through siphon recovery. The other options evaluated were a discharge valve with a submerged discharge and a free discharge above the water surface without a discharge valve.

The invert elevation at the crest of the siphon is designed to isolate the pumping plant from NCCF when the pumps are not operating and prevent the pumps from free rotating on high wet-well elevations or surges. The conceptual design is based on a maximum water level in NCCF of 14 feet and provides 2 feet of freeboard, resulting in a siphon crest invert elevation of 16.0 feet. The invert should be adjusted, as necessary, to provide appropriate protection from backflow through the siphon, based on the final design operating elevations of NCCF as well as maximum allowable wet-well elevations and surge.

The siphon discharge drops to an elevation of -1.0 foot, which is 2 feet below the minimum design water level in NCCF. The siphon outlet should be submerged at all times to maintain siphon prime; the recommended minimum siphon submergence for this is equal to one velocity head, or approximately 1.3 feet. The siphon discharges to a concrete apron designed for energy recovery and prevention of erosion in NCCF.

For a short duration at start-up, the siphons will cause the pumps to experience a higher than normal operating head until the siphon is primed. A siphon-breaker valve at the top of the siphon will remain open to support evacuation of air during pump startup and will close after a pre-set and adjustable time to engage the siphoning (approximately 30 to 60 seconds). Guidance provided for siphon design in the US Army Corps of Engineers Pump Station Design Manual (EM 1110-2-3105) indicates that the priming velocity for siphons should exceed 7 feet per second (fps) to create and maintain siphon prime. Physical hydraulic modeling of the siphon discharge should take place during preliminary design to confirm the siphon geometry and to determine if a vacuum breaker valve is required.

At pump shutdown, the siphon breaker valve will be opened to allow air into the discharge siphon to break the siphoning, which will prevent reverse flow from NCCF through the pumps and into the tunnel system. The siphon breaker valves are to be actuated butterfly valves with a backup power supply (battery, hydraulic or pneumatic) such that they can be operated in the event of a power failure. There will also be a redundant, manual actuation provision or an additional manually actuated siphon breaker valve.

The velocity in each pump discharge siphon will be approximately 10 fps at the design flow. If a variable frequency drive is utilized for pump control, the minimum pumping flow could be significantly less than rated and/or less than the minimum 7 fps required to maintain prime. This resulting lower velocity needs to be evaluated during preliminary design to ensure the siphon will remain primed throughout the normal pump operating range.

Flow measurement on each pump will be accomplished using an ultrasonic flow meter on the straight section of pipe between the pump discharge and the siphon. The ultrasonic flow meters will be flow tested, calibrated and certified by lab testing, and used during commissioning of the pumping plants as well as during operation for equipment trending.

Alternate discharge configurations were considered, such as discharging above the high water level with no siphon and discharging below the normal water level with a discharge isolation valve. During preliminary design, a cost-benefit analysis and design evaluation should be performed before finalizing the selection of the discharge siphon.

7.1.3.5 Pumps

Pump types considered for the CCF Pumping Plant application included end-suction volute pumps and vertical column discharge pumps. Although both pump designs can perform well for this application, the vertical column discharge pumps were selected as the appropriate design due to the smaller station footprint required. As shown in the Concept Drawings (Volume 2), the pumps are suspended from a fabricated support base under each motor on the main pump room floor. The floor slab structure supports both the motors and the entire pump and column assemblies. Due to the length of the pump column, intermediate supports may be necessary such that the natural frequencies of the pump, supports, and connecting structures do not conflict with the operating frequency of the pumps. A Finite Element Analysis of the system should be conducted during final design to determine the configuration of intermediate supports and mitigate the potential for natural frequency vibrations.

To provide the firm design capacity of 9,000 cfs, a total of 12 pumps will be provided in the two Pumping Plants. Eight of the pumps will have a design capacity of 1,125 cfs and four will have a design capacity of 563 cfs. Each pump will be a single-stage unit and will have a pull-out type design, facilitating removal of the rotating assembly without disconnecting the discharge piping or removing the pump column. The pump discharge is below the motor level and is connected directly into the discharge siphon. The facility overhead crane will have sufficient clearance to disassemble and remove the pump in a 20-ft section, or the entire pull-out pump column can be removed through a roof hatch using a large mobile crane.

