UBC Emergency Water Supply System - Team 14

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UBC EMERGENCY WATER SUPPLY SYSTEM
FINAL DESIGN REPORT

Prepared for UBC SEEDS Sustainability Program

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Executive Summary

Context and Overarching Objectives

As of 2017, the UBC Vancouver Campus hosts approximately 55,000 people per day with long term growth expected to peak at around 70,000 people per day. A substantial amount of people at UBC, therefore, rely on UBC's Energy and Water Services Unit to provide them with water.

Although UBC owns and operates its own water distribution system, water is currently sourced from the nearby Greater Vancouver Water District (GVWD) Sasamat Reservoir in Pacific Spirit Park. From Sasamat Reservoir, water is directed towards UBC through a series of pipes. A failure east of this area would essentially hamstring inflows of water into UBC.

The overarching objective of our project, therefore, is to design a water supply system that can provide water to the UBC Vancouver area in the event of a Metro Vancouver system failure.

Key Issues and Considerations

The proposed design is constrained by various technical and regulatory requirements such as those outlined in UBC's Technical Guidelines, as well as municipal bylaws and regulations, and city ordinances.

Other considerations include land use guidelines, tie-in and compatibility with the existing water supply system, potential for future expansion, and sustainable development.

Furthermore, given the scope and size of this project, the constructability of the project and its various infrastructure components is particularly important. In considering these issues, our team will discuss economic considerations including capital cost, operating costs, and lifecycle costs.

General Methodology

The design of our project, in general, followed an iterative solution methodology; to ensure the overall system components were designed cohesively, we adjusted necessary components and parameters of our project to meet all non-negotiable design criteria and to maximize meeting all negotiable design criteria.

Key Features of Design

Our design features two below grade reinforced concrete reservoirs with a total capacity of approximately 30 million litres, two new watermain alignments, and a booster station. The design is sized for 72 hours of reduced institutional and residential water usage and 120 hours of emergency and fire-flow water usage (at full capacity).

Each of the below grade reservoirs will contain approximately equal amounts of volume and feature a similar design consisting of multi-cell compartmentalization to provide redundancy, an adjustable weir to control inlet flow rates, and a sluice gate to control discharge flow rates. For ease of access and maintenance, inline gate valves will also be installed at selected locations along the pipe alignment.

To hydraulically connect the two adjacent reservoirs, the water levels in each reservoir will be controlled using a hydraulically controlled altitude valve that will function based on differential water pressure. Furthermore, the two reservoirs will be tied in using a transition coupler which will eventually connect to a new supply main approximately 1400 meters in length. In the event of failure of the Metro Vancouver water supply, water will be released to a new booster station that will discharge to a new watermain 1000 metres in length.

To ensure potability of water, disinfection will be provided using a sodium hypochlorite injection system. This system will inject a 12% sodium hypochlorite solution to the water inside the inlet chamber, through a diffuser, using two peristaltic pumps.

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1 Introduction

The detailed design of a water supply system at the UBC Vancouver Campus will be described in this report. The report will begin with an introduction to the project, followed by a description and analysis of various design components and criteria. Detailed design specifications, construction specifications, a draft plan of construction work, and a cost estimate and schedule will be provided.

The introduction section of this report will present an overview of the project, a description of the project objectives, and a site overview.

1.1 Project Overview

Our client for this project, UBC SEEDS (Social Ecological Economic Development Studies) Sustainability Program has expressed interest in potential solutions to address the University's resilience to short and long-term stressors regarding the tenuous water supply that is currently sourced into UBC.

Increasing population growth at the UBC Vancouver campus and fettered reliance on sourcing water from the nearby Greater Vancouver Water District (GVWD) Sasamat Reservoir in Pacific Spirit Park are the major motivating factors to develop an independent water system distribution system on the UBC campus.

1.2 Project Objectives

The project objective is to design a water supply system that can provide water to the UBC Vancouver area in the event of a Metro Vancouver system failure. Our design is sized for future projected demand at UBC, which is assumed to peak at around 70,000 people per day.

Other project objectives include meeting key technical and non-technical issues and constraints of the design. Furthermore, a project of this scope and size must meet all relevant bylaws and regulations and consider the consequences to any affected stakeholders. Our solution also seeks to integrate UBC Campus-Level Sustainability Plans in conjunction with Unit-Level Sustainability Frameworks developed by the UBC SEEDS Sustainability Program.

All relevant aspects of the design, such as distribution networks, pumping stations, and storage tanks will be designed. In addition, our team will consider design criteria including, but not limited to, cost, constructability, sustainability, and ability for future expansion.

1.3 Site Overview

The site location is the Point Grey Vancouver Campus of the University of British Columbia, which is an approximately 4 square kilometer (1000 acre) parcel of land. Although the focus of our project is the design of a water supply system at UBC, surrounding areas (such as Pacific Spirit National Park) are relevant with respect to existing water distribution infrastructure such as piping networks and available pump stations.

Figure 1 below presents an overview of the UBC area (the site location).

Figure 1. A map showing the UBC area (site location) and its corresponding pressure zones.

1.4 Member Contributions

The contributions of individual team members to the final design report and detailed design outputs are as follows:

Table 1. Team Member Contributions.

Final Report Sections	**Person(s) Responsible**
Title page, executive summary, table of contents, introduction	AC
Key Design Components	LL, AY, YZ
Design Criteria	YZ
Design Standards and Software	AY
Technical Design Considerations	AC
Technical Design Outputs	AY, YZ
Construction Specifications and Draft Plan of Construction Work	JN
Cost Estimate, Schedule, and Service Life Maintenance Plan	AYe
Sustainability	JN
Detailed Design Outputs	**Person(s) Responsible**
A-00 Base Plan	LL, YZ
A-01 Site Layout	LL, YZ
A-02 North Reservoir	YZ
A-03 South Reservoir	YZ
A-04 Reservoir Section and Details	LL
A-05 Booster Pump Station	LL
A-06 Distribution Main	AY
A-07 Supply Main	AY
A-08 Reinforcement Details	AY, YZ
Appendix B – Steel Reinforcement Calculations	AY, YZ
Appendix C – SAFE 2016 Outputs	AY
Appendix D – Cost Estimate	AYe
Appendix E – Schedule	AYe
Appendix F – Geotechnical Analysis	AYe
Appendix G – Liquefaction Analysis	AYe
Appendix H – Air Valve Calculations	LL

2 Key Design Components

In this section, the key components and parameters of the proposed design are discussed in detail. The proposed design consists of two below grade reservoirs, a booster pump station, and two new watermain alignments.

2.1 Design Overview

The design consists of two fully buried reinforced concrete reservoirs: the North Reservoir with a length of 72 metres and width of 45 metres, and the South Reservoir with a length of 92 metres and a width of 32 metres. Both reservoirs are 5.0 metres in height. Figure 2 shows a plan view of the two-reservoir system. In the figure, the South Reservoir is on the left and North Reservoir is on the right.

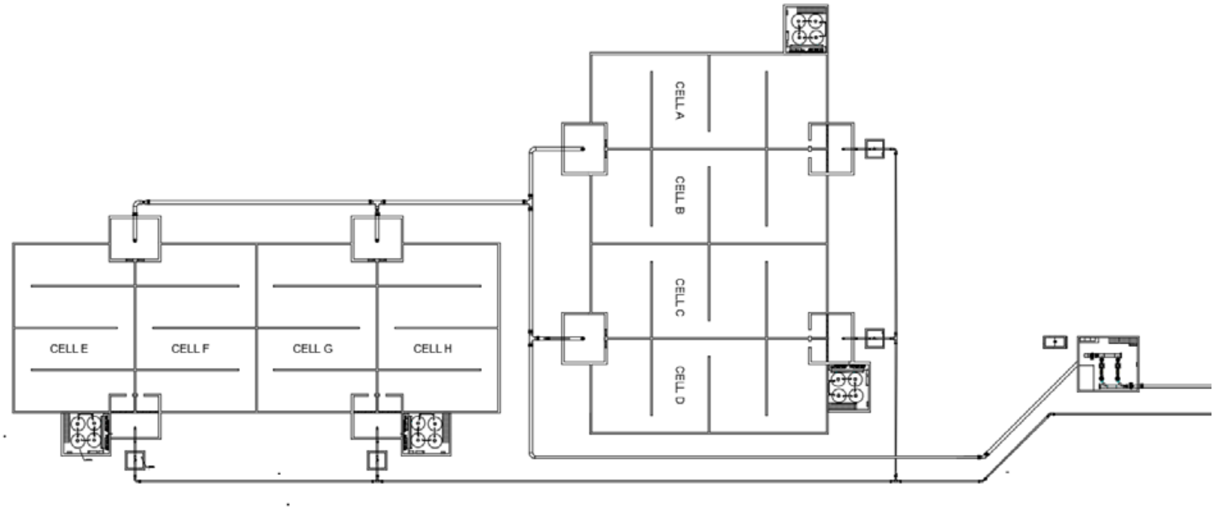


Figure 2. Plan view of reservoir system.

Fibre-reinforced plastic (FRP) baffle walls divide the reservoir into a series of cells and divert the flow of water. Water is supplied to the reservoir through a supply main. The reservoirs then convey water to the UBC water distribution system through a distribution main. The distribution main draws water from a booster pump station located east of the North Reservoir.

2.2 Structural Design

The reinforced concrete design of the reservoirs is divided into five main components: the mat foundation, foundation walls, top slab, columns, and beams. Reinforcement for each of the components is designed to provide flexural and shear resistance, with temperature and shrinkage reinforcement provided where necessary. All reinforced concrete designs follow the steps prescribed in “Reinforced Concrete Design” by Brzev and Pao (2006).

2.2.1 Mat Foundation

Coduto (2000) states that mat foundations are often used for supporting erratic structural loads, are used when the bottom of the structure is below the groundwater table, and are the industry standard in storage tank foundation design. As such, the foundation of each reservoir consists of a 500 mm thick mat foundation, with a length of 73 metres and a width of 47 metres for the North Reservoir, and a length of 93 metres and a width of 33 metres for the South Reservoir. Design loads are similar for both reservoirs, so the reinforcement designs for the two reservoirs are identical. The foundation was designed using the finite element method (a type of non-rigid method) in SAFE 2016. Outputs from SAFE 2016 including design loads, deflections, and layout of flexural reinforcement (not accounting for code requirements) are shown in Appendix C – SAFE 2016 Outputs.

Flexural reinforcement was designed for two loading cases: one with the reservoir empty and one with the reservoir at full capacity. The minimum reinforcement requirement governs the reinforcement design, since the design generated in SAFE 2016 does not meet the minimum reinforcement requirement from CSA A23.3 Cl 7.8.1. The recommended design consists of a layer of two-way 10M@400mm steel reinforcement at the top and bottom of the mat foundation. Detailed design calculations are shown in Appendix B – Steel Reinforcement Calculations.

A detail drawing of the mat foundation reinforcement design is shown in Appendix A – IFC Drawings.

2.2.2 Foundation Wall

The foundation wall was designed as a reinforced concrete basement wall as per steps outlined in Brzev & Pao, 2006. The walls are modelled as pin supported at the top and bottom, and are designed to resist shear and bending from lateral earthquake loads and earth pressures, as well as vertical loads. As with the mat foundation, since tributary areas and design loads associated with the foundation wall are similar across the two reservoirs, the reinforcement design is identical for both reservoirs.

The design consists of two layers of vertical and horizontal distributed reinforcement, with one layer on each side of the wall. For the side exposed to soil, the clear cover is 75 mm (concrete cast against and permanently exposed to earth) and for the side exposed to water, the clear cover is 60 mm (concrete exposed to chlorides). The vertical distributed reinforcement provides flexural resistance, and consists of 30M@150mm steel reinforcement. The horizontal distributed reinforcement provides shear resistance, and consists of 15M@200mm steel reinforcement. At the foundation wall and mat foundation interface, and foundation wall and top slab interface, the tie-off development length for flexural reinforcement is 1075mm. Detailed calculations for the foundation wall reinforcement design are shown in Appendix B – Steel Reinforcement Calculations.

A detail drawing of the foundation wall reinforcement design is shown in Appendix A – IFC Drawings.

2.2.3 Superstructure

The superstructure of each reservoir consists of a system of columns, beam, and one-way slabs. Each reservoir consists of 7 beams running along the length of the reservoir, supported by an array of 49 columns. The layout of the superstructure can be found in Appendix A – IFC Drawings. Sample calculations can be found in Appendix B – Steel Reinforcement Calculations.

Beams in the North Reservoir and South Reservoir are spaced 5.6m and 4.0m respectively. As columns and beams are continuously connected, the beams were analyzed as beams fixed at both ends, span lengths of 9m in the North Reservoir, and 11.5m in the South Reservoir. Flexural reinforcement is placed in areas of tension (see Appendix A – IFC Drawings). For the North Reservoir, beams are 700mm in height and 550mm in width, and use 10-35M flexural reinforcement. For the North Reservoir, beams are 750mm in height and 600mm in width, and use 8-35M reinforcement. Both beams use 10M shear reinforcement.

Columns were analyzed as concentrically loaded columns without lateral loads, as loads from water movement negligible. Columns in both reservoirs are 300mm square columns with 8-30M axial reinforcement. Steel ties are 10M@300mm. At the column and mat foundation interface, as well as the column and beam interface, the tie-off development length for axial reinforcement is 1075mm.

Top slabs were analyzed as one-way slabs running along the length of beams. Thus, the span length of the one-way slabs were taken as the spacing between beams. In the North Reservoir, top slabs are 5.6m wide and 300mm thick with 15m@140mm flexural reinforcement. In the South Reservoir, top slabs are 4m wide and 250mm thick with 15m@170mm flexural reinforcement. Top slabs in both reservoirs will have 15M@250mm temperature reinforcement.

2.2.4 Reinforcement Summary

A design summary for our structure is provided in Table 2 below. Detailed drawings, including cross sections, can be found in Appendix A – IFC Drawings

Table 2. Cross Sectional Dimensions of Structural Components

Component	North Reservoir	South Reservoir
Beams	Dimensions: 700x550mm Flexural Reinforcement (top): 10-30M (tension) Flexural Reinforcement (bottom): 5-30M (tension) Shear Reinforcement: 10M	Dimensions: 750x600mm Flexural Reinforcement (top): 8-35M (tension) Flexural Reinforcement (bottom): 5-30M (tension) Shear Reinforcement: 10M
Columns	Dimensions: 300x300mm Axial Reinforcement: 8-20M Ties: 10M@300mm	Dimensions: 300x300mm Axial Reinforcement: 8-20M Ties: 10M@300mm
Top Slab	Dimensions: 5600x300mm Flexural Reinforcement: 15M@140mm Temperature Reinforcement: 15M@250mm	Dimensions: 4000x250mm Flexural Reinforcement: 15M@170mm Temperature Reinforcement: 15M@250mm
Foundation Walls	Flexural Reinforcement 30M@150mm vertical (2 layers) Shear Reinforcement: 15M@200mm horizontal (2 layers)	Flexural Reinforcement 30M@150mm vertical (2 layers) Shear Reinforcement: 15M@200mm horizontal (2 layers)
Mat Foundation	Flexural Reinforcement: 10M@400mm grid (2 layers)	Flexural Reinforcement: 10M@400mm grid (2 layers)

2.1 Reservoirs

Due to the geometry and geology of the site location, a single 30.4 ML reservoir cannot be physically constructed without intruding into the UBC baseball turf and the Rashpal Dhillon Track & Field Oval. To address this geometric constraint, the proposed reservoir is divided into two smaller below-grade concrete reservoirs.

2.1.1 North Reservoir

The north reservoir will be located between the UBC baseball turf and the Rashpal Dhillon Track & Field Oval. It is approximately 72 m long, 45 m wide, 5 m deep and will have a total capacity of 16 ML. This reservoir will be divided into four cells that can be independently isolated as necessary.

