Subject:	**Tunnel Inspection and Maintenance Considerations (Final Draft)**
Project feature:	Tunnels
Prepared for:	California Department of Water Resources (DWR) / Delta Conveyance Office (DCO)
Prepared by:	Delta Conveyance Design and Construction Authority (DCA)
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1. Purpose and Scope

This technical memorandum (TM) provides an overview of the design intent relative to how the Delta Conveyance tunnels are accessed and inspected. The TM describes the Delta Conveyance Project (Project) and its individual components with an emphasis on the tunnels and shafts. It details each major area, providing an overview, physical description, functional descriptions, access provisions, and inspection methods to allow maintenance to be performed if needed. Inspection and maintenance of other facilities are to be evaluated in a separate TM.

2. Project Background

The Project would involve constructing a series of tunnels to convey water from intakes along the Sacramento River between Freeport and Courtland to the Southern Forebay and the existing State Water Project (SWP) Harvey O. Banks Pumping Plant (Banks) approach channel and possibly the Central Valley Project (CVP) C.W. Bill Jones Pumping Plant (Jones). The two tunnel alignments addressed in this TM includes the Central corridor and the Eastern corridor, as shown in Figure 1. At the direction of the DCA, only the 36-foot ID tunnel option sized for the Project design flow capacity of 6,000 cfs for both the Central and Eastern corridor alignments is considered for the inspection and maintenance evaluation.

