Subject:	**Delta-Mendota Canal Connection—Tunnel and Canal Options Summary Comparison (Final Draft)**
Project feature:	South Delta Conveyance Facilities
Prepared for:	California Department of Water Resources (DWR), Delta Conveyance Office (DCO)
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1. Purpose and Summary

The purpose of this technical memorandum (TM) is to summarize a reconassaince level comparison between two options for delivering water from the Southern Forebay to the Harvey O. Banks Pumping Plant (Banks PP) approach channel (CA Aqueduct) and to the Jones Pumping Plant approach channel (Delta-Mendota Canal [DMC]). This analysis is applicable to the 7,500 cfs design capacity option for the Central and Eastern Corridor options. The two options considered were:

- Tunnel Option (see Figure 1):
  - Dual tunnels (each 40-feet in diameter) extending from the south end of the Southern Forebay to the west side of the CA Aqueduct near the southern end of North Bruns Road.
  - South Delta Outlet and Control Structure on downstream end of the dual tunnels that would control and deliver flow to both the CA Aqueduct and the tunnel to the DMC.
  - A single 20-foot diameter tunnel from the South Delta Outlet and Control Structure, passing under the CA Aqueduct, traveling in a southeasterly direction, and discharging to the DMC.
  - An outlet structure on the end of the 20-foot diameter tunnel, located on the west bank of the DMC, and delivering flow into the DMC.
- Canal Option(see Figure 2):
  - Longer dual tunnels (same diameter) extending to the agricultural area on the east side of the CA Aqueduct.
  - South Delta Outlet Structure on downstream end of the dual tunnels that would deliver flow to both the CA Aqueduct and the DMC via a large canal that spans between the CA Aqueduct and the DMC (South Delta Delivery Canal, se below).
  - A canal between the CA Aqueduct and the DMC, called for this analysis the South Delta Delivery Canal.
  - On the South Delta Delivery Canal, a gated control structure (Banks Control Structure), bridge, and open canal entrance to the eastern bank of the CA Aqueduct.
  - On the South Delta Delivery Canal, a gated control structure (Jones Control Structure), bridge, and open canal entrance to the western bank of the DMC.

