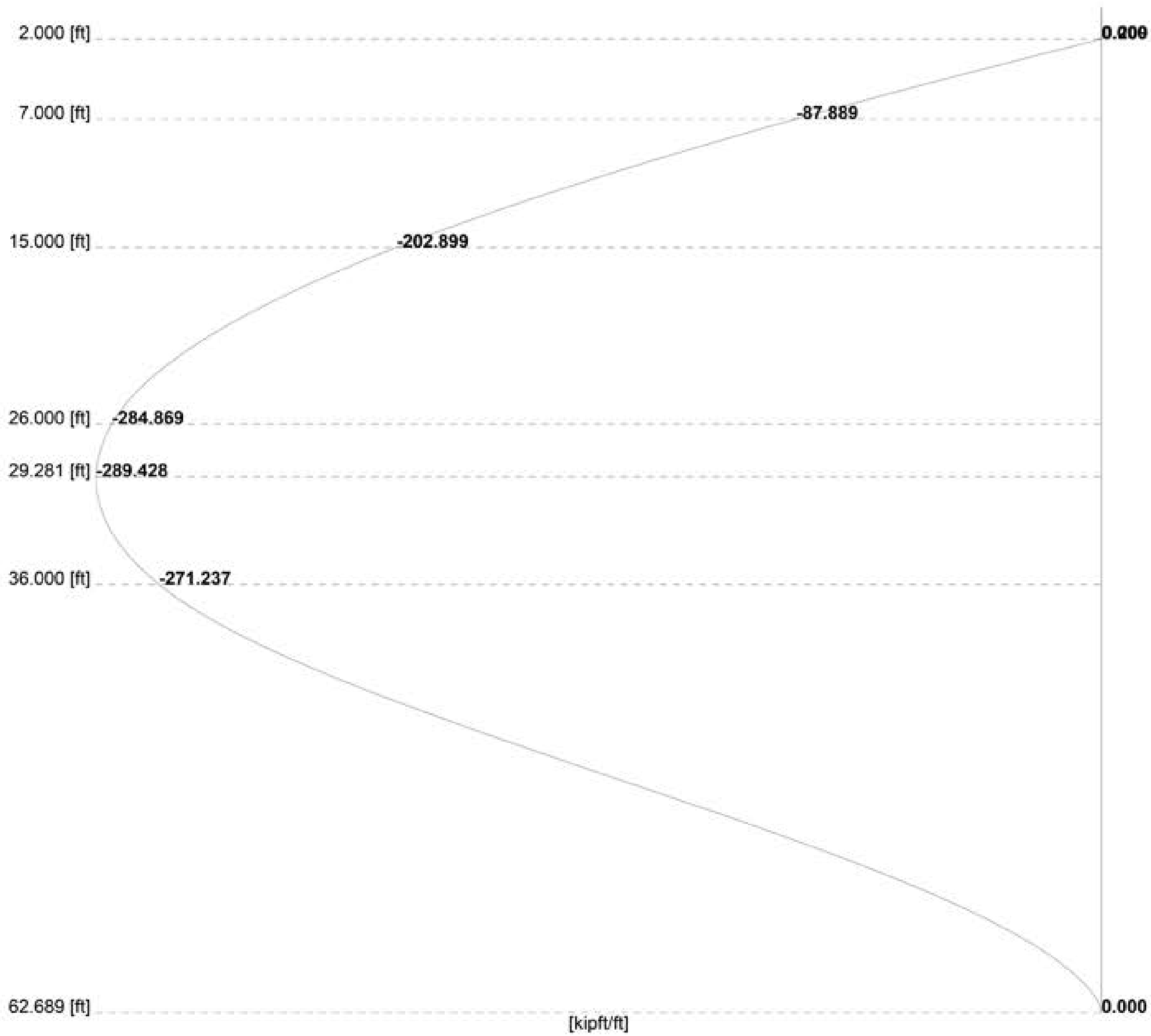
Total Pressure Diagram



Cross Force Diagram



Moment Diagram

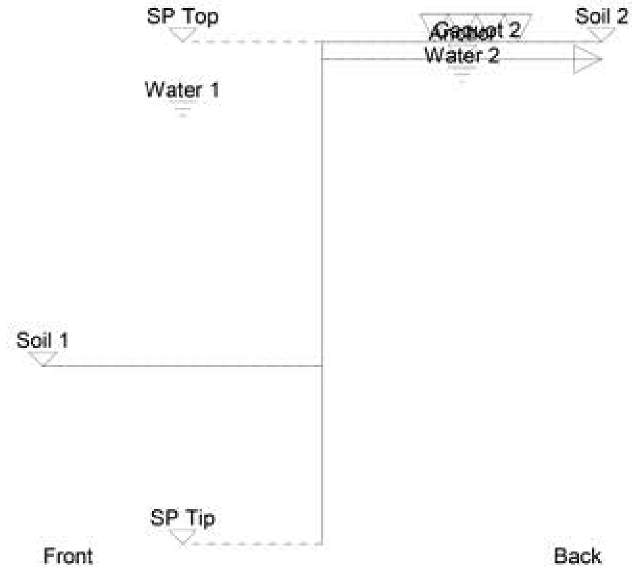


Sheet Pile Design According to Blum-Method

Project Name:	BASF North Works - Bulkhead Wall
Date:	6/10/2022
Author:	Arcadis
Company:	Arcadis
Comment:	Drained / Unusual / Structural Demand

Geodata

	Unit
Sheet Pile Top Level [ft]	0.000
Sheet Pile Tip Level [ft]	58.833
Soil Level in Front [ft]	38.000
Soil Level behind [ft]	0.000
Anchorlevel [ft]	2.000
Water Level in Front [ft]	7.000
Water Level behind [ft]	3.000
Soil Surface Inclination in Front [Deg]	0.000
Soil Surface Inclination behind [Deg]	0.000
Caquot Surcharge in Front [kip/ft2]	0.000
Caquot Surcharge behind [kip/ft2]	0.250
Anchor Inclination [Deg]	0.000
Earth Support	Free



Soil Layers

Layers in Front

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	62.000	0.110	0.048	3.498	27.000	-9.000	0.000
Layer 2	114.000	0.135	0.073	3.997	28.000	-12.000	0.500

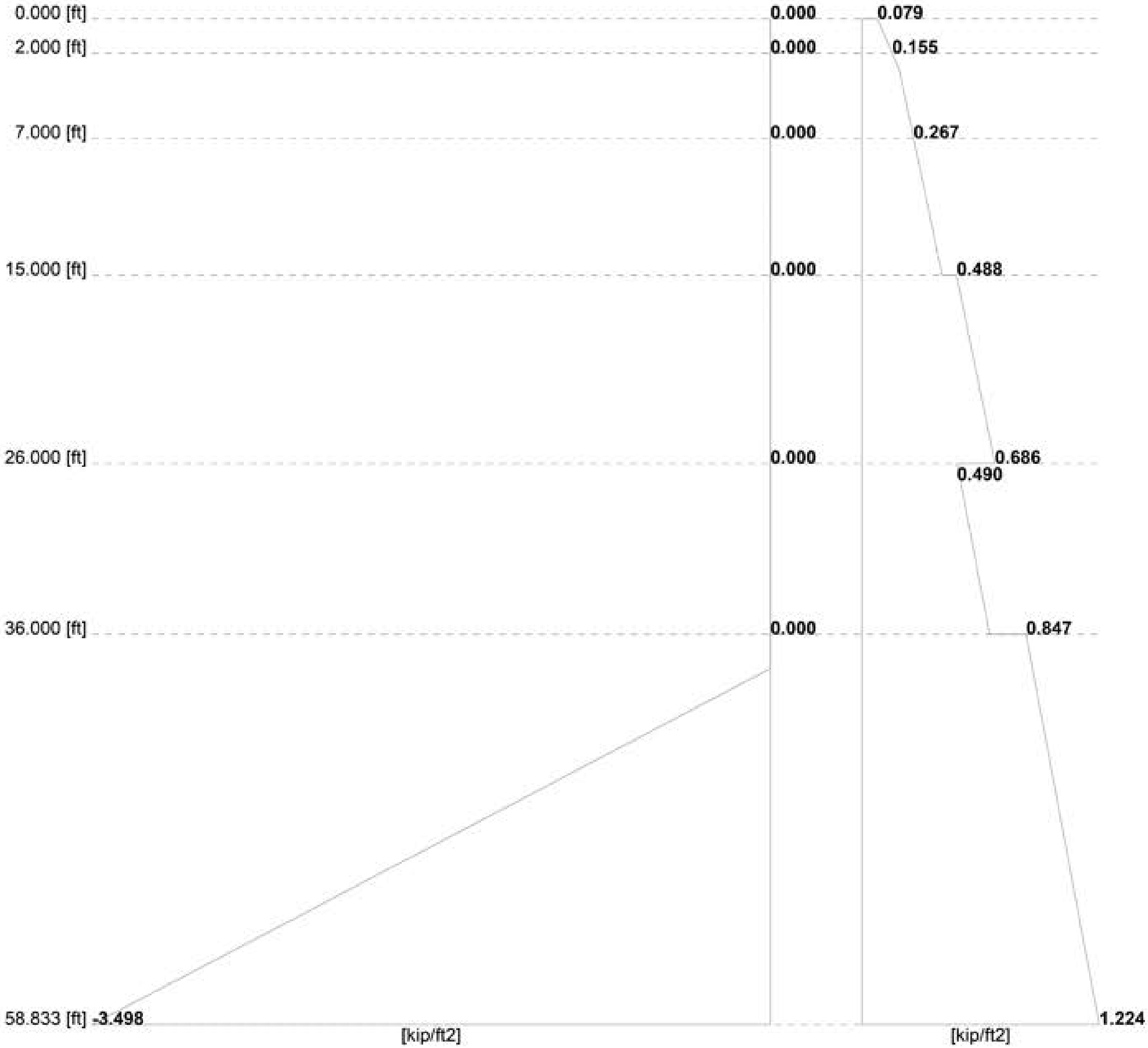
Layers behind

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	15.000	0.120	0.058	0.317	28.000	14.000	0.000
Layer 2	26.000	0.110	0.048	0.374	25.000	8.000	0.000
Layer 3	36.000	0.125	0.063	0.267	32.000	16.000	0.000
Layer 4	62.000	0.110	0.048	0.344	27.000	9.000	0.000
Layer 5	114.000	0.135	0.073	0.322	28.000	12.000	0.500

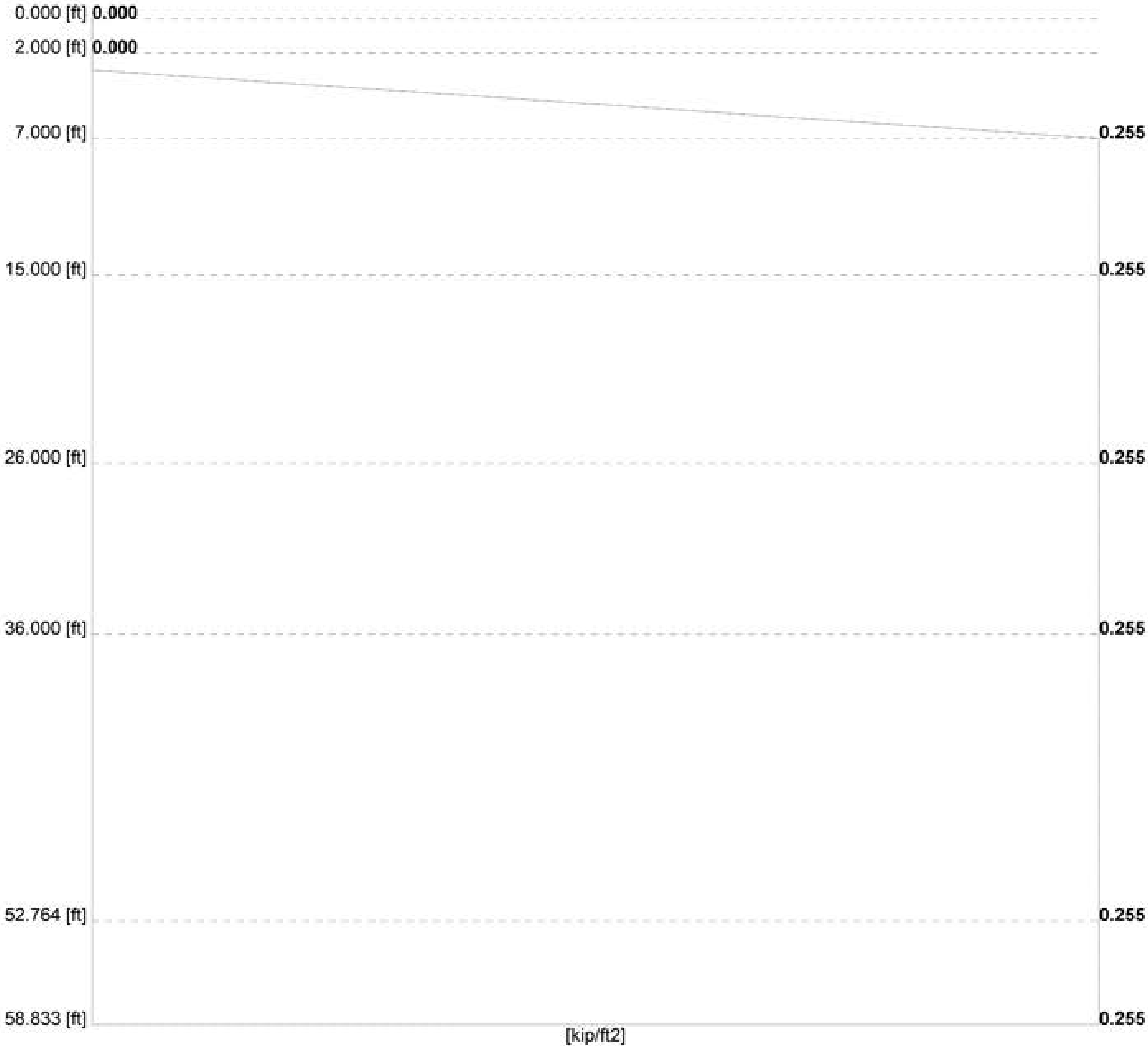
Pile Check

		Depth [ft]
Name	AZ18	
Inertia [in4/ft]	250.439	
Modulus [in3/ft]	33.480	
Area [in2/ft]	7.106	
Mass [lbs/ft2]	24.189	
Steel Grade [lb/in2]	51468.883	
Minimal Moment [kipft/ft]	-254.161	27.640
Maxmimal Moment [kipft/ft]	0.209	2.000
Normal Forces at Max. Moment [kip/ft]	2.154	27.640
Normal Forces at Min. Moment [kip/ft]	0.058	2.000
Deflection at Min. Moment [ft]	-1.500	27.640
Deflection at Max. Moment [ft]	0.000	2.000
Min. Stress at Min. Moment [lb/in2]	-91948.188	27.640
Max. Stress at Min. Moment [lb/in2]	92554.539	27.640
Min. Stress at Max. Moment [lb/in2]	-66.688	2.000
Max. Stress at Max. Moment [lb/in2]	83.134	2.000
Safety < Req. Safety = 2.000	0.556	
Sheet Pile Top Level [ft]	0.000	
Sheet Pile Tip Level [ft]	58.833	
Sheet Pile Length [ft]	58.833	
Included OverLength [ft]	0.000	
Vertical Equilibrium [kip/ft]	1.538	
Anchor Force (horiz.) [kip/ft]	-17.167	

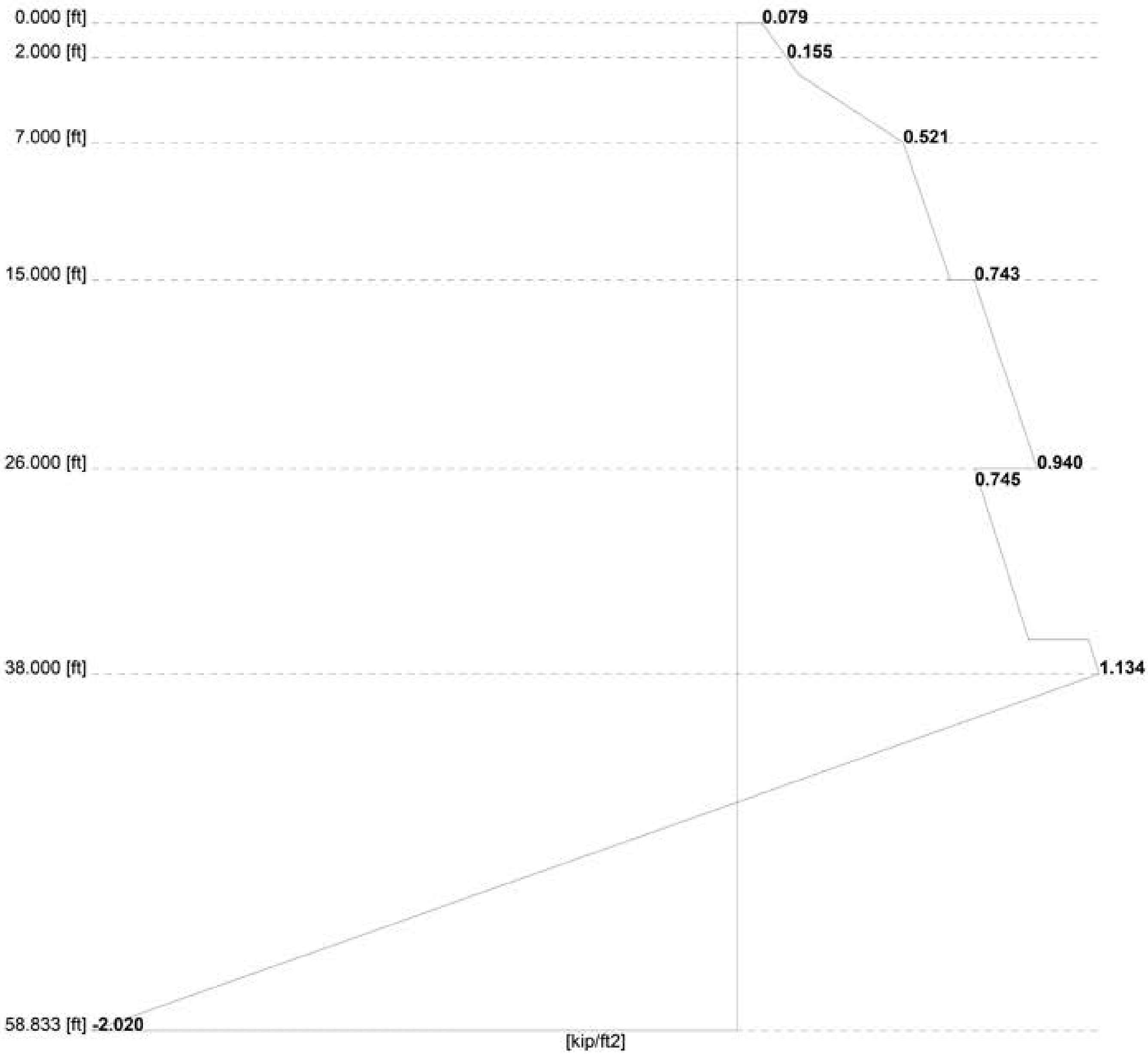
Earth Pressure Diagram



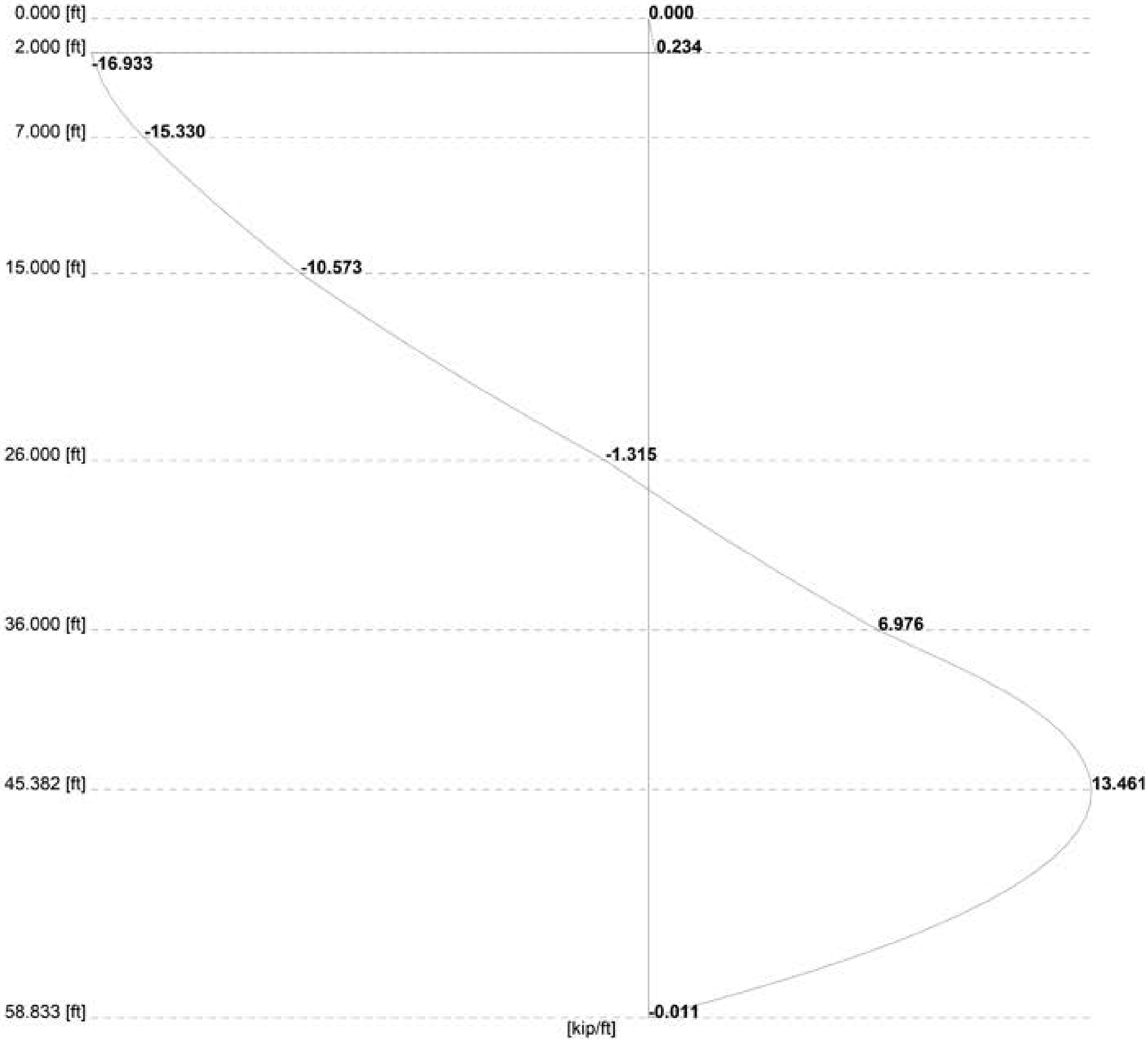
Water Pressure Diagram



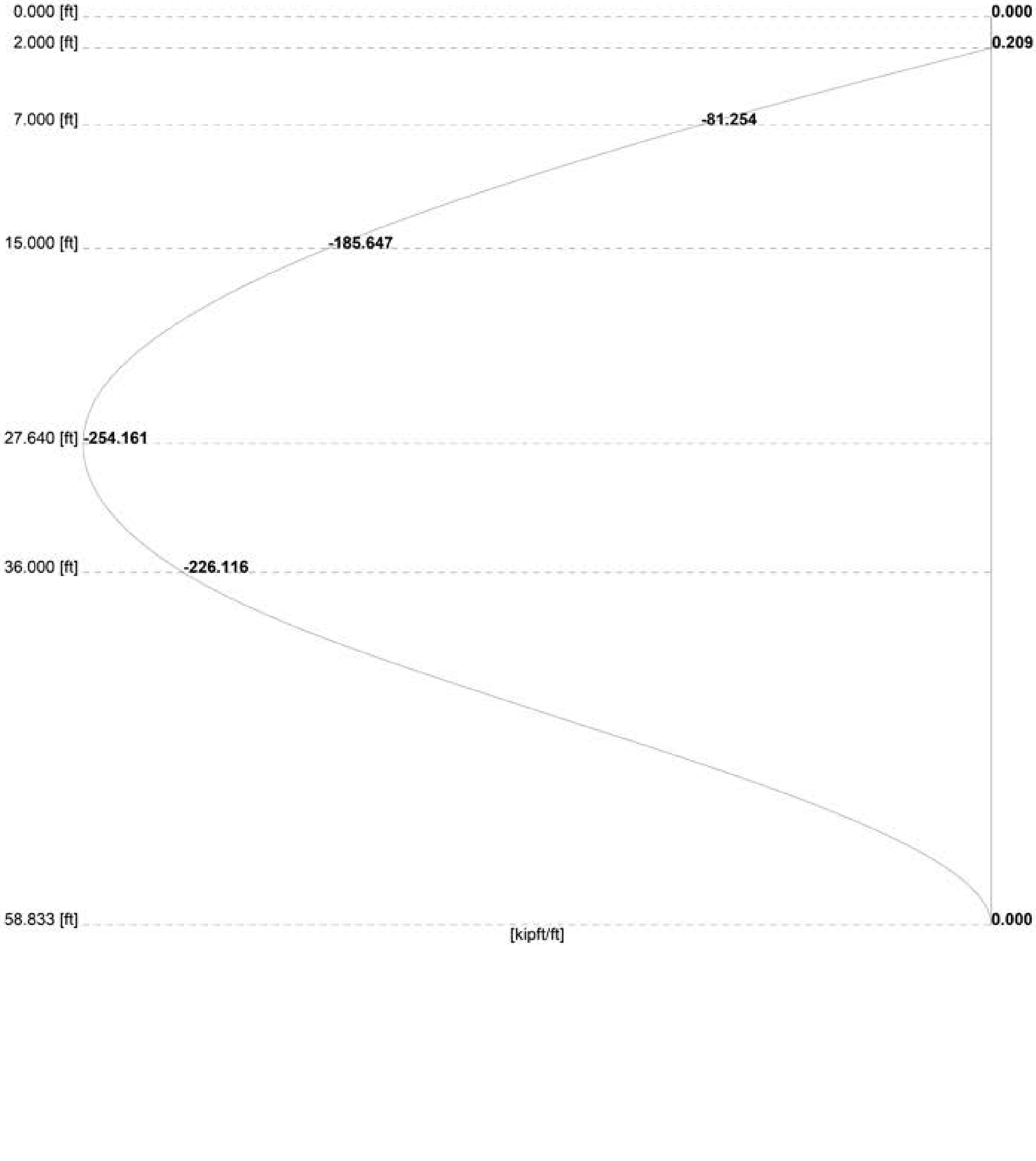
Total Pressure Diagram



Cross Force Diagram



Moment Diagram

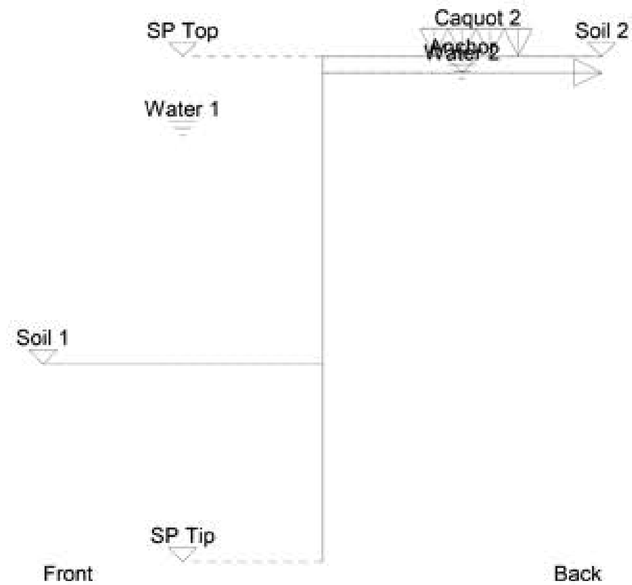


Sheet Pile Design According to Blum-Method

Project Name:	BASF North Works - Bulkhead Wall
Date:	6/10/2022
Author:	Arcadis
Company:	Arcadis
Comment:	Drained / Extreme / Embedment

Geodata

	Unit
Sheet Pile Top Level [ft]	0.000
Sheet Pile Tip Level [ft]	62.459
Soil Level in Front [ft]	38.000
Soil Level behind [ft]	0.000
Anchorlevel [ft]	2.000
Water Level in Front [ft]	8.000
Water Level behind [ft]	1.000
Soil Surface Inclination in Front [Deg]	0.000
Soil Surface Inclination behind [Deg]	0.000
Caquot Surcharge in Front [kip/ft2]	0.000
Caquot Surcharge behind [kip/ft2]	0.250
Anchor Inclination [Deg]	0.000
Earth Support	Free



Soil Layers

Layers in Front

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	62.000	0.110	0.048	3.106	24.900	-8.200	0.000
Layer 2	114.000	0.135	0.073	3.483	25.800	-10.900	0.455

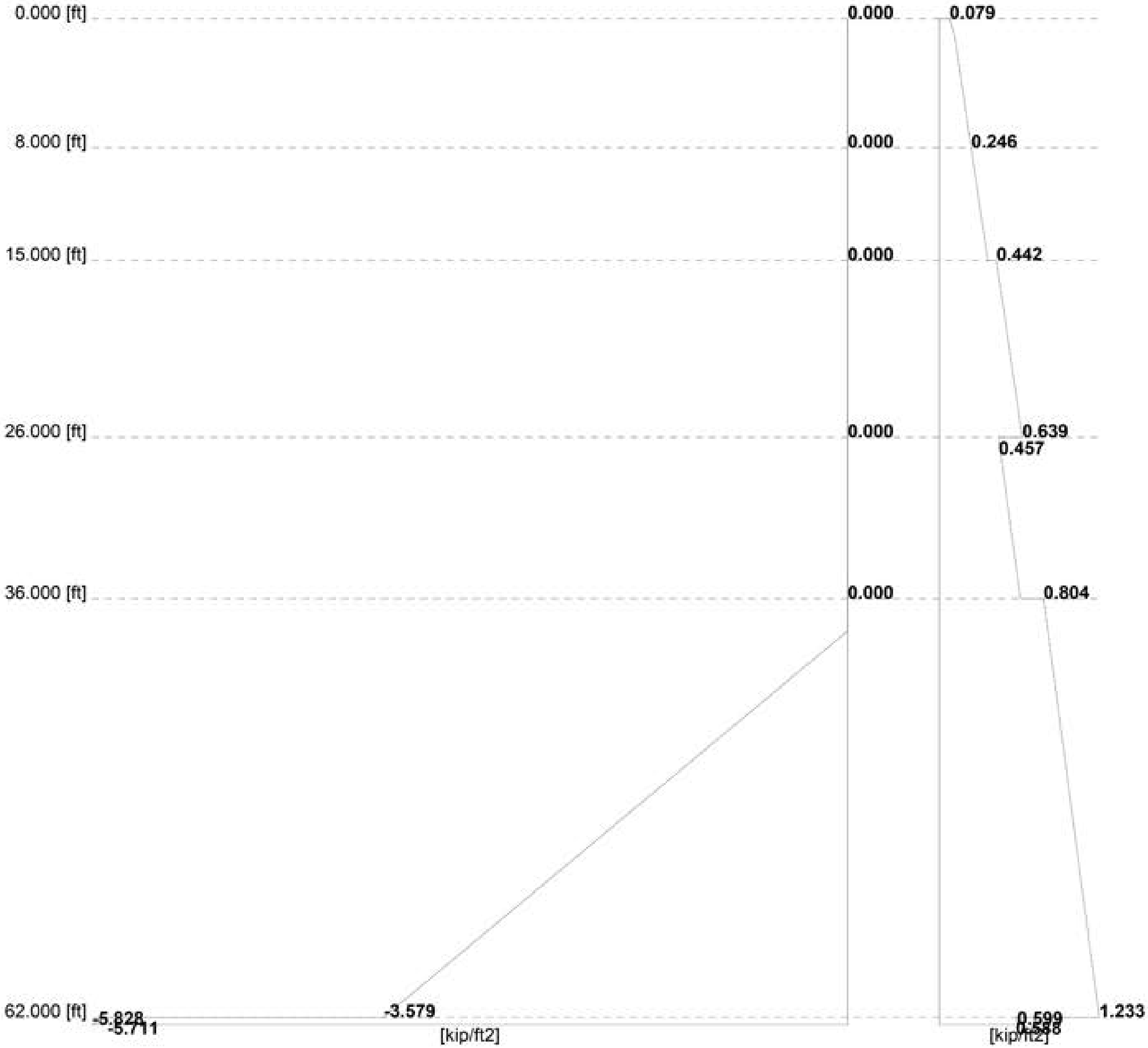
Layers behind

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	15.000	0.120	0.058	0.317	28.000	14.000	0.000
Layer 2	26.000	0.110	0.048	0.374	25.000	8.000	0.000
Layer 3	36.000	0.125	0.063	0.267	32.000	16.000	0.000
Layer 4	62.000	0.110	0.048	0.344	27.000	9.000	0.000
Layer 5	114.000	0.135	0.073	0.322	28.000	12.000	0.500

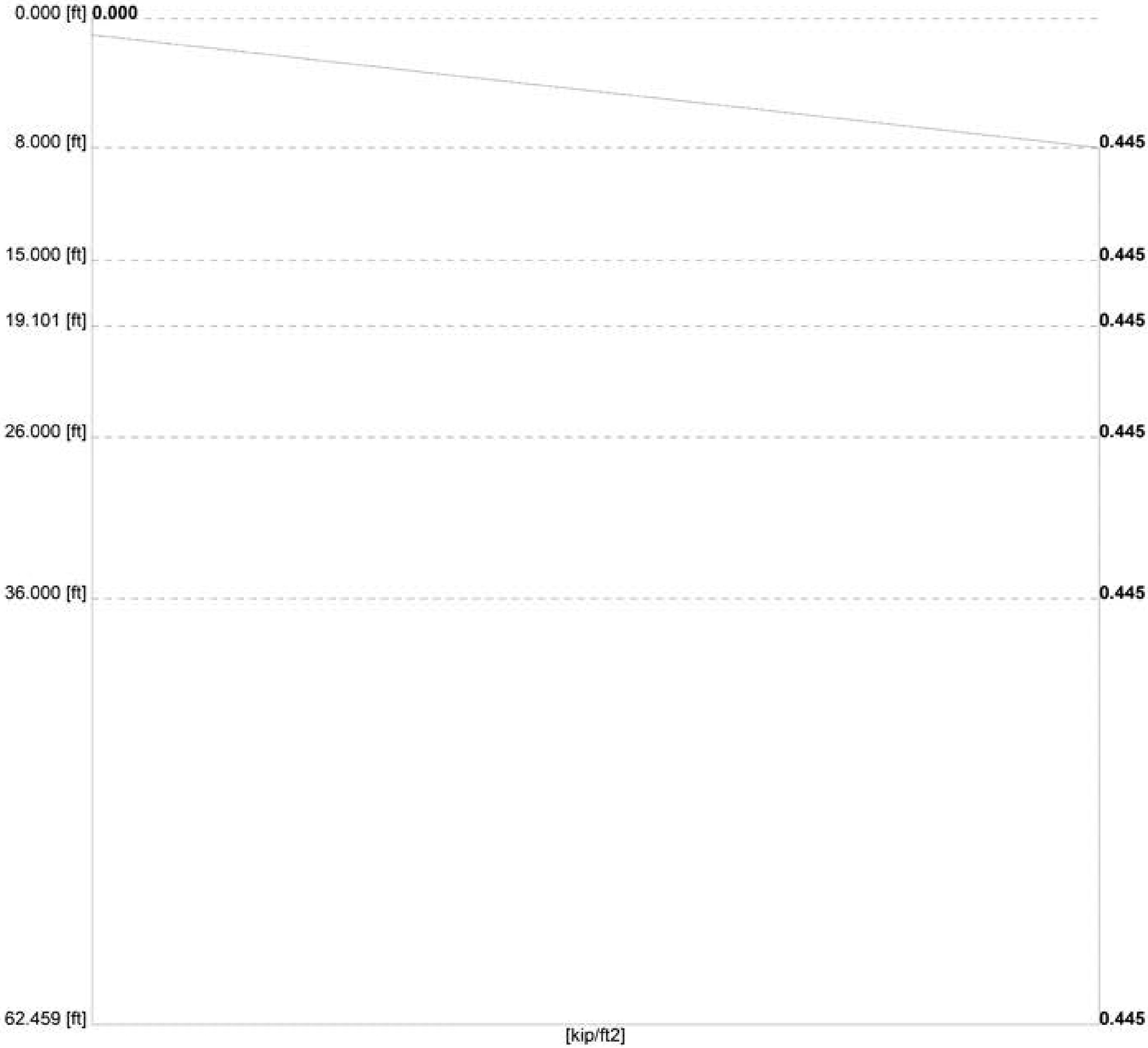
Pile Check

		Depth [ft]
Name	AZ18	
Inertia [in4/ft]	250.439	
Modulus [in3/ft]	33.480	
Area [in2/ft]	7.106	
Mass [lbs/ft2]	24.189	
Steel Grade [lb/in2]	50000.000	
Minimal Moment [kipft/ft]	-334.854	29.051
Maxmimal Moment [kipft/ft]	0.216	2.000
Normal Forces at Max. Moment [kip/ft]	2.174	29.051
Normal Forces at Min. Moment [kip/ft]	0.056	2.000
Deflection at Min. Moment [ft]	-2.227	29.051
Deflection at Max. Moment [ft]	0.000	2.000
Min. Stress at Min. Moment [lb/in2]	-121444.555	29.051
Max. Stress at Min. Moment [lb/in2]	122056.539	29.051
Min. Stress at Max. Moment [lb/in2]	-69.661	2.000
Max. Stress at Max. Moment [lb/in2]	85.418	2.000
Safety < Req. Safety = 2.000	0.410	
Sheet Pile Top Level [ft]	0.000	
Sheet Pile Tip Level [ft]	62.459	
Sheet Pile Length [ft]	62.459	
Included OverLength [ft]	0.000	
Vertical Equilibrium [kip/ft]	0.831	
Anchor Force (horiz.) [kip/ft]	-21.889	

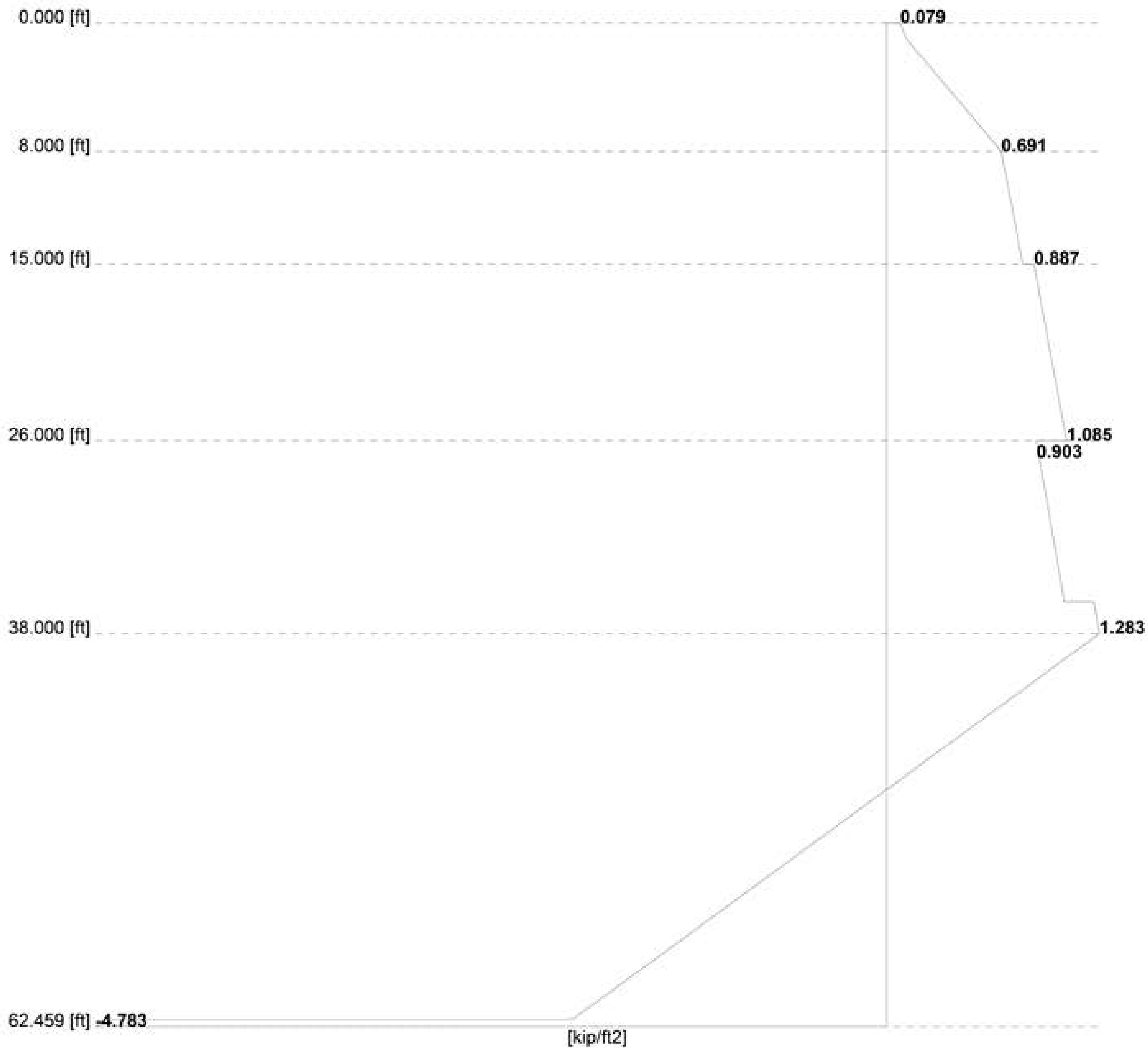
Earth Pressure Diagram



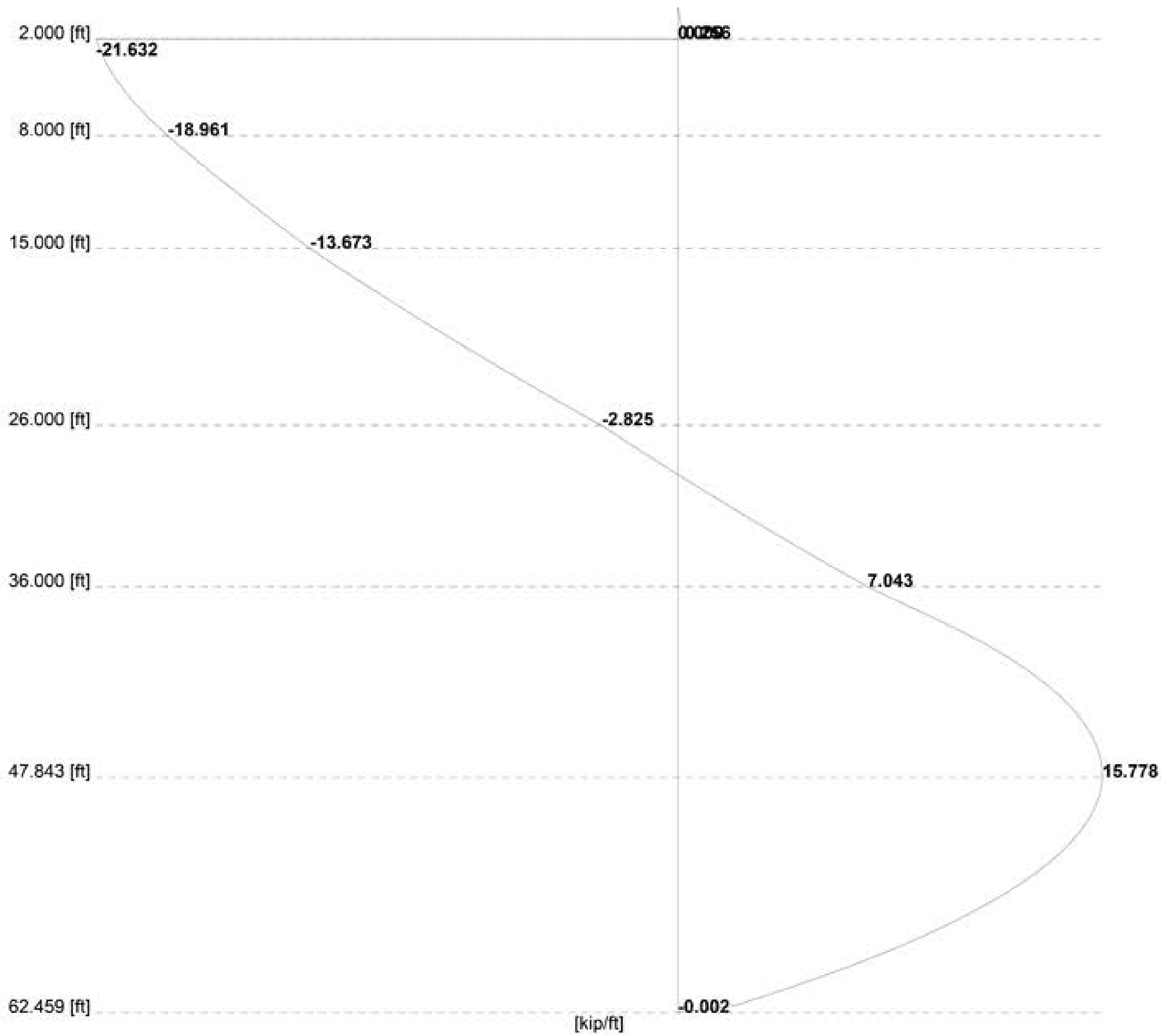
Water Pressure Diagram



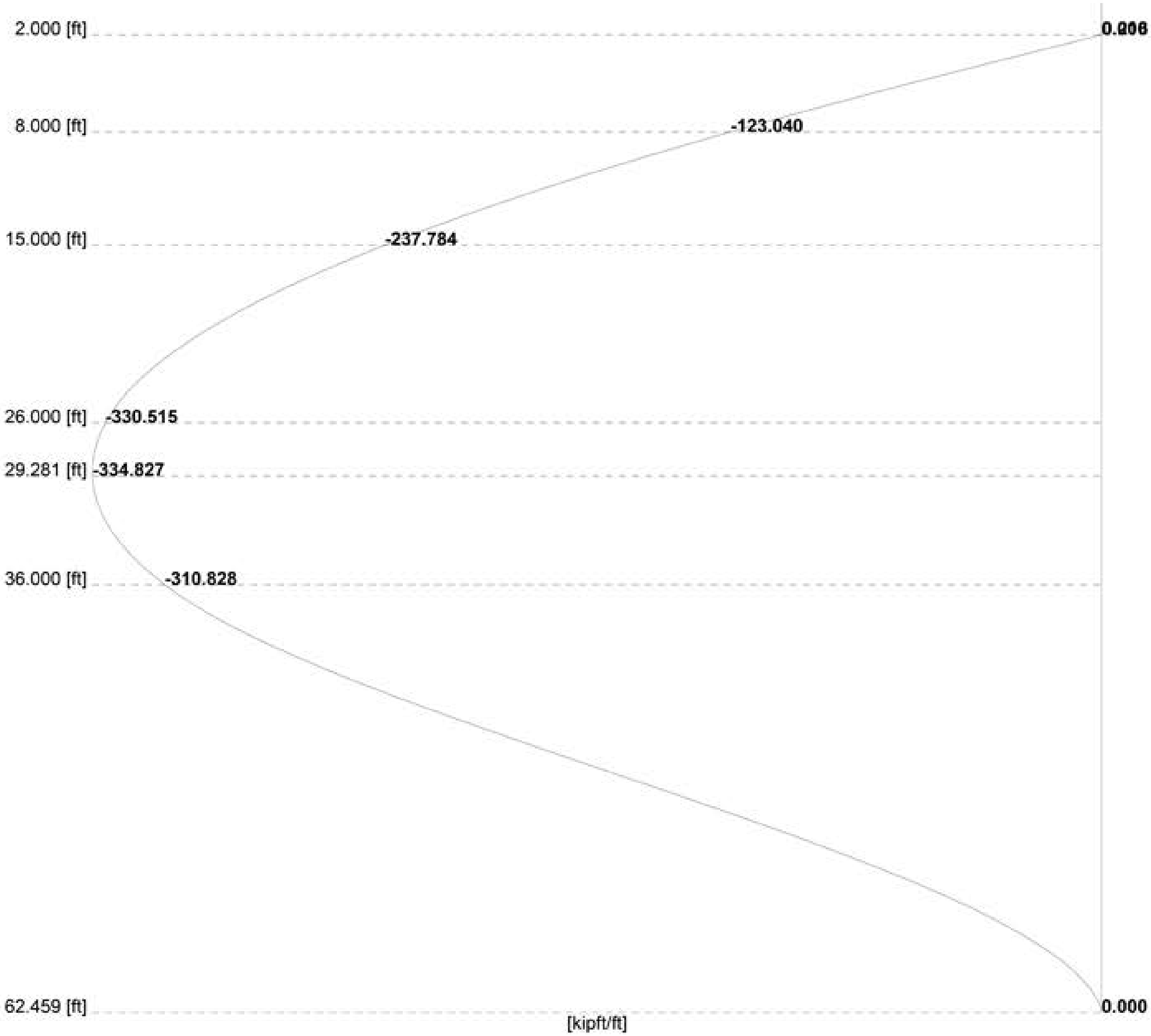
Total Pressure Diagram



Cross Force Diagram



Moment Diagram

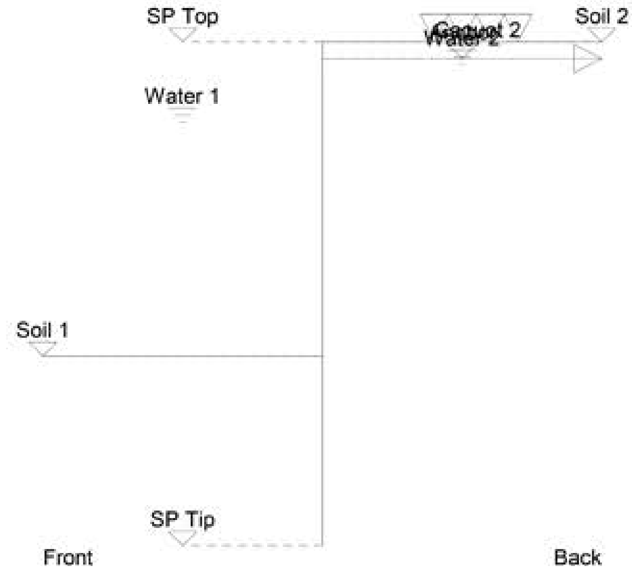


Sheet Pile Design According to Blum-Method

Project Name:	BASF North Works - Bulkhead Wall
Date:	6/10/2022
Author:	Arcadis
Company:	Arcadis
Comment:	Drained / Extreme / Structural Demand

Geodata

	Unit
Sheet Pile Top Level [ft]	0.000
Sheet Pile Tip Level [ft]	60.900
Soil Level in Front [ft]	38.000
Soil Level behind [ft]	0.000
Anchorlevel [ft]	2.000
Water Level in Front [ft]	8.000
Water Level behind [ft]	1.000
Soil Surface Inclination in Front [Deg]	0.000
Soil Surface Inclination behind [Deg]	0.000
Caquot Surcharge in Front [kip/ft2]	0.000
Caquot Surcharge behind [kip/ft2]	0.250
Anchor Inclination [Deg]	0.000
Earth Support	Free



Soil Layers

Layers in Front

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	62.000	0.110	0.048	3.498	27.000	-9.000	0.000
Layer 2	114.000	0.135	0.073	3.997	28.000	-12.000	0.500

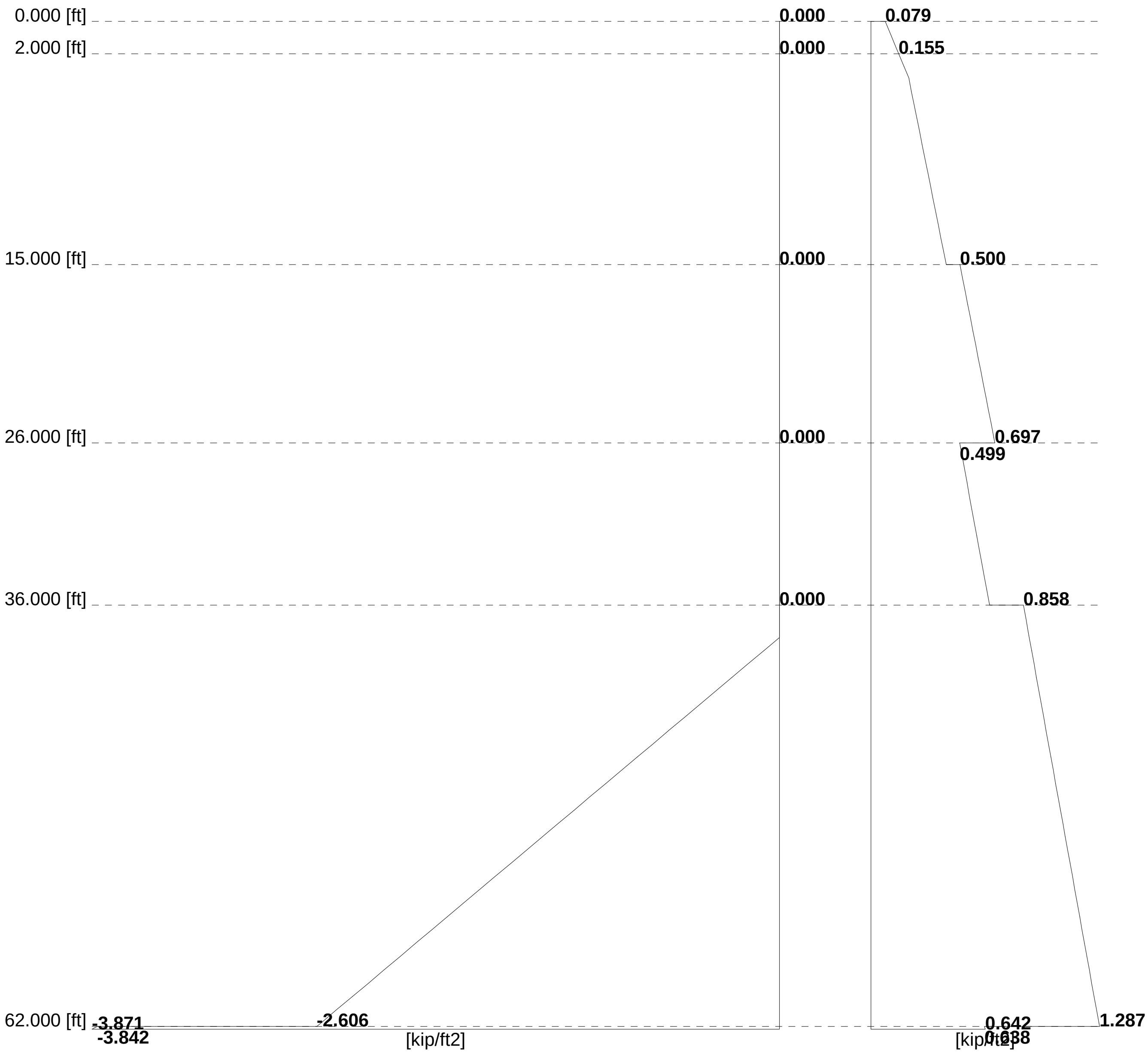
Layers behind

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	15.000	0.120	0.058	0.317	28.000	14.000	0.000
Layer 2	26.000	0.110	0.048	0.374	25.000	8.000	0.000
Layer 3	36.000	0.125	0.063	0.267	32.000	16.000	0.000
Layer 4	62.000	0.110	0.048	0.344	27.000	9.000	0.000
Layer 5	114.000	0.135	0.073	0.322	28.000	12.000	0.500