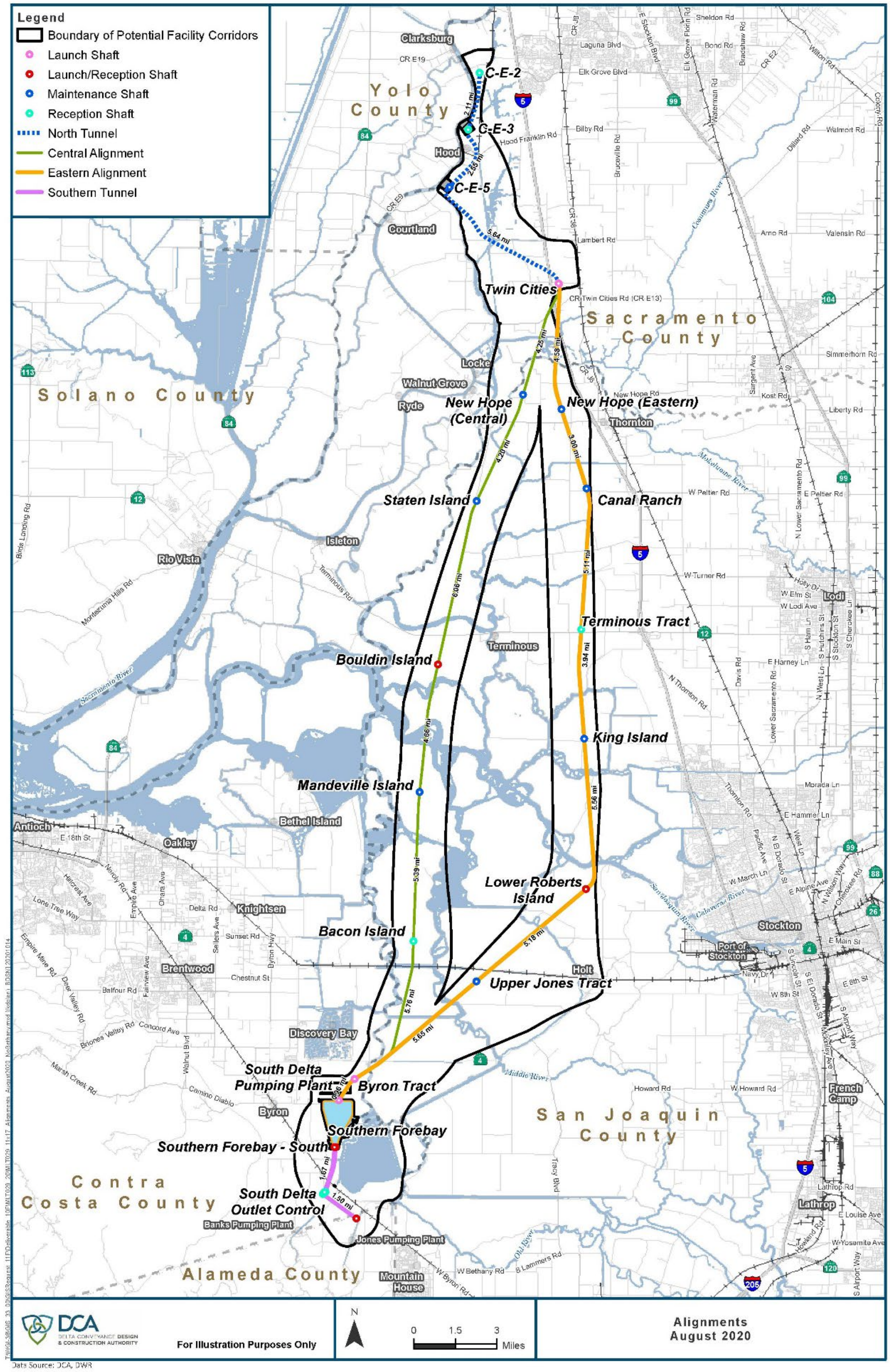

Figure 1. Delta Conveyance Facilities

2.1 Tunnel and Shaft System Description

2.1.1 Tunnels

The Project tunnel system was divided for the purposes of this TM into the following groups:

- **North Tunnel** – Single tunnel that connects the Intake along the Sacramento River to Twin Cities Complex with a double launch shaft.
- **Main Tunnel** – Single tunnel from the Twin Cities Complex to the South Delta Pumping Plant (SDPP) and Southern Forebay.
- **South Tunnels** – Dual tunnels from the Southern Forebay Outlet Structure to South Delta Outlet and Control Structure.

The tunnels would be constructed with the invert up to 190 feet below ground surface. Reach 1 is considered as the North Tunnel (north of Twin Cities), Reaches 2 through 4 are designated as the Main Tunnels, and Reaches 5 and 6 are designated as the South Tunnels (south of Southern Forebay). Tables 1 and 2 describe each reach, and Figure 1 shows the locations of the various tunnel reaches.

Table 1. Central Corridor Tunnel Descriptions

Reach	Start of TBM Drive	Completion of TBM Drive	Length of Tunnel Reach (miles)
1	Twin Cities Complex	Intakes C-E-3 and C-E-5	up to 8
2	Twin Cities Complex	Bouldin Island	14.5
3	Bouldin Island	Bacon Island	10.1
4	Byron Tract Working Shaft	Bacon Island	5.8
5	Southern Forebay Outlet Structure	South Delta Outlet and Control Structure	1.7
6	South Delta Outlet and Control Structure	Jones Outlet Structure (only if connecting to CVP)	1.5

Note:
TBM = tunnel boring machine

Table 2. Eastern Corridor Tunnel Descriptions

Reach	Start of TBM Drive	Completion of TBM Drive	Length of Tunnel Reach (miles)
1	Twin Cities Complex	Intakes C-E-3 and C-E-5	Up to 8
2	Twin Cities Complex	Terminous Tract	12.7
3	Lower Roberts Island	Terminous Tract	9.5
4	Byron Tract Working Shaft	Lower Roberts Island	10.8
5	Southern Forebay Outlet Structure	South Delta Outlet and Control Structure	1.7

Table 2. Eastern Corridor Tunnel Descriptions

Reach	Start of TBM Drive	Completion of TBM Drive	Length of Tunnel Reach (miles)
6	South Delta Outlet and Control Structure	Jones Outlet Structure (only if connecting to CVP)	1.5

Note:
TBM = tunnel boring machine

2.1.2 Shafts

A series of TBM launch and retrieval shafts as well as maintenance shafts would be required to facilitate tunnel construction described as follows:

- **Tunnel Launch Shafts** would be used to convey the TBM and associated equipment and materials into the tunnel, reusable tunnel material excavated by the TBM out of the tunnel, and workers into and out of the tunnel. The tunnel launch shaft sites each have a single shaft configuration apart from Twin Cities Complex where a double shaft configuration has been assumed to launch separate TBMs for the North and Main Tunnels. TBM launch shafts are assumed to have an inside diameter large enough to accommodate space for the TBM, thrust frame, and TBM backup sections.
- **Tunnel Reception Shafts** would provide access to the tunnel to allow for the TBM to be removed at the end of the tunnel drive. Reception shafts are assumed to be approximately 35 percent less in diameter when compared with a launch shaft.
- **Tunnel Maintenance Shafts** would be located between the launch and reception shafts (about every 4 to 6 miles) to allow for inspection, replacement, or repair of the TBM cutter head and main bearing and for other maintenance that could not be conducted from within the tunnel. The maintenance shafts would also be used during tunnel construction to provide fresh air for ventilation and an exit in case of emergency to improve worker safety. Maintenance shafts would have the same diameter as a reception shaft. Table 3 summarizes shaft dimensions for the 36-foot inside diameter tunnel.

Table 3. Summary of Shaft Sizes for 6,000 cfs Option

Tunnel ID (feet)	Launch Shaft Temporary ID (feet)	Reception and Maintenance Shaft ID (feet)
36	115	70

Note:
cfs = cubic feet per second

2.2 Tunnel Dewatering

Dewatering the Main and North Tunnels would be performed at the SDPP. Two submersible vertical turbine pumps (each with rated flow capacities of up to 69.5 cfs), including connecting discharge piping, would be temporarily installed within the North Tunnel launch shaft that has been repurposed as the tunnel's gravity/flow/surge overflow structure and would operate with 4,160 volts. Each submersible pump would be equipped with a variable frequency drive to deliver the rated dewatering capacity over the range of total dynamic head conditions associated with the tunnel. The submersible pumps would discharge directly into the Southern Forebay.

The dewatering pumps will be normally stored in the Equipment Storage Building when not in use. Each pump will be supported by a ninety degree above-ground discharge head assembly that consisted of the discharge nozzle, and base plate. Sole plates will be permanently embedded in the top deck of the SDPP shaft structure. When dewatering is required, the pumps will be suspended from the top deck of the SDPP shaft structure as shown in Figures 2 and 3 (DCA, 2020).

The dewatering pumps will discharge into SF through temporary discharge piping and appurtenances constructed on top of the shaft structure as shown in the figures. The gravity flow gates will be closed while the dewatering pumps are in operation. Each individual pump will be equipped with a magnetic flow meter, a flow control valve, and an isolation butterfly valve. Pumps will operate with adjustable frequency drives (AFDs) which are permanently installed in the SD PP Electrical Building.