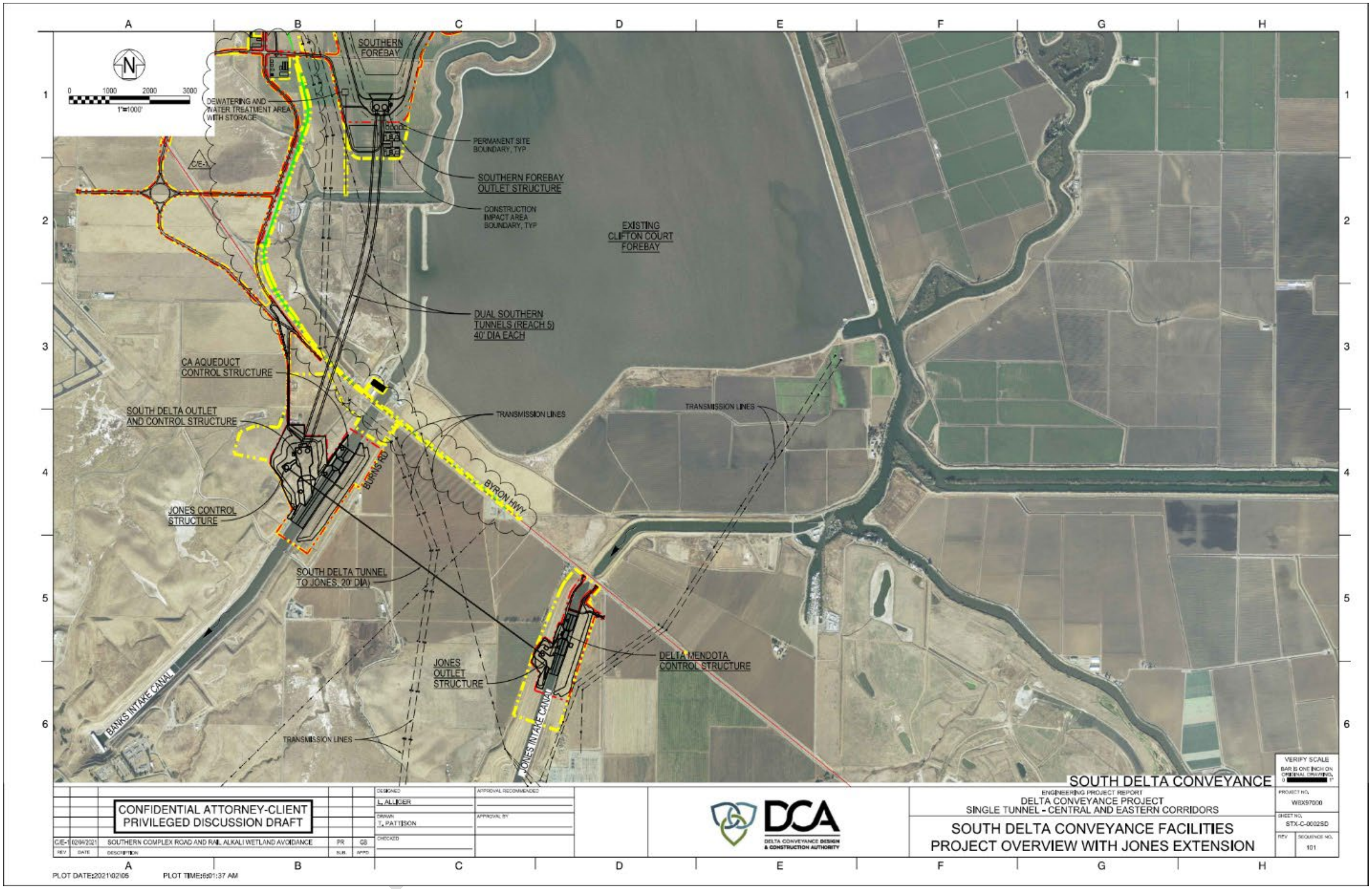

Figure 1 – Tunnel Option: Tunnel to DMC

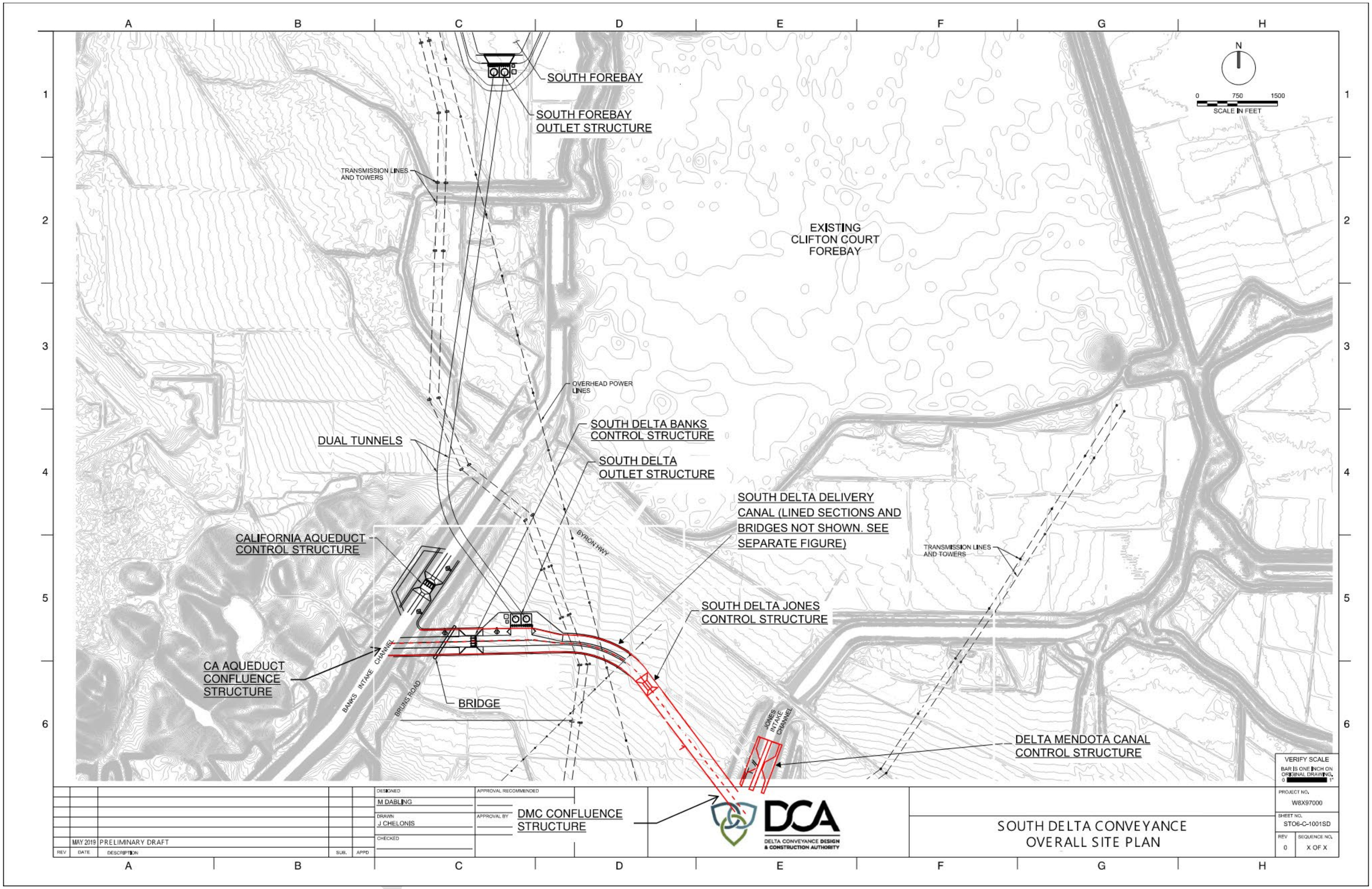

Figure 2 – Canal Option: Canal to CA Aqueduct and the DMC

The tunnel and canal options were compared on a reconnaissance level to determine the apparent best approach to delivering water to the CA Aqueduct and the DMC. The tunnel option was selected as the apparent best option and is included in the current engineering concept. This TM summarizes the comparison between the two options with associated advantages and disadvantages.

1.1 Background

In general, the tunnel option was proposed as a project feature since it would provide a relatively clean construction approach that has minimal ground disturbance and no permanent surface disturbances. The tunnel from the CA Aqueduct to the DMC extends under the WAPA and PG&E power easements. Reusable tunnel material (RTM) from the tunnel construction would be collected and hauled to the Southern Forebay where it would be used for embankment construction. Compared to the canal option, there would be far less material generated and a reduced need for surface transportation of excavated material across Byron Highway, including the associated air quality, noise, and transportation disturbances. Some of the disadvantages considered with the tunnel would be potentially higher cost and construction risk.

The canal option understandably would have significantly more ground disturbance and permanent surface facilities than the tunnel option, as well as significantly more material to excavate and haul, which could result in additional challenges both in construction and permitting.

- Overall, the major considerations for comparison of these options incude:
- Cost
- Constraints of existing utility crossings and interfaces
- Permanent ground disturbance
- Soil handling and associated air quality, noise, and transportation disturbances
- Increased noise and dust during construction

The primary positive aspect of canal construction relative to tunnel construction would be potential cost savings. This TM highlights the major advantages and disadvantages for each option and provides a reconnaissance-level cost comparison.

1.2 Summary

The reconnaissance level cost comparison indicates that the tunnel option and canal option are essentially equivalent from a cost perspective if the constructability risk of the canal option is assumed to be the same as the tunnel option. Additionally, when considering the amount of temporary and permanent disturbance, difficulty working under transmission lines and between transmission towers, additional land acquisition, construction challenges, and approval/permitting complexity with WAPA and PG&E, the Tunnel Option appears to have significant advantages for a long-term serviceable facility with relatively low maintenance. For these reasons, the tunnel delivery system to the DMC is recommended as the best apparent option for implementation as part of the Delta Conveyance Project.

2. Conceptual Development of Options

The two approaches considered for delivery of water from the Southern Forebay to the CA Aqueduct and the DMC were a tunnel option and a canal option. Key characteristics of the two approaches are summarized below. Each option would share the same version of the Southern Forebay Outlet Structure, so the comparison excludes descriptions or cost of this structure. Each option would also share the same version of the California Aqueduct and the DMC Control Structures, so they are similarly excluded from the comparison.