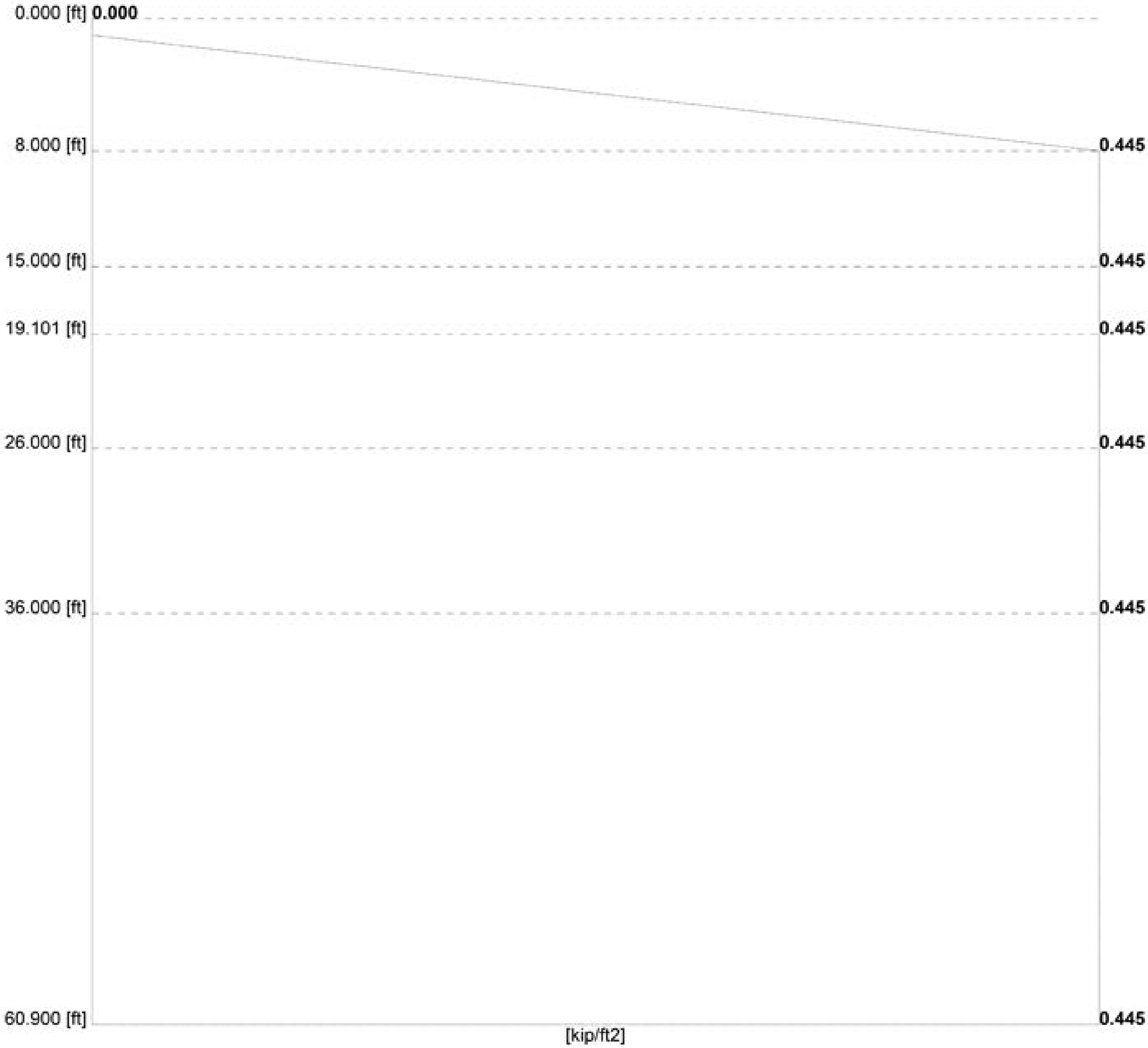
Pile Check

		Depth [ft]
Name	AZ18	
Inertia [in4/ft]	250.439	
Modulus [in3/ft]	33.480	
Area [in2/ft]	7.106	
Mass [lbs/ft2]	24.189	
Steel Grade [lb/in2]	50000.000	
Minimal Moment [kipft/ft]	-316.004	28.329
Maxmimal Moment [kipft/ft]	0.216	2.000
Normal Forces at Max. Moment [kip/ft]	2.055	28.329
Normal Forces at Min. Moment [kip/ft]	0.056	2.000
Deflection at Min. Moment [ft]	-1.990	28.329
Deflection at Max. Moment [ft]	0.000	2.000
Min. Stress at Min. Moment [lb/in2]	-114435.539	28.329
Max. Stress at Min. Moment [lb/in2]	115014.055	28.329
Min. Stress at Max. Moment [lb/in2]	-69.661	2.000
Max. Stress at Max. Moment [lb/in2]	85.418	2.000
Safety < Req. Safety = 2.000	0.435	
Sheet Pile Top Level [ft]	0.000	
Sheet Pile Tip Level [ft]	60.900	
Sheet Pile Length [ft]	60.900	
Included OverLength [ft]	0.000	
Vertical Equilibrium [kip/ft]	0.282	
Anchor Force (horiz.) [kip/ft]	-21.182	

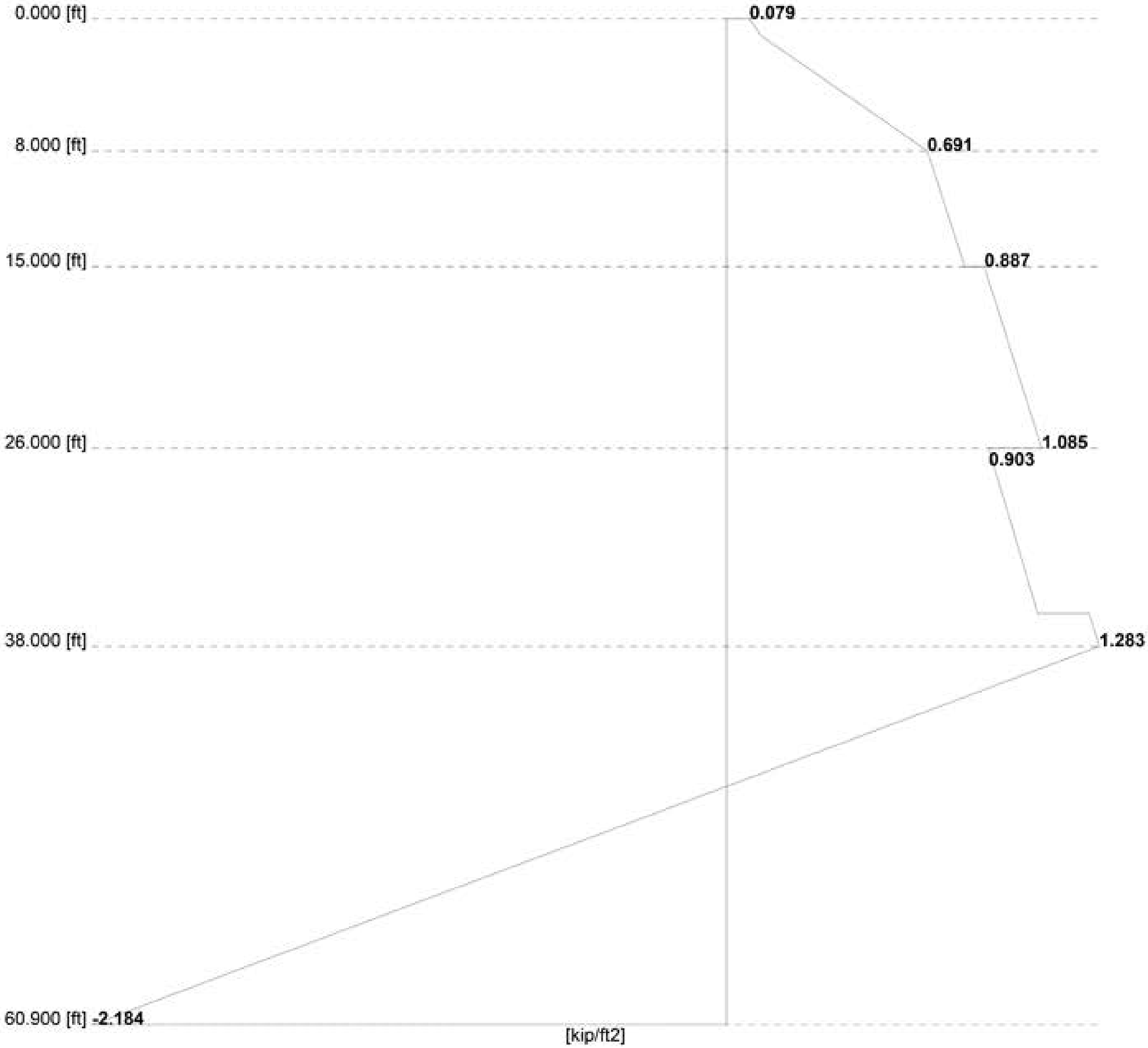
Earth Pressure Diagram



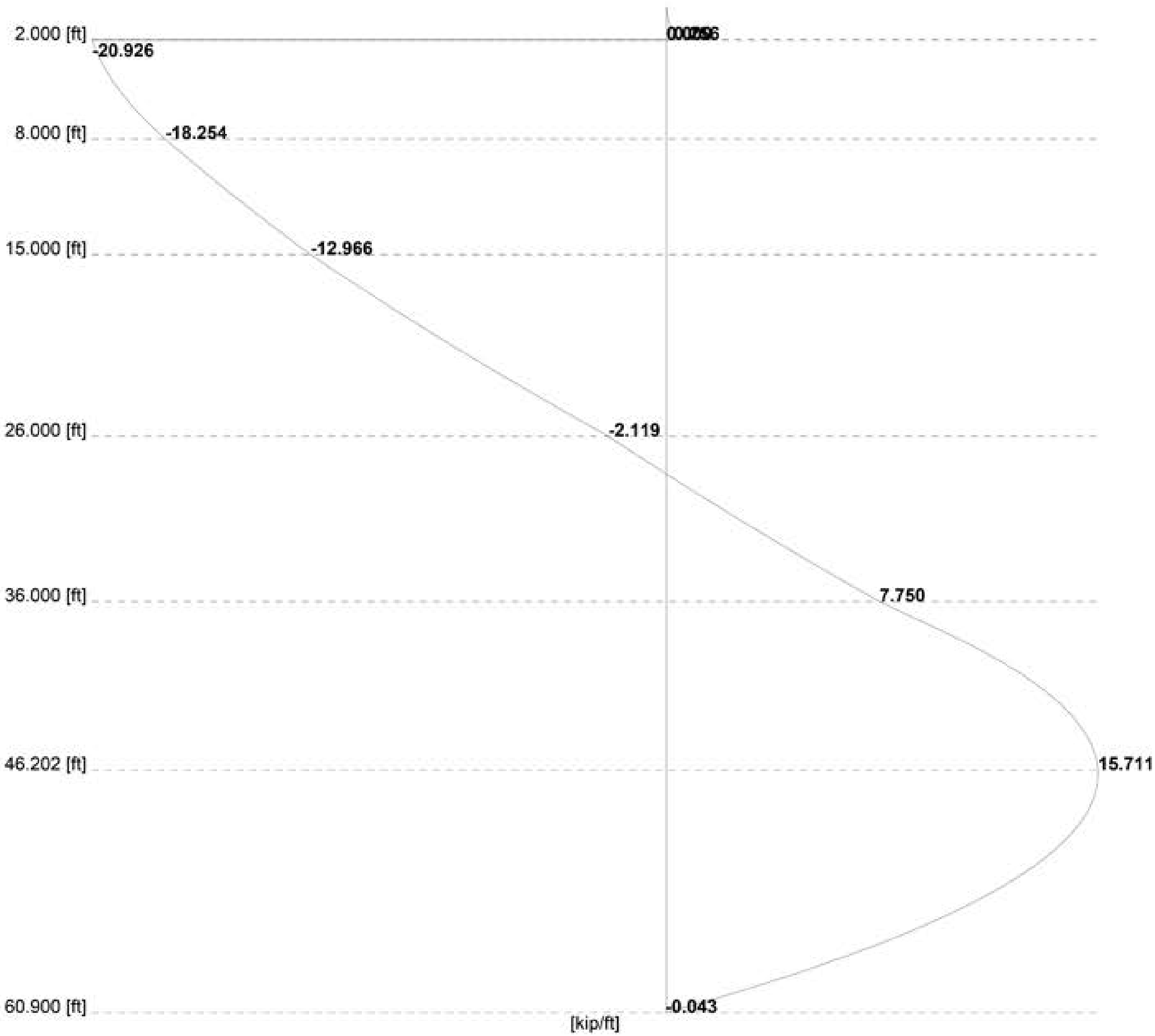
Water Pressure Diagram



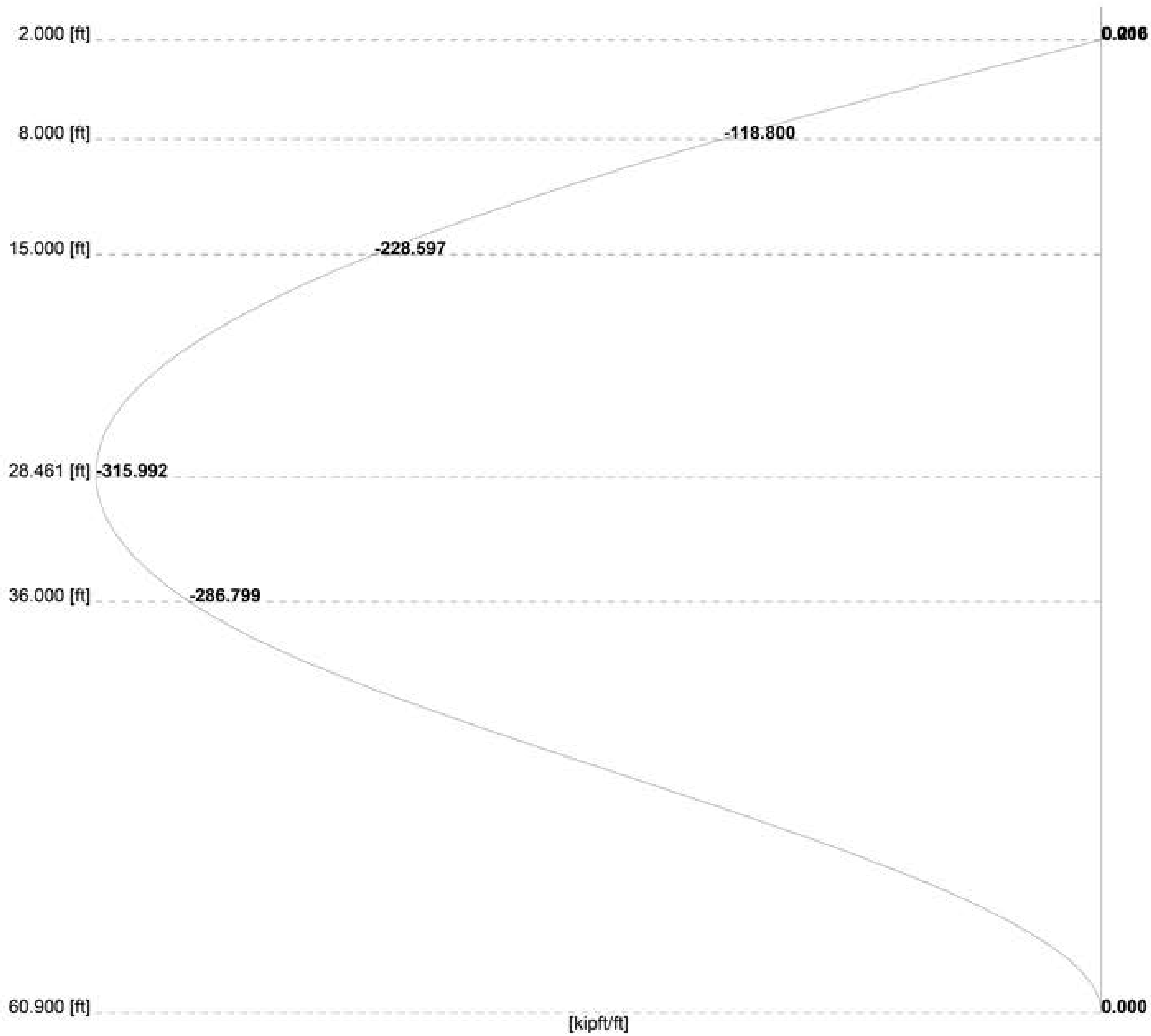
Total Pressure Diagram



Cross Force Diagram



Moment Diagram

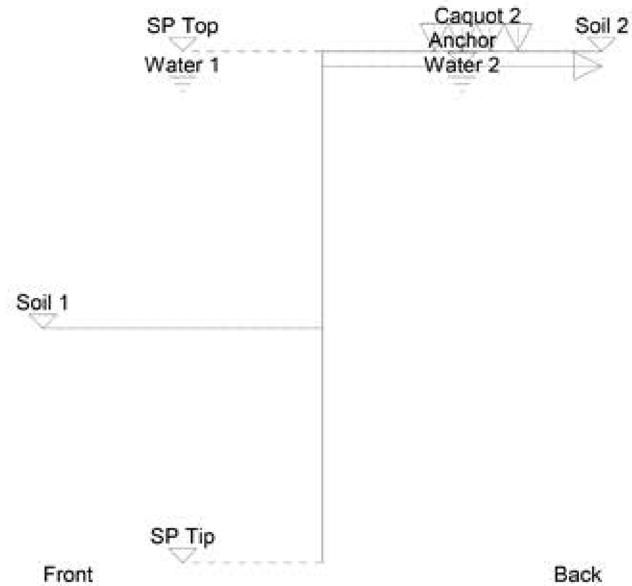


Sheet Pile Design According to Blum-Method

Project Name:	BASF North Works - Bulkhead Wall
Date:	7/20/2022
Author:	Arcadis
Company:	Arcadis
Comment:	Undrained / Usual / Embedment

Geodata

	Unit
Sheet Pile Top Level [ft]	0.000
Sheet Pile Tip Level [ft]	70.137
Soil Level in Front [ft]	38.000
Soil Level behind [ft]	0.000
Anchorlevel [ft]	2.000
Water Level in Front [ft]	3.500
Water Level behind [ft]	3.500
Soil Surface Inclination in Front [Deg]	0.000
Soil Surface Inclination behind [Deg]	0.000
Caquot Surcharge in Front [kip/ft2]	0.000
Caquot Surcharge behind [kip/ft2]	0.250
Anchor Inclination [Deg]	0.000
Earth Support	Free



Soil Layers

Layers in Front

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	62.000	0.110	0.048	1.000	0.000	0.000	0.200
Layer 2	114.000	0.135	0.073	1.000	0.000	0.000	0.667

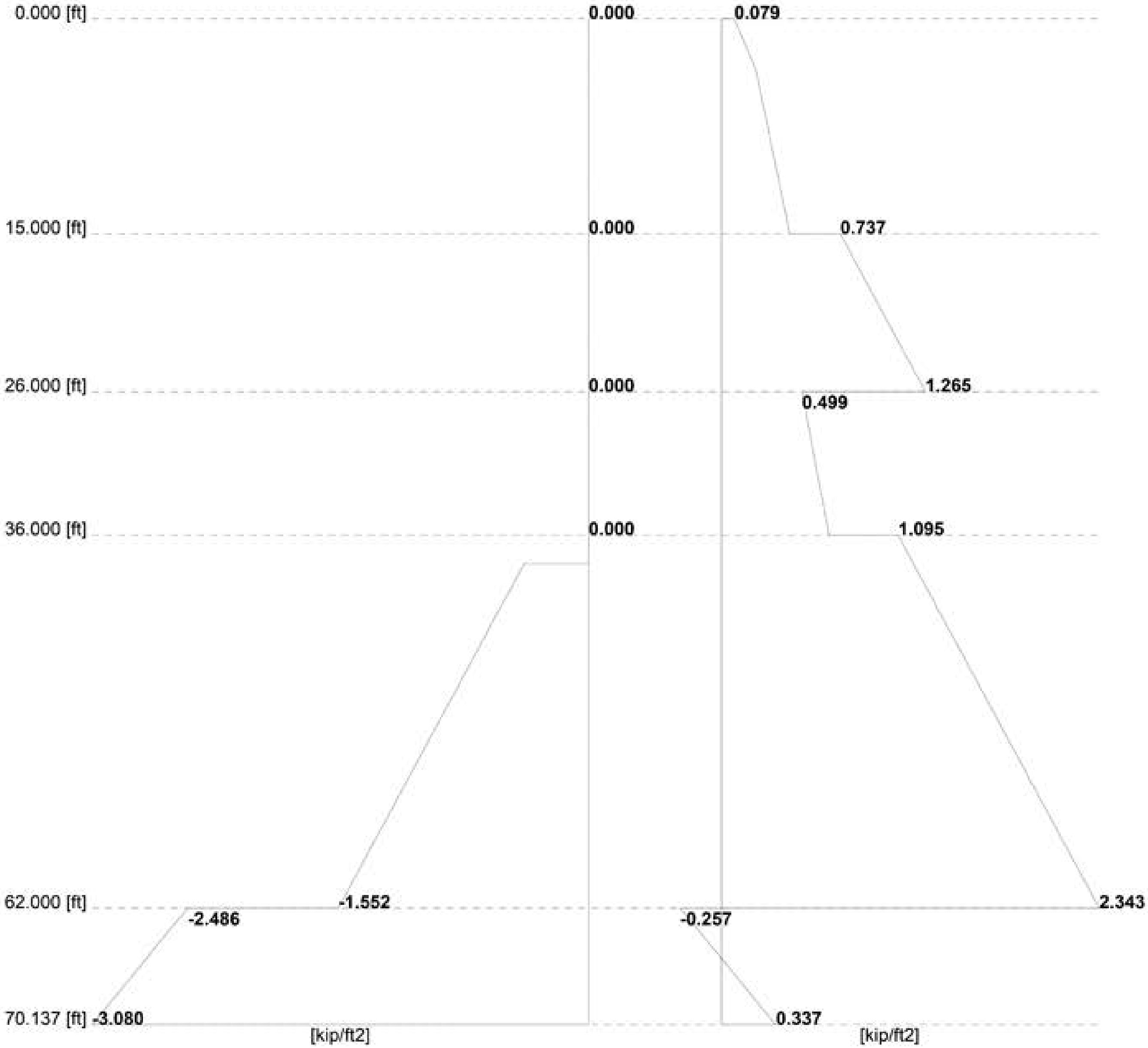
Layers behind

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	15.000	0.120	0.058	0.317	28.000	14.000	0.000
Layer 2	26.000	0.110	0.048	1.000	0.000	0.000	0.300
Layer 3	36.000	0.125	0.063	0.267	32.000	16.000	0.000
Layer 4	62.000	0.110	0.048	1.000	0.000	0.000	0.700
Layer 5	114.000	0.135	0.073	1.000	0.000	0.000	2.000

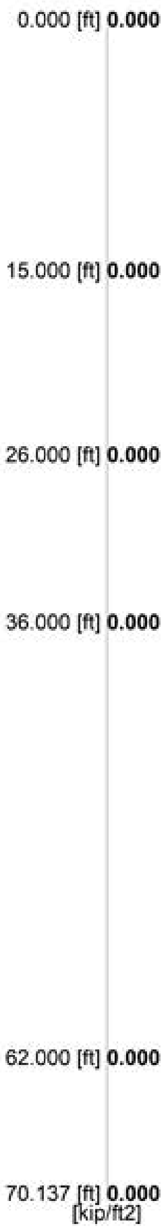
Pile Check

		Depth [ft]
Name	AZ18	
Inertia [in4/ft]	250.439	
Modulus [in3/ft]	33.480	
Area [in2/ft]	7.106	
Mass [lbs/ft2]	24.189	
Steel Grade [lb/in2]	50000.000	
Minimal Moment [kipft/ft]	-389.589	35.022
Maxmimal Moment [kipft/ft]	0.209	2.000
Normal Forces at Max. Moment [kip/ft]	2.525	35.022
Normal Forces at Min. Moment [kip/ft]	0.058	2.000
Deflection at Min. Moment [ft]	-3.442	35.022
Deflection at Max. Moment [ft]	0.000	2.000
Min. Stress at Min. Moment [lb/in2]	-142391.625	35.022
Max. Stress at Min. Moment [lb/in2]	143102.313	35.022
Min. Stress at Max. Moment [lb/in2]	-66.688	2.000
Max. Stress at Max. Moment [lb/in2]	83.134	2.000
Safety < Req. Safety = 1.500	0.349	
Sheet Pile Top Level [ft]	0.000	
Sheet Pile Tip Level [ft]	70.137	
Sheet Pile Length [ft]	70.137	
Included OverLength [ft]	0.000	
Vertical Equilibrium [kip/ft]	2.710	
Anchor Force (horiz.) [kip/ft]	-20.447	

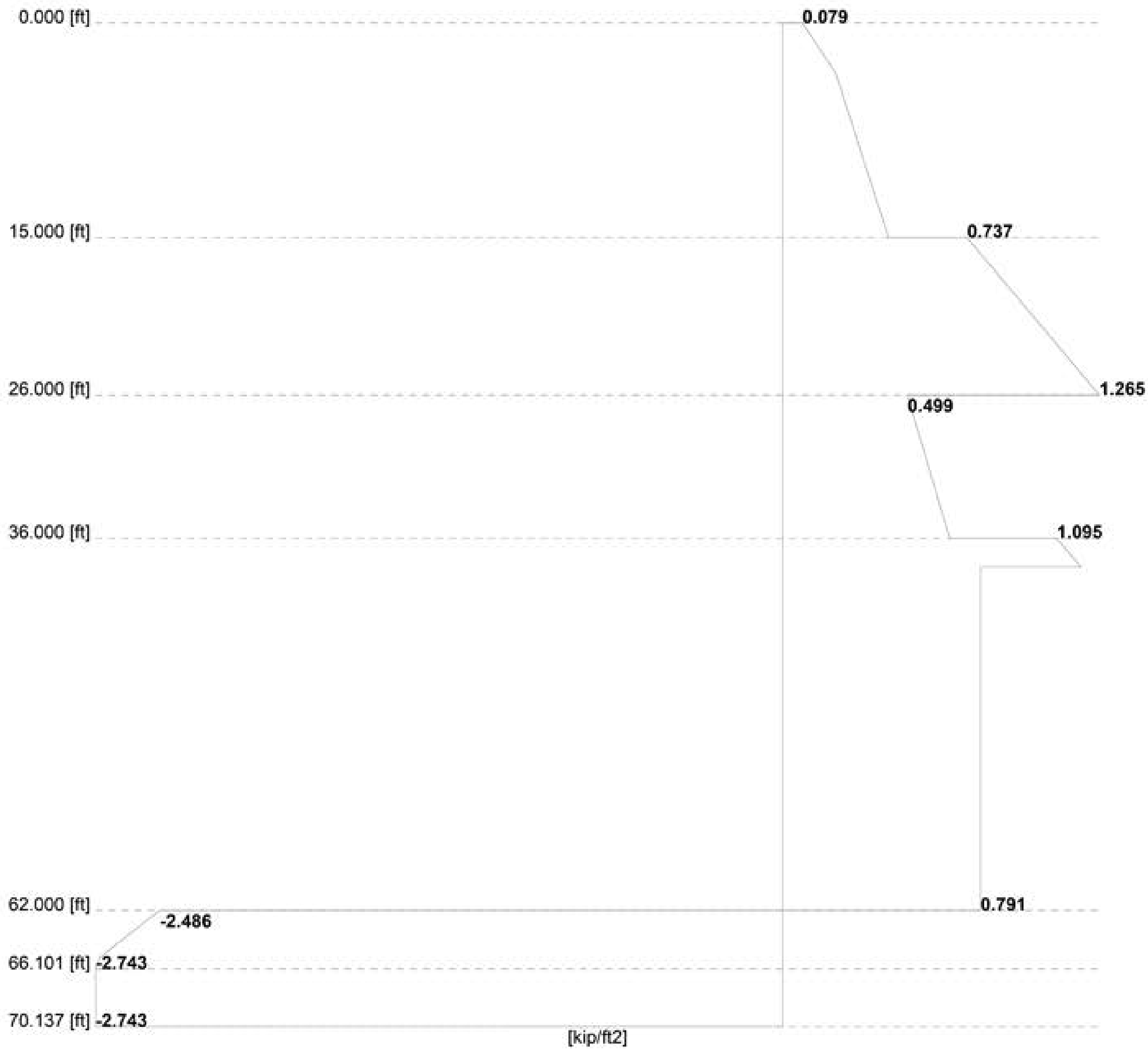
Earth Pressure Diagram



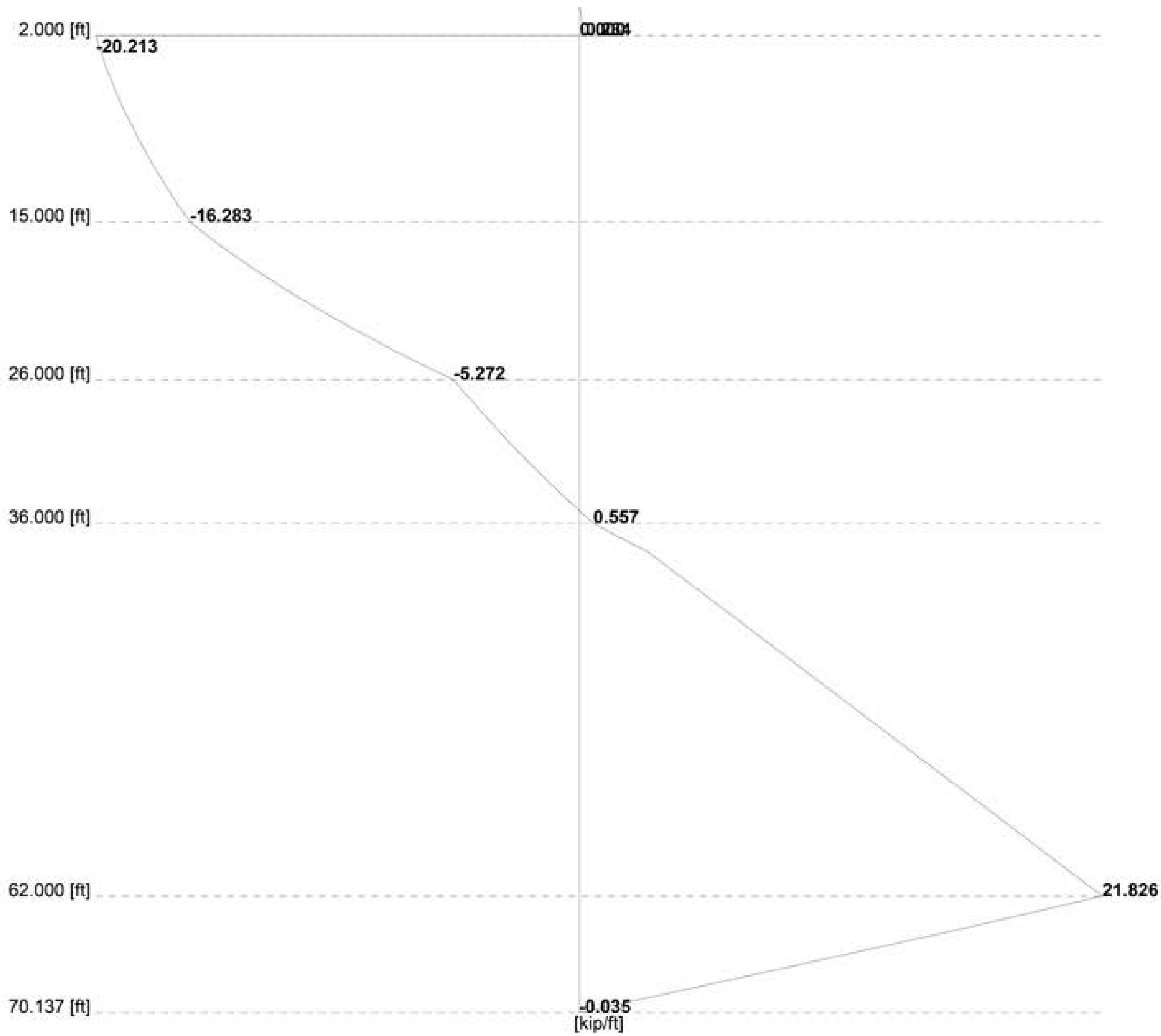
Water Pressure Diagram



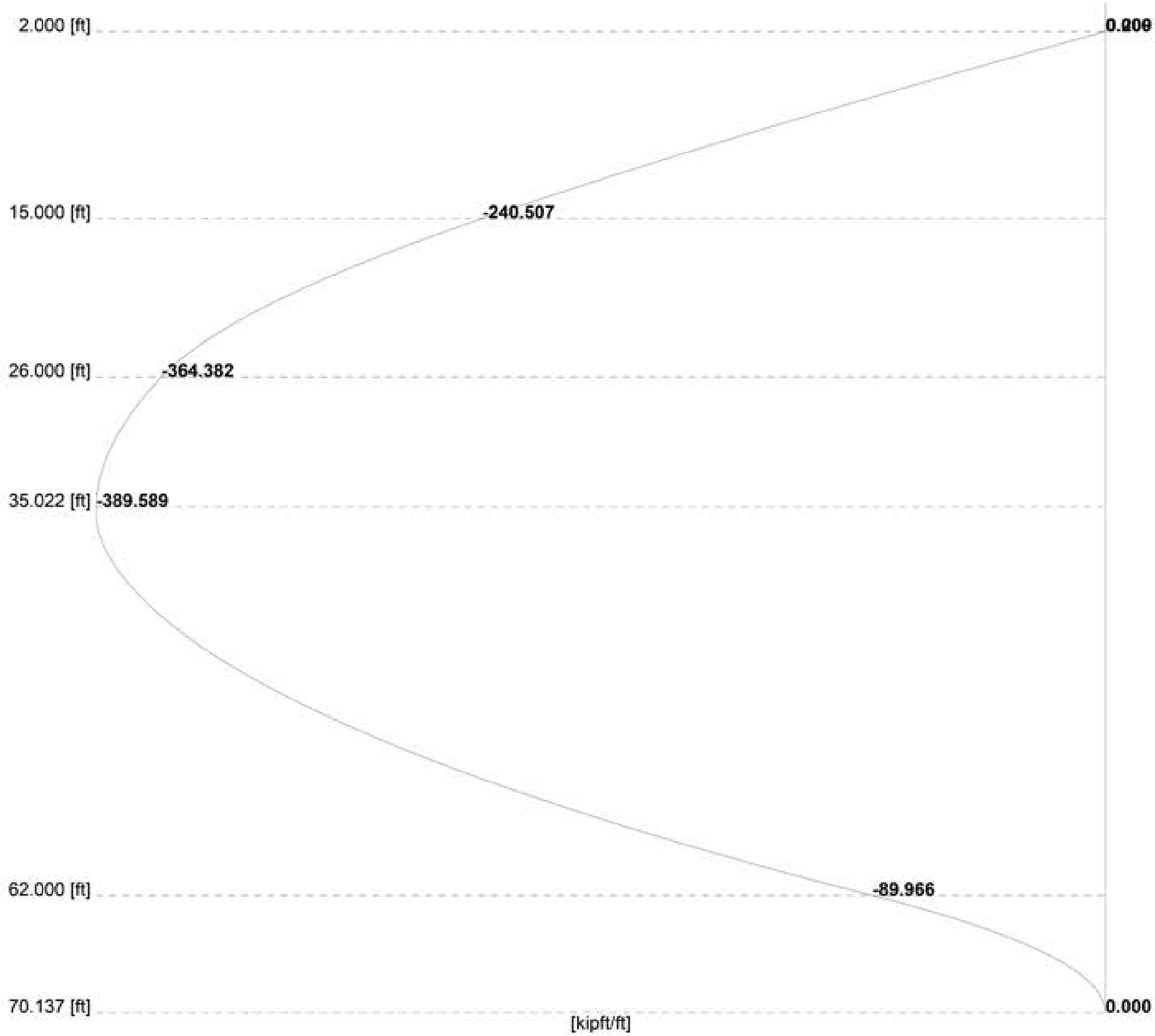
Total Pressure Diagram



Cross Force Diagram



Moment Diagram

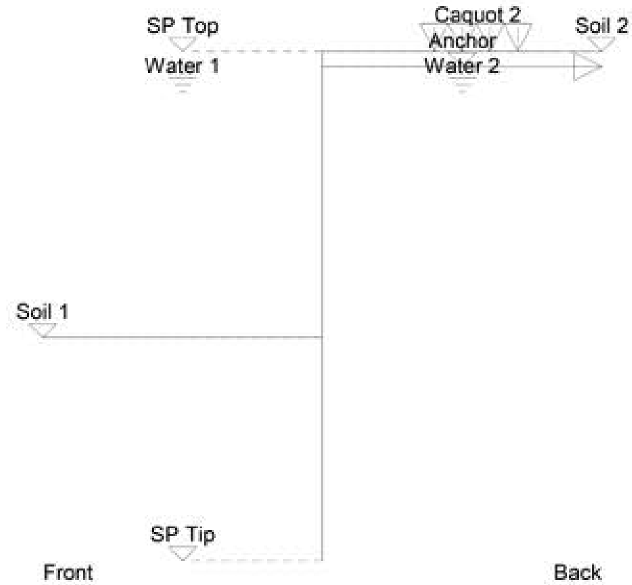


Sheet Pile Design According to Blum-Method

Project Name:	BASF North Works - Bulkhead Wall
Date:	7/20/2022
Author:	Arcadis
Company:	Arcadis
Comment:	Undrained / Usual / Structural Demand

Geodata

	Unit
Sheet Pile Top Level [ft]	0.000
Sheet Pile Tip Level [ft]	67.610
Soil Level in Front [ft]	38.000
Soil Level behind [ft]	0.000
Anchorlevel [ft]	2.000
Water Level in Front [ft]	3.500
Water Level behind [ft]	3.500
Soil Surface Inclination in Front [Deg]	0.000
Soil Surface Inclination behind [Deg]	0.000
Caquot Surcharge in Front [kip/ft2]	0.000
Caquot Surcharge behind [kip/ft2]	0.250
Anchor Inclination [Deg]	0.000
Earth Support	Free



Soil Layers

Layers in Front

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	62.000	0.110	0.048	1.000	0.000	0.000	0.300
Layer 2	114.000	0.135	0.073	1.000	0.000	0.000	1.000

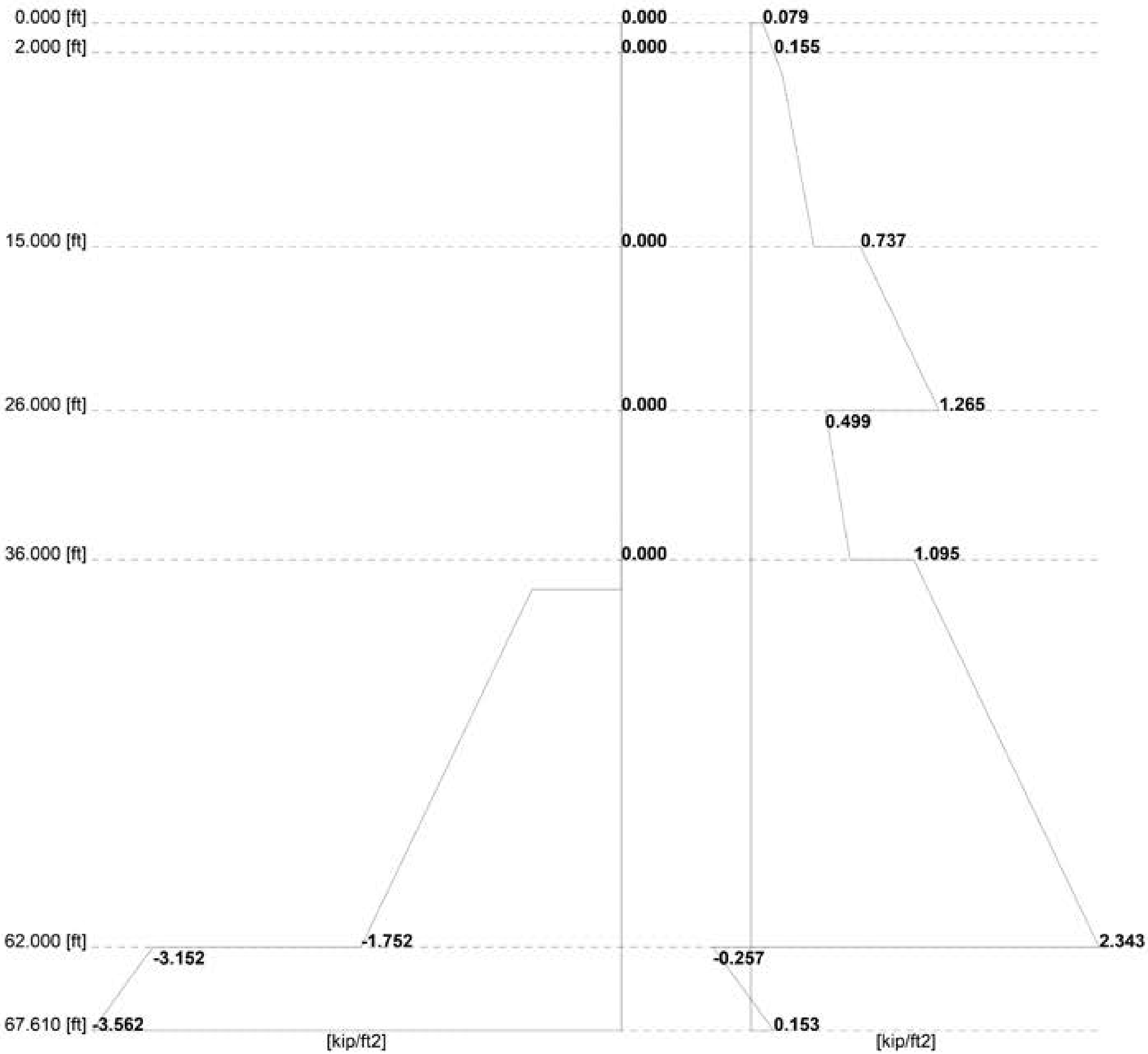
Layers behind

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	15.000	0.120	0.058	0.317	28.000	14.000	0.000
Layer 2	26.000	0.110	0.048	1.000	0.000	0.000	0.300
Layer 3	36.000	0.125	0.063	0.267	32.000	16.000	0.000
Layer 4	62.000	0.110	0.048	1.000	0.000	0.000	0.700
Layer 5	114.000	0.135	0.073	1.000	0.000	0.000	2.000

Pile Check

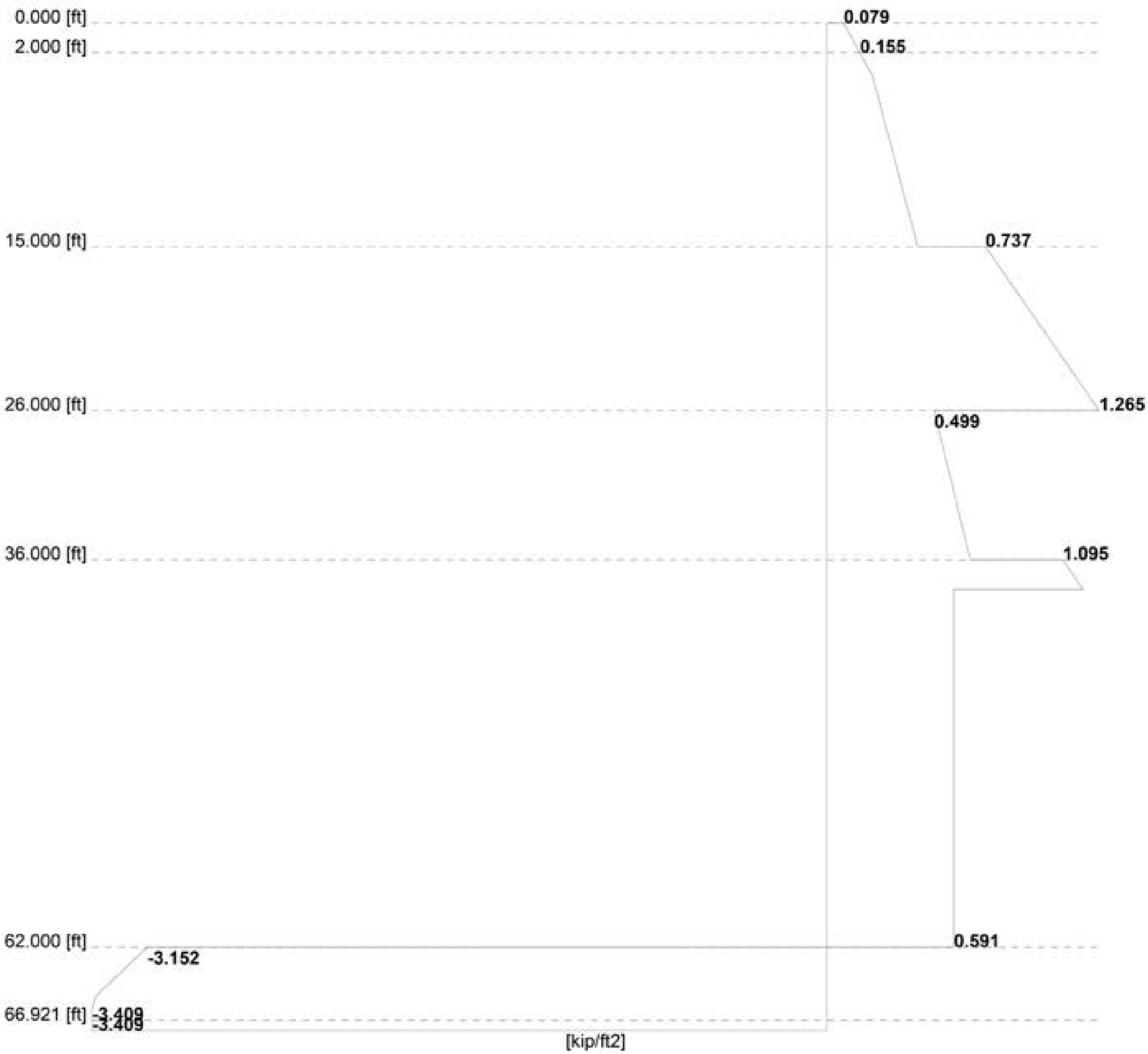
		Depth [ft]
Name	AZ18	
Inertia [in4/ft]	250.439	
Modulus [in3/ft]	33.480	
Area [in2/ft]	7.106	
Mass [lbs/ft2]	24.189	
Steel Grade [lb/in2]	51468.883	
Minimal Moment [kipft/ft]	-339.154	32.562
Maxmimal Moment [kipft/ft]	0.209	2.000
Normal Forces at Max. Moment [kip/ft]	2.081	32.562
Normal Forces at Min. Moment [kip/ft]	0.058	2.000
Deflection at Min. Moment [ft]	-2.781	32.562
Deflection at Max. Moment [ft]	0.000	2.000
Min. Stress at Min. Moment [lb/in2]	-123337.109	32.562
Max. Stress at Min. Moment [lb/in2]	123922.703	32.562
Min. Stress at Max. Moment [lb/in2]	-66.688	2.000
Max. Stress at Max. Moment [lb/in2]	83.134	2.000
Safety < Req. Safety = 1.500	0.415	
Sheet Pile Top Level [ft]	0.000	
Sheet Pile Tip Level [ft]	67.610	
Sheet Pile Length [ft]	67.610	
Included OverLength [ft]	0.000	
Vertical Equilibrium [kip/ft]	2.710	
Anchor Force (horiz.) [kip/ft]	-18.867	

Earth Pressure Diagram

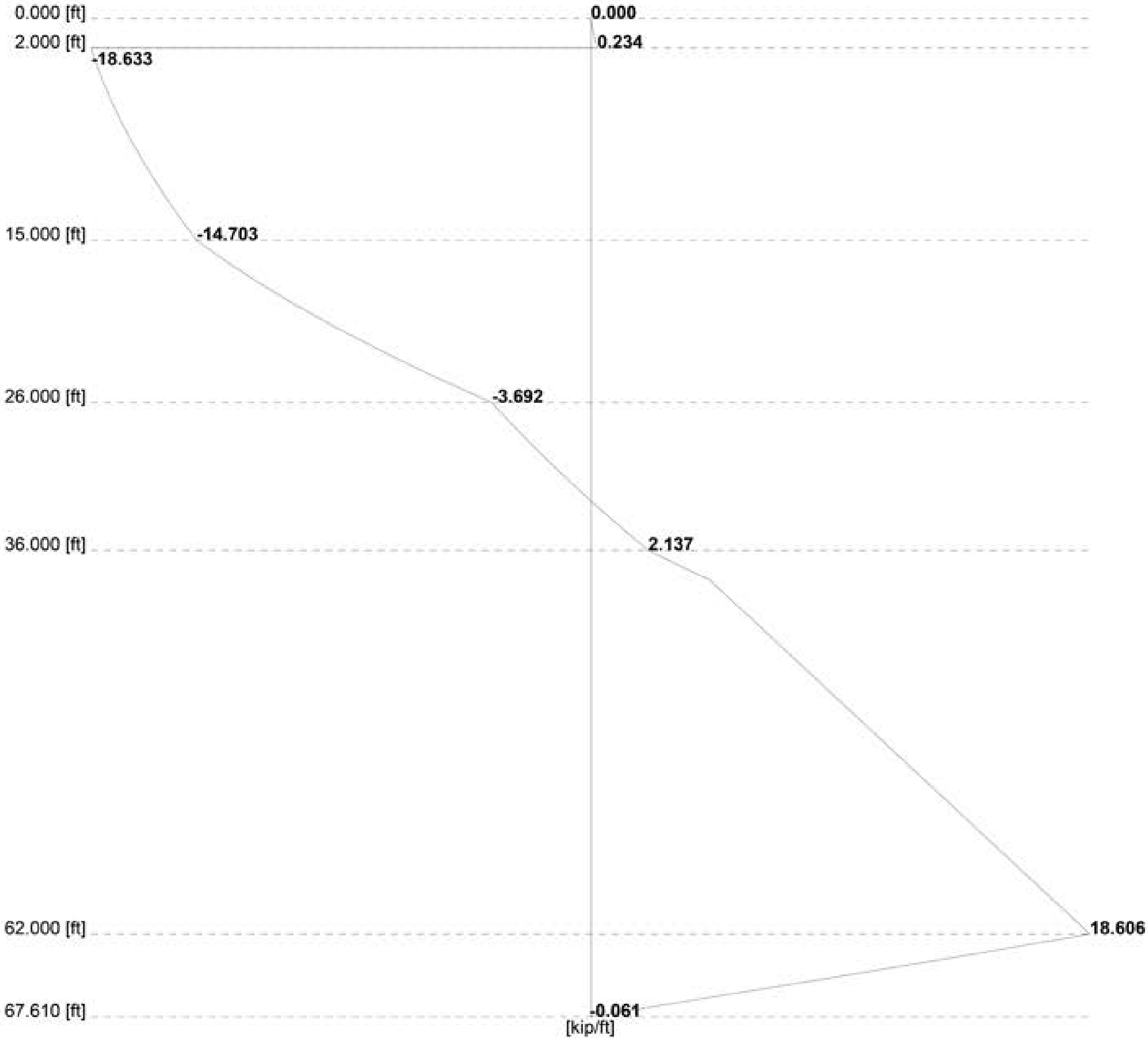


Water Pressure Diagram

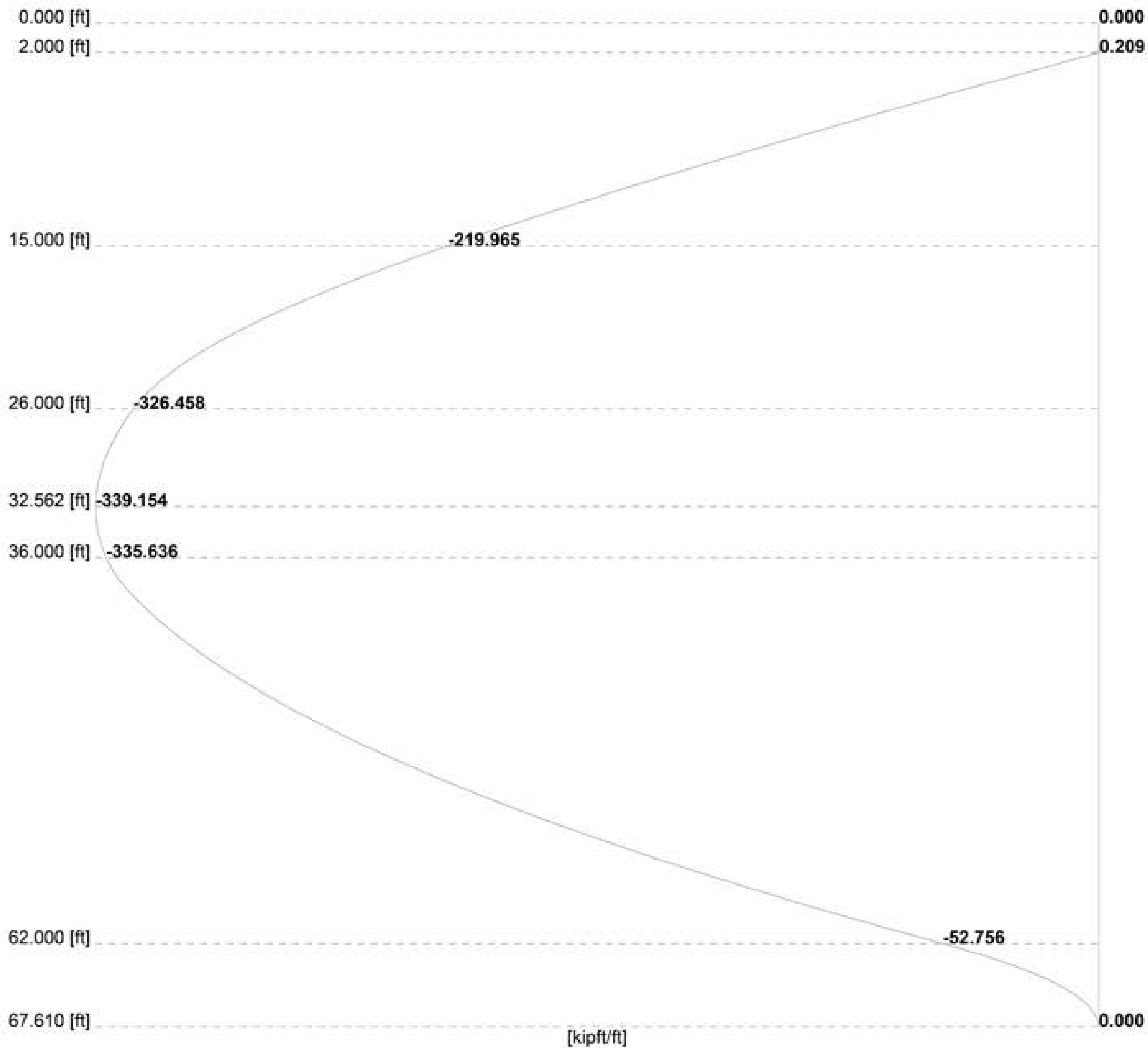
Total Pressure Diagram



Cross Force Diagram



Moment Diagram

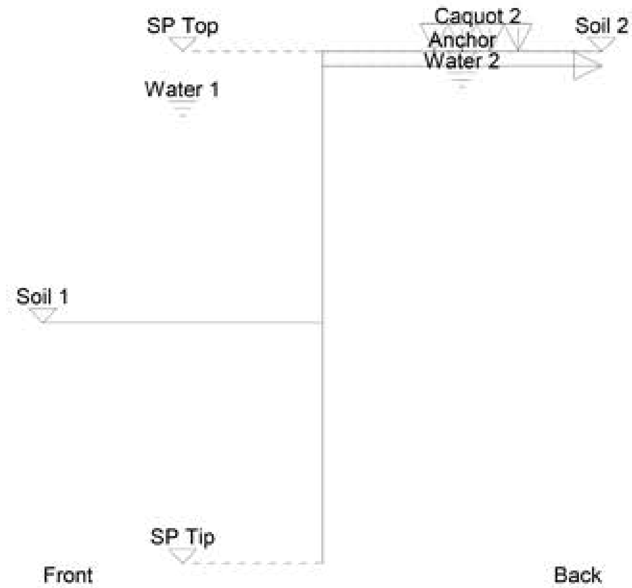


Sheet Pile Design According to Blum-Method

Project Name:	BASF North Works - Bulkhead Wall
Date:	7/19/2022
Author:	Arcadis
Company:	Arcadis
Comment:	Undrained / Unusual / Embedment