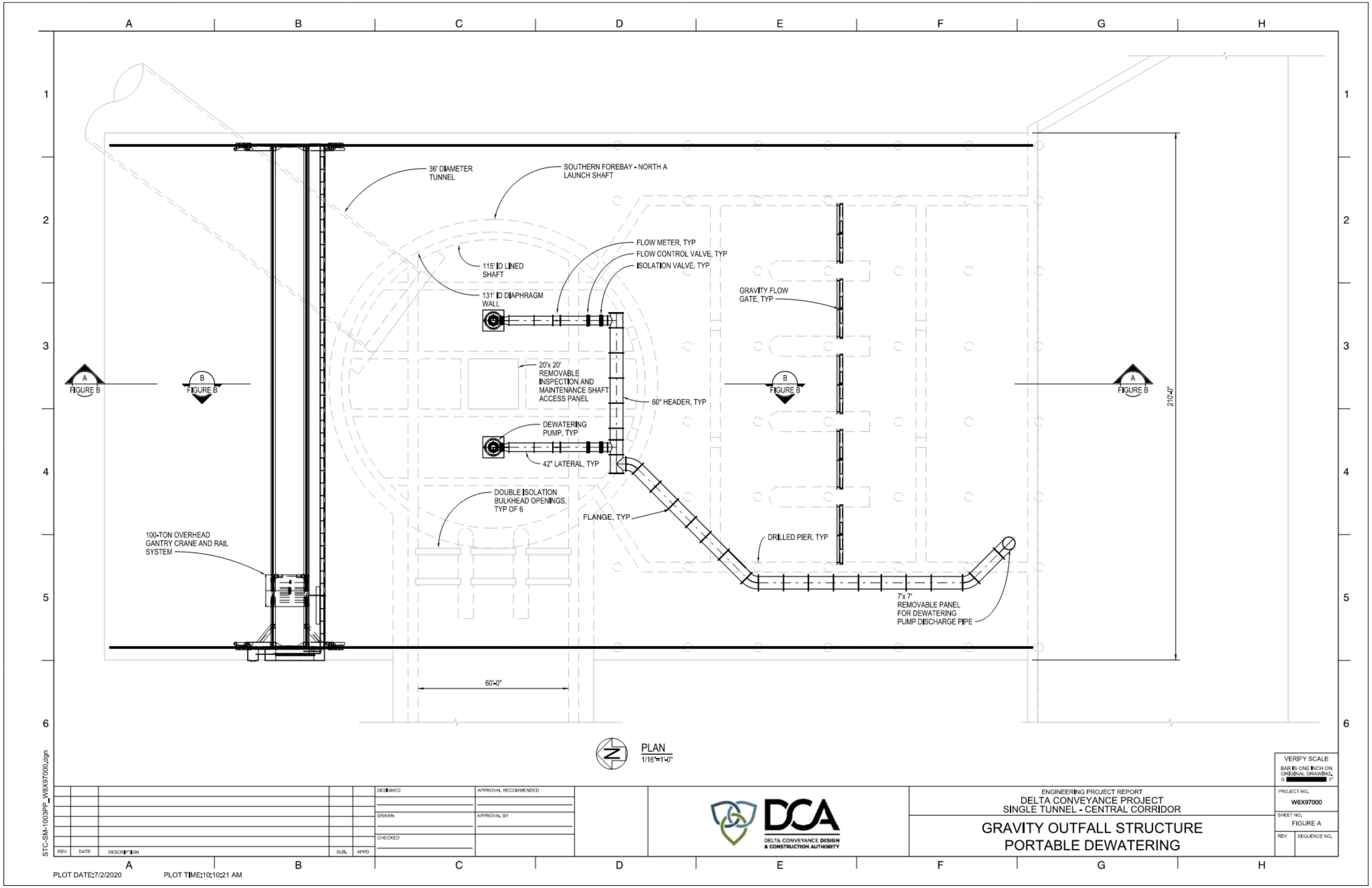

Figure 2. Portable Dewatering Pumping Plant Layout (Plan)