2.1 Tunnel Option

A preliminary sketch of the tunnel option is shown in Figure 1. This section describes the facilities starting from the outlet end of the Southern Forebay Outlet Structure, continuing through dual tunnels downstream to the South Delta Outlet and Control Structure and on to the DMC.

2.1.1 Dual Conveyance Tunnels

The Southern Forebay Outlet would include the tunnel launch shafts, which would serve as inlet drop shafts, each feeding one of the dual tunnels that extend to the CA Aqueduct (Refer to Figure 1). The alignment of the tunnels would generally take the most direct route between the Southern Forebay Outlet Structure and the South Delta Outlet and Control Structure. There would be some deviation from a straight line along the route to comply with WAPA and PG&E requirements that the tunnels not traverse under powerline towers.

The tunnels would have no intermediate structures and no day-to-day operator input would be required. Dewtering would be accomplished by pumping the tunnels out on the downstream end and discharging the flow into the CA Aqueduct

2.1.2 South Delta Outlet and Control Structure

As shown in Figure 1, the dual tunnels would terminate at the South Delta Outlet and Control Structure. This structure would be located on the western bank of the CA Aqueduct, between the existing Skinner Fish Screening facililty and the Banks PP, just southwest of the Byron Highway. To limit the length of the tunnels, the South Delta Outlet and Control Facility would be placed as far north as practical along the CA Aqueduct while allowing space to construct the CA Aqueduct Control Structure and avoid conflicts with the Byron Highway Bridge and the PG&E power transmission easment which crosses the aqueduct just south of the Byron Highway.

Figure 3 shows the general configuration of the South Delta Outlet and Control Structure. The reception shafts of the tunnel would extend vertically into a collection basin structure where the flow transitions to an open channel system. The basin would include two separate tunnel transition compartments, each associated with one of the shafts. This configuration would allow isolation of one of the tunnels for dewatering and maintenance while maintaining the other tunnel in full operation.

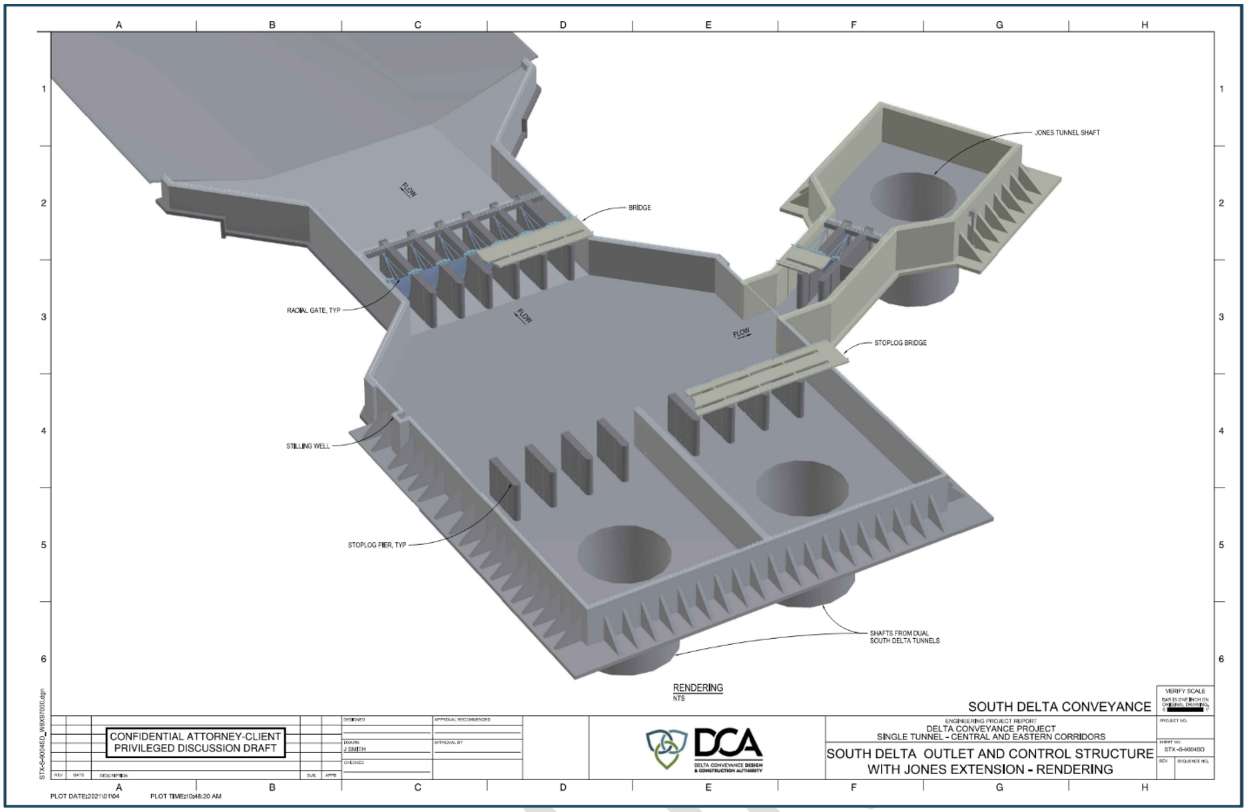

Figure 3. South Delta Outlet and Control Structure

A series of piers would be installed across the basin and oriented transverse to the flow. Each pier would have two vertical slots to accept two sets of bulkhead gates for isolation. The gates would provide double-isolation is for worker safety during maintenance activities in the tunnel. A bridge, with slot openings for the gates, crosses over the structure on top of the piers for access. Bulkheads would be stored on the site and installed with a mobile crane from the bridge deck.

Beyond the two transition compartments, the Jones Control Structure would be constructed. This structure would include an outlet bay with radial gates for flow control adjacent to a vertical inlet shaft that in turn connects to the tunnel feeding the DMC (see Section 2.1.3). Two large gates would be operated to deliver the bulk flowrates. A smaller radial gate (or vertical sluice gate) would be used to allow flow trimming to match downstream pumping needs.

Flow not diverted to the DMC would proceed from the basin into a section of the facility containing radial gates. These gates would provide flow control for water withdrawn from the Southern Forebay and distribution into the CA Aqueduct. Six large gates would be operated to deliver the bulk flowrates. A smaller radial gate (or vertical sluice gate) would be used to allow flow trimming to match downstream pumping needs.

