Subject:	**Tunnel Dewatering Pumping Facilities (Final Draft)**
Project feature:	Pumping Plant
Prepared for:	California Department of Water Resources (DWR) / Delta Conveyance Office (DCO)
Prepared by:	Delta Conveyance Design and Construction Authority (DCA)
Copies to:	File
Date/Version:	December 23, 2021
Reference no.:	EDM_PP_CE_TMO_Tunnel-Dewater-Pump-Fac_000952_V02_FD_20211223

1. Purpose

The purpose of this technical memorandum (TM) is to present dewatering analysis of the main tunnel system for the Delta Conveyance System (Project). This analysis was conducted for both the Central and Eastern tunnel alignment corridor alternatives.

1.1 Background

The Project configuration is currently being developed as a single-main tunnel system. The Project includes up to three Sacramento River intakes, a main tunnel connecting the river intakes to a new pumping plant (PP), a new Southern Forebay (SF), and tunnels and hydraulic structures connecting the new forebay to the approach channel of the existing State Water Project (SWP) Banks PP. An additional case will also be analyzed to deliver water to the existing Central Valley Project (CVP) C.W. “Bill” Jones Pumping Plant (Jones PP).

The maximum design diversion capacity from the Sacramento River into the Project has not been selected. However, the DCO has established a capacity range of 3,000 to 7,500 cubic-foot-per-second (cfs) for study. As described in the Systemwide Hydraulic and Capacity Analysis for Tunnel Diameter Selectin TM, dated March 13, 2020, the maximum tunnel flow velocity was recommended to be limited to 6 feet per second (fps) at each maximum design flow capacity. This criteria resulted in the following selections for the inside diameter (ID) of the tunnel.

- 26-foot ID at the maximum design flow capacity of 3,000 cfs
- 31-foot ID at the maximum design flow capacity of 4,500 cfs
- 36-foot ID at the maximum design flow capacity of 6,000 cfs
- 40-foot ID at the maximum design flow capacity of 7,500 cfs

For the purpose of this TM, only the 36-foot ID tunnel option was analyzed for the dewatering analysis of both the Central and Eastern Alignments.

To allow inspection, maintenance or repair, the tunnel and respective shafts would be designed to be dewatered. This TM describes the analysis conducted for dewatering both the Central and Eastern tunnel alignment corridors between the Sacramento River Intakes and the Wet Well/Gravity Flow shaft structure located within the South Delta (SD) PP site complex.

Figure 1 provides a schematic of the basic Project configuration which is applicable to both the Central and Eastern tunnel corridor options.

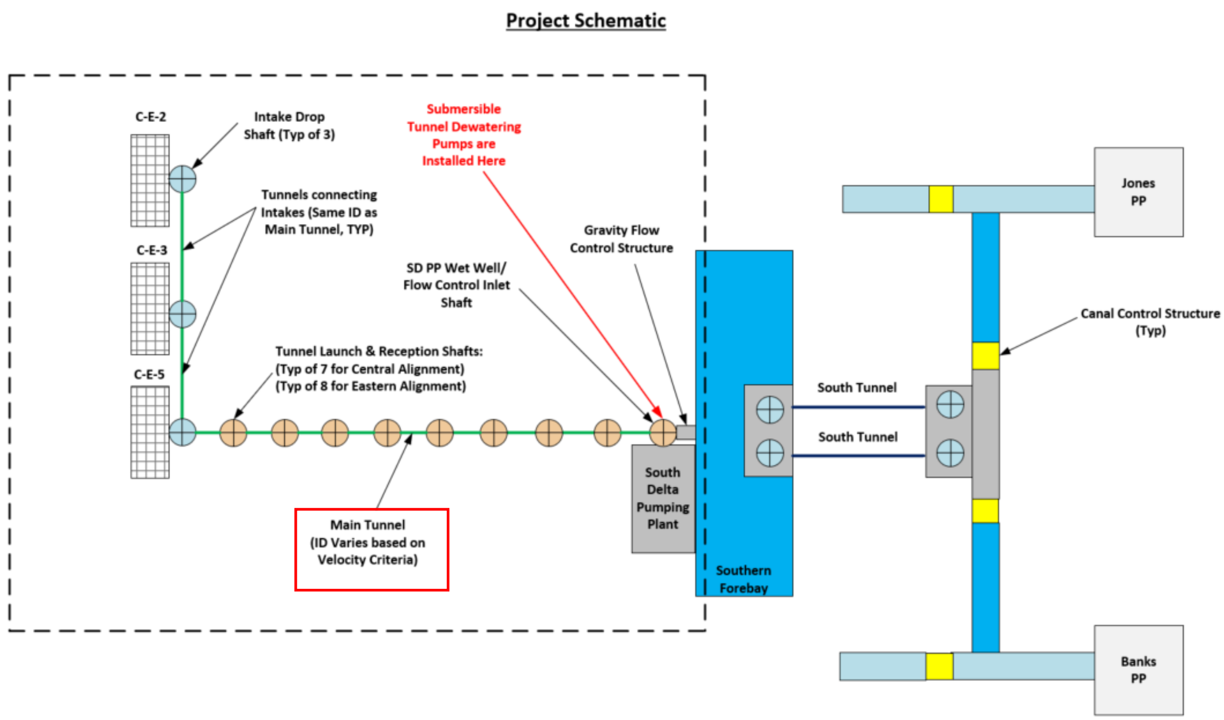


Figure 1. Delta Conveyance System Project Schematic

This dewatering evaluation was conducted between the intakes and the SD PP Wet Well/Flow Control Inlet shaft (SD PP shaft structure) within the dashed boundary shown in Figure 1. The dewatering evaluation of the south tunnels connecting the Southern Forebay (SF) to the approach channels of the existing Banks PP and Jones PP will be conducted under a separate analysis.