A number of pump manufacturers were consulted during the conceptual design evaluation, including Andritz, Fairbanks-Nijhuis, Flowserve, Flygt-Xylem, and Patterson Pump. These manufacturers all have pull-out style vertical column discharge pump selections that can meet the project design requirements. For purposes of this conceptual engineering report, pump selections were obtained from Flygt-Xylem to illustrate the performance requirements.

The pumping equipment is selected to ensure that the normal conditions of service are within the pump's Preferred Operating Range (POR). For pumps with a specific speed greater than 4500, the Hydraulic Institute defines the POR as the operating flow range between 80 and 120 percent of the pump's best efficiency point (BEP) flow. The specific speed for the raw water pumps is expected to be in the range from 7,000 to 10,000, which is within the mixed- and axial-flow type impeller regions. For mixed- and axial-flow type pumping equipment, it is important that the operating point is not to the left of the POR during normal, extended operation. Pumps in this specific speed range tend to have unstable hydraulics to the left of the POR, resulting in unbalanced and variable loading on the pump impeller. The system should also be designed such that the pumps are not required to operate to the right of the POR at the full design speed.

The equipment shall be designed with a suitable net positive suction head (NPSH) required, allowing the pumps to safely operate through the full range of design conditions, without resulting in damaging cavitation. In accordance with the Hydraulic Institute Standards for NPSH Margin in Vertical and Centrifugal Pumps (ANSI HI 9.6.1-2012), the NPSH margin ratio (NPSH available / NPSH required) shall be greater than 1.1 when operating within the full range of design conditions. For extra margin of safety the NPSH margin ratio shall be increased to 1.2. Table 7-2 summarizes the basic preliminary design criteria for the pumps and motors.

Table 7-2: Pump Conceptual Design Criteria

Criteria	Concept Design Value
Pump Type	Vertical Column Discharge
Total Number of Pumps (both Pumping Plants)	12, including 2-spares, one large pump per pump plant
Number of Large Pumps	8
Number of Small Pumps	4
Total Design Flow	9,000 cfs
Design Condition Capacity - Large Pumps	1,125 cfs
Design Condition Capacity - Small Pumps	563 cfs
Design Condition Total Dynamic Head - Large and Small Pumps	37 feet
High Head Condition (Maximum Priming Head)	40 feet
Low Head Pumping Condition (reduced speed)	~5 feet
Motor Power - Large Pumps	6,000 HP
Motor Power - Small Pumps	3,000 HP
Conceptual Selection Maximum Rotation Speed – Large Pumps	160 rpm
Conceptual Selection Maximum Rotation Speed – Small Pumps	176 rpm
Motor Enclosure	TEWAC

Note: For constant speed pumping, some low-head operating conditions require the discharge head to be artificially increased to prevent the pumps from operating beyond the pump's POR

Figure 7-4 shows the system performance with 1 to 8 large constant speed pumps. For clarity, the figure does not represent the curves for the small pumps. The 90% efficiency line represents the pump's Best Efficiency Point (BEP), which is the preferred operating point both for maximizing efficiency and minimizing equipment maintenance. The efficiency lines on either side of BEP define the Preferred Operating Range (POR). The 84% efficiency line represents 80% of BEP (left side of the pump's POR) and the 74% efficiency line represents 120% of BEP (right side of the pump's POR). The normal operating conditions should be at a point on the system curve between the 84% and 74% efficiency lines.