Vertical slots would be provided in the piers between all radial gates, both upstream and downstream. Bulkhead gates, inserted into these slots, allow isolation and dewatering of each gate bay as needed for gate maintenance and repair. The height of the gates would be set above the maximum water surface in the Southern Forebay to allow complete isolation of the downstream system if needed.

2.1.3 South Delta Tunnel to the DMC

As shown in Figure 1, a 20-foot diameter tunnel would begin at the Jones Tunnel Shaft connected to the South Delta Outlet and Control Structure (described in Section 2.1.2) and end on the western bank of the DMC at the Jones Outlet Structure.

2.1.4 Jones Outlet Structure

The Jones Outlet Structure would include a shaft at the eastern terminus of the South Delta Tunnel to the DMC. The shaft would extend vertically into a collection basin where the flow transitions to the existing open channel system. A series of piers would be installed across the basin and oriented transverse to the flow. Each pier would have two vertical slots to accept two sets of bulkhead gates for isolation. The gates would provide double-isolation is for worker safety during maintenance activities in the tunnel. A bridge, with slot openings for the gates, would cross over the structure on top of the piers for access. Bulkheads would be stored on the site and installed with a mobile crane from the bridge deck.

Beyond the piers, the structure would flare out and flow would spill directly into the DMC. Figure 4 shows the general configuration.

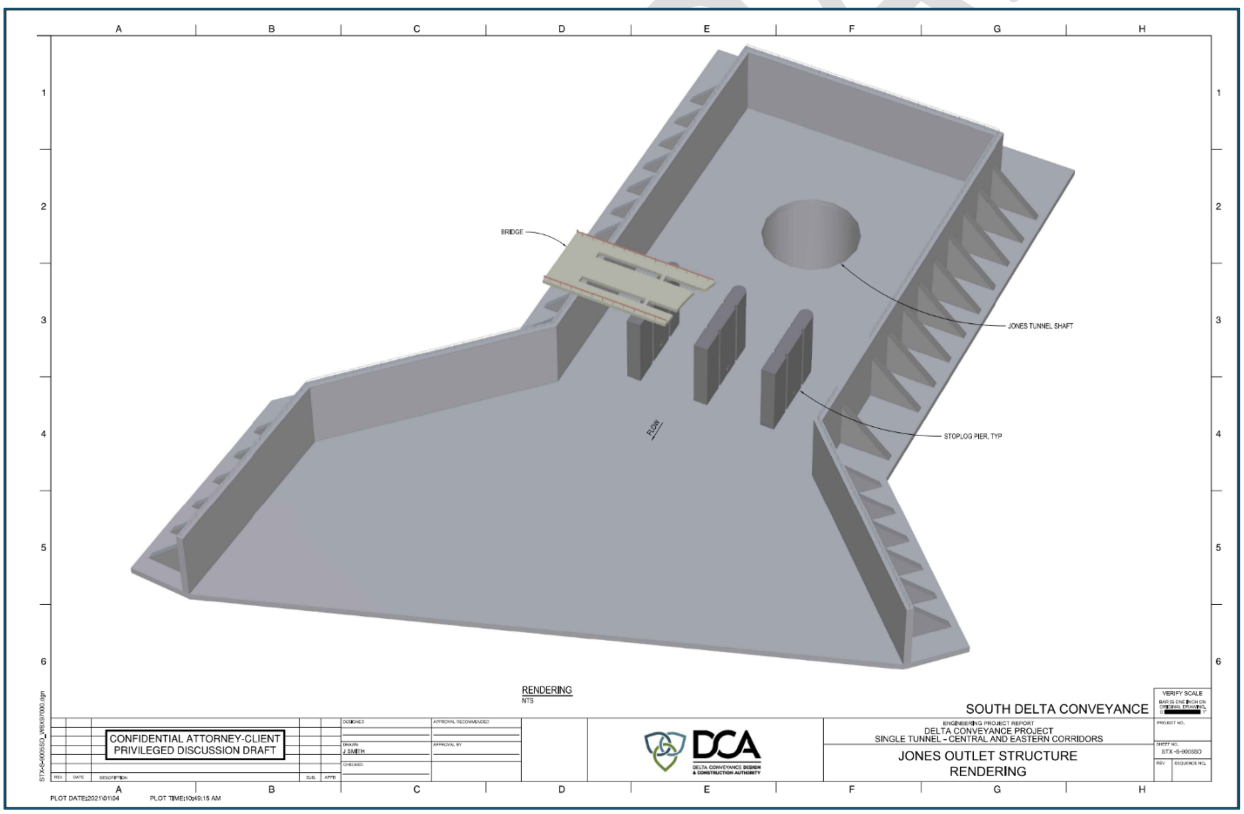

Figure 4. Jones Outlet Structure

2.2 Canal Option

A preliminary sketch of the canal option is shown in Figure 2. This section describes the facilites starting at the outlet end of the Southern Forebay Outlet Structure, continuing through the Dual Tunnels to the South Delta Outlet Structure, emptying into the South Delta Delivery Canal flowing west to the CA Aqueduct and flowing southeast to the DMC. The portion of the canal flowing west would pass through the the South Delta Banks Control Structure, and the portion of the canal flowing southeast would pass through the South Delta Jones Control Structure.

2.2.1 Dual Conveyance Tunnels

The dual tunnels for the canal option would be nearly identical to the dual tunnels for the tunnel option, except each of the tunnels would be approximately 1,890 feet longer, terminate east of the CA Aqueduct and follow a different horizontal alignment that curves to the southeast and crosses under the CA Aqueduct upstream of the CA Aqueduct Control Structure.

As with the tunnel option, the dual tunnels would have no intermediate structures and no day-to-day operator input would be required. Dewatering for maintenance would be accomplished by pumping the tunnels out on the downstream end and discharging the flow into the CA Aqueduct.

2.2.2 South Delta Outlet Structure

As shown in Figure 2, the dual tunnels would terminate at the South Delta Outlet Structure. This structure would be located on the northern bank of the new canal spanning between the CA Aqueduct and the DMC, just southwest of the Byron Highway. To limit the length of the tunnels, the structure would be placed as far north as practical while allowing space to construct the adjacent canal and control structures (described below), and have sufficent clearance beyond the eastern bank of the CA Aqueduct. It would also be located just to the west of the power transmission easment which crosses the aqueduct just south of the Byron Highway.

