Subject:	**Main Raw Water Pump Selection, Adjustable Operating Speed Requirements and Redundancy (Final Draft)**
Project feature:	Pumping Plant
Prepared for:	California Department of Water Resources (DWR) / Delta Conveyance Office (DCO)
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1. Purpose

The purpose of this Technical Memorandum (TM) is to summarize the preliminary sizing analysis for the main raw water pumps (pumps) including the recommended pumping equipment redundancy for the South Delta Pumping Plant (Pumping Plant) conceptual level design. The pump sizing analysis was conducted based on the results of the systemwide hydraulic analysis performed for the central tunnel alignment corridor for the Delta Conveyance System (Project) using Innovyze's InfoWorks Integrated Catchment Modeling (ICM) software platform.

The Delta Conveyance Project (Project) would include intakes along the Sacramento River between the confluences with American River and Sutter Slough and a tunnel between the intakes and a forebay at the downstream terminus of the main tunnel referred to as the Southern Forebay. Water would either flow by gravity or be lifted by the Pumping Plant from the tunnel into the Southern Forebay. Discharge from the Southern Forebay would occur through the Southern Forebay Outlet Structure, at the south end of the reservoir, into the South Delta Conveyance facilities (SDCF) for connection to the existing State Water Project Harvey O. Banks (Banks) Pumping Plant and Central Valley Project C.W. Bill Jones (Jones) Pumping Plant.

This TM considers a range of project design flow capacities, including 3,000, 4,500, 6,000, and 7,500 cubic feet per second (cfs). A pump sizing analysis was performed for these four project design flow capacities.

1.1 Background

The DCA performed a systemwide hydraulic and capacity analysis of the Project for design flow capacities of 4,500, 6,000 and 7,500 cfs which is described in the separate TM, Systemwide Hydraulic and Capacity Analysis for Tunnel Diameter Selection TM. Based on the results of the systemwide hydraulic and capacity analysis, it was recommended that the maximum tunnel flow velocity be limited to 6 feet per second (fps) for the maximum design flow capacities of 4,500, 6,000 and 7,500 cfs. This velocity criteria resulted in the following recommended minimum tunnel diameters for the Project:

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

This TM evaluates the pump selections for four unique pumping stations with the following design pumping capacities and corresponding main tunnel finished inside diameter (ID) as identified below.

- Scenario 1: Total pumping station flow of 7,500 cfs using 40-feet ID tunnel
- Scenario 2: Total pumping station flow of 6,000 cfs using 36-feet ID tunnel
- Scenario 3: Total pumping station flow of 4,500 cfs using 31-feet ID tunnel
- Scenario 3: Total pumping station flow of 3,000 cfs using 26-feet ID tunnel

2. Design Codes, Standards, and References

The latest adopted version of the following codes, standards, and references apply to this TM unless otherwise noted:

- American National Standards Institute, Inc. (ANSI) (2017): ANSI/HI Standard 9.6.3, Rotodynamic Pumps – Guideline for Operating Regions

3. Pump Selection

The Pumping Plant would be located within the embankment of the Southern Forebay. The wet well would receive flow from the gravity flow/surge overflow shaft which is fed by the main tunnel. Water would enter the wet well through a rectangular inlet conduit connecting the Pumping Plant wet well with the gravity flow/surge overflow shaft. The pumps would lift water from the wet well into the Southern Forebay.

3.1 South Delta Pumping Plant Hydraulics

3.1.1 Modeling Approach

The Project system would have many individual hydraulic elements that would be connected and interdependent to convey the diversion flows from the Sacramento River Intakes. Each element would have hydraulic losses that would form the energy grade lines (EGLs) and hydraulic grade lines (HGLs) throughout the entire system. To replicate the interaction of these system components from the Sacramento River intakes to the discharge point within the Southern Forebay, a hydraulic model was constructed for the Project using Innovyze's InfoWorks Integrated Catchment Modeling (ICM) software. The model configuration would consist of the following components, as shown in the concept drawings for the Central Corridor:

- Up to three intake locations on the left bank of the Sacramento River, as follows:
  - Intake 2 (C-E-2), located downstream of Scribner's bend between Clarksburg and Hood at approximate River Mile (RM 41.1
  - Intake 3 (C-E-3), located upstream of Hood at approximate RM 39.4
  - Intake 5 (C-E-5), located immediately upstream of the confluence with Snodgrass Slough at approximate RM 36.8
- A single tunnel connecting C-E-2, C-E-3 and C-E-5 to the Pumping Plant including tunnel launch, reception and working shafts

- Pumping Plant, which conveys water to the Southern Forebay located on the northwestern side of the existing Clifton Court Forebay

3.1.2 System Head Curves Development

System head curves were developed from the ICM model for the envelop of expected hydraulic conditions for the Project over the full range of each maximum design flow condition. The pump suction conditions were the result of the hydraulic analysis performed between the Intakes and the Pumping Plant wet well. Two conditions were considered for the pump discharge: a siphon condition and an unprimed condition.

- **For the discharge siphon condition**, the water surface level within the Southern Forebay is the downstream boundary condition. For the siphon discharge condition each pump discharge piping system terminates within a diffuser structure in the Southern Forebay. The diffuser structure utilizes a weir that establishes a minimum free water surface that maintains vacuum pressures within each discharge pipe to within acceptable limits.
- **For the unprimed condition**, the pump discharge piping high-point elevation (which is above the maximum water surface level of the Southern Forebay) will be the downstream boundary condition.

3.1.2.1 Criteria

The system head curves are developed for the High Head (Unprimed), High Head (Primed), Design Head (Primed), Normal Low Head (Primed) and Extreme Low Head (Primed) static head conditions as discussed below.

- **The High Head (Unprimed)** system head curve is the maximum total dynamic head conditions required for operating any combinations of pumps. This condition represents the maximum static head conditions, systemwide head losses associated with the highest friction factor for the tunnel, and no discharge siphon established within the pump discharge piping system. Pumps are sized to start and operate at their maximum rated speeds under these conditions within their designated POR for any pump combination. The maximum design flow condition is not required to be achieved under these system head conditions.
- **The High Head (Primed)** system head curve was developed with the identical boundary conditions and systemwide head losses used to develop the High Head (Unprimed) system head curve, except this system head curve reflects a fully primed discharge siphon in each pump discharge piping system. These conditions represent the highest total heads under a pump discharge siphon condition.
- **The Design Head (Primed)** system head curve is the design head conditions whereby the maximum design flow of the Project must be achieved with the largest pumping unit out of service. This system head curve was developed with the systemwide head losses associated with the highest friction factor for the tunnel and a fully primed discharge siphon condition for each pump in operation.
- **The Normal Low Head (Primed)** system head curve is the lowest total dynamic head conditions for the pumps under normal low static head conditions and was developed with the lowest systemwide head losses associated with the lowest friction factor for the tunnel, and fully primed discharge siphon conditions for each pump in operation. Pumps will be required to operate at reduced speed conditions a lower Sacramento River diversion rates to maintain operation within each pump’s defined POR. Higher pumped flow capacities along this system head curve will permit pump combinations to operate at their maximum rated speeds within each pump’s POR.

- **The Extreme Low Head (Primed)** system head is the lowest possible total head conditions and represents the extreme low static head condition and developed with systemwide head losses associated with the lowest friction factor for the tunnel, and unprimed discharge siphon conditions.

The following criteria was used for system head curve development.

- **Project Design Flow Range:** System head curves were conducted over the full range of flows between 0 cfs and the maximum design flow capacities of 3,000, 4,500, 6,000 and 7,500 cfs. Table 1 below indicates the combination of available Intakes for each Project maximum design flow capacity.

Table 1. Proposed Project Capacity (cfs)

Intake	3,000	4,500	6,000	7,500
C-E-2	Not used	Not used	Not used	1,500
C-E-3	Not used	3,000	3,000	3,000
C-E-5	3,000	1,500	3,000	3,000

- **Water Surface Elevations:** Tables 2, 3, 4, and 5 provide the design water surface elevations (WSEs) for the Project maximum design flow scenarios considered in this analysis that establish static head conditions. All elevations are based on the North American Vertical Datum of 1988 (NAVD88).