Each reservoir cell will be equipped with a 2400mm x 2400mm adjustable weir to control the inlet flow rate and a 1200mm x 1200mm sluice gate to control the discharge flow rate. Both the weir and sluice gate will be controlled through a hand wheel located above the reservoir. To minimize the cost associated with valves and pipes, two cells will share a common inlet and outlet chamber. Flows to the inlet chamber will be fed from a 300 mm stainless steel pipe and the water from the outlet chamber will discharge to a 600 mm stainless steel pipe. Stainless steel was selected as the preferred material because of its relatively low corrosion rate compared to ductile iron. Figure 3 shows the proposed configuration of the north reservoir. The major components of the north reservoir are summarized in the table below.

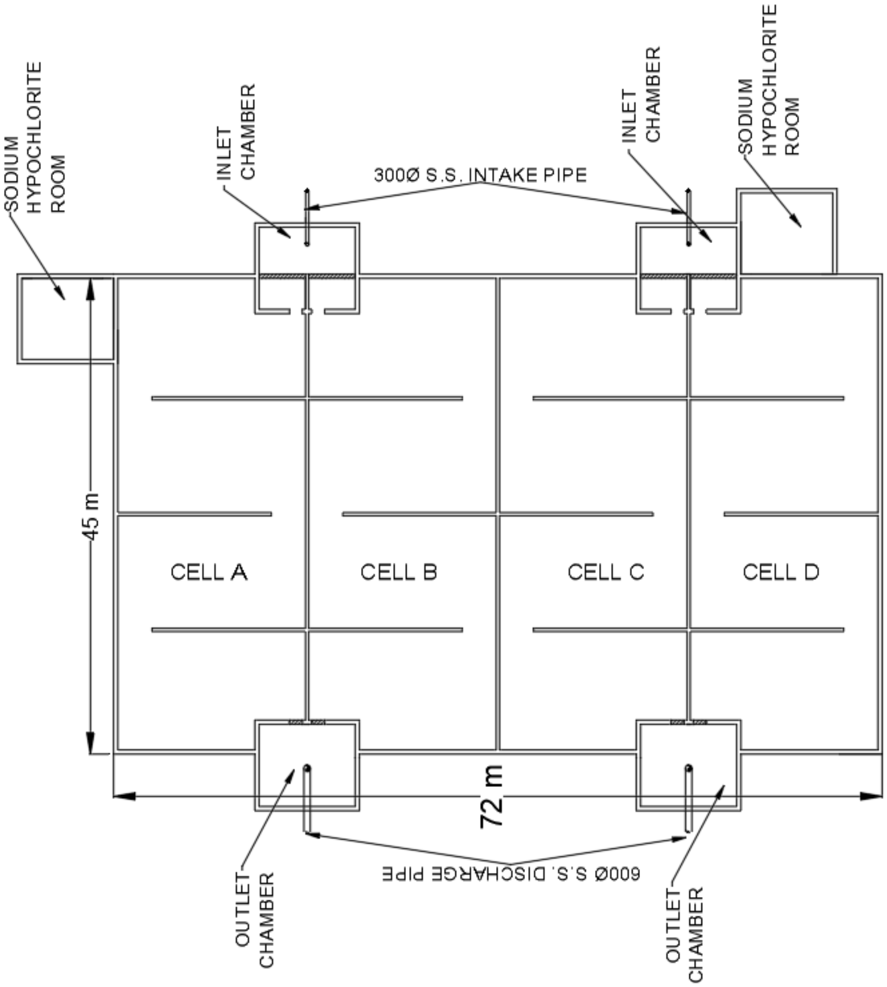


Figure 3: Configuration and components of the north reservoir

Table 3: Major components and specifications of the north reservoir

Component	Cell A	Cell B	Cell C	Cell D
Inlet Control	Adjustable 2400mm x 2400mm weir gate as per AWWA C560	Adjustable 2400mm x 2400mm weir gate as per AWWA C560	Adjustable 2400mm x 2400mm weir gate as per AWWA C560	Adjustable 2400mm x 2400mm weir gate as per AWWA C560
Discharge Control	1200mm x 1200mm cast-iron sluice gate as per AWWA C560	1200mm x 1200mm cast-iron sluice gate as per AWWA C560	1200mm x 1200mm cast-iron sluice gate as per AWWA C560	1200mm x 1200mm cast-iron sluice gate as per AWWA C560
Inlet pipe	300 mm stainless steel as per AWWA C220		300 mm stainless steel as per AWWA C220	
Discharge Pipe	600 mm stainless steel as per AWWA C220		600 mm stainless steel as per AWWA C220	
Inlet Chamber	Shared between Cell A and B		Shared between Cell C and D	
Outlet Chamber	Shared between Cell A and B		Shared between Cell C and D	

2.1.2 South Reservoir

The south reservoir will be located between the UBC Baseball Turf and the boulevard north of West 16th Avenue. It is 92 m long, 32 m wide, 5 m deep and will have a total capacity of 14.4 ML. The south reservoir will also be divided into four cells for resiliency and ease of maintenance.

Similar to the north reservoir, the flow rate through the cells will be controlled by an adjustable 2400mm x 2400mm weir at the inlet and a 1200mm x 1200mm sluice gate at the discharge. The configuration and size of the inlet and outlet chamber as well as the intake and discharge pipes will also be similar to the north reservoir. Figure 4 shows the proposed configuration of the South Reservoir. The major components of the south reservoir are summarized in Table 4 below.

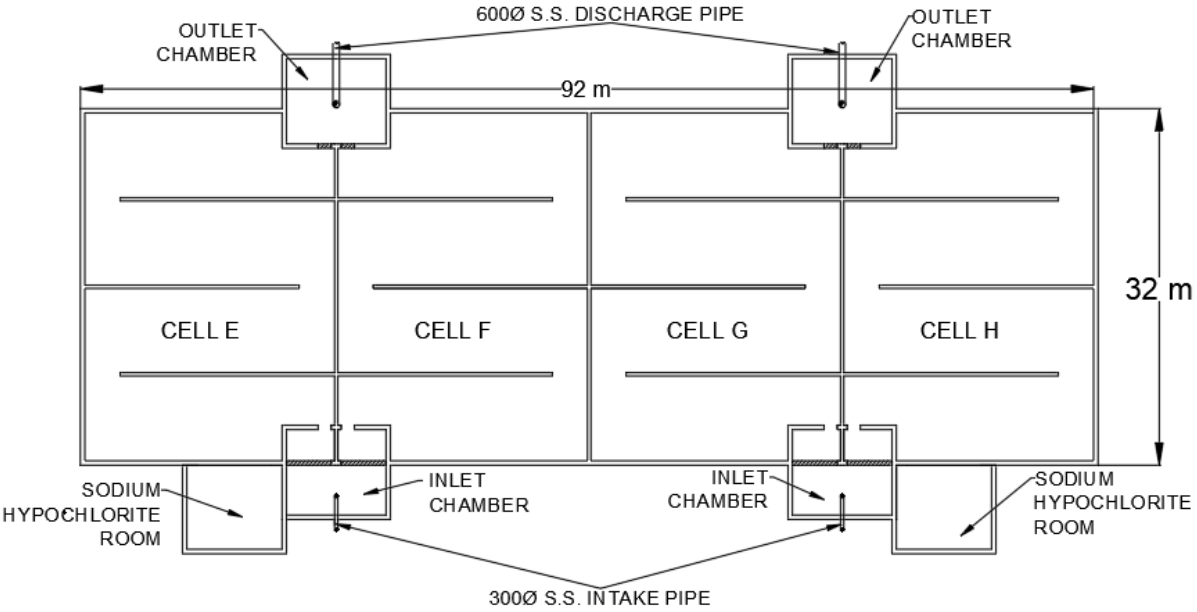


Figure 4: Configuration and components of the south reservoir

Table 4: Major components and specifications of the south reservoir

Component	Cell E	Cell F	Cell G	Cell H
Inlet Control	Adjustable 2400mm x 2400mm weir gate as per AWWA C560	Adjustable 2400mm x 2400mm weir gate as per AWWA C560	Adjustable 2400mm x 2400mm weir gate as per AWWA C560	Adjustable 2400mm x 2400mm weir gate as per AWWA C560
Discharge Control	1200mm x 1200mm cast-iron sluice gate as per AWWA C560	1200mm x 1200mm cast-iron sluice gate as per AWWA C560	1200mm x 1200mm cast-iron sluice gate as per AWWA C560	1200mm x 1200mm cast-iron sluice gate as per AWWA C560
Inlet pipe	300 mm stainless steel as per AWWA C220		300 mm stainless steel as per AWWA C220	
Discharge Pipe	600 mm stainless steel as per AWWA C220		600 mm stainless steel as per AWWA C220	
Inlet Chamber	Shared between Cell E and F		Shared between Cell G and H	
Outlet Chamber	Shared between Cell E and F		Shared between Cell G and H	

2.1.3 Level Control

The water level of the north and south reservoir will be controlled using a 300mm Cla-Val altitude valve. The altitude valves will be located upstream of the 300 mm inlet pipes and will function based on differential water pressure. To maintain high levels of stored water inside the reservoirs, the altitude valves are set to open at 90% reservoir volume and close at 100%. The altitude valve will be housed, below grade, on a 3600mm x 3600mm concrete chamber located upstream of the inlet chamber. The altitude valve chamber can be accessed through a 1200mm x 1200mm access hatch located at grade. Figure 5 below shows the elevation view of the altitude valve chamber.

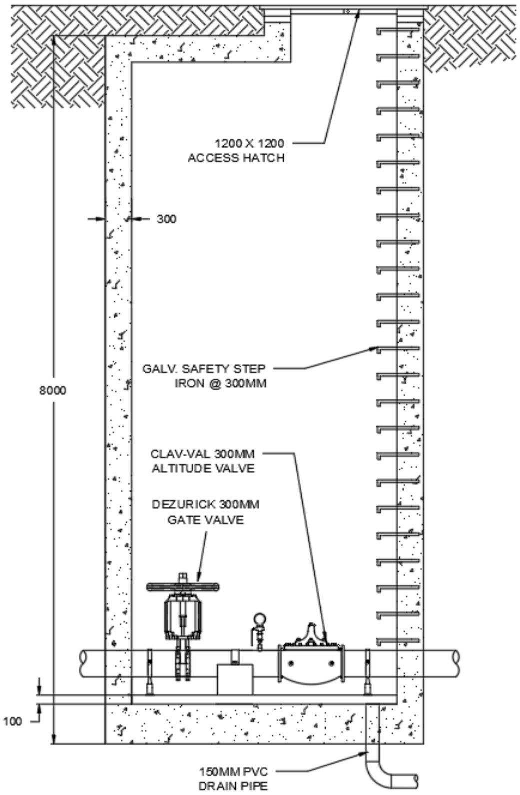


Figure 5: Elevation view of the altitude valve chamber

2.1.4 Civil Pipe

The 300 mm stainless steel inlet pipes of both reservoirs will each be tied in to a 300 mm ductile iron pipe using a transition coupler located downstream of the altitude valve. The 300 mm ductile iron pipes will then be tied in to a common 300 mm intake header which will then be connected to the main supply line.

Similarly, the 600 mm stainless steel discharge pipes will be tied in to a 610 mm ductile iron pipe using a transition coupler. The 600 mm ductile iron pipes will then be connected to a common 600 mm discharge header which will be connected to the intake header of the proposed booster station.

To allow isolation during maintenance and repair, inline gate valves will be installed at selected locations along the pipe alignment.

The material and specification of the civil pipes are summarized in Table 5 below.

Table 5: Major components and specifications related to civil piping

Component	Specification
Common Intake Header to Reservoir Intake Pipe Connector	300 mm ductile-iron pipe as per AWWA C151
Discharge Pipe to Common Discharge Header Connector	600 mm ductile-iron pipe as per AWWA C151
Intake Header	300 mm ductile-iron pipe as per AWWA C151
Discharge Header	610 mm ductile-iron pipe as per AWWA C151
Fittings	As per AWWA C153
Isolation Valves	Gate Valves as per AWWA C509
Thrust Blocks	As required

2.1.5 Reservoir Access and Ventilation

Access inside the reservoir will be provided by a 900 mm by 900 mm access hatch and a stainless-steel ladder. Air vents will also be installed at each cell to allow the reservoir to depressurize. To prevent tampering and contamination of the water inside the reservoir, protective grilles will be installed at each vent opening. Lastly, floor drains connected to a 200 mm PVC pipe will be installed at each cell to allow drainage during maintenance.

2.2 Booster Pump Station

Water from the reservoir will be conveyed using an underground booster pump station to ensure that UBC's distribution pressure requirements are met. The booster pump station will be located directly south of the Rashpal Dhillon Track & Field Oval with an offset of approximately 25 m from the north edge of pavement on West 16th Avenue.

2.2.1 Pump Specification

Two 75 horsepower Goulds Model 19BF pumps, each sized to provide 137 L/s at 33m Total Dynamic Head, will be used to convey water from the reservoir to UBC's distribution system. The pumps were sized based on the system curve of the new water main alignment which connects the reservoir to the proposed tie-in point located in between University Boulevard and Agronomy road along Westbrook Mall. The pumps will be configured in parallel and will follow a duty-standby operation sequence. Each pump will also be equipped with variable frequency drives to improve its efficiency and decrease power consumption. Figure 6 below shows the pump curve of the proposed pump overlaid on the system demand curve.

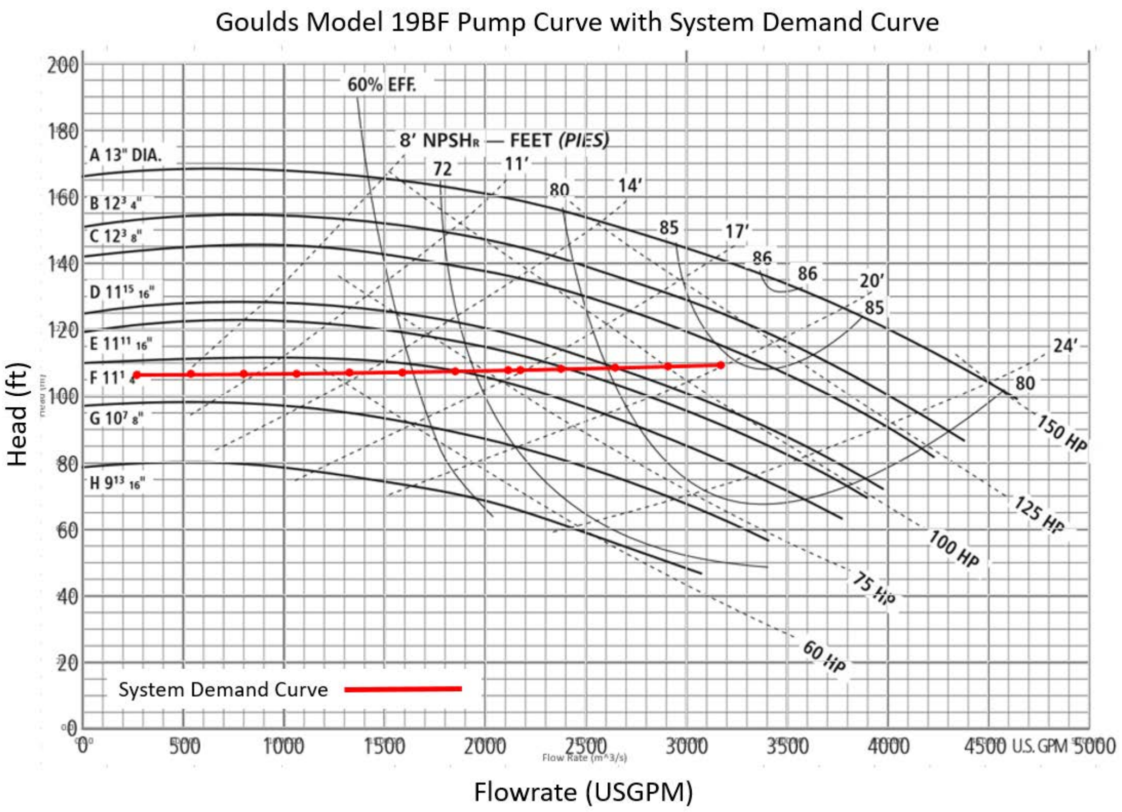


Figure 6: Proposed pump curve plotted against the system demand curve

2.2.2 Piping, Fittings and Valves

The 600mm discharge header of the reservoirs will be connected to the 600mm intake header of the booster station. Flow from intake header well then be branched to the pumps through two prefabricated 600mm x 250mm tee stainless steel spool. Both pumps will discharge to a common 600mm discharge header which is connected to the 600mm distribution main. Flow isolation within the booster station will be provided using a combination of DeZurick gate valves and butterfly valves.