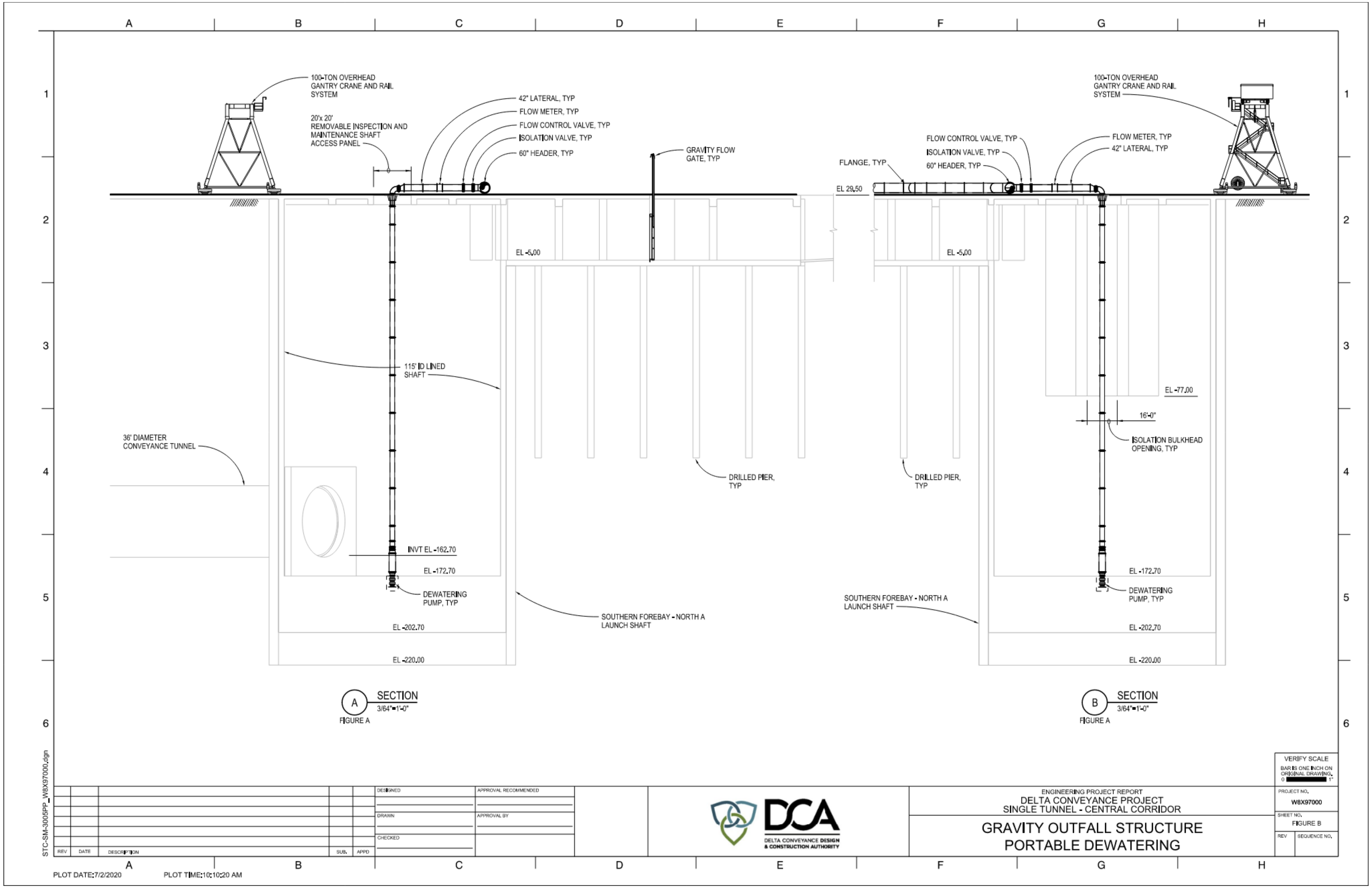

Figure 3. Portable Dewatering Pumping Plant Layout (Section)

2.2.1 Discharge Rate and Time

The number of days required to dewater the system from the intakes to the SDPP for both the Central and Eastern tunnel alignments are summarized in Table 4.

Table 4. Dewatering Times for Various Flow Scenarios

Flow (cfs)	Tunnel ID (feet)	Intake Shaft ID (feet)	Maintenance and Reception Shaft ID (feet)	Southern Forebay Launch Shaft ID (feet)	Central Alignment Dewater Days	Eastern Alignment Dewater Days
6,000	36	83	36	115	24	25

Source (DCA, 2020)

Note:

cfs = cubic feet per second

The dewatering time assumes two high-capacity submersible pumps would be used with discharge capacities of 28,200 gallons per minute per pump. Details associated with the calculations to determine dewatering times for the entire system are described in a separate TM (DCA, 2021).

3. Tunnel Inspections

Although the Project tunnels would be designed to be maintenance-free during the 100-year design life, it is nevertheless possible that the need for inspection and maintenance could arise. This could occur for the following:

- Excessive grit/sediment accumulation
- Abrasion of invert
- Excessive water exfiltration/infiltration
- Structural failure of tunnel lining element
- Structural damage caused by a seismic event
- Reduction in flow caused by invasive mussel growth

3.1 Inspection Frequency

The tunnels and shafts would be designed to be a low-maintenance facility, and therefore, inspections would be anticipated to be infrequent. An inspection schedule would need to be established for the tunnel system through meetings and discussions with DWR's operations and maintenance group.

Consideration should be given to an initial inspection during the construction contract's warranty period, within about 1 year after the system is placed into operation. After the initial inspection, it would be recommended that a tunnel inspection be completed every 10 years for the first 50 years and every 5 years after 50 years from initial operation.

Nonscheduled inspections would also be needed following seismic events or when a significant reduction in flow is detected. It is recommended that a tunnel inspection be performed immediately following an earthquake with a magnitude of 5.5 or more on the Richter scale occurring on a fault within 100 miles of the tunnel. Reduction in flow could be caused by many things, such as leakage through a damaged tunnel segment or if an invasive mussel species enters the tunnel system and starts to reproduce at an aggressive rate.