Table 2. Design WSEs for System Head Curves Development at the Maximum Design Flow Condition of 7,500 cfs

Pump Head Condition	Sac River WSE	Southern Forebay WSE	Wet Well WSE
High head	3.61	17.5	-39.0
Design head	4.47	15.3	-37.8
Normal low head	5.75	10.0[a]	-19.3
Extreme low head	26.3	10.0[a]	3.0

[a] weir elevation downstream of pump discharge piping

Notes:

WSE = water surface elevation

TDH = Total dynamic head

All values are in feet

Table 3. Design WSEs for System Head Curves Development at the Maximum Design Flow Condition of 6,000 cfs

Pump Head Condition	Sac River WSE	Southern Forebay WSE	Wet Well WSE
High head	3.8	17.5	-45.0
Design head	4.7	15.3	-44.0
Normal low head	5.9	10.0[a]	-21.2
Extreme low head	27.3	10.0[a]	0.6

[a] weir elevation downstream of pump discharge piping

Notes:

WSE = water surface elevation

TDH = Total dynamic head

All values are in feet

Table 4. Design WSEs for System Head Curves Development at the Maximum Design Flow Condition of 4,500 cfs

Pump Head Condition	Sac River WSE	Southern Forebay WSE	Wet Well WSE
High head	3.7	17.5	-53.6
Design head	4.6	15.3	-52.4
Normal Low Head	5.9	10.0[a]	-27.3
Extreme Low head	27.3	10.0[a]	-4.9

[a] weir elevation downstream of pump discharge piping

Notes:

WSE = water surface elevation

TDH = Total dynamic head

All values are in feet

Table 5. Design WSEs for System Head Curves Development at the Maximum Design Flow Condition of 3,000 cfs

Pump Head Condition	Sac River WSE	Southern Forebay WSE	Wet Well WSE
High head	3.6	17.5	-58.4
Design head	4.5	15.3	-56.9
Normal Low Head	5.8	10.0[a]	-30.0
Extreme Low head	26.3	10.0[a]	-8.9

[a] weir elevation downstream of pump discharge piping

Notes:

WSE = water surface elevation

TDH = Total dynamic head

All values are in feet

- This analysis included the following Standard Roughness Coefficients:
  - Manning's n of 0.016 was used to develop the "High Head" and "Design Head" system head curves and represents the highest friction conditions
  - Manning's n of 0.014 was used to develop the "Low Head" and "Extreme Low Head" system head curves and represents the lowest fiction conditions
  - Pipe friction absolute roughness values of 0.1 mm to 1.5 mm was used to calculate minor losses within piping systems
- **Siphon and Non-siphon Conditions:** Each pump would incorporate discharge piping that would be capable of developing a discharge siphon as shown in the concept drawings. The invert elevation (bottom) at the crest of the siphon would be designed to isolate the Pumping Plant wet well from the Southern Forebay without the use of non-return (check) valves. Static head conditions associated with a discharge siphon condition would utilize the water surface operating range within the pump discharge energy dissipation basin as noted in Tables 2 through 5.

Static head requirements with pumping through an unprimed discharge siphon were also incorporated into the system head curves and pump sizing evaluation for steady-state operations, as this condition would occur each time the pump is started, the siphon would fail to generate. This non-siphon condition would assume no hydraulic connection between the Pumping Plant wet well and the Southern Forebay. Therefore, no vacuum would be established in the pump discharge piping arrangement; and then, the downstream static head value associated with the unprimed condition would be established at the top of pipe elevation within the goose-neck arrangement of each pump's discharge piping.

3.1.2.2 Methodology

The Pumping Plant maximum and minimum total dynamic head (TDH) conditions within the design flow ranges for the Project were determined as follows:

- Calculated the maximum and minimum free WSEs within the Pumping Plant wet well by determining the maximum and minimum hydraulic grade line (HGL) profile envelopes between the Sacramento River intakes and the Pumping Plant wet well.
- Calculated the minimum WSE in the Pumping Plant wet well based on the minimum Sacramento River elevation and the tunnel head loss calculated with the highest Manning's *n* value at the maximum flow condition.
- Calculated the maximum WSE in the Pumping Plant wet well based on the maximum Sacramento River elevation and zero-flow within the tunnel.
- Computed the TDH required to lift flow from the PP wet well HGL elevation to the primed and unprimed discharge head of the pumps. TDH calculation also includes both friction and minor losses developed within the vertical pump discharge column and discharge piping.
- System head curves were developed for the High Head, Design Head, Normal Low Head, and Extreme Low Head conditions using the criteria defined above including the applicable criteria defined in the Hydraulics Analysis Criteria TM (Draft).

3.2 Pump Selection Design Criteria

Vertical-column (standard and pull-out style) pump designs are considered as the main raw water pump type for this evaluation. The Pumping Plant wet well would incorporate either individual formed suction intakes (FSI) or individual open-top intake cans for each pump.

The pump selection process considered several combinations of pump sizes and corresponding operating speed ranges that would maintain each pump within the Preferred Operating Region (POR), as defined by the ANSI/HI Standard 9.6.3, throughout the design head conditions between 10 percent and 100 percent of the established design flow capacity of the Pumping Plant. For a maximum design flow capacity of 7,500 cfs, the Pumping Plant design flow range would be 750 to 7,500 cfs. When pump operating conditions fall outside of the POR, pump performance was required to be well within the manufacturer's recommended Allowable Operating Region (AOR).

The initial pump selection screening included combinations of higher and smaller capacity pumps which provide operational flexibility for pumping the full range of the expected river diversion flows. The rated capacity of the smaller pumps was sized slightly higher than 50 percent of the large pump's rated capacity. Each smaller capacity pump was identical. Each larger capacity pump was identical.

Each candidate pump considered was evaluated within the design conditions highlighted under Section 3.1. Additional design criteria for the candidate pumps included:

- Capable of achieving minimum flows (10 percent of the maximum design flow capacity) at all anticipated wet-well and Southern Forebay operating levels associated with the design head conditions with a single pump
- Capable of achieving maximum flows (100 percent of the maximum design flow capacity) at all anticipated wet-well and Southern Forebay operating levels with the largest pump out of service
- No unachievable flowrates among operating combinations of pumps within the designated design flow range (10 percent to 100 percent of the maximum design flow capacity)
- Pumps operate primarily within their POR within the envelop of system flow and head conditions
- Pumps may operate outside their POR but preferably well within the manufacturer's defined AOR within the envelop of system flow and head conditions

3.3 Candidate Pump Manufacturer and Performance Requirements

A number of pump manufacturers were consulted during this evaluation, including Fairbanks Morse, Flygt-Xylem, Patterson Pumps, Morrison Pump, and Ebara. The candidate manufacturers' pump performance curves were evaluated based on the required envelop of system flow and head conditions as defined in the above sections of this TM. For purposes of this TM, pump selections obtained by Flygt-Xylem were used to illustrate the performance requirements for each of the Project's maximum design flow options.

3.3.1 Pumping Plant Maximum Design Flow Condition of 7,500 cfs

Figure 1 shows the system head curves developed for the high head, design head, normal low head and extreme low head static head conditions defined in Table 2 that determine the envelope of expected hydraulic conditions associated with the maximum design flow capacity of 7,500 cfs for the Project.

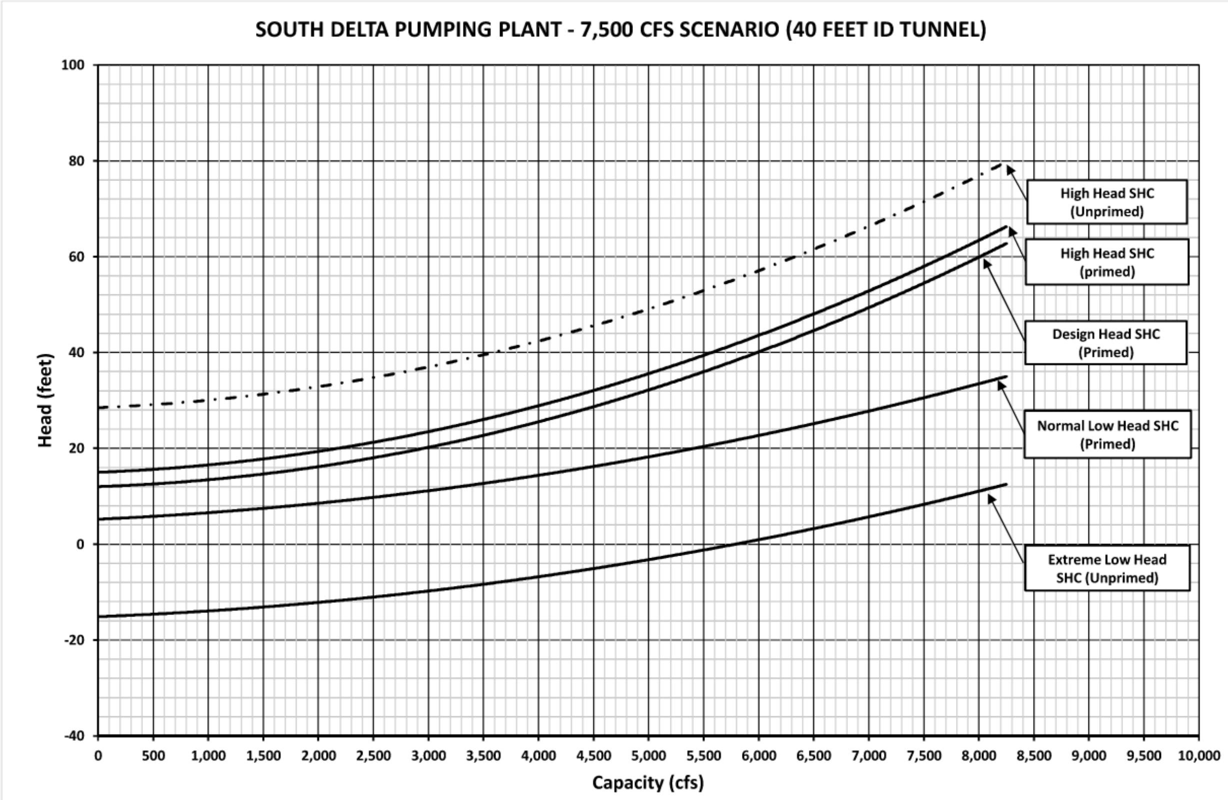

Figure 1. System Head Curves with the Maximum Design Flow Capacity of 7,500 cfs

As shown in Figure 2, the system head curves were plotted against the candidate pump performance curves.

Under the Extreme Low Head (Primed) condition, gravity flow through the tunnel would be established and pumps would be bypassed and therefore, pump performance at this system head curve was not evaluated.