Figure 5 shows the general configuration of the South Delta Outlet Structure (as well as the adjacent South Delta Banks Control Structure to be described in Section 2.2.4). The termination shafts of the tunnel would extend vertically into a collection basin where the flow transitions to an open channel system. The basin would have two separate tunnel transition compartments, each associated with one of the shafts. This configuration would allow isolation of one of the tunnels for dewatering and maintenance while maintaining the other tunnel in full operation.

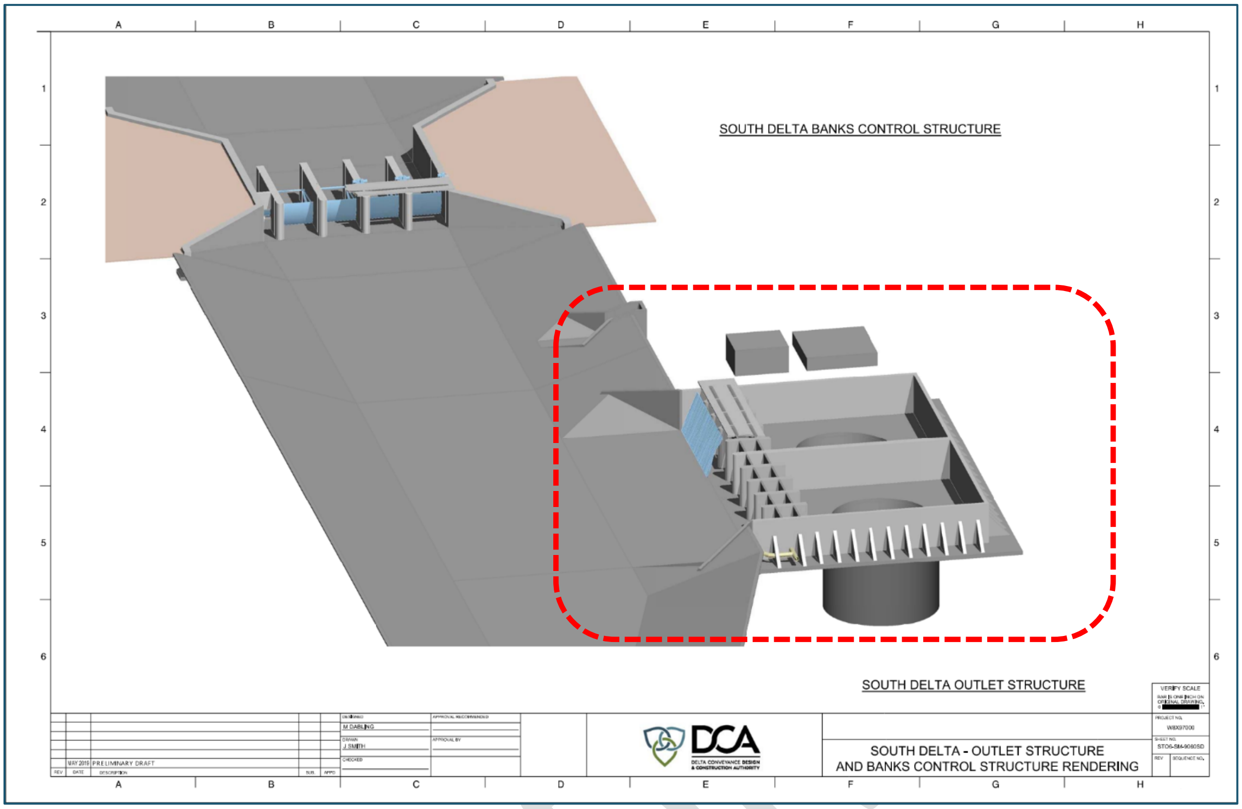

Figure 5. South Delta Outlet Structure

2.2.3 South Delta Delivery Canal

2.2.3.1 General Description

The South Delta Delivery Canal would begin at the South Delta Outlet Structure and flow west to the CA Aqueduct and southeast to the DMC (see plan and profile, Figure 6). The canal alignment is shown as a markup to a prior version when a new control structure in the DMC was planned to be located further north.

The portion of the canal flowing west would carry up to 10,670 cfs and pass through the the South Delta Banks Control Structure, and would have a canal section with a bottom width of 200 feet and top widths varying from 493 to 620 feet.

The portion of the canal flowing southeast would pass through the South Delta Jones Control Structure carry up to 1,500 cfs, with a bottom width of 20 feet and top widths varying from 278 to 500 feet. The portion of the canal between the South Delta Banks and Jones Control Structures, including short sections downstream of each control structure, would include energy dissapation, if needed, and be lined with concrete and articulated blocks.