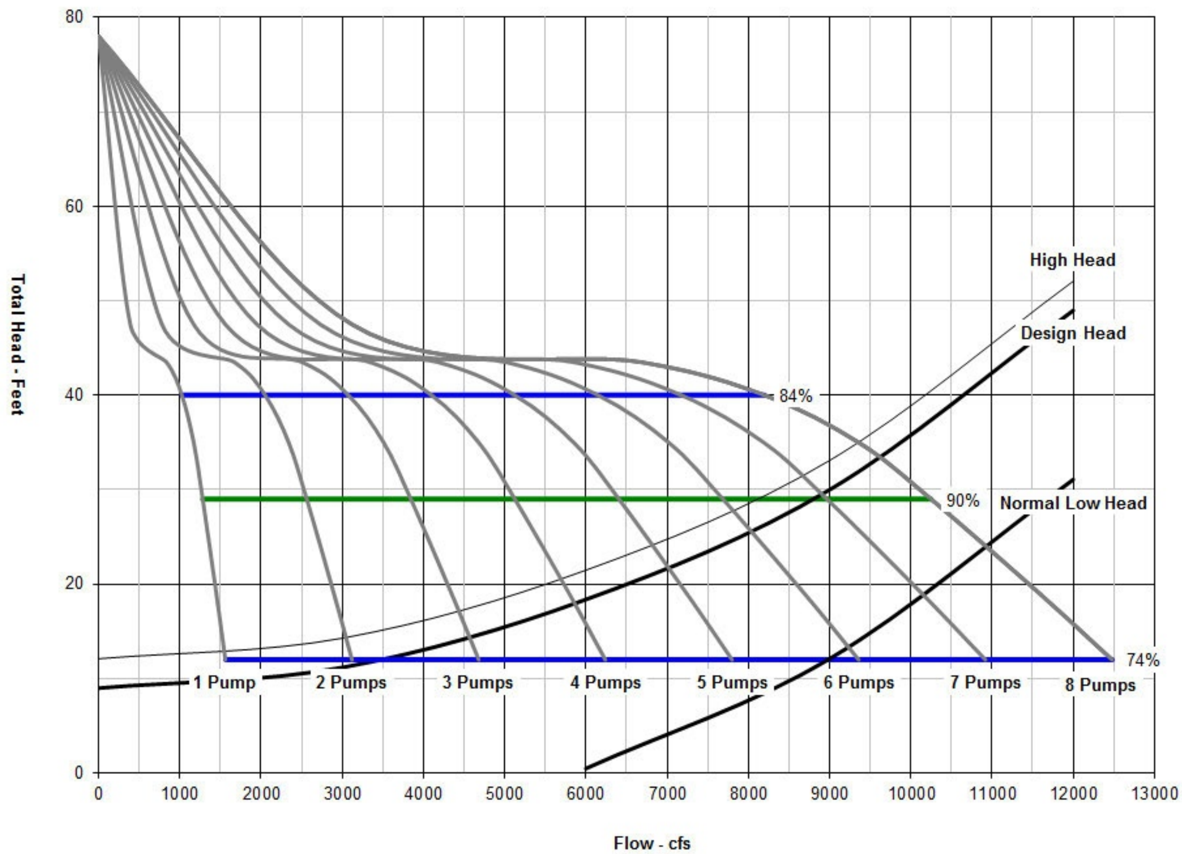

Figure 7-4: Pump and System Curves for 1 to 8 Large Constant Speed Pumps

As is illustrated on the constant speed pump curves (Figure 7-4), the large pumps will provide flow increments of approximately 1,000 cfs with each additional pump that is put into service (note that the increments are larger at low flows and smaller at high flows due to the steepening of the system curve). Inclusion of the small pumps in the operating scheme reduces the operating flow increments by approximately half.

When operating with 5, 6, 7, or 8 pumps, the operating envelope between the Normal Low Head system curve and the Design System Curve is within the pump's POR. However, with four or fewer pumps operating, an increasing amount of the lower head portion of the typical operating envelope falls outside the POR. If constant speed operation is determined to be the preferred method of controlling the pumps, it will be necessary to artificially increase the head on the pump discharge in some scenarios when operating fewer than five pumps. Opening the vacuum breaker valves on the siphon discharge would serve to increase the discharge head during low head operating conditions by preventing the siphons from priming.

Table 7-3: Range of Flows for Variable Speed Operation at the Design Head and Normal Low-Head Operating Conditions

Number of Pumps Operating	Range of Flows for the Design Head Operating Condition (cfs)	Range of Flows for the Normal Low-Head Operating Condition (cfs)
8 Large (7 Large/2 Small; 6 Large/4 Small)	5,500 to 9,000	~8,000 * to 9,000 **
7 Large (6 Large/2 Small; 5 Large/4 Small)	5,200 to 8,300	~8,000 * to 9,000 **
6 Large (5 Large/2 Small; 4 Large/4 Small)	5,000 to 7,500	~8,000 * to 9,000
5 Large (4 Large/2 Small; 3 Large/4 Small)	4,300 to 6,500	~5,000 * to 7,500
4 Large (3 Large/2 Small; 2 Large/4 Small)	3,500 to 5,500	Gravity Flow ***
3 Large (2 Large/2 Small; 1 Large/4 Small)	2,800 to 4,600	Gravity Flow ***
2 Large (1 Large/2 Small; 4 Small)	1,900 to 3,000	Gravity Flow ***
1 Large (2 Small)	1,000 to 1,400	Gravity Flow ***
1 Small	500 to 800	Gravity Flow ***