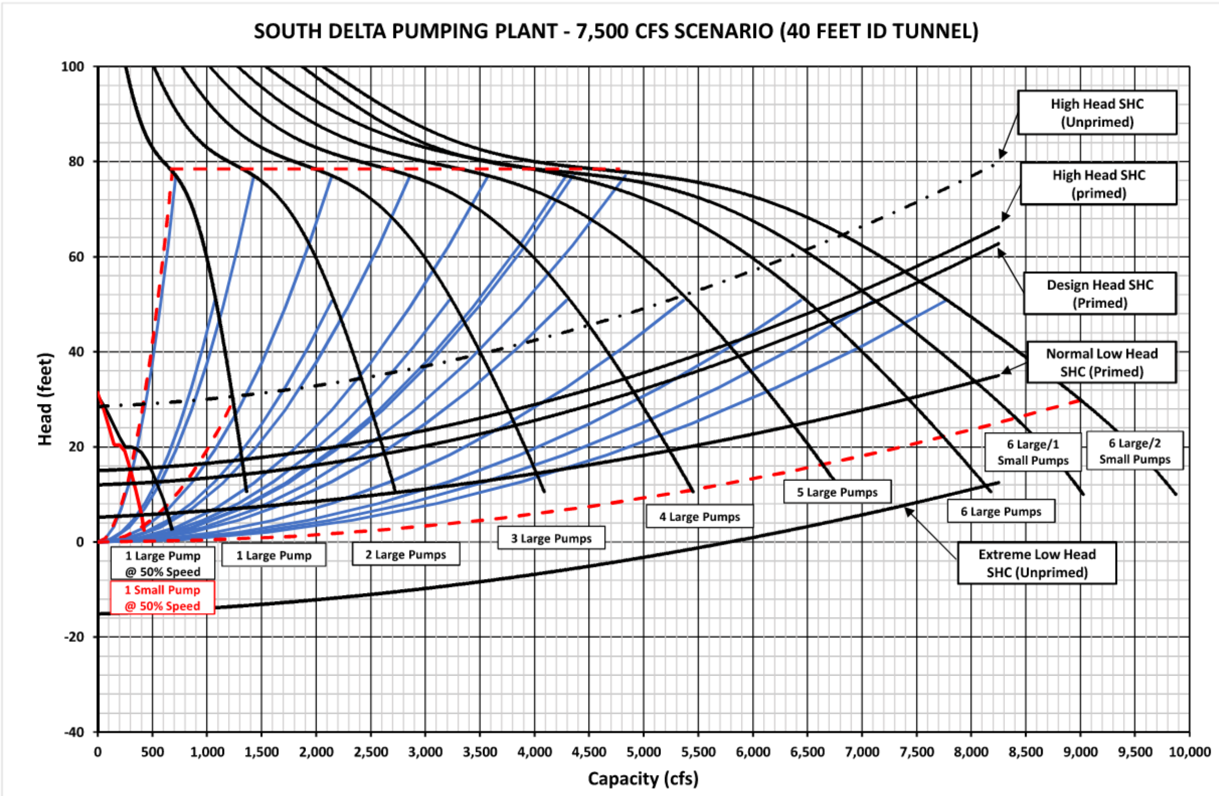

Figure 2. Pump Selection for the Maximum Design Flow Capacity of 7,500 cfs

The high flow capacity candidate pump selection (identified in Figure 2 as "Large Pump") is the Xylem, Model 78850 pump at the maximum rated operating speed of 200 revolutions per minute (rpm). The lower flow capacity pump selection (identified in Figure 2 as "Small Pump") is the Xylem, Model 78399 pump at the maximum rated operating speed of 255 rpm. Model 78850 is a 9,000 horsepower (hp) pump with a design flow capacity of 960 cfs @ 62.5 feet of TDH. Model 78839 is a 6,000-hp pump with a design flow capacity of 600 cfs @ 62.5 feet of TDH. The Model 78850 is one of the larger pumps manufactured by Xylem that meet the Project's flow and head conditions and has successful service history for projects of similar head and flow capacities.

The POR for each pump and for parallel operation has been plotted in Figure 2. The minimum and maximum flows defining the POR are shown with blue curves and are plotted across the system head curves for each pump. The minimum and maximum flow envelope defining the pump manufacturer's AOR is shown with red dashed curves and is plotted across the system head curves for a single pump and all pumps operating in parallel.

As shown in Figure 2, the maximum design flow of 7,500 cfs at the design head condition is 54.3 feet under primed discharge siphon condition. The maximum design flow condition is established with six large capacity pumps and two smaller capacity pumps operating in parallel at their maximum rated speeds and within the POR of all pumps in operation. To achieve the minimum flow of 750 cfs (10 percent of the maximum design flow of 7,500 cfs), operating a single larger capacity pump at slightly higher than 50 percent of its rated speed is required. The minimum flow can also be achieved by operating a smaller capacity pump at reduced speed. To maintain operation within each pump's POR for flows less than the maximum design flow capacity of 7,500 cfs along the Design Head system head curve, the pumps must operate in parallel at reduced speeds. These speeds can be determined by the intersection of the POR affinity curves with the Design Head system head curves as shown in Figure 2. The operating range of the pumps can be extended within the AOR along the Design Head system head curve (to achieve higher capacities per pump) but will still require parallel operation at reduced speeds.

Operation of the pumps along the High Head (Unprimed) system head curves can be accomplished within the full operating speed range of each pump and maintain performance within each pump's AOR as can be seen in Figure 2. The maximum pumped flow is 6,850 cfs based on the pump combination shown in Figure 2. However, this maximum capacity can be increased by starting additional higher capacity pumps if required. The minimum achievable pumped flow capacity using a single, higher capacity pump operating at reduced speed is 420 cfs (well below the minimum Project design flow capacity of 750 cfs). This is determined by the intersection of the POR with the High Head (Unprimed) curve as shown in Figure 2.

Operation of the pump combinations along the Normal Low Head (Primed) system head curve is restricted along the POR and will require all pumps to operate at reduced speed. The maximum flow achievable with eight pumps (six higher capacity pumps and two lower capacity pumps) is 4,200 cfs. Pump operation outside of the POR but well within the AOR allows the maximum design flow capacity of 7,500 cfs to be achieved with the same eight pumps operating at reduced speed combinations. The minimum achievable pumped flow capacity using a single, higher capacity pump operating at 50 percent of its maximum rated speed is about 630 cfs and occurs at the extreme limit of the pump's AOR. To maintain operation further within the pump's AOR at this low flow condition, the pump can be operated in the "Unprimed" condition which will develop system head conditions based on the highpoint static head of the pump discharge piping and will maintain pump performance well within the pump's AOR.

3.3.1.1 Evaluation of Variable Speed Operation

The purpose of this evaluation is to determine the minimum number of adjustable speed drives (AFDs) required for the candidate pumps (in any combination) to achieve: 1) all steady-state flow capacities within the complete design flow range of 750 to 7,500 cfs along the Design Head (Primed) system curve conditions within each pump's POR; 2) all achievable steady-state flow capacities from the minimum design flow of 750 cfs up to the maximum attainable flow capacity of 7,390 cfs (six higher capacity pumps and 2 lower capacity pumps) along the High Head (Primed) system curve conditions within each pump's POR; and 3) all steady-state flow capacities within the complete design flow range of 750 to 7,500 cfs along the Normal Low Head (Primed) system curve conditions within each pumps AOR.

As shown in Figure 2, to operate the higher capacity and lower capacity pumps at maximum speed and maintain their operation within the POR for the Design Head (Primed) system head conditions, a minimum total dynamic head (TDH) of 51 feet is required based on each pump's maximum flow within their POR. The total dynamic head condition of 51 feet or higher is achieved along the Design Head (primed) system head curve at flow capacities of 7,140 cfs and above. For the pump combination shown in Figure 2, a minimum of six higher capacity pumps and one smaller capacity pump operating in parallel at reduced speeds are required to develop 7,140 cfs of pumped flow capacity. Therefore, to maintain pump operation within the POR for flow capacities between 750 and 7,140 cfs, all pump combinations must operate with variable frequency drives. On this basis, only one lower capacity pump can utilize a constant speed driver (while all others utilize variable speed drives) and can only be operated for flows above 7,140 cfs, and must be the last pump in the starting sequence.

To operate the higher capacity and lower capacity pumps at maximum speed along the High Head (Primed) system head curve, and maintain pump operation within the POR, a minimum pumped flow capacity of 6,800 cfs is required. To achieve the pumped flow capacity of 6,800 cfs, based on the pump combination shown in Figure 2, six higher capacity pumps and one smaller capacity pump must be in operating in parallel at reduced speeds. Therefore, only one lower capacity pump can operate with a constant speed driver and can only be operated for flows above 7,140 cfs, and must be the last pump in the starting sequence.

To operate the higher capacity and lower capacity pumps at maximum speed along the Normal Low Head (Primed) system head curve, a minimum system head condition of 30 feet is required based on each pump's maximum flow and corresponding minimum head within the AOR. The total dynamic head condition of 30 feet is achieved along the Normal Low Head (primed) system head curve at flow capacities of 7,400 cfs and above. For the pump combination shown in Figure 2, a minimum of six higher capacity pumps operating in parallel at maximum speed is required to develop 7,400 cfs of pumped flow capacity. Therefore, to maintain pump operation within the AOR for flow capacities between 750 and 7,400 cfs, all pumps must operate with variable frequency drives. On this basis, two lower capacity pumps can operate with a constant speed driver (while all others utilize variable speed drives) and can only be operated at flows above 7,400 cfs and must be the last two pumps in the starting sequence.