3.2 Review of Existing Tunnel Records

Records for each tunnel reach would need to be thoroughly reviewed and evaluated prior to conducting an inspection. Important records that are normally part of the tunnel file include the construction plans, as-built drawings, specifications, and photographs. The history of the operations, maintenance, inspection, and repair records should also be reviewed. The goals should be to formulate appropriate inspection procedures and develop inspection documents, including forms, survey control, and sketches.

3.3 Inspection Methods

Manned or unmanned inspections could be used to inspect the tunnels. Inspection procedures and equipment or vehicles used would be adapted to the specific conditions existing during operations that could include methane, hydrogen sulfide, or low-oxygen environment. Typically, routine tunnel inspections could be performed using remotely operated vehicles (ROVs) that record high resolution camera video. The following methods could be used for inspection.

- **Autonomous underwater vehicle (AUV)** – A vehicle capable of underwater deployment that can perform preprogrammed inspection tasks. AUV is untethered and independently acquires and stores inspection data for subsequent download, processing, and evaluation by operators/engineers. AUVs need to be retrieved at a downstream shaft location from where they are launched. AUV technology is commonly used in the scientific and defense communities for ocean survey and information gathering.
- **ROV** – A vehicle deployed underwater that is tethered to the surface controls and directed by an operator at the surface, providing live, real-time feedback to operators/engineers for most data. Long distance ROVs such as the ASI Mohican (dimensions of 2.5-feet x 3.7-feet) will require a vertical access shaft with a diameter of 15 feet to perform the ROV work. Submersible ROVs need to be retrieved at the same location from which they are launched. ROV technology is commonly used for tunnel and pipeline inspection, power utilities inspection, and for offshore oil and gas pipeline inspection and repair.

The major advantage of using a submersible method is that the tunnel would not have to be dewatered, therefore minimizing impact to operations. Table 5 compares some of the main capabilities between AUV and ROV inspections.

Table 5. Comparison of AUV and ROV Capabilities

Data	AUV	ROV
Range	Approximately 40 miles	Approximately 8.5 miles
Communications	Untethered	Tethered
Bottom Time (submerged)	8 to 10 hours	Unlimited
Control	Preprogrammed, cannot change direction once launched	Live operator, can stop, steer, change elevation
Real-time Imagery	N/A	Yes – Video plus other information

Table 5. Comparison of AUV and ROV Capabilities

Data	AUV	ROV
Visual Images	Fuzzy images from tunnel centerline	Clearer images with better illumination and less optical backscatter
3D LiDAR Scanning	Pre-programmed intervals and locations cannot be changed once a vehicle is launched	Real-time imagery, pilot operates to specific locations
Crack Width	Visually approximate to approximately a half inch	Measure with gauge mounted on ROV to a quarter inch
Identify Leaking Zones	N/A	Visual detection by tell tales (nylon string)
Identify Specific Leaking Cracks	N/A	Visual detection by release of dye at suspect cracks
Identify Pin Size Holes	N/A	Detection by hydrophones
Recommended Maximum Water Velocity	0.75 ft/sec	0.75 ft/sec
Passes required to perform inspection on 36-foot ID Tunnel	Four passes	One pass using a sonar array and stopping at locations detected by sonar to take camera and video recordings
Detect Voids	N/A	Underwater GPR (under development)

Notes:
AUV = Autonomous underwater vehicle
ft/sec = foot/feet per second
GPR = ground-penetrating radar
N/A = not applicable
ROV = remotely operated vehicle

Manned inspections in the dry would be considered when conditions suggest structural issues need to be addressed within the tunnel. A typical inspection team would consist of inspectors/engineers and surveyors who would drive or walk through the tunnel and physically document the tunnel condition. Because of the tunnel size, a specialized vehicle, such as scissor lift truck, would be needed to inspect the tunnel.

The feasibility of performing manned inspections in the wet by boat could potentially be another inspection method. The boat would have to be large enough to carry the inspection team along with the necessary supplies and equipment. There would be many challenges, limitations, and safety issues, not just with the inspection team but also with the rescue team in the event of an emergency.