Geodata

	Unit
Sheet Pile Top Level [ft]	0.000
Sheet Pile Tip Level [ft]	71.711
Soil Level in Front [ft]	38.000
Soil Level behind [ft]	0.000
Anchorlevel [ft]	2.000
Water Level in Front [ft]	7.000
Water Level behind [ft]	3.000
Soil Surface Inclination in Front [Deg]	0.000
Soil Surface Inclination behind [Deg]	0.000
Caquot Surcharge in Front [kip/ft2]	0.000
Caquot Surcharge behind [kip/ft2]	0.250
Anchor Inclination [Deg]	0.000
Earth Support	Free



Soil Layers

Layers in Front

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	62.000	0.110	0.048	1.000	0.000	0.000	0.240
Layer 2	114.000	0.135	0.073	1.000	0.000	0.000	0.800

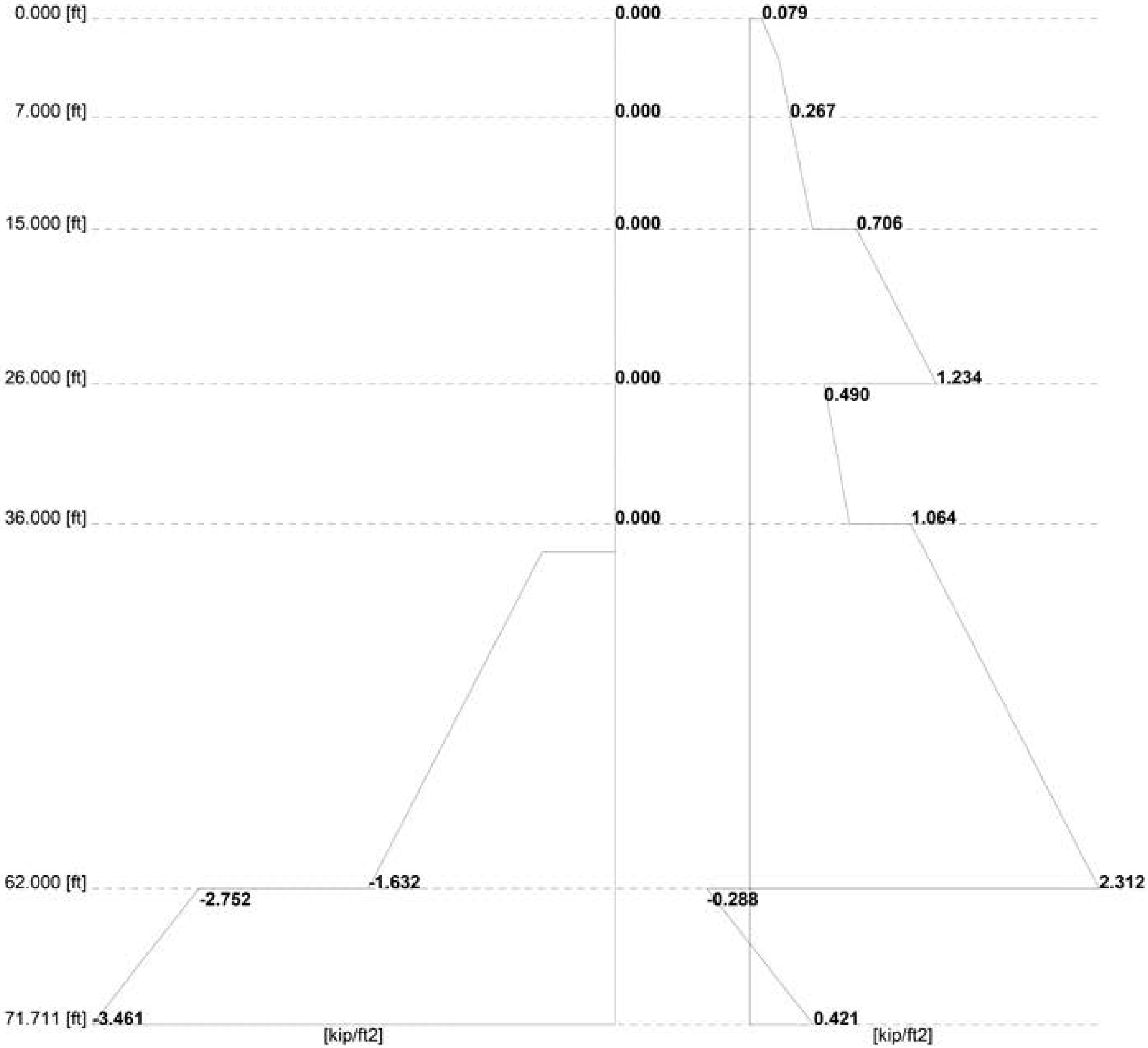
Layers behind

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	15.000	0.120	0.058	0.317	28.000	14.000	0.000
Layer 2	26.000	0.110	0.048	1.000	0.000	0.000	0.300
Layer 3	36.000	0.125	0.063	0.267	32.000	16.000	0.000
Layer 4	62.000	0.110	0.048	1.000	0.000	0.000	0.700
Layer 5	114.000	0.135	0.073	1.000	0.000	0.000	2.000

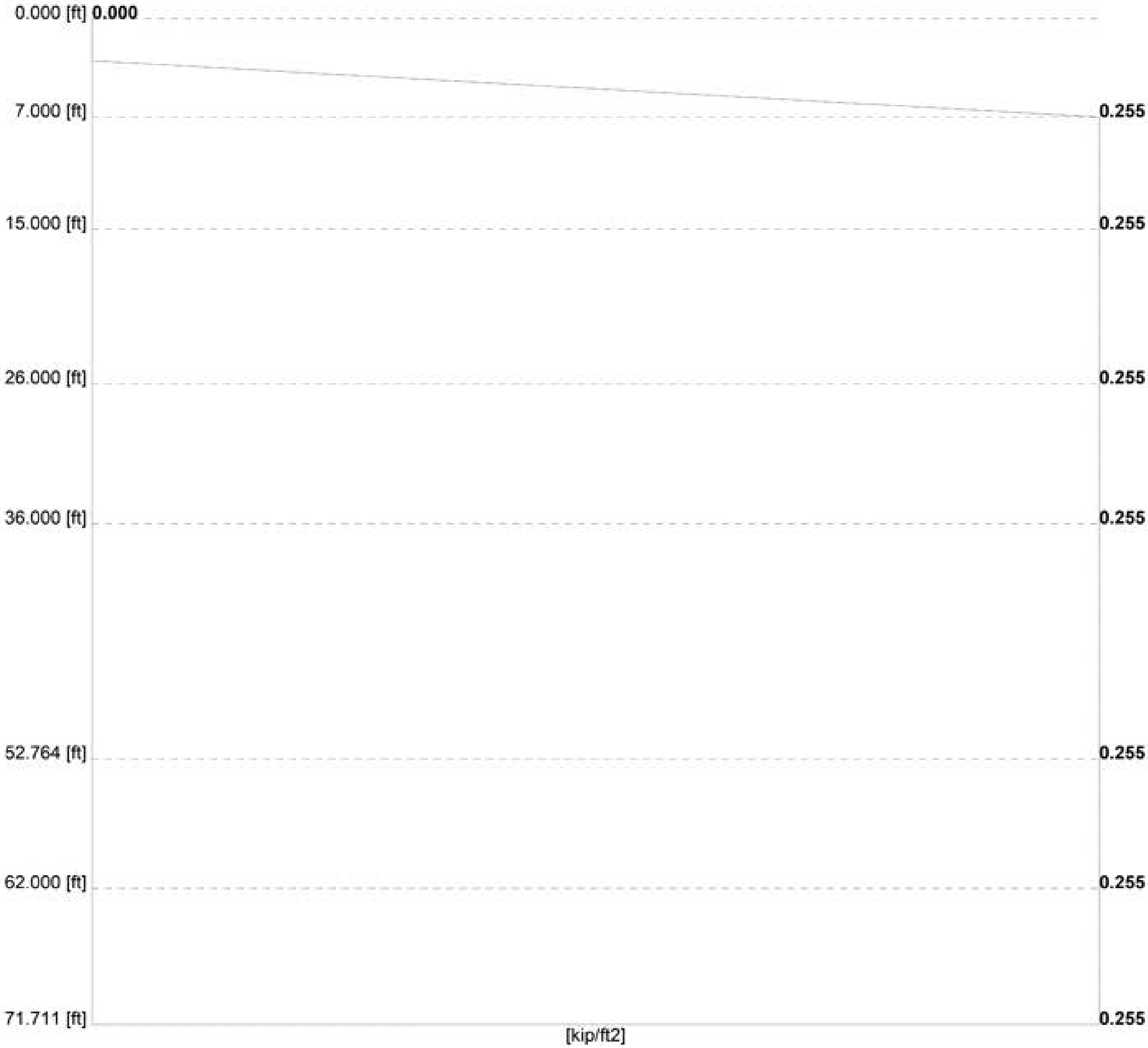
Pile Check

		Depth [ft]
Name	AZ18	
Inertia [in4/ft]	250.439	
Modulus [in3/ft]	33.480	
Area [in2/ft]	7.106	
Mass [lbs/ft2]	24.189	
Steel Grade [lb/in2]	51468.883	
Minimal Moment [kipft/ft]	-501.842	34.202
Maxmimal Moment [kipft/ft]	0.209	2.000
Normal Forces at Max. Moment [kip/ft]	2.325	34.202
Normal Forces at Min. Moment [kip/ft]	0.058	2.000
Deflection at Min. Moment [ft]	-4.588	34.202
Deflection at Max. Moment [ft]	0.000	2.000
Min. Stress at Min. Moment [lb/in2]	-183360.859	34.202
Max. Stress at Min. Moment [lb/in2]	184015.344	34.202
Min. Stress at Max. Moment [lb/in2]	-66.688	2.000
Max. Stress at Max. Moment [lb/in2]	83.134	2.000
Safety < Req. Safety = 1.500	0.280	
Sheet Pile Top Level [ft]	0.000	
Sheet Pile Tip Level [ft]	71.711	
Sheet Pile Length [ft]	71.711	
Included OverLength [ft]	0.000	
Vertical Equilibrium [kip/ft]	2.657	
Anchor Force (horiz.) [kip/ft]	-27.074	

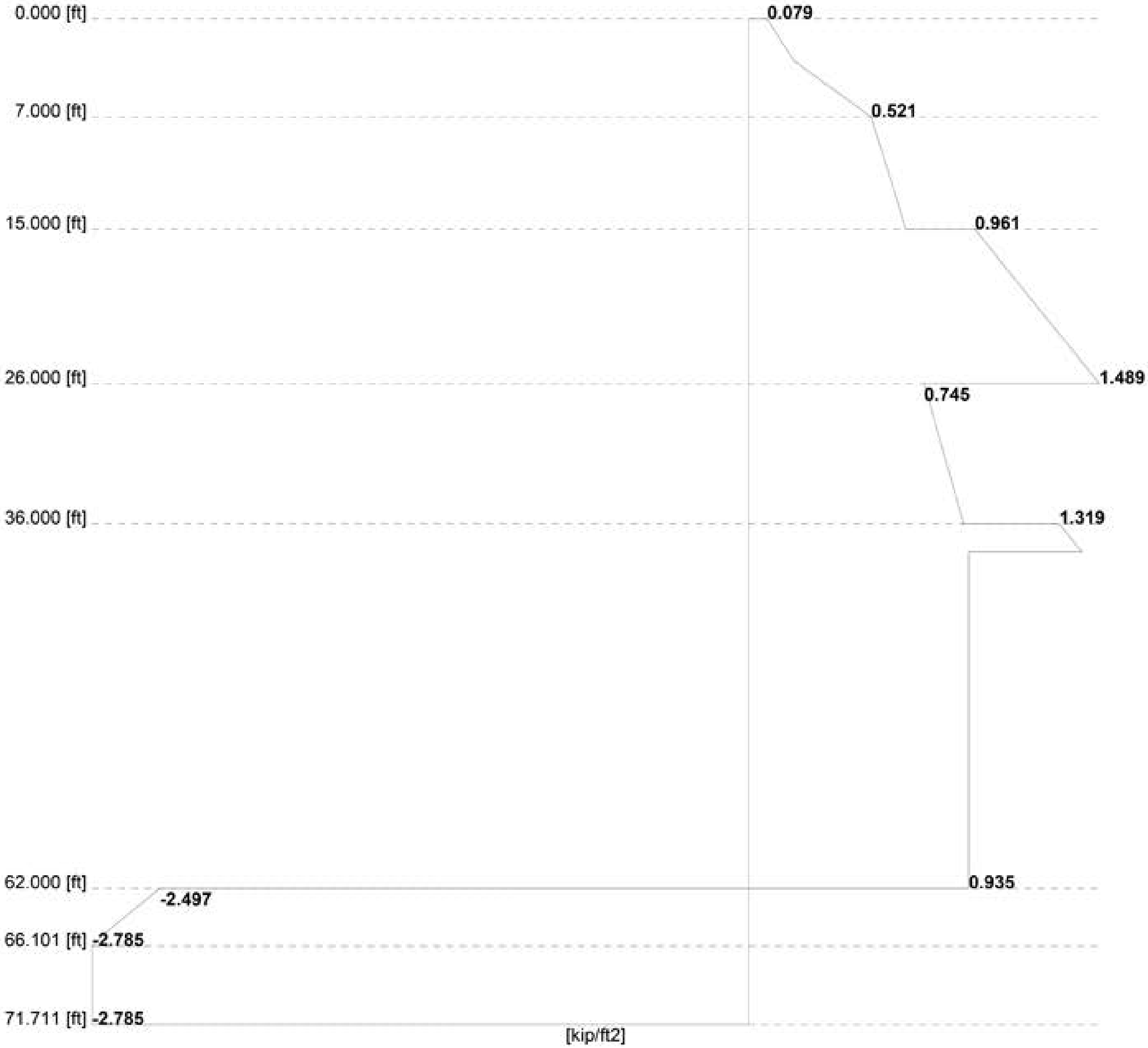
Earth Pressure Diagram



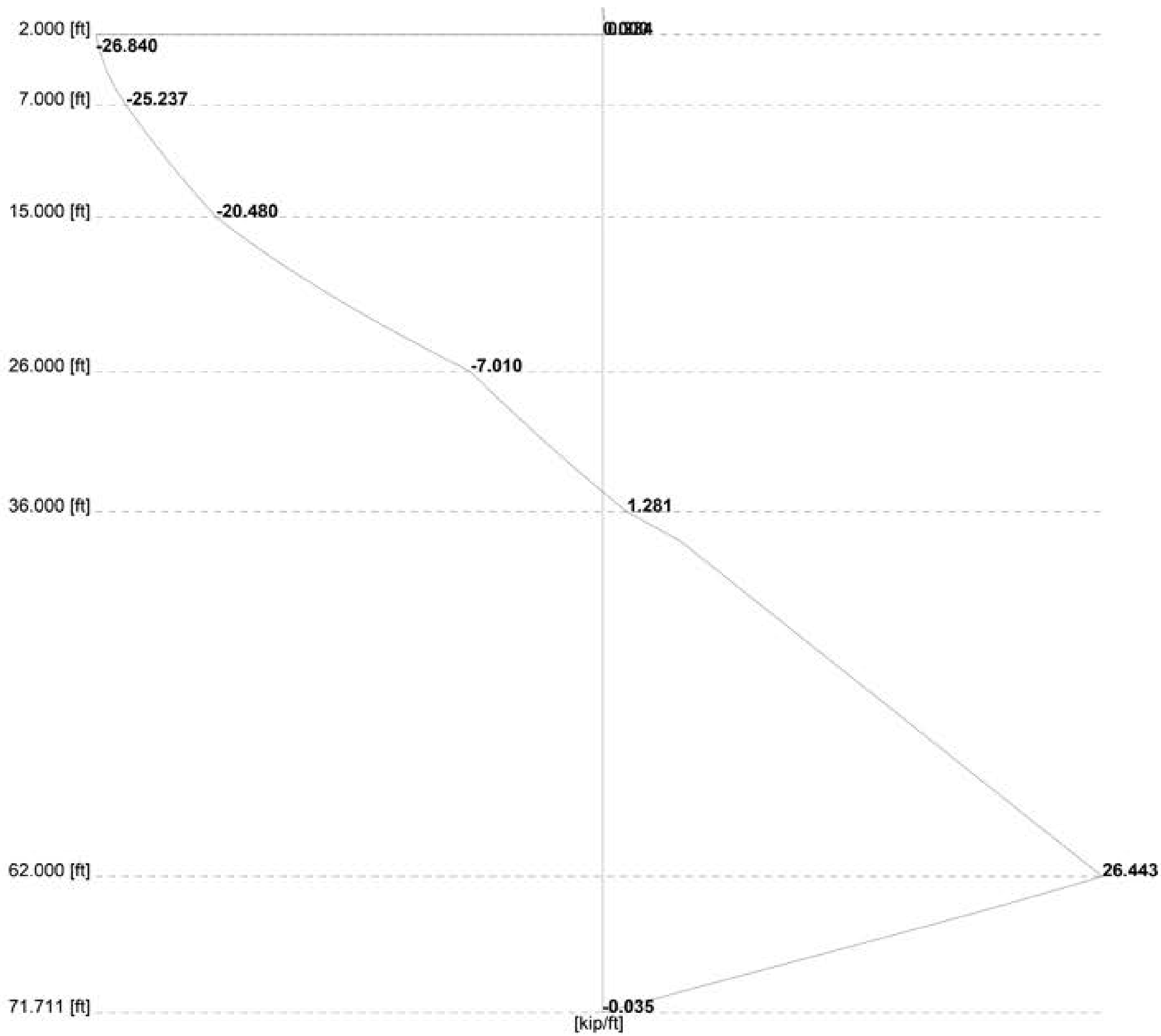
Water Pressure Diagram



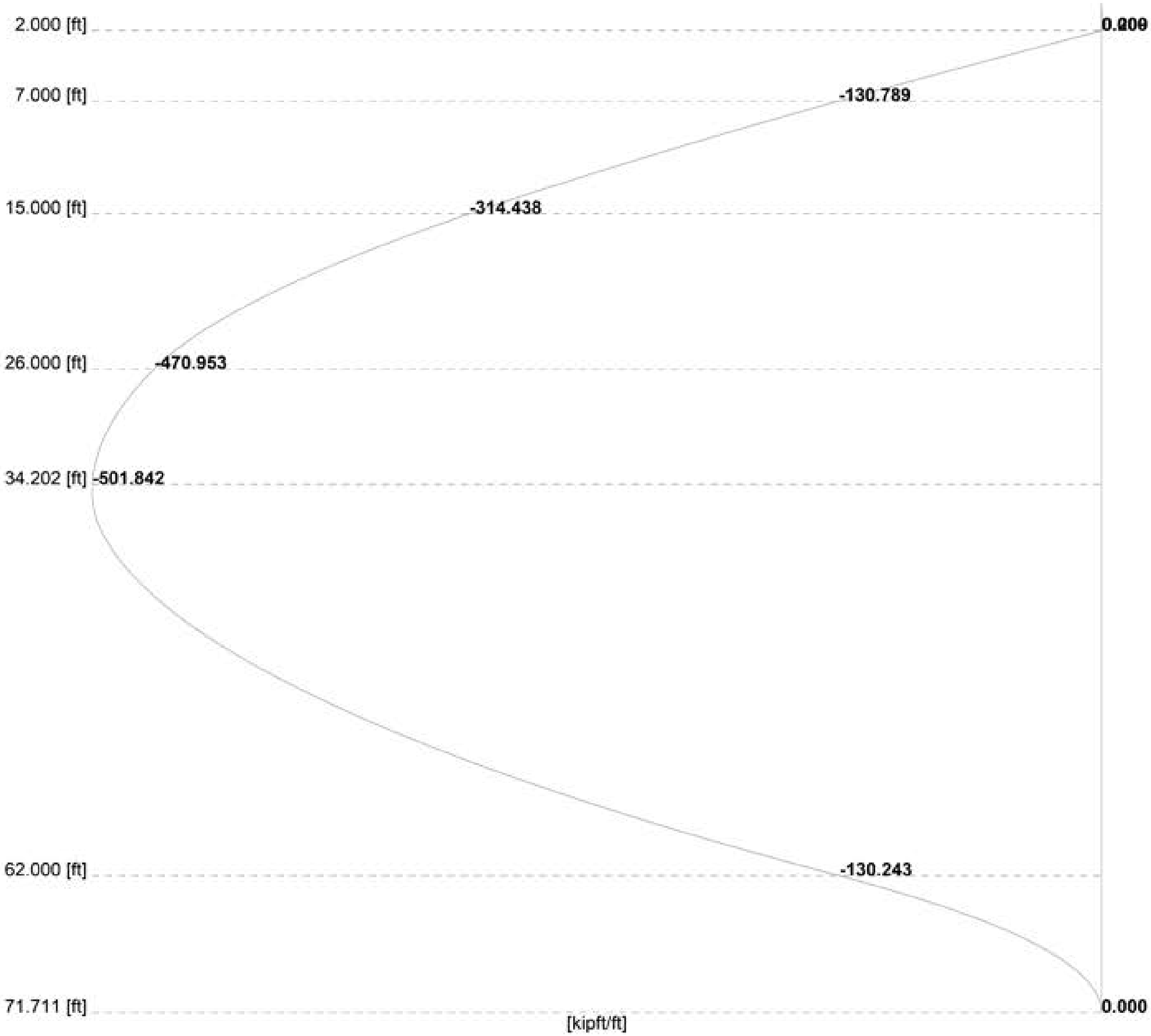
Total Pressure Diagram



Cross Force Diagram



Moment Diagram

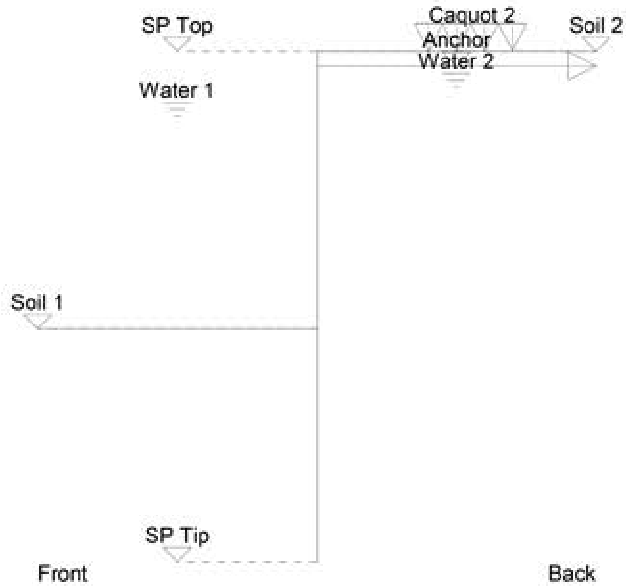


Sheet Pile Design According to Blum-Method

Project Name:	BASF North Works - Bulkhead Wall
Date:	7/19/2022
Author:	Arcadis
Company:	Arcadis
Comment:	Undrained / Unusual / Structural Demand

Geodata

	Unit
Sheet Pile Top Level [ft]	0.000
Sheet Pile Tip Level [ft]	69.940
Soil Level in Front [ft]	38.000
Soil Level behind [ft]	0.000
Anchorlevel [ft]	2.000
Water Level in Front [ft]	7.000
Water Level behind [ft]	3.000
Soil Surface Inclination in Front [Deg]	0.000
Soil Surface Inclination behind [Deg]	0.000
Caquot Surcharge in Front [kip/ft2]	0.000
Caquot Surcharge behind [kip/ft2]	0.250
Anchor Inclination [Deg]	0.000
Earth Support	Free



Soil Layers

Layers in Front

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	62.000	0.110	0.048	1.000	0.000	0.000	0.300
Layer 2	114.000	0.135	0.073	1.000	0.000	0.000	1.000

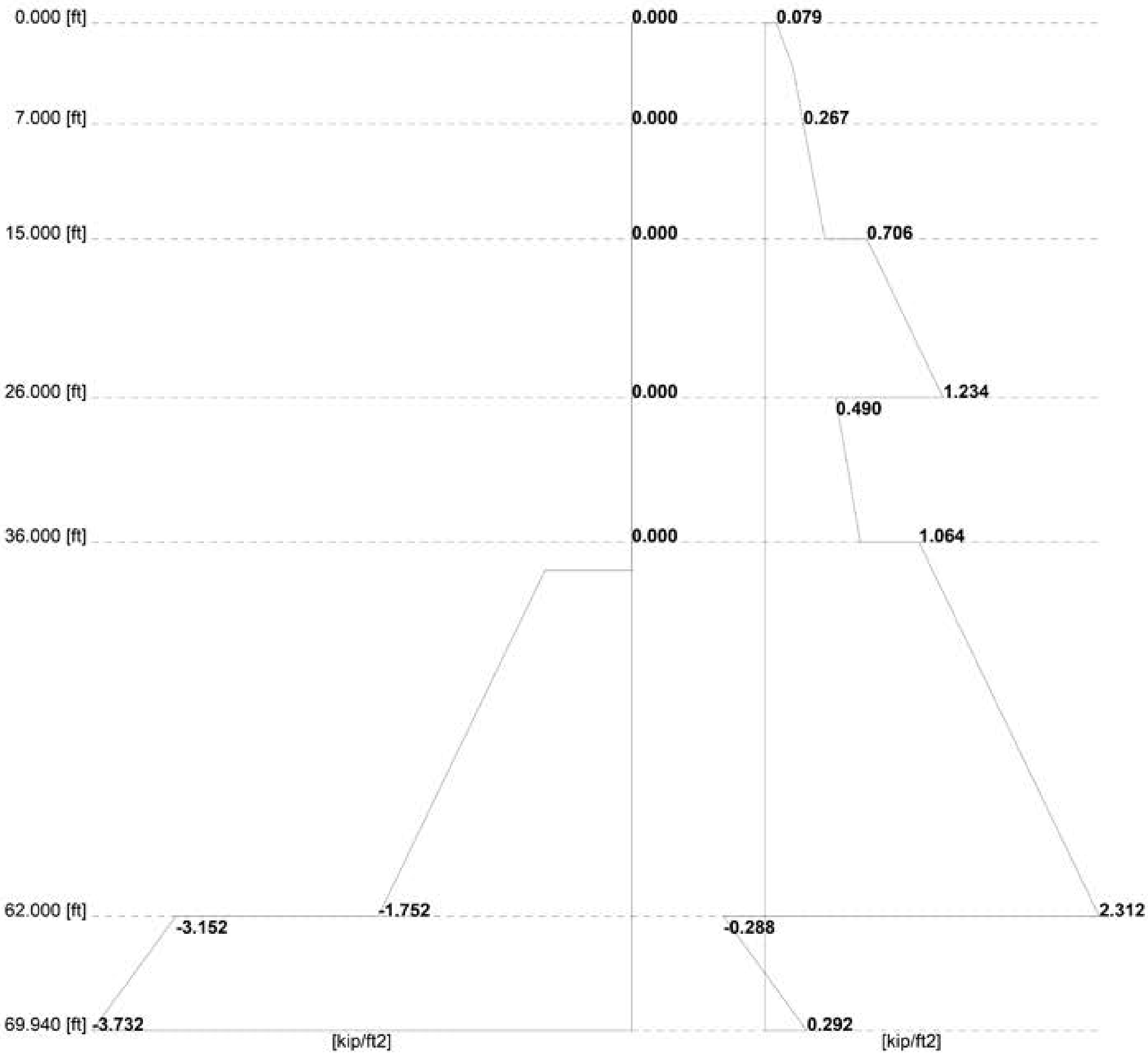
Layers behind

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	15.000	0.120	0.058	0.317	28.000	14.000	0.000
Layer 2	26.000	0.110	0.048	1.000	0.000	0.000	0.300
Layer 3	36.000	0.125	0.063	0.267	32.000	16.000	0.000
Layer 4	62.000	0.110	0.048	1.000	0.000	0.000	0.700
Layer 5	114.000	0.135	0.073	1.000	0.000	0.000	2.000

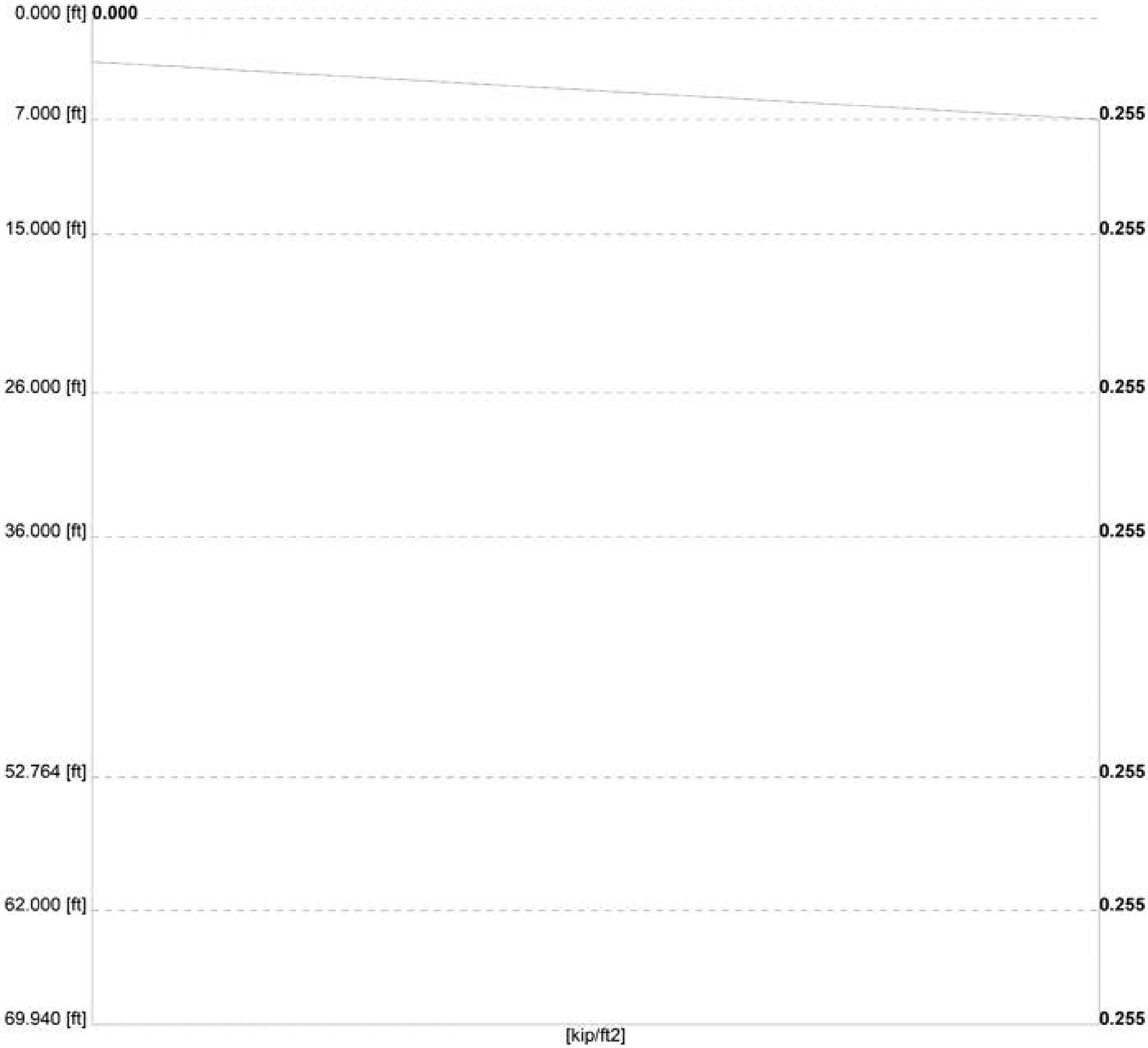
Pile Check

		Depth [ft]
Name	AZ18	
Inertia [in4/ft]	250.439	
Modulus [in3/ft]	33.480	
Area [in2/ft]	7.106	
Mass [lbs/ft2]	24.189	
Steel Grade [lb/in2]	51468.883	
Minimal Moment [kipft/ft]	-466.935	33.349
Maxmimal Moment [kipft/ft]	0.209	2.000
Normal Forces at Max. Moment [kip/ft]	2.179	33.349
Normal Forces at Min. Moment [kip/ft]	0.058	2.000
Deflection at Min. Moment [ft]	-4.069	33.349
Deflection at Max. Moment [ft]	0.000	2.000
Min. Stress at Min. Moment [lb/in2]	-170225.141	33.349
Max. Stress at Min. Moment [lb/in2]	170838.484	33.349
Min. Stress at Max. Moment [lb/in2]	-66.688	2.000
Max. Stress at Max. Moment [lb/in2]	83.134	2.000
Safety < Req. Safety = 1.500	0.301	
Sheet Pile Top Level [ft]	0.000	
Sheet Pile Tip Level [ft]	69.940	
Sheet Pile Length [ft]	69.940	
Included OverLength [ft]	0.000	
Vertical Equilibrium [kip/ft]	2.657	
Anchor Force (horiz.) [kip/ft]	-25.980	

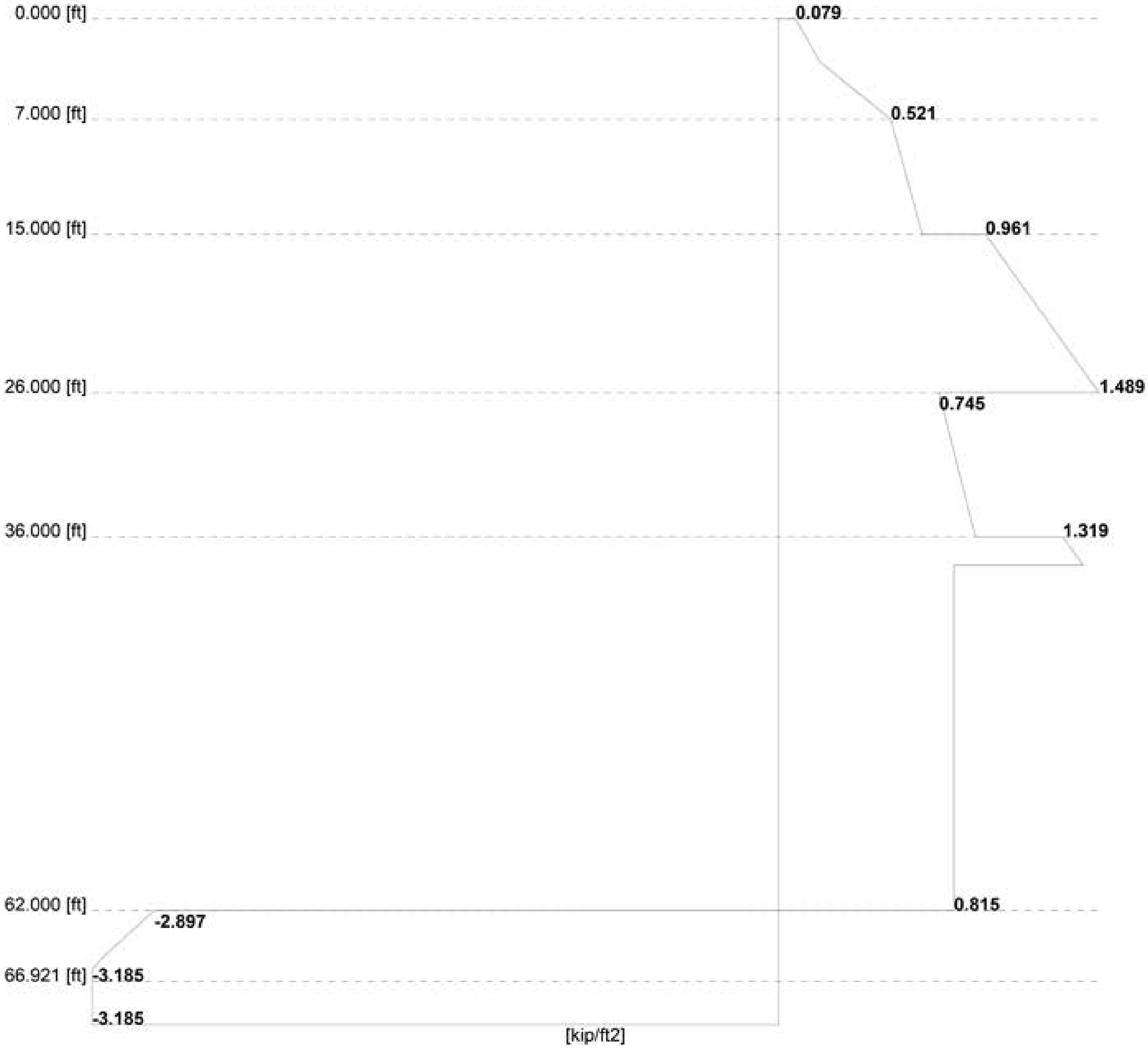
Earth Pressure Diagram



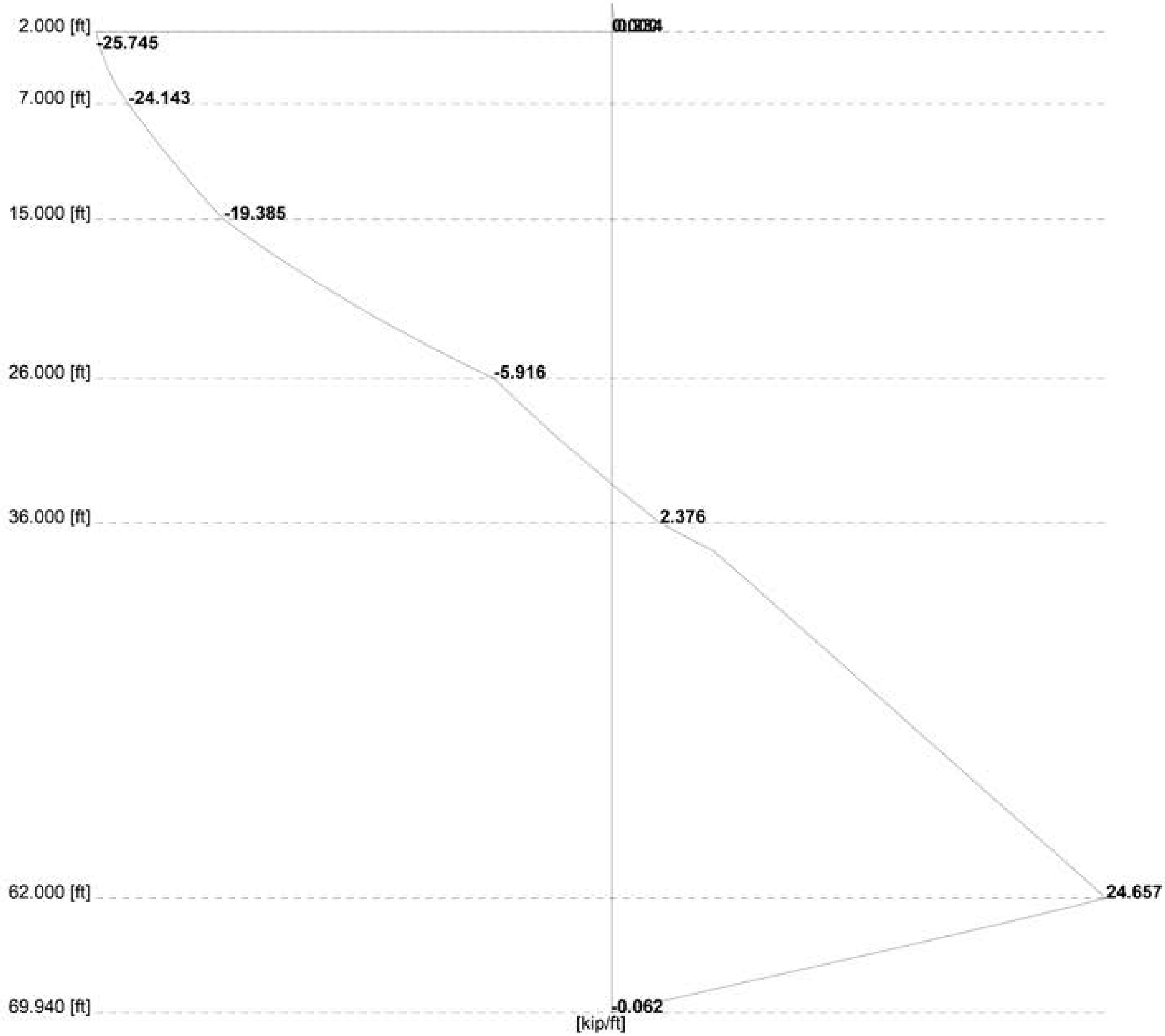
Water Pressure Diagram



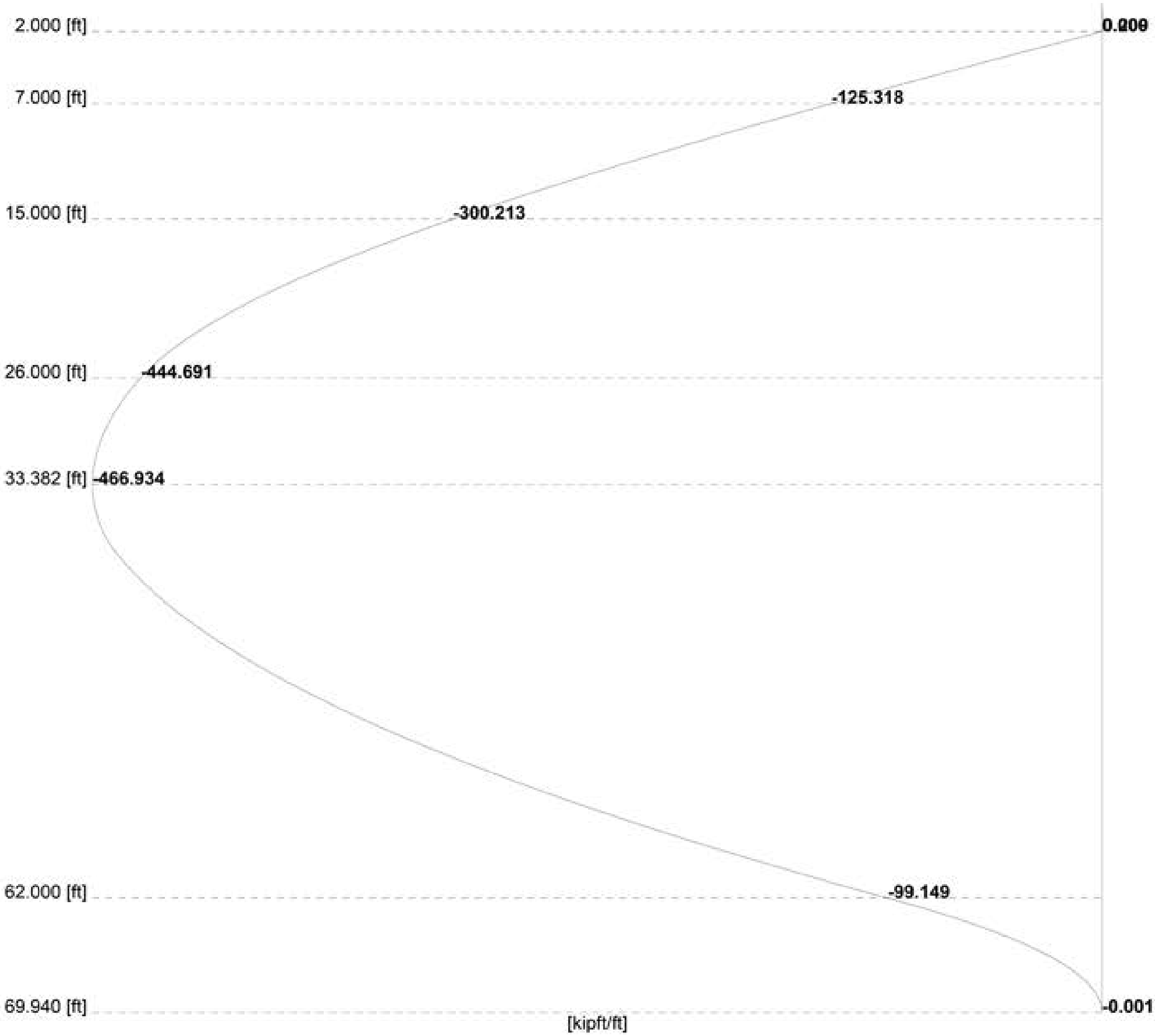
Total Pressure Diagram



Cross Force Diagram



Moment Diagram

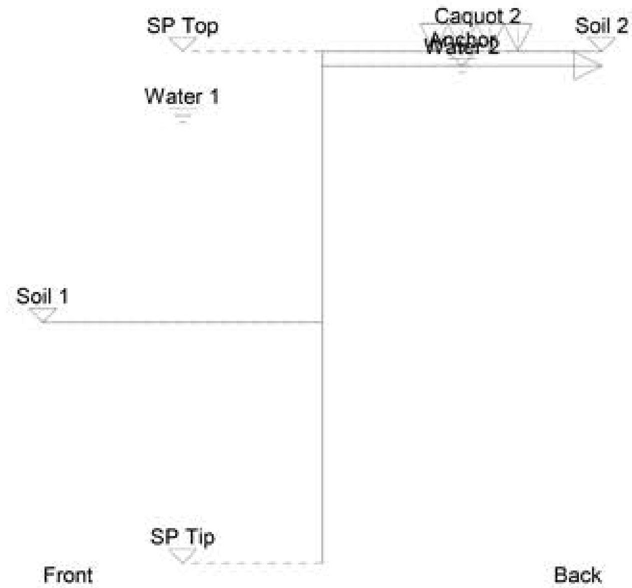


Sheet Pile Design According to Blum-Method

Project Name:	BASF North Works - Bulkhead Wall
Date:	7/20/2022
Author:	Arcadis
Company:	Arcadis
Comment:	Undrained / Extreme / Embedment

Geodata

	Unit
Sheet Pile Top Level [ft]	0.000
Sheet Pile Tip Level [ft]	71.810
Soil Level in Front [ft]	38.000
Soil Level behind [ft]	0.000
Anchorlevel [ft]	2.000
Water Level in Front [ft]	8.000
Water Level behind [ft]	1.000
Soil Surface Inclination in Front [Deg]	0.000
Soil Surface Inclination behind [Deg]	0.000
Caquot Surcharge in Front [kip/ft2]	0.000
Caquot Surcharge behind [kip/ft2]	0.250
Anchor Inclination [Deg]	0.000
Earth Support	Free



Soil Layers

Layers in Front

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	62.000	0.110	0.048	1.000	0.000	0.000	0.273
Layer 2	114.000	0.135	0.073	1.000	0.000	0.000	0.909

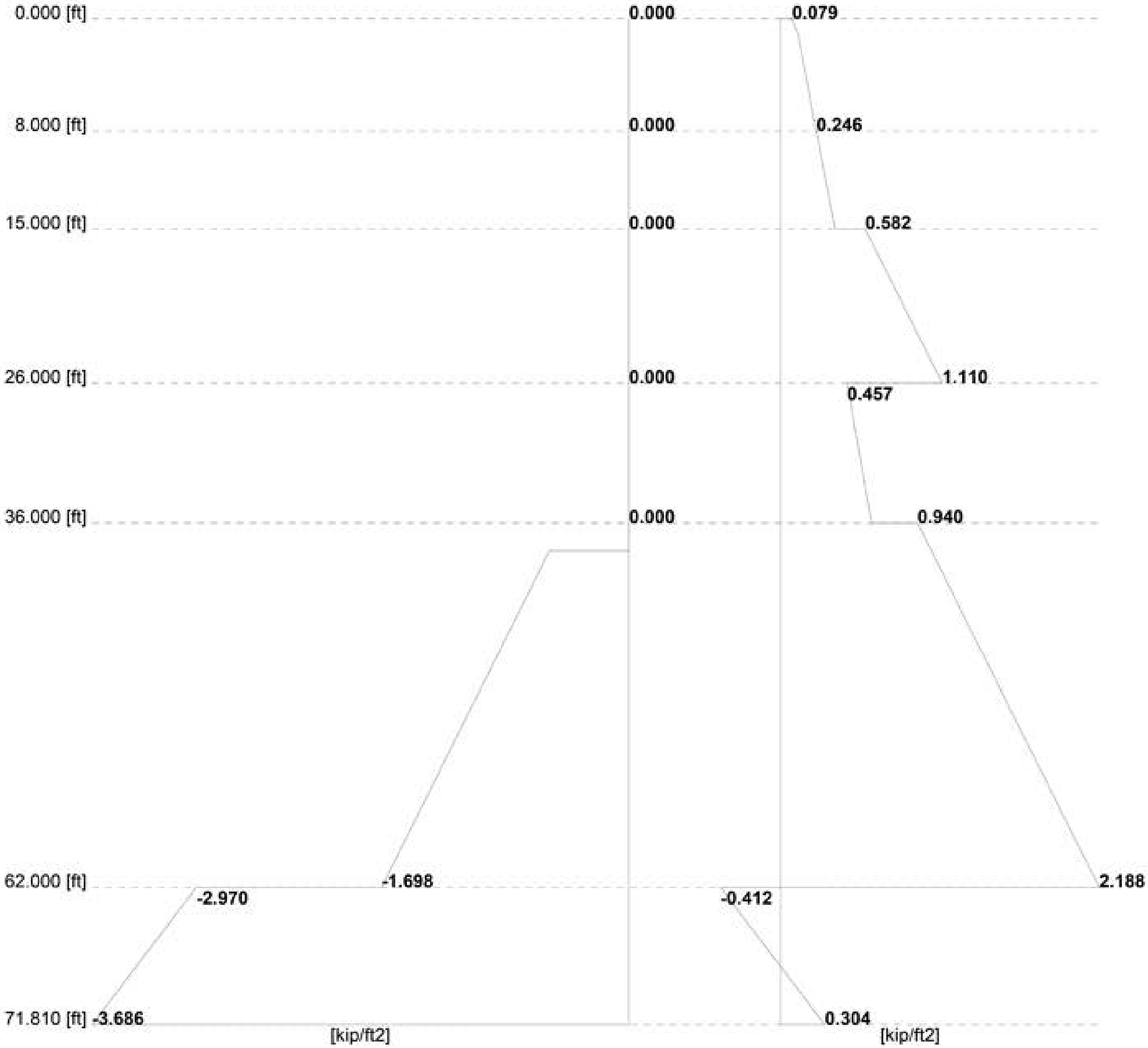
Layers behind

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	15.000	0.120	0.058	0.317	28.000	14.000	0.000
Layer 2	26.000	0.110	0.048	1.000	0.000	0.000	0.300
Layer 3	36.000	0.125	0.063	0.267	32.000	16.000	0.000
Layer 4	62.000	0.110	0.048	1.000	0.000	0.000	0.700
Layer 5	114.000	0.135	0.073	1.000	0.000	0.000	2.000

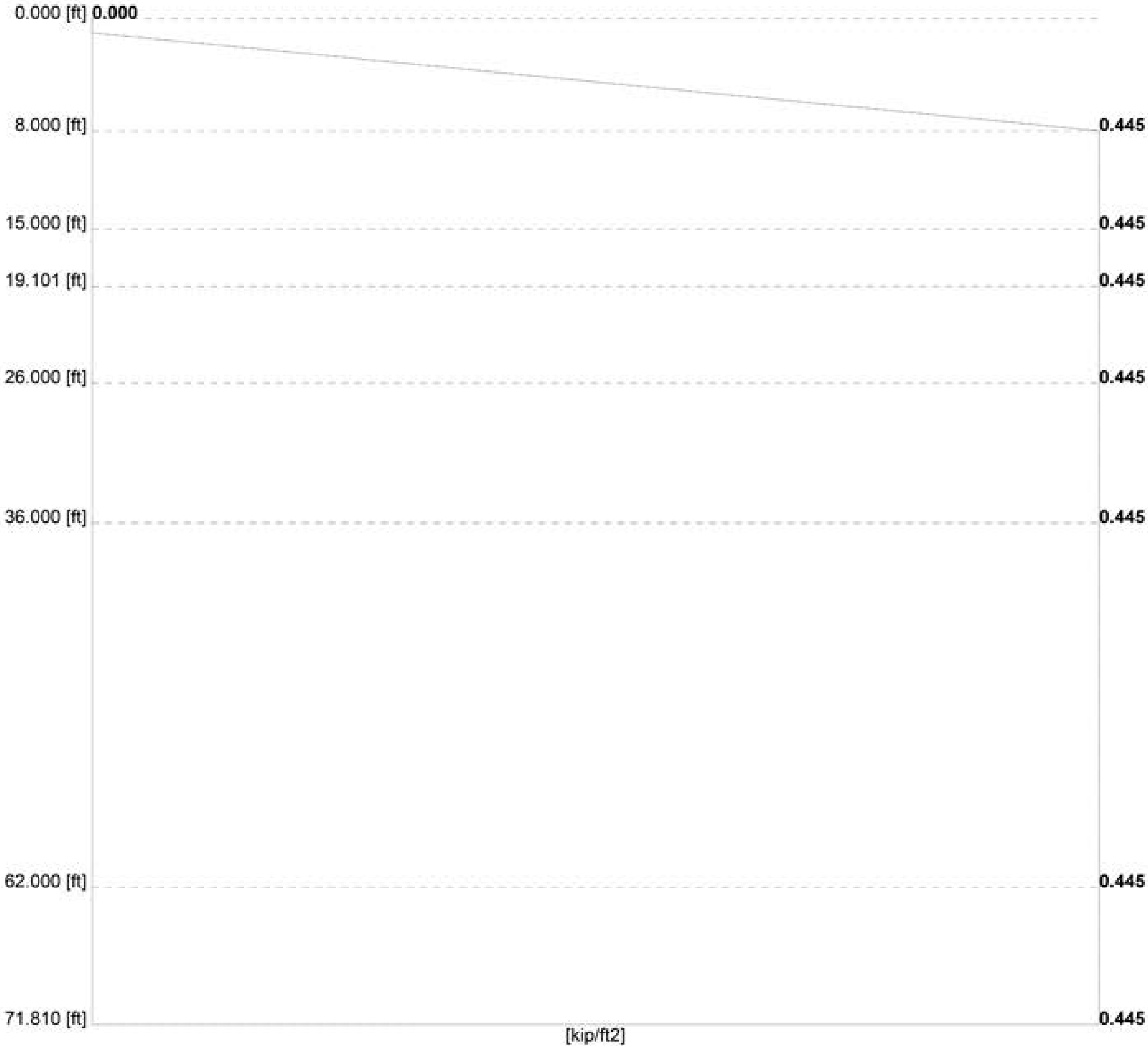
Pile Check

		Depth [ft]
Name	AZ18	
Inertia [in4/ft]	250.439	
Modulus [in3/ft]	33.480	
Area [in2/ft]	7.106	
Mass [lbs/ft2]	24.189	
Steel Grade [lb/in2]	50000.000	
Minimal Moment [kipft/ft]	-541.036	33.874
Maxmimal Moment [kipft/ft]	0.216	2.000
Normal Forces at Max. Moment [kip/ft]	2.120	33.874
Normal Forces at Min. Moment [kip/ft]	0.056	2.000
Deflection at Min. Moment [ft]	-4.940	33.874
Deflection at Max. Moment [ft]	0.000	2.000
Min. Stress at Min. Moment [lb/in2]	-197367.625	33.874
Max. Stress at Min. Moment [lb/in2]	197964.344	33.874
Min. Stress at Max. Moment [lb/in2]	-69.661	2.000
Max. Stress at Max. Moment [lb/in2]	85.418	2.000
Safety < Req. Safety = 1.500	0.253	
Sheet Pile Top Level [ft]	0.000	
Sheet Pile Tip Level [ft]	71.810	
Sheet Pile Length [ft]	71.810	
Included OverLength [ft]	0.000	
Vertical Equilibrium [kip/ft]	2.435	
Anchor Force (horiz.) [kip/ft]	-30.021	