From the above evaluation, to achieve all steady-state flow capacities within the complete design flow range of 750 to 7,500 cfs along the Design Head (Primed) system curve conditions within each pump's POR, it is recommended to equip all pumps (higher capacity and lower capacity) with variable speed drives. Since it was determined only one lower capacity pump can be equipped with a constant speed driver and cannot be started until a pumped flow of 7,140 cfs is developed it is recommended that all pumps (higher capacity and lower capacity pumps) be equipped with variable speed drives. It was further determined that maintaining each pump within the POR and AOR for all conditions will require variable speed drivers for all system head curve conditions evaluated. By equipping all pumps with variable speed drives there will be no restrictions in the starting sequence (for all duty and standby pumps) for any combination of higher and lower capacity pumps.

3.3.1.2 Pump Redundancy

To ensure the operational reliability of the Pumping Plant the following pumping equipment redundancy has been included in the concept design.

- For the higher capacity pumps, six duty pumps with two standby pumps (N+2) have been included. The higher capacity pumps are the primary pumps that establish the majority of the pumped flow for the system. As such, these pumps are considered critical to the system. Repair of these pumps can require extended periods of time and therefore, two standby pumps are recommended.
- For the lower capacity pumps, two duty pumps with one standby pump (N+1) have been included. The lower capacity pumps are primarily used for flow trimming and are less critical since there are two standby pumps for the higher capacity pumps. As such, for the lower capacity pumps one standby pump is recommended.

Based on the above recommended pumping unit redundancies a total of eight higher capacity pumps and three lower capacity pumps (11 pumps total) are shown on the concept drawings. With eleven pumps installed, the Pumping Plant can achieve the maximum design flow capacity of 7,500 cfs with up to three pumps out of service (i.e., two higher capacity pumps and one lower capacity pump).

3.3.2 Pumping Plant Maximum Design Flow Condition of 6,000 cfs

Figure 3 shows the system head curves developed for the high head, design head, normal low head and extreme low head static head conditions defined in Table 3 that determine the envelope of expected hydraulic conditions associated with the maximum design flow capacity of 6,000 cfs for the Project.

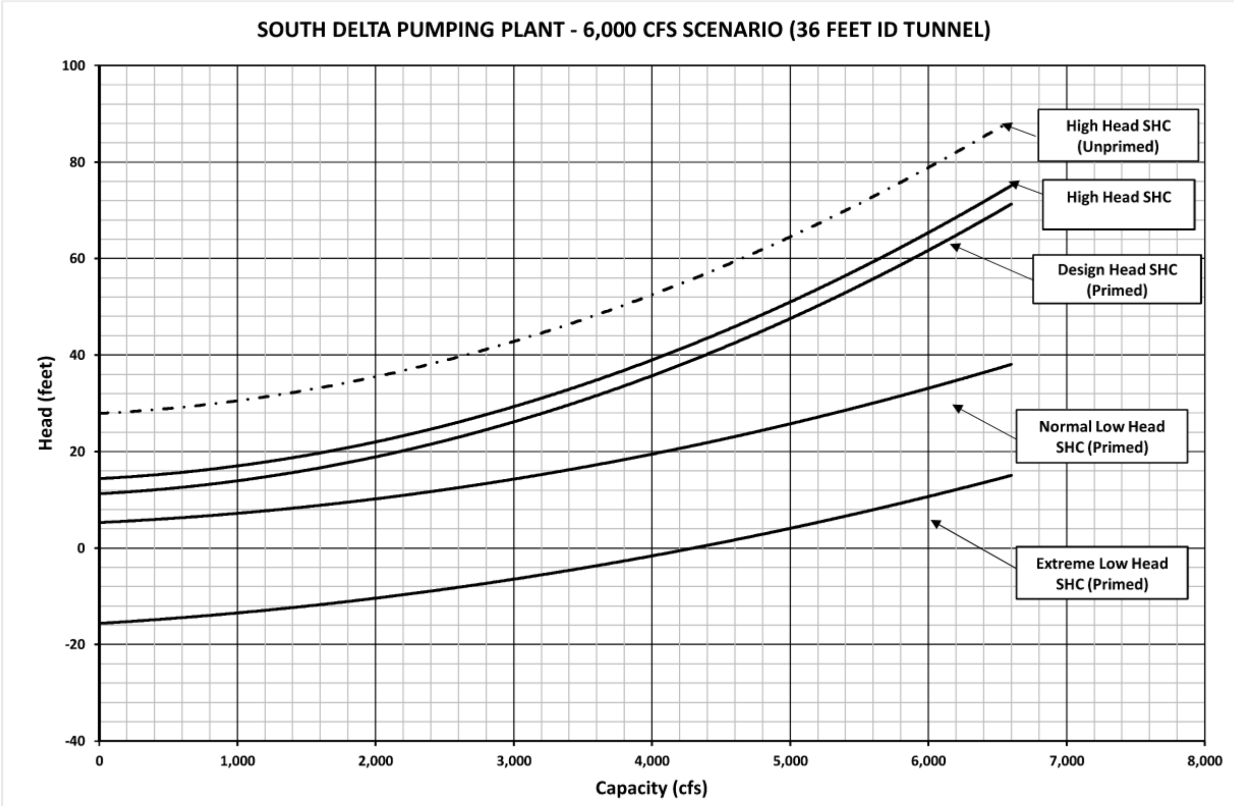

Figure 3. System Head Curves with the Maximum Design Flow Capacity of 6,000 cfs

As can be seen in Figure 4, the system head curves were plotted against the candidate pump performance curves.

Under the Extreme Low Head (Primed) condition, gravity flow through the tunnel would be established and pumps would be bypassed and therefore, pump performance at this system head curve was not evaluated.

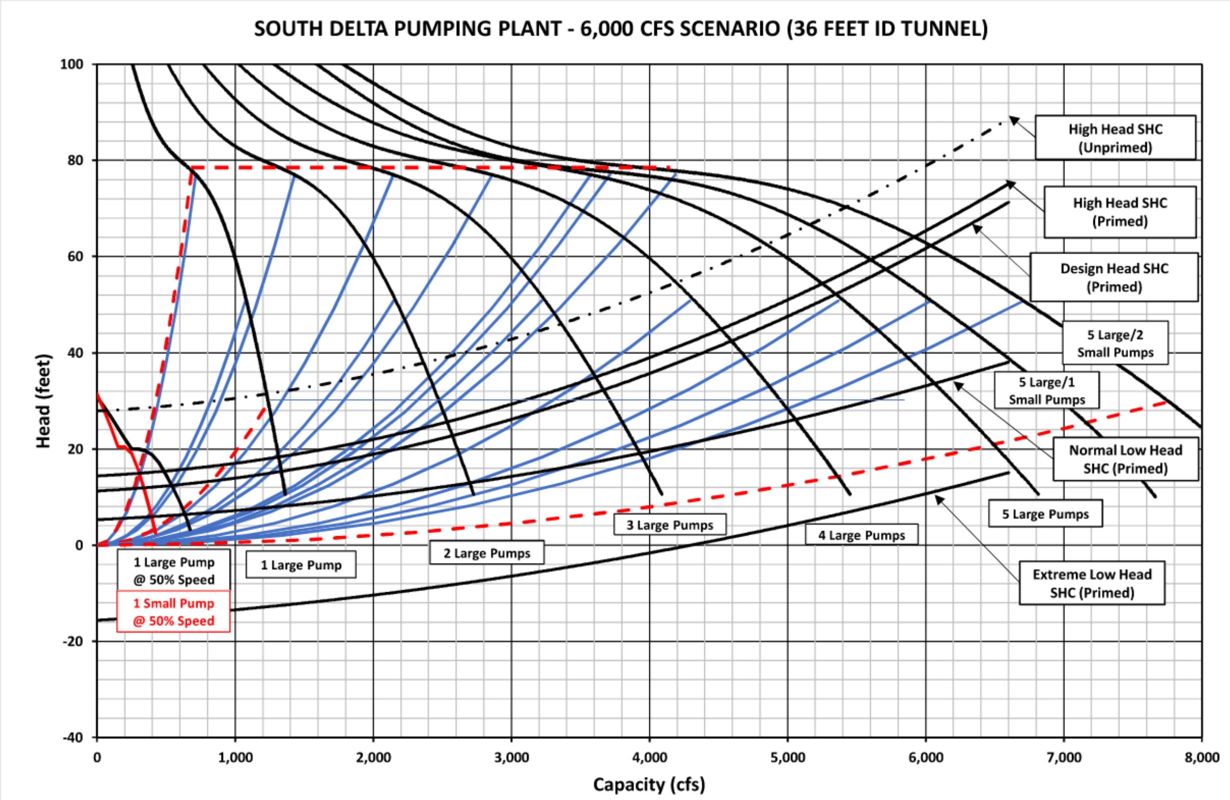

Figure 4. Pump Selection for the Maximum Design Flow Capacity of 6,000 cfs

The high flow capacity candidate pump selection (identified in Figure 4 as "Large Pump") is the Xylem, Model 78850 pump at the maximum rated operating speed of 200 revolutions per minute (rpm). The lower flow capacity pump selection (identified in Figure 4 as "Small Pump") is the Xylem, Model 78399 pump at the maximum rated operating speed of 255 rpm. Model 78850 is a 9,000 horsepower (hp) pump with a design flow capacity of 960 cfs @ 62.5 feet of TDH. Model 78839 is a 6,000-hp pump with a design flow capacity of 600 cfs @ 62.5 feet of TDH.