Intake No. 2 (C-E-2) and the connecting tunnel between C-E-2 and Intake No. 3 (C-E-3) was not included in this analysis since the Project configuration evaluated is for the maximum system design flow capacity of 6,000 cfs and therefore only includes C-E-3 and Intake No. 5 (C-E-5).

The following Project configuration was considered for this evaluation:

- Central and Eastern corridor tunnel alignment alternatives
- Two intake locations on the left bank of the Sacramento River, as follows:
  - Intake No. 3 (C-E-3), located upstream of Hood at approximate River Mile 39.4
  - Intake No. 5 (C-E-5), located immediately upstream of confluence with Snodgrass Slough at approximate River Mile 36.8
- Tunnel connecting the intakes to the SD PP shaft structure
- Tunnel shaft locations included in the analysis of the Central corridor alignment (between the C-E-5 drop shaft and the SD PP shaft structure per Figure 1:
  - Twin Cities
  - New Hope
  - Staten Island
  - Bouldin Island
  - Mandevelle Island

- Bacon Island
- Byron Tract
- SD PP Shaft Structure

- Tunnel shaft locations included in the analysis of the Eastern corridor alignment (between the C-E-5 drop shaft and the SD shaft structure per Figure 1:
  - Twin Cities
  - New Hope
  - Canal Tract
  - Terminous Tract
  - King Island
  - Lower Roberts Island
  - Upper Jones Tract
  - Byron Tract
  - SD PP Shaft Structure

2. Methodology

The methodology utilized to evaluate tunnel dewatering involved the following process:

1) Conduct a separate, dewatering analysis for the Central and Eastern tunnel alignment corridor options for the Project using the systemwide end-to-end hydraulic model.
2) Conduct the analysis using the 36-foot ID tunnel, sized for the maximum design flow capacity of 6,000 cfs, for the Central and Eastern tunnel alignment configurations using Sacramento River flow diversions from C-E-3 and C-E-5.
3) Conduct the dewatering analysis by initially utilizing the permanent raw water pumps to the lowest recommended water level and then utilizing portable submersible pumps (installed at the SD PP shaft structure).

3. Tools

3.1 Conveyance System Hydraulic Model

Hydraulic models for the Central and Eastern tunnel corridors were constructed for the Project between the Sacramento River Intakes and the SD PP Shaft Structure using the Infoworks Integrated Catchment Modeling (ICM) software. This model was used in sizing the tunnels and estimating the system headlosses and was also used to analyze dewatering of the tunnels.

4. Criteria

The following criteria were developed to guide the evaluation of achievable dewatering flows for the Central and Eastern tunnel alignment options.

- Standard Roughness Coefficients: Mannings “n” of 0.016 was utilized as the maximum standard roughness coefficient for the hydraulic analysis to evaluate the range of resultant dewatering flow conditions associated with the maximum internal friction factor for the tunnel.
- Froude Number: 0.8 was selected to evaluate dewatering flows to avoid critical depths that form hydraulic jumps within sections of the tunnel.

- Governing Equations and Modeling Approach
  - The intakes, connecting conduits, sediment basins, tunnel and hydraulic control structures were modeled within the systemwide hydraulic model. The modeling approach and governing equations are defined in the Hydraulic Analysis Criteria (Draft) TM, dated May 29, 2020.
  - Rating curves for minor losses are pre-programmed into the Infoworks model. These have been reviewed and determined to be acceptable for application in the modeling effort.
- Tunnel and Shaft Diameters: The tunnel diameter is 36 feet and shaft IDs and locations are as shown on the concept drawings.
- Portable Submersible Pumps:
  - Discharge pressure: 1 atm (atmospheric)
  - Pumps must operate within the manufacturer's defined allowable operating region (AOR)
  - **Water Surface Elevations:** Table 1 provide the design water surface elevations (WSELs) that establish static head conditions. All elevations are based on the North American Vertical Datum of 1988 (NAVD88).

Table 1. Design WSELs for System Head Curves Development

Pump Head Condition	SD PP Shaft Structure WSEL[a]	Discharge Piping Elevation
High Head	-162.70	34.0
Intermediate Head	-50.0	34.0
Low Head	28.0[b]	34.0

[a] WSEL of Gravity Flow/Surge Overflow Shaft at SD PP (North A Launch Shaft)
[b] Based on 200-year flood level and sea-level rise (SLR)

- Pump discharge pipe friction absolute roughness values of 0.1 mm to 1.5 mm was used to calculate minor losses within piping systems
- Minimum variable operating speed for dewatering pumps was limited to 50 percent of the pump's maximum rated operating speed.