Health and safety considerations would need to be evaluated prior to entering a shaft or tunnel. Coordination with standby rescue teams and emergency services would be performed in advance when dealing with confined space. The Occupational Safety and Health Administration (OSHA) requires that a competent person make frequent and regular inspections of the job sites, materials, and equipment during the course of the work. Hazards identified as being potentially dangerous to personnel need to be properly eliminated prior to a worker's entering the confined space. Inspections should be conducted in accordance with the requirements stipulated in the confined space safety regulations.

3.4 Shaft Work Site

Protecting the shaft from potential floods needs to be considered because the existing ground level could be as much as 18 feet below sea level and up to 40 feet below flood level. The provision of a raised pad in combination with an extended shaft collar could be used to prevent the shaft and tunnel from flooding as depicted on Figure 4. To help provide life safety for workers, mobile crane, temporary lighting and other life-critical systems such as ventilation could be sited on the elevated pad above severe flood inundation levels.

3.4.1 Shaft Access

For security purposes, the shafts would be provided with concrete covers to prevent unauthorized personnel from entering the tunnel. At the shaft locations, access consisting of removable panels of approximately 15 feet by 15 feet would be needed to allow tunnel inspection equipment to be lowered into the tunnel. Typically, a crane would be required to remove the concrete slabs. A minimum shaft inside diameter of 36 feet is needed, however, the launch and reception\maintenance shafts would have a final inside diameter of 115 and 70 feet respectively for the 6,000 cfs option. The shaft pads have also been sized to provide a minimum 60 feet beyond the width of the shaft opening to allow for future maintenance.

For safety and security considerations, no fixed ladders would be recommended for access shafts. Personnel access should be designed based on primary access by stairs and secondary access via man cage lowered and hoisted by mobile crane. Similarly, inspection equipment would be lowered and hoisted by mobile crane. Inspection and maintenance can be staged from any shaft location, and a minimum of two locations would be needed to provide the necessary tunnel ventilation. In addition to DWR safety requiring emergency access shafts upstream and downstream from the inspection shaft, access would also need to be performed in accordance with the permit required for confined space entry as defined by the OSHA regulations.

Staging areas to perform inspection and maintenance activities would be provided adjacent to and on top of the shaft pads at each shaft location. Table 6 summarizes the items needed by DWR operation and maintenance personnel post construction.