The POR for each pump and for parallel operation has been plotted in Figure 4. The minimum and maximum flows defining the POR are shown with blue curves and are plotted across the system head curves for each pump. The minimum and maximum flow envelope defining the pump manufacturer's AOR is shown with red dashed line curves and is plotted across the system head curves for a single pump and, all pumps operating in parallel.

As can be seen in Figure 4, the maximum design flow of 6,000 cfs at the Design Head condition is 61.0 feet under primed discharge siphon condition. The maximum design flow condition is established with five large capacity pumps and two smaller capacity pumps operating in parallel at their maximum rated speeds and within the POR of all pumps in operation. To achieve the minimum flow of 600 cfs (10 percent of the maximum design flow of 6,000 cfs), operating a single larger capacity pump at slightly higher than 50 percent of its rated speed is required. The minimum flow can also be achieved by operating a smaller capacity pump at reduced speed. To maintain operation within each pump's POR for flows less than the maximum design flow capacity of 6,000 cfs along the Design Head system head curve, the pumps must operate in parallel at reduced speeds. These speeds can be determined by the intersection of the POR affinity curves with the Design Head system head curves as shown in Figure 4. The operating range of the pumps can be extended within the AOR along the Design Head system head curve (to achieve higher capacities per pump) but will still require parallel operation at reduced speeds.

Operation of the pumps along the High Head (Unprimed) system head curve can be accomplished within the full operating speed range of each pump and maintain performance within each pump's AOR as can be seen in Figure 4. The maximum pumped flow under this condition is 5,480 cfs based on the pump combination shown in Figure 4. However, this maximum capacity can be increased by starting additional higher capacity pumps if required. The minimum achievable pumped flow capacity using a single, higher capacity pump operating at reduced speed is 420 cfs (well below the minimum Project design flow capacity of 600 cfs). This is determined by the intersection of the POR with the High Head (Unprimed) curve as shown in Figure 2.

Operation of the pump combinations along the Normal Low Head (Primed) system head curve is restricted along the POR and will require all pumps to operate in reduced speed. The maximum flow achievable with seven pumps (five higher capacity pumps and two lower capacity pumps) is 4,200 cfs. Pump operation outside of the POR but well within the AOR allows the maximum design flow capacity of 6,000 cfs to be achieved with the same seven pumps operating at reduced speed combinations. The minimum achievable pumped flow capacity using a single, higher capacity pump operating at 50 percent of its maximum rated speed is about 630 cfs and occurs at the extreme limit of the pump's AOR. The minimum achievable pumped flow capacity using a single, lower capacity pump operating at 50 percent of its maximum rated speed is about 400 cfs and occurs within the pump's POR. To maintain operation of a single higher capacity pump well within the pump's AOR at this low flow condition, the pump can be operated in the "Unprimed" condition which will develop system head conditions based on the highpoint static head of the pump discharge piping.

3.3.2.1 Evaluation of Variable Speed Operation

The purpose of this evaluation is to determine is to determine the minimum number of adjustable speed drives (AFDs) required for the candidate pumps (in any combination) to achieve: 1) all steady-state flow capacities within the complete design flow range of 600 to 6,000 cfs along the Design Head (Primed) system curve conditions within each pump's POR; 2) all achievable steady-state flow capacities from the minimum design flow of 600 cfs up to the maximum attainable flow capacity of 5,920 cfs (five higher capacity pumps and 2 lower capacity pumps) along the High Head (Primed) system curve conditions within each pump's POR; and 3) all steady-state flow capacities within the complete design flow range of 600 to 6,000 cfs along the Normal Low Head (Primed) system curve conditions within each pumps AOR.

As shown in Figure 4, to operate the higher capacity and lower capacity pumps at maximum speed and maintain their operation within the POR for the Design Head (Primed) system head conditions, a minimum system head condition of 51 feet is required based on each pump's maximum flow and corresponding minimum head within the POR. The total dynamic head condition of 51 feet is achieved along the Design Head (primed) system head curve at flow capacities of 5,250 cfs and above. For the pump combination shown in Figure 4, a minimum of five higher capacity pumps operating in parallel at reduced speed is required to develop 5,250 cfs of pumped flow capacity. Therefore, to maintain pump operation within the POR for flow capacities between 600 and 5,250 cfs, all pump combinations must operate with variable frequency drives. On this basis, only two lower capacity pumps can utilize constant speed drivers (while all others utilize variable speed drives) and can only be operated for flows above 5,250 cfs and must be the last two pumps in the starting sequence.

To operate the higher capacity and lower capacity pumps at maximum speed along the High Head (Primed) system head curve, and to maintain pump operation within the POR, a minimum pumped flow capacity of 5,000 cfs is required. To achieve the pumped flow capacity of 5,000 cfs, based on the pump combination shown in Figure 4, five higher capacity pumps must be in operation at reduced speeds.

Therefore, two lower capacity pumps can operate with a constant speed driver and can only be operated for flows above 5,000 cfs and must be the last two pumps in the starting sequence.

To operate the higher capacity and lower capacity pumps at maximum speed along the Normal Low Head (Primed) system head curve, a minimum system head condition of 30 feet is required based on each pump's maximum flow and corresponding minimum head within the AOR. The total dynamic head condition of 30 feet is achieved along the Normal Low Head (primed) system head curve at flow capacities of 5,600 cfs and above. For the pump combination shown in Figure 4, a minimum of five higher capacity pumps operating in parallel at reduced speeds is required to develop 5,600 cfs of pumped flow capacity. Therefore, to maintain pump operation within the AOR for flow capacities between 600 and 5,600 cfs, all pumps must operate with variable frequency drives. On this basis, two lower capacity pumps can operate with a constant speed driver (while all others utilize variable speed drives) which can only be operated at flows above 5,600 cfs and must be the last pumps in the starting sequence.

From the above evaluation, to achieve all steady-state flow capacities within the complete design flow range of 600 to 6,000 cfs along the Design Head (Primed) system curve conditions within each pump's POR, it is recommended to equip all pumps (higher capacity and lower capacity) with variable speed drives. Since it was determined only two lower capacity pumps can be equipped with constant speed drives and cannot be started until a pumped flow of 5,250 cfs is developed it is recommended that all pumps (higher capacity and lower capacity pumps) be equipped with variable speed drives so that the smaller capacity pumps can be operated at lower design flow conditions. It was further determined that maintaining each pump within the POR and AOR for all conditions will require variable speed drivers for all system head curve conditions evaluated. By equipping all pumps with variable speed drives there will be no restrictions in the starting sequence for any combination of higher and lower capacity pumps.

3.3.2.2 Pump Redundancy

To ensure the operational reliability of Pumping Plant the following pumping equipment redundancy has been included in the concept design.

- For the higher capacity pumps, five duty pumps with two standby pumps (N+2) have been included. The higher capacity pumps are the primary pumps that establish the majority of the pumped flow for the system. As such, these pumps are considered critical to the system. Repair of these pumps can require extended periods of time and therefore, two standby pumps are recommended.
- For the lower capacity pumps, two duty pumps with one standby pump (N+1) have been included. The lower capacity pumps are primarily used for flow trimming and are less critical since there are two standby pumps for the higher capacity pumps. As such, for the lower capacity pumps one standby pump is recommended.

Based on the above recommended pumping unit redundancies a total of seven higher capacity pumps and three lower capacity pumps (10 pumps total) are shown on the concept drawings. With ten pumps installed, the Pumping Plant can achieve the maximum design flow capacity of 7,500 cfs with up to three pumps out of service (i.e., two higher capacity pumps and one lower capacity pump).

Figure 5 shows the system head curves developed for the high head, design head, normal low head and extreme low head static head conditions defined in Table 4 that determine the envelope of expected hydraulic conditions associated with the maximum design flow capacity of 4,500 cfs for the Project.

As can be seen in Figure 5, the system head curves were plotted against the candidate pump performance curves.