5. Assumptions and Boundary Conditions

Basic assumptions and boundary conditions that apply to identifying and evaluating the Project include the following:

- Alignment of tunnels (Central and Eastern) and locations of the intakes, shafts, SD PP, and SF are as shown in Figure 2. The Northern Tunnel alignment is shown in dashed blue line, whereas; the Central and Eastern tunnel alignments are depicted in green and orange respectively, where both Central and Eastern alignments begin at Twin Cities Shaft and end at the SD PP shaft structure.
  - Central Tunnel Alignment (31.27 miles)
  - Eastern Tunnel Alignment (33.98 miles)
- Only the North Tunnel segments from Intake C-E-3 to Twin Cities shafts were incorporated in the overall dewatering volume calculation since the tunnel section connecting C-E-2 and C-E-3 is not included in the Project configuration for the system design flow capacity of 6,000 cfs.

- Dewatering Using Permanent Pumps:
  - Initial HGL within the Tunnel and WSEL within the SD PP wet well: 4.5 feet
  - Final WSEL within the SD PP wet well: -50.0 feet (min submergence requirement for the main pumps)
  - Seven pumps (5 large and 2 small) in operation at maximum rated speeds. These are the maximum number of duty pumps required for the normal 6000 cfs flow scenario
  - All pumps are controlled in the ICM model by real time control (RTC) rules:
    - All pumps are operated within their maximum and minimum speed range. Speed range was defined between 50 percent to 100 percent of the manufacturer's maximum rated speed for each pump.
    - All pumps are operated within their allowable operating range (AOR) over their full operating speed range.
    - Pumps automatically shut down if they cannot meet the above two requirements.
- Dewatering Using Portable Submersible Pumps:
  - Portable submersible pumps would be temporarily installed in the North A launch Shaft located just upstream of the SD PP near the SF.
  - Initial WSEL within the SD PP wet well: -50 feet, the level at which the permanent pumps shut down due to NPSHr requirements
  - Final WSEL within the tunnel: -162.70 feet (tunnel invert elevation at the Southern Forebay – North A Launch Shaft)
  - Fixed flow pumps were analyzed with varying constant flow rates from 7000 cfs to 100 cfs to establish recommended maximum dewatering flows corresponding to WSELs in the Southern Forebay – North A Launch Shaft.
- The dewatering volume calculations do not include volumes at the intake facilities except the intake drop shafts. It is assumed that the radial gates upstream of the intake drop shafts would be closed during dewatering process.

  The SD PP wet well volume from WSEL of -50.0 feet to -77.0 feet (invert elevation of inlet wet well conduit) was used in the overall dewatering calculations. The wet well dimensions are as shown on the concept drawings.