To prevent backflow, a 300mm Valmatic check valve will be installed at the downstream pipe of each pump. Surge relief valves will also be installed at the inlet header to relieve pressure in the event of a water hammer. Furthermore, Victaulic couplings will be installed at selected joints to allow easy removal of valves and equipment during maintenance.

Valves to be used at the booster pump station will be externally epoxy coated. All piping, valves and fitting and other wetted components will be constructed using ANSI/NSF 61 approved materials. The material and specification of the pipes and valves for the booster station are summarized in Table 6 below.

Table 6: Material and specification of the pipes and valves to be used in the booster station

Component	Specification
Intake Header	600 mm stainless steel as per AWWA C220
Discharge Header	600 mm stainless steel as per AWWA C220
Intake Header Isolation Valve	600 mm DeZurick butterfly valve
Discharge Header Isolation Valve	600 mm DeZurick butterfly valve
Isolation Upstream of Pump	250 mm DeZurick gate valve
Isolation Downstream of Pump	300 mm DeZurick gate valve
Backflow Prevention	300 mm Valmatic check valve

2.2.3 Electrical Components

The booster pump station will have a Motor Control Centre (MCC) equipped with a circuit breaker, automatic transfer switch, Uninterruptible Power Supply (UPS), variable frequency drives and Human Machine Interface (HMI) control. Also, a diesel operated standby generator will be installed on a secured kiosk, above grade, to provide backup power in case of a power failure. Table 7 below summarizes the recommended manufacturers for the electrical components of the booster station.

Table 7: Recommended manufacturers for the electrical component of the booster station

Component	Recommended Manufacturers
Motor Control Centre	Eaton
Automatic Transfer Switch	Eaton
Uninterrupted Power Supply	Toshiba 200VA
Human Control Interface (HMI) and PLC	Allen-Bradley
Standby Diesel Generator	Cummins

All electrical work and components will be as per the Canadian Electrical Code.

2.3 New Water Main Alignments

To hydraulically connect the proposed reservoir to the existing water distribution system, two new pipe alignments are proposed.

2.3.1 Supply Main Alignment

This supply main connects the existing Metro Vancouver (GVRD) supply line to the intake header of the proposed reservoirs. The supply alignment runs along West 16th Avenue and is approximately 1400 m long. Based on the pipe length, flow rate and pressure distribution requirement, a 300 mm ductile iron pipe will be used for the supply main.

The proposed supply main will have two key tie-in locations. The first tie-in location will be a branch tie-in to the existing 610 mm high pressure feeder main at the intersection of Cleveland Trail and 16th avenue. This connection will branch water going to the high-pressure feeder main to the proposed supply main. The second tie-in location will be a tie-in to feed the proposed reservoirs. The west end section of the supply main will be tied in to the 300 mm intake header of the proposed reservoirs. Figure 7 shows the proposed alignment and tie-in locations of the supply main.

Figure 7: Supply main alignment and proposed tie-in locations

2.3.2 Discharge Main Alignment

This discharge main connects the proposed reservoir to UBC's main distribution line. The total length of the discharge main alignment is approximately 1000 m. This alignment will cut through the south area of the Rashpal Dhillon Track & Field Oval where it turns north following Westbrook Mall.

The proposed discharge main will have three key tie-in locations. The first tie-in location will be a tie-in to the discharge header of the booster pump station. This tie-in directs water from both reservoirs to the discharge main. The second tie-in location will be a branch tie in to the existing 300 mm feeder main located south east of the Rashpal Dhillon Track & Field Oval. This connection will supply water to the low pressure zone through an existing Pressure Relief Valve (PRV) located directly south of the proposed tie-in location. The last tie-in location will be a tie-in to the existing 610 mm feeder main located between University Boulevard and Agronomy road along Westbrook Mall to supply the high pressure zone. Based on pressure requirements, design flow rate, and existing infrastructure, a 610 mm ductile iron pipe will be used for the discharge main. Figure 8 shows the proposed alignment and tie-in locations of the discharge main.

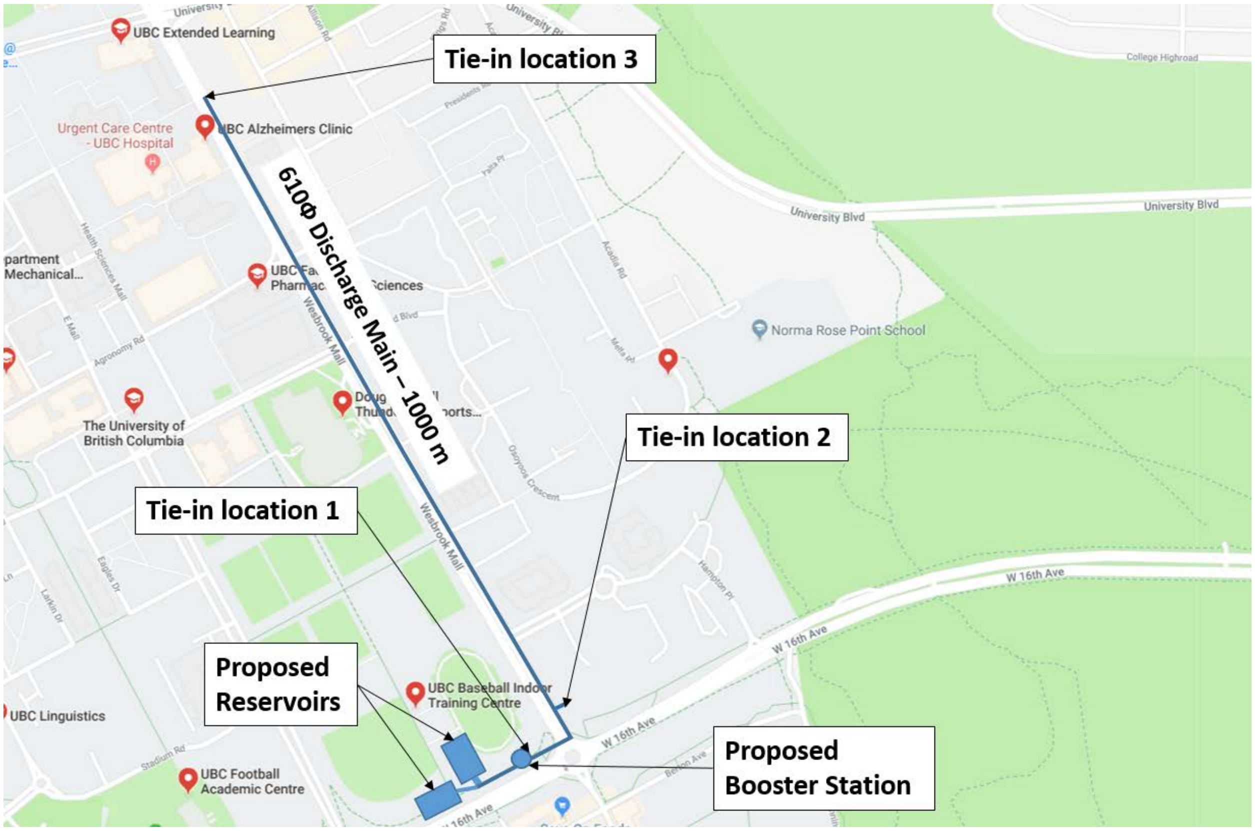


Figure 8: Discharge main alignment and proposed tie-in locations

Furthermore,

Table 8Table 8 below summarizes the components and specifications of the proposed supply and discharge main.

Table 8: Major components and specifications of the supply and discharge main alignment

Component	Supply Main	Discharge Main
Pipe	300 mm ductile-iron pipe as per AWWA C151	610 mm ductile-iron pipe as per AWWA C151
Air Valves	As per AWWA C512 (Typical manufacturers include Valmatic and Cla-Val)	
Fittings	As per AWWA C153	
Isolation Valves	Gate Valves as per AWWA C509	
Thrust Blocks	As required	

2.4 Treatment

Disinfection will be provided using a sodium hypochlorite injection system. This system will inject a 12% sodium hypochlorite solution to the water inside the inlet chamber, through a diffuser, using two peristaltic pumps. The sodium hypochlorite system was selected as the preferred chlorine booster because of its low cost and reliable dosing accuracy.

The sodium hypochlorite injection system will be located on a vault chamber adjacent to the inlet chamber of each reservoir cell. A total chlorine analyzer will be installed post-reservoir to monitor chlorine residuals at the discharge location. Chlorine concentration readings from the chlorine analyzer will then be used to determine the chlorine dosing rate at the inlet chamber.

Both the sodium hypochlorite pump skid system and 12% sodium hypochlorite solution will be sourced from ClearTech.

2.5 Disinfection

Prior to commissioning, the water supply system will be disinfected using the methods summarized in Table 9 below.

Table 9: Proposed Disinfection Method

System	Method
North and South Reservoir	Chlorination Method 1 as per AWWA C652
Supply and Discharge Main	Slug Method as per AWWA C651
Pipe Headers and Connector	Continuous Feed Method as per AWWA C651

2.6 Baffle Walls

FRP baffle walls control the flow of water to provide the necessary concentration and contact time (CT value) required for adequate secondary disinfection via chlorination. The use of FRP is a more sustainable option over concrete, as it allows the overall reduction in concrete use. Prefabricated FRP panels also allow for easier construction assembly. FRP Corrugated Baffle Walls manufactured by NEFCO Systems will be used. Detailed drawings can be found on the manufacturer's website.

2.7 Concrete

The reservoirs will need to be constructed from low permeability concrete to prevent the absorption of water and chloride (from disinfection), which allows for better durability performance. The use of supplementary cementitious materials (SCMs) in the concrete mix will be used to achieve these properties. SCMs are a variety of industrial by-products that can be used as a cementing agent in concrete production. Thus, the use of SCMs produces sustainable concrete as it uses recycled materials in place of cement.

Lafarge Canada's Ultra Series Ready-Mix will be used, or an equivalent ready-mix approved by the Engineer. The Ultra Series mix shall include the use of silica fume and fly ash to achieve low permeability. Uniformly graded aggregates shall be also be used to achieve low permeability. The concrete must have a 28 day strength of 25 MPa.

2.8 Geotechnical Design

No significant changes were made to the geotechnical design of the reservoir aside from the calculation of the lateral loads and earthquake loads found in the corresponding section of the report. However, the current geotechnical parameters were extrapolated from geotechnical investigations that were not site specific. The assumed geotechnical parameters pose a risk since the actual site conditions could be completely different due to the spatial variability of the subsurface. This risk can be mitigated if a site specific geotechnical investigation was conducted to improve the geotechnical parameters. Improved geotechnical parameters could lead to cost savings for the client since there would be less risk of encountering unforeseen subsurface conditions during construction.

2.8.1 Subsurface Conditions

A geotechnical model was developed using data from Piteau Associates' 2002 hydrogeological and geotechnical assessment of UBC. The geotechnical model was interpolated from drill holes TH01-04 and BH63-4 as they were the closest drill holes to the site. The site is assumed to contain glacial down to around 15 m. The excavation of the reservoir is planned to be 5 m deep, therefore, only glacial till will be encountered during the excavation. It is recommended that a site specific geotechnical investigation be undertaken before construction begins to fully understand the site's subsurface conditions.

2.8.2 Foundation Choice

The foundation of the reservoir will be a shallow foundation due to the ease of construction and high compatibility for a reservoir. The slab will be 500 mm thick and span the entire area of the excavation. The high bearing capacity of the glacial till will be sufficient to carry the loading of the reservoir.

2.8.3 Liquefaction Potential

The liquefaction potential of the site was determined via the liquefaction triggering method proposed by Youd et. al (2001). The results of the liquefaction analysis, found in Appendix G – Liquefaction Analysis, concluded that the depth at which the reservoir will be constructed at is expected to liquefy if a magnitude 7.5 earthquake occurred. Therefore, the site’s liquefaction resistance must be increased in order for the site to be resilient during liquefaction events. It is recommended that ground improvement be conducted at site before construction in order to increase the liquefaction resistance of the site.

2.8.4 Ground Improvement

As the site is located in a location that is very sensitive to high noise and vibrations such as the nearby school and football field, it is recommended that ground improvement method that emits low noise and vibrations be undertaken. Vibro-replacement with stone columns or jet grouting would work well for the ground improvement at this site as they are effective at improving the liquefaction resistance of glacial till as well as being relatively quiet and exerts less vibrations compared to other methods.

3 Design Standards and Software

3.1 Design Standards

Design loads were specified according to the National Building Code of Canada (NBCC) 2015, Division B, Part 4 (Structural Design). In particular, dead, live, rain, snow, and earthquake load combinations were developed based on specifications outlined in NBCC 2015. The concrete reinforcement design adheres to Canadian Standards Association (CSA) A23.3 guidelines, which is generally consistent with American Concrete Institute (ACI) guidelines. The hydrotechnical design adheres to the UBC Technical Guidelines and specifications outlined in American Water Works Association (AWWA) guidelines. Construction standards and methods adhere to UBC Technical Guidelines as well as MMCD guidelines. This includes work such as excavation, pipe installation, and placement of fill material.

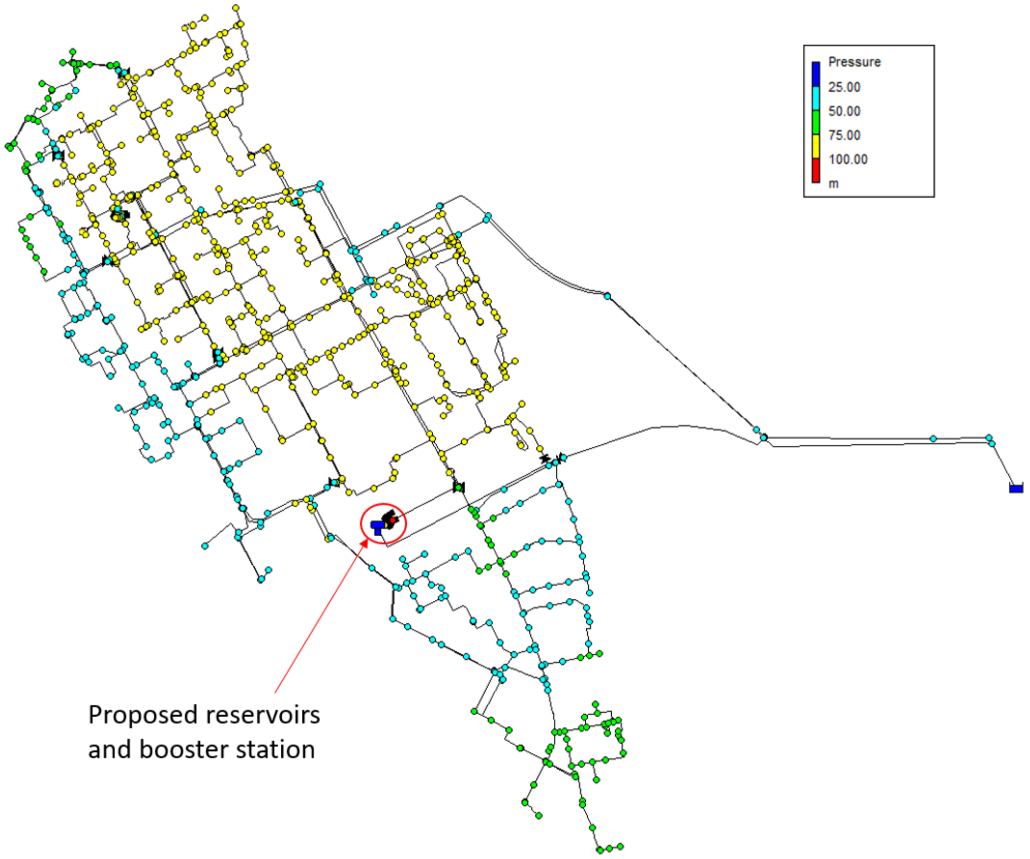
3.2 Design Software

To perform structural analysis, RISA-2D was used to preform preliminary analysis of the beam system to determine the shear and bending moment profiles. SAFE 2016 was used to design the steel reinforcement of the mat foundations, and check deflections to inform design of the mat thickness. For the hydrotechnical analysis, EPANET was used to model system pressures and flow rates in the UBC water supply system with the proposed reservoirs, booster pump station, and distribution and supply mains. Microsoft Excel 2016 was used to develop the pump and system curves to select the optimal pumps for the booster pump station. AutoCAD Civil 3D was used to develop all IFC design drawings, including drawings for the reservoir system, booster pump station, and distribution and supply mains.