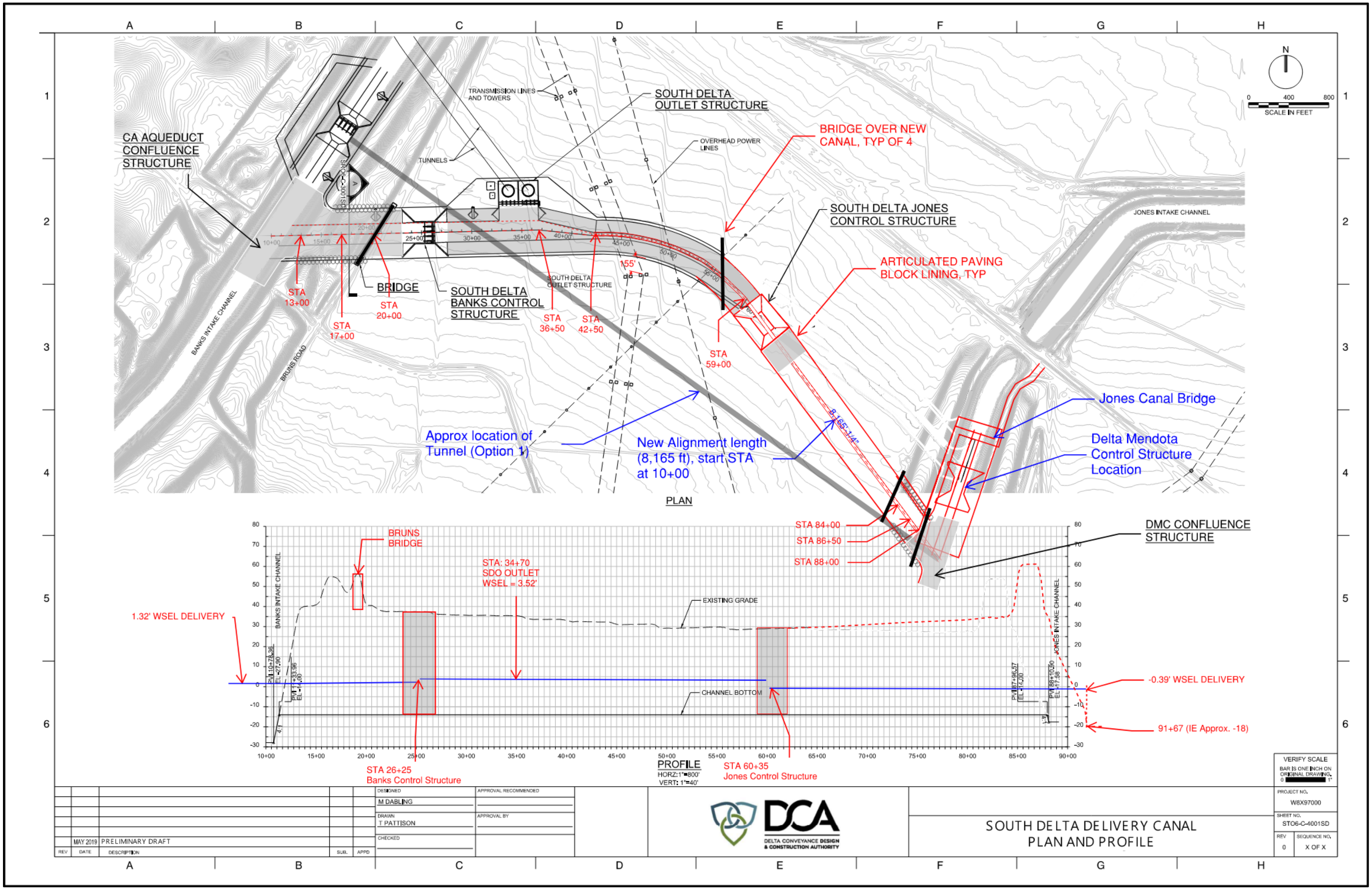

Figure 6. South Delta Delivery Canal, Plan and Profile

2.2.3.2 Canal Alignment and Construction Considerations

The canal alignment between the CA Aqueduct and the DMC is dictated by the position of control structures planned for the CA Aqueduct and the DMC and the major WAPA and PG&E powerline easements that run approximately N-S through the area. Several restrictions would be expected to be placed on work in this easement by WAPA and PG&E. The following major constraints relevant to the design and construction of a canal in this location were assumed based on working with other transmission lines in the area:

- Excavations must be greater than 100 feet from the tower footings
- No dewatering activities will be authorized that could affect the stability of the transmission tower footings
- No ground elevation changes are allowed which would reduce the ground to conductor clearance below 35 feet
- The powerline easement prohibits piling up or placing material within the easement boundaries
- Berms shall not be placed next to the base of transmission line towers
- Equipment within the easement shall not exceed 14 feet in height above existing grade

Canal construction and long-term maintenance would require an additional buffer (beyond the 100 foot offset listed above) for an access/maintenance road on both sides of the canal. Therefore the edge of canal excavation would be held at least 150 feet from any of the tower footings.

Groundwater control would also be a challenge in terms of dewatering the large area for the canal. Well points and/or slurry walls, typical methods for groundwater control, both require the use of drilling rigs. Drilling rigs would not be practical with the height restriction. Alternative approaches such as drain trenches or underdrain piping may need to be installed under the power lines.

Construction of a canal of this size and depth is usually performed with very large earth-moving equiment, height restrictions under the powerlines may initially require other methods and smaller equipment within the powerline easements until the excavation is deep enough to facilitate larger equipment.

All of the items mentioned may be manageable, but the combination of complex constuctability issues complex instituional coordination with PG&E and WAPA, and the requirement for different methods and equipment decreases the actual feasibility of this option and, at a minimum, would decrease production and increase overall costs.

2.2.3.3 Hydraulics

Based on preliminary hydraulic calculations, the canal portion flowing west to the CA Aqueduct would have a bottom width of 200 feet and top widths varying from 493 to 620 feet, and the canal portion from southeast to the DMC would have a bottom width of 20 feet and top widths varying from 278 to 500 feet. In both case, the canal would have 3:1 sideslopes. The proposed invert of the canal would be at EL -14.0’ over the entire reach. Other design parameters for the canal as considered in this analysis are as follows:

- Manning’s roughness: 0.025
- Maximum allowable velocity: 3 feet per second
- Design flow to the CA Aqueduct of 10,670 cfs

- Design flow to the DMC of 1,500 cfs
- Design water surface elevation in the CA Aqueduct at the confluence with the South Delta Delivery Canal: 1.1 feet to meet typical minimum water level at inlet to Banks Pumping Plant
- Design water surface elevation in the DMC at the confluence with the South Delta Delivery Canal: -0.39 feet to meet typical minimum water level at inlet to Jones Pumping Plant
- Sizing of system elements such that the minimum required driving water surface elevation in the Southern Forebay for full flow capacity would not exceed 5.23 feet (to be the same as the tunnel option)

The canal would be entirely in cut, with depths normally ranging from 43 to 55 feet; however there are two embankment cuts on either end of the canal resulting in 70 to 80 feet depths. The entire width of permanent disturbance, including excavation width and permanent access/maintenance road on each side, would range from 334 feet to 676 feet. The entire canal systems would be about 8,010 feet in length.

The portion of the canal between the South Delta Banks and South Delta Jones Control Structures, portions downstream of each control structure, and portions at the confluence of the CA Aqueduct and DMC would include energy dissapation, if needed, and be lined with concrete and articulated blocks. The lining would span a total length of 4,700 feet (exclusive of portions in the CA Aqueduct and DMC at the two confluences.

2.2.4 South Delta Banks and Jones Control Structures

The South Delta Banks and South Delta Jones Control Structures would be positioned in the South Delta Delivery Canal downstream in both directions from the South Delta Outlet Structure to control flow respectively to the CA Aqueduct and to the DMC.