3.3.3 Pumping Plant Maximum Design Flow Condition of 4,500 cfs

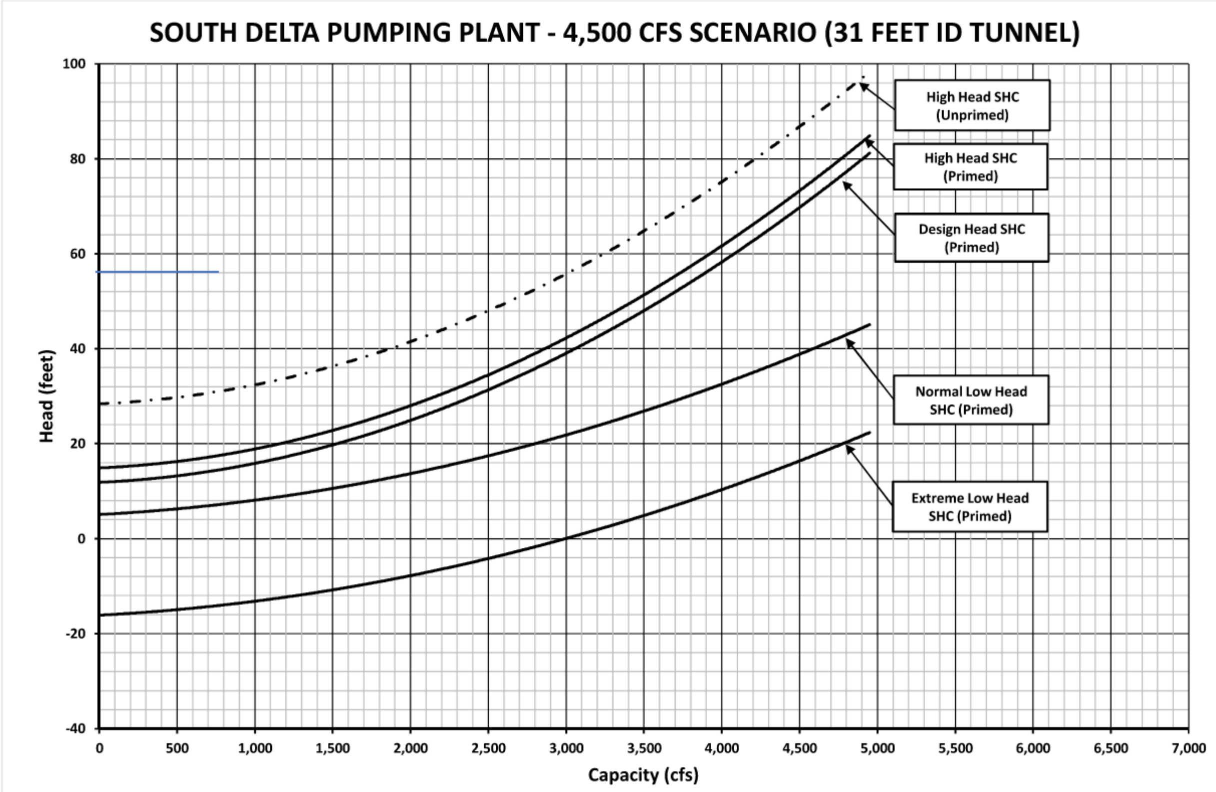

Figure 5. System Head Curves with the Maximum Design Flow Capacity of 4,500 cfs

Under the Extreme Low Head (Primed) condition, gravity flow through the tunnel would be established and pumps would be bypassed and therefore, pump performance at this system head curve was not evaluated.

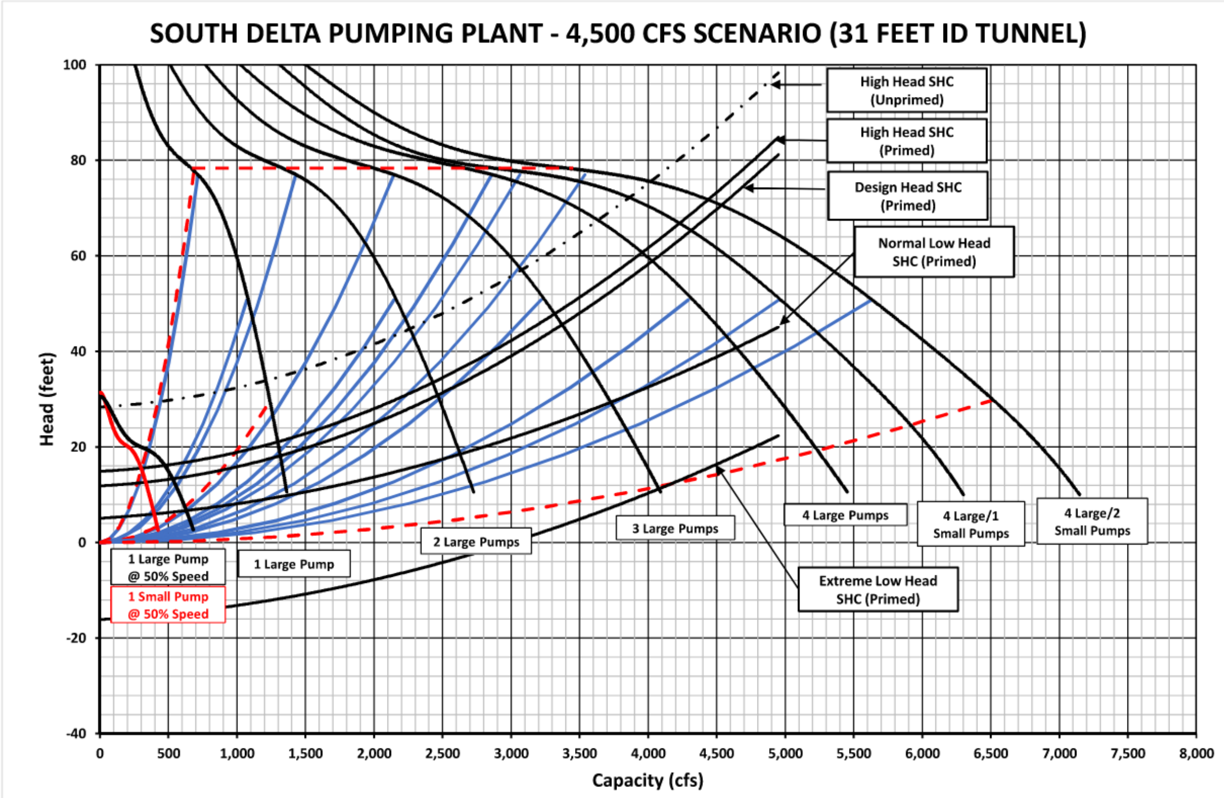

Figure 6. Pump Selection for the Maximum Design Flow Capacity of 4,500 cfs

The high flow capacity candidate pump selection (identified in Figure 6 as "Large Pump") is the Xylem, Model 78850 pump at the maximum rated operating speed of 200 revolutions per minute (rpm). The lower flow capacity pump selection (identified in Figure 6 as "Small Pump") is the Xylem, Model 78399 pump at the maximum rated operating speed of 255 rpm. Model 78850 is a 9,000 horsepower (hp) pump with a design flow capacity of 960 cfs @ 62.5 feet of TDH. Model 78839 is a 6,000-hp pump with a design flow capacity of 600 cfs @ 62.5 feet of TDH.

The POR for each pump and for parallel operation has been plotted in Figure 6. The minimum and maximum flows defining the POR are shown with blue curves and are plotted across the system head curves for each pump. The minimum and maximum flow envelope defining the pump manufacturer's AOR is shown with red dashed curves and is plotted across the system head curves for a single pump and all pumps operating in parallel.

As can be seen in Figure 6, the maximum design flow of 4,500 cfs at the Design Head condition is 69.2 feet under primed discharge siphon condition. The maximum design flow condition is established with four large capacity pumps and two smaller capacity pumps operating in parallel at their maximum rated speeds and within the POR of all pumps in operation. To achieve the minimum flow of 450 cfs (10 percent of the maximum design flow of 4,500 cfs), operating a single smaller capacity pump at slightly higher than 50 percent of its rated speed is required. To maintain operation within each pump's POR for flows less than the maximum design flow capacity of 4,500 cfs along the Design Head system head curve, the pumps must operate in parallel at reduced speeds. These speeds can be determined by the intersection of the POR affinity curves with the Design Head system head curves as shown in Figure 4. The operating range of the pumps can be extended within the AOR along the Design Head system head curve (to achieve higher capacities per pump) but will still require parallel operation at reduced speeds.

Operation of the pumps along the High Head (Unprimed) system head curve can be accomplished within the full operating speed range of each pump and maintain performance within each pump's AOR as can be seen in Figure 6. The maximum pumped flow under this condition is 4,000 cfs based on the pump combination shown in Figure 6. However, this maximum capacity can be increased by starting additional higher capacity pumps if required. The minimum achievable pumped flow capacity using a single, higher capacity pump operating at reduced speed is 420 cfs (below the minimum Project design flow capacity of 450 cfs). This is determined by the intersection of the POR with the High Head (Unprimed) curve as shown in Figure 2. The minimum achievable pumped flow capacity using a single, smaller capacity pump operating at reduced speed is approximately 390 cfs (below the minimum Project design flow capacity of 450 cfs).

Operation of the pump combinations along the Normal Low Head (Primed) system head curve is restricted along the POR and will require all pumps to operate in reduced speed. The maximum flow achievable with six pumps (four higher capacity pumps and two lower capacity pumps operating at reduced speed) is 4,500 cfs. Pump operation outside of the POR but well within the AOR allows the maximum design flow capacity of 4,500 cfs to be achieved with the five pumps (four higher capacity pumps and one lower capacity pump) operating at reduced speed combinations. The minimum achievable pumped flow capacity using a single, higher capacity pump operating at 50 percent of its maximum rated speed is about 630 cfs and occurs at the extreme limit of the pump's AOR. The minimum achievable pumped flow capacity using a single, smaller capacity pump operating at 50 percent of its maximum rated speed is about 400 cfs and occurs at the extreme limit of the pump's POR.

3.3.3.1 Evaluation of Variable Speed Operation

The purpose of this evaluation is to determine the minimum number of adjustable speed drives (AFDs) required for the candidate pumps (in any combination) to achieve: 1) all steady-state flow capacities within the complete design flow range of 450 to 4,500 cfs along the Design Head (Primed) system curve conditions within each pump's POR; 2) all achievable steady-state flow capacities from the minimum design flow of 450 cfs up to the maximum attainable flow capacity of 4,420 cfs (four higher capacity pumps and 2 lower capacity pumps) along the High Head (Primed) system curve conditions within each pump's POR; and 3) all steady-state flow capacities within the complete design flow range of 450 to 4,500 cfs along the Normal Low Head (Primed) system curve conditions within each pumps AOR.

As shown in Figure 6, to operate the higher capacity and lower capacity pumps at maximum speed and maintain their operation within the POR for the Design Head (Primed) system head conditions, a minimum total dynamic head of 51 feet is required based on each pump's maximum flow and corresponding minimum head within the POR. The total dynamic head condition of 51 feet is achieved along the Design Head (primed) system head curve at flow capacities of 3,700 cfs and above. For the pump combination shown in Figure 6, a minimum of four higher capacity pumps operating in parallel at reduced speeds is required to develop 3,700 cfs of pumped flow capacity. Therefore, to maintain pump operation within the POR for flow capacities between 450 and 3,700 cfs, all pump combinations must operate with variable frequency drives. On this basis only two lower capacity pumps can utilize constant speed drivers (while all others utilize variable speed drives) and can only be operated for flows above 3,700 cfs and must be the last pumps in the starting sequence.