4 Modelling

4.1 EPANET

An EPANET model of the proposed water distribution system was developed to ensure that the system complies with UBC's pressure distribution requirement. The system was modelled using the 2015 Maximum Day Demand (MDD) as provided by the client. Figure 9 below shows the pressure distribution within UBC's water distribution network once the proposed water distribution system is commissioned.



Proposed reservoirs
and booster station

Figure 9. EPANET Model.

Based on modelling results, pressures within the system ranges between 43.5 psi and 120.2 psi.

For the low pressure zones, UBC's minimum pressure requirement is approximately 40 psi.

Therefore, the proposed system meets the client's pressure distribution requirements.

5 Technical Design Considerations

Various technical design considerations were judiciously examined during the design of our water supply system. During the detailed technical design of our project, our team focused on the following three focus areas:

1. Structural and Earthquake
2. Geotechnical
3. Hydraulic

5.1 Analysis

In considering the three focus areas detailed above, our team aims to build a simple yet robust design that increases constructability while reducing costs.

Regarding the structural and earthquake focus area, our technical design considered the possibility of natural disasters and the project’s ability to maintain its resilience. Henceforth, the construction of baffle walls was incorporated to reduce possible structural damage.

In the geotechnical focus area, our team investigated liquefaction and foundation issues. The relevant design, therefore, accounts for such issues by construction using appropriate soil and cover during construction.

Finally, hydraulic consideration includes issues regarding pressure zones and tie-in locations. In completing our design, our team built the piping network and ran a simulation in EPANET to ensure its reliability.

Detailed justification and considerations for each of the key component's technical considerations can be found in each of the project component's respective section.

5.2 Technical Requirements

Designs need to meet certain requirements in order to provide the University of British Columbia with a temporary supply of water in the case where water supply provided by Metro Vancouver is disrupted. It was determined by the design team that the following technical requirements must be met in order to meet the institution's needs for water. These are:

1. Supply institutional and residential average day demands (ADD) for 72h with reduced research, washroom, and shower use, for the full build-out population of 70,000 people per day under UBC's long term growth strategy.
2. Supply UBC Hospital with water to provide critical functions that support public health and life safety for 120h.
3. Supply fire flows for 3h per day for 5 days (15h).
4. Supply the minimum balancing volume, to account for inflows and outflows from the reservoirs during normal operations.
5. Supply water for drinking and sanitation for the approximately 17,000 residents within a 1h walk from UBC, for 5 days (120h).

The total reservoir volume required to support these functions is 30.4 million litres. The design life shall be 75 years.

5.3 Regulatory Requirements

All designs will be located within the University of British Columbia on the University Endowment Lands (UEL). The UEL is an unincorporated area that is located to the west of the

City of Vancouver and is part of Metro Vancouver. The UEL is not part of the City of Vancouver and therefore, construction located within the UEL is not subject to Vancouver Building Bylaw. It is however under provincial jurisdiction and must follow the British Columbia Building Code. The University of British Columbia also has established its own University of British Columbia Technical Guidelines that establish a minimum for which the designs must meet. The design is subject to and must meet or exceed the provisions outlined in both the University of British Columbia Technical Guidelines as well as the British Columbia Building Code. Although the design is does not need to meet the Vancouver Building Bylaw, it is recommended it is given consideration as infrastructure compatibility with the City of Vancouver may be required. Additionally, all construction must follow safe work practices as provincially mandated in the Occupational Health and Safety Regulation in force under the Workers Compensation Act as the UEL is within the inspection jurisdiction of the WorkSafeBC.

5.4 Design Loads

5.4.1 Lateral Loads

Lateral earth loads were determined by the active earth pressures method. The wall of the reservoir was assumed to be a retaining wall. The surcharge load was taken to be the weight of the top soil. The active earth pressures from the soils and the surcharge load were then calculated and combined to find the total lateral loads. The lateral earth loads range from 15.7 kPa at the top of the reservoir to 127 kPa at the bottom of the reservoir and can be approximated by a linear relationship along the height of the reservoir. Earthquake Loads were calculated using the online design tool, Jabacus, which is based on the Equivalent Static Method. A Site Class C was assumed. A diagram of the lateral loads is shown in Figure 10.

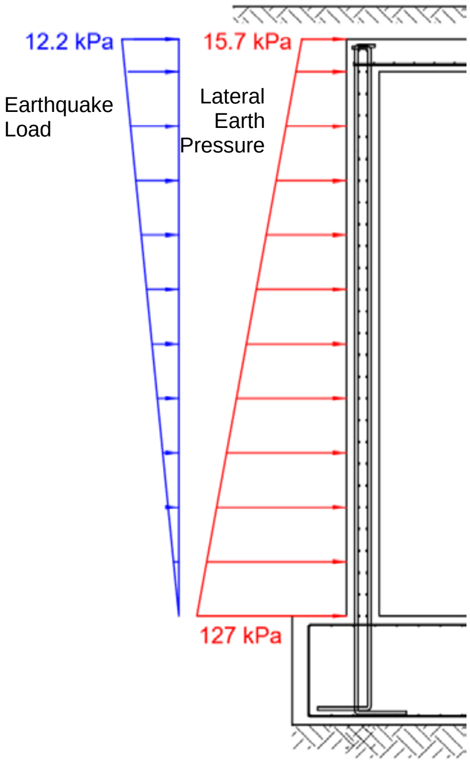


Figure 10. Lateral Loads.

5.4.2 Vertical Loads

Vertical loads were determined using the National Building Code of Canada 2015. Dead load was taken as the sum of the self-weight of concrete and weight of top soil (designed to be 300mm for landscaping purposes). As the surface of the reservoir will be available to public access, the live load was determined to be 4.8kPa based on the "Recreational Area" occupancy defined by the UBC Technical Guidelines. Snow and rain load was determined using coefficients provided by Jabacus. The governing load combination was determined to be 23.3 kPa for both reservoirs. Please refer to Appendix B – Steel Reinforcement Calculations for detailed calculations.

6 Technical Design Outputs

6.1 Supply and Distribution Mains

IFC drawings showing the horizontal and vertical alignments of the supply and distribution mains are found in Appendix A – IFC Drawings. The drawings consist of a plan view and profile view. The plan view shows the horizontal alignment of the proposed water mains and tie-ins with the existing UBC water distribution system. The profile view shows ground elevations, pipe invert elevations, and the cover over the water main along its length.

6.2 Reinforcement Details

Details showing the concrete reinforcement design for the mat foundation, foundation walls, top slab, columns, and beams are included in Appendix A – IFC Drawings.

7 Construction Specifications

Specifications for construction should follow all UBC Technical Design Requirements as well as the Master Municipal Construction Design (MMCD) Platinum edition. All testing should follow CSA standards and should be conducted by individuals approved by the Canadian Council of Independent Laboratories.

8 Draft Plan of Construction Work

8.1 North and South Reservoirs

Before work can begin, an environmental sweep must be conducted that encompasses all areas where work will be occurring. Then all utilities must be daylighted by BC One Call and marked. After that, grubbing and stripping can begin where all vegetation and topsoil will be removed from the excavation footprint and then temporarily stored on site for use after. This work will be done with excavators and dump trucks. The excavators should excavate to foundation level the foot print with an additional 1.5m excavated around the perimeter used to facilitate subsequent work. The excavators will excavate using the strip method and bench loading the dump trucks where possible in order to maintain order and save time. Excavated material that is not topsoil will then be hauled off site leaving onsite only the material required for backfilling.

Before the work on the foundation can begin, a ground inspection by an engineer must be conducted to ensure that the ground is free from organics and has competent soil. All organics must be removed and all soft spots must be sub excavated and replaced with competent soil. After the ground passes the base inspection, the soil needs to be compacted and pass soil density testing by a qualified inspector. Formwork for the foundation will then be erected around the perimeter of the foundation. Rebar for the foundation slab will then be placed. The rebar and formwork must be inspected before any concrete can be poured. Concrete must be tested for slump, air, temperature, and compressive strength before placement. Failed concrete cannot be placed until it passes testing. All concrete must be tested before the placements of superplasticizer and all concrete must be poured within its expiry time. Concrete cylinders casted for compressive strengths tests must be stored onsite for 24 hours before being stored in the lab. Concrete will be placed using a concrete pump truck. Placed concrete will be finished after pouring and must be covered if there is rain. The floor slab should be poured as one unit in order to ensure there are no joints that can leak.

After the floor slab is completed, work can begin on the concrete reservoir walls as well as reservoir columns. Rebar will be erected and inspected and after that, form work will be installed and inspected. Waterstop must be installed between the floor slab and the wall slabs in order to prevent leakage in the joints. The concrete will be placed inside the formwork using a pump truck and vibrated due to the depth of form. Care will be taken in order not to over vibrate the concrete causing segregation. The concrete formwork must remain in place for several days until the concrete is set enough for removal. After the walls and columns are in place and set, work can begin on the reservoir cap. Formwork can be installed for the cap followed by rebar placement for the concrete. Waterstop must be installed between the reservoir walls and the top cap in order to prevent leakage through the joint before the concrete for the top cap can be poured. The formwork must be left in place until the concrete is set enough for its removal.

Piping will be installed for supplying and draining the reservoirs and then the reservoir will be filled and left for testing. Perimeter drains must be installed along the exterior of the foundation. A trench will be dug around the perimeter and filter cloth must be placed from one side to the next. Granular crush is then placed in the trench and weeping tile is installed. The perforated pipe weeping tile shall be covered in a filter sock to prevent soil from entering into the weeping tile. The weeping tile should connect to a perculation trench that drains away from the foundation. Crushed granular will be then placed on top of the weeping tile until the trench is level. The reservoir walls will be coated with a polymer waterproofing membrane to prevent water ingress into the reservoir. The walls will be cleaned in order to remove impurities and loose particles and then the polymer membrane will be placed.

After the polymer is dried, the reservoir will be backfilled along the wall with native soil stockpiled onsite from the excavation. Hatches will be installed on the reservoir cap for access and then polymer membrane will be installed on the cap using the same method as listed above. Soil will then be placed around and on top of the reservoir with a final layer of native top soil previously stored on site being placed along the disturbed portions of the site. Finally, the top soil will be hydroseeded in order to prevent erosion, facilitate water infiltration, and return the site back to its previous condition.

8.2 Supply and Discharge Main

Before work can begin, an environmental sweep must be conducted that encompasses all areas where work will be occurring. More details about the environmental requirements can be found HERE. Then all utilities must be daylighted by BC One Call and marked. Steps must be taken in order to protect the public from the excavation. Fencing and signs must be installed around the perimeter of trench excavation. For sections that are aligned parallel with roads or right of ways, it is expected that there will be existing utilities such as sewer mains, gas lines etc. Trenching must be completed as per UBC Technical Guidelines Section 3.2 and MMCD Section 02666.

Once the trench has been excavated to the specified depth, a ground inspection must take place ensuring that the ground is competent. Granular bedding shall be placed as per UBC Technical Guidelines Section 3.3 and MMCD Section 0266. Bottom thickness of the granular bedding shall be 100mm for the supply main and 150mm for the discharge main. Pipe installation will adhere to UBC Technical Guidelines Section 3.4 and MMCD Section 02666. The shall be lowered into place by an excavator and connected into place using push on spigot type joints. The placement of pipes will go in one direction from one end to the other as to avoid the water main distorting in the middle due to soil loads. The pipe must be inspected by a Mechanical Distribution Engineer and UBC Energy & Water Services Head Plumber following UBC Technical Guidelines Section 3.8. After the pipes have passed inspection, the pipe can be surrounded and covered by the bedding granular. For granular fill, native material can be used provided that it is free from rock greater than 25mm. A sieve test will be conducted in order to determine if the native material is suitable for backfill. Backfill shall be compacted to 98% of standard proctor dry density and tested. Lifts shall not exceed 100mm in thickness. For trench sections that are parallel to a road, road sub-base will placed on top of trench backfill and compacted and tested. Road base will then be placed and compacted with asphalt being paved on top of the road base.

9 Cost Estimate

The total costs for this reservoir has been estimated at $21,899,000 with a yearly operational and maintenance cost of $517,430. The total cost includes detailed design, permitting, project management, construction and annual yearly operational and maintenance costs.

9.1 Detailed Design Costs

The estimated fee for the detailed design of this project was $99,484. The deliverables for the detailed design included a conceptual design and a design report. A breakdown of the estimated fee for the detailed design can be found in the project proposal.

9.2 Permitting Costs

This project does not require an environmental assessment. Since the permitting phase follows the environmental assessment phase per Chilibeck (2017), permits from a federal and provincial level will not apply as there is no environmental assessment. However, $100,000 as a contingency in case any other permitting issues arise.

9.3 Construction Costs

A detailed list of construction costs have been provided in Appendix D – Cost Estimate. This cost estimate is a class C level estimate and is a blended cost that includes labour and materials. The estimated construction costs for this underground reservoir is $21,899,000. The costs have been compiled from RSMeans and other industry sourced references. Quantities have been calculated from the drawings provided in the appendix. Concrete costs are expected to be the major cost for this project because of the large quantity to be used as well as its associated cost. A lump sum for ground improvement has been included due to the liquefiable potential of the site.

9.4 Operating and Maintenance Costs

Yearly maintenance and operating costs have been calculated to be $517,430 per year. A detailed cost calculation has been included in

Appendix D – Cost Estimate. The numbers for the power consumption has been determined from technical specifications. The rate of 12 cents per kWh for the electricity cost has been determined from BC Hydro’s preferred rate for industrial users. The costs for water treatment, maintenance and operations have been determined from technical manuals.

10 Schedule

A final schedule has been developed for this project based on a start date of May 1st, 2018. The schedule has been developed based on major components of the project. The Gantt chart can be found in

Appendix E – Schedule . The schedule has been based on a work schedule of 5 days a week with an initial starting workforce of one crew. Additional workforces will be added as needed as additional components of the project begins. It is anticipated that the majority of the construction will be completed by October 28th, 2019. Minor details such as surveying and other miscellaneous items have been excluded as these will be conducted within the construction timeframe.

11 Service Life Maintenance Plan

A preliminary plan has been developed for the maintenance of the reservoirs and booster stations. The two reservoirs and booster stations are estimated to have a long service life based on their design and material quality. The long service life of the reservoirs and booster stations can be maintained as long as water quality testing is conducted on a biweekly basis and regular pump maintenance is conducted on the pump station. The associated costs with these maintenance tasks can be found in Appendix D – Cost Estimate.