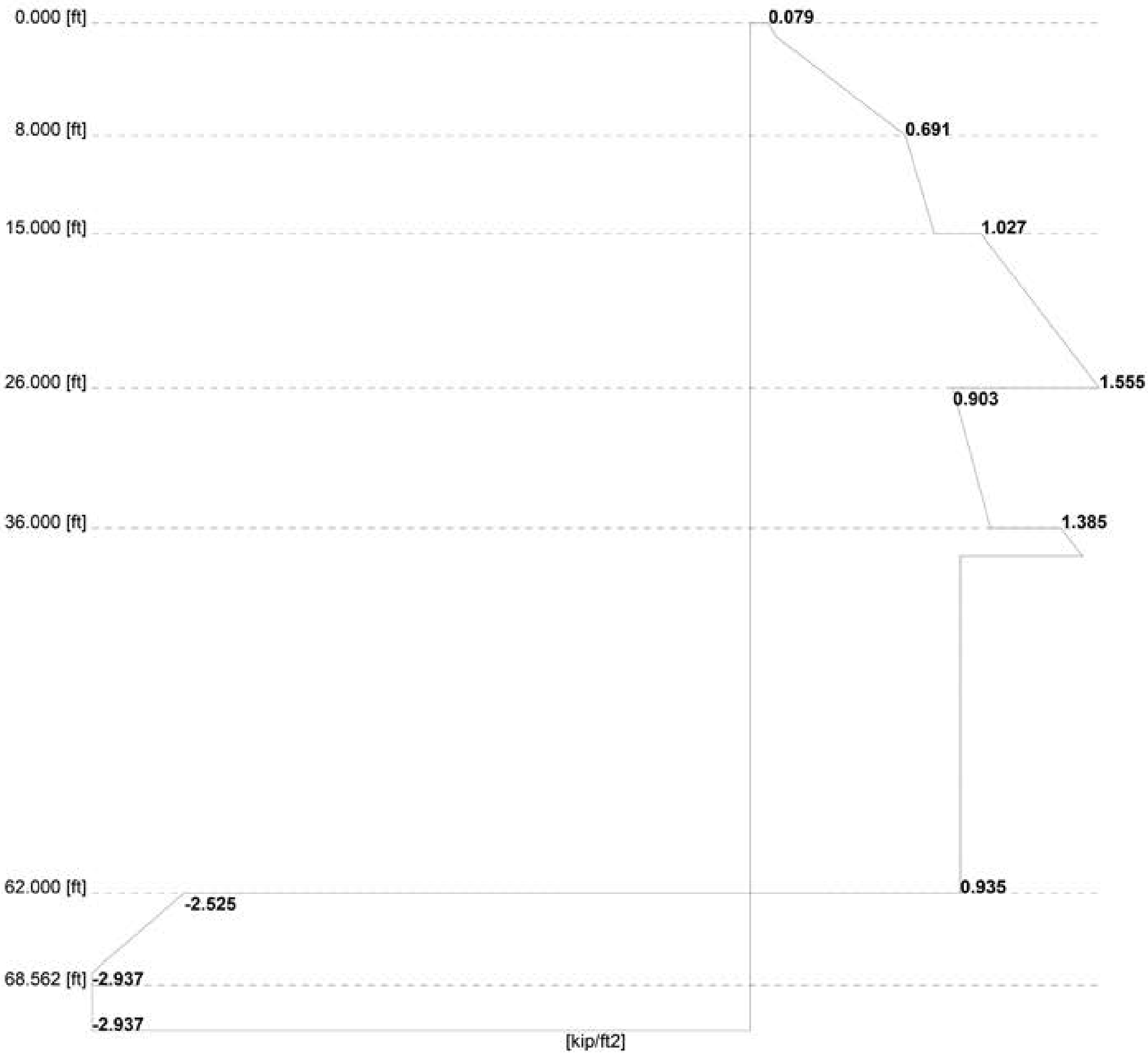
Earth Pressure Diagram



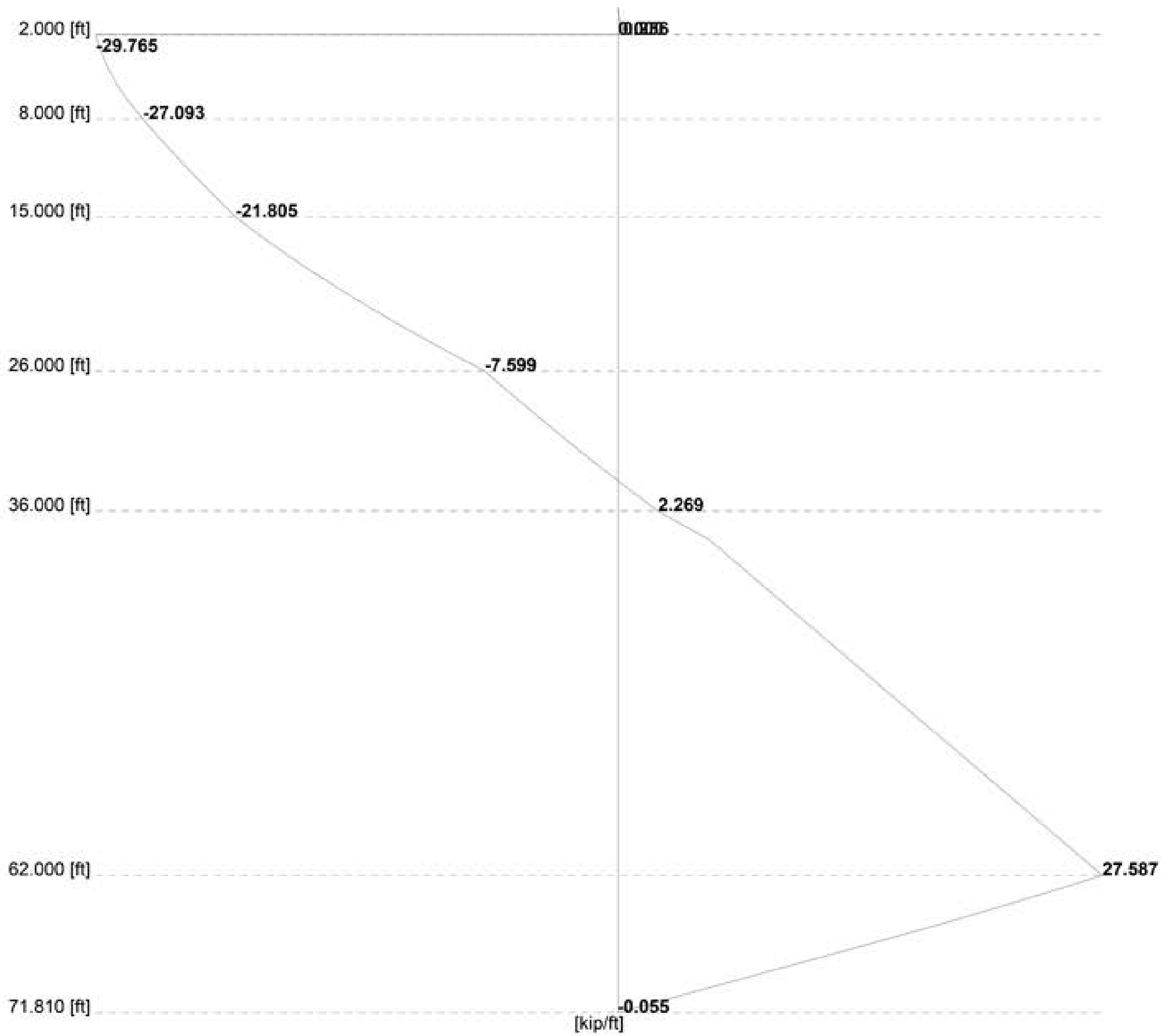
Water Pressure Diagram



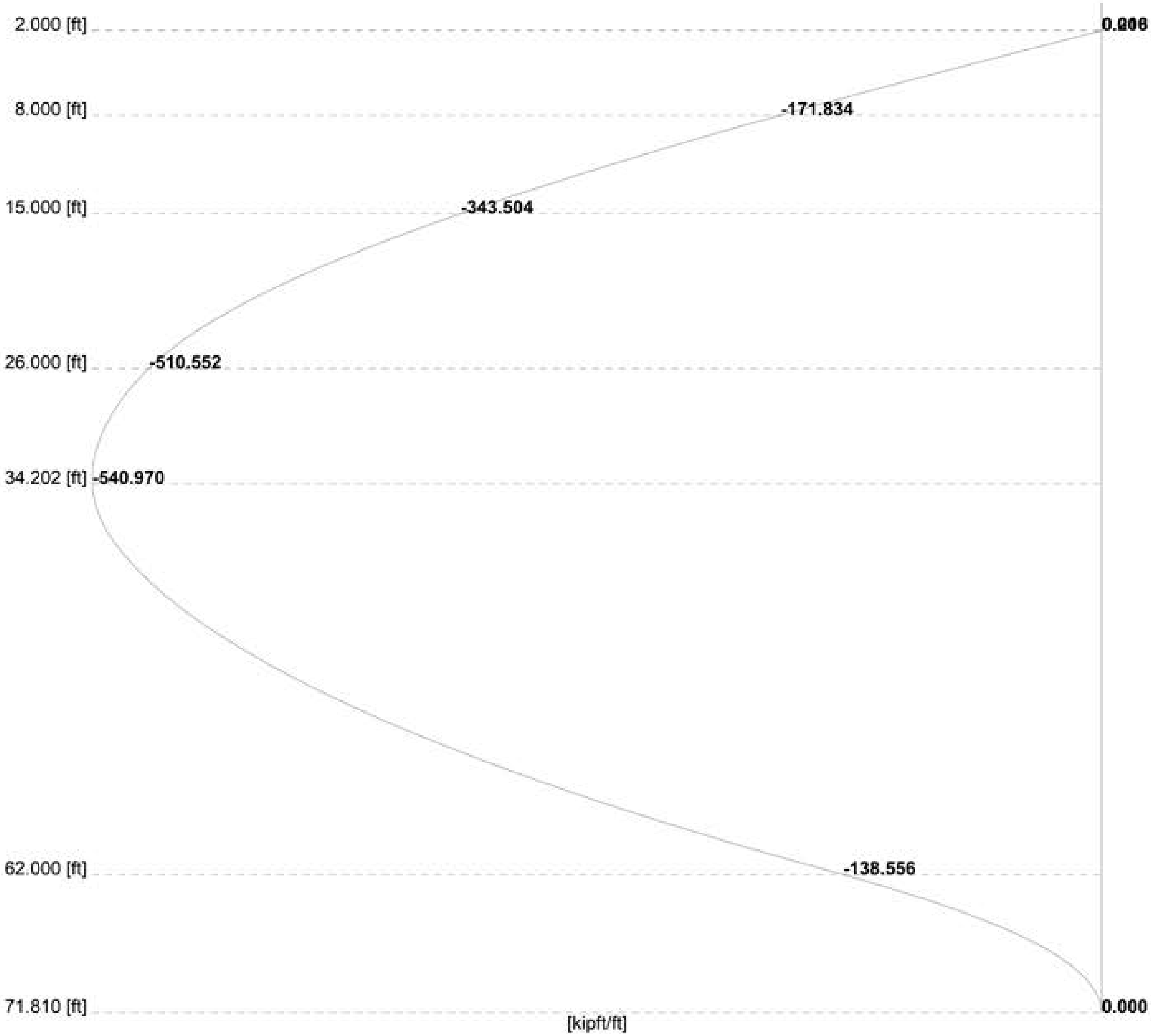
Total Pressure Diagram



Cross Force Diagram



Moment Diagram

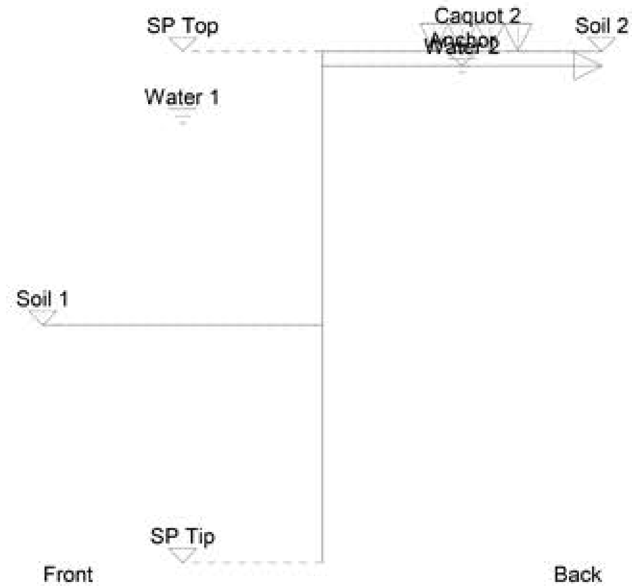


Sheet Pile Design According to Blum-Method

Project Name:	BASF North Works - Bulkhead Wall
Date:	7/20/2022
Author:	Arcadis
Company:	Arcadis
Comment:	Undrained / Extreme / Structural Demand

Geodata

	Unit
Sheet Pile Top Level [ft]	0.000
Sheet Pile Tip Level [ft]	70.990
Soil Level in Front [ft]	38.000
Soil Level behind [ft]	0.000
Anchorlevel [ft]	2.000
Water Level in Front [ft]	8.000
Water Level behind [ft]	1.000
Soil Surface Inclination in Front [Deg]	0.000
Soil Surface Inclination behind [Deg]	0.000
Caquot Surcharge in Front [kip/ft2]	0.000
Caquot Surcharge behind [kip/ft2]	0.250
Anchor Inclination [Deg]	0.000
Earth Support	Free



Soil Layers

Layers in Front

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	62.000	0.110	0.048	1.000	0.000	0.000	0.300
Layer 2	114.000	0.135	0.073	1.000	0.000	0.000	1.000

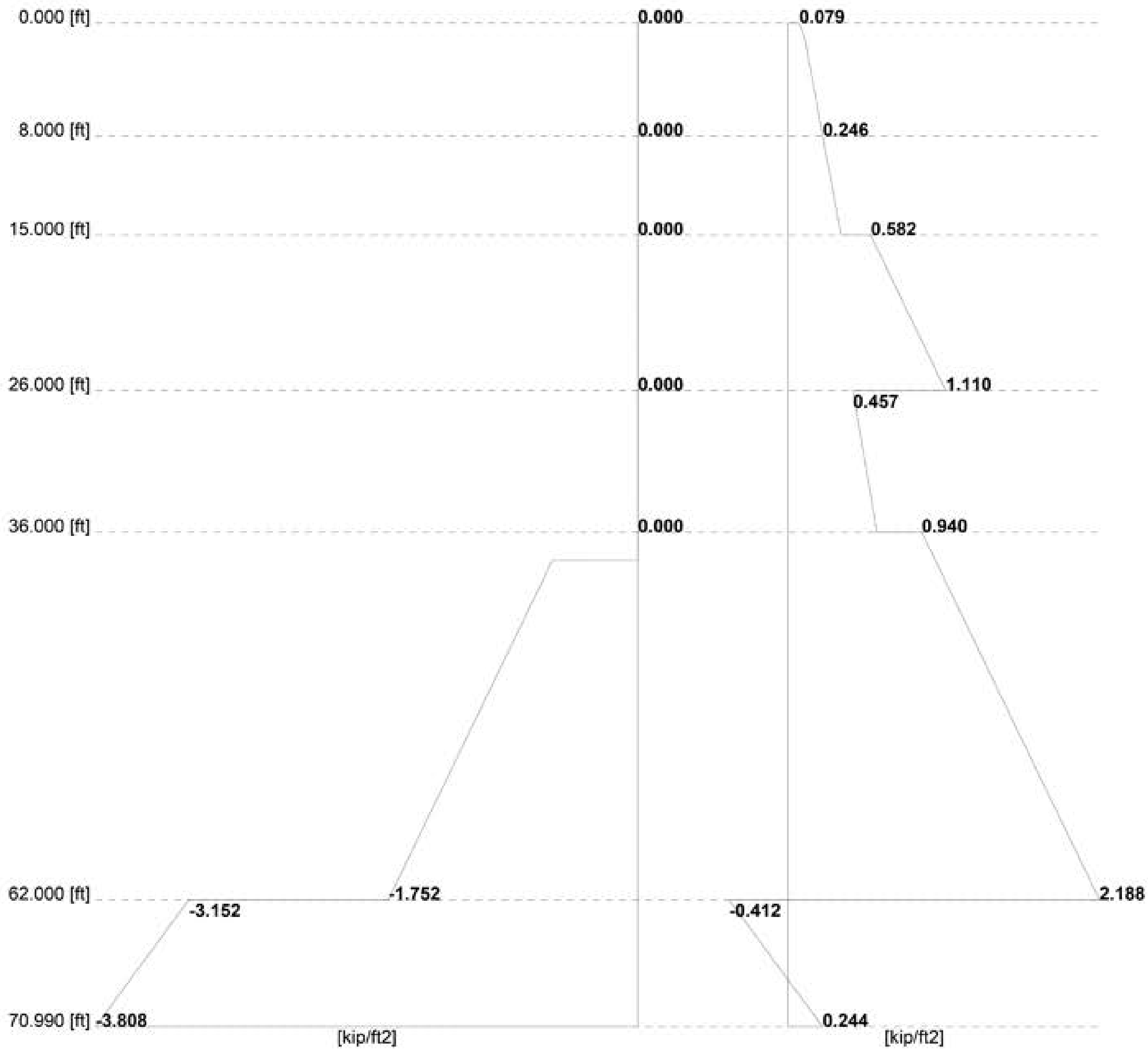
Layers behind

	Layer Tip [ft]	Density Moist [kip/ft3]	Density Submerged [kip/ft3]	Kph	Phi [Deg]	Delta [Deg]	Cohesion [kip/ft2]
Layer 1	15.000	0.120	0.058	0.317	28.000	14.000	0.000
Layer 2	26.000	0.110	0.048	1.000	0.000	0.000	0.300
Layer 3	36.000	0.125	0.063	0.267	32.000	16.000	0.000
Layer 4	62.000	0.110	0.048	1.000	0.000	0.000	0.700
Layer 5	114.000	0.135	0.073	1.000	0.000	0.000	2.000

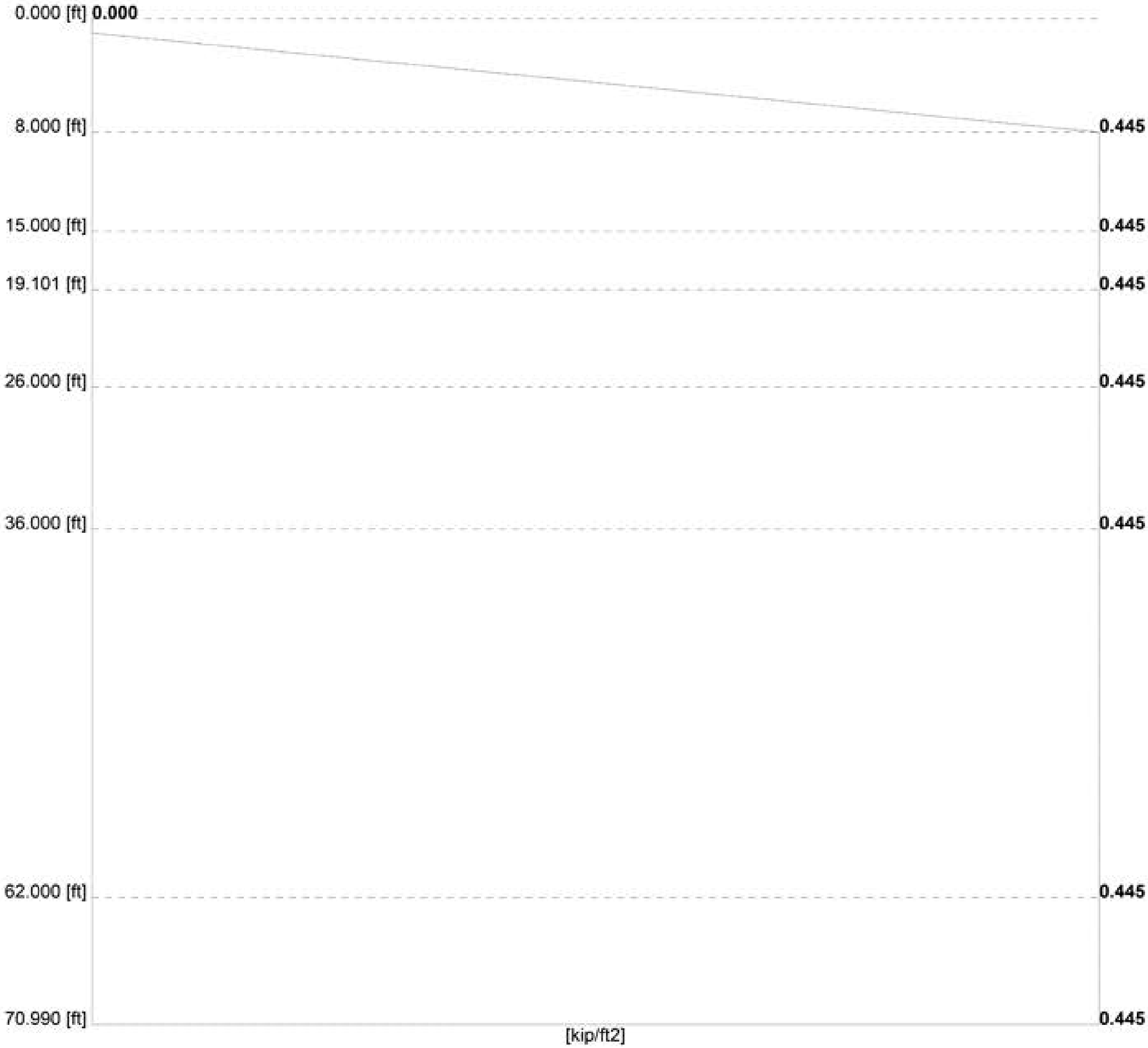
Pile Check

		Depth [ft]
Name	AZ18	
Inertia [in4/ft]	250.439	
Modulus [in3/ft]	33.480	
Area [in2/ft]	7.106	
Mass [lbs/ft2]	24.189	
Steel Grade [lb/in2]	50000.000	
Minimal Moment [kipft/ft]	-524.779	33.349
Maxmimal Moment [kipft/ft]	0.216	2.000
Normal Forces at Max. Moment [kip/ft]	1.982	33.349
Normal Forces at Min. Moment [kip/ft]	0.056	2.000
Deflection at Min. Moment [ft]	-4.679	33.349
Deflection at Max. Moment [ft]	0.000	2.000
Min. Stress at Min. Moment [lb/in2]	-191129.891	33.349
Max. Stress at Min. Moment [lb/in2]	191687.656	33.349
Min. Stress at Max. Moment [lb/in2]	-69.661	2.000
Max. Stress at Max. Moment [lb/in2]	85.418	2.000
Safety < Req. Safety = 1.500	0.261	
Sheet Pile Top Level [ft]	0.000	
Sheet Pile Tip Level [ft]	70.990	
Sheet Pile Length [ft]	70.990	
Included OverLength [ft]	0.000	
Vertical Equilibrium [kip/ft]	2.435	
Anchor Force (horiz.) [kip/ft]	-29.506	

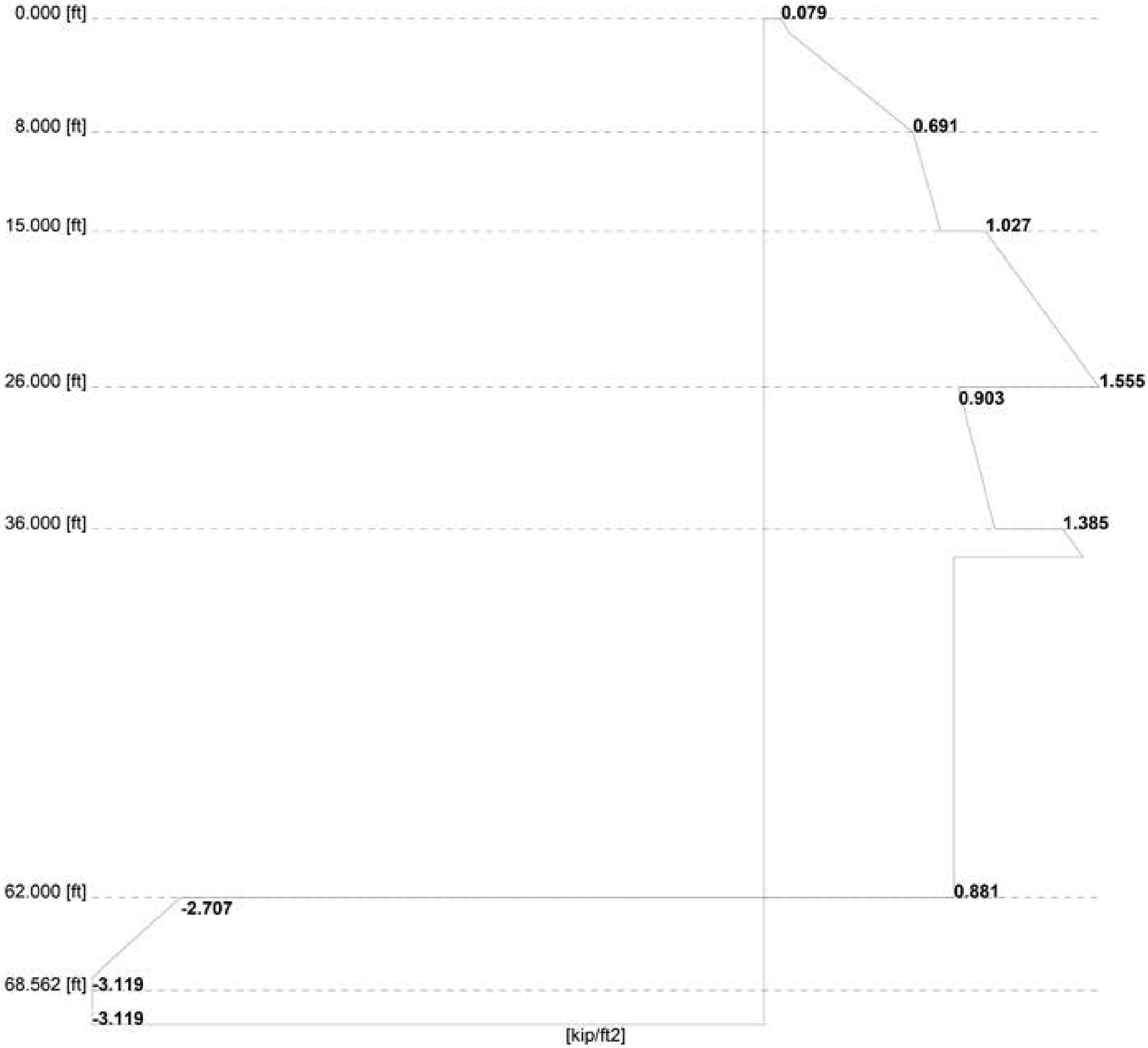
Earth Pressure Diagram



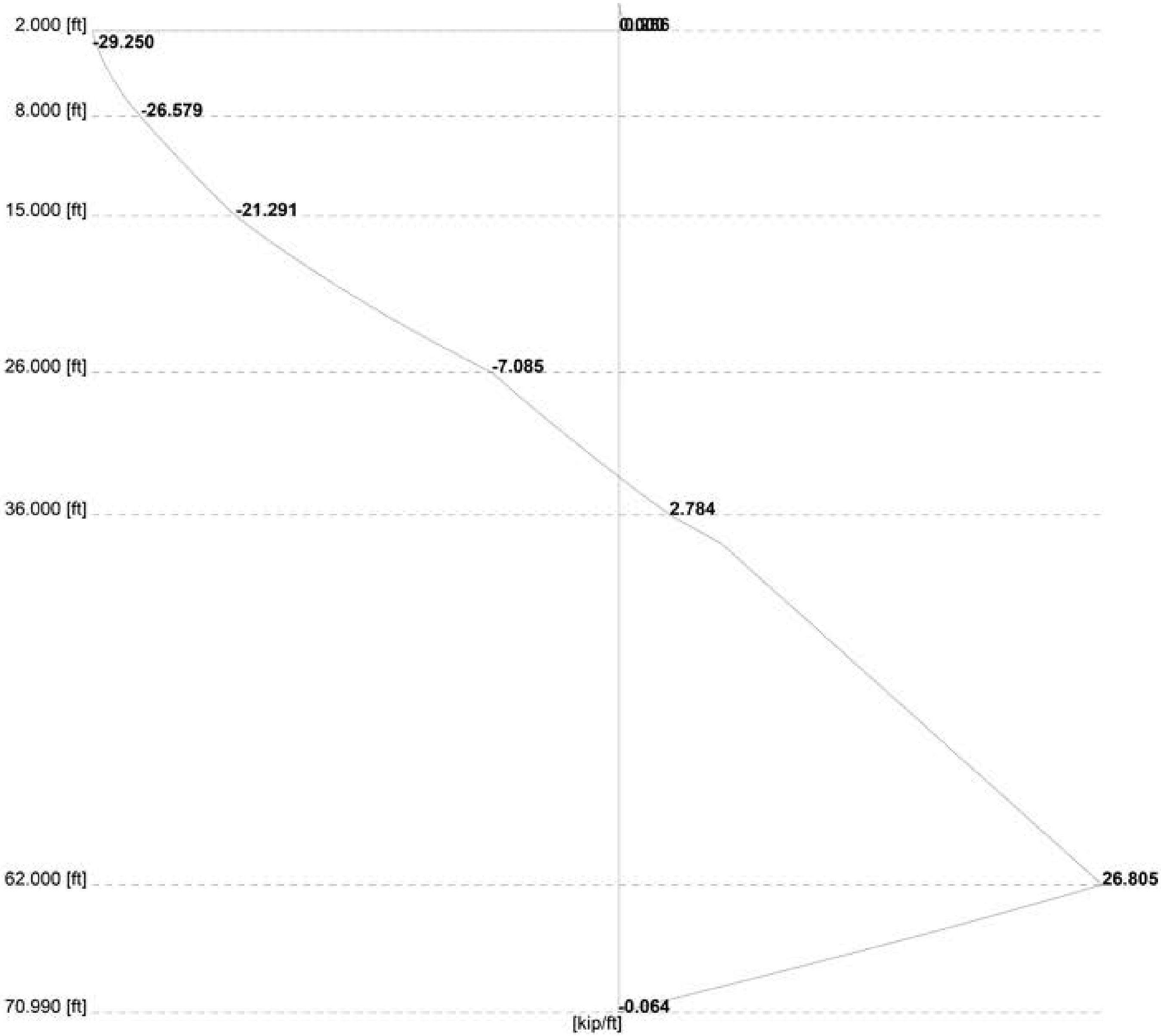
Water Pressure Diagram



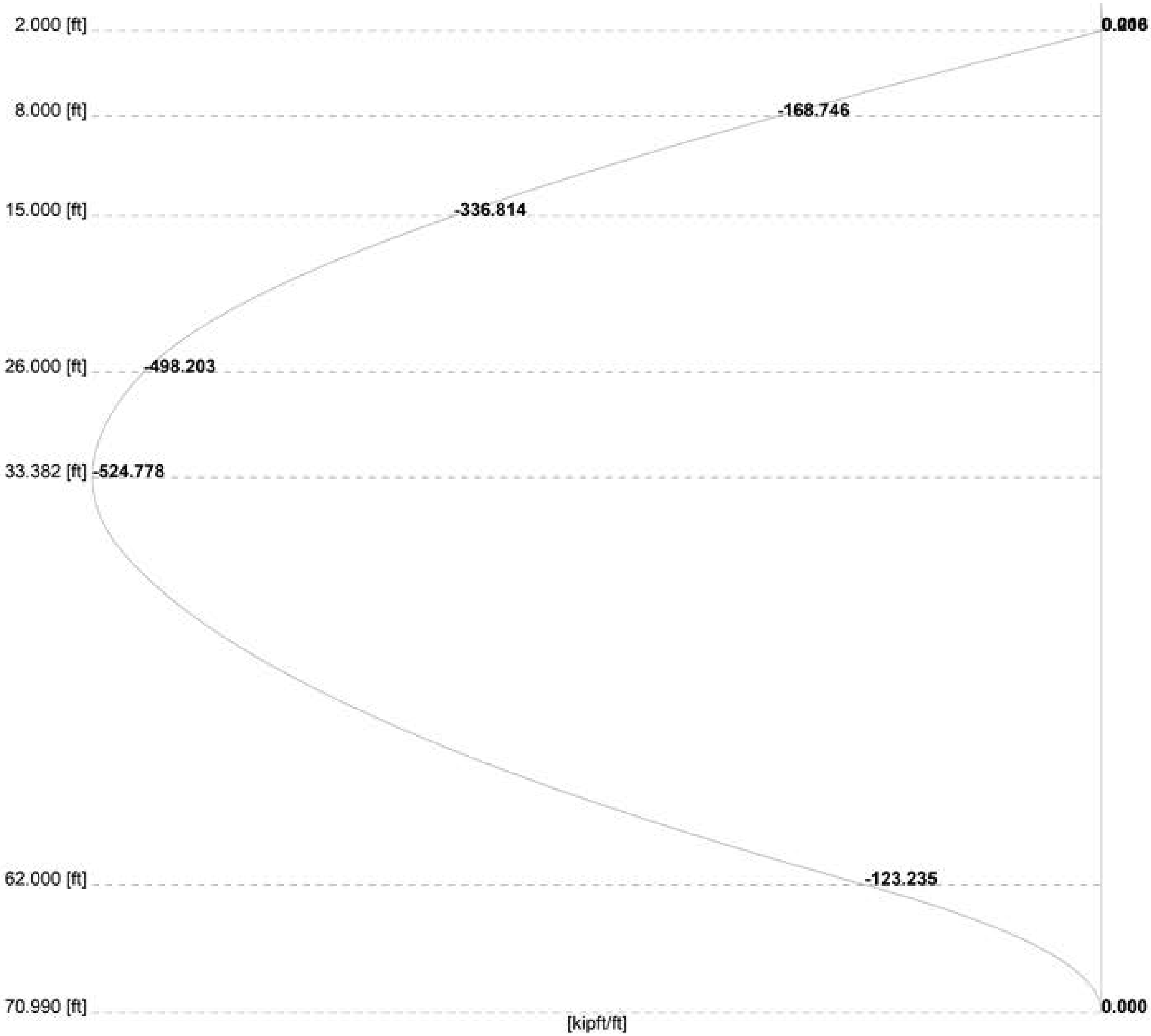
Total Pressure Diagram



Cross Force Diagram



Moment Diagram

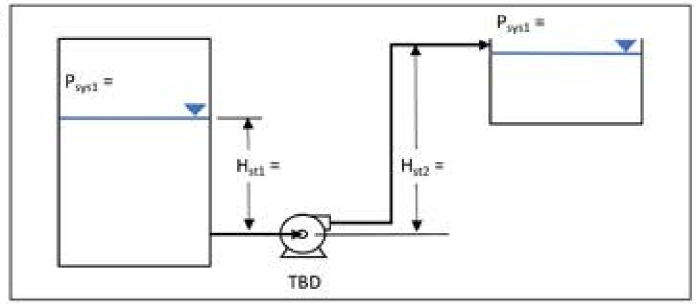


ARCADIS Design & Consultancy for natural and built assets

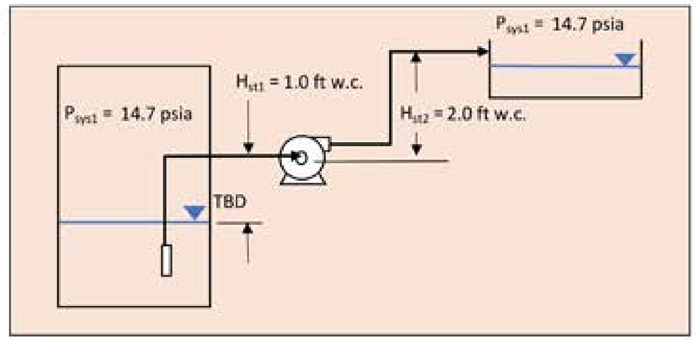
PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	1-Jun-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	2-Jun-2022
SUBJECT:	Between T-101 and Clarifier	APPVD. BY:	[NAME]	DATE:	[DATE]

Pump ID:	TBD
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	30
Design Flow Rate (gpm):	60
Maximum Flow Rate (gpm):	100
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	60
Elevation of Fluid to be Pumped (ft):	1
Pump Impeller Centerline Elevation (ft):	2
Discharge Elevation (ft):	4
Static Head of Discharge Line , H_{st2} (ft):	2
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	-1
Static Head of Liquid to be Pumped, H_{st1} (ft):	
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.592
Fluid density, ρ (lb/ft^3):	62.36
Fluid Kinematic Viscosity, η (ft^2/s):	1.21E-05
Include Exit Headloss at Discharge, H_v:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	30.0	40.0	50.0	60.0	73.3	86.6	100.0
(gpd):	42,000	56,000	70,000	84,000	102,620	121,240	140,000
(MGD):	0.04	0.06	0.07	0.08	0.10	0.12	0.14
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	**Pressure Loss (ft w.c.)**	**Equipment Tag**	**Pressure Loss (ft w.c.)**
Subtotal:	*0.0*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 0.0

ARCADIS Design & Consultancy for natural and built assets	PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE: 1-Jun-2022
	JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE: 2-Jun-2022
	SUBJECT:	Between T-101 and Clarifier	APPVD. BY:	[NAME]	DATE: [DATE]

Suction Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	2.9
Pipe Length, L (ft):	10.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	2.06897E-05

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.05	2	0.1
Standard Tee, thru branch	1.08	1	1.08
Standard Elbow, 90°	0.54	2	1.08
			0
			0
			0
			0
		Total K:	2.3

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.46	1.94	2.43	2.91	3.56	4.21	4.86
Eqn. (2) - Reynolds Number, Re:	2.92E+04	3.87E+04	4.85E+04	5.81E+04	7.11E+04	8.41E+04	9.71E+04
Pipe Friction Factor, f:	0.0237	0.0222	0.0211	0.0203	0.0194	0.0188	0.0182
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0032	0.0054	0.008	0.0111	0.0158	0.0214	0.0276
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	23.05	24.60	25.88	26.90	28.15	29.05	30.01
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	33.05	34.60	35.88	36.90	38.15	39.05	40.01
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.11**	**0.19**	**0.29**	**0.41**	**0.60**	**0.84**	**1.10**

Suction Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	2.9
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	2.06897E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.46	1.94	2.43	2.91	3.56	4.21	4.86
Eqn. (2) - Reynolds Number, Re:	2.92E+04	3.87E+04	4.85E+04	5.81E+04	7.11E+04	8.41E+04	9.71E+04
Pipe Friction Factor, f:	0.0237	0.0222	0.0211	0.0203	0.0194	0.0188	0.0182
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0032	0.0054	0.008	0.0111	0.0158	0.0214	0.0276
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	1-Jun-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	2-Jun-2022
SUBJECT:	Between T-101 and Clarifier	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	**0.0**

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Piping Headloss, $H_{p(suction)}$ (ft w.c.):	**0.11**	**0.19**	**0.29**	**0.41**	**0.60**	**0.84**	**1.10**
Eqn. (6) Available Net Positive Suction Head, $NPSH_a$ (ft w.c.):	**32.25**	**32.17**	**32.07**	**31.95**	**31.76**	**31.52**	**31.26**

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	1-Jun-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	2-Jun-2022
SUBJECT:	Between T-101 and Clarifier	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	2.9
Pipe Length, L (ft):	22.25
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	2.06897E-05

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.05	2	0.1
			0
Standard Elbow, 90°	0.54	1	0.54
			0
Standard Tee, thru branch	1.08	1	1.08
2x3 reducer	0.28	1	0.28
			0
		Total K:	2.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.46	1.94	2.43	2.91	3.56	4.21	4.86
Eqn. (2) - Reynolds Number, Re:	2.92E+04	3.87E+04	4.85E+04	5.81E+04	7.11E+04	8.41E+04	9.71E+04
Pipe Friction Factor, f:	0.0237	0.0222	0.0211	0.0203	0.0194	0.0188	0.0182
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0032	0.0054	0.008	0.0111	0.0158	0.0214	0.0276
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	20.39	21.77	22.91	23.81	24.91	25.71	26.56
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	42.64	44.02	45.16	46.06	47.16	47.96	48.81
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.14**	**0.24**	**0.36**	**0.51**	**0.75**	**1.03**	**1.35**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	1-Jun-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	2-Jun-2022
SUBJECT:	Between T-101 and Clarifier	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Lenth, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	1-Jun-2022
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SUBJECT:	Between T-101 and Clarifier	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 6 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	1-Jun-2022
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SUBJECT:	Between T-101 and Clarifier	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 7 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 8 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY: S. Hannula	DATE: 1-Jun-2022
JOB NO.:	30133323	CHKD. BY: M. Samp	DATE: 2-Jun-2022
SUBJECT:	Between T-101 and Clarifier	APPVD. BY: [NAME]	DATE: [DATE]

Discharge Line Segment No. 9 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 10 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	**0.14**	**0.24**	**0.36**	**0.51**	**0.75**	**1.03**	**1.35**
Exit Velocity at Liquid Discharge, v (ft/s):	**1.46**	**1.94**	**2.43**	**2.91**	**3.56**	**4.21**	**4.86**
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	**0.03**	**0.06**	**0.09**	**0.13**	**0.20**	**0.28**	**0.37**
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	**3.28**	**3.49**	**3.74**	**4.05**	**4.55**	**5.15**	**5.82**
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	**3.44**	**3.66**	**3.93**	**4.25**	**4.78**	**5.41**	**6.11**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	1-Jun-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	2-Jun-2022
SUBJECT:	Between T-101 and Clarifier	APPVD. BY:	[NAME]	DATE:	[DATE]

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{gpm}{440.0312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

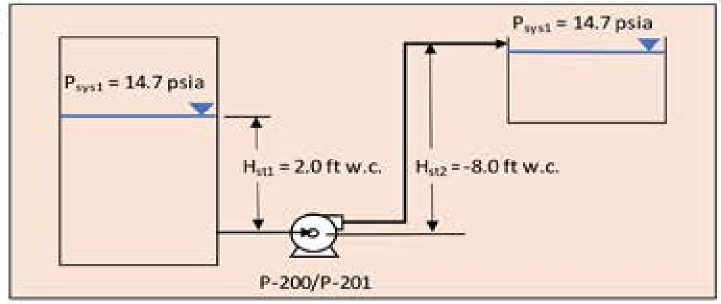
Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

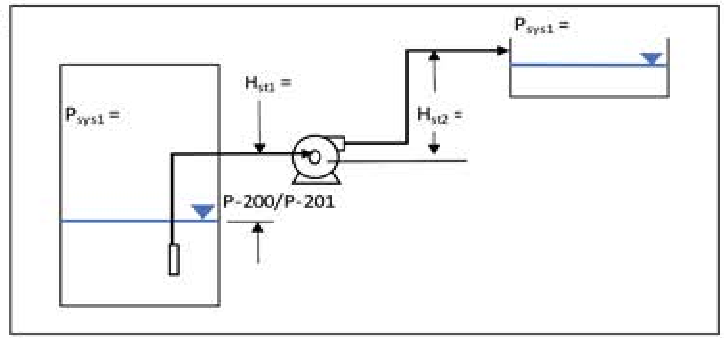
PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-200/201 Transfer Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Pump ID:	P-200/P-201
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	30
Design Flow Rate (gpm):	60
Maximum Flow Rate (gpm):	100
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	60
Elevation of Fluid to be Pumped (ft):	3
Pump Impeller Centerline Elevation (ft):	1
Discharge Elevation (ft):	-7
Static Head of Discharge Line , H_{st2} (ft):	-8
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	2
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.592
Fluid density, ρ (lb/ft^3):	62.36
Fluid Kinematic Viscosity, η (ft^2/s):	1.21E-05
Include Exit Headloss at Discharge, H_v:	Yes

Flooded Suction:



Suction Lift:



Notes:

Bag filter, GAC, IX delta P @ max fouling
Assume constant T-200 level of 1000 gallons/3 feet

Flow Rates (gpm):	30.0	40.0	50.0	60.0	73.3	86.6	100.0
(gpd):	42,000	56,000	70,000	84,000	102,620	121,240	140,000
(MGD):	0.04	0.06	0.07	0.08	0.10	0.12	0.14
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	**Pressure Loss (ft w.c.)**	**Equipment Tag**	**Pressure Loss (ft w.c.)**
Flow Meter	15.0	IX vessels at max delta P	57.0
Bag filter at max delta P	23.1		
GAC vessels at max delta P	46.2		
Subtotal:	*84.3*	*Subtotal:*	*57.0*

Total Headloss (ft w.c.): **141.3**

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-200/201 Transfer Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	2.9
Pipe Length, L (ft):	10.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	2.06897E-05

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.05	2	0.1
Standard Tee, thru branch	1.08	1	1.08
			0
			0
			0
			0
			0
		Total K:	1.2

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.46	1.94	2.43	2.91	3.56	4.21	4.86
Eqn. (2) - Reynolds Number, Re:	2.92E+04	3.87E+04	4.85E+04	5.81E+04	7.11E+04	8.41E+04	9.71E+04
Pipe Friction Factor, f:	0.0237	0.0222	0.0211	0.0203	0.0194	0.0188	0.0182
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0032	0.0054	0.008	0.0111	0.0158	0.0214	0.0276
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	12.03	12.85	13.52	14.05	14.70	15.17	15.67
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	22.03	22.85	23.52	24.05	24.70	25.17	25.67
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.07**	**0.12**	**0.19**	**0.27**	**0.39**	**0.54**	**0.71**

Suction Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	2.9
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	2.06897E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.46	1.94	2.43	2.91	3.56	4.21	4.86
Eqn. (2) - Reynolds Number, Re:	2.92E+04	3.87E+04	4.85E+04	5.81E+04	7.11E+04	8.41E+04	9.71E+04
Pipe Friction Factor, f:	0.0237	0.0222	0.0211	0.0203	0.0194	0.0188	0.0182
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0032	0.0054	0.008	0.0111	0.0158	0.0214	0.0276
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
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SUBJECT:	P-200/201 Transfer Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Piping Headloss, $H_{p(suction)}$ (ft w.c.):	**0.07**	**0.12**	**0.19**	**0.27**	**0.39**	**0.54**	**0.71**
Eqn. (6) Available Net Positive Suction Head, $NPSH_a$ (ft w.c.):	**35.29**	**35.24**	**35.17**	**35.09**	**34.97**	**34.82**	**34.65**

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SUBJECT:	P-200/201 Transfer Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	2.9
Pipe Length, L (ft):	1,700.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	2.06897E-05

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.05	16	0.8
Swing Check Valve (wye style)	1.8	1	1.8
Standard Elbow, 90°	0.54	16	8.64
Standard Tee, thru flow	0.36	9	3.24
Standard Tee, thru branch	1.08	4	4.32
2x3 reducer	0.28	1	0.28
			0
		Total K:	19.1

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.46	1.94	2.43	2.91	3.56	4.21	4.86
Eqn. (2) - Reynolds Number, Re:	2.92E+04	3.87E+04	4.85E+04	5.81E+04	7.11E+04	8.41E+04	9.71E+04
Pipe Friction Factor, f:	0.0237	0.0222	0.0211	0.0203	0.0194	0.0188	0.0182
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0032	0.0054	0.008	0.0111	0.0158	0.0214	0.0276
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	194.56	207.70	218.53	227.14	237.68	245.27	253.35
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	1,894.56	1,907.70	1,918.53	1,927.14	1,937.68	1,945.27	1,953.35
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**6.06**	**10.30**	**15.35**	**21.39**	**30.62**	**41.63**	**53.91**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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SUBJECT:	P-200/201 Transfer Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Lenth, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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Discharge Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 6 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY: S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY: M. Samp	DATE:	6-May-2022
SUBJECT:	P-200/201 Transfer Pumps	APPVD. BY: [NAME]	DATE:	[DATE]

Discharge Line Segment No. 7 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 8 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-200/201 Transfer Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 9 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 10 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	30	40	50	60	73.3	86.6	100
Eqn. (1) - Velocity, v (ft/s):	1.30	1.74	2.17	2.60	3.18	3.76	4.34
Eqn. (2) - Reynolds Number, Re:	2.75E+04	3.68E+04	4.59E+04	5.49E+04	6.72E+04	7.94E+04	9.17E+04
Pipe Friction Factor, f:	0.024	0.0225	0.0214	0.0205	0.0197	0.019	0.0184
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0025	0.0041	0.0061	0.0084	0.0121	0.0163	0.0211
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	**6.06**	**10.30**	**15.35**	**21.39**	**30.62**	**41.63**	**53.91**
Exit Velocity at Liquid Discharge, v (ft/s):	**1.46**	**1.94**	**2.43**	**2.91**	**3.56**	**4.21**	**4.86**
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	**0.03**	**0.06**	**0.09**	**0.13**	**0.20**	**0.28**	**0.37**
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	**137.46**	**141.78**	**146.93**	**153.09**	**162.51**	**173.75**	**186.29**
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	**144.33**	**148.87**	**154.28**	**160.74**	**170.64**	**182.44**	**195.60**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-200/201 Transfer Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{gpm}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_P = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

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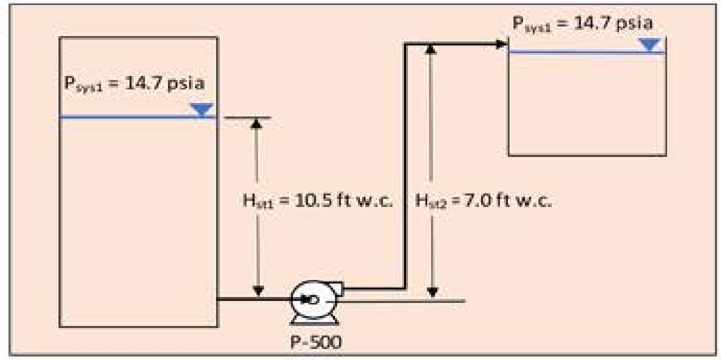
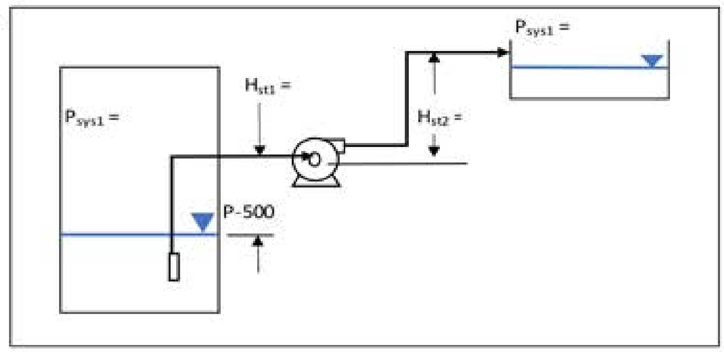
PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-50 Sludge Transfer Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Pump ID:	P-500
Fluid:	Sludge
Fluid Description:	EQ Underflow
Enter Specific Weight of Sludge, λ (lb_m/ft^3):	71.4
Coefficient of Rigidity from Sludge Rheology Curves, η (lb_m/ft-s):	0.04
Enter Vapor Pressure if Other than Water (psi):	0.26
Enter Solids Content of the Sludge (%):	1.0%
Enter Yield Stress from Sludge Rheology Curves, s (lb_f/ft^2):	0.28
Minimum Flow Rate (gpm):	2
Design Flow Rate (gpm):	5
Maximum Flow Rate (gpm):	10
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	60
Elevation of Fluid to be Pumped (ft):	11.5
Pump Impeller Centerline Elevation (ft):	1
Discharge Elevation (ft):	8
Static Head of Discharge Line , H_{st2} (ft):	7
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	10.5
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.601
Fluid density, ρ (lb_f/ft^3):	71.4
Coefficient of Rigidity, η (lb_m/ft-s):	0.040
Include Exit Headloss at Discharge, H_v:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	2.0	3.0	4.0	5.0	6.7	8.4	10.0
(gpd):	2,800	4,200	5,600	7,000	9,380	11,760	14,000
(MGD):	0.00	0.00	0.01	0.01	0.01	0.01	0.01
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Flow Meter	15.0		
Subtotal:	*15.0*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 15.0

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-50 Sludge Transfer Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	1.5
Pipe Inner Diameter, ID (in):	1.5
Pipe Length, L (ft):	20.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	0.00004

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.06	1	0.06
Gate Valve	0.15	2	0.3
Standard Elbow, 90°	0.63	3	1.89
			0
			0
			0
			0
		Total K:	2.3

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.36	0.54	0.73	0.91	1.22	1.53	1.82
Eqn. (2) - Reynolds Number, Re:	8.03E+01	1.20E+02	1.63E+02	2.03E+02	2.72E+02	3.41E+02	4.06E+02
Eqn. (3) - Hedstrom Number, He:	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03
Pipe Friction Factor, f:	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0033	0.0075	0.0137	0.0212	0.0382	0.0600	0.0849
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	6.25	6.25	6.25	6.25	6.25	6.25	6.25
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	26.25	26.25	26.25	26.25	26.25	26.25	26.25
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.09**	**0.20**	**0.36**	**0.56**	**1.00**	**1.58**	**2.23**

Suction Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT: BASF Northworks Perimeter Barrier Remedy	BY: S. Hannula	DATE: 4-May-2022
JOB NO.: 30133323	CHKD. BY: M. Samp	DATE: 6-May-2022
SUBJECT: P-50 Sludge Transfer Pump	APPVD. BY: [NAME]	DATE: [DATE]

Suction Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-50 Sludge Transfer Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Piping Headloss, $H_{p(suction)}$ (ft w.c.):	**0.09**	**0.20**	**0.36**	**0.56**	**1.00**	**1.58**	**2.23**
Eqn. (7) Available Net Positive Suction Head, $NPSH_a$ (ft w.c.):	**43.77**	**43.66**	**43.50**	**43.30**	**42.86**	**42.28**	**41.63**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-50 Sludge Transfer Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	1.5
Pipe Inner Diameter, ID (in):	1.5
Pipe Length, L (ft):	20.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	0.00004

Valve/Fitting Tag	K	No. Units	Total K
Standard Elbow, 90°	0.63	3	1.89
			0
Gate Valve	0.15	1	0.15
			0
			0
3x2 reducer	0.28	1	0.28
2x0.75 reducer	0.43	1	0.43
		Total K:	2.8

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.36	0.54	0.73	0.91	1.22	1.53	1.82
Eqn. (2) - Reynolds Number, Re:	8.03E+01	1.20E+02	1.63E+02	2.03E+02	2.72E+02	3.41E+02	4.06E+02
Eqn. (3) - Hedstrom Number, He:	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0022	0.0050	0.0091	0.0142	0.0254	0.0400	0.0566
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	11.46	11.46	11.46	11.46	11.46	11.46	11.46
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	31.46	31.46	31.46	31.46	31.46	31.46	31.46
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.07**	**0.16**	**0.29**	**0.45**	**0.80**	**1.26**	**1.78**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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SUBJECT:	P-50 Sludge Transfer Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	**0.0**

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Lenth, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	**0.0**

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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Discharge Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 6 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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Discharge Line Segment No. 7 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 8 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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Discharge Line Segment No. 9 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 10 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.07	0.16	0.29	0.45	0.80	1.26	1.78
Exit Velocity at Liquid Discharge, v (ft/s):	0.36	0.54	0.73	0.91	1.22	1.53	1.82
Eqn. (8) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.00	0.01	0.01	0.02	0.04	0.05
Eqn. (9) Total Dynamic Head, TDH (ft w.c.):	11.66	11.86	12.16	12.52	13.32	14.38	15.56
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	12.24	12.45	12.77	13.15	13.99	15.10	16.34

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.
7. Wastewater Engineering Treatment, Disposal, and Reuse, Third Edition, Metcalf & Eddy, Inc., 1991.
8. EPA 625/1-79-011, Process Design Manual for Sludge Treatment and Disposal, U.S. EPA, Sept. 1979.