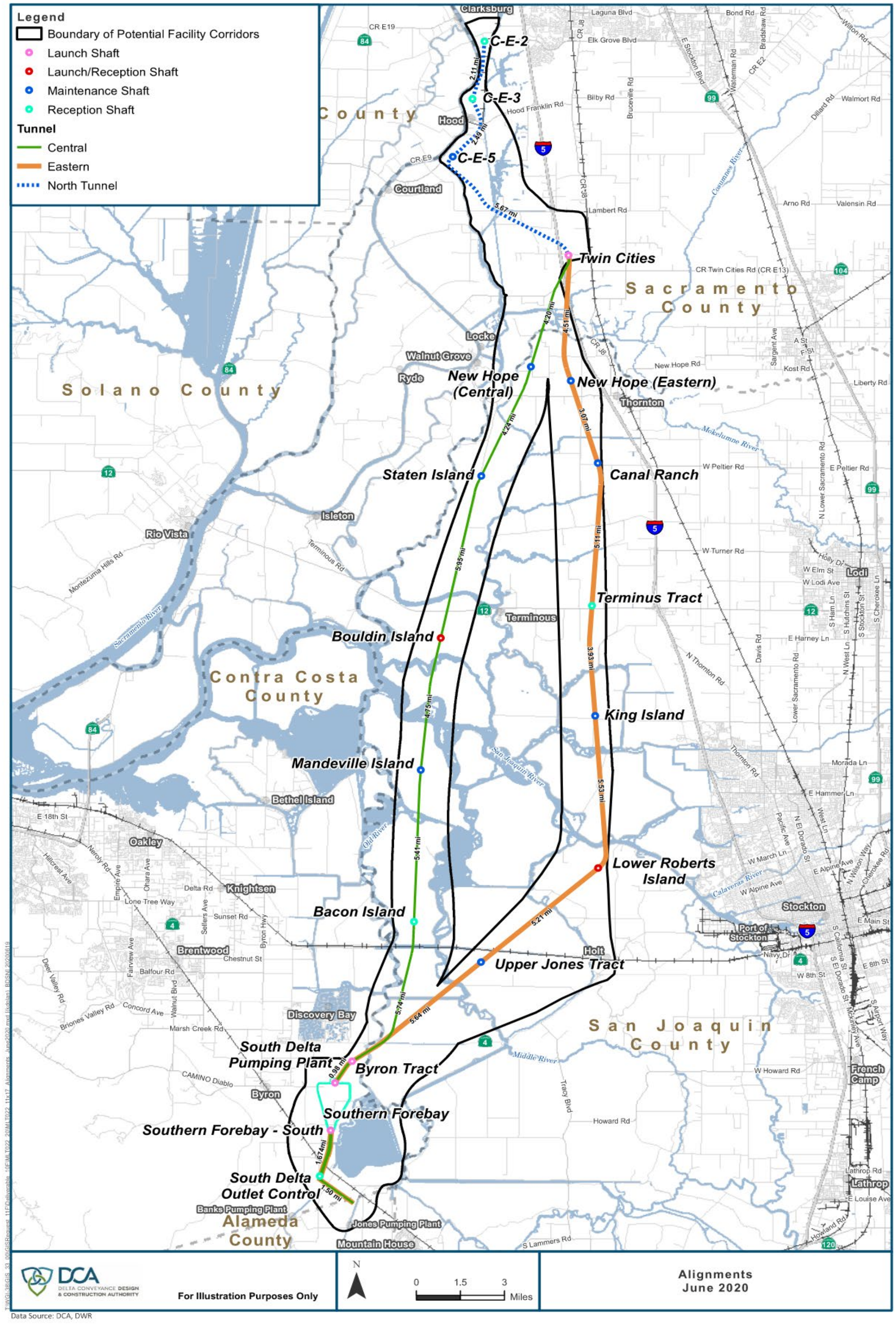


Figure 2. Tunnel Alignments

6. Tunnel Dewatering Hydraulic Evaluation

The tunnel dewatering process considered the use of the main pumps within the SD PP and using portable submersible pumps that would be installed within the SD PP shaft structure. The main pumps were used to initially dewater the tunnel shafts and SD PP wet well down to a hydraulic grade line of -50 feet (minimum recommended water surface elevation within the SD PP wet well for main pump operation). The portable submersible pumps would then be operated and complete the tunnel dewatering process. This analysis assumed the radial gates upstream of the intake drop shafts would be closed and no additional flow from the intakes or volume from the sediment basins would enter the tunnels at the start of the dewatering process.

During dewatering, specially at shallow flow depths (lower water surface elevations) within the tunnel and at certain gravity flow capacities, flow velocities and depths may approach critical hydraulic conditions and become unstable resulting in the formation of hydraulic jumps. The formation of hydraulic jumps within the tunnel may result in too low of a net positive suction head available (NPSHa) condition at the pump causing a pump shut down due to insufficient flow and/or insufficient suction head entering the pump suction.

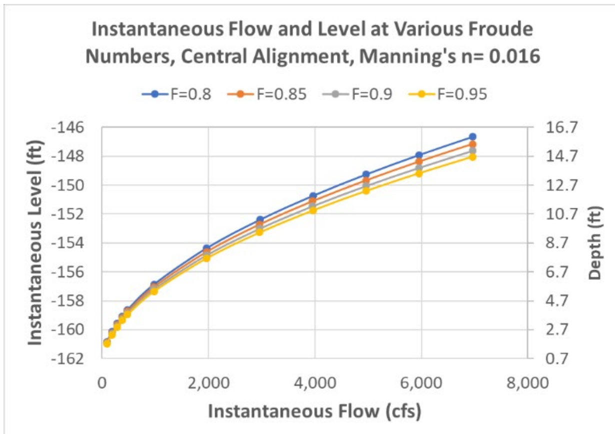
This hydraulic analysis was conducted to determine maximum recommended dewatering flow capacities corresponding to the WSELs within the tunnel to avoid the formation of hydraulic jumps within the tunnel, and to provide guidelines for the selection and operation of the submersible pumps for dewatering the tunnel.

6.1 Tunnel Dewatering

6.1.1 Modeling Results

Figure 3 provides the results of tunnel dewatering flows for the Central and Eastern tunnel alignments whereby hydraulic jumps within each tunnel would not be formed (i.e., flows are subcritical). As can be seen in Figure 3, dewatering flows (identified as Instantaneous Flow) are plotted along the x-axis and tunnel WSEL (referenced at the tunnel exit into the SD PP shaft structure) are plotted along the y-axis. Subcritical flow curves versus tunnel WSEL were plotted at Froude Numbers of 0.8, 0.85, 0.9 and 0.95. The Froude Number of 0.80 was selected for this analysis to provide a conservative estimate against the critical flows and critical depths associated with dewatering rates associated with the Project's main tunnel.

To determine the maximum subcritical flows for either tunnel alignment alternative in Figure 3, select a WSEL within the SD PP Shaft, find the intersection of the subcritical flow curve associated with the Froude Number of 0.80 at the selected SD PP Shaft WSEL and determine the corresponding instantaneous flow. The instantaneous flow value provides the maximum tunnel dewatering flow rate that can be achieved without forming a hydraulic jump within the tunnel. The instantaneous WSELs at the tunnel exit into the SD PP Shaft are shown in Figure 3 between the tunnel invert elevation of -162.7 feet and -146.0. As can be seen in Figure 3, for instantaneous WSELs in the SD PP shaft structure above 147.9 feet, permissible tunnel dewatering flows are above the maximum design flow capacity of 6,000 cfs for the Project. As such use of the main pumps within the SD PP may operate unrestricted up to the pumping plant's maximum design flow capacity of 6,000 cfs down to a WSEL within the wet well of -50.0 feet. For WSELs within the SD PP shaft structure of less than -148.0 feet, dewatering flows must not exceed the instantaneous flows shown in Figure 3.