12 Sustainability

Environmentalism is an important priority for this project. The goal is to ensure that steps are taken in all aspects of the project from its design as well as construction.

12.1 Design

Environmentalism has been designed into the project from the very beginning. Care was taken to ensure that both economic viability and environmental protection were assessed during the design phase. A concrete reservoir was selected because the structure can be buried underground after construction. This enables the land use of the site to remain the same as before construction. Additionally, grass will be planted to make sure that the site will blend in with its environment and become part of the ecosystem. Top soil removed in excavation will reused onsite where possible and the site will be hydroseeded in order to prevent erosion, facilitate water infiltration, and promote ecology. The land above the reservoir can be used as a park space fostering physical activity and exercise which promotes a health in the community. Additionally we have designed for a rain garden to be placed on top of the structure that will encourage healthy eating. The promotion of public and community space will foster community bonding within the local area.

12.2 Construction

Construction can contribute to emissions and ecosystem damage and steps need to be taken in order to minimize these effects. An environmental sweeps must be carried out on site before any work can begin. The sweeps will look for wildlife that must be removed off site or a may require a buffer zone in which no work can be done. Machinery that is stationary for over 12hrs will require drip trays underneath them in order to catch any fluids that may leak from them. Equipment will be serviced on time and in good running condition to ensure that there are no leaks and operating efficiently. There will be a no idle policy on site to further reduce emissions. Spill kits must be in every piece of machinery with drip trays being readily available should they be needed. Garbage on site must be disposed of in their proper containers and products that can be recycled will be recycled in order to reduce waste generated by construction. Native material suitable for construction must be used in preference to importing material from offsite. This is ensure that the ecosystem of the site remains as close to its original condition as possible. During construction, erosion control must be implemented where necessary. Environmental monitoring will occur during construction in order to make sure that the environmental policies are being followed.

13 Conclusion

Our preferred design features two below grade reinforced concrete reservoirs with a total capacity of 30.4 million litres, two new watermain alignments, and a booster station. The design is sized for 72 hours of reduced institutional and residential water usage and 120 hours of emergency and fire-flow water usage (at full capacity). The capital cost of the system is approximately 20 million dollars, with a scheduled start date of May 2018 and project completion scheduled for September 2018.

- The north reservoir is located between the UBC baseball turf and the Rashpal Dhillon Track & Field Oval. It has a capacity of 16 million litres and is 72 metres long, 45 meters wide, and 5 meters deep.
- The south reservoir is located between the UBC Baseball Turf and the boulevard north of West 16th Avenue. It has a capacity of 14.4 million litres and is sized at 92 metres long, 32 meters wide, and 5 meters deep.

The reservoirs will be hydraulically connected and feature a similar design consisting of multi-cell compartmentalization, an adjustable weir to control inlet flow rates, and a sluice gate to control discharge flow rates. A sodium hypochlorite injection system will be used to disinfect the water in the system.

Two new watermain alignments will be built to facilitate proper distribution and pressurization of the water supply system; they are 1400 metres and 1000 metres in length, respectively.

14 References

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Images

Image of pressure zones

http://energy.ubc.ca/ubcs-utility-infrastructure/water/

Appendix A – IFC Drawings

A-00 Base Plan

A-01 Site Layout

A-02 North Reservoir

A-03 South Reservoir

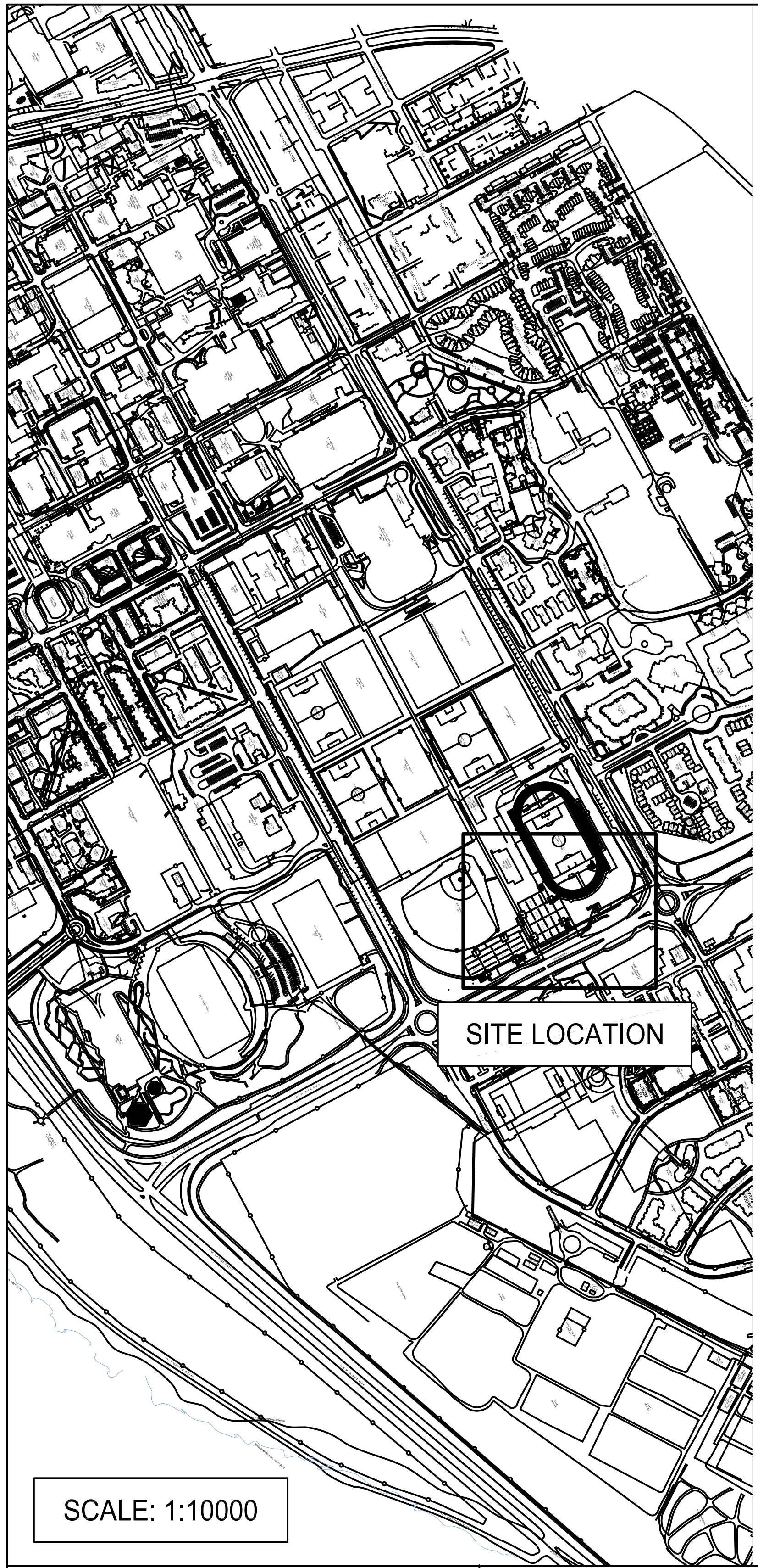
A-04 Reservoir Section and Details

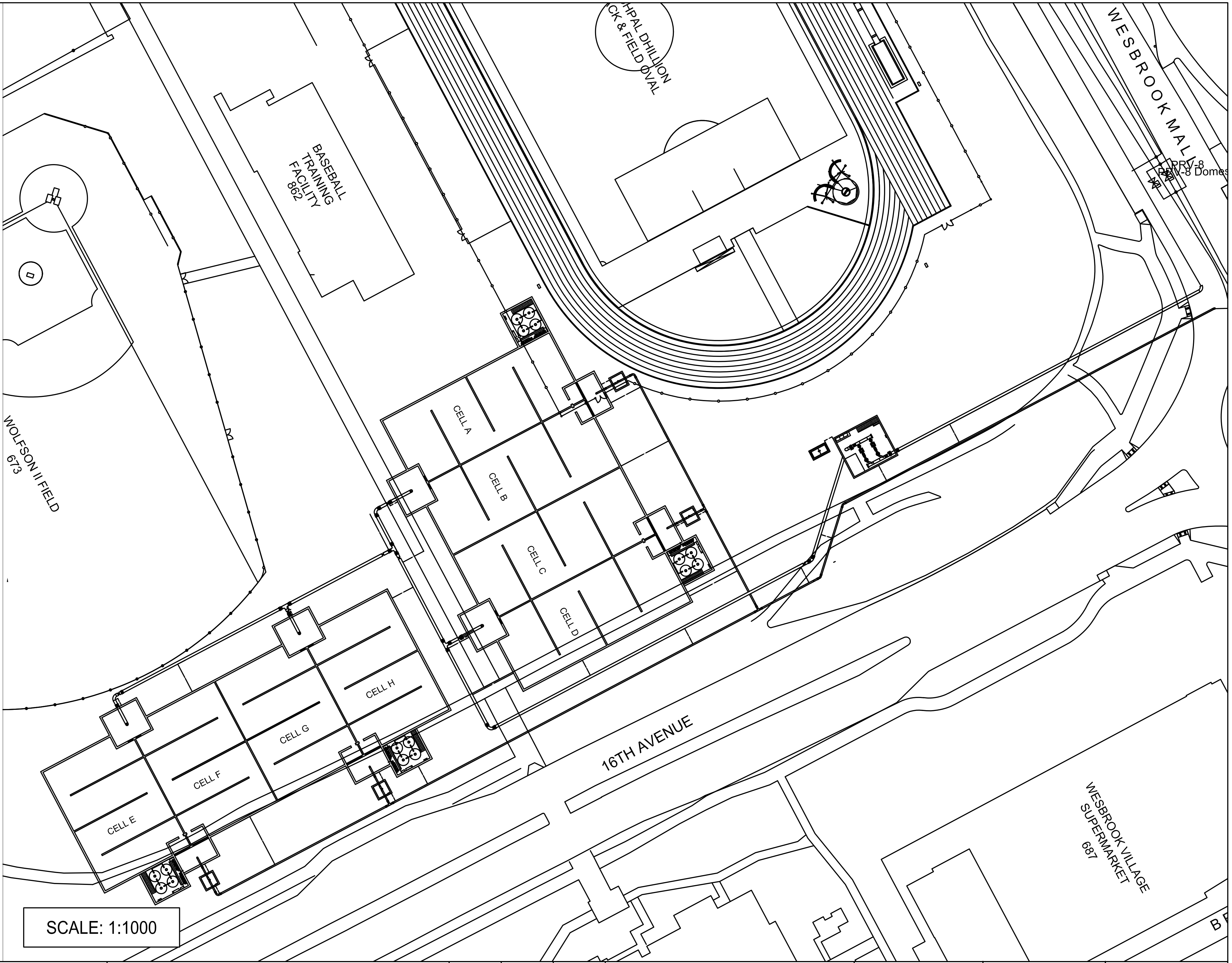
A-05 Booster Pump Station

A-06 Distribution Main

A-07 Supply Main

A-08 Reinforcement Details





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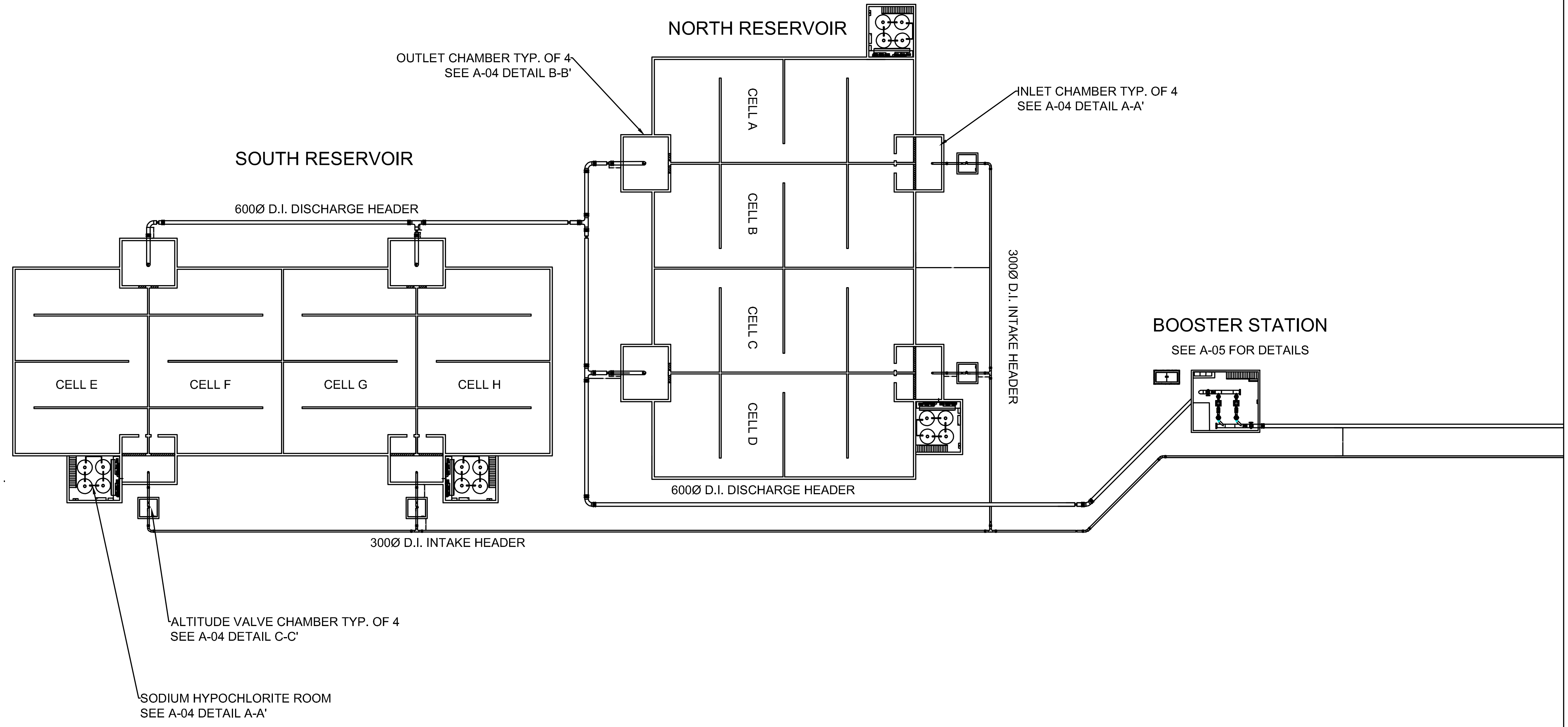


QDS ENGINEERING

ISSUE FOR CONSTRUCTION

PROJECT:

UBC EMERGENCY WATER
SUPPLY SYSTEM

DRAWING TITLE:

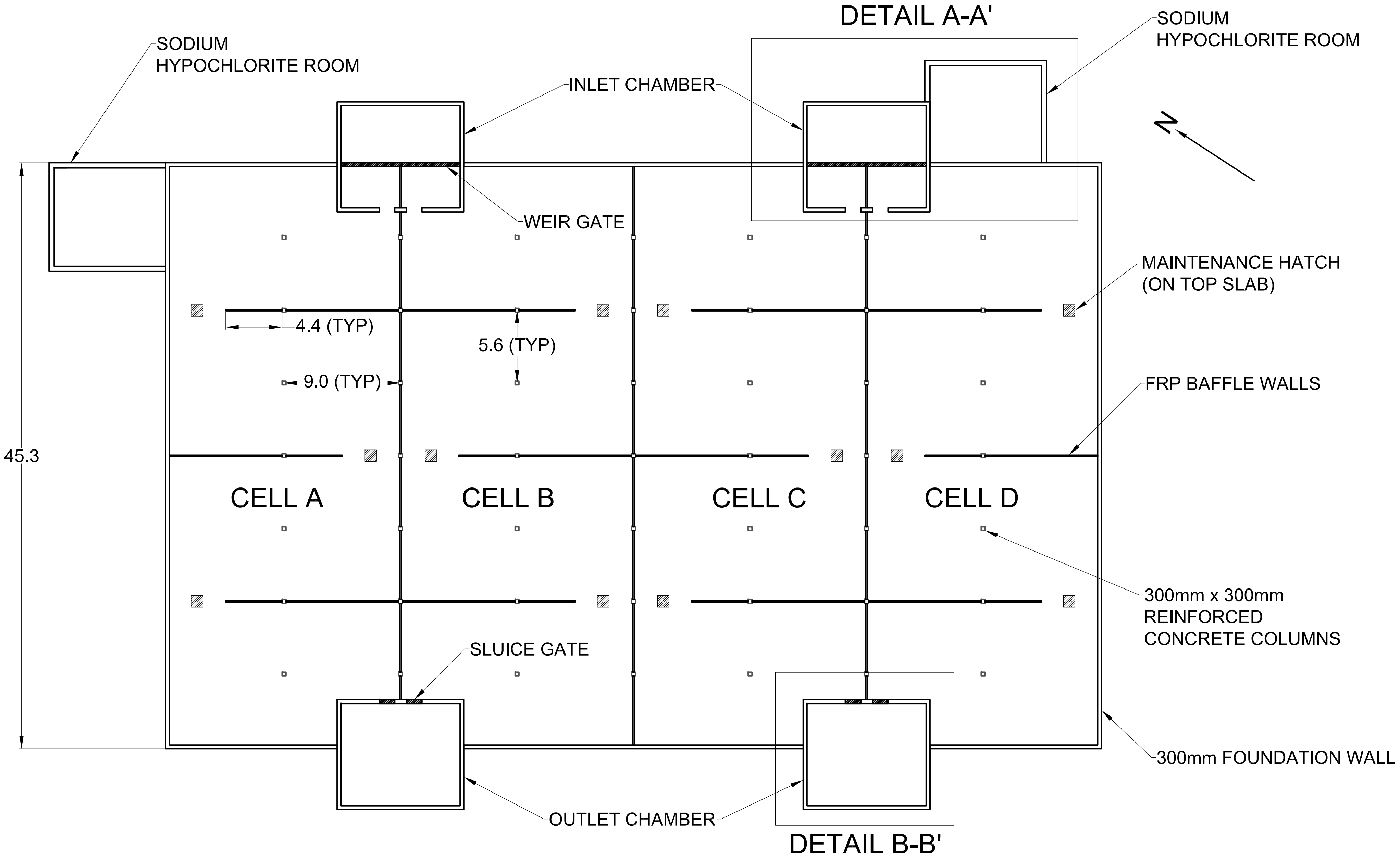
SITE LAYOUT

REV NO.	DATE	BY	DESCRIPTION

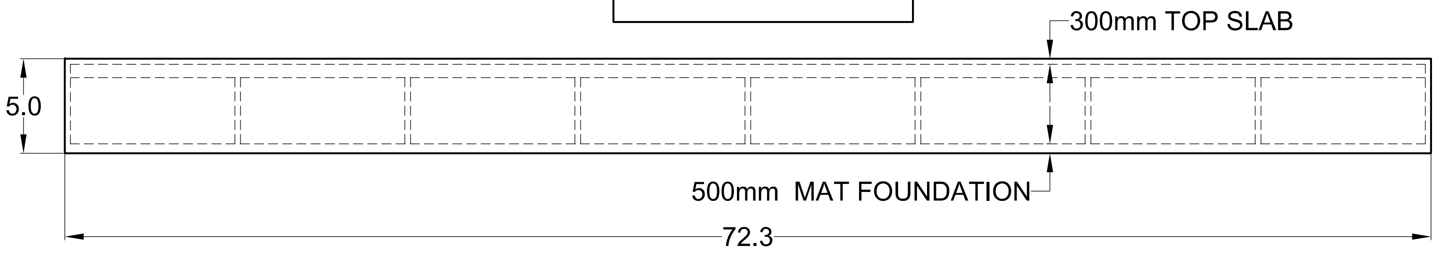
SEAL

DESIGNED: LL
CHECKED: YZ
DRAWN: LL
APPROVED: AC

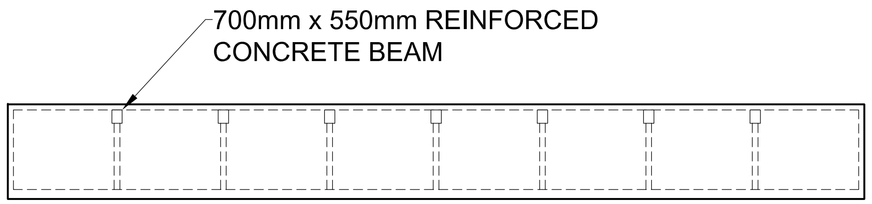
SCALE: 1:400
DATE: 04/09/18
REV: 0
SHEET: A-01



PLAN VIEW



ELEVATION VIEW



PROFILE VIEW

NOTES

1. ALL DIMENSIONS IN METRES UNLESS OTHERWISE SPECIFIED.
2. SEE SHEET A-**04 RESERVOIR SECTION AND DETAILS** FOR DETAILS A-A' AND B-B'.
3. SEE SHEET **A-08 REINFORCEMENT DETAILS** FOR COMPLETE CONCRETE AND REINFORCEMENT DIMENSIONS AND DETAILS.
4. TOP SLAB, BEAMS NOT SHOWN IN PLAN VIEW FOR CLARITY.
5. BAFFLE WALLS, CHAMBERS, SODIUM HYPOCHLORITE ROOM NOT SHOWN IN ELEVATION VIEWS FOR CLARITY.

QDS ENGINEERING

ISSUE FOR CONSTRUCTION

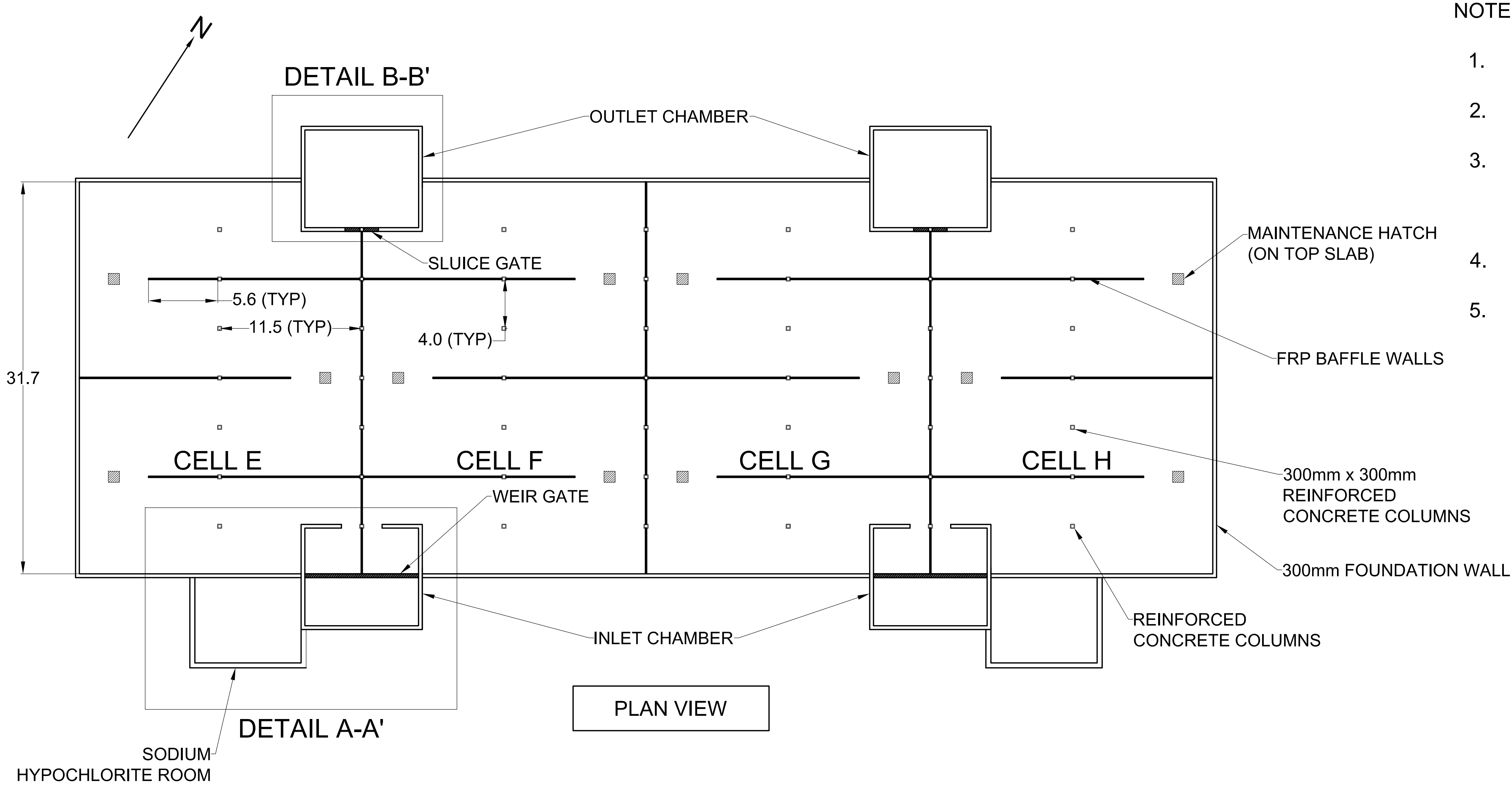
PROJECT:
UBC EMERGENCY WATER SUPPLY SYSTEM

DRAWING TITLE:
NORTH RESERVOIR

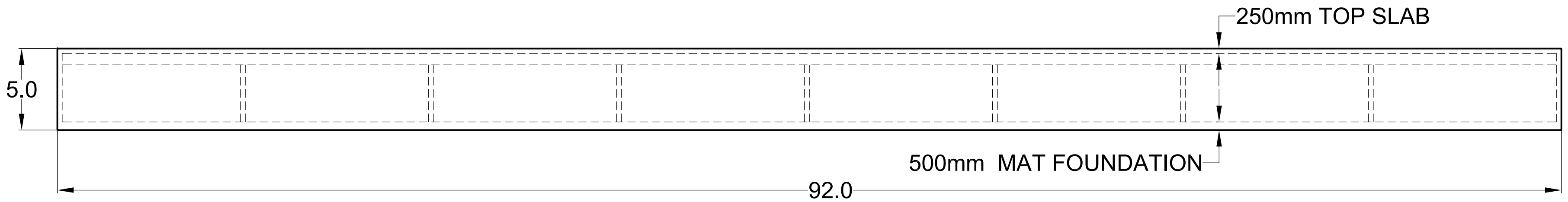
REV NO.	DATE	BY	DESCRIPTION

SEAL

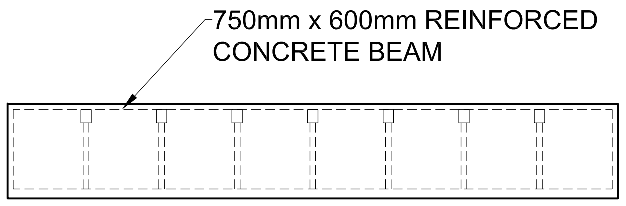
DESIGNED: LL	SCALE: 1:400
CHECKED: YZ	DATE: 04/09/18
DRAWN: YZ	REV: 0
APPROVED: AC	SHEET: A-02



PLAN VIEW



ELEVATION VIEW



PROFILE VIEW

NOTES

1. ALL DIMENSIONS IN METRES UNLESS OTHERWISE SPECIFIED.
2. SEE SHEET A**-04 RESERVOIR SECTION AND DETAILS** FOR DETAILS A-A' AND B-B'.
3. SEE SHEET **A-08 REINFORCEMENT DETAILS** FOR COMPLETE CONCRETE AND REINFORCEMENT DIMENSIONS AND DETAILS.
4. TOP SLAB, BEAMS NOT SHOWN IN PLAN VIEW FOR CLARITY.
5. BAFFLE WALLS, CHAMBERS, SODIUM HYPOCHLORITE ROOM NOT SHOWN IN ELEVATION VIEWS FOR CLARITY.

QDS ENGINEERING

ISSUE FOR CONSTRUCTION

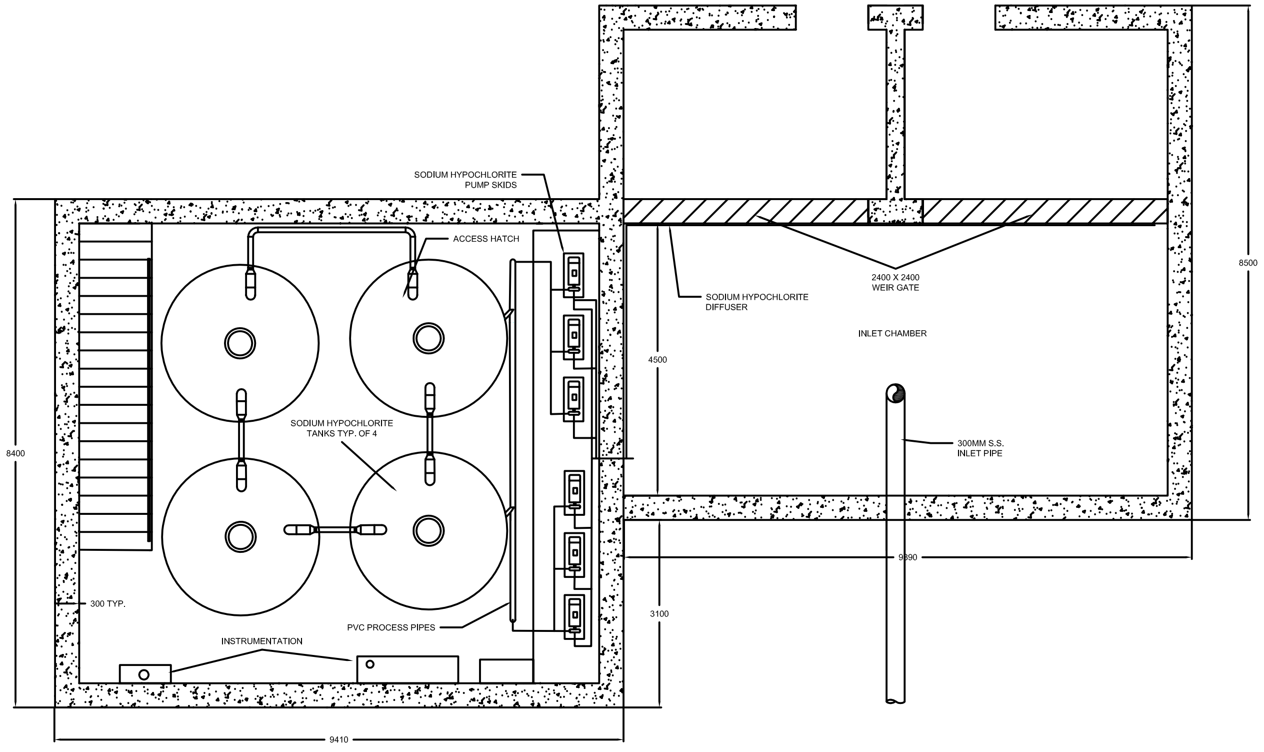
PROJECT:
UBC EMERGENCY WATER
SUPPLY SYSTEM