Equations:

Eqn. (1):

$$v = \frac{\frac{gpm}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{\lambda \cdot v \cdot \frac{ID}{12}}{\eta}$$

Ecn. (3):

$$He = \frac{\left(\frac{ID}{12}\right)^2 \cdot s \cdot \lambda \cdot g_c}{\eta^2}$$

where:

$$g_c = 32.174 \frac{lb \cdot ft}{lb_f \cdot s^2}$$

Eqn. (4):

$$H_{\left(\frac{lb_f}{ft^2 \cdot ft}\right)} = \frac{2 \cdot f \cdot \lambda \cdot v^2}{g_c \cdot \frac{ID}{12}}$$

$$H_{\left(\frac{ft\,w.c.}{ft}\right)} = \left(\frac{2.31}{144}\right) \cdot H_{\left(\frac{lb_f}{ft^2 \cdot ft}\right)}$$

Eqn. (5a):

$$L_p = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (5b):

$$L_{eq} = L + L_p$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (7):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (8):

$$H_v = \frac{v^2}{2 \cdot g}$$

where:

$$g = 32.174 \frac{ft}{s^2}$$

Eqn. (9):

Suction Lift:

$$TDH - 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st}$$

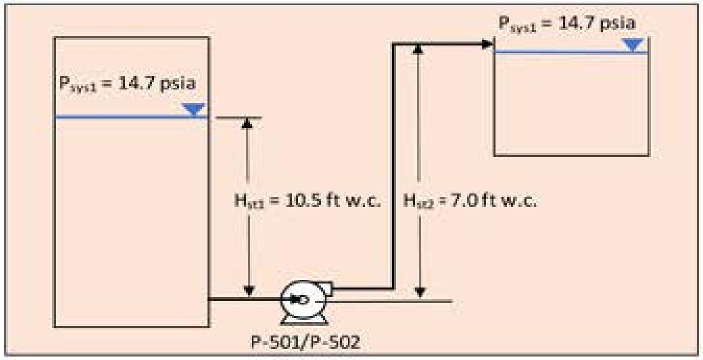
Flooced Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st}$$

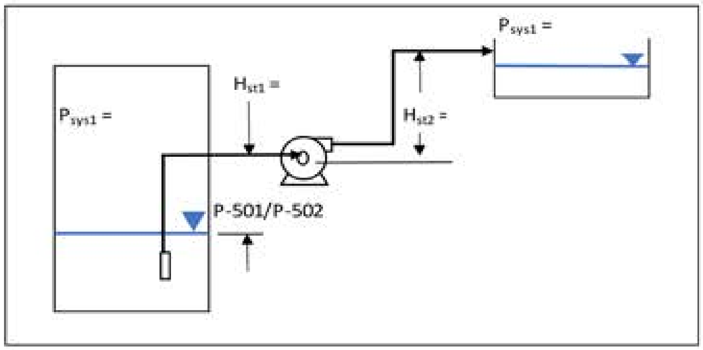
PROJECT: BASF Northworks Perimeter Barrier Remedy	BY: S. Hannula	DATE: 4-May-2022
JOB NO.: 30133323	CHKD. BY: M. Samp	DATE: 6-May-2022
SUBJECT: P-501/P-502 Sludge Transfer Pumps	APPVD. BY: [NAME]	DATE: [DATE]

Pump ID:	P-501/P-502
Fluid:	Sludge
Fluid Description:	Clarifier Underflow
Enter Specific Weight of Sludge, λ (lb_m/ft^3):	71.4
Coefficient of Rigidity from Sludge Rheology Curves, η (lb_m/ft-s):	0.04
Enter Vapor Pressure if Other than Water (psi):	0.26
Enter Solids Content of the Sludge (%):	1.0%
Enter Yield Stress from Sludge Rheology Curves, s (lb_f/ft^2):	0.28
Minimum Flow Rate (gpm):	2
Design Flow Rate (gpm):	5
Maximum Flow Rate (gpm):	10
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	60
Elevation of Fluid to be Pumped (ft):	11.5
Pump Impeller Centerline Elevation (ft):	1
Discharge Elevation (ft):	8
Static Head of Discharge Line , H_{st2} (ft):	7
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	10.5
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.601
Fluid density, ρ (lb_f/ft^3):	71.4
Coefficient of Rigidity, η (lb_m/ft-s):	0.040
Include Exit Headloss at Discharge, H_v:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	2.0	3.0	4.0	5.0	6.7	8.4	10.0
(gpd):	2,800	4,200	5,600	7,000	9,380	11,760	14,000
(MGD):	0.00	0.00	0.01	0.01	0.01	0.01	0.01
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Flow Meter	15.0		
Subtotal:	*15.0*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 15.0

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PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-501/P-502 Sludge Transfer Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	1.5
Pipe Inner Diameter, ID (in):	1.5
Pipe Length, L (ft):	20.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	0.00004

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.06	1	0.06
Gate Valve	0.15	2	0.3
Standard Elbow, 90°	0.63	2	1.26
Standard Tee, thru branch	1.26	1	1.26
			0
			0
			0
		Total K:	**2.9**

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.36	0.54	0.73	0.91	1.22	1.53	1.82
Eqn. (2) - Reynolds Number, Re:	8.03E+01	1.20E+02	1.63E+02	2.03E+02	2.72E+02	3.41E+02	4.06E+02
Eqn. (3) - Hedstrom Number, He:	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03
Pipe Friction Factor, f:	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0033	0.0075	0.0137	0.0212	0.0382	0.0600	0.0849
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	28.00	28.00	28.00	28.00	28.00	28.00	28.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.09**	**0.21**	**0.38**	**0.59**	**1.07**	**1.68**	**2.38**

Suction Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	**0.0**

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY: S. Hannula	DATE: 4-May-2022
JOB NO.:	30133323	CHKD. BY: M. Samp	DATE: 6-May-2022
SUBJECT:	P-501/P-502 Sludge Transfer Pumps	APPVD. BY: [NAME]	DATE: [DATE]

Suction Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-501/P-502 Sludge Transfer Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	**0.0**

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Piping Headloss, $H_{p(suction)}$ (ft w.c.):	**0.09**	**0.21**	**0.38**	**0.59**	**1.07**	**1.68**	**2.38**
Eqn. (7) Available Net Positive Suction Head, $NPSH_a$ (ft w.c.):	**43.77**	**43.65**	**43.48**	**43.27**	**42.79**	**42.18**	**41.48**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-501/P-502 Sludge Transfer Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	1.5
Pipe Inner Diameter, ID (in):	1.5
Pipe Length, L (ft):	20.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	0.00004

Valve/Fitting Tag	K	No. Units	Total K
Standard Elbow, 90°	0.63	3	1.89
			0
Gate Valve	0.15	1	0.15
			0
			0
			0
			0
		Total K:	2.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.36	0.54	0.73	0.91	1.22	1.53	1.82
Eqn. (2) - Reynolds Number, Re:	8.03E+01	1.20E+02	1.63E+02	2.03E+02	2.72E+02	3.41E+02	4.06E+02
Eqn. (3) - Hedstrom Number, He:	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0022	0.0050	0.0091	0.0142	0.0254	0.0400	0.0566
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	8.50	8.50	8.50	8.50	8.50	8.50	8.50
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	28.50	28.50	28.50	28.50	28.50	28.50	28.50
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.06**	**0.14**	**0.26**	**0.40**	**0.72**	**1.14**	**1.61**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula
JOB NO.:	30133323	CHKD. BY:	M. Samp
SUBJECT:	P-501/P-502 Sludge Transfer Pumps	APPVD. BY:	[NAME]

DATE:	4-May-2022
DATE:	6-May-2022
DATE:	[DATE]

Discharge Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Lenth, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-501/P-502 Sludge Transfer Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 6 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY: S. Hannula	DATE: 4-May-2022
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SUBJECT:	P-501/P-502 Sludge Transfer Pumps	APPVD. BY: [NAME]	DATE: [DATE]

Discharge Line Segment No. 7 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 8 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 9 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 10 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.06	0.14	0.26	0.40	0.72	1.14	1.61
Exit Velocity at Liquid Discharge, v (ft/s):	0.36	0.54	0.73	0.91	1.22	1.53	1.82
Eqn. (8) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.00	0.01	0.01	0.02	0.04	0.05
Eqn. (9) Total Dynamic Head, TDH (ft w.c.):	11.65	11.85	12.15	12.50	13.31	14.36	15.54
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	12.23	12.44	12.76	13.13	13.98	15.08	16.32

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.
7. Wastewater Engineering Treatment, Disposal, and Reuse, Third Edition, Metcalf & Eddy, Inc., 1991.
8. EPA 625/1-79-011, Process Design Manual for Sludge Treatment and Disposal, U.S. EPA, Sept. 1979.

Equations:

Eqn. (1):

$$v = \frac{\frac{gpm}{448.8312}}{\frac{\pi}{4}\cdot\left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{\lambda \cdot v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$He = \frac{\left(\frac{ID}{12}\right)^2 \cdot s \cdot \lambda \cdot g_c}{\eta^2}$$

where:

$$g_c = 32.174\frac{lb \cdot ft}{lb_f \cdot s^2}$$

Eqn. (4):

$$H_{\left(\frac{lb_f}{ft^2 \cdot ft}\right)} = \frac{2 \cdot f \cdot \lambda \cdot v^2}{g_c \cdot \frac{ID}{12}}$$

$$H_{\left(\frac{ft\,w.c.}{ft}\right)} = \left(\frac{2.31}{144}\right)\cdot H_{\left(\frac{lb_f}{ft^2 \cdot ft}\right)}$$

Eqn. (5a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (5b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (7):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (8):

$$H_v = \frac{v^2}{2 \cdot g}$$

where:

$$g = 32.174\frac{ft}{s^2}$$

Eqn. (9):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

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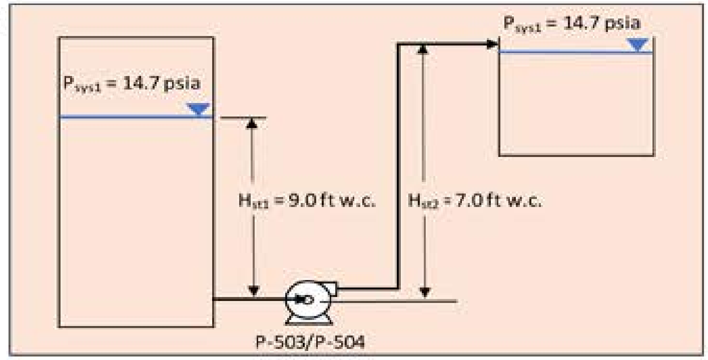
SUBJECT:	P-503/P-504 Sludge Transfer Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

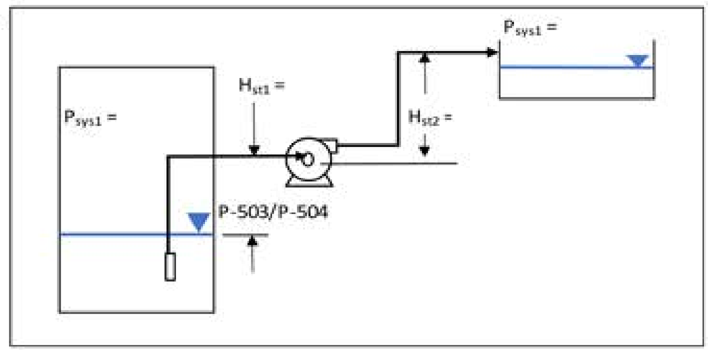
Pump ID:	P-503/P-504
Fluid:	Sludge
Fluid Description:	Settled Sludge
Enter Specific Weight of Sludge, λ (lb_m/ft^3):	71.4
Coefficient of Rigidity from Sludge Rheology Curves, η (lb_m/ft-s):	0.04
Enter Vapor Pressure if Other than Water (psi):	0.26
Enter Solids Content of the Sludge (%):	3.0%
Enter Yield Stress from Sludge Rheology Curves, s (lb_f/ft^2):	0.28
Minimum Flow Rate (gpm):	2
Design Flow Rate (gpm):	5
Maximum Flow Rate (gpm):	10
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	60
Elevation of Fluid to be Pumped (ft):	10
Pump Impeller Centerline Elevation (ft):	1
Discharge Elevation (ft):	8
Static Head of Discharge Line , H_{st2} (ft):	7
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	9
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.601
Fluid density, ρ (lb_f/ft^3):	71.4
Coefficient of Rigidity, η (lb_m/ft-s):	0.040
Include Exit Headloss at Discharge, H_v:	Yes

Notes:

Flooded Suction:



Suction Lift:



Flow Rates (gpm):	2.0	3.0	4.0	5.0	6.7	8.4	10.0
(gpd):	2,800	4,200	5,600	7,000	9,380	11,760	14,000
(MGD):	0.00	0.00	0.01	0.01	0.01	0.01	0.01
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	**Pressure Loss (ft w.c.)**	**Equipment Tag**	**Pressure Loss (ft w.c.)**
Flow Meter	15.0		
Subtotal:	*15.0*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 15.0

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SUBJECT:	P-503/P-504 Sludge Transfer Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	1.5
Pipe Inner Diameter, ID (in):	1.5
Pipe Length, L (ft):	10.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	0.00004

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.06	2	0.12
			0
Standard Elbow, 90°	0.63	2	1.26
Standard Tee, thru branch	1.26	1	1.26
			0
			0
			0
		Total K:	2.6

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.36	0.54	0.73	0.91	1.22	1.53	1.82
Eqn. (2) - Reynolds Number, Re:	8.03E+01	1.20E+02	1.63E+02	2.03E+02	2.72E+02	3.41E+02	4.06E+02
Eqn. (3) - Hedstrom Number, He:	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03
Pipe Friction Factor, f:	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0033	0.0075	0.0137	0.0212	0.0382	0.0600	0.0849
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	7.33	7.33	7.33	7.33	7.33	7.33	7.33
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	17.33	17.33	17.33	17.33	17.33	17.33	17.33
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.06**	**0.13**	**0.24**	**0.37**	**0.66**	**1.04**	**1.47**

Suction Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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SUBJECT:	P-503/P-504 Sludge Transfer Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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Suction Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Piping Headloss, $H_{p(suction)}$ (ft w.c.):	**0.06**	**0.13**	**0.24**	**0.37**	**0.66**	**1.04**	**1.47**
Eqn. (7) Available Net Positive Suction Head, $NPSH_a$ (ft w.c.):	**42.30**	**42.23**	**42.12**	**41.99**	**41.70**	**41.32**	**40.89**

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Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	1.5
Pipe Inner Diameter, ID (in):	1.5
Pipe Length, L (ft):	20.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	0.00004

Valve/Fitting Tag	K	No. Units	Total K
			0
Standard Elbow, 90°	0.63	2	1.26
Gate Valve	0.15	1	0.15
Standard Tee, thru branch	1.26	1	1.26
Standard Tee, thru flow	0.42	1	0.42
			0
			0
		Total K:	3.1

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.36	0.54	0.73	0.91	1.22	1.53	1.82
Eqn. (2) - Reynolds Number, Re:	8.03E+01	1.20E+02	1.63E+02	2.03E+02	2.72E+02	3.41E+02	4.06E+02
Eqn. (3) - Hedstrom Number, He:	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03	6.28E+03
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0022	0.0050	0.0091	0.0142	0.0254	0.0400	0.0566
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	12.88	12.88	12.88	12.88	12.88	12.88	12.88
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	32.88	32.88	32.88	32.88	32.88	32.88	32.88
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.07**	**0.16**	**0.30**	**0.47**	**0.84**	**1.32**	**1.86**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

ARCADIS Design & Consultancy for natural and built assets	PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY: S. Hannula	DATE:	4-May-2022
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Discharge Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Lenth, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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Discharge Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 6 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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Discharge Line Segment No. 7 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 8 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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Discharge Line Segment No. 9 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 10 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	8
Pipe Inner Diameter, ID (in):	7.981
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	7.51785E-06

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	3	4	5	6.7	8.4	10
Eqn. (1) - Velocity, v (ft/s):	0.01	0.02	0.03	0.03	0.04	0.05	0.06
Eqn. (2) - Reynolds Number, Re:	1.19E+01	2.37E+01	3.56E+01	3.56E+01	4.75E+01	5.94E+01	7.12E+01
Eqn. (3) - Hedstrom Number, He:	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05	1.78E+05
Pipe Friction Factor, f:	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Eqn. (4) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Eqn. (5a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (6) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-503/P-504 Sludge Transfer Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.07	0.16	0.30	0.47	0.84	1.32	1.86
Exit Velocity at Liquid Discharge, v (ft/s):	0.36	0.54	0.73	0.91	1.22	1.53	1.82
Eqn. (8) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.00	0.01	0.01	0.02	0.04	0.05
Eqn. (9) Total Dynamic Head, TDH (ft w.c.):	13.13	13.29	13.55	13.85	14.52	15.40	16.38
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	13.79	13.95	14.23	14.54	15.25	16.17	17.20

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.
7. Wastewater Engineering Treatment, Disposal, and Reuse, Third Edition, Metcalf & Eddy, Inc., 1991.
8. EPA 625/1-79-011, Process Design Manual for Sludge Treatment and Disposal, U.S. EPA, Sept. 1979.

Equations:

Eqn. (1):

$$v = \frac{\frac{gpm}{448.8312}}{\frac{\pi}{4}\cdot\left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{\lambda \cdot v \cdot \frac{ID}{12}}{\eta}$$

Ecn. (3):

$$He = \frac{\left(\frac{ID}{12}\right)^2 \cdot s \cdot \lambda \cdot g_c}{\eta^2}$$

where:

$$g_c = 32.174\frac{lb \cdot ft}{lb_f \cdot s^2}$$

Eqn. (4):

$$H_{\left(\frac{lb_f}{ft^2 \cdot ft}\right)} = \frac{2 \cdot f \cdot \lambda \cdot v^2}{g_c \cdot \frac{ID}{12}}$$

$$H_{\left(\frac{ft\ w.c.}{ft}\right)} = \left(\frac{2.31}{144}\right) \cdot H_{\left(\frac{lb_f}{ft^2 \cdot ft}\right)}$$

Eqn. (5a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (5b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (7):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (8):

$$H_v = \frac{v^2}{2 \cdot g}$$

where:

$$g = 32.174\frac{ft}{s^2}$$

Eqn. (9):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

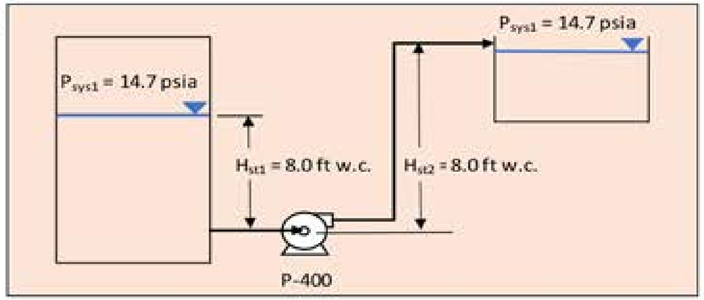
$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY: S. Hannula	DATE: 4-May-2022
JOB NO.:	30133323	CHKD. BY: M. Samp	DATE: 6-May-2022
SUBJECT:	P-400 pH Adjustment Pump	APPVD. BY: [NAME]	DATE: [DATE]

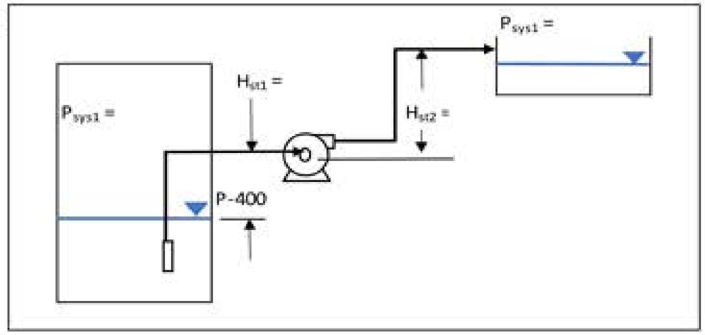
Pump ID:	P-400
Fluid:	Water
Fluid Description:	Acid
Enter Fluid Density if Other than Water (lb/ft^3):	81
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	0.1
Design Flow Rate (gpm):	0.15
Maximum Flow Rate (gpm):	0.2
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	60
Elevation of Fluid to be Pumped (ft):	10
Pump Impeller Centerline Elevation (ft):	2
Discharge Elevation (ft):	10
Static Head of Discharge Line , H_{st2} (ft):	8
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	8
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.592
Fluid density, ρ (lb/ft^3):	62.36
Fluid Kinematic Viscosity, η (ft^2/s):	1.21E-05
Include Exit Headloss at Discharge, H_v:	Yes

Notes:

Flooded Suction:



Suction Lift:



Flow Rates (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
(gpd):	140	140	140	280	280	280	280
(MGD):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	**Pressure Loss (ft w.c.)**	**Equipment Tag**	**Pressure Loss (ft w.c.)**
Flow Meter			
Subtotal:	*0.0*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 0.0

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-400 pH Adjustment Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	0.5
Pipe Inner Diameter, ID (in):	0.546
Pipe Length, L (ft):	10.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Uncoated Steel
Roughness, e (ft):	0.00013
e / ID:	0.002857143

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.08	3	0.24
			0
			0
			0
			0
			0
			0
		Total K:	0.2

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.14	0.14	0.14	0.27	0.27	0.27	0.27
Eqn. (2) - Reynolds Number, Re:	5.26E+02	5.26E+02	5.26E+02	1.02E+03	1.02E+03	1.02E+03	1.02E+03
Pipe Friction Factor, f:	0.1216	0.1216	0.1216	0.063	0.063	0.063	0.063
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0008	0.0008	0.0008	0.0016	0.0016	0.0016	0.0016
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.09	0.09	0.09	0.17	0.17	0.17	0.17
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	10.09	10.09	10.09	10.17	10.17	10.17	10.17
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.01**	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**	**0.02**

Suction Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	2.9
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 80 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	2.06897E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.00E+02	2.00E+02	2.00E+02	2.00E+02
Pipe Friction Factor, f:	0	0	0	0.3204	0.3204	0.3204	0.3204
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-400 pH Adjustment Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	**0.0**

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	**0.0**

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-400 pH Adjustment Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Piping Headloss, $H_{p(suction)}$ (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.02**	**0.02**	**0.02**	**0.02**
Eqn. (6) Available Net Positive Suction Head, $NPSH_a$ (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**41.34**	**41.34**	**41.34**	**41.34**

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-400 pH Adjustment Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	0.5
Pipe Inner Diameter, ID (in):	0.546
Pipe Length, L (ft):	85.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	0.00010989

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.08	2	0.16
Standard Elbow, 90°	0.81	4	3.24
Swing Check Valve (wye style)	2.7	1	2.7
			0
			0
			0
			0
		Total K:	6.1

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.14	0.14	0.14	0.27	0.27	0.27	0.27
Eqn. (2) - Reynolds Number, Re:	5.26E+02	5.26E+02	5.26E+02	1.02E+03	1.02E+03	1.02E+03	1.02E+03
Pipe Friction Factor, f:	0.1216	0.1216	0.1216	0.063	0.063	0.063	0.063
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0008	0.0008	0.0008	0.0016	0.0016	0.0016	0.0016
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	2.28	2.28	2.28	4.41	4.41	4.41	4.41
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	87.28	87.28	87.28	89.41	89.41	89.41	89.41
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.07**	**0.07**	**0.07**	**0.14**	**0.14**	**0.14**	**0.14**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT: BASF Northworks Perimeter Barrier Remedy	BY: S. Hannula	DATE: 4-May-2022
JOB NO.: 30133323	CHKD. BY: M. Samp	DATE: 6-May-2022
SUBJECT: P-400 pH Adjustment Pump	APPVD. BY: [NAME]	DATE: [DATE]

Discharge Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Lenth, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

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PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-400 pH Adjustment Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 6 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-400 pH Adjustment Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 7 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 8 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

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PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-400 pH Adjustment Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 9 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 10 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.14**	**0.14**	**0.14**	**0.14**
Exit Velocity at Liquid Discharge, v (ft/s):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.27**	**0.27**	**0.27**	**0.27**
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.16**	**0.16**	**0.16**	**0.16**
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.17**	**0.17**	**0.17**	**0.17**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-400 pH Adjustment Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{gpm}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_p = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_p$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot \left(P_{sys1} - P_{vap}\right) - H_{p(suction)} \perp H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot \left(P_{sys2} - P_{sys1}\right) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot \left(P_{sys2} - P_{sys1}\right) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

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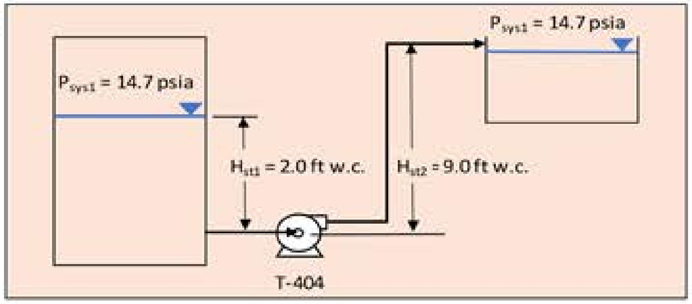
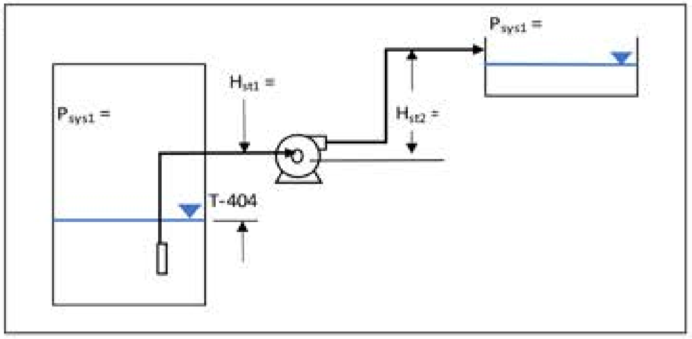
PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-404 pH Adjustment Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Pump ID:	T-404
Fluid:	Water
Fluid Description:	Polymer
Enter Fluid Density if Other than Water (lb/ft^3):	75
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	0.1
Design Flow Rate (gpm):	0.4
Maximum Flow Rate (gpm):	0.7
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	60
Elevation of Fluid to be Pumped (ft):	3
Pump Impeller Centerline Elevation (ft):	1
Discharge Elevation (ft):	10
Static Head of Discharge Line , H_{st2} (ft):	9
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	2
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.592
Fluid density, ρ (lb/ft^3):	62.36
Fluid Kinematic Viscosity, η (ft^2/s):	1.21E-05
Include Exit Headloss at Discharge, H_v:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	0.1	0.2	0.3	0.4	0.5	0.6	0.7
(gpd):	140	280	420	560	700	840	980
(MGD):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Flow Meter			
Subtotal:	*0.0*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 0.0

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PROJECT: BASF Northworks Perimeter Barrier Remedy	BY: S. Hannula	DATE: 4-May-2022
JOB NO.: 30133323	CHKD. BY: M. Samp	DATE: 6-May-2022
SUBJECT: P-404 pH Adjustment Pump	APPVD. BY: [NAME]	DATE: [DATE]

Suction Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	0.5
Pipe Inner Diameter, ID (in):	0.546
Pipe Length, L (ft):	10.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	0.00010989

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.08	3	0.24
			0
			0
			0
			0
			0
			0
		Total K:	0.2

Segment Flowrate (gpm):	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Eqn. (1) - Velocity, v (ft/s):	0.14	0.27	0.41	0.55	0.69	0.82	0.96
Eqn. (2) - Reynolds Number, Re:	5.26E+02	1.02E+03	1.54E+03	2.07E+03	2.59E+03	3.08E+03	3.61E+03
Pipe Friction Factor, f:	0.1216	0.063	0.0415	0.049	0.0456	0.0433	0.0413
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0008	0.0016	0.0024	0.0051	0.0074	0.0099	0.013
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.09	0.17	0.26	0.22	0.24	0.25	0.26
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	10.09	10.17	10.26	10.22	10.24	10.25	10.26
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.01**	**0.02**	**0.02**	**0.05**	**0.08**	**0.10**	**0.13**

Suction Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	2.9
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	2.06897E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.02	0.02	0.03	0.03
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.00E+02	2.00E+02	3.99E+02	3.99E+02	5.99E+02	5.99E+02
Pipe Friction Factor, f:	0	0.3204	0.3204	0.1602	0.1602	0.1068	0.1068
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.02	0.02	0.03	0.03
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	4.23E+02	4.23E+02	6.34E+02	6.34E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.1514	0.1514	0.101	0.101
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.02	0.02	0.03	0.03
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	4.23E+02	4.23E+02	6.34E+02	6.34E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.1514	0.1514	0.101	0.101
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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Suction Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.02	0.02	0.03	0.03
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	4.23E+02	4.23E+02	6.34E+02	6.34E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.1514	0.1514	0.101	0.101
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Piping Headloss, $H_{p(suction)}$ (ft w.c.):	**#VALUE!**	**0.02**	**0.02**	**0.05**	**0.08**	**0.10**	**0.13**
Eqn. (6) Available Net Positive Suction Head, $NPSH_a$ (ft w.c.):	**#VALUE!**	**35.34**	**35.34**	**35.31**	**35.28**	**35.26**	**35.23**

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Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	0.5
Pipe Inner Diameter, ID (in):	0.546
Pipe Length, L (ft):	60.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	0.00010989

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.08	2	0.16
Standard Elbow, 45°	0.43	4	1.72
Swing Check Valve (wye style)	2.7	1	2.7
			0
			0
			0
			0
		Total K:	4.6

Segment Flowrate (gpm):	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Eqn. (1) - Velocity, v (ft/s):	0.14	0.27	0.41	0.55	0.69	0.82	0.96
Eqn. (2) - Reynolds Number, Re:	5.26E+02	1.02E+03	1.54E+03	2.07E+03	2.59E+03	3.08E+03	3.61E+03
Pipe Friction Factor, f:	0.1216	0.063	0.0415	0.049	0.0456	0.0433	0.0413
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0008	0.0016	0.0024	0.0051	0.0074	0.0099	0.013
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	1.71	3.31	5.02	4.25	4.57	4.81	5.05
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	61.71	63.31	65.02	64.25	64.57	64.81	65.05
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.05**	**0.10**	**0.16**	**0.33**	**0.48**	**0.64**	**0.85**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.02	0.02	0.03	0.03
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	4.23E+02	4.23E+02	6.34E+02	6.34E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.1514	0.1514	0.101	0.101
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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Discharge Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.02	0.02	0.03	0.03
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	4.23E+02	4.23E+02	6.34E+02	6.34E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.1514	0.1514	0.101	0.101
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Lenth, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.02	0.02	0.03	0.03
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	4.23E+02	4.23E+02	6.34E+02	6.34E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.1514	0.1514	0.101	0.101
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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Discharge Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.02	0.02	0.03	0.03
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	4.23E+02	4.23E+02	6.34E+02	6.34E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.1514	0.1514	0.101	0.101
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 6 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.02	0.02	0.03	0.03
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	4.23E+02	4.23E+02	6.34E+02	6.34E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.1514	0.1514	0.101	0.101
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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Discharge Line Segment No. 7 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.02	0.02	0.03	0.03
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	4.23E+02	4.23E+02	6.34E+02	6.34E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.1514	0.1514	0.101	0.101
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 8 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.02	0.02	0.03	0.03
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	4.23E+02	4.23E+02	6.34E+02	6.34E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.1514	0.1514	0.101	0.101
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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Discharge Line Segment No. 9 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.02	0.02	0.03	0.03
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	4.23E+02	4.23E+02	6.34E+02	6.34E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.1514	0.1514	0.101	0.101
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 10 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.02	0.02	0.03	0.03
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	4.23E+02	4.23E+02	6.34E+02	6.34E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.1514	0.1514	0.101	0.101
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	**#VALUE!**	**0.10**	**0.16**	**0.33**	**0.48**	**0.64**	**0.85**
Exit Velocity at Liquid Discharge, v (ft/s):	**#VALUE!**	**0.27**	**0.41**	**0.55**	**0.69**	**0.82**	**0.96**
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**	**0.01**
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	**#VALUE!**	**7.12**	**7.18**	**7.38**	**7.57**	**7.75**	**7.99**
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	**#VALUE!**	**7.48**	**7.54**	**7.75**	**7.95**	**8.14**	**8.39**

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4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{gpm}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_P = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_P$$

Eqn. (5):

$$H_P = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

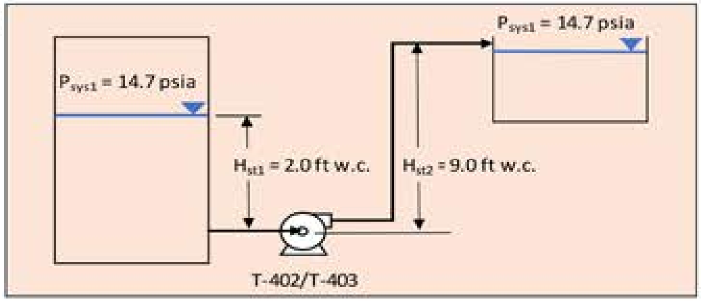
ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-402/T-403 MetClear/Coagulation Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

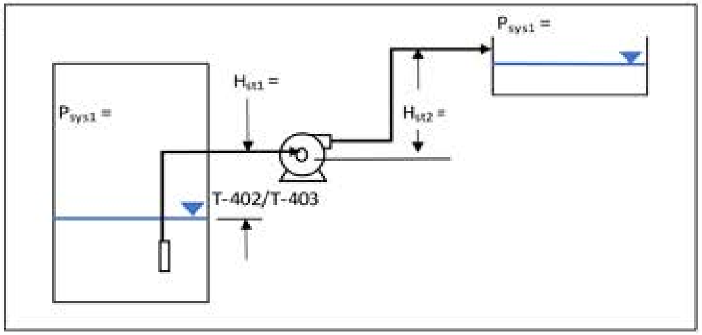
Pump ID:	T-402/T-403
Fluid:	Water
Fluid Description:	Acid/Base
Enter Fluid Density if Other than Water (lb/ft^3):	71
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	0.1
Design Flow Rate (gpm):	0.15
Maximum Flow Rate (gpm):	0.2
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	60
Elevation of Fluid to be Pumped (ft):	3
Pump Impeller Centerline Elevation (ft):	1
Discharge Elevation (ft):	10
Static Head of Discharge Line , H_{st2} (ft):	9
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	2
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.592
Fluid density, ρ (lb/ft^3):	62.36
Fluid Kinematic Viscosity, η (ft^2/s):	1.21E-05
Include Exit Headloss at Discharge, H_v:	Yes

Notes:

Flooded Suction:



Suction Lift:



Flow Rates (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
(gpd):	140	140	140	280	280	280	280
(MGD):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	**Pressure Loss (ft w.c.)**	**Equipment Tag**	**Pressure Loss (ft w.c.)**
Flow Meter			
Subtotal:	*0.0*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 0.0

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PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-402/T-403 MetClear/Coagulation Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	0.5
Pipe Inner Diameter, ID (in):	0.546
Pipe Length, L (ft):	10.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	0.00010989

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.08	3	0.24
			0
			0
			0
			0
			0
			0
		Total K:	0.2

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.14	0.14	0.14	0.27	0.27	0.27	0.27
Eqn. (2) - Reynolds Number, Re:	5.26E+02	5.26E+02	5.26E+02	1.02E+03	1.02E+03	1.02E+03	1.02E+03
Pipe Friction Factor, f:	0.1216	0.1216	0.1216	0.063	0.063	0.063	0.063
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0008	0.0008	0.0008	0.0016	0.0016	0.0016	0.0016
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.09	0.09	0.09	0.17	0.17	0.17	0.17
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	10.09	10.09	10.09	10.17	10.17	10.17	10.17
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.01**	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**	**0.02**

Suction Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	2.9
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 80 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	2.06897E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.00E+02	2.00E+02	2.00E+02	2.00E+02
Pipe Friction Factor, f:	0	0	0	0.3204	0.3204	0.3204	0.3204
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-402/T-403 MetClear/Coagulation Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
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SUBJECT:	P-402/T-403 MetClear/Coagulation Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Piping Headloss, $H_{p(suction)}$ (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.02**	**0.02**	**0.02**	**0.02**
Eqn. (6) Available Net Positive Suction Head, $NPSH_a$ (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**35.34**	**35.34**	**35.34**	**35.34**

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SUBJECT:	P-402/T-403 MetClear/Coagulation Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]		

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	0.5
Pipe Inner Diameter, ID (in):	0.546
Pipe Length, L (ft):	60.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	0.00010989

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.08	2	0.16
Standard Elbow, 45°	0.43	4	1.72
Swing Check Valve (wye style)	2.7	1	2.7
			0
			0
			0
			0
		Total K:	4.6

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.14	0.14	0.14	0.27	0.27	0.27	0.27
Eqn. (2) - Reynolds Number, Re:	5.26E+02	5.26E+02	5.26E+02	1.02E+03	1.02E+03	1.02E+03	1.02E+03
Pipe Friction Factor, f:	0.1216	0.1216	0.1216	0.063	0.063	0.063	0.063
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0008	0.0008	0.0008	0.0016	0.0016	0.0016	0.0016
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	1.71	1.71	1.71	3.31	3.31	3.31	3.31
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	61.71	61.71	61.71	63.31	63.31	63.31	63.31
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.05**	**0.05**	**0.05**	**0.10**	**0.10**	**0.10**	**0.10**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

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SUBJECT:	P-402/T-403 MetClear/Coagulation Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Lenth, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

ARCADIS Design & Consultancy for natural and built assets	PROJECT: BASF Northworks Perimeter Barrier Remedy	BY: S. Hannula	DATE: 4-May-2022
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	SUBJECT: P-402/T-403 MetClear/Coagulation Pumps	APPVD. BY: [NAME]	DATE: [DATE]

Discharge Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 6 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

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PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-402/T-403 MetClear/Coagulation Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 7 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 8 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-402/T-403 MetClear/Coagulation Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 9 Headloss:

Flow Ratio:	1	**Valve/Fitting Tag**	**K**	**No. Units**	**Total K**
Nominal Pipe Diameter (in):	3				0
Pipe Inner Diameter, ID (in):	3.068				0
Pipe Length, L (ft):	0.00				0
Pipe Material:	SCH 40 - Steel				0
Pipe Type:	Smooth Pipes (PE and other thermoplastics)				0
					0
Roughness, e (ft):	0.000005				0
e / ID:	1.95567E-05			**Total K:**	**0.0**

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 10 Headloss:

Flow Ratio:	1	**Valve/Fitting Tag**	**K**	**No. Units**	**Total K**
Nominal Pipe Diameter (in):	3				0
Pipe Inner Diameter, ID (in):	3.068				0
Pipe Length, L (ft):	0.00				0
Pipe Material:	SCH 40 - Steel				0
Pipe Type:	Smooth Pipes (PE and other thermoplastics)				0
					0
Roughness, e (ft):	0.000005				0
e / ID:	1.95567E-05			**Total K:**	**0.0**

Segment Flowrate (gpm):	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Eqn. (1) - Velocity, v (ft/s):	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Eqn. (2) - Reynolds Number, Re:	0.00E+00	0.00E+00	0.00E+00	2.11E+02	2.11E+02	2.11E+02	2.11E+02
Pipe Friction Factor, f:	0	0	0	0.3029	0.3029	0.3029	0.3029
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.10**	**0.10**	**0.10**	**0.10**
Exit Velocity at Liquid Discharge, v (ft/s):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.27**	**0.27**	**0.27**	**0.27**
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**7.12**	**7.12**	**7.12**	**7.12**
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	**#VALUE!**	**#VALUE!**	**#VALUE!**	**7.48**	**7.48**	**7.48**	**7.48**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-402/T-403 MetClear/Coagulation Pumps	APPVD. BY:	[NAME]	DATE:	[DATE]

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{gpm}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_p = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_p$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \perp H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

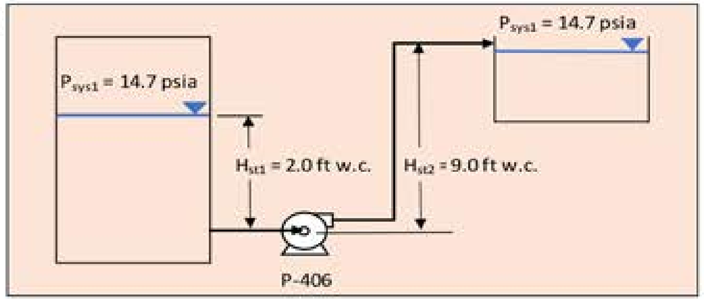
$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-406 Sludge Floc Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

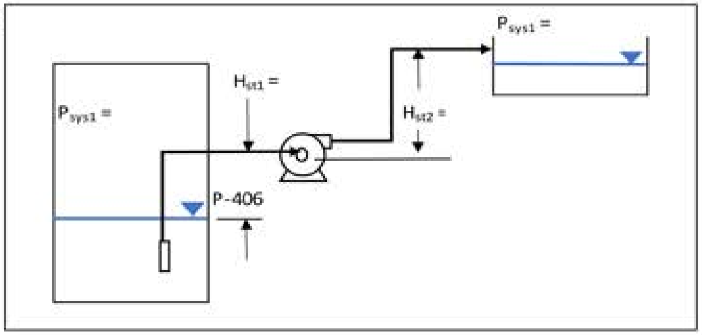
Pump ID:	P-406
Fluid:	Water
Fluid Description:	Polymer
Enter Fluid Density if Other than Water (lb/ft^3):	75
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	0.1
Design Flow Rate (gpm):	0.3
Maximum Flow Rate (gpm):	0.5
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	60
Elevation of Fluid to be Pumped (ft):	3
Pump Impeller Centerline Elevation (ft):	1
Discharge Elevation (ft):	10
Static Head of Discharge Line , H_{st2} (ft):	9
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	2
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.592
Fluid density, ρ (lb/ft^3):	62.36
Fluid Kinematic Viscosity, η (ft^2/s):	1.21E-05
Include Exit Headloss at Discharge, H_v:	Yes

Notes:

Flooded Suction:



Suction Lift:



Flow Rates (gpm):	0.1	0.2	0.3	0.3	0.4	0.5	0.5
(gpd):	140	280	420	420	560	700	700
(MGD):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Flow Meter			
Subtotal:	*0.0*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 0.0

PROJECT:	BASF Northworks Perimeter Barrier Remedy
JOB NO.:	30133323
SUBJECT:	P-406 Sludge Floc Pump
BY:	S. Hannula
CHKD. BY:	M. Samp
APPVD. BY:	[NAME]
DATE:	4-May-2022
DATE:	6-May-2022
DATE:	[DATE]

Suction Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	0.5
Pipe Inner Diameter, ID (in):	0.546
Pipe Length, L (ft):	10.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	0.00010989

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.08	3	0.24
			0
			0
			0
			0
			0
			0
		Total K:	0.2

Segment Flowrate (gpm):	0.1	0.2	0.3	0.3	0.4	0.5	0.5
Eqn. (1) - Velocity, v (ft/s):	0.14	0.27	0.41	0.41	0.55	0.69	0.69
Eqn. (2) - Reynolds Number, Re:	5.26E+02	1.02E+03	1.54E+03	1.54E+03	2.07E+03	2.59E+03	2.59E+03
Pipe Friction Factor, f:	0.1216	0.063	0.0415	0.0415	0.049	0.0456	0.0456
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0008	0.0016	0.0024	0.0024	0.0051	0.0074	0.0074
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.09	0.17	0.26	0.26	0.22	0.24	0.24
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	10.09	10.17	10.26	10.26	10.22	10.24	10.24
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.01**	**0.02**	**0.02**	**0.02**	**0.05**	**0.08**	**0.08**

Suction Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	2.9
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 80 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	2.06897E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.3	0.4	0.5	0.5
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.01	0.02	0.02	0.02
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.00E+02	2.00E+02	2.00E+02	3.99E+02	3.99E+02	3.99E+02
Pipe Friction Factor, f:	0	0.3204	0.3204	0.3204	0.1602	0.1602	0.1602
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

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PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-406 Sludge Floc Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.3	0.4	0.5	0.5
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.01	0.02	0.02	0.02
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	2.11E+02	4.23E+02	4.23E+02	4.23E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.3029	0.1514	0.1514	0.1514
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.3	0.4	0.5	0.5
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.01	0.02	0.02	0.02
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	2.11E+02	4.23E+02	4.23E+02	4.23E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.3029	0.1514	0.1514	0.1514
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-406 Sludge Floc Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.3	0.4	0.5	0.5
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.01	0.02	0.02	0.02
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	2.11E+02	4.23E+02	4.23E+02	4.23E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.3029	0.1514	0.1514	0.1514
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Piping Headloss, $H_{p(suction)}$ (ft w.c.):	**#VALUE!**	**0.02**	**0.02**	**0.02**	**0.05**	**0.08**	**0.08**
Eqn. (6) Available Net Positive Suction Head, $NPSH_a$ (ft w.c.):	**#VALUE!**	**35.34**	**35.34**	**35.34**	**35.31**	**35.28**	**35.28**

ARCADIS Design & Consultancy for natural and built assets	PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE: 4-May-2022
	JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE: 6-May-2022
	SUBJECT:	P-406 Sludge Floc Pump	APPVD. BY:	[NAME]	DATE: [DATE]

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	0.5
Pipe Inner Diameter, ID (in):	0.546
Pipe Length, L (ft):	20.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	0.00010989

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.08	2	0.16
Standard Elbow, 45°	0.43	4	1.72
Swing Check Valve (wye style)	2.7	1	2.7
			0
			0
			0
			0
		Total K:	4.6

Segment Flowrate (gpm):	0.1	0.2	0.3	0.3	0.4	0.5	0.5
Eqn. (1) - Velocity, v (ft/s):	0.14	0.27	0.41	0.41	0.55	0.69	0.69
Eqn. (2) - Reynolds Number, Re:	5.26E+02	1.02E+03	1.54E+03	1.54E+03	2.07E+03	2.59E+03	2.59E+03
Pipe Friction Factor, f:	0.1216	0.063	0.0415	0.0415	0.049	0.0456	0.0456
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0008	0.0016	0.0024	0.0024	0.0051	0.0074	0.0074
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	1.71	3.31	5.02	5.02	4.25	4.57	4.57
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	21.71	23.31	25.02	25.02	24.25	24.57	24.57
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.02**	**0.04**	**0.06**	**0.06**	**0.12**	**0.18**	**0.18**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.3	0.4	0.5	0.5
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.01	0.02	0.02	0.02
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	2.11E+02	4.23E+02	4.23E+02	4.23E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.3029	0.1514	0.1514	0.1514
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-406 Sludge Floc Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Discharge Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.3	0.4	0.5	0.5
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.01	0.02	0.02	0.02
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	2.11E+02	4.23E+02	4.23E+02	4.23E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.3029	0.1514	0.1514	0.1514
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Lenth, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.3	0.4	0.5	0.5
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.01	0.02	0.02	0.02
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	2.11E+02	4.23E+02	4.23E+02	4.23E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.3029	0.1514	0.1514	0.1514
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.3	0.4	0.5	0.5
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.01	0.02	0.02	0.02
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	2.11E+02	4.23E+02	4.23E+02	4.23E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.3029	0.1514	0.1514	0.1514
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 6 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.3	0.4	0.5	0.5
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.01	0.02	0.02	0.02
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	2.11E+02	4.23E+02	4.23E+02	4.23E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.3029	0.1514	0.1514	0.1514
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 7 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.3	0.4	0.5	0.5
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.01	0.02	0.02	0.02
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	2.11E+02	4.23E+02	4.23E+02	4.23E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.3029	0.1514	0.1514	0.1514
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 8 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.3	0.4	0.5	0.5
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.01	0.02	0.02	0.02
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	2.11E+02	4.23E+02	4.23E+02	4.23E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.3029	0.1514	0.1514	0.1514
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY: S. Hannula	DATE: 4-May-2022
JOB NO.:	30133323	CHKD. BY: M. Samp	DATE: 6-May-2022
SUBJECT:	P-406 Sludge Floc Pump	APPVD. BY: [NAME]	DATE: [DATE]

Discharge Line Segment No. 9 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.3	0.4	0.5	0.5
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.01	0.02	0.02	0.02
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	2.11E+02	4.23E+02	4.23E+02	4.23E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.3029	0.1514	0.1514	0.1514
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 10 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	0.1	0.2	0.3	0.3	0.4	0.5	0.5
Eqn. (1) - Velocity, v (ft/s):	0.00	0.01	0.01	0.01	0.02	0.02	0.02
Eqn. (2) - Reynolds Number, Re:	0.00E+00	2.11E+02	2.11E+02	2.11E+02	4.23E+02	4.23E+02	4.23E+02
Pipe Friction Factor, f:	0	0.3029	0.3029	0.3029	0.1514	0.1514	0.1514
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0	0	0
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	#VALUE!	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	**#VALUE!**	**0.04**	**0.06**	**0.06**	**0.12**	**0.18**	**0.18**
Exit Velocity at Liquid Discharge, v (ft/s):	**#VALUE!**	**0.27**	**0.41**	**0.41**	**0.55**	**0.69**	**0.69**
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	**#VALUE!**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	**#VALUE!**	**7.06**	**7.08**	**7.08**	**7.17**	**7.27**	**7.27**
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	**#VALUE!**	**7.41**	**7.43**	**7.43**	**7.53**	**7.63**	**7.63**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-406 Sludge Floc Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{gpm}{448.8312}}{\frac{\pi}{4}\cdot\left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_p = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_p$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \perp H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

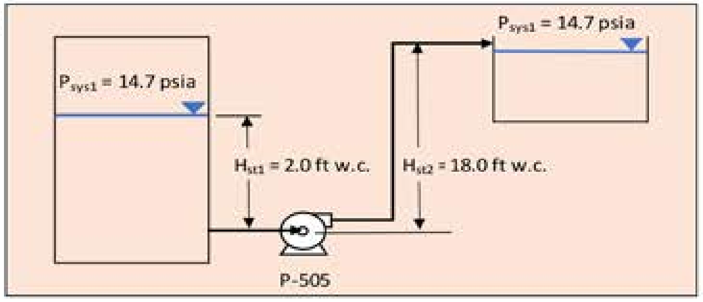
$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-505 Sump Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

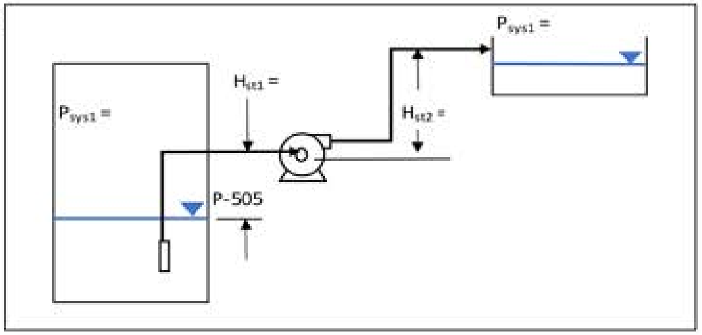
Pump ID:	P-505
Fluid:	Water
Fluid Description:	Water
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	10
Design Flow Rate (gpm):	15
Maximum Flow Rate (gpm):	20
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	60
Elevation of Fluid to be Pumped (ft):	-4
Pump Impeller Centerline Elevation (ft):	-6
Discharge Elevation (ft):	12
Static Head of Discharge Line , H_{st2} (ft):	18
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	2
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.592
Fluid density, ρ (lb/ft^3):	62.36
Fluid Kinematic Viscosity, η (ft^2/s):	1.21E-05
Include Exit Headloss at Discharge, H_v:	Yes

Notes:

Flooded Suction:



Suction Lift:



Flow Rates (gpm):	10.0	11.7	13.4	15.0	16.7	18.4	20.0
(gpd):	14,000	16,380	18,760	21,000	23,380	25,760	28,000
(MGD):	0.01	0.02	0.02	0.02	0.02	0.03	0.03
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Subtotal:	*0.0*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 0.0

ARCADIS Design & Consultancy for natural and built assets	PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE: 4-May-2022
	JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE: 6-May-2022
	SUBJECT:	P-505 Sump Pump	APPVD. BY:	[NAME]	DATE: [DATE]

Suction Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	0.5
Pipe Inner Diameter, ID (in):	0.546
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	0.00010989

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	10	11.7	13.4	15	16.7	18.4	20
Eqn. (1) - Velocity, v (ft/s):	13.70	16.03	18.36	20.55	22.88	25.21	27.41
Eqn. (2) - Reynolds Number, Re:	5.15E+04	6.03E+04	6.90E+04	7.73E+04	8.60E+04	9.48E+04	1.03E+05
Pipe Friction Factor, f:	0.0212	0.0205	0.0199	0.0195	0.0191	0.0187	0.0185
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	1.359	1.7992	2.2911	2.8126	3.4151	4.0592	4.7473
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	2.9
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 80 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	2.06897E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	10	11.7	13.4	15	16.7	18.4	20
Eqn. (1) - Velocity, v (ft/s):	0.49	0.57	0.65	0.73	0.81	0.89	0.97
Eqn. (2) - Reynolds Number, Re:	9.79E+03	1.14E+04	1.30E+04	1.46E+04	1.62E+04	1.78E+04	1.94E+04
Pipe Friction Factor, f:	0.0311	0.0299	0.0289	0.028	0.0273	0.0267	0.0261
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0005	0.0006	0.0008	0.001	0.0012	0.0014	0.0016
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-505 Sump Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

Suction Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	10	11.7	13.4	15	16.7	18.4	20
Eqn. (1) - Velocity, v (ft/s):	0.43	0.51	0.58	0.65	0.72	0.80	0.87
Eqn. (2) - Reynolds Number, Re:	9.09E+03	1.08E+04	1.23E+04	1.37E+04	1.52E+04	1.69E+04	1.84E+04
Pipe Friction Factor, f:	0.0317	0.0303	0.0293	0.0285	0.0277	0.027	0.0265
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0004	0.0005	0.0006	0.0007	0.0009	0.0011	0.0012
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	10	11.7	13.4	15	16.7	18.4	20
Eqn. (1) - Velocity, v (ft/s):	0.43	0.51	0.58	0.65	0.72	0.80	0.87
Eqn. (2) - Reynolds Number, Re:	9.09E+03	1.08E+04	1.23E+04	1.37E+04	1.52E+04	1.69E+04	1.84E+04
Pipe Friction Factor, f:	0.0317	0.0303	0.0293	0.0285	0.0277	0.027	0.0265
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0004	0.0005	0.0006	0.0007	0.0009	0.0011	0.0012
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT: BASF Northworks Perimeter Barrier Remedy	BY: S. Hannula	DATE: 4-May-2022
JOB NO.: 30133323	CHKD. BY: M. Samp	DATE: 6-May-2022
SUBJECT: P-505 Sump Pump	APPVD. BY: [NAME]	DATE: [DATE]

Suction Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	10	11.7	13.4	15	16.7	18.4	20
Eqn. (1) - Velocity, v (ft/s):	0.43	0.51	0.58	0.65	0.72	0.80	0.87
Eqn. (2) - Reynolds Number, Re:	9.09E+03	1.08E+04	1.23E+04	1.37E+04	1.52E+04	1.69E+04	1.84E+04
Pipe Friction Factor, f:	0.0317	0.0303	0.0293	0.0285	0.0277	0.027	0.0265
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0004	0.0005	0.0006	0.0007	0.0009	0.0011	0.0012
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Suction Piping Headloss, $H_{p(suction)}$ (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Eqn. (6) Available Net Positive Suction Head, $NPSH_a$ (ft w.c.):	**35.36**	**35.36**	**35.36**	**35.36**	**35.36**	**35.36**	**35.36**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY: S. Hannula	DATE: 4-May-2022
JOB NO.:	30133323	CHKD. BY: M. Samp	DATE: 6-May-2022
SUBJECT:	P-505 Sump Pump	APPVD. BY: [NAME]	DATE: [DATE]

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	1.5
Pipe Inner Diameter, ID (in):	1.5
Pipe Length, L (ft):	55.00
Pipe Material:	SCH 80 - PVC/CPVC
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	0.00004

Valve/Fitting Tag	K	No. Units	Total K
Standard Elbow, 90°	0.63	2	1.26
			0
			0
			0
			0
3 x 1.5 reducer	0.38	1	0.38
			0
		Total K:	1.6