The main component of each structure would be a series of radial gates between piers. The Banks structure would be significantly wider, with more piers and bays because of a much larger rate of flow to be delivered. In both cases, there would be multiple larger radial gates and a single smaller gate for flow trimming. The final number and type of gates would be determined during final design. Vertical stoplog slots in the piers, upstream and dowstream of the gates, would be provided for isolation of individual gate bays. Stilling wells would be located upstream and downstream of the gate structure for monitoring flow levels and setting gate openings. The entrance and exit of the structure includes concrete transition sections leading from the existing canal trapezoidal section to the vertical section through the gates. Articulated paving blocks would be placed in the canal spanning the entire reach between each structure.

Figures 7 and 8 depict the conceptual configuration of these structures.

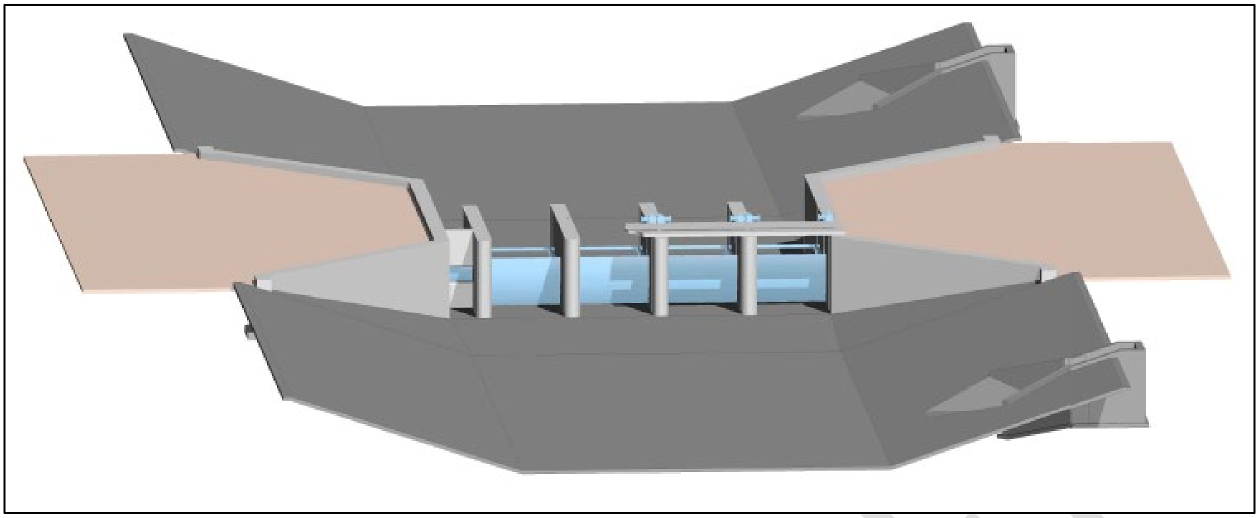

Figure 7. South Delta Banks Control Structure

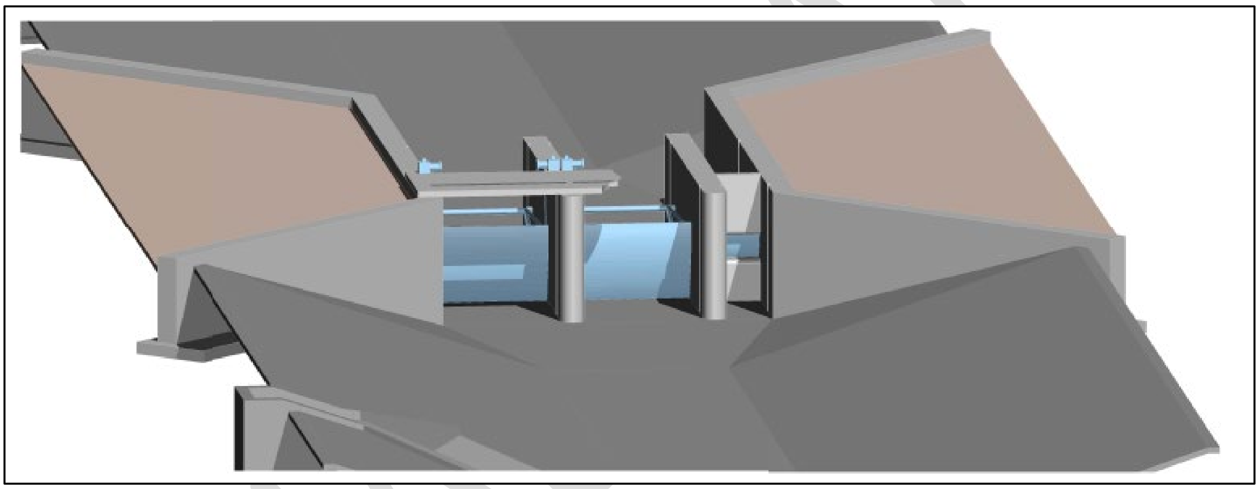

Figure 8. South Delta Jones Control Structure

2.2.5 Other Structures and Bridges

The confluence of the South Delta Delivery Canal with the CA Aqueduct on the west end and the DMC on the southeast end would include a lined canal section with a flared opening and articulated paving block lining in the both the new and existing canals to help transition flow into the receiving channels. Construction of the confluence structures would be a phased process integrated within the overall construction of the canal system. Cofferdams would be required to isolate excavation work in the new canal from ongoing operation of the CA Aqueduct and DMC at each end. It is anticipated that a soil plug would be left in place for the last 50-100 feet adjacent to the operating canals, and a row of sheetpile installed within the plug across the width of the new canal to be subquently excavated. When the remainder of the new canal is complete, including the various structures and lined reaches within it, the soil plug would be removed at each end. The final step would be to extract the sheetpile to fully open the system to water flow. It is anticipated that articulated paving block lining of the CA Aqueduct and the DMC at the confluence structures would be accomplished "in the wet". Some underwater excavation work would be required to place the paving blocks and remove portions of the soil plugs.