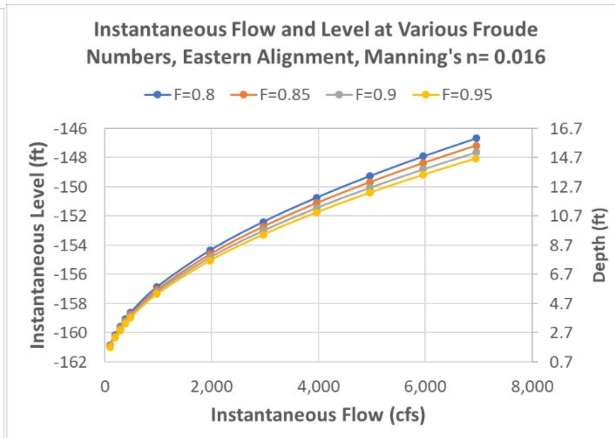


Figure 3. Instantaneous Flow and Level at Froude Numbers of 0.80, 0.85, 0.90 and 0.95 (Left: Central Alignment, Right: Eastern Alignment)

Tables 2 and 3 show the results of the analysis which provides the maximum recommended dewatering flow capacities within the tunnel corresponding to the WSELs within the SD PP Shaft at and below -147.9 that would not result in the formation of hydraulic jumps throughout the entire main tunnel alignment.

Table 2. Maximum Recommended Dewatering Flows Versus Water Levels for Central Alignment

Froude Number = 0.8		
Tunnel Flow (cfs)	**WSEL in SD PP Shaft (feet)**	**Depth above Tunnel Invert Elevation at SD PP Shaft (feet)**
7,000	-146.7	16.0
6,000	-147.9	14.8
5,000	-149.3	13.4
4,000	-150.7	12.0
3,000	-152.4	10.3
2,000	-154.3	8.4
1,000	-156.9	5.8
500	-158.6	4.1
400	-159.1	3.6
300	-159.6	3.1
200	-160.2	2.5
100	-160.9	1.8

Table 3. Maximum Recommended Dewatering Flows Versus Water Levels for Eastern Alignment

Froude Number = 0.8		
Tunnel Flow (cfs)	**WSEL in SD PP Shaft (feet)**	**Depth above Tunnel Invert Elevation at SD PP Shaft (feet)**
7,000	-146.7	16.0
6,000	-147.9	14.8
5,000	-149.3	13.4
4,000	-150.7	12.0
3,000	-152.4	10.3
2,000	-154.4	8.3
1,000	-156.9	5.8
500	-158.6	4.1
400	-159.1	3.6
300	-159.6	3.1
200	-160.2	2.5
100	-160.9	1.8

7. Dewatering

The dewatering volumes required to completely drain the Project from intakes to the SD PP shaft structure were calculated for the Central and Eastern tunnel alignments, including each alignment's respective shafts, and the SD PP wet well. The dewatering volume calculations do not include volumes at the intake facilities except the intake drop shafts. It is assumed that the radial gates upstream of the intake drop shafts would be closed during dewatering process.

7.1 Dewatering Volume

Table 4 provides the total dewatering volume calculated for both the Central and Eastern alignments.

Table 4. Total Dewatering Volumes

Tunnel ID	Total Volume (cubic feet)	
	Central Alignment	**Eastern Alignment**
36-foot	217,002,185	232,257,797

7.2 Dewatering Pumps

For this evaluation, portable submersible vertical turbine pumps were considered as the dewatering pumps for elevations below -50.0 feet. The dewatering pumps would normally be stored per the manufacturer's instructions in the Equipment Storage Building when not in use (or left permanently installed and periodically exercised per the manufacturer's instructions). Each pump would be supported by a ninety degree above-ground discharge head assembly that consists of the discharge nozzle, and base plate. Sole plates would be permanently embedded in the top deck of the SD PP shaft structure. When dewatering is required, the pumps would be suspended from the top deck of the SD PP shaft structure as shown in Figures 4 and 5. The dewatering pumps would discharge into the SF through temporary discharge piping and appurtenances constructed on top of the shaft structure as shown in Figures 4 and 5. The gravity flow gates would be closed while the dewatering pumps are in operation. Each individual pump would be equipped with a magnetic flow meter, a flow control valve, and an isolation butterfly valve. Pumps would operate with adjustable frequency drives (AFDs) which are permanently installed in the SD PP Electrical Building.

7.2.1 Candidate Pump Manufacturer and Performance Requirements

The pump manufacturer Andritz was consulted for selections of candidate submersible vertical turbine pumps. The pump considered in this analysis is among the largest Andritz offers for the range of flow and head conditions associated with dewatering the main tunnel. The candidate manufacturer's pump performance curve was evaluated based on the required envelope of system flow and head conditions as previously defined. The pump selection from Andritz was used to illustrate the performance requirements at various system head conditions.

Figure 6 shows the system head curves developed for High Head and Low Head conditions as discussed below.