DRAWING TITLE:
SOUTH RESERVOIR

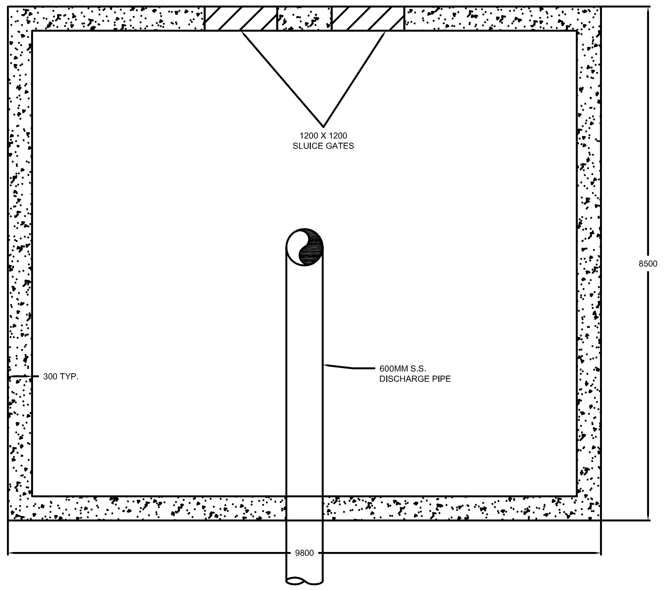
REV NO.	DATE	BY	DESCRIPTION

SEAL

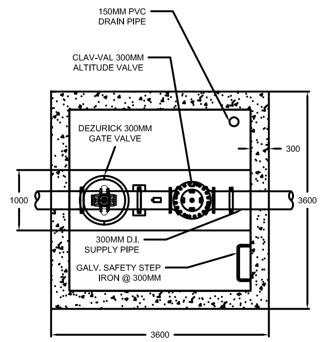
DESIGNED: LL	**SCALE: 1:400**
CHECKED: YZ	**DATE: 04/09/18**
DRAWN: YZ	**REV: 0**
APPROVED: AC	**SHEET: A-03**



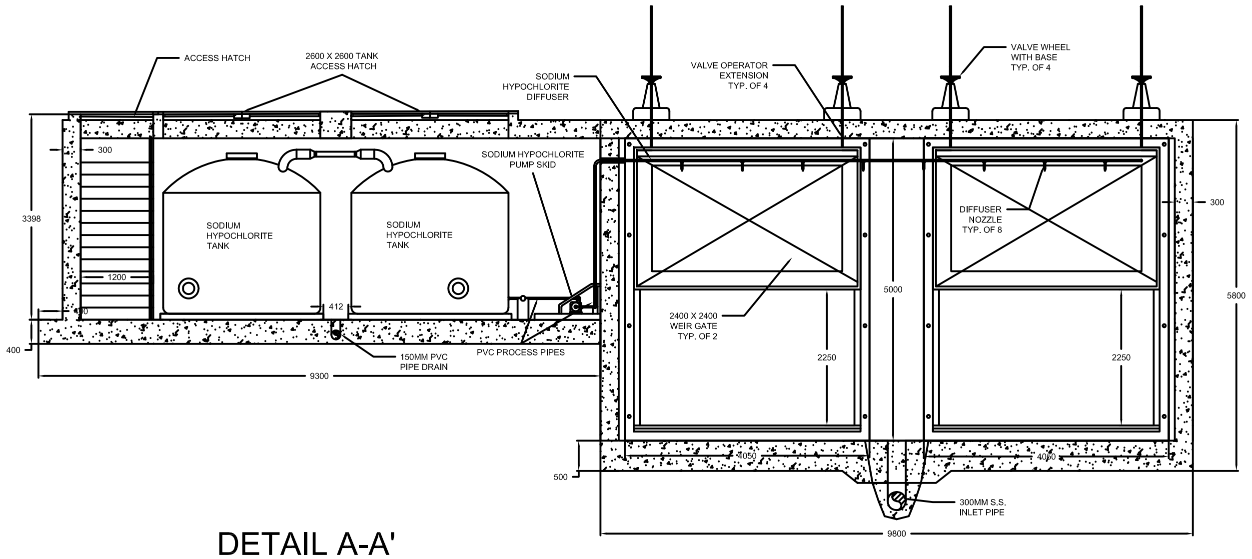
DETAIL A-A'
INLET CHAMBER AND SODIUM
HYPOCHLORITE ROOM - PLAN



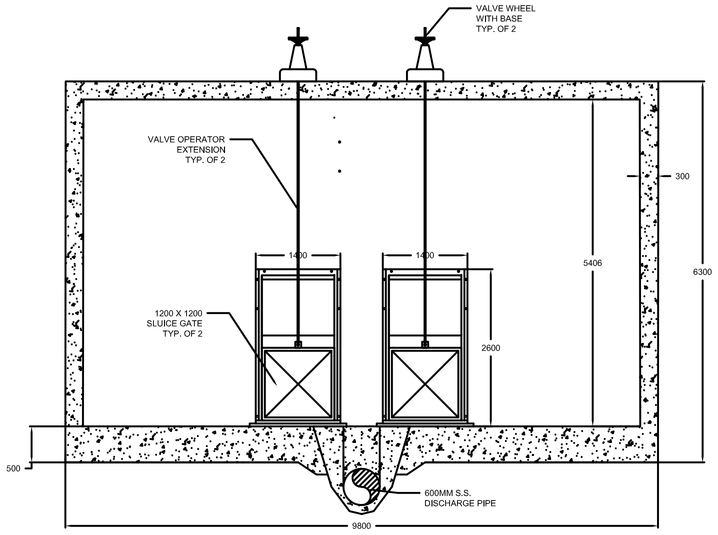
DETAIL B-B'
OUTLET CHAMBER - PLAN



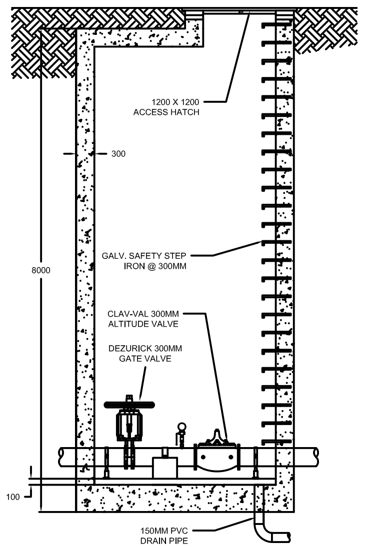
DETAIL C-C'
ALTITUDE VALVE
CHAMBER -(PLAN)



DETAIL A-A'
INLET CHAMBER AND SODIUM
HYPOCHLORITE ROOM - ELEVATION



DETAIL B-B'
SLUICE GATE - ELEVATION



DETAIL C-C'
ALTITUDE VALVE
CHAMBER -(ELEVATION VIEW)

QDS ENGINEERING

ISSUE FOR CONSTRUCTION

PROJECT:

UBC EMERGENCY WATER
SUPPLY SYSTEM

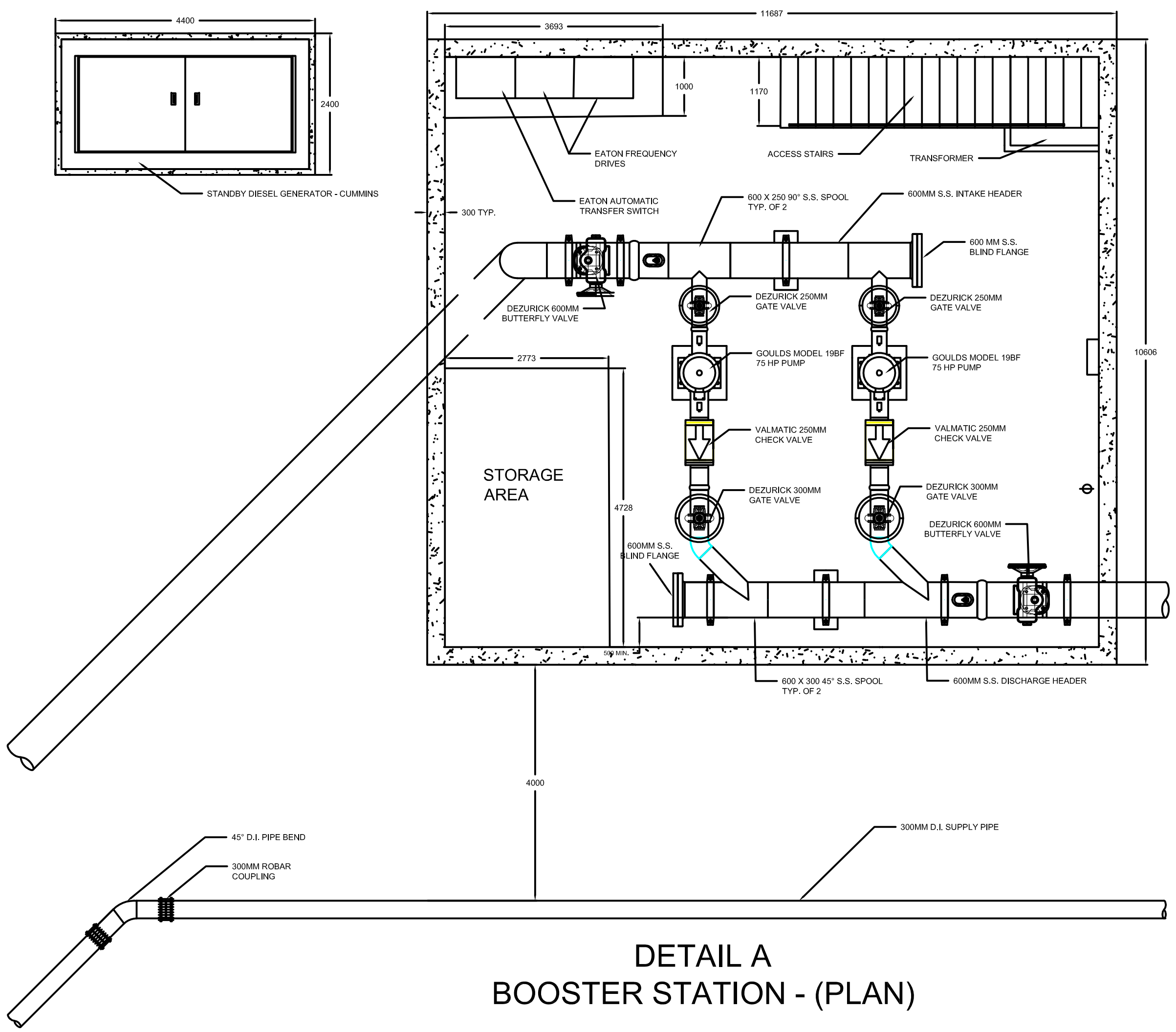
DRAWING TITLE:

RESERVOIR SECTION AND DETAILS

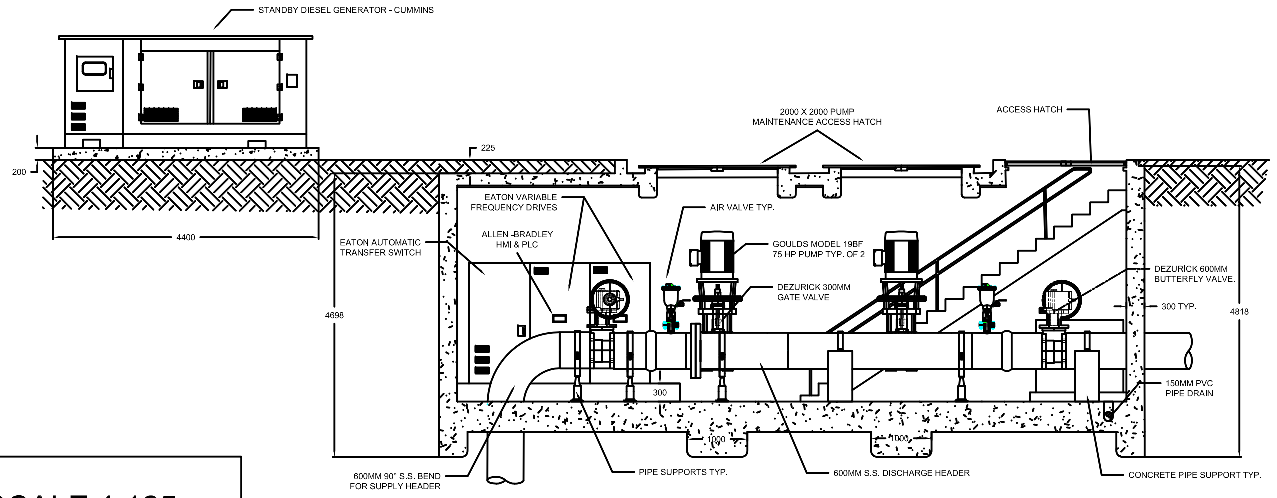
REV NO.	DATE	BY	DESCRIPTION

SEAL

DESIGNED: LL	**SCALE: 1:125**
CHECKED: YZ	**DATE: 04/09/18**
DRAWN: LL	**REV: 0**
APPROVED: AC	**SHEET: A-04**

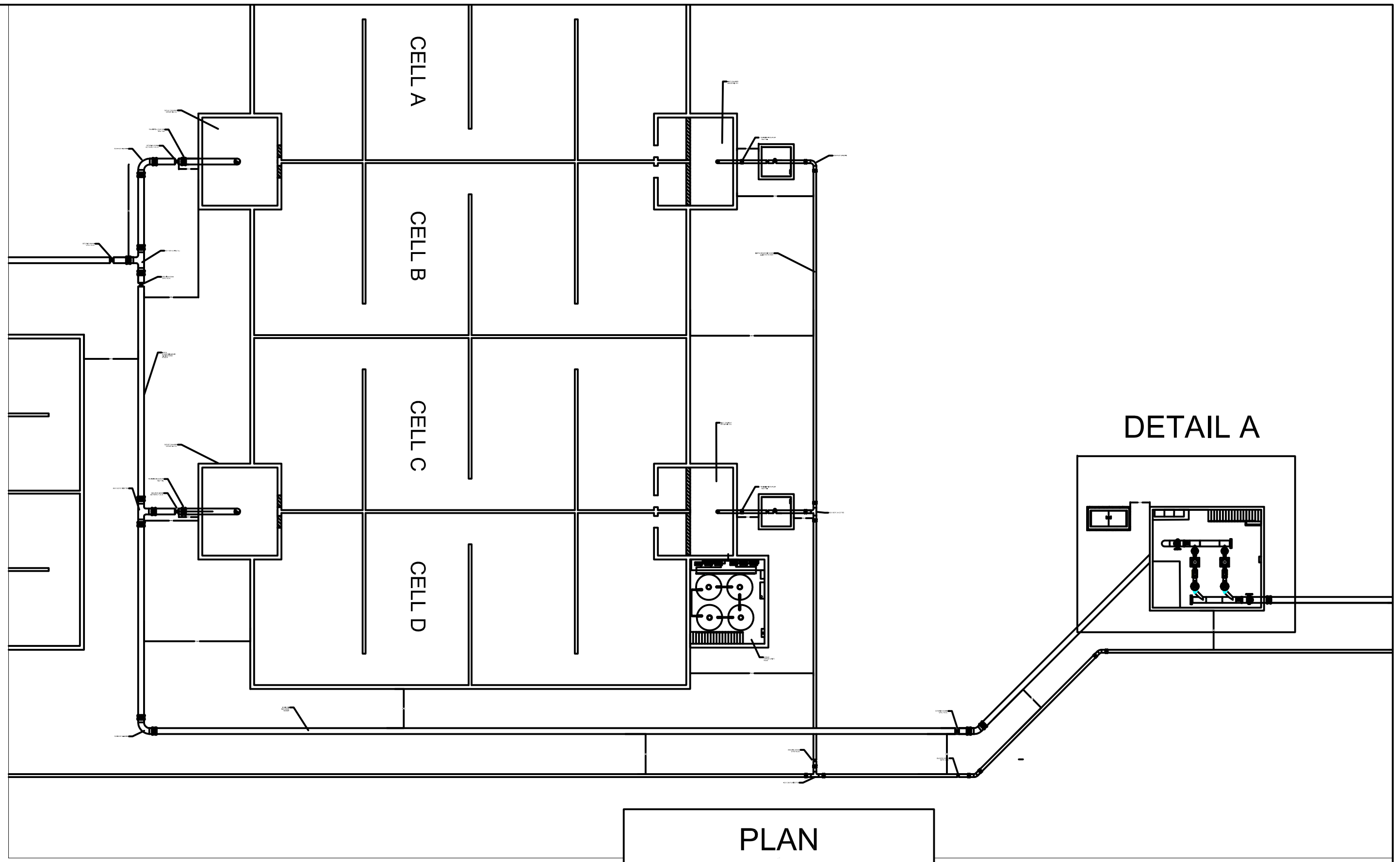


DETAIL A
BOOSTER STATION - (PLAN)