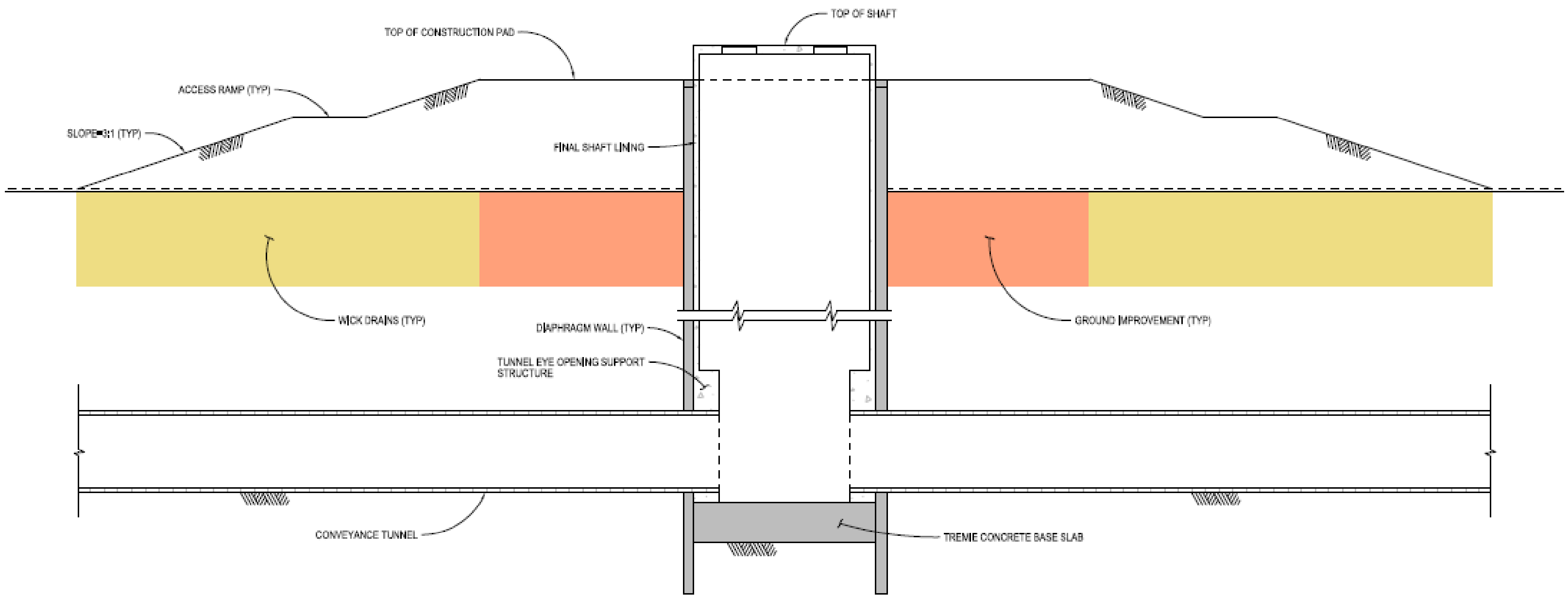

Figure 4. Typical Shaft Pad Section

Table 6. Shaft Site Requirements

Item	Requirement
Office Trailer	10 feet x 40 feet
Porta-Potties	1 per 10 employees
Parking Spots	Accommodate 15 crew cab trucks and 5 large pieces of equipment 150 feet x 200 feet (includes area for office trailer)
Fuel Cell Trailer	500-gallon capacity
Mobile Crane	40 feet x 40 feet concrete slab
Generator	Area includes a containment pad
Staging Area	100 feet x 150 feet
Ventilation	6-foot diameter
Portable Lighting	Lights mounted on 4 trailers

3.5 Maintenance Activities

Design features of the gravity tunnel system should preclude the need for planned maintenance; necessary maintenance activities would be the result of inspection findings. However, it is anticipated that at some point during the service life of the system, some maintenance would be required. The maintenance work could range from cleaning out the tunnel invert with a loader or possibly patching or repairing the tunnel lining. Maintenance activities should also comply with the confined space regulations referred to previously for inspections.

4. Summary

Several shaft types would be used to construct the tunnels, including launch, reception, and maintenance shafts. Post-construction, these shafts would be used for tunnel access so that periodic inspections, repair, and maintenance activities could be performed. The types of access anticipated include the following:

- Periodic visual inspections by ROV or AUV.
- Manned inspection to closely review some aspects of the structure or its components identified by the ROV inspections that require further verification.
- Manned maintenance to perform light maintenance close to shafts, such as removing silt from the tunnel invert.
- Manned maintenance to perform heavier maintenance within the tunnel reaches or at the shafts, such as tunnel lining structural repair after a maximum credible earthquake.

The first inspection should occur during the construction contract warranty period, and it is recommended that subsequent tunnel inspections be completed every 10 years for the first 50 years and every 5 years thereafter. Nonscheduled inspections would also be needed following seismic events or when a significant reduction in flow is detected.

Current shaft spacing ranges from 4 to 6 miles, which allows inspections and maintenance activities to be performed safely and efficiently. The finished diameter of the shaft would match the finished diameter of the tunnel to accommodate surge conditions. The finished shaft diameter would range from 70 to 115 feet depending on the project design capacity. Access would need to be performed in accordance with confined space entry requirements as defined by the OSHA regulations.

5. References

Delta Conveyance Design and Construction Authority (DCA). 2021. Tunnel Dewatering Pumping Facilities Technical Memorandum. Final Draft.

6. 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 (EDM) and the DCA.

Approval Names and Roles			
Prepared by	**Internal Quality Control review by**	**Consistency review by**	**Approved for submission by**
Steve Dubnewych / EDM Tunnels Lead	Martin Ellis/ EDM Shafts Lead	Gwen Buchholz / DCA Environmental Consultant Phil Ryan / EDM Design Manager	Terry Krause / EDM Project Manager

This interim document is considered preliminary and was prepared under the responsible charge of Steve Dubnewych, California Professional Engineering License C66922.

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.