- The High Head system head curve (SHC) is the maximum total dynamic head conditions encountered by each of the two dewatering pumps while operating in parallel. This condition represents the maximum static head condition with the highest friction factor for the pump discharge piping.
- The Low Head SHC is the minimum total dynamic head conditions encountered by each of the two dewatering pumps. This condition represents the minimum static head condition with the lowest friction factor for the pump discharge piping.

The system head curves were plotted against the candidate pump performance curve at maximum and reduced pump rotational speeds as shown in Figure 6.

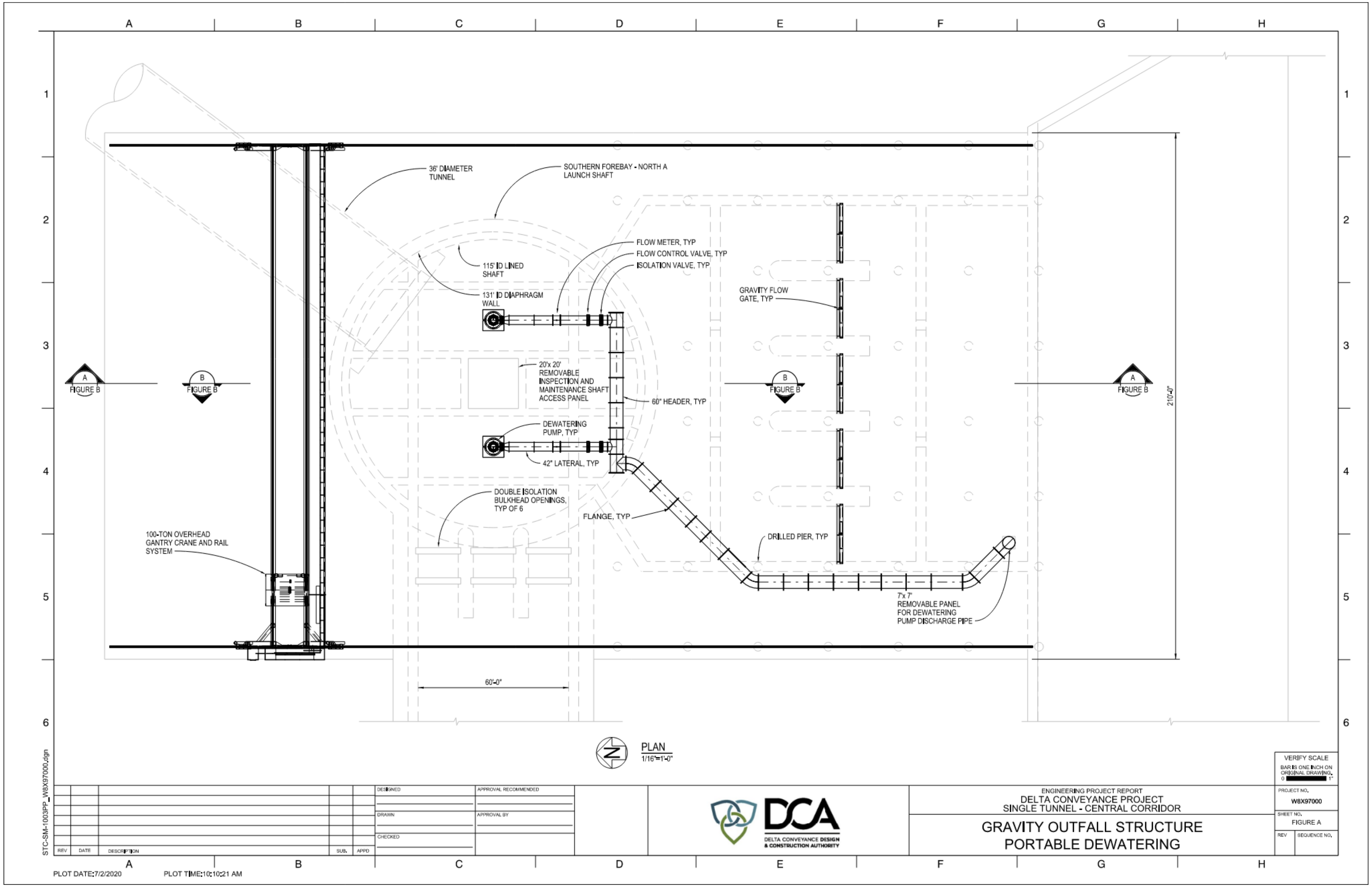


Figure 4. Portable Dewatering Pumping Plant Layout (Plan)