Notes:

* Although the right side of the POR does not indicate that pumping below ~ 6,000 cfs is acceptable, pump manufacturers have indicated that when operating below 80% speed, the equipment can operate to the right of the POR to a TDH as low as 0 feet without adverse effects. For operation in this range, an NPSH margin ratio of 1.2 must be achieved to remain within Hydraulic Institute Standard requirements.

** To prevent exceeding 9,000 cfs, the pump speed must be limited when operating below the Design Head system curve.

*** Condition is conducive to gravity flow or operation with more pumps at low speed.

Variable pitch blade pumps were investigated for their ability to allow for wider operation ranges without a VFD. Evaluation determined the additional mechanical equipment and maintenance of the variable pitch blade system was not as attractive as constant speed or VFD's. VFD's are further discussed in the energy analysis section and should be further investigated during preliminary design as the system constraints become further developed.

7.1.3.6 Energy Analysis – Variable Speed and Constant Speed Pumping

Pump operation in a variable speed mode would facilitate delivery of a wider range of flows without artificially increasing the total dynamic head and remaining within the pump's POR. Figure 7-5 through Figure 7-8 show pump and system curves utilizing eight, six, three, and one large 1,125 cfs pump and Figure 7-9 presents the range of operation for one small 563 cfs pump. As with the constant speed scenario, the large and small pumps can be operated simultaneously, with two small pumps roughly delivering the same flow as one large pump.

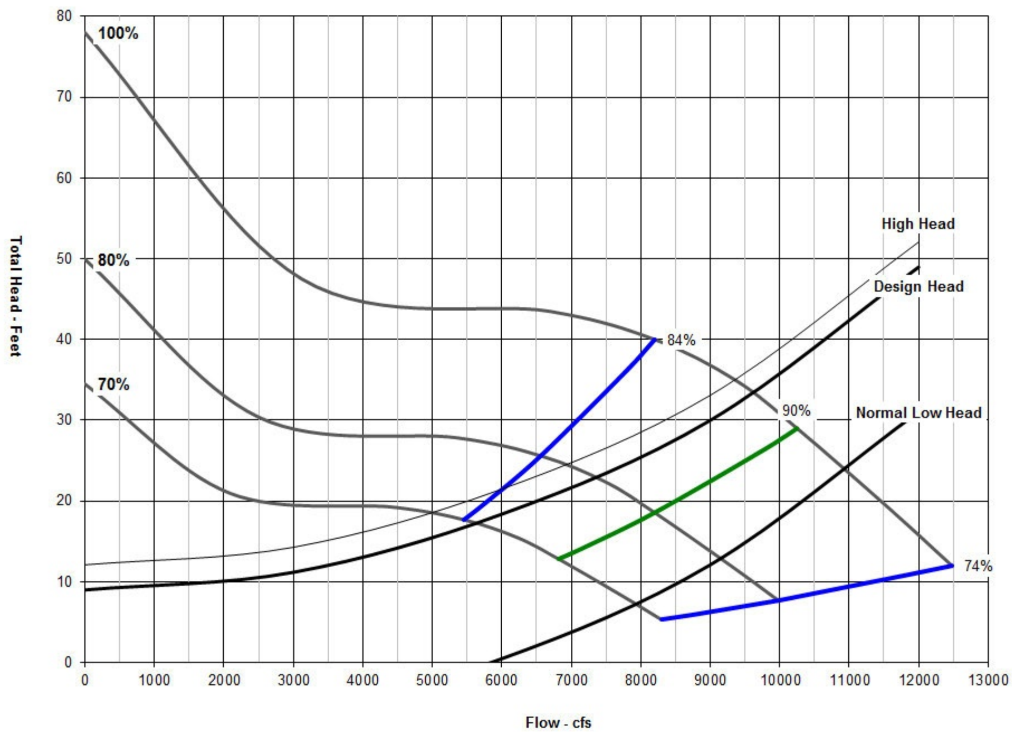

Figure 7-5: Pump and System Curves for 8 Large Variable Speed Pumps Operating