Segment Flowrate (gpm):	10	11.7	13.4	15	16.7	18.4	20
Eqn. (1) - Velocity, v (ft/s):	1.82	2.12	2.43	2.72	3.03	3.34	3.63
Eqn. (2) - Reynolds Number, Re:	1.88E+04	2.19E+04	2.51E+04	2.81E+04	3.13E+04	3.45E+04	3.75E+04
Pipe Friction Factor, f:	0.0264	0.0254	0.0246	0.024	0.0234	0.0228	0.0224
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0109	0.0142	0.0181	0.0221	0.0267	0.0316	0.0367
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	7.77	8.07	8.33	8.54	8.76	8.99	9.15
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	62.77	63.07	63.33	63.54	63.76	63.99	64.15
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.68**	**0.90**	**1.15**	**1.40**	**1.70**	**2.02**	**2.35**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	10	11.7	13.4	15	16.7	18.4	20
Eqn. (1) - Velocity, v (ft/s):	0.43	0.51	0.58	0.65	0.72	0.80	0.87
Eqn. (2) - Reynolds Number, Re:	9.09E+03	1.08E+04	1.23E+04	1.37E+04	1.52E+04	1.69E+04	1.84E+04
Pipe Friction Factor, f:	0.0317	0.0303	0.0293	0.0285	0.0277	0.027	0.0265
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0004	0.0005	0.0006	0.0007	0.0009	0.0011	0.0012
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 3 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	10	11.7	13.4	15	16.7	18.4	20
Eqn. (1) - Velocity, v (ft/s):	0.43	0.51	0.58	0.65	0.72	0.80	0.87
Eqn. (2) - Reynolds Number, Re:	9.09E+03	1.08E+04	1.23E+04	1.37E+04	1.52E+04	1.69E+04	1.84E+04
Pipe Friction Factor, f:	0.0317	0.0303	0.0293	0.0285	0.0277	0.027	0.0265
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0004	0.0005	0.0006	0.0007	0.0009	0.0011	0.0012
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 4 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Lenth, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	10	11.7	13.4	15	16.7	18.4	20
Eqn. (1) - Velocity, v (ft/s):	0.43	0.51	0.58	0.65	0.72	0.80	0.87
Eqn. (2) - Reynolds Number, Re:	9.09E+03	1.08E+04	1.23E+04	1.37E+04	1.52E+04	1.69E+04	1.84E+04
Pipe Friction Factor, f:	0.0317	0.0303	0.0293	0.0285	0.0277	0.027	0.0265
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0004	0.0005	0.0006	0.0007	0.0009	0.0011	0.0012
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 5 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	10	11.7	13.4	15	16.7	18.4	20
Eqn. (1) - Velocity, v (ft/s):	0.43	0.51	0.58	0.65	0.72	0.80	0.87
Eqn. (2) - Reynolds Number, Re:	9.09E+03	1.08E+04	1.23E+04	1.37E+04	1.52E+04	1.69E+04	1.84E+04
Pipe Friction Factor, f:	0.0317	0.0303	0.0293	0.0285	0.0277	0.027	0.0265
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0004	0.0005	0.0006	0.0007	0.0009	0.0011	0.0012
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 6 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	10	11.7	13.4	15	16.7	18.4	20
Eqn. (1) - Velocity, v (ft/s):	0.43	0.51	0.58	0.65	0.72	0.80	0.87
Eqn. (2) - Reynolds Number, Re:	9.09E+03	1.08E+04	1.23E+04	1.37E+04	1.52E+04	1.69E+04	1.84E+04
Pipe Friction Factor, f:	0.0317	0.0303	0.0293	0.0285	0.0277	0.027	0.0265
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0004	0.0005	0.0006	0.0007	0.0009	0.0011	0.0012
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

PROJECT:	BASF Northworks Perimeter Barrier Remedy
JOB NO.:	30133323
SUBJECT:	P-505 Sump Pump
BY:	S. Hannula
CHKD. BY:	M. Samp
APPVD. BY:	[NAME]
DATE:	4-May-2022
DATE:	6-May-2022
DATE:	[DATE]

Discharge Line Segment No. 7 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	10	11.7	13.4	15	16.7	18.4	20
Eqn. (1) - Velocity, v (ft/s):	0.43	0.51	0.58	0.65	0.72	0.80	0.87
Eqn. (2) - Reynolds Number, Re:	9.09E+03	1.08E+04	1.23E+04	1.37E+04	1.52E+04	1.69E+04	1.84E+04
Pipe Friction Factor, f:	0.0317	0.0303	0.0293	0.0285	0.0277	0.027	0.0265
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0004	0.0005	0.0006	0.0007	0.0009	0.0011	0.0012
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 8 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	10	11.7	13.4	15	16.7	18.4	20
Eqn. (1) - Velocity, v (ft/s):	0.43	0.51	0.58	0.65	0.72	0.80	0.87
Eqn. (2) - Reynolds Number, Re:	9.09E+03	1.08E+04	1.23E+04	1.37E+04	1.52E+04	1.69E+04	1.84E+04
Pipe Friction Factor, f:	0.0317	0.0303	0.0293	0.0285	0.0277	0.027	0.0265
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0004	0.0005	0.0006	0.0007	0.0009	0.0011	0.0012
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 9 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	10	11.7	13.4	15	16.7	18.4	20
Eqn. (1) - Velocity, v (ft/s):	0.43	0.51	0.58	0.65	0.72	0.80	0.87
Eqn. (2) - Reynolds Number, Re:	9.09E+03	1.08E+04	1.23E+04	1.37E+04	1.52E+04	1.69E+04	1.84E+04
Pipe Friction Factor, f:	0.0317	0.0303	0.0293	0.0285	0.0277	0.027	0.0265
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0004	0.0005	0.0006	0.0007	0.0009	0.0011	0.0012
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Line Segment No. 10 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	3.068
Pipe Length, L (ft):	0.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	1.95567E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	10	11.7	13.4	15	16.7	18.4	20
Eqn. (1) - Velocity, v (ft/s):	0.43	0.51	0.58	0.65	0.72	0.80	0.87
Eqn. (2) - Reynolds Number, Re:	9.09E+03	1.08E+04	1.23E+04	1.37E+04	1.52E+04	1.69E+04	1.84E+04
Pipe Friction Factor, f:	0.0317	0.0303	0.0293	0.0285	0.0277	0.027	0.0265
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0004	0.0005	0.0006	0.0007	0.0009	0.0011	0.0012
Eqn. (4a) - Fittings Equivalent Length, L_F (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	**0.68**	**0.90**	**1.15**	**1.40**	**1.70**	**2.02**	**2.35**
Exit Velocity at Liquid Discharge, v (ft/s):	**1.82**	**2.12**	**2.43**	**2.72**	**3.03**	**3.34**	**3.63**
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	**0.05**	**0.07**	**0.09**	**0.12**	**0.14**	**0.17**	**0.20**
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	**16.73**	**16.97**	**17.24**	**17.52**	**17.84**	**18.19**	**18.55**
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	**17.57**	**17.82**	**18.10**	**18.40**	**18.73**	**19.10**	**19.48**

PROJECT:	BASF Northworks Perimeter Barrier Remedy	BY:	S. Hannula	DATE:	4-May-2022
JOB NO.:	30133323	CHKD. BY:	M. Samp	DATE:	6-May-2022
SUBJECT:	P-505 Sump Pump	APPVD. BY:	[NAME]	DATE:	[DATE]

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{gpm}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_p = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_p$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \perp H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 1	APPVD. BY:		DATE:	

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.29	0.51	0.80	1.10	1.76	2.60	4.16
Exit Velocity at Liquid Discharge, v (ft/s):	0.33	0.44	0.56	0.67	0.89	1.11	1.45
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.00	0.00	0.01	0.01	0.02	0.03
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	6.49	6.71	7.00	7.31	7.97	8.82	10.39
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	6.81	7.05	7.35	7.68	8.37	9.26	10.91

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_p = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_p$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot \left(P_{sys1} - P_{vap}\right) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot \left(P_{sys2} - P_{sys1}\right) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot \left(P_{sys2} - P_{sys1}\right) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 1	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	2.067
Pipe Length, L (ft):	25.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Coated Steel
Roughness, e (ft):	0.00018
e / ID:	0.001044993

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	**0.06**	1	**0.06**
Stop Check Valve, flow thru	**7.5**	1	**7.5**
Standard Elbow, 90°	**0.57**	1	**0.57**
			0
Standard Tee, thru branch	**1.14**	1	**1.14**
			0
			0
		Total K:	**9.3**

Segment Flowrate (gpm):	3	4	5	6	8	10	13
Eqn. (1) - Velocity, v (ft/s):	0.29	0.38	0.48	0.57	0.76	0.96	1.24
Eqn. (2) - Reynolds Number, Re:	3.54E+03	4.64E+03	5.86E+03	6.96E+03	9.28E+03	1.17E+04	1.51E+04
Pipe Friction Factor, f:	0.0424	0.0393	0.037	0.0354	0.033	0.0313	0.0296
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0003	0.0005	0.0008	0.001	0.0017	0.0026	0.0041
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	37.66	40.63	43.16	45.11	48.39	51.01	53.94
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	62.66	65.63	68.16	70.11	73.39	76.01	78.94
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.02**	**0.03**	**0.05**	**0.07**	**0.12**	**0.20**	**0.32**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	675.00
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
Standard Elbow, 45°	**0.3**	2	**0.6**
Standard Tee, thru branch	**1.14**	1	**1.14**
			0
			0
			0
			0
		Total K:	**1.7**

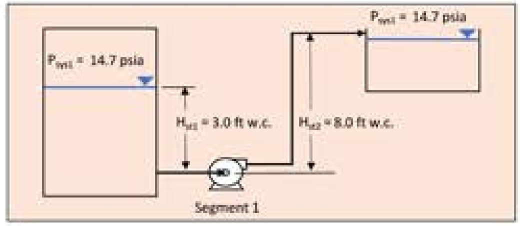
Segment Flowrate (gpm):	3	4	5	6	8	10	13
Eqn. (1) - Velocity, v (ft/s):	0.33	0.44	0.56	0.67	0.89	1.11	1.45
Eqn. (2) - Reynolds Number, Re:	3.74E+03	4.99E+03	6.34E+03	7.59E+03	1.01E+04	1.26E+04	1.64E+04
Pipe Friction Factor, f:	0.0407	0.0375	0.035	0.0333	0.0309	0.0291	0.0272
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0004	0.0007	0.0011	0.0015	0.0024	0.0035	0.0056
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	6.83	7.41	7.94	8.35	9.00	9.55	10.22
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	681.83	682.41	682.94	683.35	684.00	684.55	685.22
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.27**	**0.48**	**0.75**	**1.03**	**1.64**	**2.40**	**3.84**

ARCADIS Design & Consultancy for natural and built assets

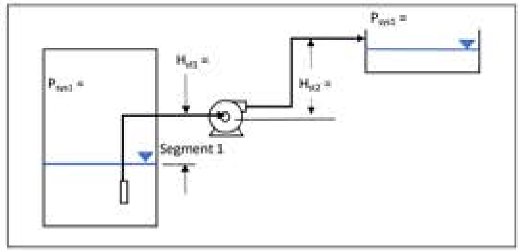
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 1	APPVD. BY:		DATE:	

Pump ID:	Segment 1
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	3.2
Design Flow Rate (gpm):	6.4
Maximum Flow Rate (gpm):	12.8
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	-12
Pump Impeller Centerline Elevation (ft):	-15
Discharge Elevation (ft):	-7
Static Head of Discharge Line , H_{st2} (ft):	8
Suction Lift of Liquid to be Pumped, H_{sl} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	3
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	3	4	5	6	8	10	13
(gpd):	4,200	5,600	7,000	8,400	11,200	14,000	18,200
(MGD):	0.00	0.01	0.01	0.01	0.01	0.01	0.02
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Flowmeter	1.2		
Subtotal:	*1.2*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 1.2

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 2	APPVD. BY:		DATE:	

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.01	0.03	0.04	0.07	0.10	0.14	0.22
Exit Velocity at Liquid Discharge, v (ft/s):	0.19	0.33	0.44	0.56	0.67	0.78	1.00
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.00	0.00	0.00	0.01	0.01	0.02
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	6.21	6.23	6.24	6.27	6.31	6.35	6.44
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	6.52	6.54	6.55	6.58	6.63	6.67	6.76

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 2	APPVD. BY:		DATE:	

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	2.067
Pipe Length, L (ft):	25.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Coated Steel
Roughness, e (ft):	0.00018
e / ID:	0.001044993

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	**0.06**	1	**0.06**
Stop Check Valve, flow thru	**7.5**	1	**7.5**
Standard Elbow, 90°	**0.57**	1	**0.57**
			0
Standard Tee, thru branch	**1.14**	1	**1.14**
			0
			0
		Total K:	**9.3**

Segment Flowrate (gpm):	2	3	4	5	6	7	9
Eqn. (1) - Velocity, v (ft/s):	0.19	0.29	0.38	0.48	0.57	0.67	0.86
Eqn. (2) - Reynolds Number, Re:	2.32E+03	3.54E+03	4.64E+03	5.86E+03	6.96E+03	8.18E+03	1.05E+04
Pipe Friction Factor, f:	0.048	0.0424	0.0393	0.037	0.0354	0.034	0.0321
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0002	0.0003	0.0005	0.0008	0.001	0.0014	0.0021
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	33.27	37.66	40.63	43.16	45.11	46.96	49.74
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	58.27	62.66	65.63	68.16	70.11	71.96	74.74
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.01**	**0.02**	**0.03**	**0.05**	**0.07**	**0.10**	**0.16**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	12.50
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
Standard Elbow, 45°	**0.3**	1	**0.3**
Standard Tee, thru branch	**1.14**	1	**1.14**
			0
			0
			0
			0
		Total K:	**1.4**

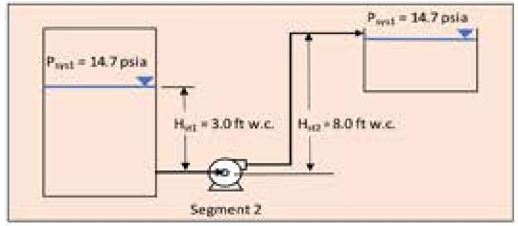
Segment Flowrate (gpm):	2	3	4	5	6	7	9
Eqn. (1) - Velocity, v (ft/s):	0.22	0.33	0.44	0.56	0.67	0.78	1.00
Eqn. (2) - Reynolds Number, Re:	2.49E+03	3.74E+03	4.99E+03	6.34E+03	7.59E+03	8.84E+03	1.13E+04
Pipe Friction Factor, f:	0.0461	0.0407	0.0375	0.035	0.0333	0.032	0.0299
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0002	0.0004	0.0007	0.0011	0.0015	0.0019	0.0029
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	4.99	5.65	6.13	6.57	6.91	7.19	7.69
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	17.49	18.15	18.63	19.07	19.41	19.69	20.19
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.01**	**0.01**	**0.02**	**0.03**	**0.04**	**0.06**

ARCADIS Design & Consultancy for natural and built assets

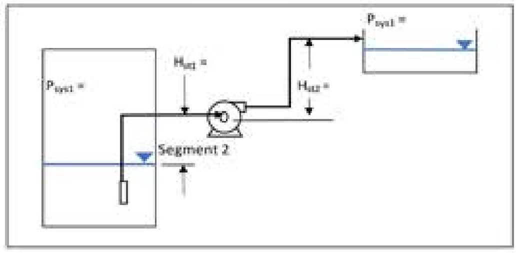
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 2	APPVD. BY:		DATE:	

Pump ID:	Segment 2
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	2.35
Design Flow Rate (gpm):	4.7
Maximum Flow Rate (gpm):	9.4
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	-12
Pump Impeller Centerline Elevation (ft):	-15
Discharge Elevation (ft):	-7
Static Head of Discharge Line , H_{st2} (ft):	8
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	3
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	2	3	4	5	6	7	9
(gpd):	2,800	4,200	5,600	7,000	8,400	9,800	12,600
(MGD):	0.00	0.00	0.01	0.01	0.01	0.01	0.01
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Flowmeter	1.2		
Subtotal:	*1.2*	*Subtotal:*	*0.0*

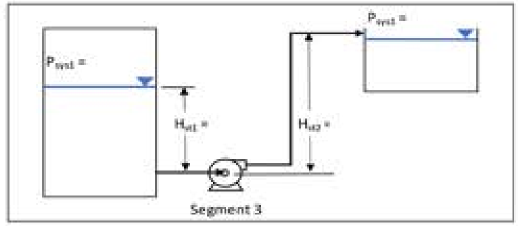
Total Headloss (ft w.c.): 1.2

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 3	APPVD. BY:		DATE:	

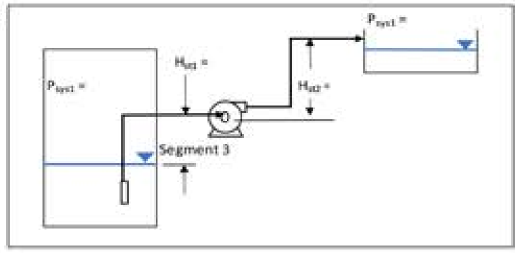
Pump ID:	Segment 3
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	5.55
Design Flow Rate (gpm):	11.1
Maximum Flow Rate (gpm):	22.2
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	0
Pump Impeller Centerline Elevation (ft):	0
Discharge Elevation (ft):	0
Static Head of Discharge Line , H_{st2} (ft):	0
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Notes:

Flooded Suction:



Suction Lift:



Flow Rates (gpm):	6	8	10	11	15	19	22
(gpd):	8,400	11,200	14,000	15,400	21,000	26,600	30,800
(MGD):	0.01	0.01	0.01	0.02	0.02	0.03	0.03
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)		
Subtotal:	*0.0*	*Subtotal:*	*0.0*	**Total Headloss (ft w.c.):**	**0.0**

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 3	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	825.00
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	6	8	10	11	15	19	22
Eqn. (1) - Velocity, v (ft/s):	0.67	0.89	1.11	1.22	1.67	2.11	2.45
Eqn. (2) - Reynolds Number, Re:	7.59E+03	1.01E+04	1.26E+04	1.38E+04	1.89E+04	2.39E+04	2.78E+04
Pipe Friction Factor, f:	0.0333	0.0309	0.0291	0.0284	0.0263	0.0249	0.024
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0015	0.0024	0.0035	0.0041	0.0071	0.0108	0.014
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	825.00	825.00	825.00	825.00	825.00	825.00	825.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**1.24**	**1.98**	**2.89**	**3.38**	**5.86**	**8.91**	**11.55**

PROJECT: BASF Above Grade System Sump Hydraulics	BY: S. Hannula	DATE: 10-May-2022
JOB NO.: 30005248	CHKD. BY: M. Samp	DATE: 10-May-2022
SUBJECT: Segment 3	APPVD. BY:	DATE:

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	1.24	1.98	2.89	3.38	5.86	8.91	11.55
Exit Velocity at Liquid Discharge, v (ft/s):	0.67	0.89	1.11	1.22	1.67	2.11	2.45
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.01	0.01	0.02	0.02	0.04	0.07	0.09
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	1.25	1.99	2.91	3.40	5.90	8.98	11.64
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	1.31	2.09	3.06	3.57	6.20	9.43	12.22

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 4	APPVD. BY:		DATE:	

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.04	0.10	0.17	0.22	0.38	0.58	0.74
Exit Velocity at Liquid Discharge, v (ft/s):	0.44	0.67	0.89	1.00	1.33	1.67	1.89
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.01	0.01	0.02	0.03	0.04	0.06
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	6.24	6.31	6.38	6.44	6.61	6.82	7.00
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	6.55	6.63	6.70	6.76	6.94	7.16	7.35

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4}\cdot\left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v\cdot\frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f\cdot v^2}{2\cdot g\cdot\frac{ID}{12}} = \frac{f\cdot v^2}{2\cdot(32.174)\cdot\frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k\cdot\frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31\cdot(P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2\cdot g} = \frac{v^2}{2\cdot(32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31\cdot(P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31\cdot(P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

ARCADIS Design & Consultancy for natural and built assets	PROJECT: BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
	JOB NO.: 30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
	SUBJECT: Segment 4	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	2.067
Pipe Length, L (ft):	25.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Coated Steel
Roughness, e (ft):	0.00018
e / ID:	0.001044993

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.06	1	0.06
Stop Check Valve, flow thru	7.5	1	7.5
Standard Elbow, 90°	0.57	1	0.57
			0
Standard Tee, thru branch	1.14	1	1.14
			0
			0
		Total K:	9.3

Segment Flowrate (gpm):	4	6	8	9	12	15	17
Eqn. (1) - Velocity, v (ft/s):	0.38	0.57	0.76	0.86	1.15	1.43	1.63
Eqn. (2) - Reynolds Number, Re:	4.64E+03	6.96E+03	9.28E+03	1.05E+04	1.40E+04	1.75E+04	1.99E+04
Pipe Friction Factor, f:	0.0393	0.0354	0.033	0.0321	0.0301	0.0288	0.0281
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0005	0.001	0.0017	0.0021	0.0036	0.0053	0.0067
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	40.63	45.11	48.39	49.74	53.05	55.44	56.82
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	65.63	70.11	73.39	74.74	78.05	80.44	81.82
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.03**	**0.07**	**0.12**	**0.16**	**0.28**	**0.43**	**0.55**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	12.50
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
Standard Elbow, 45°	0.3	1	0.3
Standard Tee, thru branch	1.14	1	1.14
			0
			0
			0
			0
		Total K:	1.4

Segment Flowrate (gpm):	4	6	8	9	12	15	17
Eqn. (1) - Velocity, v (ft/s):	0.44	0.67	0.89	1.00	1.33	1.67	1.89
Eqn. (2) - Reynolds Number, Re:	4.99E+03	7.59E+03	1.01E+04	1.13E+04	1.51E+04	1.89E+04	2.14E+04
Pipe Friction Factor, f:	0.0375	0.0333	0.0309	0.0299	0.0278	0.0263	0.0255
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0007	0.0015	0.0024	0.0029	0.0048	0.0071	0.0089
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	6.13	6.91	7.44	7.69	8.27	8.75	9.02
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	18.63	19.41	19.94	20.19	20.77	21.25	21.52
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.01**	**0.03**	**0.05**	**0.06**	**0.10**	**0.15**	**0.19**

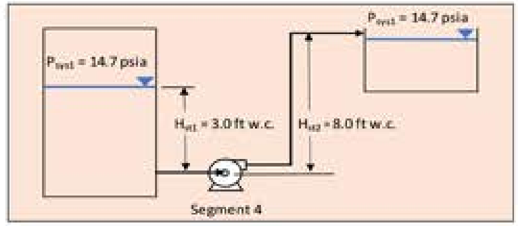
ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 4	APPVD. BY:		DATE:	

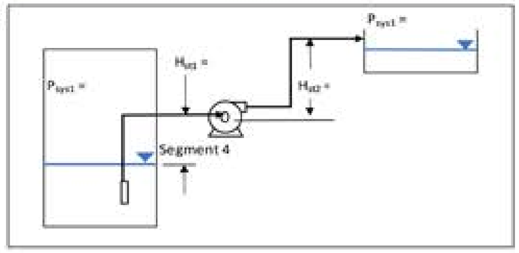
Pump ID:	Segment 4
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	4.3
Design Flow Rate (gpm):	8.6
Maximum Flow Rate (gpm):	17.2
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	-12
Pump Impeller Centerline Elevation (ft):	-15
Discharge Elevation (ft):	-7
Static Head of Discharge Line , H_{st2} (ft):	8
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	3
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Notes:

Flooded Suction:



Suction Lift:



Flow Rates (gpm):	4	6	8	9	12	15	17
(gpd):	5,600	8,400	11,200	12,600	16,800	21,000	23,800
(MGD):	0.01	0.01	0.01	0.01	0.02	0.02	0.02
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	**Pressure Loss (ft w.c.)**	**Equipment Tag**	**Pressure Loss (ft w.c.)**
Flowmeter	1.2		
Subtotal:	*1.2*	*Subtotal:*	*0.0*

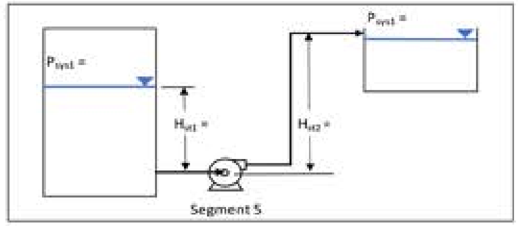
Total Headloss (ft w.c.): 1.2

ARCADIS Design & Consultancy for natural and built assets

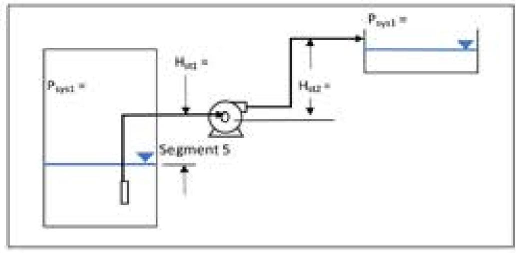
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 5	APPVD. BY:		DATE:	

Pump ID:	Segment 5
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	9.85
Design Flow Rate (gpm):	19.7
Maximum Flow Rate (gpm):	39.4
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	0
Pump Impeller Centerline Elevation (ft):	0
Discharge Elevation (ft):	0
Static Head of Discharge Line , H_{st2} (ft):	0
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	10	13	16	20	26	32	39
(gpd):	14,000	18,200	22,400	28,000	36,400	44,800	54,600
(MGD):	0.01	0.02	0.02	0.03	0.04	0.04	0.05
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Subtotal:	*0.0*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): **0.0**

PROJECT:	BASF Above Grade System Sump Hydraulics	BY: S. Hannula	DATE: 10-May-2022
JOB NO.:	30005248	CHKD. BY: M. Samp	DATE: 10-May-2022
SUBJECT:	Segment 5	APPVD. BY:	DATE:

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	475.00
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
Standard Elbow, 45°	0.3	2	0.6
			0
			0
			0
			0
			0
			0
		Total K:	0.6

Segment Flowrate (gpm):	10	13	16	20	26	32	39
Eqn. (1) - Velocity, v (ft/s):	1.11	1.45	1.78	2.22	2.89	3.56	4.34
Eqn. (2) - Reynolds Number, Re:	1.26E+04	1.64E+04	2.02E+04	2.52E+04	3.27E+04	4.03E+04	4.92E+04
Pipe Friction Factor, f:	0.0291	0.0272	0.0259	0.0246	0.0231	0.022	0.0211
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0035	0.0056	0.008	0.0118	0.0188	0.0271	0.0387
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	3.29	3.52	3.70	3.90	4.15	4.36	4.54
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	478.29	478.52	478.70	478.90	479.15	479.36	479.54
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**1.67**	**2.68**	**3.83**	**5.65**	**9.01**	**12.99**	**18.56**

PROJECT: BASF Above Grade System Sump Hydraulics	BY: S. Hannula	DATE: 10-May-2022
JOB NO.: 30005248	CHKD. BY: M. Samp	DATE: 10-May-2022
SUBJECT: Segment 5	APPVD. BY:	DATE:

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	1.67	2.68	3.83	5.65	9.01	12.99	18.56
Exit Velocity at Liquid Discharge, v (ft/s):	1.11	1.45	1.78	2.22	2.89	3.56	4.34
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.02	0.03	0.05	0.08	0.13	0.20	0.29
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	1.69	2.71	3.88	5.73	9.14	13.19	18.85
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	1.77	2.85	4.07	6.02	9.60	13.85	19.79

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_p = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_p$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 6	APPVD. BY:		DATE:	

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.00	0.00	0.00	0.00	0.01	0.03	0.03
Exit Velocity at Liquid Discharge, v (ft/s):	0.10	0.10	0.10	0.10	0.19	0.33	0.33
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	6.20	6.20	6.20	6.20	6.21	6.23	6.23
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	6.51	6.51	6.51	6.51	6.52	6.54	6.54

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 6	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	2.067
Pipe Length, L (ft):	25.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Coated Steel
Roughness, e (ft):	0.00018
e / ID:	0.001044993

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.06	1	0.06
Stop Check Valve, flow thru	7.5	1	7.5
Standard Elbow, 90°	0.57	1	0.57
			0
Standard Tee, thru branch	1.14	1	1.14
			0
			0
		Total K:	9.3

Segment Flowrate (gpm):	1	1	1	1	2	3	3
Eqn. (1) - Velocity, v (ft/s):	0.10	0.10	0.10	0.10	0.19	0.29	0.29
Eqn. (2) - Reynolds Number, Re:	1.22E+03	1.22E+03	1.22E+03	1.22E+03	2.32E+03	3.54E+03	3.54E+03
Pipe Friction Factor, f:	0.0524	0.0524	0.0524	0.0524	0.048	0.0424	0.0424
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0	0.0002	0.0003	0.0003
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	30.47	30.47	30.47	30.47	33.27	37.66	37.66
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	55.47	55.47	55.47	55.47	58.27	62.66	62.66
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.02**	**0.02**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	12.50
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
Standard Elbow, 45°	0.3	1	0.3
Standard Tee, thru branch	1.14	1	1.14
			0
			0
			0
			0
		Total K:	1.4

Segment Flowrate (gpm):	1	1	1	1	2	3	3
Eqn. (1) - Velocity, v (ft/s):	0.11	0.11	0.11	0.11	0.22	0.33	0.33
Eqn. (2) - Reynolds Number, Re:	1.25E+03	1.25E+03	1.25E+03	1.25E+03	2.49E+03	3.74E+03	3.74E+03
Pipe Friction Factor, f:	0.0514	0.0514	0.0514	0.0514	0.0461	0.0407	0.0407
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0001	0.0001	0.0001	0.0001	0.0002	0.0004	0.0004
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	4.48	4.48	4.48	4.48	4.99	5.65	5.65
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	16.98	16.98	16.98	16.98	17.49	18.15	18.15
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**

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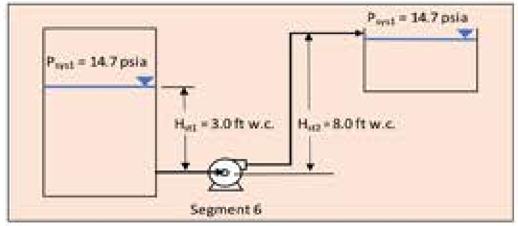
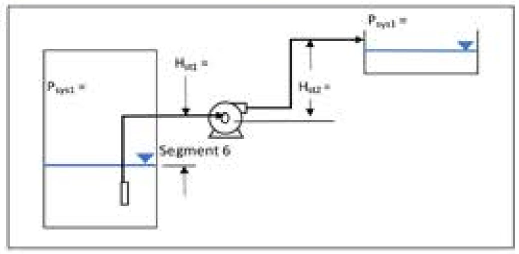
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 6	APPVD. BY:		DATE:	

Pump ID:	Segment 6
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	0.65
Design Flow Rate (gpm):	1.3
Maximum Flow Rate (gpm):	2.6
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	-12
Pump Impeller Centerline Elevation (ft):	-15
Discharge Elevation (ft):	-7
Static Head of Discharge Line , H_{st2} (ft):	8
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	3
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	1	1	1	1	2	3	3
(gpd):	1,400	1,400	1,400	1,400	2,800	4,200	4,200
(MGD):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	**Pressure Loss (ft w.c.)**	**Equipment Tag**	**Pressure Loss (ft w.c.)**		
Flowmeter	1.2				
Subtotal:	*1.2*	*Subtotal:*	*0.0*	**Total Headloss (ft w.c.):**	**1.2**

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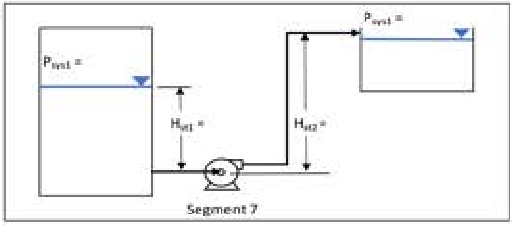
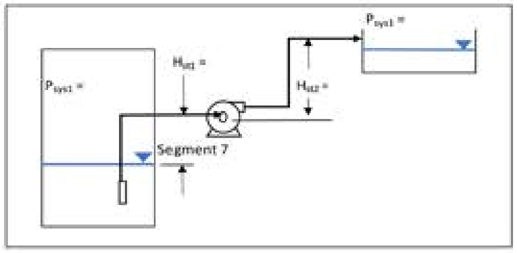
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 7	APPVD. BY:		DATE:	

Pump ID:	Segment 7
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	10.5
Design Flow Rate (gpm):	21
Maximum Flow Rate (gpm):	42
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	0
Pump Impeller Centerline Elevation (ft):	0
Discharge Elevation (ft):	0
Static Head of Discharge Line , H_{st2} (ft):	0
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	11	14	17	21	28	35	42
(gpd):	15,400	19,600	23,800	29,400	39,200	49,000	58,800
(MGD):	0.02	0.02	0.02	0.03	0.04	0.05	0.06
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Subtotal:	*0.0*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): **0.0**

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 7	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	700.00
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
Standard Elbow, 45°	0.3	1	0.3
			0
			0
			0
			0
			0
			0
		Total K:	0.3

Segment Flowrate (gpm):	11	14	17	21	28	35	42
Eqn. (1) - Velocity, v (ft/s):	1.22	1.56	1.89	2.33	3.11	3.89	4.67
Eqn. (2) - Reynolds Number, Re:	1.38E+04	1.77E+04	2.14E+04	2.64E+04	3.52E+04	4.41E+04	5.29E+04
Pipe Friction Factor, f:	0.0284	0.0267	0.0255	0.0243	0.0227	0.0216	0.0207
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0041	0.0063	0.0089	0.0128	0.0214	0.0318	0.0439
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	1.69	1.79	1.88	1.97	2.11	2.22	2.32
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	701.69	701.79	701.88	701.97	702.11	702.22	702.32
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**2.88**	**4.42**	**6.25**	**8.99**	**15.03**	**22.33**	**30.83**

PROJECT: BASF Above Grade System Sump Hydraulics	BY: S. Hannula	DATE: 10-May-2022
JOB NO.: 30005248	CHKD. BY: M. Samp	DATE: 10-May-2022
SUBJECT: Segment 7	APPVD. BY:	DATE:

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	2.88	4.42	6.25	8.99	15.03	22.33	30.83
Exit Velocity at Liquid Discharge, v (ft/s):	1.22	1.56	1.89	2.33	3.11	3.89	4.67
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.02	0.04	0.06	0.08	0.15	0.24	0.34
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	2.90	4.46	6.31	9.07	15.18	22.57	31.17
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	3.05	4.68	6.63	9.52	15.94	23.70	32.73

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 8	APPVD. BY:		DATE:	

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.01	0.01	0.01	0.03	0.04	0.07	0.10
Exit Velocity at Liquid Discharge, v (ft/s):	0.19	0.19	0.19	0.33	0.44	0.56	0.67
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	6.21	6.21	6.21	6.23	6.24	6.27	6.31
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	6.52	6.52	6.52	6.54	6.55	6.58	6.63

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 8	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	2.067
Pipe Length, L (ft):	25.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Coated Steel
Roughness, e (ft):	0.00018
e / ID:	0.001044993

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.06	1	0.06
Stop Check Valve, flow thru	7.5	1	7.5
Standard Elbow, 90°	0.57	1	0.57
			0
Standard Tee, thru branch	1.14	1	1.14
			0
			0
		Total K:	9.3

Segment Flowrate (gpm):	2	2	2	3	4	5	6
Eqn. (1) - Velocity, v (ft/s):	0.19	0.19	0.19	0.29	0.38	0.48	0.57
Eqn. (2) - Reynolds Number, Re:	2.32E+03	2.32E+03	2.32E+03	3.54E+03	4.64E+03	5.86E+03	6.96E+03
Pipe Friction Factor, f:	0.048	0.048	0.048	0.0424	0.0393	0.037	0.0354
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0002	0.0002	0.0002	0.0003	0.0005	0.0008	0.001
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	33.27	33.27	33.27	37.66	40.63	43.16	45.11
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	58.27	58.27	58.27	62.66	65.63	68.16	70.11
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.01**	**0.01**	**0.01**	**0.02**	**0.03**	**0.05**	**0.07**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	12.50
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

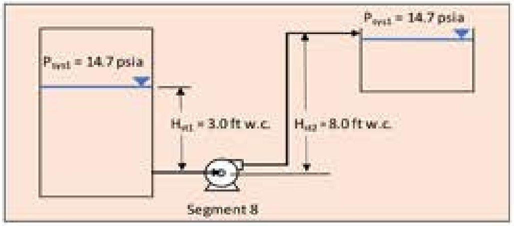
Valve/Fitting Tag	K	No. Units	Total K
			0
Standard Elbow, 45°	0.3	1	0.3
Standard Tee, thru branch	1.14	1	1.14
			0
			0
			0
			0
		Total K:	1.4

Segment Flowrate (gpm):	2	2	2	3	4	5	6
Eqn. (1) - Velocity, v (ft/s):	0.22	0.22	0.22	0.33	0.44	0.56	0.67
Eqn. (2) - Reynolds Number, Re:	2.49E+03	2.49E+03	2.49E+03	3.74E+03	4.99E+03	6.34E+03	7.59E+03
Pipe Friction Factor, f:	0.0461	0.0461	0.0461	0.0407	0.0375	0.035	0.0333
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0002	0.0002	0.0002	0.0004	0.0007	0.0011	0.0015
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	4.99	4.99	4.99	5.65	6.13	6.57	6.91
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	17.49	17.49	17.49	18.15	18.63	19.07	19.41
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**	**0.02**	**0.03**

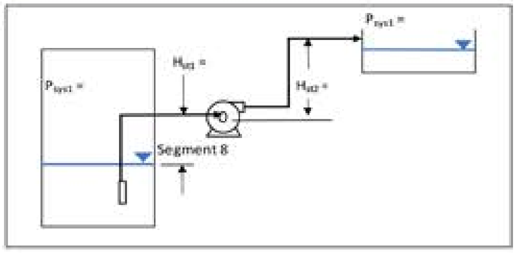
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 8	APPVD. BY:		DATE:	

Pump ID:	Segment 8
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	1.5
Design Flow Rate (gpm):	3
Maximum Flow Rate (gpm):	6
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	-12
Pump Impeller Centerline Elevation (ft):	-15
Discharge Elevation (ft):	-7
Static Head of Discharge Line , H_{st2} (ft):	8
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	3
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	2	2	2	3	4	5	6
(gpd):	2,800	2,800	2,800	4,200	5,600	7,000	8,400
(MGD):	0.00	0.00	0.00	0.00	0.01	0.01	0.01
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	**Pressure Loss (ft w.c.)**	**Equipment Tag**	**Pressure Loss (ft w.c.)**
Flowmeter	1.2		
Subtotal:	*1.2*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 1.2

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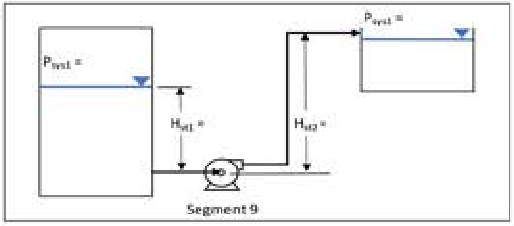
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 9	APPVD. BY:		DATE:	

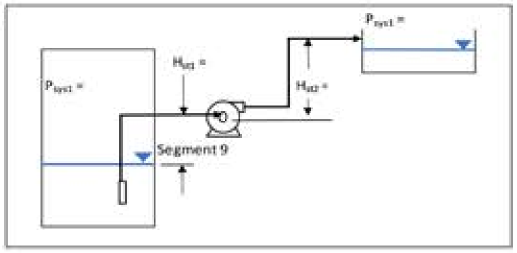
Pump ID:	Segment 9
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	12
Design Flow Rate (gpm):	24
Maximum Flow Rate (gpm):	48
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	0
Pump Impeller Centerline Elevation (ft):	0
Discharge Elevation (ft):	0
Static Head of Discharge Line , H_{st2} (ft):	0
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Notes:

Flooded Suction:



Suction Lift:



Flow Rates (gpm):	12	16	20	24	32	40	48
(gpd):	16,800	22,400	28,000	33,600	44,800	56,000	67,200
(MGD):	0.02	0.02	0.03	0.03	0.04	0.06	0.07
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Subtotal:	*0.0*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 0.0

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 9	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	275.00
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
Standard Elbow, 90°	**0.57**	1	**0.57**
			0
			0
			0
Standard Tee, thru branch	**1.14**	1	**1.14**
3" x 2" reducer	**0.28**	1	**0.28**
			0
		Total K:	**2.0**

Segment Flowrate (gpm):	12	16	20	24	32	40	48
Eqn. (1) - Velocity, v (ft/s):	1.33	1.78	2.22	2.67	3.56	4.45	5.34
Eqn. (2) - Reynolds Number, Re:	1.51E+04	2.02E+04	2.52E+04	3.03E+04	4.03E+04	5.04E+04	6.05E+04
Pipe Friction Factor, f:	0.0278	0.0259	0.0246	0.0235	0.022	0.021	0.0202
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0048	0.008	0.0118	0.0163	0.0271	0.0405	0.056
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	11.44	12.27	12.92	13.53	14.45	15.14	15.74
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	286.44	287.27	287.92	288.53	289.45	290.14	290.74
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**1.37**	**2.30**	**3.40**	**4.70**	**7.84**	**11.75**	**16.28**

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PROJECT: BASF Above Grade System Sump Hydraulics	BY: S. Hannula	DATE: 10-May-2022
JOB NO.: 30005248	CHKD. BY: M. Samp	DATE: 10-May-2022
SUBJECT: Segment 9	APPVD. BY:	DATE:

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	1.37	2.30	3.40	4.70	7.84	11.75	16.28
Exit Velocity at Liquid Discharge, v (ft/s):	1.33	1.78	2.22	2.67	3.56	4.45	5.34
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.03	0.05	0.08	0.11	0.20	0.31	0.44
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	1.40	2.35	3.48	4.81	8.04	12.06	16.72
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	1.47	2.47	3.65	5.05	8.44	12.66	17.56

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 10	APPVD. BY:		DATE:	

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.04	0.04	0.04	0.09	0.09	0.09	0.18
Exit Velocity at Liquid Discharge, v (ft/s):	0.11	0.11	0.11	0.22	0.22	0.22	0.33
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	6.24	6.24	6.24	6.29	6.29	6.29	6.38
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	6.55	6.55	6.55	6.60	6.60	6.60	6.70

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_P = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 10	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	2.067
Pipe Length, L (ft):	25.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Coated Steel
Roughness, e (ft):	0.00018
e / ID:	0.001044993

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.06	1	0.06
Stop Check Valve, flow thru	7.5	1	7.5
Standard Elbow, 90°	0.57	1	0.57
Standard Elbow, 45°	0.3	1	0.3
			0
			0
			0
		Total K:	8.4

Segment Flowrate (gpm):	1	1	1	2	2	2	3
Eqn. (1) - Velocity, v (ft/s):	0.10	0.10	0.10	0.19	0.19	0.19	0.29
Eqn. (2) - Reynolds Number, Re:	1.22E+03	1.22E+03	1.22E+03	2.32E+03	2.32E+03	2.32E+03	3.54E+03
Pipe Friction Factor, f:	0.0524	0.0524	0.0524	0.048	0.048	0.048	0.0424
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0.0002	0.0002	0.0002	0.0003
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	27.71	27.71	27.71	30.25	30.25	30.25	34.25
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	52.71	52.71	52.71	55.25	55.25	55.25	59.25
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**	**0.01**	**0.02**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	400.00
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
Standard Elbow, 45°	0.3	1	0.3
Standard Tee, thru branch	1.14	1	1.14
			0
			0
			0
			0
		Total K:	1.4

Segment Flowrate (gpm):	1	1	1	2	2	2	3
Eqn. (1) - Velocity, v (ft/s):	0.11	0.11	0.11	0.22	0.22	0.22	0.33
Eqn. (2) - Reynolds Number, Re:	1.25E+03	1.25E+03	1.25E+03	2.49E+03	2.49E+03	2.49E+03	3.74E+03
Pipe Friction Factor, f:	0.0514	0.0514	0.0514	0.0461	0.0461	0.0461	0.0407
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0001	0.0001	0.0001	0.0002	0.0002	0.0002	0.0004
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	4.48	4.48	4.48	4.99	4.99	4.99	5.65
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	404.48	404.48	404.48	404.99	404.99	404.99	405.65
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.04**	**0.04**	**0.04**	**0.08**	**0.08**	**0.08**	**0.16**

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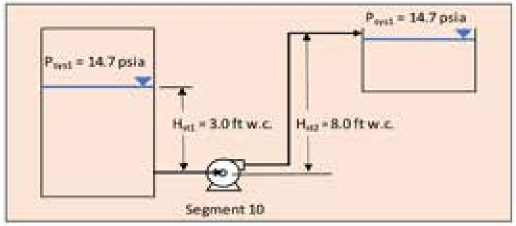
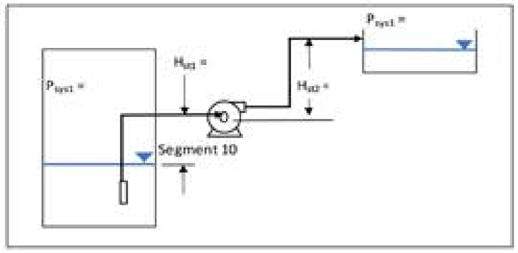
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 10	APPVD. BY:		DATE:	

Pump ID:	Segment 10
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	0.85
Design Flow Rate (gpm):	1.7
Maximum Flow Rate (gpm):	3.4
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	-12
Pump Impeller Centerline Elevation (ft):	-15
Discharge Elevation (ft):	-7
Static Head of Discharge Line, H_{st2} (ft):	8
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	3
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	1	1	1	2	2	2	3
(gpd):	1,400	1,400	1,400	2,800	2,800	2,800	4,200
(MGD):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Flowmeter	1.2		
Subtotal:	*1.2*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 1.2

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 11	APPVD. BY:		DATE:	

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.00	0.00	0.00	0.01	0.01	0.01	0.03
Exit Velocity at Liquid Discharge, v (ft/s):	0.10	0.10	0.10	0.19	0.19	0.19	0.33
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	6.20	6.20	6.20	6.21	6.21	6.21	6.23
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	6.51	6.51	6.51	6.52	6.52	6.52	6.54

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_p = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_p$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 11	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	2.067
Pipe Length, L (ft):	25.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Coated Steel
Roughness, e (ft):	0.00018
e / ID:	0.001044993

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.06	1	0.06
Stop Check Valve, flow thru	7.5	1	7.5
Standard Elbow, 90°	0.57	1	0.57
			0
Standard Tee, thru branch	1.14	1	1.14
			0
			0
		Total K:	9.3

Segment Flowrate (gpm):	1	1	1	2	2	2	3
Eqn. (1) - Velocity, v (ft/s):	0.10	0.10	0.10	0.19	0.19	0.19	0.29
Eqn. (2) - Reynolds Number, Re:	1.22E+03	1.22E+03	1.22E+03	2.32E+03	2.32E+03	2.32E+03	3.54E+03
Pipe Friction Factor, f:	0.0524	0.0524	0.0524	0.048	0.048	0.048	0.0424
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0.0002	0.0002	0.0002	0.0003
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	30.47	30.47	30.47	33.27	33.27	33.27	37.66
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	55.47	55.47	55.47	58.27	58.27	58.27	62.66
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**	**0.01**	**0.02**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	12.50
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

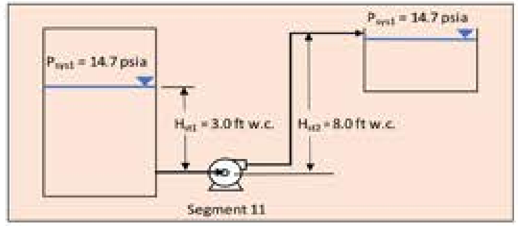
Valve/Fitting Tag	K	No. Units	Total K
			0
Standard Elbow, 45°	0.3	1	0.3
Standard Tee, thru branch	1.14	1	1.14
			0
			0
			0
			0
		Total K:	1.4

Segment Flowrate (gpm):	1	1	1	2	2	2	3
Eqn. (1) - Velocity, v (ft/s):	0.11	0.11	0.11	0.22	0.22	0.22	0.33
Eqn. (2) - Reynolds Number, Re:	1.25E+03	1.25E+03	1.25E+03	2.49E+03	2.49E+03	2.49E+03	3.74E+03
Pipe Friction Factor, f:	0.0514	0.0514	0.0514	0.0461	0.0461	0.0461	0.0407
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0001	0.0001	0.0001	0.0002	0.0002	0.0002	0.0004
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	4.48	4.48	4.48	4.99	4.99	4.99	5.65
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	16.98	16.98	16.98	17.49	17.49	17.49	18.15
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**

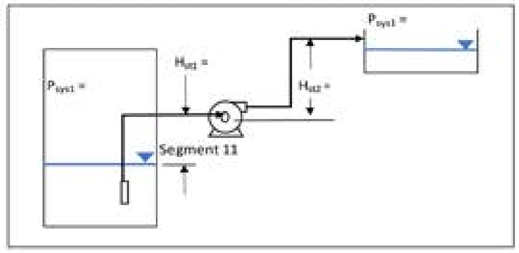
PROJECT:	BASF Above Grade System Sump Hydraulics	BY: S. Hannula	DATE: 10-May-2022
JOB NO.:	30005248	CHKD. BY: M. Samp	DATE: 10-May-2022
SUBJECT:	Segment 11	APPVD. BY:	DATE:

Pump ID:	Segment 11
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	0.85
Design Flow Rate (gpm):	1.7
Maximum Flow Rate (gpm):	3.4
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	-12
Pump Impeller Centerline Elevation (ft):	-15
Discharge Elevation (ft):	-7
Static Head of Discharge Line , H_{st2} (ft):	8
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	3
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	1	1	1	2	2	2	3
(gpd):	1,400	1,400	1,400	2,800	2,800	2,800	4,200
(MGD):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

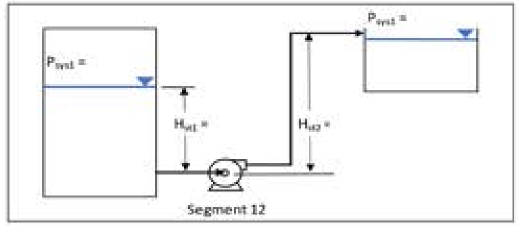
Equipment Tag	**Pressure Loss (ft w.c.)**	**Equipment Tag**	**Pressure Loss (ft w.c.)**		
Flowmeter	1.2				
Subtotal:	*1.2*	*Subtotal:*	*0.0*	**Total Headloss (ft w.c.):**	**1.2**

PROJECT:	BASF Above Grade System Sump Hydraulics
JOB NO.:	30005248
SUBJECT:	Segment 12
BY:	S. Hannula
CHKD. BY:	M. Samp
APPVD. BY:	
DATE:	10-May-2022
DATE:	10-May-2022
DATE:	

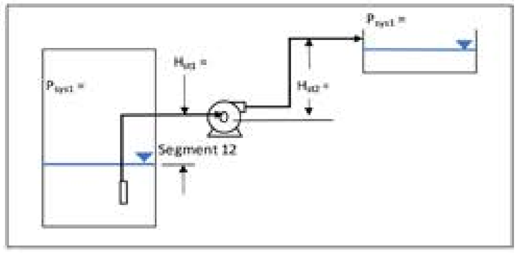
Pump ID:	Segment 12
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	1.7
Design Flow Rate (gpm):	3.4
Maximum Flow Rate (gpm):	6.8
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	0
Pump Impeller Centerline Elevation (ft):	0
Discharge Elevation (ft):	0
Static Head of Discharge Line , H_{st2} (ft):	0
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Notes:

Flooded Suction:



Suction Lift:



Flow Rates (gpm):	2	2	2	3	4	5	7
(gpd):	2,800	2,800	2,800	4,200	5,600	7,000	9,800
(MGD):	0.00	0.00	0.00	0.00	0.01	0.01	0.01
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Subtotal:	*0.0*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 0.0

PROJECT: BASF Above Grade System Sump Hydraulics	BY: S. Hannula	DATE: 10-May-2022	
JOB NO.: 30005248	CHKD. BY: M. Samp	DATE: 10-May-2022	
SUBJECT: Segment 12	APPVD. BY:	DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	550.00
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	2	2	2	3	4	5	7
Eqn. (1) - Velocity, v (ft/s):	0.22	0.22	0.22	0.33	0.44	0.56	0.78
Eqn. (2) - Reynolds Number, Re:	2.49E+03	2.49E+03	2.49E+03	3.74E+03	4.99E+03	6.34E+03	8.84E+03
Pipe Friction Factor, f:	0.0461	0.0461	0.0461	0.0407	0.0375	0.035	0.032
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0002	0.0002	0.0002	0.0004	0.0007	0.0011	0.0019
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	550.00	550.00	550.00	550.00	550.00	550.00	550.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.11**	**0.11**	**0.11**	**0.22**	**0.39**	**0.61**	**1.05**

ARCADIS Design & Consultancy for natural and built assets	PROJECT: BASF Above Grade System Sump Hydraulics	BY: S. Hannula		DATE: 10-May-2022
	JOB NO.: 30005248	CHKD. BY: M. Samp		DATE: 10-May-2022
	SUBJECT: Segment 12	APPVD. BY:		DATE:

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.11	0.11	0.11	0.22	0.39	0.61	1.05
Exit Velocity at Liquid Discharge, v (ft/s):	0.22	0.22	0.22	0.33	0.44	0.56	0.78
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	0.11	0.11	0.11	0.22	0.39	0.61	1.06
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	0.12	0.12	0.12	0.23	0.41	0.64	1.11

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 13	APPVD. BY:		DATE:	

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.00	0.00	0.00	0.01	0.01	0.01	0.03
Exit Velocity at Liquid Discharge, v (ft/s):	0.10	0.10	0.10	0.19	0.19	0.19	0.33
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	6.20	6.20	6.20	6.21	6.21	6.21	6.23
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	6.51	6.51	6.51	6.52	6.52	6.52	6.54

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 13	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	2.067
Pipe Length, L (ft):	25.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Coated Steel
Roughness, e (ft):	0.00018
e / ID:	0.001044993

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.06	1	0.06
Stop Check Valve, flow thru	7.5	1	7.5
Standard Elbow, 90°	0.57	1	0.57
			0
Standard Tee, thru branch	1.14	1	1.14
			0
			0
		Total K:	9.3

Segment Flowrate (gpm):	1	1	1	2	2	2	3
Eqn. (1) - Velocity, v (ft/s):	0.10	0.10	0.10	0.19	0.19	0.19	0.29
Eqn. (2) - Reynolds Number, Re:	1.22E+03	1.22E+03	1.22E+03	2.32E+03	2.32E+03	2.32E+03	3.54E+03
Pipe Friction Factor, f:	0.0524	0.0524	0.0524	0.048	0.048	0.048	0.0424
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0	0	0	0.0002	0.0002	0.0002	0.0003
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	30.47	30.47	30.47	33.27	33.27	33.27	37.66
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	55.47	55.47	55.47	58.27	58.27	58.27	62.66
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**	**0.01**	**0.02**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	12.50
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
Standard Elbow, 45°	0.3	1	0.3
Standard Tee, thru branch	1.14	1	1.14
			0
			0
			0
			0
		Total K:	1.4

Segment Flowrate (gpm):	1	1	1	2	2	2	3
Eqn. (1) - Velocity, v (ft/s):	0.11	0.11	0.11	0.22	0.22	0.22	0.33
Eqn. (2) - Reynolds Number, Re:	1.25E+03	1.25E+03	1.25E+03	2.49E+03	2.49E+03	2.49E+03	3.74E+03
Pipe Friction Factor, f:	0.0514	0.0514	0.0514	0.0461	0.0461	0.0461	0.0407
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0001	0.0001	0.0001	0.0002	0.0002	0.0002	0.0004
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	4.48	4.48	4.48	4.99	4.99	4.99	5.65
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	16.98	16.98	16.98	17.49	17.49	17.49	18.15
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**

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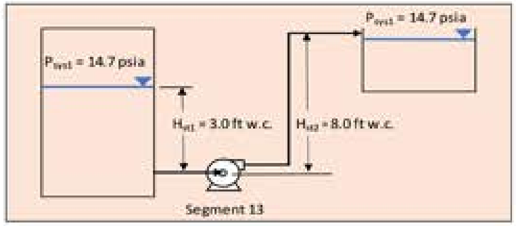
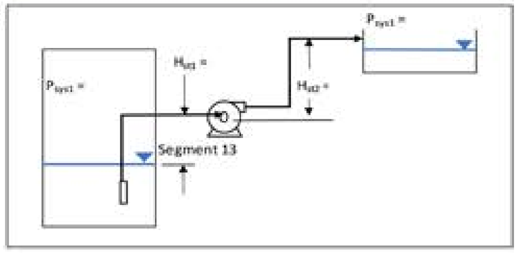
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 13	APPVD. BY:		DATE:	

Pump ID:	Segment 13
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	0.85
Design Flow Rate (gpm):	1.7
Maximum Flow Rate (gpm):	3.4
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	-12
Pump Impeller Centerline Elevation (ft):	-15
Discharge Elevation (ft):	-7
Static Head of Discharge Line , H_{st2} (ft):	8
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	3
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	1	1	1	2	2	2	3
(gpd):	1,400	1,400	1,400	2,800	2,800	2,800	4,200
(MGD):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

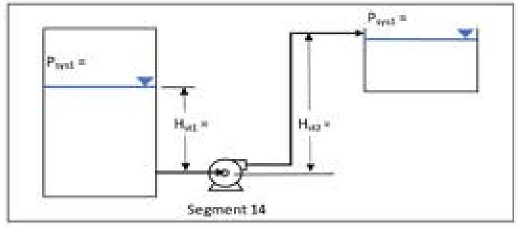
Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Flowmeter	1.2		
Subtotal:	*1.2*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 1.2