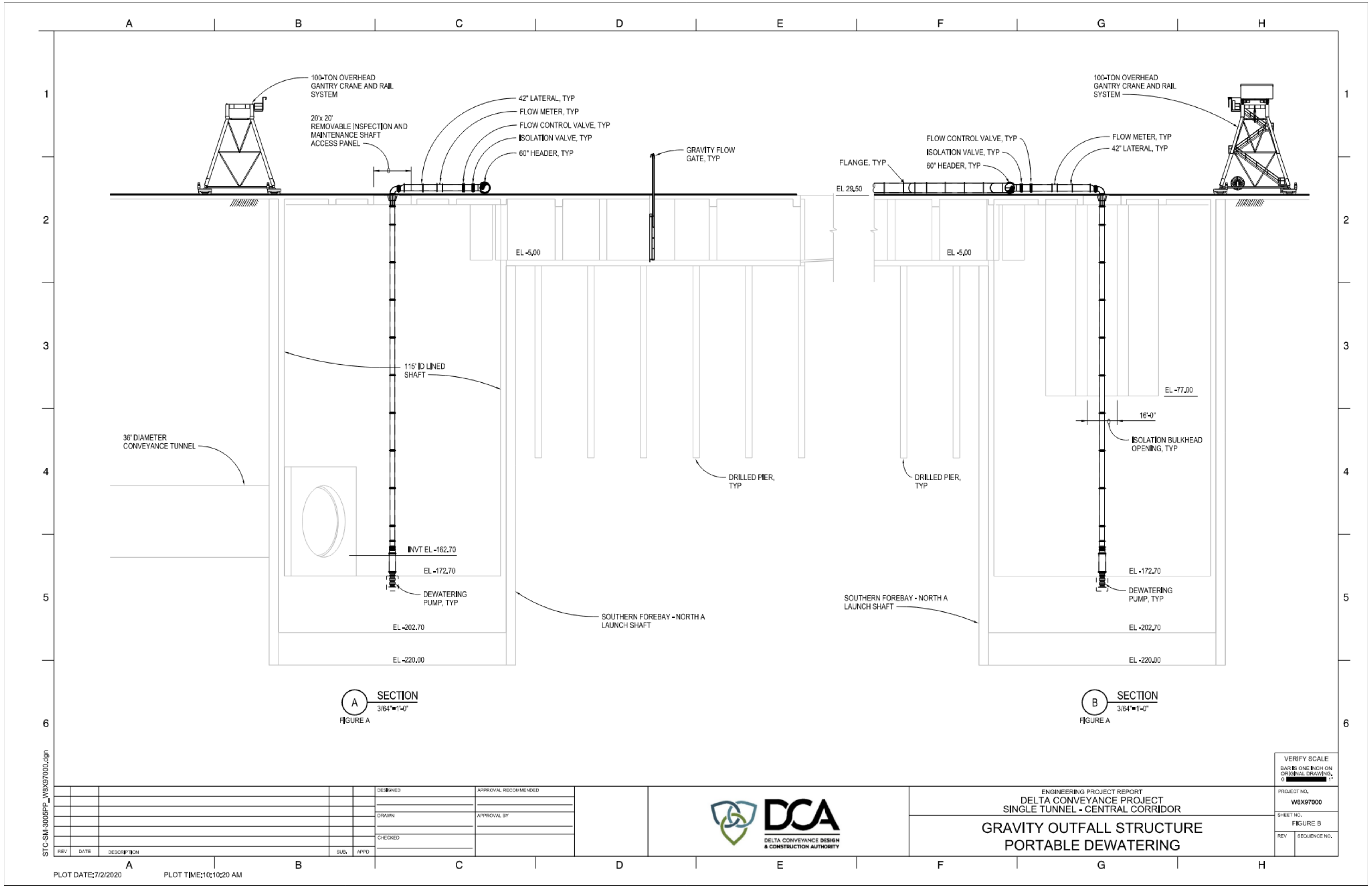


Figure 5. Portable Dewatering Pumping Plant Layout (Section)