Each would be spanned by a bridge to maintain access across the new canal along Bruns Road (adjacent to the CA Aqueduct) and the existing service road along the west bank of the DMC. Each bridge would cross the canal at an angle and be of sufficient length to require multiple skewed piers. The Bruns Road bridge would be 32 feet wide with two 12-foot paved lanes and 4-foot wide shoulders. The bridge over the DMC service road would be 24 feet wide with a concrete deck. Additionally, the canal would cross at least five existing farm roads (four running north-south and one running east-west), It is assumed that construction of the canal would result in some permanent revised and consolidated access, but for the purposes of this analysis, two additional bridges have been allocated within this reach (each 24 feet wide). The Bruns Road bridge would require a BBID pipeline that cannot be taken out of service to be hung on the bridge.

3. Reconnaissance-Level Cost Comparison

A reconnaissance-level cost comparison was conducted for the two options. The cost comparison in this TM uses un-burdened costs that do not include markups of any kind. Costs are not all inclusive and only represent the items required to compare the two options.

The cost comparisons are shown in Table 1 for both the tunnel and canal options.

Table 1. Reconnaissance Level Cost Comparison

Description	Unit	No. of Units	Unit Cost ($)	Extended Cost
Tunnel Option				
Tunnels and Shafts - Dual Tunnel Reach	LS	1	$ 409,000,000	$ 409,000,000
South Delta Outlet and Control Structure	LS	1	$ 135,000,000	$ 135,000,000
Jones Tunnel Shaft/Structure and South Delta Single Tunnel to DMC	LS	1	$ 160,000,000	$ 160,000,000
Jones Outlet Structure	LS	1	$ 79,000,000	$ 79,000,000
Total				**$ 783,000,000**
Canal Option				
Tunnels and Shafts - Dual Tunnel Reach	LS	1	$ 409,000,000	$ 409,000,000
Additional Dual Tunnel Length	LF	3,780	$ 27,000	$ 102,100,000
South Delta Outlet Structure	LS	1	$ 76,000,000	$ 76,000,000
Canal Excavation	CY	3,456,800	$ 15	$ 51,900,000 [c,d]
Articulated Blocks	SF	1,838,000	$ 11	$ 20,200,000
South Delta Banks Control Structure	LS	1	$105,000,000	$ 105,000,000
South Delta Jones Control Structure	LS	1	$ 52,500,000	$ 52,500,000
CA Aqueduct Confluence Structure	LS	1	$ 6,200,000	$ 6,200,000
DMC Confluence Structure	LS	1	$ 3,100,000	$ 3,100,000
Bruns Road Bridge *(32' W)*	SF	18,048	$ 400	$ 7,200,000
DMC Service Bridge *(24' W)*	SF	6,192	$ 400	$ 2,500,000
Two Farm Road Bridges *(24' W)*	SF	12,384	$ 400	$5,000,000
Total				**$ 840,700,000 [a,b]**

Notes:

[a] Costs are for comparison only and are un-burdened

[b] Added constructability risk would result in higher costs, which are not reflected in this estimate

[c] Unit costs do NOT include added cost of working under power lines

[d] Unit costs include dewatering and disposal of material (transported to the Southern Forebay for use)

4. Listing Of Advantages and Disadvantages

The costs for the Tunnel Option and Canal Option as presented above are considered equivalent at this level of estimating. However, each option has associated advantages and disadvantages. These include items that can affect overall cost that cannot be quantified at this juncture (risk and difficulty of construction), environmental or public concerns, and difficulties in land acquistion or permitting. Below is a summary of these items for each alternative.

4.1 Tunnel Option

- **Advantages**
  - Significantly reduces disturbance and permanent surface features.
  - No dewatering required.
  - Eliminates most interference with powerlines and towers.
  - Significantly reduces the exposure for noise and dust by reducing the amount of material being handled and transported for use in constructing the Southern Forebay.
  - Reduces exposure for vandalism and safety during operations.
- **Disadvantages**
  - Typical increased risk associated with underground construction.
  - May require longer schedule.
  - Inspection, maintenance, repair could be more costly and complex than the canal option.

4.2 Canal Option

- **Advantages**
  - Possibly shorter schedule (excavation work from the surface generally faster than tunnel).
  - Major source of embankment fill material for Southern Forebay.
  - Inspection, maintenance, repair generally less complicated due to access.
- **Disadvantages**
  - Significantly increases disturbance and permanent surface facilities.
  - Requires more land acquisition.
  - High risk and high level of cost uncertainty associated with work beneath and around the powerlines.
  - Dewatering for construction may affect adjacent groundwater elevations and could require more extensive methods, including slurry walls, which are not included in the cost comparison.
  - Power transmission agencies have strict requirements for any proposed crossings of their easements. To stay within the maximum allowable equipment height (14’), alternative construction alternatives would need to be implemented that would decrease production, increase cost, and increase risk. Actual feasibility of constructing the facilities in the powerline easement in accordance with these restrictions is considered questionable and would take more detailed analysis.

– It is unknown how receptive WAPA and/or PG&E would be to a large canal system (water feature) crossing their easement. There has been considerable resistance in past project planning to any portion of the proposed forebay encroaching on their easement.

– More noise and dust when excavating canal (versus Tunnel Option) due to much larger volume of material to be handled.

– Substantially more traffic on Byron Highway to transport large volume of excavated material to the Southern Forebay.

– Because the canal option is generally constructed and operated at-grade, there is a larger potential for public attraction, vandalism, and injury.

5. Recommendations

While the canal option cost as presented above is approximately 7 percent higher, at this level of estimating the costs for the two options should be considered equivalent (if the constructability risk of the canal option is assumed to be the same as the tunnel option). However when considering the amount of temporary and permanant disturbance, additional land acquisistion, approval/permitting challenges with WAPA and PG&E, and construction risks and challenges, the tunnel option appears to have significant advantages over the canal option for a long-term serviceable facility with relatively low maintenance. for these reasons, the tunnel option is recommended as the best apparent option for implementation as part of the Delta Conveyance Project.

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 and the DCA.

Approval Names and Roles			
Prepared by	**Internal Quality Control review by**	**Consistency review by**	**Approved for submission by**
Ron Fehringer / EDM Project Engineer	Phil Ryan / EDM Design Manager	Gwen Buchholz / DCA Environmental Consultant	Terry Krause / EDM Project Manager

This interim document is considered preliminary and was prepared under the responsible charge of Philip K. Ryan, California Professional Engineering License C41087.