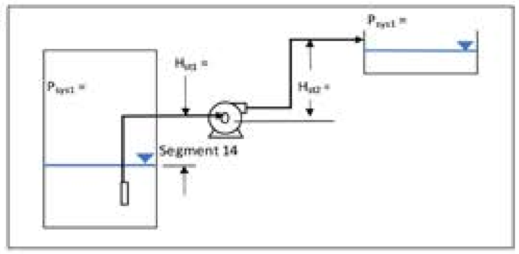
PROJECT: BASF Above Grade System Sump Hydraulics	BY: S. Hannula	DATE: 10-May-2022
JOB NO.: 30005248	CHKD. BY: M. Samp	DATE: 10-May-2022
SUBJECT: Segment 14	APPVD. BY:	DATE:

Pump ID:	Segment 14
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	2.55
Design Flow Rate (gpm):	5.1
Maximum Flow Rate (gpm):	10.2
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	0
Pump Impeller Centerline Elevation (ft):	0
Discharge Elevation (ft):	0
Static Head of Discharge Line , H_{st2} (ft):	0
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	3	4	5	5	7	9	10
(gpd):	4,200	5,600	7,000	7,000	9,800	12,600	14,000
(MGD):	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Subtotal:	*0.0*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 0.0

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 14	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	440.00
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	3	4	5	5	7	9	10
Eqn. (1) - Velocity, v (ft/s):	0.33	0.44	0.56	0.56	0.78	1.00	1.11
Eqn. (2) - Reynolds Number, Re:	3.74E+03	4.99E+03	6.34E+03	6.34E+03	8.84E+03	1.13E+04	1.26E+04
Pipe Friction Factor, f:	0.0407	0.0375	0.035	0.035	0.032	0.0299	0.0291
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0004	0.0007	0.0011	0.0011	0.0019	0.0029	0.0035
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	440.00	440.00	440.00	440.00	440.00	440.00	440.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.18**	**0.31**	**0.48**	**0.48**	**0.84**	**1.28**	**1.54**

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 14	APPVD. BY:		DATE:	

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.18	0.31	0.48	0.48	0.84	1.28	1.54
Exit Velocity at Liquid Discharge, v (ft/s):	0.33	0.44	0.56	0.56	0.78	1.00	1.11
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.00	0.00	0.00	0.01	0.02	0.02
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	0.18	0.31	0.48	0.48	0.85	1.30	1.56
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	0.19	0.33	0.50	0.50	0.89	1.37	1.64

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot \left(P_{sys1} - P_{vap}\right) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot \left(P_{sys2} - P_{sys1}\right) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot \left(P_{sys2} - P_{sys1}\right) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 15	APPVD. BY:		DATE:	

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.04	0.07	0.10	0.14	0.27	0.44	0.58
Exit Velocity at Liquid Discharge, v (ft/s):	0.44	0.56	0.67	0.78	1.11	1.45	1.67
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.00	0.01	0.01	0.02	0.03	0.04
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	6.24	6.27	6.31	6.35	6.49	6.67	6.82
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	6.55	6.58	6.63	6.67	6.81	7.00	7.16

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4}\cdot\left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v\cdot\frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f\cdot v^2}{2\cdot g\cdot\frac{ID}{12}} = \frac{f\cdot v^2}{2\cdot(32.174)\cdot\frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k\cdot\frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H\cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31\cdot(P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2\cdot g} = \frac{v^2}{2\cdot(32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31\cdot(P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31\cdot(P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

PROJECT: BASF Above Grade System Sump Hydraulics	BY: S. Hannula	DATE: 10-May-2022
JOB NO.: 30005248	CHKD. BY: M. Samp	DATE: 10-May-2022
SUBJECT: Segment 15	APPVD. BY:	DATE:

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	2.067
Pipe Length, L (ft):	25.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Coated Steel
Roughness, e (ft):	0.00018
e / ID:	0.001044993

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.06	1	0.06
Stop Check Valve, flow thru	7.5	1	7.5
Standard Elbow, 90°	0.57	1	0.57
			0
Standard Tee, thru branch	1.14	1	1.14
			0
			0
		Total K:	9.3

Segment Flowrate (gpm):	4	5	6	7	10	13	15
Eqn. (1) - Velocity, v (ft/s):	0.38	0.48	0.57	0.67	0.96	1.24	1.43
Eqn. (2) - Reynolds Number, Re:	4.64E+03	5.86E+03	6.96E+03	8.18E+03	1.17E+04	1.51E+04	1.75E+04
Pipe Friction Factor, f:	0.0393	0.037	0.0354	0.034	0.0313	0.0296	0.0288
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0005	0.0008	0.001	0.0014	0.0026	0.0041	0.0053
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	40.63	43.16	45.11	46.96	51.01	53.94	55.44
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	65.63	68.16	70.11	71.96	76.01	78.94	80.44
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.03**	**0.05**	**0.07**	**0.10**	**0.20**	**0.32**	**0.43**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	12.50
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
Standard Elbow, 45°	0.3	1	0.3
Standard Tee, thru branch	1.14	1	1.14
			0
			0
			0
			0
		Total K:	1.4

Segment Flowrate (gpm):	4	5	6	7	10	13	15
Eqn. (1) - Velocity, v (ft/s):	0.44	0.56	0.67	0.78	1.11	1.45	1.67
Eqn. (2) - Reynolds Number, Re:	4.99E+03	6.34E+03	7.59E+03	8.84E+03	1.26E+04	1.64E+04	1.89E+04
Pipe Friction Factor, f:	0.0375	0.035	0.0333	0.032	0.0291	0.0272	0.0263
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0007	0.0011	0.0015	0.0019	0.0035	0.0056	0.0071
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	6.13	6.57	6.91	7.19	7.91	8.46	8.75
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	18.63	19.07	19.41	19.69	20.41	20.96	21.25
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.01**	**0.02**	**0.03**	**0.04**	**0.07**	**0.12**	**0.15**

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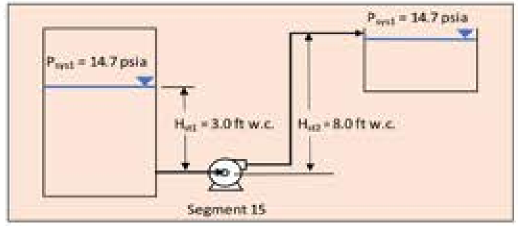
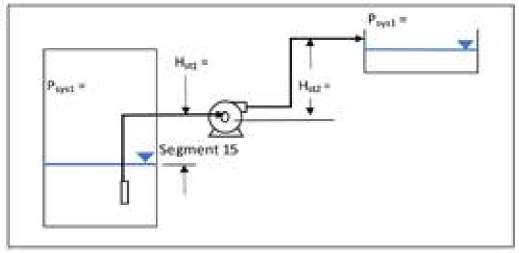
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 15	APPVD. BY:		DATE:	

Pump ID:	Segment 15
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	3.65
Design Flow Rate (gpm):	7.3
Maximum Flow Rate (gpm):	14.6
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	-12
Pump Impeller Centerline Elevation (ft):	-15
Discharge Elevation (ft):	-7
Static Head of Discharge Line , H_{st2} (ft):	8
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	3
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	4	5	6	7	10	13	15
(gpd):	5,600	7,000	8,400	9,800	14,000	18,200	21,000
(MGD):	0.01	0.01	0.01	0.01	0.01	0.02	0.02
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Flowmeter	1.2		
Subtotal:	*1.2*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 1.2

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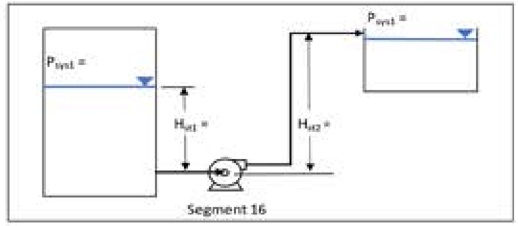
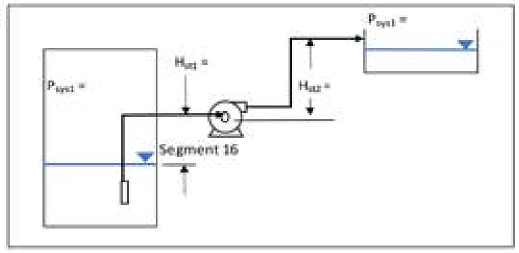
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 16	APPVD. BY:		DATE:	

Pump ID:	Segment 16
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	6.2
Design Flow Rate (gpm):	12.4
Maximum Flow Rate (gpm):	24.8
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	0
Pump Impeller Centerline Elevation (ft):	0
Discharge Elevation (ft):	0
Static Head of Discharge Line , H_{st2} (ft):	0
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	6	8	10	12	16	20	25
(gpd):	8,400	11,200	14,000	16,800	22,400	28,000	35,000
(MGD):	0.01	0.01	0.01	0.02	0.02	0.03	0.04
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)		
Subtotal:	*0.0*	*Subtotal:*	*0.0*	**Total Headloss (ft w.c.):**	**0.0**

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 16	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	275.00
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
Standard Elbow, 45°	0.3	1	0.3
			0
			0
			0
			0
			0
			0
		Total K:	0.3

Segment Flowrate (gpm):	6	8	10	12	16	20	25
Eqn. (1) - Velocity, v (ft/s):	0.67	0.89	1.11	1.33	1.78	2.22	2.78
Eqn. (2) - Reynolds Number, Re:	7.59E+03	1.01E+04	1.26E+04	1.51E+04	2.02E+04	2.52E+04	3.15E+04
Pipe Friction Factor, f:	0.0333	0.0309	0.0291	0.0278	0.0259	0.0246	0.0233
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0015	0.0024	0.0035	0.0048	0.008	0.0118	0.0175
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	1.44	1.55	1.65	1.72	1.85	1.95	2.06
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	276.44	276.55	276.65	276.72	276.85	276.95	277.06
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.41**	**0.66**	**0.97**	**1.33**	**2.21**	**3.27**	**4.85**

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 16	APPVD. BY:		DATE:	

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.41	0.66	0.97	1.33	2.21	3.27	4.85
Exit Velocity at Liquid Discharge, v (ft/s):	0.67	0.89	1.11	1.33	1.78	2.22	2.78
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.01	0.01	0.02	0.03	0.05	0.08	0.12
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	0.42	0.67	0.99	1.36	2.26	3.35	4.97
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	0.44	0.70	1.04	1.43	2.37	3.52	5.22

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 17	APPVD. BY:		DATE:	

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.01	0.01	0.01	0.03	0.04	0.07	0.10
Exit Velocity at Liquid Discharge, v (ft/s):	0.19	0.19	0.19	0.33	0.44	0.56	0.67
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	6.21	6.21	6.21	6.23	6.24	6.27	6.31
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	6.52	6.52	6.52	6.54	6.55	6.58	6.63

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4}\cdot\left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v\cdot\frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f\cdot v^2}{2\cdot g\cdot\frac{ID}{12}} = \frac{f\cdot v^2}{2\cdot(32.174)\cdot\frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k\cdot\frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H\cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31\cdot\left(P_{sys1} - P_{vap}\right) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2\cdot g} = \frac{v^2}{2\cdot(32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31\cdot\left(P_{sys2} - P_{sys1}\right) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31\cdot\left(P_{sys2} - P_{sys1}\right) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 17	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	2.067
Pipe Length, L (ft):	25.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Coated Steel
Roughness, e (ft):	0.00018
e / ID:	0.001044993

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.06	1	0.06
Stop Check Valve, flow thru	7.5	1	7.5
Standard Elbow, 90°	0.57	1	0.57
			0
Standard Tee, thru branch	1.14	1	1.14
			0
			0
		Total K:	9.3

Segment Flowrate (gpm):	2	2	2	3	4	5	6
Eqn. (1) - Velocity, v (ft/s):	0.19	0.19	0.19	0.29	0.38	0.48	0.57
Eqn. (2) - Reynolds Number, Re:	2.32E+03	2.32E+03	2.32E+03	3.54E+03	4.64E+03	5.86E+03	6.96E+03
Pipe Friction Factor, f:	0.048	0.048	0.048	0.0424	0.0393	0.037	0.0354
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0002	0.0002	0.0002	0.0003	0.0005	0.0008	0.001
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	33.27	33.27	33.27	37.66	40.63	43.16	45.11
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	58.27	58.27	58.27	62.66	65.63	68.16	70.11
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.01**	**0.01**	**0.01**	**0.02**	**0.03**	**0.05**	**0.07**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	12.50
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

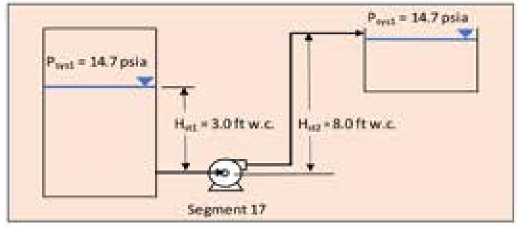
Valve/Fitting Tag	K	No. Units	Total K
			0
Standard Elbow, 45°	0.3	1	0.3
Standard Tee, thru branch	1.14	1	1.14
			0
			0
			0
			0
		Total K:	1.4

Segment Flowrate (gpm):	2	2	2	3	4	5	6
Eqn. (1) - Velocity, v (ft/s):	0.22	0.22	0.22	0.33	0.44	0.56	0.67
Eqn. (2) - Reynolds Number, Re:	2.49E+03	2.49E+03	2.49E+03	3.74E+03	4.99E+03	6.34E+03	7.59E+03
Pipe Friction Factor, f:	0.0461	0.0461	0.0461	0.0407	0.0375	0.035	0.0333
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0002	0.0002	0.0002	0.0004	0.0007	0.0011	0.0015
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	4.99	4.99	4.99	5.65	6.13	6.57	6.91
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	17.49	17.49	17.49	18.15	18.63	19.07	19.41
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**	**0.02**	**0.03**

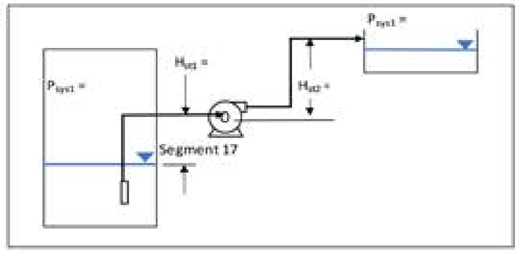
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 17	APPVD. BY:		DATE:	

Pump ID:	Segment 17
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	1.5
Design Flow Rate (gpm):	3
Maximum Flow Rate (gpm):	6
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	-12
Pump Impeller Centerline Elevation (ft):	-15
Discharge Elevation (ft):	-7
Static Head of Discharge Line , H_{st2} (ft):	8
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	3
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	2	2	2	3	4	5	6
(gpd):	2,800	2,800	2,800	4,200	5,600	7,000	8,400
(MGD):	0.00	0.00	0.00	0.00	0.01	0.01	0.01
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Flowmeter	1.2		
Subtotal:	*1.2*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 1.2

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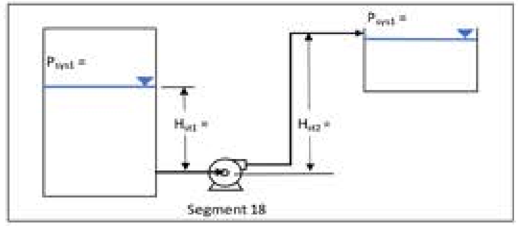
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 18	APPVD. BY:		DATE:	

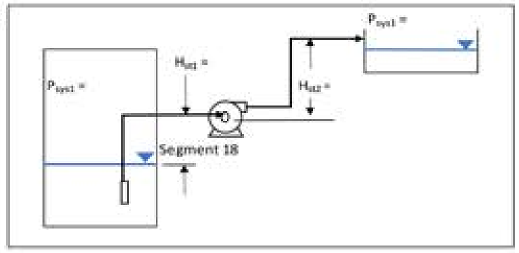
Pump ID:	Segment 18
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	7.7
Design Flow Rate (gpm):	15.4
Maximum Flow Rate (gpm):	30.8
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	0
Pump Impeller Centerline Elevation (ft):	0
Discharge Elevation (ft):	0
Static Head of Discharge Line, H_{st2} (ft):	0
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Notes:

Flooded Suction:



Suction Lift:



Flow Rates (gpm):	8	10	12	15	20	25	31
(gpd):	11,200	14,000	16,800	21,000	28,000	35,000	43,400
(MGD):	0.01	0.01	0.02	0.02	0.03	0.04	0.04
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Subtotal:	*0.0*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 0.0

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 18	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	450.00
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
			0
			0
			0
			0
			0
			0
		Total K:	0.0

Segment Flowrate (gpm):	8	10	12	15	20	25	31
Eqn. (1) - Velocity, v (ft/s):	0.89	1.11	1.33	1.67	2.22	2.78	3.45
Eqn. (2) - Reynolds Number, Re:	1.01E+04	1.26E+04	1.51E+04	1.89E+04	2.52E+04	3.15E+04	3.91E+04
Pipe Friction Factor, f:	0.0309	0.0291	0.0278	0.0263	0.0246	0.0233	0.0222
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0024	0.0035	0.0048	0.0071	0.0118	0.0175	0.0257
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	450.00	450.00	450.00	450.00	450.00	450.00	450.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**1.08**	**1.58**	**2.16**	**3.20**	**5.31**	**7.88**	**11.57**

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 18	APPVD. BY:		DATE:	

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	1.08	1.58	2.16	3.20	5.31	7.88	11.57
Exit Velocity at Liquid Discharge, v (ft/s):	0.89	1.11	1.33	1.67	2.22	2.78	3.45
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.01	0.02	0.03	0.04	0.08	0.12	0.19
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	1.09	1.60	2.19	3.24	5.39	8.00	11.76
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	1.14	1.68	2.30	3.40	5.66	8.40	12.35

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4}\cdot\left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v\cdot\frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f\cdot v^2}{2\cdot g\cdot\frac{ID}{12}} = \frac{f\cdot v^2}{2\cdot(32.174)\cdot\frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k\cdot\frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H\cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31\cdot(P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2\cdot g} = \frac{v^2}{2\cdot(32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31\cdot(P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31\cdot(P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

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PROJECT: BASF Above Grade System Sump Hydraulics	BY: S. Hannula	DATE: 10-May-2022
JOB NO.: 30005248	CHKD. BY: M. Samp	DATE: 10-May-2022
SUBJECT: Segment 19	APPVD. BY:	DATE:

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.01	0.01	0.01	0.03	0.04	0.07	0.10
Exit Velocity at Liquid Discharge, v (ft/s):	0.19	0.19	0.19	0.33	0.44	0.56	0.67
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	6.21	6.21	6.21	6.23	6.24	6.27	6.31
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	6.52	6.52	6.52	6.54	6.55	6.58	6.63

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 19	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	2.067
Pipe Length, L (ft):	25.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Coated Steel
Roughness, e (ft):	0.00018
e / ID:	0.001044993

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	0.06	1	0.06
Stop Check Valve, flow thru	7.5	1	7.5
Standard Elbow, 90°	0.57	1	0.57
			0
Standard Tee, thru branch	1.14	1	1.14
			0
			0
		Total K:	9.3

Segment Flowrate (gpm):	2	2	2	3	4	5	6
Eqn. (1) - Velocity, v (ft/s):	0.19	0.19	0.19	0.29	0.38	0.48	0.57
Eqn. (2) - Reynolds Number, Re:	2.32E+03	2.32E+03	2.32E+03	3.54E+03	4.64E+03	5.86E+03	6.96E+03
Pipe Friction Factor, f:	0.048	0.048	0.048	0.0424	0.0393	0.037	0.0354
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0002	0.0002	0.0002	0.0003	0.0005	0.0008	0.001
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	33.27	33.27	33.27	37.66	40.63	43.16	45.11
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	58.27	58.27	58.27	62.66	65.63	68.16	70.11
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.01**	**0.01**	**0.01**	**0.02**	**0.03**	**0.05**	**0.07**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	12.50
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

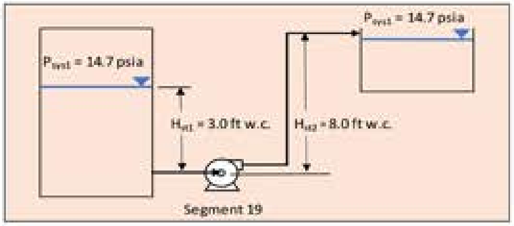
Valve/Fitting Tag	K	No. Units	Total K
			0
Standard Elbow, 45°	0.3	1	0.3
Standard Tee, thru branch	1.14	1	1.14
			0
			0
			0
			0
		Total K:	1.4

Segment Flowrate (gpm):	2	2	2	3	4	5	6
Eqn. (1) - Velocity, v (ft/s):	0.22	0.22	0.22	0.33	0.44	0.56	0.67
Eqn. (2) - Reynolds Number, Re:	2.49E+03	2.49E+03	2.49E+03	3.74E+03	4.99E+03	6.34E+03	7.59E+03
Pipe Friction Factor, f:	0.0461	0.0461	0.0461	0.0407	0.0375	0.035	0.0333
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0002	0.0002	0.0002	0.0004	0.0007	0.0011	0.0015
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	4.99	4.99	4.99	5.65	6.13	6.57	6.91
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	17.49	17.49	17.49	18.15	18.63	19.07	19.41
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**	**0.02**	**0.03**

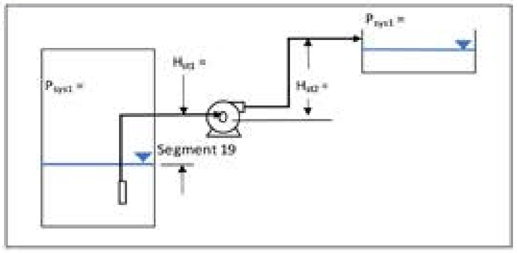
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 19	APPVD. BY:		DATE:	

Pump ID:	Segment 19
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	1.5
Design Flow Rate (gpm):	3
Maximum Flow Rate (gpm):	6
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	-12
Pump Impeller Centerline Elevation (ft):	-15
Discharge Elevation (ft):	-7
Static Head of Discharge Line, H_{st2} (ft):	8
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	3
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	2	2	2	3	4	5	6
(gpd):	2,800	2,800	2,800	4,200	5,600	7,000	8,400
(MGD):	0.00	0.00	0.00	0.00	0.01	0.01	0.01
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Flowmeter	1.2		
Subtotal:	*1.2*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 1.2

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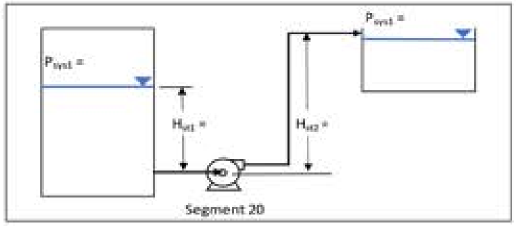
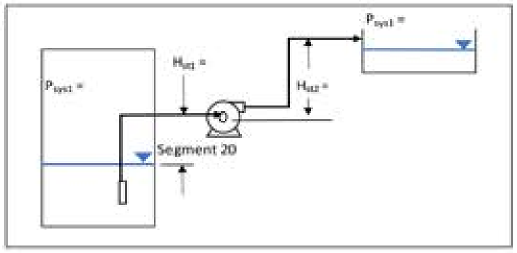
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 20	APPVD. BY:		DATE:	

Pump ID:	Segment 20
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	9.2
Design Flow Rate (gpm):	18.4
Maximum Flow Rate (gpm):	36.8
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	0
Pump Impeller Centerline Elevation (ft):	0
Discharge Elevation (ft):	0
Static Head of Discharge Line , H_{st2} (ft):	0
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	9	12	15	18	24	30	37
(gpd):	12,600	16,800	21,000	25,200	33,600	42,000	51,800
(MGD):	0.01	0.02	0.02	0.03	0.03	0.04	0.05
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)		
Subtotal:	*0.0*	*Subtotal:*	*0.0*	**Total Headloss (ft w.c.):**	**0.0**

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 20	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	450.00
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
Standard Elbow, 45°	0.3	1	0.3
			0
			0
			0
			0
			0
			0
		Total K:	0.3

Segment Flowrate (gpm):	9	12	15	18	24	30	37
Eqn. (1) - Velocity, v (ft/s):	1.00	1.33	1.67	2.00	2.67	3.33	4.11
Eqn. (2) - Reynolds Number, Re:	1.13E+04	1.51E+04	1.89E+04	2.27E+04	3.03E+04	3.77E+04	4.66E+04
Pipe Friction Factor, f:	0.0299	0.0278	0.0263	0.0252	0.0235	0.0224	0.0213
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0029	0.0048	0.0071	0.0098	0.0163	0.0242	0.035
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	1.60	1.72	1.82	1.90	2.04	2.14	2.25
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	451.60	451.72	451.82	451.90	452.04	452.14	452.25
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**1.31**	**2.17**	**3.21**	**4.43**	**7.37**	**10.94**	**15.83**

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 20	APPVD. BY:		DATE:	

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	1.31	2.17	3.21	4.43	7.37	10.94	15.83
Exit Velocity at Liquid Discharge, v (ft/s):	1.00	1.33	1.67	2.00	2.67	3.33	4.11
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.02	0.03	0.04	0.06	0.11	0.17	0.26
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	1.33	2.20	3.25	4.49	7.48	11.11	16.09
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	1.40	2.31	3.41	4.71	7.85	11.67	16.89

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_p = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_p$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 21	APPVD. BY:		DATE:	

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.01	0.01	0.01	0.03	0.04	0.07	0.10
Exit Velocity at Liquid Discharge, v (ft/s):	0.19	0.19	0.19	0.33	0.44	0.56	0.67
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	6.21	6.21	6.21	6.23	6.24	6.27	6.31
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	6.52	6.52	6.52	6.54	6.55	6.58	6.63

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

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PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 21	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	2.067
Pipe Length, L (ft):	25.00
Pipe Material:	SCH 40 - Steel
Pipe Type:	Coated Steel
Roughness, e (ft):	0.00018
e / ID:	0.001044993

Valve/Fitting Tag	K	No. Units	Total K
Ball Valve	**0.06**	1	**0.06**
Stop Check Valve, flow thru	**7.5**	1	**7.5**
Standard Elbow, 90°	**0.57**	1	**0.57**
			0
Standard Tee, thru branch	**1.14**	1	**1.14**
			0
			0
		Total K:	**9.3**

Segment Flowrate (gpm):	2	2	2	3	4	5	6
Eqn. (1) - Velocity, v (ft/s):	0.19	0.19	0.19	0.29	0.38	0.48	0.57
Eqn. (2) - Reynolds Number, Re:	2.32E+03	2.32E+03	2.32E+03	3.54E+03	4.64E+03	5.86E+03	6.96E+03
Pipe Friction Factor, f:	0.048	0.048	0.048	0.0424	0.0393	0.037	0.0354
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0002	0.0002	0.0002	0.0003	0.0005	0.0008	0.001
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	33.27	33.27	33.27	37.66	40.63	43.16	45.11
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	58.27	58.27	58.27	62.66	65.63	68.16	70.11
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.01**	**0.01**	**0.01**	**0.02**	**0.03**	**0.05**	**0.07**

Discharge Line Segment No. 2 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	12.50
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
			0
Standard Elbow, 45°	**0.3**	1	**0.3**
Standard Tee, thru branch	**1.14**	1	**1.14**
			0
			0
			0
			0
		Total K:	**1.4**

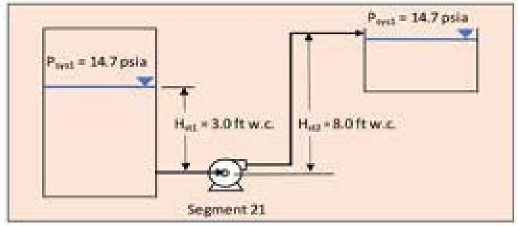
Segment Flowrate (gpm):	2	2	2	3	4	5	6
Eqn. (1) - Velocity, v (ft/s):	0.22	0.22	0.22	0.33	0.44	0.56	0.67
Eqn. (2) - Reynolds Number, Re:	2.49E+03	2.49E+03	2.49E+03	3.74E+03	4.99E+03	6.34E+03	7.59E+03
Pipe Friction Factor, f:	0.0461	0.0461	0.0461	0.0407	0.0375	0.035	0.0333
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0002	0.0002	0.0002	0.0004	0.0007	0.0011	0.0015
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	4.99	4.99	4.99	5.65	6.13	6.57	6.91
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	17.49	17.49	17.49	18.15	18.63	19.07	19.41
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.00**	**0.00**	**0.00**	**0.01**	**0.01**	**0.02**	**0.03**

PROJECT: BASF Above Grade System Sump Hydraulics	BY: S. Hannula	DATE: 10-May-2022	
JOB NO.: 30005248	CHKD. BY: M. Samp	DATE: 10-May-2022	
SUBJECT: Segment 21	APPVD. BY:	DATE:	

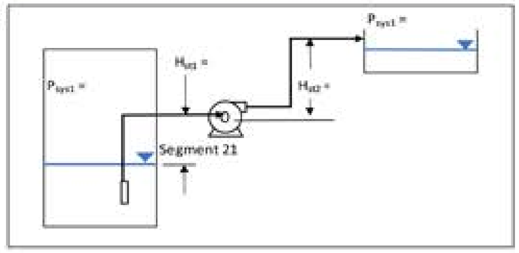
Pump ID:	Segment 21
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	1.5
Design Flow Rate (gpm):	3
Maximum Flow Rate (gpm):	6
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	-12
Pump Impeller Centerline Elevation (ft):	-15
Discharge Elevation (ft):	-7
Static Head of Discharge Line , H_{st2} (ft):	8
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	3
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Notes:

Flooded Suction:



Suction Lift:



Flow Rates (gpm):	2	2	2	3	4	5	6
(gpd):	2,800	2,800	2,800	4,200	5,600	7,000	8,400
(MGD):	0.00	0.00	0.00	0.00	0.01	0.01	0.01
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

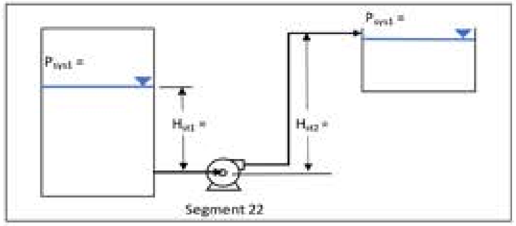
In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)		
Flowmeter	1.2				
Subtotal:	*1.2*	*Subtotal:*	*0.0*	**Total Headloss (ft w.c.):**	**1.2**

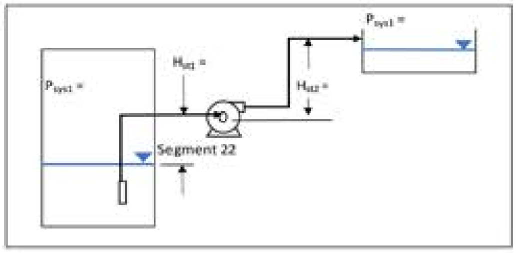
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 22	APPVD. BY:		DATE:	

Pump ID:	Segment 22
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	10.7
Design Flow Rate (gpm):	21.4
Maximum Flow Rate (gpm):	42.8
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	0
Pump Impeller Centerline Elevation (ft):	0
Discharge Elevation (ft):	0
Static Head of Discharge Line , H_{st2} (ft):	0
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	11	14	17	21	28	35	43
(gpd):	15,400	19,600	23,800	29,400	39,200	49,000	60,200
(MGD):	0.02	0.02	0.02	0.03	0.04	0.05	0.06
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)
Subtotal:	*0.0*	*Subtotal:*	*0.0*

Total Headloss (ft w.c.): 0.0

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 22	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	2
Pipe Inner Diameter, ID (in):	1.917
Pipe Length, L (ft):	300.00
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	3.12989E-05

Valve/Fitting Tag	K	No. Units	Total K
Standard Tee, thru branch	**1.14**	1	**1.14**
			0
Standard Elbow, 90°	**0.57**	1	**0.57**
			0
			0
3" x 2" reducer	**0.28**	1	**0.28**
			0
		Total K:	**2.0**

Segment Flowrate (gpm):	11	14	17	21	28	35	43
Eqn. (1) - Velocity, v (ft/s):	1.22	1.56	1.89	2.33	3.11	3.89	4.78
Eqn. (2) - Reynolds Number, Re:	1.38E+04	1.77E+04	2.14E+04	2.64E+04	3.52E+04	4.41E+04	5.42E+04
Pipe Friction Factor, f:	0.0284	0.0267	0.0255	0.0243	0.0227	0.0216	0.0206
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0041	0.0063	0.0089	0.0128	0.0214	0.0318	0.0458
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	11.19	11.91	12.47	13.08	14.00	14.72	15.43
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	311.19	311.91	312.47	313.08	314.00	314.72	315.43
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**1.28**	**1.97**	**2.78**	**4.01**	**6.72**	**10.01**	**14.45**

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 22	APPVD. BY:		DATE:	

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	1.28	1.97	2.78	4.01	6.72	10.01	14.45
Exit Velocity at Liquid Discharge, v (ft/s):	1.22	1.56	1.89	2.33	3.11	3.89	4.78
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.02	0.04	0.06	0.08	0.15	0.24	0.36
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	1.30	2.01	2.84	4.09	6.87	10.25	14.81
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	1.37	2.11	2.98	4.29	7.21	10.76	15.55

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

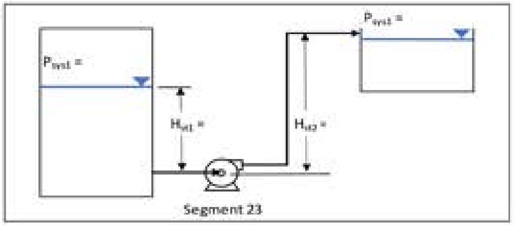
$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

ARCADIS Design & Consultancy for natural and built assets

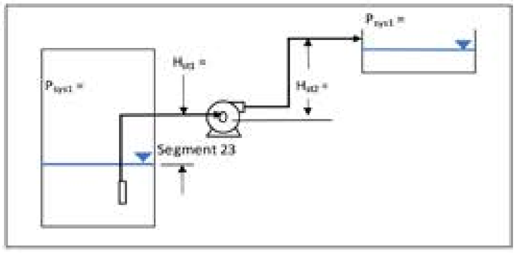
PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 23	APPVD. BY:		DATE:	

Pump ID:	Segment 23
Fluid:	Water
Fluid Description:	Groundwater
Enter Fluid Density if Other than Water (lb/ft^3):	
Enter Fluid Viscosity if Other than Water (cp):	
Enter Vapor Pressure if Other than Water (psi):	
Minimum Flow Rate (gpm):	22.7
Design Flow Rate (gpm):	45.4
Maximum Flow Rate (gpm):	90.8
Pressure of System to be Pumped, P_{sys1} (psia):	14.7
Pressure of System Discharged, P_{sys2} (psia):	14.7
Fluid Temperature (°F):	50
Elevation of Fluid to be Pumped (ft):	-7
Pump Impeller Centerline Elevation (ft):	-7
Discharge Elevation (ft):	10
Static Head of Discharge Line, H_{st2} (ft):	17
Suction Lift of Liquid to be Pumped, H_{st1} (ft):	
Static Head of Liquid to be Pumped, H_{st1} (ft):	
Safety Factor:	5.0%
Vapor Pressure (ft. w.c.):	0.411
Fluid density, ρ (lb/ft^3):	62.41
Fluid Kinematic Viscosity, η (ft^2/s):	1.41E-05
Include Exit Headloss at Discharge, H_e:	Yes

Flooded Suction:



Suction Lift:



Notes:

Flow Rates (gpm):	23	30	37	45	60	75	91
(gpd):	32,200	42,000	51,800	63,000	84,000	105,000	127,400
(MGD):	0.03	0.04	0.05	0.06	0.08	0.11	0.13
Optional - Pump Head (ft w.c.):							
Optional - NSPH Required (ft w.c.):							

In-Line Equipment Headloss:

Equipment Tag	Pressure Loss (ft w.c.)	Equipment Tag	Pressure Loss (ft w.c.)		
Subtotal:	*0.0*	*Subtotal:*	*0.0*	**Total Headloss (ft w.c.):**	**0.0**

ARCADIS Design & Consultancy for natural and built assets

PROJECT:	BASF Above Grade System Sump Hydraulics	BY:	S. Hannula	DATE:	10-May-2022
JOB NO.:	30005248	CHKD. BY:	M. Samp	DATE:	10-May-2022
SUBJECT:	Segment 23	APPVD. BY:		DATE:	

Discharge Line Segment No. 1 Headloss:

Flow Ratio:	1
Nominal Pipe Diameter (in):	3
Pipe Inner Diameter, ID (in):	2.825
Pipe Length, L (ft):	350.00
Pipe Material:	SDR 11 - HDPE
Pipe Type:	Smooth Pipes (PE and other thermoplastics)
Roughness, e (ft):	0.000005
e / ID:	2.12389E-05

Valve/Fitting Tag	**K**	**No. Units**	**Total K**
			0
			0
			0
			0
			0
			0
			0
		Total K:	**0.0**

Segment Flowrate (gpm):	23	30	37	45	60	75	91
Eqn. (1) - Velocity, v (ft/s):	1.18	1.54	1.89	2.30	3.07	3.84	4.66
Eqn. (2) - Reynolds Number, Re:	1.97E+04	2.57E+04	3.16E+04	3.84E+04	5.13E+04	6.41E+04	7.78E+04
Pipe Friction Factor, f:	0.026	0.0244	0.0233	0.0222	0.0209	0.0199	0.0191
Eqn. (3) - Head Loss Across Pipe Segment, H (ft w.c./ft):	0.0024	0.0038	0.0055	0.0078	0.013	0.0194	0.0274
Eqn. (4a) - Fittings Equivalent Length, L_f (ft):	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eqn. (4b) Equivalent Length of Pipe Segment, L_{eq} (ft):	350.00	350.00	350.00	350.00	350.00	350.00	350.00
Eqn. (5) Pipe Segment Headloss, H_p (ft w.c.):	**0.84**	**1.33**	**1.93**	**2.73**	**4.55**	**6.79**	**9.59**

ARCADIS Design & Consultancy for natural and built assets

PROJECT: BASF Above Grade System Sump Hydraulics	BY: S. Hannula	DATE: 10-May-2022
JOB NO.: 30005248	CHKD. BY: M. Samp	DATE: 10-May-2022
SUBJECT: Segment 23	APPVD. BY:	DATE:

Discharge Piping Headloss, $H_{p(discharge)}$ (ft w.c.):	0.84	1.33	1.93	2.73	4.55	6.79	9.59
Exit Velocity at Liquid Discharge, v (ft/s):	1.18	1.54	1.89	2.30	3.07	3.84	4.66
Eqn. (7) Exit Loss at Liquid Discharge, H_v (ft w.c.):	0.02	0.04	0.06	0.08	0.15	0.23	0.34
Eqn. (8) Total Dynamic Head, TDH (ft w.c.):	17.86	18.37	18.99	19.81	21.70	24.02	26.93
Design System TDH with 5.0% Factor of Safety, (ft w.c.):	18.75	19.29	19.94	20.80	22.79	25.22	28.28

References:

1. Crane Co., Technical Paper No. 410: Flow of Fluids Through Valves, Fittings, and Pipe, 1988.
2. Cameron Hydraulic Data, 18th Edition, 2nd Printing, 1995.
3. Piping Handbook, 7th edition, Mohinder L. Nayyar, McGraw-Hill, New York, NY, 2000.
4. Lamont, Peter A. (1981, May). Common Pipe Flow Formulas Compared with the Theory of Roughness, Journal of the American Water Works Association, Denver, CO.
5. Hydraulic Institute, Engineering Data Book, 2nd Edition.
6. Plastic Pipe Institute's Handbook of Polyethylene Pipe, 2nd. Edition.

Equations:

Eqn. (1):

$$v = \frac{\frac{Q_{(gpm)}}{448.8312}}{\frac{\pi}{4} \cdot \left(\frac{ID}{12}\right)^2}$$

Eqn. (2):

$$Re = \frac{v \cdot \frac{ID}{12}}{\eta}$$

Eqn. (3):

$$H = \frac{f \cdot v^2}{2 \cdot g \cdot \frac{ID}{12}} = \frac{f \cdot v^2}{2 \cdot (32.174) \cdot \frac{ID}{12}}$$

Eqn. (4a):

$$L_F = \frac{k \cdot \frac{ID}{12}}{f}$$

Eqn. (4b):

$$L_{eq} = L + L_F$$

Eqn. (5):

$$H_p = H \cdot L_{eq}$$

Eqn. (6):

$$NSPH_a = 2.31 \cdot (P_{sys1} - P_{vap}) - H_{p(suction)} \pm H_{st1}$$

Eqn. (7):

$$H_v = \frac{v^2}{2 \cdot g} = \frac{v^2}{2 \cdot (32.174)}$$

Eqn. (8):

Suction Lift:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} + H_{st1}$$

Flooded Suction:

$$TDH = 2.31 \cdot (P_{sys2} - P_{sys1}) + H_{st2} + Inline\ Equipment\ Headloss + H_{p(discharge)} + H_v + H_{p(suction)} - H_{st1}$$

Appendix C

Preliminary Cost Estimate and Bill of Materials

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Appendix C - Cost Estimate and Bill of Materials
Table 1. Valves
Basis of Design Report (Preliminary 30% Design)
Perimeter Barrier Remedy
BASF North Works Site, Wyandotte, Michigan

Item	Quantity	Reference Drawings	Description	Manufacturer/Model (or approved equal)

Notes:
1. Valves will be provided with 95% design submittal.

Appendix C - Cost Estimate and Bill of Materials
Table 2. Instrumentation
Basis of Design Report (Preliminary 30% Design)
Perimeter Barrier Remedy
BASF North Works Site, Wyandotte, Michigan

Item	Quantity	Reference Drawings	Description
1	12	I-103	Flow Meter Type: Magnetic Flow Meter Lining: PTFE Size: 2 inch Flow Transmitter (Integral Mount) Power: 240 V Signal: 4-20 mA Range: 0-25 GPM
2	1	I-105	Flow Meter Type: Magnetic Flow Meter Lining: PTFE Size: 3 inch Flow Transmitter (Integral Mount) Power: 240 V Signal: 4-20 mA Range: 0-150 GPM
3	48	I-103	Level Switch Media Type: Groundwater Wetted Material: Polypropylene/Stainless Steel Length: 20 feet
4	25	I-104, I-107	Level Switch Media Type: Process Water, Chemical Wetted Material: Polypropylene Type: Ultrasonic
5	12	I-103	Level Transducer Type: Submersible Rating: 10 PSI Material: Polyurethane/Stainless Steel
6	8	P-005	Level Transmitter Type: Radar
7	16	I-103, I-107	Pressure Indicator Type: Bourdon Tube Range: 0-25 PSI
8	6	I-105, I-106, I-108	Pressure Indicator Type: Bourdon Tube Range: 0-100 PSI
9	6	I-105, I-106	Pressure Transmitter Rating: 0-100 PSI

Appendix C - Cost Estimate and Bill of Materials
Table 3. Equipment
Basis of Design Report (Preliminary 30% Design)
Perimeter Barrier Remedy
BASF North Works Site, Wyandotte, Michigan

Item	Quantity	Tag	Reference Drawings	Connection (Inches)	Description	Manufacturer/Model (or approved equal)
1	8	P-001, P-002, P-003, P-004, P-005, P-006, P-017, P-018	I-103	1.25	Extraction Well Pumps Type: Submersible 3.5 gpm @ 88 ft head 6 gpm @ 80 ft head Size: 3 inch Material: Polyethylene/Stainless steel Power: 2 HP	Grundfos 10 SQE-100NE
2	16	P-007, P-008, P-009, P-010, P-011, P-012, P-013, P-014, P-015, P-016, P-019, P-020, P-021, P-022, P-023, P-024	I-103	1.5	Extraction Well Pumps Type: Submersible 14.6 gpm @ 85 ft head 17.2 gpm @ 106 ft head 12.8 gpm @ 122 ft head Size: 3 inch Material: Polyethylene/Stainless steel Power: 1 HP	Grundfos 22 SQE-110NE
3	2	P-100, P-101	I-104	1.5	Transfer Pumps 50 gpm @ 8.5 ft head 100 gpm @ 11 ft head HP: 3 Phase/Volt: 3/480 RPM: 3500	Goulds
4	2	P-200, P-201	I-105	2x3	Transfer Pumps 50 gpm @ 155 ft head 100 gpm @ 195 ft head HP: 10 Phase/Volt: 3/480 RPM: 3500	Goulds e-SH series or 3657/3757 series
5	1	P-400	I-107	1.25	Dosing Pump Range: 0.5-2 gpm Signal: 4-20 mA Amps/Volts: 70A/240V	Grundfos DME series
6	5	P-401, P-402, P-403, P-405, P-406	I-107	0.5	Dosing Pump	Grundfos DDA series
7	1	P-404	I-107	0.75	Dosing Pump Range: 0.15-0.6 gpm Signal: 4-20 mA Amps/Volts: 70A/240V	Grundfos DDA series
8	5	P-500, P-501, P-502, P-503, P-504	I-108	0.75, 0.25	Sludge Wasting Pumps 15 gpm @ 15 ft head	All-Flo

Appendix C - Cost Estimate and Bill of Materials
Table 3. Equipment
Basis of Design Report (Preliminary 30% Design)
Perimeter Barrier Remedy
BASF North Works Site, Wyandotte, Michigan

Item	Quantity	Tag	Reference Drawings	Connection (Inches)	Description	Manufacturer/Model (or approved equal)
9	1	P-505	I-108	1.5	Sump Pump 30 gpm @ 22 ft head HP: 0.5 Phase/Volt: 1/115	Goulds
10	2	BF-200, BF-201	I-105	2	Bag Filter Housing Assume Bag Trade Size 2, 2x filters Height: 48", Diameter: 8"	PRM
11	2	T-300, T-301	I-106	2	GAC Vessels: 4x vessels lead/lag EBCT: 14 min each BV: 196 ft3 GAC Fill: 5,000 lb 72" diameter, 9'11" height	Calgon
12	2	T-302, T-303	I-106	2	IX Resin Housing Diameter: 2.7' Height: 5' BV: 27 ft3 PFA 694	Calgon
13	1	F-500	I-108	2	Filter Press. Capacity: 19 cu. ft. 11.5' L x 5' W x 63" H	Sperry
14	1	AC-500	I-108	0.5	Air Compressor Single Stage Max Pressure: 120 PSI HP: 3.5	Quincy
15	1	CF-500	I-108	0.5	Coalescing Filter Flow: 20 CFM	Trident
16	1	AF-500	I-108	0.5	Air Filter Flow: 20 CFM	Trident
17	1	DD-500	I-108	0.5	Dessicate Dryer Flow: 20 CFM Phase/Volts: 1/240	Trident
18	1	--	--	--	Stairs to platform Platform Height 9'. Width: 3'	FS Industries

Appendix C - Cost Estimate and Bill of Materials
Table 4. Tanks
Basis of Design Report (Preliminary 30% Design)
Perimeter Barrier Remedy
BASF North Works Site, Wyandotte, Michigan

Item	Quantity	Tag	Reference Drawings	Description	Manufacturer/Model (or approved equal)
1	1	T-100	I-104	Equalization Tank Type: Fiberglass, Cone Bottom Volume: 20,000 GAL Diameter: 15' Height: 16'	Belding
2	1	T-101	I-104	Neutralization Tank Type: Polyethylene, Flat Bottom Volume: 2,000 GAL Diameter: 90" Height: 83"	Plastic-Mart
3	1	T-102, T-103, T-104	I-104	Mix Tank/Clarifier Inclined Parallel Plate Clarifier Length: 11.25' Width: 6.4' Height: 12.25'	MW-Watermark
4	1	T-200	I-105	Pumpout Tank Type: Polyethylene, Flat Bottom Volume: 2,000 GAL Diameter: 90" Height: 83"	Plastic-Mart
5	1	T-400	I-107	Chemical Stock Tank Type: Polyethylene, Flat Bottom Volume: 7,000 GAL Diameter: 142" Height: 125"	Plastic-Mart
6	5	T-401, T-402, T-403, T-405, T-406	I-107	Chemical Stock Tank Type: Polyethylene, Flat Bottom Volume: 55 GAL Diameter: 23" Height: 38"	Plastic-Mart
7	1	T-404	I-107	Chemical Stock Tank Type: Polyethylene, Flat Bottom Volume: 550 GAL Diameter: 52" Height: 66"	Plastic-Mart

Appendix C - Cost Estimate and Bill of Materials
Table 4. Tanks
Basis of Design Report (Preliminary 30% Design)
Perimeter Barrier Remedy
BASF North Works Site, Wyandotte, Michigan

Item	Quantity	Tag	Reference Drawings	Description	Manufacturer/Model (or approved equal)
8	1	T-500	I-108	Sludge Holding Tank Type: Polyethylene, Cone Bottom Volume: 2,000 GAL Diameter: 90" Height: 102"	Plastic-Mart
9	1	T-501	I-108	Solids Holding Tank Type: Frac Tank Volume: 10 CU YD	US Ecology, Inc.