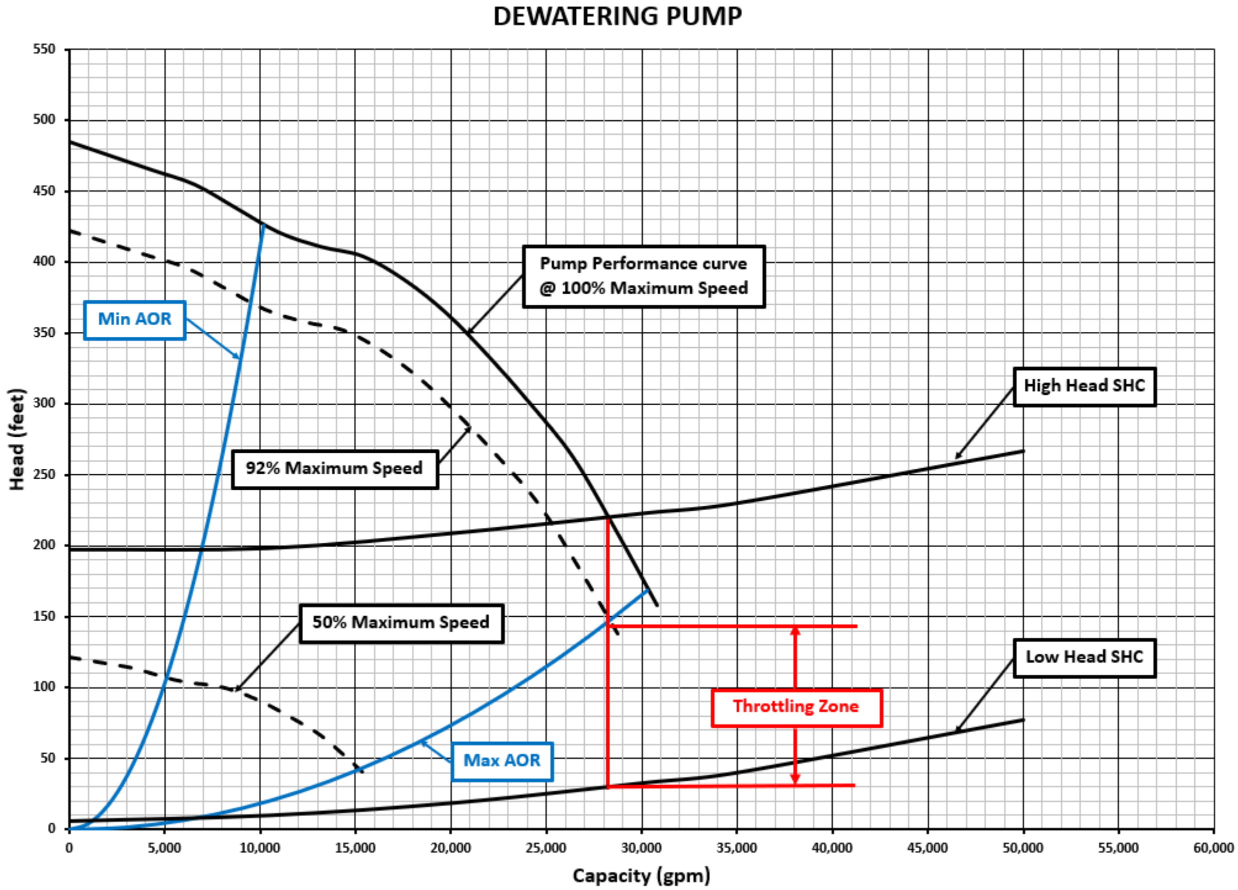


Figure 6. Candidate Pump Performance Curve Versus System Head Curves

The candidate pump selection is the Andritz, Model HDM6780.3/2 pump with a maximum rated operating speed of 1190 revolutions per minute (rpm), 2,000 horsepower (hp), with a rated capacity of 28,200 gpm (62.83 cfs) at 220 feet of TDH. The minimum and maximum flows defining the pump's AOR are also plotted with blue curves as shown in Figure 6.

As can be seen in Figure 6, the maximum flow achievable at the High Head system head curve conditions is 28,200 gpm (62.8 cfs) at 220.0 feet. The maximum flow condition of the pump is established at its maximum rated speed.

As can be seen in Figure 6, the entire Low Head SHC conditions are outside the allowable operating range (AOR) of the pump even with the use of a variable speed drive. Under these system head conditions, a flow control valve would be used for throttling. Operating the pump at 92 percent of its maximum speed and by generating 110 feet of pressure drop through the flow control valve(s), a flow rate of 28,200 gpm (62.8 cfs) can be achieved. The flow control valve can be placed in the fully open position for total dynamic head conditions above 140 feet and flow control of the pump at the rated pump capacity condition of 28,200 gpm would be accomplished by varying the pumps operating speed.

Based on the discussion above, the two dewatering pumps (operating in parallel) can deliver up to a combined flow rate of 56,400 gpm (125.7 cfs) for all system head conditions associated with the dewatering process. Each pump would be operated with a variable speed drive. The flow meters associated with each pump would be used to control the operating speed of each pump based on a flow set-point. The flow control valves for each pump would be modulated to maintain a set-point inlet pressure between the pump discharge and the control valve. The pump selection would maintain the dewatering flow rate well within the maximum flow rates established in Tables 2 and 3 throughout the entire dewatering process.

7.3 Dewatering Duration

For WSELs between -50.00 and -160.20 feet (within the SD PP shaft structure), two dewatering pumps each operating at 28,200 gpm can drain the central and eastern alignment tunnels in 20 and 21 days respectively. For WSELs between -160.2 feet and -161.9, the dewatering pumps would operate at reduced speeds and then ultimately only one pump would operate at reduced speed due to lower flow capacities that would develop a hydraulic jump within the tunnel. The estimated time duration to dewater tunnel for WSELs between -160.2 and -161.9 feet would be an additional four days for each alignment. Therefore, the estimated total time to dewater the Central tunnel alignment is 24 days and the total estimated time to dewater the Eastern tunnel alignment is 25 days. For the extreme low WSEL range between -160.2 and -161.9 feet a smaller submersible pump should be investigated and will be further evaluated during the preliminary design phase.

8. Document History and Quality Assurance

Reviewers listed have completed an internal quality review check and approval process for deliverable documents that is consistent with procedures and directives identified by the Engineering Design Manager and the DCA.

Approval Names and Roles

Prepared by	Internal Quality Control review by	Consistency review by	Approved for submission by
Tony Naimey / EDM Pumping Plant Lead	Ted Davis / QC Reviewer	Gwen Buchholz / DCA Environmental Consultant	Terry Krause / EDM Project Manger

This interim document is considered preliminary and was prepared under the responsible charge of Anthony M. Naimey, California Professional Engineering License M28450.

Note to Reader

This is an early foundational technical document. Contents therefore reflect the timeframe associated with submission of the initial and final drafts. Only minor editorial and document date revisions have been made to the current Conformed Final Draft for Administrative Draft Engineering Project Report version