To operate the higher capacity and lower capacity pumps at maximum speed along the High Head (Primed) system head curve, and maintain pump operation within the POR, a minimum pumped flow capacity of 3,500 cfs is required. To achieve the pumped flow capacity of 3,500 cfs, based on the pump combination shown in Figure 6, four higher capacity pumps must be in operation at reduced speeds.

Therefore, only two lower capacity pumps can operate with constant speed drivers and can only be operated for flows above 3,500 cfs and must be the last pumps in the starting sequence.

To operate the higher capacity and lower capacity pumps at maximum speed along the Normal Low Head (Primed) system head curve, a minimum system head condition of 30 feet is required based on each pump's maximum flow and corresponding minimum head within the AOR. The total dynamic head condition of 30 feet is achieved along the Normal Low Head (primed) system head curve at flow capacities of 3,740 cfs and above. For the pump combination shown in Figure 6, a minimum of three higher capacity pumps operating in parallel at maximum speed is required to develop 3,740 cfs of pumped flow capacity. Therefore, to maintain pump operation within the AOR for flow capacities between 450 and 3,740 cfs, all pumps must operate with variable frequency drives. On this basis, two lower capacity pumps can operate with constant speed drivers (while all others utilize variable speed drives) and they can only be operated at flows above 3,740 cfs and must be the last two pumps in the starting sequence.

From the above evaluation, to achieve all steady-state flow capacities within the complete design flow range of 450 to 4,500 cfs along the Design Head (Primed) system curve conditions within each pump's POR, even though it was determined that one higher capacity and two lower capacity pumps could be equipped with constant speed drivers it is recommended to equip all pumps (higher and lower capacity pumps) with variable frequency drives so that there will be no restrictions in the starting sequence for any combination of higher and lower capacity pumps.

3.3.3.2 Pump Redundancy

To ensure the operational reliability of the Pumping Plant the following pumping equipment redundancy has been included in the concept design.

- For the higher capacity pumps, four duty pumps with two standby pumps (N+2) have been included. The higher capacity pumps are the primary pumps that establish the majority of the pumped flow for the system. As such, these pumps are considered critical to the system. Repair of these pumps can require extended periods of time and therefore, two standby pumps are recommended.
- For the lower capacity pumps, two duty pumps with one standby pump (N+1) have been included. The lower capacity pumps are primarily used for flow trimming and are less critical since there are two standby pumps for the higher capacity pumps. As such, for the lower capacity pumps one standby pump is recommended.

Based on the above recommended pumping unit redundancies a total of six higher capacity pumps and three lower capacity pumps (9 pumps total) are shown on the concept drawings. With nine pumps installed, the Pumping Plant can achieve the maximum design flow capacity of 4,500 cfs with up to three pumps out of service (i.e., two higher capacity pumps and one lower capacity pump).

3.3.4 Pumping Plant Maximum Design Flow Condition of 3,000 cfs

Figure 7 shows the system head curves developed for the high head, design head, normal low head and extreme low head static head conditions defined in Table 5 that determine the envelope of expected hydraulic conditions associated with the maximum design flow capacity of 3,000 cfs for the Project.

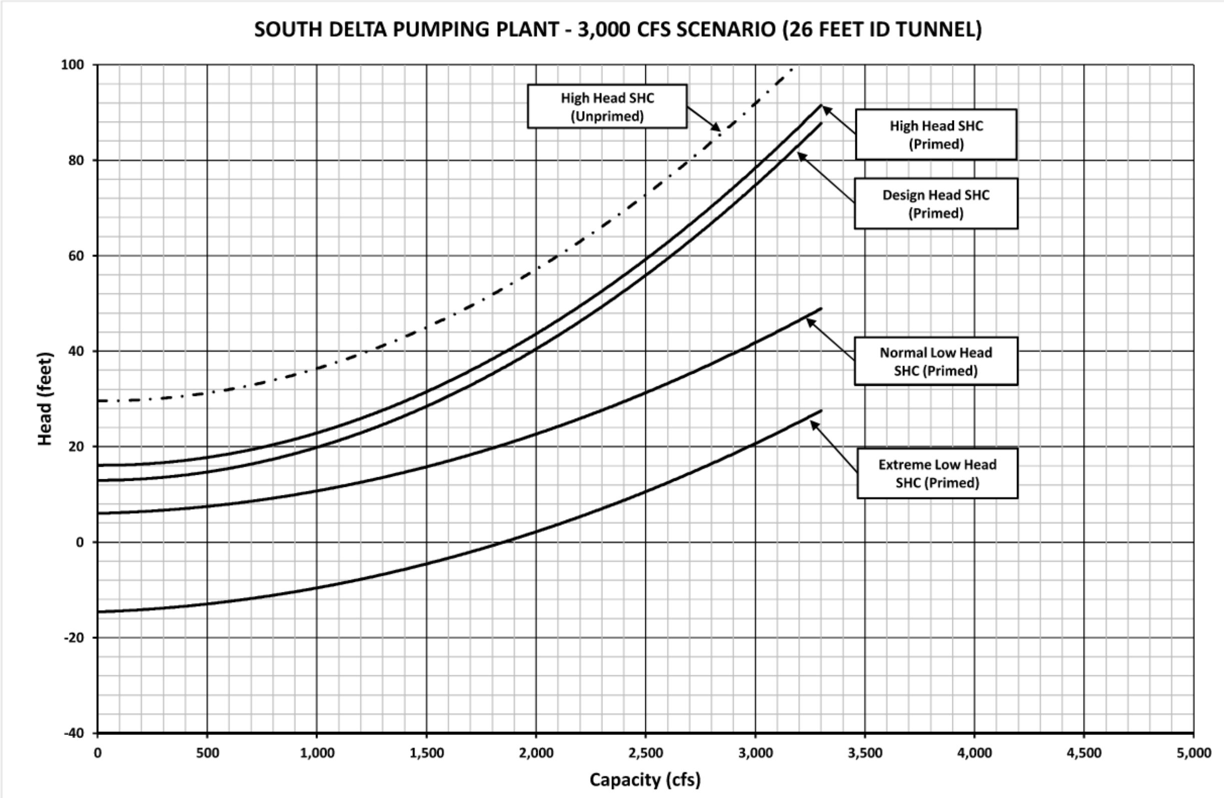

Figure 7. System Head Curves with the Maximum Design Flow Capacity of 3,000 cfs

As can be seen in Figure 8, the system head curves were plotted against the candidate pump performance curves.

Under the Extreme Low Head (Primed) condition, gravity flow through the tunnel would be established and pumps would be bypassed and therefore, pump performance at this system head curve was not evaluated.

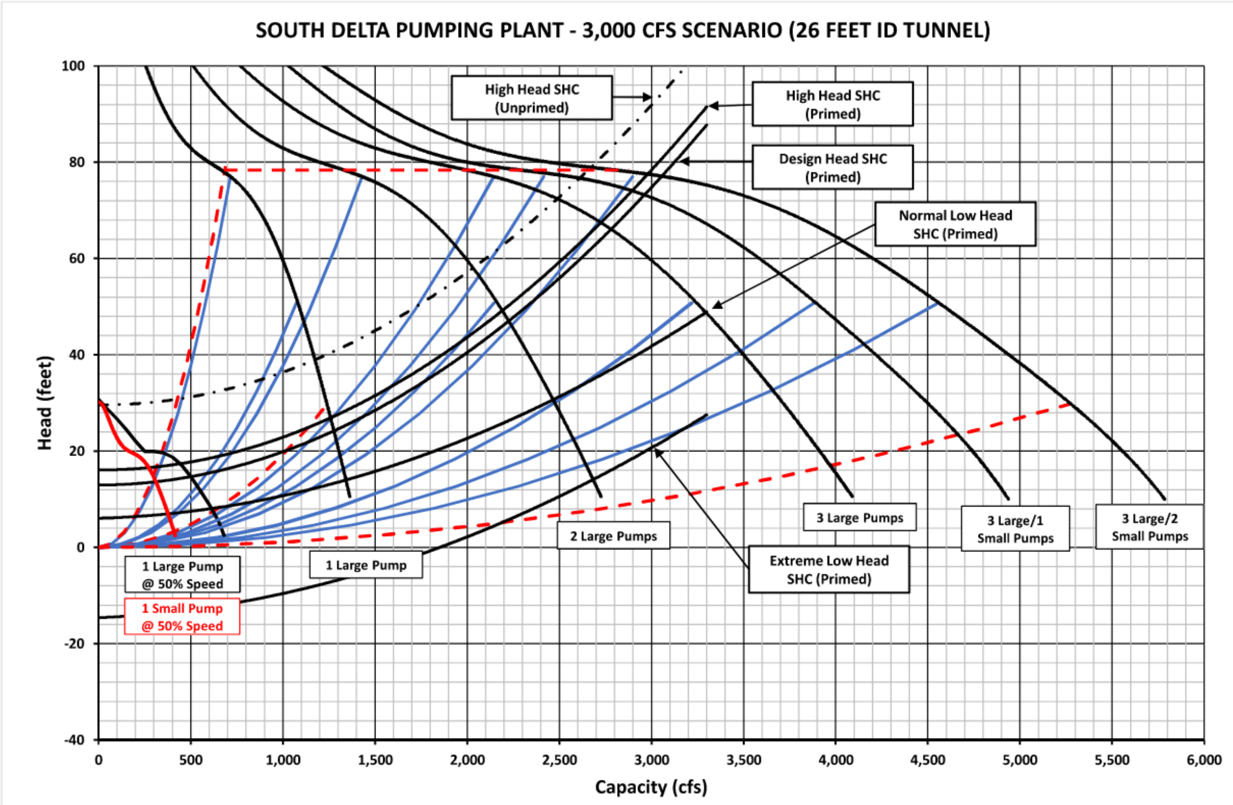

Figure 8. Pump Selection for the Maximum Design Flow Capacity of 3,000 cfs

The high flow capacity candidate pump selection (identified in Figure 8 as "Large Pump") is the Xylem, Model 78850 pump at the maximum rated operating speed of 200 revolutions per minute (rpm). The lower flow capacity pump selection (identified in Figure 8 as "Small Pump") is the Xylem, Model 78399 pump at the maximum rated operating speed of 255 rpm. Model 78850 is a 9,000 horsepower (hp) pump with a design flow capacity of 960 cfs @ 62.5 feet of TDH. Model 78839 is a 6,000-hp pump with a design flow capacity of 600 cfs @ 62.5 feet of TDH.