Appendix C - Cost Estimate and Bill of Materials
Steel Bulkhead and Containment Barrier
Basis of Design Report (Preliminary 30% Design)
Perimeter Barrier Remedy
BASF North Works Site, Wyandotte, Michigan

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Item No.	Description	Estimated Quantity	Unit	Unit Cost	Estimated Cost	Comments
Drain Installation						
1	Mobilization / Demobilization	1	LS	$150,000.00	$ 150,000	
2	Site Preparation/Erosion Control Installation	10	DY	$5,500.00	$ 55,000	Minor access improvements, installation of temporary erosion and sedimentation controls, and installation of temporary fencing.
3	Geophysical Survey/Utility Locate	1	LS	$100,000.00	$ 100,000	Geophysical subsurface investigation using GPR/EM and other locating tools along the entire length of the proposed conveyance trenching.
4	Pre-Excavation	30	DY	$8,500.00	$ 255,000	Pre-Excavation include costs for large excavators with breaker attachments to remove existing subsurface infrastructure and backfill with sand/general fill. Assumes concrete can be broken with hydraulic breaker attachments.
5	One-Pass Trench Excavation/Backfill	4,700	LF	$250.00	$ 1,175,000	One-Pass Trencher costs assume approximately 200 LF per day excavation with one-pass trencher and bucket. Assumes backfill installation to happen in parallel.
6	Utility Relocations	4	EA	$8,500.00	$ 34,000	Utility relocations cost assumes that water lines and stormwater lines will need to be temporarily disconnected and reconnected during trenching. Cost assumes that electrical utilities can be crossed without disconnection and lines can be installed underneath shallow electrical conduits.
7	Pipe Installation	4,700	LF	$15.00	$ 70,500	Pipe Installation cost includes labor, equipment and materials to install a 4-inch perforated HDPE pipe in the bottom of the collection trench excavated above.
8	Backfill - Material	4,178	CY	$45.00	$ 188,000	Backfill material cost assumes none of the excavated spoils can be re-used. Assumes imported pea gravel and general fill to supplement excavated spoils. Cost includes 20% fluff factor for compaction.
9	Collection Sumps - Material	12	EA	$25,000.00	$ 300,000	4'x4'x12' deep concrete vault.
10	Collection Sumps - Installation	24	DY	$10,500.00	$ 252,000	Includes excavation, use of a crane to lift and set the vault and backfill. Assumes 2 days per vault.
11	Soil Waste	5,222	Ton	$285.00	$ 1,488,333	Soil Waste cost assumes 100% of excavated spoils to be sent offsite as waste. Assumes average PFOA concentration <1 PPM permitting disposal at Wayne Disposal, MI.
12	Waste Management/Loadout	20	DY	$8,500.00	$ 170,000	Waste Management and Loadout of Trucks. Assumes 12 trucks per day.
13	Soil Stabilizer	3,481	CY	$20.00	$ 69,630	Soil Stabilizer cost assumes use of BASF TRO-C stabilizer to be mixed with excavated spoils to permit offsite transportation.
14	Site Restoration	1	LS	$75,000.00	$ 75,000	Site restoration cost includes seed and straw installation for the trench.
				Drain Installation Subtotal	**$ 4,382,463**	
Groundwater Conveyance Installation						
15	Soft Digging	20	DY	$5,500.00	$ 110,000	Assumes soft digging 3-feet around utilities to permit mechanical excavation.
16	Trenching	47	DY	$8,500.00	$ 402,333	Assumes use of conventional trenching methods. Assumes 150 LF per day.
17	Pipe Installation	7,100	LF	$12.00	$ 85,200	2-inch SDR-11 HDPE installation, including labor.
18	Backfill - Material	1,420	CY	$45.00	$ 63,900	Assumes 2' wide, 4.5' deep trench. Assumes 50% of spoils can be re-used. Includes 20% for compaction
19	Soil Waste	1,775	Ton	$285.00	$ 505,875	Assumes 2' wide, 4.5' deep trench. Assumes 50% of spoils can be re-used. Assumes average PFOA concentration <1 PPM permitting disposal at Wayne Disposal, MI.
20	Soil Stabilizer	1,183	CY	$20.00	$ 23,667	Soil Stabilizer cost assumes use of BASF TRO-C stabilizer to be mixed with excavated spoils to permit offsite transportation.
21	Sump Pumps	12	EA	$3,500.00	$ 42,000	Grundfos SQE Submersible Pump
22	Yard Electrical	1	LS	$200,000.00	$ 200,000	Includes conduit, wire and disconnects to well field. Assumes they are ran in same trench as water piping.
23	Site Restoration	1	LS	$50,000.00	$ 50,000	Site restoration cost includes seed and straw installation for the trench.
				Groundwater Conveyance Installation Subtotal	**$ 1,482,975**	

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Item No.	Description	Estimated Quantity	Unit	Unit Cost	Estimated Cost	Comments
Treatment System Installation						
24	Mobilization / Demobilization	1	LS	$50,000.00	$ 50,000	
25	Site Preparation/Erosion Control Installation	10	DY	$5,500.00	$ 55,000	
26	Building Over excavation for Foundation	10	DY	$8,500.00	$ 85,000	Assumes over excavation to 4-feet below grade surface. Assumes no imported structural fill required.
27	Foundation Installation	222	CY	$1,000.00	$ 222,222	Assumes a 6" slab with turn down footers for each corner.
28	PEMB Erection	6,000	SF	$150.00	$ 900,000	Includes an 80'x75' pre-engineered metal building with 20' eave height purchase and installation. Includes overhead lights.
29	Sludge Wasting Pumps	5	EA	$3,000.00	$ 15,000	All-Flo 15 GPM @ 15' TDH
30	Transfer Pumps	2	EA	$2,500.00	$ 5,000	Goulds e-SH series (50 GPM @ 155' TDH, 100 GPM @ 195' TDH)
31	Sump Pump	1	EA	$1,500.00	$ 1,500	Goulds 30 GPM @ 22' TDH
32	Dosing Pumps	7	EA	$1,500.00	$ 10,500	
33	LPGAC Skid	1	LS	$200,000.00	$ 200,000	Calgon 10,000 lb, 2 vessel skid (Lead/Lag) with manifold
34	IX Resin Skid	1	LS	$75,000.00	$ 75,000	Calgon
35	Bag Filter Skid	1	LS	$10,000.00	$ 10,000	PRM Two Filter Skid
36	Filter Press	1	EA	$105,000.00	$ 105,000	Sperry 19 cu ft Unit
37	Air Compressor Skid	1	EA	$35,000.00	$ 35,000	Quincy Single Stage
38	EQ Tank	1	EA	$5,000.00	$ 5,000	Cone Bottom, 2000 Gal Tank
39	Neutralization Tank	1	EA	$3,000.00	$ 3,000	Float Bottom, 2000 Gal Tank
40	Inclined Plate Clarifier	1	EA	$125,000.00	$ 125,000	MW Watermark Clarifier with mix tank and parallel plate clarifier
41	Pumpout Tank	1	EA	$5,000.00	$ 5,000	Cone Bottom, 2000 Gal Tank
42	Sludge Holding Tank	1	EA	$5,000.00	$ 5,000	Cone Bottom, 2000 Gal Tank
43	Large Chemical Stock Tank	1	EA	$12,000.00	$ 12,000	Flat Bottom, 7000 Gal Tank
44	Small Chemical Stock Tank	1	EA	$1,500.00	$ 1,500	Flat Bottom, 550 Gal Tank
45	Instrumentation	1	LS	$100,000.00	$ 100,000	Includes flow meters, pressure transducers, level transducers, etc.
46	Pipe, Fittings, Supports and Valves	1	LS	$100,000.00	$ 100,000	
47	Conduit, Wire and Fittings	1	LS	$75,000.00	$ 75,000	
48	MCP/MCC	1	LS	$150,000.00	$ 150,000	
49	Stairs/Platforms/Misc. Metals	1	LS	$100,000.00	$ 100,000	
50	HVAC Installation	1	LS	$65,000.00	$ 65,000	
51	Electrical Installation	40	DY	$4,500.00	$ 180,000	
52	Mechanical Installation	60	DY	$6,500.00	$ 390,000	
53	Start-Up	1	LS	$150,000.00	$ 300,000	
				Treatment System Installation Subtotal	**$ 3,385,722**	

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Item No.	Description	Estimated Quantity	Unit	Unit Cost	Estimated Cost	Comments
Bulkhead Sheetpile Wall Installation						
54	Mobilization/Demobilization	1	%	7.5%	$1,891,050	
55	Contractor Work Plans	1	%	2.5%	$630,350	
56	Site Preparation	1	LS	$200,000	$200,000	
57	Demolition & Obstruction Removal Allowance	1	LS	$700,000	$700,000	Includes debris removal along river bottom prior to headwall installation
58	Headwall Steel Procurement (Coated Steel)	6,741,231	LBS	$1.25	$8,427,000	Assumes 1725 LF of W44x230 / AZ19 Combination wall, 68-foot-long king piles and intermediate sheet piles; 1650-foot-long main wall plus 75-foot-long return wall
59	Headwall Installation	117,300	SF	$35	$4,106,000	
60	Interlock Sealant - Material and Installation	37,080	LF	$8	$297,000	Based on recent sheetpile job in Brooklyn. 2 joints sealed and 1 joint welded
61	Shear Pin - Material & Fabrication	275	EA	$1,000	$275,000	Assumes 8 ft long pins, 66 ft long casing, shop fabricated.
62	Shear Pin - Installation	275	EA	$5,500	$1,513,000	
63	Concrete Cap	1,725	LF	$350	$604,000	Assumes 4' x 4' reinforced concrete cap, includes formwork, excludes earthwork.
64	Anchor Wall Steel Procurement (Coated Steel)	2,744,940	LBS	$1.25	$3,432,000	Assumes 40-ft deep AZ42-700N sheet pile (total wall length = 1650 feet)
65	Pre-trenching	1	LS	$250,000	$250,000	Pretrenching along anchor wall alignment
66	Anchor Wall Installation	66,000	SF	$20	$1,320,000	
67	Waler Steel Procurement (Coated Steel)	82,500	LBS	$1.25	$103,000	
68	Waler Installation	1,650	LF	$125	$207,000	Waler at anchor wall only (kingpiles will be connection point at headwall)
69	Tierod Steel Procurement (Coated Steel)	225,431	LBS	$1.50	$339,000	Assumes 105' long 1-3/8" diam. 150ksi tierods at each king pile
70	Miscellaneous Hardware for Anchoring (Materials and Installation)	1	LS	$275,000	$275,000	
71	Concrete Demolition	248	EA	$1,100	$273,000	Demolition of existing concrete seawall for tierod installation
72	Excavation, Backfilling & Compaction	17,547	CY	$29	$509,000	Excavation for concrete cap and tiedrods. Assumes no off haul of material
73	Tierod Installation	248	EA	$1,200	$298,000	
74	Backfill Material Procurement (Aggregate)	14,850	CY	$65	$966,000	normal weight fill beneath the existing dock
75	Access Points for Backfill Placement	60	EA	$5,000	$300,000	Excavation of soil and demo of concrete slab below dock for backfill access points. Assumes access point every 25 ft along wall.
76	Backfill Placement	14,850	CY	$35	$520,000	
77	Miscellaneous Improvements	1	LS	$300,000	$300,000	
		Bulkhead Sheetpile Wall Installation Subtotal		**$**	**27,735,400**	

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Item No.	Description	Estimated Quantity	Unit	Unit Cost	Estimated Cost	Comments
Subsurface Barrier Wall Installation						
78	Mobilization / Demobilization	1	LS	$540,000.00	$ 540,000	Based on 10% construction costs, excluding T&D
79	Temporary Construction Facilities and Controls	5	Month	$50,000.00	$ 250,000	Based on recent remediation construction contracts.
80	Contractor's Health and Safety Program	5	Month	$50,000.00	$ 250,000	Based on recent remediation construction contracts.
81	Construction Layout and Surveying	1	LS	$50,000.00	$ 50,000	
82	Double Silt Fence	3,000	LF	$5.00	$ 15,000	Based on engineering experience, assuming fence with wire backing, assuming installed along downgradient sides of slurry wall to protect from impacts to surface water.
83	Working Platform - Geotextile	5,550	SY	$2.00	$ 11,100	Assumes platform width of 25 ft for length of barrier wall.
84	Working Platform Furnishing and Placing Soil	4,930	Tons	$20.00	$ 98,600	Based on engineering experience of cost per CY to furnish/install soil for slurry wall platform, working platform 25' wide at top, 2' high, and with side slopes of 2:1
85	Site Access Road Installation	2,500	SY	$18.00	$ 45,000	Crushed 3/4" stone base, compacted, 12" deep. For an assumed length of 1,500 ft.
86	Site Access Road - Geotextile	2,500	SY	$2.00	$ 5,000	Based on engineering experience for geotextile material, installed, assuming the surface area of the site access road
87	Bermed/Lined Soil Conditioning Pad	1	LS	$40,000.00	$ 40,000	Based on engineering experience for soil conditioning/dewatering pad, assuming 6-in-thick concrete pad roughly 100' x 100' in size with fencing
88	Bermed/Lined Mixing Pad	1	LS	$30,000.00	$ 30,000	Based on engineering experience for slurry mixing pit or batch plant type operation.
89	Excavation of Near Surface Fill Soils/Obstructions (Pre-trenching)	715	CY	$15.00	$ 10,725	Assuming a pre-trenching depth of 6' deep and 4' wide along 25% of the wall length (to be based on geophysical survey findings).
90	Backfill Pre-trench Excavation	1,220	Tons	$20.00	$ 24,400	
91	Slurry Trench Excavation and Backfilling of Trench (Soil-cement Wall)	44,550	VSF	$20.00	$ 891,000	Excavation under slurry, backfill with treated borrow soils.
92	Purchase Reagents for Soil-Cement Wall	435	Tons	$210.00	$ 91,350	Based on recent Aurora, IN project bids.
93	Furnishing Borrow Soil for Soil-Cement Wall	7,260	Tons	$15.00	$ 108,900	Assumes a material loss of 10%
94	Mixing of Materials Prior to Installation for Soil-Cement Wall	1	LS	$50,000.00	$ 50,000	
95	Steel Sheet Piling - Materials	955,900	Lbs	$1.25	$ 1,194,875	Assumes NZ-22 pile section for drivability through fill layer and embedment into clay.
96	Steel Sheet Piling - Installation	43,450	VSF	$40.00	$ 1,738,000	Based on recent project experience and estimates.
97	Localized Jet Grouting, Work Around Utilities and Structures	1	LS	$250,000.00	$ 250,000	
98	Transfer of Excavated Soils for Dewatering or Slurry Mixing	4,840	CY	$6.00	$ 29,040	Based on engineering experience for loading, includes loading excavated soils from pre-trenching and slurry excavation on trucks and transporting to soil conditioning pad for dewatering.
99	Portland Cement	155	Tons	$210.00	$ 32,550	Including material and delivery only, assuming Portland cement equal to 2% weight of soils excavated from pre-trenching activities and slurry wall trench for dewatering.
100	Mixing/Loadout of Excavated Soils conditioned with Portland Cement	4,940	CY	$6.00	$ 29,640	Based on engineering experience for mixing excavated soils with Portland cement for dewatering.
101	Transportation and Disposal of Excavated Soils	8,400	Tons	$180.00	$ 1,512,000	Updated for soil disposal at US Ecology for PFAS > 1 ppm. Assumes 1.7 conversion from CY to tons.
102	Utility Reinstallations	1	LS	$50,000.00	$ 50,000	
103	Geotextile	1,600	SY	$2.00	$ 3,200	Installed, assuming an area of 3200' x 4.5' to be covered.
104	General Fill	1,815	Tons	$20.00	$ 36,300	Including delivery, placement, and compaction, assuming a volume of 3200' x 4.5' x 2' required
105	Asphalt	1,280	SY	$50.00	$ 64,000	Assumes 5 ft wide strip for north and south barrier walls.
				Subsurface Barrier Wall Installation Subtotal	**$ 7,450,680**	

CONSTRUCTION SUBTOTAL	$ 44,437,240
Construction Management/Design during Construction Services/Project Management Services (10%)	$ 4,443,724
TOTAL COST	$ 48,880,964
CONSTRUCTION LOW ESTIMATE (-30%)	$ 34,216,675
CONSTRUCTION HIGH ESTIMATE (+50%)	$ 73,321,446

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Notes:

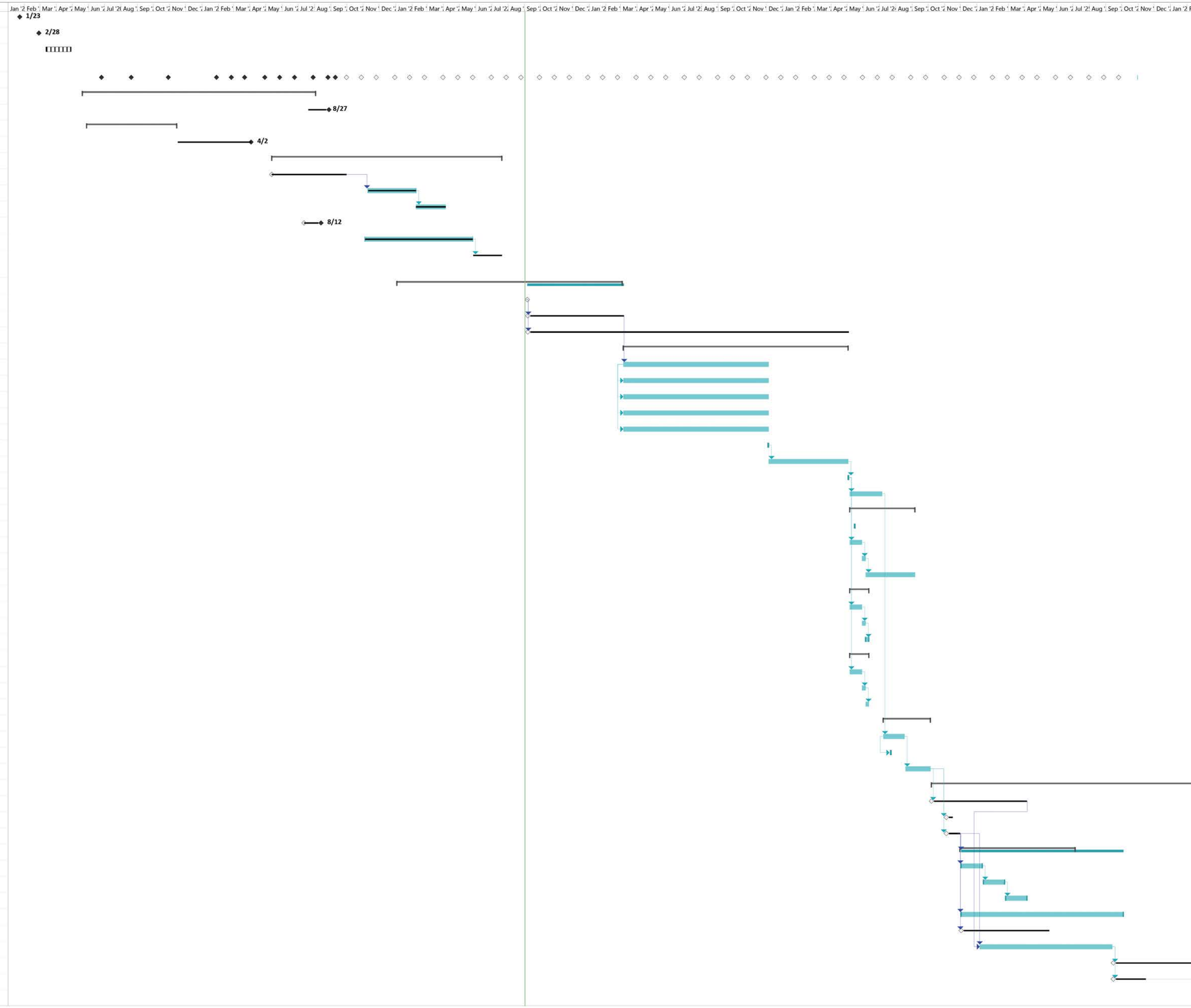
1. Cost estimates are based on Arcadis' past experience and vendor estimates. Arcadis prepared these estimates using current and generally accepted cost estimation methods. These estimates are based on assumptions concerning future events, and actual costs may be affected by known and unknown risks, including, but not limited to, changes in general economic and business conditions, site conditions which were unknown to Arcadis at the time the estimates were prepared, future changes in site conditions, regulatory or enforcement policy changes, and delays in performance. Actual costs may vary from these estimates, and such variations may be material. Arcadis is not licensed as accountants or securities attorneys, and therefore make no representations that these cost estimates form an appropriate basis for complying with financial reporting requirements for such costs.

2. In providing opinions of probable construction costs, the Client understands that Arcadis has no control over costs; the price of labor, equipment, or materials; or the construction contractor's methods of pricing. The opinions of probable construction costs provided herein are to be made on the basis of Arcadis qualifications and experience. Arcadis makes no warranty, expressed or implied, as to the accuracy of such opinions as compared to bid or actual costs. Utilization of this cost estimate information beyond the stated purpose is not recommended.

Appendix D

Preliminary Construction Schedule

ID	Task Name	%	Duration	Start	Finish
1	Notice to Proceed	100%	0 days	Thu 1/23/20	Thu 1/23/20
2	Kickoff Meeting with USEPA	100%	0 days	Fri 2/28/20	Fri 2/28/20
3	COVID-19 Impact: All non-business-essential personnel/contractors restricted from site access	100%	32 days	Fri 3/13/20	Mon 4/27/20
4	**USEPA Check-In Meetings**	**23%**	**1384 days**	**Thu 6/25/20**	**Thu 10/30/25**
70	**Hydraulic Pre-Design Investigation (PDI) Activities**	**100%**	**306 days**	**Wed 5/20/20**	**Mon 8/2/21**
84	Submittal of PDI Findings - Hydraulic Testing	100%	29 days	Tue 7/20/21	Fri 8/27/21
85	**Geotechnical PDI Activities**	**100%**	**121 days**	**Thu 5/28/20**	**Fri 11/13/20**
94	Submittal of PDI Findings - Geotechnical/Barrier Alignment	100%	96 days	Mon 11/16/20	Fri 4/2/21
95	**Treatability Testing Activities**	**100%**	**303 days**	**Tue 5/11/21**	**Tue 7/19/22**
96	Bench-scale testing of slurry wall mixes	100%	98 days	Tue 5/11/21	Wed 9/29/21
97	Long-term testing of slurry wall mixes	100%	60 days	Wed 11/10/21	Mon 2/7/22
98	Report Preparation and Submittal of Treatability Study Findings - Slurry V	100%	40 days	Tue 2/8/22	Mon 4/4/22
99	Above grade treatment treatability test refinement	100%	24 days	Mon 7/12/21	Thu 8/12/21
100	Treatability testing of above grade treatment technologies	100%	141 days	Thu 11/4/21	Wed 5/25/22
101	Report Preparation and Submittal of Treatability Study Findings - Above Grade Treatment	100%	38 days	Fri 5/27/22	Tue 7/19/22
102	**Preliminary Design (30%)**	**0%**	**305 days**	**Mon 1/3/22**	**Fri 3/3/23**
103	Submittal of Preliminary Design Package	0%	1 day	Tue 9/6/22	Tue 9/6/22
104	EPA Review/Comment	0%	129 days	Wed 9/7/22	Mon 3/6/23
105	**Address Data Gaps (if necessary)**	0%	433 days	Wed 9/7/22	Fri 5/3/24
106	**Pre-Final Design (95%)**	**0%**	**304 days**	**Mon 3/6/23**	**Thu 5/2/24**
107	Development of Performance Standards	0%	196 days	Mon 3/6/23	Mon 12/4/23
108	Barrier Wall(s) Design	0%	196 days	Mon 3/6/23	Mon 12/4/23
109	Groundwater Extraction System Design	0%	196 days	Mon 3/6/23	Mon 12/4/23
110	Above Grade Treatment System Design	0%	196 days	Mon 3/6/23	Mon 12/4/23
111	Supporting Documents (QAPP, HASP, O&M Plan, CQAP)	0%	196 days	Mon 3/6/23	Mon 12/4/23
112	Target Submittal of Pre-Final Design Package	0%	1 day	Mon 12/4/23	Mon 12/4/23
113	EPA Review/Comment	0%	108 days	Tue 12/5/23	Thu 5/2/24
114	**Final Design (100%)**	**0%**	**1 day**	**Fri 5/3/24**	**Fri 5/3/24**
115	**Bid Package Development**	**0%**	**45 days**	**Mon 5/6/24**	**Fri 7/5/24**
116	**Joint Permit Application**	**0%**	**89 days**	**Mon 5/6/24**	**Thu 9/5/24**
117	Pre-Application Meeting with Agencies	0%	1 day	Wed 5/15/24	Wed 5/15/24
118	Prepare Application	0%	17 days	Mon 5/6/24	Tue 5/28/24
119	BASF Review	0%	5 days	Wed 5/29/24	Tue 6/4/24
120	Address Comments, Agency Review and Public Hearing (if needed)	0%	67 days	Wed 6/5/24	Thu 9/5/24
121	**POTW Permit**	**0%**	**26 days**	**Mon 5/6/24**	**Mon 6/10/24**
122	Prepare Application	0%	17 days	Mon 5/6/24	Tue 5/28/24
123	BASF Review	0%	5 days	Wed 5/29/24	Tue 6/4/24
124	Address Comments and Submit Application	0%	4 days	Wed 6/5/24	Mon 6/10/24
125	**USCG Notice to Mariners**	**0%**	**26 days**	**Mon 5/6/24**	**Mon 6/10/24**
126	Prepare Draft Notice	0%	17 days	Mon 5/6/24	Tue 5/28/24
127	BASF Review	0%	5 days	Wed 5/29/24	Tue 6/4/24
128	Address Comment and Submit Notice	0%	4 days	Wed 6/5/24	Mon 6/10/24
129	Contractor Bid Phase	**0%**	**65 days**	**Mon 7/8/24**	**Fri 10/4/24**
130	Submit Request for Bids	0%	30 days	Mon 7/8/24	Fri 8/16/24
131	Bid Walk	0%	1 day	Mon 7/22/24	Mon 7/22/24
132	Contractor Selection and Contracting	0%	35 days	Mon 8/19/24	Fri 10/4/24
133	**Construction**	**0%**	**625 days**	**Mon 10/7/24**	**Fri 2/26/27**
134	Material/Long lead Equipment Procurement	0%	130 days	Mon 10/7/24	Fri 4/4/25
135	Mobilization to Site	0%	2 wks	Mon 11/4/24	Fri 11/15/24
136	Site Preparation	0%	4 wks	Mon 11/4/24	Fri 11/29/24
137	**Barrier Remedy Construction**	**0%**	**155 days**	**Fri 11/29/24**	**Fri 7/4/25**
138	Southern Sheet Pile Wall Construction	0%	30 days	Mon 12/2/24	Fri 1/10/25
139	Northern Sheet Pile Wall Construction	0%	30 days	Mon 1/13/25	Fri 2/21/25
140	Soil-Cement Barrier Construction	0%	30 days	Mon 2/24/25	Fri 4/4/25
141	Steel Bulkhead Construction	0%	11 mons	Mon 12/2/24	Fri 10/3/25
142	Groundwater Extraction System Construction	0%	6 mons	Mon 12/2/24	Fri 5/16/25
143	Above Grade Treatment System Construction	0%	9 mons	Mon 1/6/25	Fri 9/12/25
144	System Startup and Optimization	0%	18 mons	Mon 9/15/25	Fri 1/29/27
145	Site Restoration	0%	45 days	Mon 9/15/25	Fri 11/14/25
146	Demobilization	0%	20 days	Mon 2/1/27	Fri 2/26/27



Appendix E

Subsurface Barrier Options Summary Table

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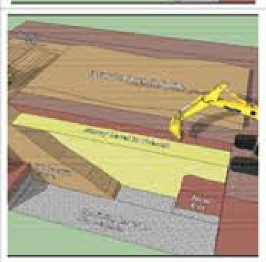
Site Understanding	Subsurface Conditions/Impacts	Implementation Considerations	
	General Site Lithology (Ref. Arcadis, Draft Geotechnical Data Report, February 2021): Fill material extending from ground surface to 12 to 32 feet below ground surface (ft bgs). The fill consists of distilled blow off (DBO) interbedded with crushed concrete, crushed stone, gravel, sand, and clay and is mixed with various debris that includes wood, organics, rubber, coal, glass and brick fragments. Beneath the fill layer, a very soft silt (alluvium) layer is found mostly in the northern portion, and noted as discontinuous, with thicknesses between 7 and 15 feet. A loose to dense sand layer follows the alluvium or fill layer, ranging in thickness from 5 to 17 feet. A soft to medium stiff clay layer follows at depths between approximately 25 and 44 ft bgs. It's thickness ranges from 21 to 27 feet and is underlain by glacial till. Groundwater flows toward the Detroit River. Depth to groundwater ranges from 3 to 6 ft bgs. To mitigate potential off-site migration of impacted groundwater, a barrier system will be installed, in combination with a groundwater collection trench, along a portion of the eastern Site boundary. The barrier wall is also planned along the northern and southern Site boundaries for groundwater control. Barrier wall to extend into clay layer minimum of 3 ft for an effective vertical seal at depth. Anticipated total length of barrier wall is approximately 3,200 linear feet. Obstructions from former site structures and buried debris may be encountered on site during barrier wall installation.	Varying thicknesses of different soils. Fluctuation in depths to clay (Termination boundary). Variability in Fill/Native Soils. Debris/Concrete/Waste. Groundwater - Depth, Quality, COCs, and pH. Utilities, Building Structures, Bulkhead Infrastructure. End Use of Property (Barrier Wall Alignment)	

Barrier Wall Alternatives	Diagram	Alternative Description	Geology Considerations	Issues of Installation/Feasibility	Effectiveness	Constructability	Approximate Relative Cost Range
Option 1 - Ex-situ Mixed Site Soil-Cement Barrier via Excavator		• Slurry wall trench is excavated utilizing conventional and specialized long stick excavators. • Excavation/Trenching performed under an engineered fluid (bentonite slurry) for trench support. • Separate on-site blending and backfilling operations, pending barrier wall design (soil/bentonite/cement). • The peat and DBO site soils/materials from trench excavation are separated and transported for off-site disposal. Remaining suitable site soils are blended on-site per wall design and placed into the trench.	• Obstructions can often easily be removed when encountered using hydraulic excavator. • Excavator can easily manage changes in excavation depth to the termination layer. • Verifiable continuity of the key in material (low permeability soil). Proper key into native clay layer is visually verified. • DBO and peat materials present a challenge for consistent and controllable finished wall properties. Both materials will require separation from other excavated soils.	• Common and established technology; multiple contractors qualified to construct; equipment readily available. • Requires a wide bench/platform for wall construction and working area properly prepared to allow effective mixing and preparation of the backfill. • Practicality of effectively separating the DBO and peat from the appropriate soils for mixing is questionable. If not properly separated greater potential for wall inconsistencies. Also, uncertainty with how much suitable material will be available and how much for importing. Removing of materials > 3 inches in diameter also critical to meeting permeability. • Messy operation and proper containment of slurry and backfill along the working trench is required to ensure a relatively clean site.	• Results of treatability testing program indicate that a blend of cement, slag and site soils produces a barrier wall that meets the performance criteria for strength and hydraulic conductivity. • Because of the poor quality site soils (general heterogeneity, DBO, peat, obstructions) and potential issues with adequate separation of these materials during mixing, the effectiveness of this wall option if implemented is questionable. There is the potential for zones of higher permeability or of low wall strength as a result and both will impact the wall's overall performance as a groundwater barrier. • Allows for confirmation of key into clay for bottom of seal.	• Requires area for mixing/blending of soils/cement in a central location. Typical area of 100 ft x 100 ft, with a hard surface or former building slab. • Batch plant area for slurry mixing and pumping to working wall alignment. • Working wall platform width of 25 ft. • Truck traffic on existing plant roads, off-site public roads, and new access roads, where necessary, travelling from blending area to working wall construction and vice versa, and for transporting excavated soils for off-site disposal. • Due to the time for proper mixing/blending of site soils, the duration of this option is expected to be **5 months.**	**$5.9M to $10.4M**
Option 2 - Ex-situ Mixed Imported Soil-Cement Barrier via Excavator		• Slurry wall trench is excavated utilizing conventional and specialized long stick excavators. • Excavation/Trenching performed under an engineered fluid (bentonite slurry) for trench support. • Separate on-site blending and backfilling operations, pending barrier wall design (soil/bentonite/cement). • Soils/materials from trench excavation are transported for off-site disposal. Trench backfilled with borrow sourced soils blended on-site with cement/bentonite per wall design.	• Obstructions can often easily be removed when encountered using hydraulic excavator. • Excavator can easily manage changes in excavation depth to the termination layer. • Verifiable continuity of the key in material (low permeability soil). Proper key into native clay layer is visually verified.	• Common and established technology; multiple contractors qualified to construct; equipment readily available. • Requires a wide bench/platform for wall construction and working area properly prepared to allow effective mixing and preparation of the backfill. • Use of borrow sourced soil for wall mix allows for consistent material type and an end product meeting performance criteria. • Messy operation and proper containment of slurry and backfill along the working trench is required to ensure a relatively clean site.	• Results of treatability testing program indicate that a blend of cement, slag and borrow sourced sand produces a barrier wall that meets the performance criteria for strength and hydraulic conductivity. • Use of imported borrow soils mitigates the concerns of the poor quality site soils. With the consistency of the mix with the borrow site soils during implementation, the performance of the wall as a groundwater barrier is maintained. A higher-quality, more consistent wall than Option 1. • Allows for confirmation of key into clay for bottom seal.	• Requires area for mixing/blending of soils/cement in a central location. Expect mixing accomplished with pug mill type mixer, which will produce a uniform mix and allow for faster production rates. • Truck traffic on existing plant roads, off-site public roads, and new access roads, where necessary, travelling from blending area to working wall construction and vice versa, and for transporting excavated soils for off-site disposal. • Batch plant area for slurry mixing and pumping to working wall alignment. • Working wall platform width of 25 ft. • Expected wall construction duration of **4 months**.	**$5.8M to $10.3M**
Option 3 - Steel Sheet Piles		• Excavation of fill for removal of debris along the wall alignment and backfilling the trench with borrow soil as necessary. • Installation/Driving of sheet piles to impermeable layer. • Joint sealant or welding required for watertight wall system at all pile interlocks. • Protective Cap or cover placed over top of the sheet pile. May be above ground or below the ground surface.	• Accurate profile of clay surface needed in order to ensure that seepage below the sheeting does not occur. • Cannot visually verify that the sheet pile has been embedded into the low permeability layer, and variation in clay surface at NW adds to concerns with developing that bottom seal. • Debris, utilities, and other structures must be removed from the entire alignment prior to installation.	• Common and established technology; multiple contractors qualified to construct; equipment readily available. • Sheet pile installation can cause vibrations which may damage sensitive structures. • Large obstructions and debris if not effectively removed prior to installation can potentially cause refusal of the sheet piling. • Accurate clay surface profile required for effective bottom sealing of piles. • Greater potential for seals between sheets to become damaged which may result in leakage.	• Potential for damaged seals between sheets could decrease effectiveness of this wall type. • Potential for piles to not create wall seal at bottom. Refusal on remaining debris at depth also potential for impeding bottom wall seal. • In areas adjacent to collection trench, sheet piles could be designed to provide lateral support of excavation.	• Vibrations and noise during pile installation when working near sensitive features or receptors. • Relatively short piles could allow for temporary staging areas in close proximity to working wall alignment. Brought from a main staging area once daily to minimize traffic through the facility or on adjacent public roadways, and for transporting excavated soils for off-site disposal. • No working platform required for this wall option. • Expected wall construction duration of **6 months**.	**$7.5M to $13.3M**
Option 4 - Cement Bentonite Barrier (Self-Hardening Slurry)		• Cement bentonite, water and other admixtures if needed are mixed and then pumped into the trench as excavation proceeds. • Once the excavation is to full depth, the bottom is scraped cleaned of loose soil and cement bentonite slurry is allowed to harden. This process continues until a continuous barrier wall is formed.	• Obstructions can often easily be removed when encountered using hydraulic excavator. • Excavator can easily manage changes in excavation depth to the termination layer. • Verifiable continuity of the key in material (low permeability soil). Proper key into native clay layer is visually verified. • Sudden slurry loss to the formation is possible if a high permeability zone is encountered.	• Requires a specialty contractor with experience installing/sequencing this wall type and working with self-hardening slurry. • Requires a wide bench/platform for wall construction. • No soil (imported or existing) is required. • Messy operation and proper containment of slurry and backfill along the working trench is required to ensure a relatively clean site. • Bleads or excessive water separation can occur requiring the continuous topping off of the slurry until hardening has occurred which can increase cost. • Slow set time of slurry.	• Controlled mixing of slurry and consistency of slurry materials allows for an effective groundwater barrier wall. • Allows for confirmation of key into clay for bottom seal. • Proper sequencing and overlap of wall panels required to ensure consistent wall properties and minimize loss of slurry. • Requires frequent cleaning of trench bottom to ensure no buildup of cobbles or larger stones that sink to base.	• Blending area not required for this wall type. Area for soil conditioning prior to off-site disposal should be included to address any excavated soils that do not meet facility acceptance criteria. • Truck traffic on existing plant roads, off-site public roads, and new access roads, where necessary, transporting excavated soils for off-site disposal. • Batch plant area for slurry mixing and pumping to working wall alignment. • Working wall platform width of 25 ft. • Expected wall construction duration of **5 months**.	**$6.1M to $10.8M**
Option 5 - Soil-Cement Barrier via Trencher		• Advance trencher from ground surface to bottom of fill layer for removal of unsuitable site soils. As trencher progresses along wall alignment, trench is backfill with imported sand. Supporting excavator positioned along alignment for removal of obstructions where trencher is limited. • Complete a second pass with the trencher for insitu mixing of the sand backfill, native soils and cement/bentonite. • Soils/materials from first trencher pass are transported for off-site disposal.	• Obstructions in the fill layer will present challenges to thorough mixing. DBO and peat materials also present a challenge for consistent and controllable finished wall properties. Both require removal with a first pass of the trencher (and excavator support where needed) through the fill and peat layers.	• Requires retainage of specialty contractors that have one-pass trenching capability and equipment. • The boom for the trencher has limitations in adjustment during installation. Variable clay surface along the alignment requires adjustment of booms during mixing.	• Results of treatability testing program indicate that a blend of cement, slag and site soils produces a barrier wall that meets the performance criteria for strength and hydraulic conductivity. • Use of imported borrow soils mitigates the concerns of the poor quality site soils. With the consistency of the mix with the borrow site soils during implementation, the performance of the wall as a groundwater barrier is maintained. • Confirmation of key into clay for bottom seal difficult with this wall type due to variable clay surface.	• A blending area not required for this wall type. Area for soil conditioning prior to off-site disposal should be included to address any excavated soils that do not meet facility acceptance criteria. • Truck traffic on existing plant roads, off-site public roads, and new access roads, where necessary, transporting excavated soils for off-site disposal. • Batch plant area for reagent storage. • Working wall platform width of 25 ft. • Expected wall construction duration of **5 months**.	**$7.5M to $13.2M**

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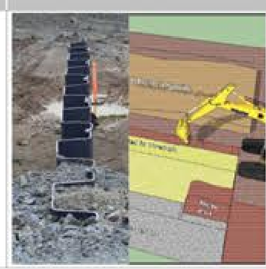
Site Understanding	Subsurface Conditions/Impacts	Implementation Considerations	
	General Site Lithology (Ref. Arcadis, Draft Geotechnical Data Report, February 2021): Fill material extending from ground surface to 12 to 32 feet below ground surface (ft bgs). The fill consists of distilled blow off (DBO) interbedded with crushed concrete, crushed stone, gravel, sand, and clay and is mixed with various debris that includes wood, organics, rubber, coal, glass and brick fragments. Beneath the fill layer, a very soft silt (alluvium) layer is found mostly in the northern portion, and noted as discontinuous, with thicknesses between 7 and 15 feet. A loose to dense sand layer follows the alluvium or fill layer, ranging in thickness from 5 to 17 feet. A soft to medium stiff clay layer follows at depths between approximately 25 and 44 ft bgs. It's thickness ranges from 21 to 27 feet and is underlain by glacial till. Groundwater flows toward the Detroit River. Depth to groundwater ranges from 3 to 6 ft bgs. To mitigate potential off-site migration of impacted groundwater, a barrier system will be installed, in combination with a groundwater collection trench, along a portion of the eastern Site boundary. The barrier wall is also planned along the northern and southern Site boundaries for groundwater control. Barrier wall to extend into clay layer minimum of 3 ft for an effective vertical seal at depth. Anticipated total length of barrier wall is approximately 3,200 linear feet. Obstructions from former site structures and buried debris may be encountered on site during barrier wall installation.	Varying thicknesses of different soils. Fluctuation in depths to clay (Termination boundary). Variability in Fill/Native Soils. Debris/Concrete/Waste. Groundwater - Depth, Quality, COCs, and pH. Utilities, Building Structures, Bulkhead Infrastructure. End Use of Property (Barrier Wall Alignment)	

Barrier Wall Alternatives	Diagram	Alternative Description	Geology Considerations	Issues of Installation/Feasibility	Effectiveness	Constructability	Approximate Relative Cost Range
Option 6 - Combination Soil-Cement Barrier and Steel Sheet Piles		• Combines imported soil-cement slurry wall (Option 2) for southeastern wall alignment and sheet pile wall for northern and southern segments (Option 3). • North sheet pile alignment (approx. 950 feet) in Perry Place street limits. South sheet pile alignment (approx. 900 feet) mostly along facility side of Desana James Drive. • Slurry wall portion is approximately 1,350 feet and offsets the impoundment embankment and shoreline sufficient distance for working platform and equipment operation. .	• Accurate profile of clay surface needed in order to ensure that seepage below the sheeting does not occur. • Visual verification of embedment into clay layer possible with slurry wall portion but not for sheet pile segments. • Debris, utilities, and other structures must be removed from the sheet pile alignment prior to installation. Slurry wall construction can more easily address obstructions during wall installation.	• Common and established technology; multiple contractors qualified to construct; equipment readily available. • Vibrations from sheet pile installation when in close proximity to sensitive structures/utilities. • Large obstructions and debris potentially cause refusal of sheet piling above clay surface. Option considers this with slurry wall section through deeper fill area (along shoreline) and sheeting where fill layer thickness decreases and lower potential for encountering deeper obstructions. • Potential for odors during pre-trenching. • Wide bench/platform for slurry wall construction and messy operations mostly limited to BASF property.	• Overall both wall types meet performance criteria; sheet pile wall more at risk to leaks from potential issues when installed.. • Potential for damaged seals between sheets could decrease effectiveness of sheet pile segments. More opportunities for leaks given interlocks at each pile. Potential for piles to not create wall seal at bottom. Refusal on remaining debris at depth also potential for impeding bottom wall seal. • Slurry wall allows for confirmation of key into clay for bottom seal. • Consistency of slurry wall properties with borrow soil mix during implementation.	• Vibrations and noise during sheet pile installation when working near sensitive features or receptors. • Relatively short piles could allow for temporary staging areas in close proximity to working wall alignment. • Working platform for slurry wall limited to BASF facility and not in public roadways, reduces disturbance of public roads and time working outside of facility. • Central area for mixing/blending of soils/cement in proximity to slurry wall alignment. • Expected wall construction duration of **5 months**.	**$7.1M to $12.5M**

Legend:
Indicates Preferable Aspect
Indicates Reasonably Acceptable Aspect
Indicates Unsatisfactory Aspect

Notes:
lf : linear feet
CY: cubic yards
Costs should be considered feasibility level with an accuracy within -15% to +50%

Disclaimer:
Arcadis prepared these estimates using current and generally accepted engineering cost estimation methods. These estimates are based on assumptions concerning future events, and actual costs may be affected by known and unknown risks, including, but not limited to changes in general economic and business conditions, site conditions which were unknown to Arcadis at the time the estimates were prepared, future changes in site conditions, regulatory or enforcement policy changes, and delays in performance. Actual costs may vary from these estimates, and such variations may be material. We are not licensed as accountants or securities attorneys, and therefore make no representations that these cost estimates form an appropriate basis for complying with financial reporting requirements for such costs.

Appendix F

Draft Final Perimeter Barrier Remedy Design Drawing List

Appendix F - Draft Final Interim Barrier Remedy Design Drawing List
Basis of Design Report (Preliminary 30% Design)
Perimeter Barrier Remedy
BASF North Works Site, Wyandotte, Michigan

Discipline	Drawing	Title
General	0154-WYN-G-001	Cover Sheet
	0154-WYN-G-002	Drawing Index
	0154-WYN-G-003	General Notes
Civil	0154-WYN-SITE-C-101	Overall Site Plan
	0154-WYN-B30-C-102	Area A - Proposed Northern Perimeter Sheet Pile Barrier and Collection Drain Alignment
	0154-WYN-E6N-C-103	Area B - Proposed Collection Drain Alignment
	0154-WYN-D15N-C-104	Area C - Proposed Collection Drain Alignment Proposed Bulkhead and Collection Trench Alignment
	0154-WYN-E5N-C-105	Area D - Proposed Bulkhead and Collection Drain Alignment
	0154-WYN-D15S-C-106	Area E - Proposed Bulkhead, Soil-Cement Barrier and Collection Drain Alignment
	0154-WYN-C15S-C-107	Area F - Proposed Southern Perimeter Barrier and Collection Drain Alignment
	0154-WYN-SITE-C108	Traffic Control Plan
	0154-WYN-E5N-C-109	Treatment Building Site Preparations Plan
	0154-WYN-B30-C-110	Area A Site Preparations Plan
	0154-WYN-E6N-C-111	Area B Site Preparations Plan
	0154-WYN-D15N-C-112	Area C Site Preparations Plan
	0154-WYN-E5N-C-113	Area D Site Preparations Plan
	0154-WYN-D15S-C-114	Area E Site Preparations Plan
	0154-WYN-C15S-C-115	Area F Site Preparations Plan
	0154-WYN-E5N-C-116	Treatment Building Site Restoration Plan
	0154-WYN-B30-C-117	Area A Site Restoration Plan
	0154-WYN-E6N-C-118	Area B Site Restoration Plan
	0154-WYN-D15N-C-119	Area C Site Restoration Plan
	0154-WYN-E5N-C-120	Area D Site Restoration Plan
	0154-WYN-D15S-C-121	Area E Site Restoration Plan
	0154-WYN-C15S-C-122	Area F Site Restoration Plan
	0154-WYN-B30-C-201	Area A Plan/Profile - Proposed Northern Upland Barrier Wall and Collection Drain
	0154-WYN-E6N-C-202	Area B Plan/Profile - Proposed Collection Drain
	0154-WYN-D15N-C-203	Area C Plan/Profile - Proposed Collection Drain
	0154-WYN-E5N-C-204	Area D Plan/Profile - Proposed Bulkhead and Collection Drain
	0154-WYN-D15S-C-205	Area E Plan/Profile - Proposed Bulkhead, Eastern Upland Barrier Wall and Collection Trench
	0154-WYN-C15S-C-206	Area F Plan/Profile - Proposed Southern Upland Barrier Wall and Collection Drain
	0154-WYN-E5N-C-207	Potable Water Plan/Profile
	0154-WYN-SITE-C-301	Subsurface Barrier Wall Details - Soil-Cement and Sheet Pile
	0154-WYN-SITE-C-302	Bulkhead Cross Section 1 of 2
	0154-WYN-SITE-C-303	Bulkhead Cross Section 2 of 2
	0154-WYN-SITE-C-500	Upland Barrier Wall Details
	0154-WYN-SITE-C-501	Bulkhead Details 1 of 2
	0154-WYN-SITE-C-502	Bulkhead Details 2 of 2
	0154-WYN-SITE-C-503	Sump and Collection Drain Details
	0154-WYN-SITE-C-504	Civil Details
	0154-WYN-SITE-C-505	Soil Erosion and Sedimentation Control Details 1 of 3
	0154-WYN-SITE-C-506	Soil Erosion and Sedimentation Control Details 2 of 3
	0154-WYN-SITE-C-507	Soil Erosion and Sedimentation Control Details 3 of 3
	0154-WYN-SITE-C-508	Extraction Well Details
	0154-WYN-SITE-C-509	Site Restoration Details
	0154-WYN-Site-C-600	Piping Schedules

Appendix F - Draft Final Interim Barrier Remedy Design Drawing List
Basis of Design Report (Preliminary 30% Design)
Perimeter Barrier Remedy
BASF North Works Site, Wyandotte, Michigan

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Discipline	Drawing	Title
Structural	0154-WYN-E5N-S-001	Structural Notes and Abbreviations
	0154-WYN-E5N-S-002	Building Specification Sheet (1 of 2)
	0154-WYN-E5N-S-003	Building Specification Sheet (2 of 2)
	0154-WYN-E5N-S-004	Statement of Special Inspections
	0154-WYN-E5N-S-101	Treatment Building Foundation Plan
	0154-WYN-E5N-S-102	Treatment Building Slab Plan
	0154-WYN-E5N-S-103	Treatment Building Roof Framing Plan
	0154-WYN-SITE-S-104	Sump Control/Power Panel Foundation Plan
	0154-WYN-E5N-S-300	Treatment Building Section
	0154-WYN-E5N-S-500	Treatment Building Foundation Details (Sheet 1 of 2)
	0154-WYN-E5N-S-501	Treatment Building Foundation Details (Sheet 2 of 2)
	0154-WYN-SITE-S-502	Sump Control/Power Panel Foundation Details
	0154-WYN-E5N-S-503	Pipe Support Details
	0154-WYN-E5N-S-504	Structural Details (Sheet 1 of 2)
	0154-WYN-E5N-S-505	Structural Details (Sheet 2 of 2)
Architectural	0154-WYN-E5N-A-001	General Notes and Code Information
	0154-WYN-E5N-A-002	Treatment Building Life Safety Plan
	0154-WYN-E5N-A-100	Treatment Building Floor Plan
	0154-WYN-E5N-A-101	Treatment Building Roof Plans
	0154-WYN-E5N-A-300	Treatment Building Exterior Elevations
	0154-WYN-E5N-A-301	Treatment Building Sections
	0154-WYN-E5N-A-302	Treatment Building Wall Sections
	0154-WYN-E5N-A-500	Door Schedule and Details
	0154-WYN-E5N-A-600	Room Finish Schedule
Process	0154-WYN-E5N-I-001	Process Flow Diagram Legend, Symbols and Abbreviations Sheet 1
	0154-WYN-E5N-I-002	Process Flow Diagram Legend, Symbols and Abbreviations Sheet 2
	0154-WYN-E5N-I-100	Process Flow Diagram
	0154-WYN-E5N-I-101	Process Flow Diagram - Mass Balance
	0154-WYN-E5N-I-102	Piping & Instrumentation Diagram - Sump Pumping Flow Headers
	0154-WYN-E5N-I-103	Piping & Instrumentation Diagram - Chemical Injection and Clarification
	0154-WYN-E5N-I-104	Piping & Instrumentation Diagram - Filtration Feed and Bag Filters
	0154-WYN-E5N-I-105	Piping & Instrumentation Diagram - GAC Vessels and System Discharge
	0154-WYN-E5N-I-106	Piping & Instrumentation Diagram - Chemical Feed
	0154-WYN-E5N-I-107	Piping & Instrumentation Diagram - Solids Removal
Mechanical	0154-WYN-E5N-M-001	Mechanical Legend and Abbreviations
	0154-WYN-E5N-M-100	Treatment Building General Arrangement Plan
	0154-WYN-E5N-M-101	Equalization Tank, Neutralization Tank, and Sludge Holding Tank Layout Plan
	0154-WYN-E5N-M-102	Chemical Storage Layout Plan
	0154-WYN-E5N-M-103	LGAC and Resin Layout Plan
	0154-WYN-E5N-M-104	Bag Filtration and Pump Out Tank Layout Plan
	0154-WYN-E5N-M-105	Sump Layout Plan
	0154-WYN-E5N-M-300	Equalization Tank, Neutralization Tank, and Sludge Holding Tank Layout Sections
	0154-WYN-E5N-M-301	LGAC and Resin Sections
	0154-WYN-E5N-M-302	Bag Filtration and Pump Out Tank Sections
	0154-WYN-E5N-M-303	Sump Section
	0154-WYN-E5N-M-500	Metals Treatment Details
	0154-WYN-E5N-M-501	LGAC and Resin Details
	0154-WYN-E5N-M-600	Tank Nozzle Schedules
	0154-WYN-E5N-M-601	
	0154-WYN-E5N-M-602	
	0154-WYN-E5N-M-603	
	0154-WYN-E5N-M-604	
	0154-WYN-E5N-M-605	
	0154-WYN-E5N-M-900	Mechanical Isometric 1
	0154-WYN-E5N-M-901	Mechanical Isometric 2

Discipline	Drawing	Title
HVAC	0154-WYN-E5N-H-001	HVAC Notes and Abbreviations
	0154-WYN-E5N-H-002	HVAC Specifications
	0154-WYN-E5N-H-100	HVAC Floor Plan
	0154-WYN-E5N-H-500	HVAC Details
	0154-WYN-E5N-H-600	HVAC Schedules, Sequence of Operations, and Air Flow Diagram
Plumbing	0154-WYN-E5N-PL-001	Plumbing Notes and Legend
	0154-WYN-E5N-PL-100	Overall Building Plan
	0154-WYN-E5N-PL-101	Enlarged Plans
Electrical	0154-WYN-E5N-E-001	Symbols and Legend
	0154-WYN-E5N-E-101	Treatment Building Power Plan
	0154-WYN-E5N-E-102	Treatment Building Instrumentation Plan
	0154-WYN-E5N-E-103	Treatment Building Grounding Plan
	0154-WYN-E5N-E-104	Area A/B Sump Power Plans
	0154-WYN-E5N-E-105	Area C/D Sump Power Plans
	0154-WYN-E5N-E-106	Area E/F Sump Power Plans
	0154-WYN-E5N-E-300	Sump Power Elevation View
	0154-WYN-E5N-E-600	Treatment Building One-Line Diagram
	0154-WYN-E5N-E-601	Sump One-Line Diagram
	0154-WYN-E5N-E-602	Treatment Building Control Panel Wiring Diagram
	0154-WYN-E5N-E-603	Sump Control Panel Wiring Diagram
	0154-WYN-E5N-E-604	Treatment Building Conduit and Cable Schedule
	0154-WYN-E5N-E-605	Sump Conduit and Cable Schedule
	0154-WYN-E5N-E-606	Load Schedules
	E-10	
Controls	0154-WYN-E5N-I-200	MCP Main Control Panel Enclosure
	0154-WYN-E5N-I-201	Main Control Panel Layout and BOM
	0154-WYN-SITE-I-202	Sump Control Panel Enclosure
	0154-WYN-SITE-I-203	Sump Control Panel Layout and BOM
	0154-WYN-SITE-I-204	Communication Network Diagram
	0154-WYN-SITE-I-205	MCE 380 VAC Power Distribution
	0154-WYN-SITE-I-206	MCP Power Distribution

Appendix G

Perimeter Barrier Treatment System Specifications

DIVISION 01: GENERAL REQUIREMENTS		BARRIER	SYSTEM	CONVEYANCE
Section 01400	Quality Control	☒	☒	☒
Section 01650	Checkout and Startup Procedures	☒	☒	☒
Section 01730	Operation and Maintenance Data	☒	☒	☒

DIVISION 02: SITE CONSTRUCTION		BARRIER	SYSTEM	CONVEYANCE
Section 02100	Surveying	☒	☒	☒
Section 02120	Geotechnical Monitoring Instrumentation	☒	☐	☒
Section 02110	Clearing, Grubbing, and Stripping	☒	☒	☒
Section 02200	Earthwork	☒	☒	☒
Section 02225	Compacted Clay Liner	☒	☐	☐
Section 02230	Aggregate Base	☒	☐	☒
Section 02235	Asphalt Concrete	☐	☒	☐
Section 02240	Soil-Cement Barrier Wall	☒	☐	☐
Section 02270	Surface Water Management and Erosion Control	☒	☒	☐
Section 02271	Resuspension Control	☒	☐	☐
Section 02321	Trench Excavation and Backfill	☒	☐	☒
Section 02325	Dredging	☒	☐	☐
Section 02360	Steel Sheet Piling	☒	☐	☐
Section 02427	Bank Protection	☒	☐	☐
Section 02630	Drainage Structures and Piping	☒	☒	☒
Section 02760	Pavement Markings	☐	☒	☐

DIVISION 03: CONCRETE		BARRIER	SYSTEM	CONVEYANCE
Section 03100	Concrete Formwork	☒	☒	☐
Section 03200	Concrete Reinforcement	☒	☒	☐
Section 03300	Cast-in-Place Concrete	☒	☒	☐
Section 03346	Concrete Slab Finishing	☐	☒	☐
Section 03370	Concrete Curing	☒	☒	☐
Section 03500	Precast Concrete	☐	☐	☐

DIVISION 04: NOT USED

DIVISION 05: METALS		BARRIER	SYSTEM	CONVEYANCE
Section 05120	Structural Steel	☒	☒	☐
Section 05410	Cold Formed Metal Framing	☐	☒	☐
Section 05500	Metal Fabrication	☒	☒	☐
Section 05501	Anchor Bolts and Anchors	☒	☒	☐
Section 05510	Metal Stairs	☐	☒	☐
Section 05511	Aluminum Stairs	☐	☒	☐
Section 05520	Handrails and Railings	☒	☒	☐
Section 05531	Gratings and Floor Plates	☐	☒	☐
Section 05542	Access Hatch Covers	☐	☐	☒

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DIVISION 06: WOOD AND PLASTICS		BARRIER	SYSTEM	CONVEYANCE
Section 06100	Rough Carpentry	☐	☒	☐
Section 06410	Plastic Laminate and Clad Wood Cabinets	☐	☐	☐

DIVISION 07: THERMAL AND MOISTURE PROTECTION		BARRIER	SYSTEM	CONVEYANCE
Section 07210	Building Insulation	☐	☒	☐
Section 07920	Joint Sealants	☐	☒	☐

DIVISION 08: DOORS AND WINDOWS		BARRIER	SYSTEM	CONVEYANCE
Section 08110	Standard Interior Steel Doors and Frames	☐	☒	☐

DIVISION 09: FINISHES		BARRIER	SYSTEM	CONVEYANCE
Section 09260	Gypsum Board	☐	☒	☐
Section 09510	Acoustical Panel Ceilings	☐	☐	☐
Section 09655	Fluid-Applied Flooring	☐	☒	☐
Section 09900	Painting	☐	☒	☐

DIVISION 10: SPECIALTIES		BARRIER	SYSTEM	CONVEYANCE
Section 10155	Metal Toilet Compartments	☐	☐	☐
Section 10500	Lockers	☐	☐	☐
Section 10522	Portable Fire Protection Specialties	☐	☒	☐
Section 10800	Toilet and Bath Accessories	☐	☐	☐

DIVISION 11: EQUIPMENT		BARRIER	SYSTEM	CONVEYANCE
Section 11180	Multimedia Filter System	☐	☒	☐
Section 11250	Filters and Strainers	☐	☒	☐
Section 11310	Pumps, Metering Pumps, and Appurtenances	☐	☒	☒
Section 11316	Submersible Mixing Equipment	☐	☒	☐
Section 11351	Clarifiers	☐	☒	☐
Section 11377	Air Compressors	☐	☐	☐
Section 11414	Hydrated Lime Feed System	☐	☒	☐
Section 11522	Plate and Frame Filter Press	☐	☒	☐
Section 11610	Blowers	☐	☐	☐
Section 11631	Aeration Diffusers	☐	☐	☐
Section 11720	Granulated-Activated Carbon System	☐	☒	☐
Section 11730	Vapor Phase Granular-Activated Carbon System	☐	☐	☐
Section 11776	Ion Exchange Equipment	☐	☒	☐

DIVISION 12: FURNISHINGS		BARRIER	SYSTEM	CONVEYANCE
Section 12360	Countertops	☐	☐	☐
Section 12363	Solid Surfacing Fabrications	☐	☐	☐

DIVISION 13: SPECIAL CONSTRUCTION		BARRIER	SYSTEM	CONVEYANCE
Section 13122	Metal Building Systems	☐	☒	☐
Section 13123	Equipment Container	☐	☐	☐
Section 13124	Pre-Fabricated Metal Building	☐	☒	☐
Section 13201	Fiberglass Reinforced Plastic Tanks	☐	☐	☐
Section 13202	Steel Storage Tanks	☐	☐	☐
Section 13203	Polyethylene Storage Tanks	☐	☒	☐
Section 13700	Fabric Enclosure	☐	☐	☐

DIVISION 14: CONVEYANCE SYSTEMS		BARRIER	SYSTEM	CONVEYANCE
Section 14630	Bridge Cranes	☐	☐	☐

DIVISION 15: MECHANICAL		BARRIER	SYSTEM	CONVEYANCE
Section 15050	Process Piping and Appurtenances	☐	☒	☒
Section 15083	Heat Tracing System for Process Piping and Equipment	☐	☐	☐
Section 15100	Valves, Flow Controls and Appurtenances	☐	☒	☒
Section 15135	Gauges and Meters	☐	☒	☒
Section 15190	Mechanical Identification	☐	☒	☒
Section 15260	Piping Insulation	☐	☐	☐
Section 15290	Ductwork Insulation	☐	☒	☐
Section 15330	Wet-Pipe Sprinkler System	☐	☒	☐
Section 15410	Plumbing Piping	☐	☒	☐
Section 15430	Plumbing Specialties	☐	☒	☐
Section 15440	Plumbing Fixtures	☐	☒	☐
Section 15450	Plumbing Equipment	☐	☒	☐
Section 15650	Split System Fan Coil Units	☐	☒	☐
Section 15836	Electric Space Heating	☐	☒	☐
Section 15870	Power Ventilators	☐	☒	☐
Section 15890	Ductwork	☐	☒	☐
Section 15910	Ductwork Accessories	☐	☒	☐
Section 15911	Duct Heating System - Electric	☐	☒	☐
Section 15940	Air Outlets and Inlets	☐	☒	☐
Section 15941	Louvers	☐	☒	☐
Section 15981	Electrical Instruments and Control Elements	☐	☒	☐
Section 15985	Sequence of Operation	☐	☒	☐
Section 15990	Testing, Adjusting and Balancing	☐	☒	☐

DIVISION 16: ELECTRICAL		BARRIER	SYSTEM	CONVEYANCE
Section 16050	General Provisions for Electrical Systems	☐	☒	☒
Section 16070	Hangers and Supports for Electrical Systems	☐	☒	☐
Section 16075	Identification for Electrical Systems	☐	☒	☒
Section 16121	Instrumentation Cable	☐	☒	☒
Section 16122	Low-Voltage Electrical Power Conductors and Cable	☐	☒	☒
Section 16130	Outlets, Junctions, and Pull Boxes	☐	☒	☒
Section 16131	Rigid and Flexible Conduit	☐	☒	☒
Section 16139	Cable Trays	☐	☒	☐
Section 16143	Disconnect Switches	☐	☒	☒
Section 16161	Grounding Systems, Lightning Protection System and Surge Protection Devices	☐	☒	☐
Section 16271	Dry Type Transformers	☐	☒	☐
Section 16423	Motor Control Centers	☐	☒	☐
Section 16425	Low-Voltage Variable Frequency Drives	☐	☒	☒
Section 16440	Panelboards	☐	☒	☐
Section 16445	Instrumentation and Controls for Process Systems	☐	☒	☒
Section 16447	Fiber Optic Cabling	☐	☐	☐
Section 16501	Lighting	☐	☒	☐

Note:
Where specification applies to multiple components of the remedy, a single specification will be provided

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