The POR for each pump and for parallel operation has been plotted in Figure 8. The minimum and maximum flows defining the POR are shown with blue curves and are plotted across the system head curves for each pump. The minimum and maximum flow envelope defining the pump manufacturer's AOR is shown with red dashed curves and is plotted across the system head curves for a single pump and all pumps operating in parallel.

As can be seen in Figure 8, the maximum design flow of 3,000 cfs at the Design Head condition is 74.1 feet under primed discharge siphon condition. The maximum design flow condition is established with three large capacity pumps and two smaller capacity pumps operating in parallel at their maximum rated speeds and within the POR of all pumps in operation. To achieve the minimum flow of 300 cfs (10 percent of the maximum design flow of 3,000 cfs), operating a single smaller capacity pump at slightly lower than 50 percent of its rated speed is required. To maintain operation within each pump's POR for flows less than the maximum design flow capacity of 3,000 cfs along the Design Head system head curve, the pumps must operate in parallel at reduced speeds. These speeds can be determined by the intersection of the POR affinity curves with the Design Head system head curves as shown in Figure 8. The operating range of the pumps are extended within the AOR along the Design Head system head curve (to achieve higher capacities per pump) but will still require parallel operation at reduced speeds.

Operation of the pumps along the High Head (Unprimed) system head curve can be accomplished within the full operating speed range of each pump and maintain performance within each pump's POR and AOR as can be seen in Figure 8. The maximum pumped flow under this condition is 2,700 cfs based on the pump combination shown in Figure 8. This maximum capacity can be increased by starting additional higher capacity pumps since capacities above 2,700 cfs will fall outside of the pumps' AOR. The minimum achievable pumped flow capacity using a single, higher capacity pump or lower capacity pump is 420 cfs as can be seen by the intersection of a single pump's AOR and POR with the system head curve. Therefore, the minimum Project design flow capacity target of 300 cfs is not achievable and is established as 420 cfs for the maximum design flow capacity of 3,000 cfs for the above pump selection. Further adjustments to the performance characteristics of the lower capacity pumps would result in attaining a minimum design capacity flow of 300 cfs and will be further reviewed for this design flow option.

Operation of the pump combinations along the Normal Low Head (Primed) system head curve can be accomplished within the full operating range of three higher capacity and one smaller capacity pumps running at reduced speeds and within the POR of all pumps in operation. The minimum achievable pumped flow capacity using a single, higher capacity pump operating at 50 percent of its maximum rated speed is about 630 cfs and occurs at the extreme limit of the pump's AOR. The minimum achievable pumped flow capacity using a single, smaller capacity pump operating at 50 percent of its maximum rated speed is about 390 cfs and occurs at the extreme limit of the pump's AOR. To maintain operation within the pump's AOR at this low flow condition, the pump can be operated in the "Unprimed" condition which will develop system head conditions based on the highpoint static head of the pump discharge piping and will maintain pump performance well within the pump's AOR.

3.3.4.1 Evaluation of Variable Speed Operation

The purpose of this evaluation is to determine the minimum number of adjustable speed drives (AFDs) required for the candidate pumps (in any combination) to achieve: 1) all steady-state flow capacities within the complete design flow range of 300 to 3,000 cfs along the Design Head (Primed) system curve conditions within each pump's POR; 2) all achievable steady-state flow capacities from the minimum design flow of 300 cfs up to the maximum attainable flow capacity of 2,960 cfs (three higher capacity pumps and 2 lower capacity pumps) along the High Head (Primed) system curve conditions within each pump's POR; and 3) all steady-state flow capacities within the complete design flow range of 300 to 3,000 cfs along the Normal Low Head (Primed) system curve conditions within each pumps AOR.

As shown in Figure 8, to operate the higher capacity and lower capacity pumps at maximum speed and maintain their operation within the POR for the Design Head (Primed) system head conditions, a minimum system head condition of 51 feet is required based on each pump's maximum flow and corresponding minimum head within the POR. The total dynamic head condition of 51 feet is achieved along the Design Head (primed) system head curve at flow capacities of 2,350 cfs and above. For the pump combination shown in Figure 8, a minimum of three higher capacity pumps operating in parallel at reduced speeds is required to develop 2,350 cfs of pumped flow capacity. Therefore, to maintain pump operation within the POR for flow capacities between 300 and 2,350 cfs, all pump combinations must operate with variable frequency drives. On this basis only two lower capacity pumps can utilize constant speed drivers (while all others utilize variable speed drives) and can only be operated for flows above 2,350 cfs and must be the last pumps in the starting sequence.

To operate the higher capacity and lower capacity pumps at maximum speed along the High Head (Primed) system head curve, and to maintain pump operation within the POR, a minimum pumped flow capacity of 2,350 cfs is required. To achieve the pumped flow capacity of 2,350 cfs, based on the pump combination shown in Figure 8, three higher capacity pumps must be in operation at reduced speeds.

Therefore, only two lower capacity pumps can operate with constant speed drivers and can only be operated for flows above 2,250 cfs and must be the last pumps in the starting sequence.

To operate the higher capacity and lower capacity pumps at maximum speed along the Normal Low Head (Primed) system head curve, a minimum system head condition of 30 feet is required based on each pump's maximum flow and corresponding minimum head within the AOR. The total dynamic head condition of 30 feet is achieved along the Normal Low Head (primed) system head curve at flow capacities of 2,400 cfs and above. For the pump combination shown in Figure 8, a minimum of two higher capacity pumps operating in parallel at reduced speeds are required to develop 2,400 cfs of pumped flow capacity. Therefore, to maintain pump operation within the AOR for flow capacities between 630 and 2,400 cfs, all pumps must operate with variable frequency drives. Alternatively, as can be seen in Figure 8, three large capacity and two small capacity pumps operating in parallel at reduced speeds can achieve the flow capacities between 350 cfs to 3,000 cfs within the pumps' POR. On this basis, no pumps can operate with constant speed drivers.

From the above evaluation, to achieve all steady-state flow capacities within the complete design flow range of 300 to 3,000 cfs along the Design Head (Primed) system curve conditions within each pump's POR, it is recommended to equip all pumps (higher capacity and lower capacity) with variable speed drives. Since it was determined that two lower capacity pumps can be equipped with constant speed drivers and cannot be started until a pumped flow of 2,350 cfs is developed, it is recommended that all pumps (higher capacity and lower capacity) be equipped with variable speed drives to allow flow control and no flow gaps for the entire design flow range. It was further determined that maintaining each pump within the POR and AOR for all conditions will require variable speed drivers for all system head curve conditions evaluated. By equipping all pumps with variable speed drives there will be no restrictions in the starting sequence for any combination of higher and lower capacity pumps.

3.3.4.2 Pump Redundancy

To ensure the operational reliability of the Pumping Plant the following pumping equipment redundancy has been included in the concept design.

- For the higher capacity pumps, three duty pumps with two standby pumps (N+2) have been included. The higher capacity pumps are the primary pumps that establish the majority of the pumped flow for the system. As such, these pumps are considered critical to the system. Repair of these pumps can require an extended period of time and therefore, two standby pumps are recommended.
- For the lower capacity pumps, two duty pumps with one standby pump (N+1) have been included. The lower capacity pumps are primarily used for flow trimming and are less critical since there are two standby pumps for the higher capacity pumps. As such, for the lower capacity pumps one standby pump is recommended.

Based on the above recommended pumping unit redundancies a total of five higher capacity pumps and three lower capacity pumps (8 pumps total) are shown on the concept drawings. With eight pumps installed, the Pumping Plant can achieve the maximum design flow capacity of 3,000 cfs with up to three pumps out of service (i.e., two higher capacity pumps and one lower capacity pump).

4. References

American National Standards Institute, Inc. (ANSI). 2017. ANSI/HI Standard 9.6.3, Rotodynamic Pumps – Guideline for Operating Regions

Delta Conveyance Design and Construction Authority (DCA). 2021. Hydraulics Analysis Criteria TM. Draft. Prepared for Department of Water Resources (DWR)/Delta Conveyance Office (DCO). June 30.

5. 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 / EDM QC Reviewer	Gwen Buchholz / DCA Environmental Consultant	Terry Krause / EDM Project Manager
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.