SCALE 1:125

DETAIL A
BOOSTER STATION - ELEVATION



PLAN
SCALE 1:750

NOTES

1. CONCRETE PENETRATIONS TO BE GASKET SEALED. PIPE PENETRATIONS TO BE SLEEVED, GROUTED AND CAPPED WITH SEALANT
2. COUPLINGS, FITTINGS AND VALVES TO BE FULLY RESTRAINED
3. PROVIDE ADAPTERS AS REQUIRED TO SUIT CONNECTIONS
4. SPOOL DIMENSIONS FOR THE BOOSTER STATION TO BE REVIEWED BY THE ENGINEER PRIOR TO FABRICATION
5. PIPES TO PRESSURE TEST TO 100 PSI
6. CONTRACTOR TO CONFIRM LOCATIONS OF EXISTING UTILITIES PRIOR TO CONSTRUCTION

QDS ENGINEERING

ISSUE FOR CONSTRUCTION

PROJECT:
UBC EMERGENCY WATER SUPPLY SYSTEM

DRAWING TITLE:
BOOSTER PUMP STATION

REV NO.	DATE	BY	DESCRIPTION

SEAL

DESIGNED: LL	**SCALE: AS SHOWN**
CHECKED: YZ	**DATE: 04/09/18**
DRAWN: LL	**REV: 0**
APPROVED: AC	**SHEET: A-05**

PLAN
SCALE 1:2000

NOTES

1. CONCRETE PENETRATIONS TO BE GASKET SEALED. PIPE PENETRATIONS TO BE SLEEVED, GROUTED AND CAPPED WITH SEALANT
2. COUPLINGS, FITTINGS AND VALVES TO BE FULLY RESTRAINED
3. PROVIDE ADAPTERS AS REQUIRED TO SUIT CONNECTIONS
4. SPOOL DIMENSIONS FOR THE BOOSTER STATION TO BE REVIEWED BY THE ENGINEER PRIOR TO FABRICATION
5. PIPES TO PRESSURE TEST TO 100 PSI
6. CONTRACTOR TO CONFIRM LOCATIONS OF EXISTING UTILITIES PRIOR TO CONSTRUCTION

PROFILE
SCALE H: 1:2000 V: 1:250

QDS ENGINEERING	PROJECT: UBC EMERGENCY WATER SUPPLY SYSTEM	DRAWING TITLE: DISTRIBUTION MAIN WESBROOK MALL	SEAL	DESIGNED: LL	SCALE: 1:2000
ISSUE FOR CONSTRUCTION				CHECKED: LL	DATE: 04/09/18
				DRAWN: AY	REV: 0
				APPROVED: AC	SHEET: A-07

REV NO.	DATE	BY	DESCRIPTION

PLAN
SCALE 1:2000

NOTES

1. CONCRETE PENETRATIONS TO BE GASKET SEALED. PIPE PENETRATIONS TO BE SLEEVED, GROUTED AND CAPPED WITH SEALANT
2. COUPLINGS, FITTINGS AND VALVES TO BE FULLY RESTRAINED
3. PROVIDE ADAPTERS AS REQUIRED TO SUIT CONNECTIONS
4. SPOOL DIMENSIONS FOR THE BOOSTER STATION TO BE REVIEWED BY THE ENGINEER PRIOR TO FABRICATION
5. PIPES TO PRESSURE TEST TO 100 PSI
6. CONTRACTOR TO CONFIRM LOCATIONS OF EXISTING UTILITIES PRIOR TO CONSTRUCTION

PROFILE
SCALE H: 1:2000 V: 1:250

QDS ENGINEERING

ISSUE FOR CONSTRUCTION

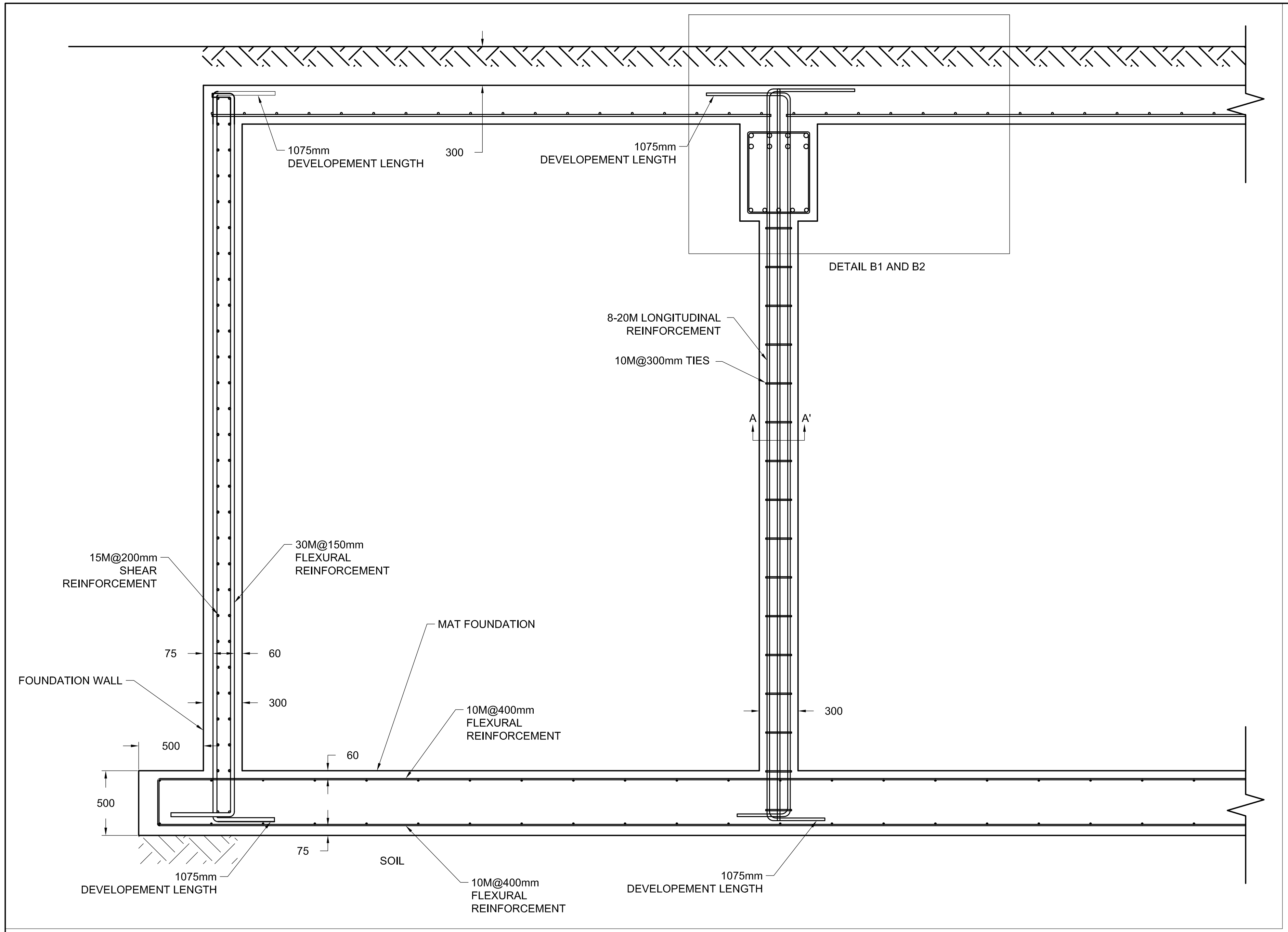
PROJECT:
UBC EMERGENCY WATER
SUPPLY SYSTEM

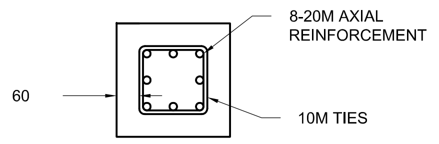
DRAWING TITLE:
SUPPLY MAIN
16TH AVENUE

REV NO.	DATE	BY	DESCRIPTION

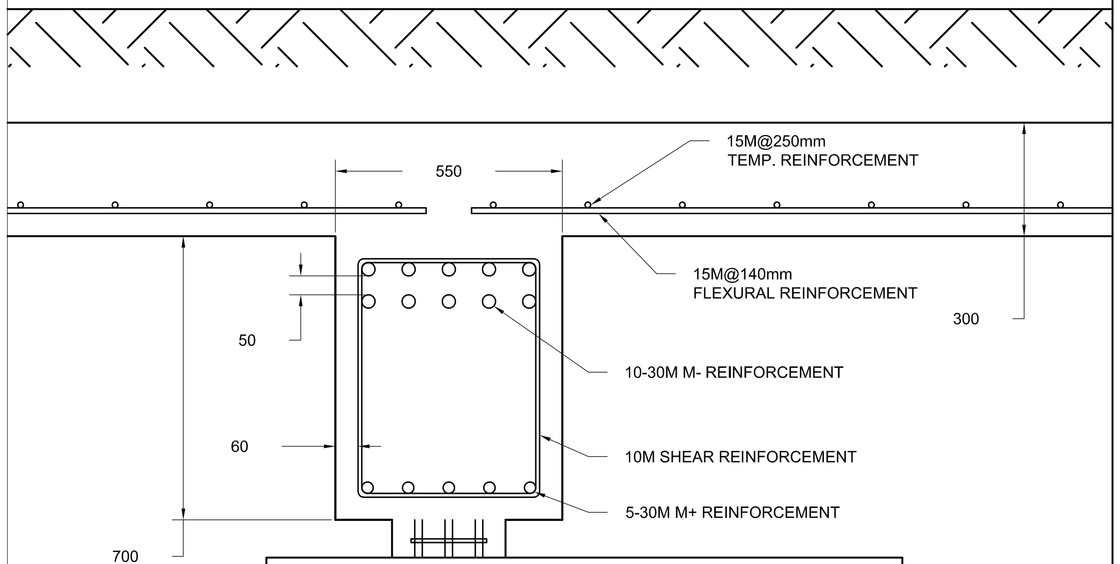
SEAL

DESIGNED: LL	SCALE: 1:2000
CHECKED: LL	DATE: 04/09/18
DRAWN: AY	REV: 0
APPROVED: AC	SHEET: A-07

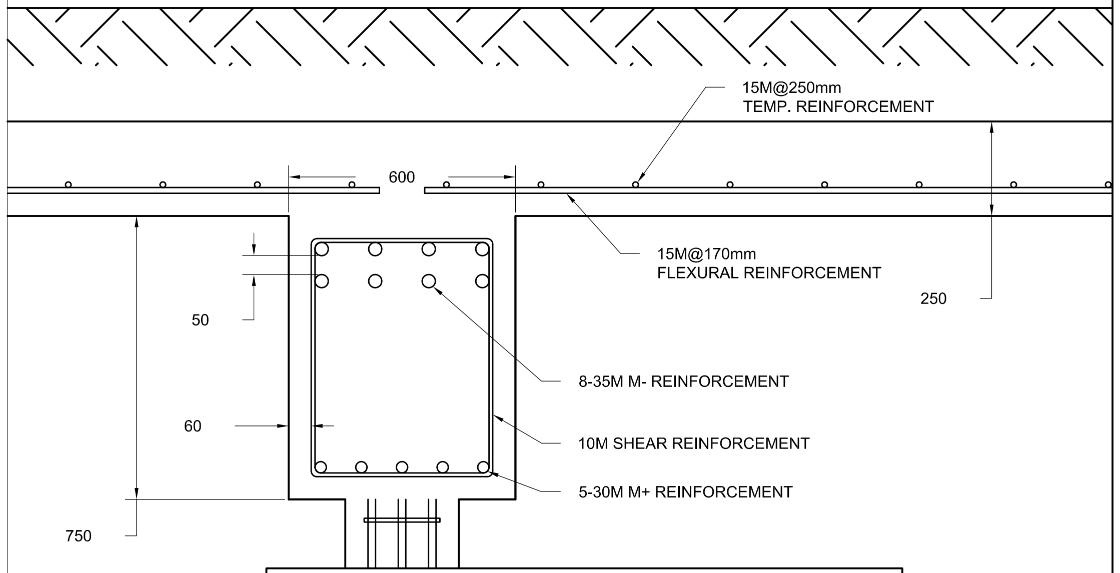




DETAIL A-A' COLUMN CROSS SECTION



DETAIL B1 NORTH RESERVOIR DETAILS



DETAIL B2 SOUTH RESERVOIR DETAILS

NOTES:

1. ALL DIMENSIONS IN MILLIMETERS UNLESS OTHERWISE SPECIFIED.
2. REINFORCEMENT TO BE 400MPa DEFORMED STEEL BARS.

QDS ENGINEERING

ISSUE FOR CONSTRUCTION

PROJECT:
UBC EMERGENCY WATER
SUPPLY SYSTEM

DRAWING TITLE:
REINFORCEMENT DETAILS

REV NO.	DATE	BY	DESCRIPTION

SEAL

DESIGNED: AY/YZ	**SCALE: NTS**
CHECKED: JN	**DATE: 04/09/18**
DRAWN: AY/YZ	**REV: 0**
APPROVED: AC	**SHEET: A-08**

Appendix B – Steel Reinforcement Calculations

Foundation Wall

Assume typical basement wall design, pin-supported at the top (slab) and bottom (mat foundation) as referenced in Brzev & Pao, 2006. Design vertical and horizontal distributed reinforcement as per CSA A23.3.

Given:

$f_c' = 25 \text{ MPa}$

$f_y = 400\ MPa$

$\phi_c = 0.65$

$\phi_s = 0.85$

Determine critical design bending moments and shear forces.

$$V_f \approx \frac{\text{distributed lateral earth load } \times h}{2} + \frac{\text{average of earthquake load distribution } \times h}{2}$$

$$= \frac{27.18\ \times 5}{2} + \frac{99.82\ \times 5}{2} = 234\ kN/m \text{ at the bottom of foundation wall}$$

$$M_f = \frac{\text{average of lateral and earthquake load distributions} \times h^2}{8} = \frac{77 \times 5}{8}$$

$$= 241\, \frac{kNm}{m} \text{ approximately at midpoint of foundation wall}$$

Design walls for combined effects of flexure and axial loads.

(a) Determine wall thickness (Cl 14.3.6.1).

$$t_{min} = max \begin{cases} \dfrac{1}{25}h = \dfrac{3000\ mm}{25} = 120\ mm \\ 190\ mm \text{ for cast-in-place foundation walls} \end{cases}$$

$$t_{min} = 190\ mm$$

Use t = 300 mm.

(b) Calculate required area of vertical tension reinforcement.

Determine the effective depth:

Use 30M bars and 75 mm cover (for concrete cast against & permanently exposed to earth).

$$d = t - cover - \frac{d_b}{2} = 300 - 75 - \frac{30}{2} = 210\ mm$$

Calculate area of tension reinforcement using the direct procedure:

$$M_r = M_f = 275\ kNm$$

$$b = 1000\ mm$$

$$A_s = 0.0015 f_c' b \left(d - \sqrt{d^2 - \frac{3.85 M_r}{f_c' b}} \right)$$

$$= 0.0015 \times 25 \times 1000 \left(210 - \sqrt{210^2 - \frac{3.85 \times (241 \times 10^6)}{25 \times 1000}} \right) = 4741\ mm^2/m$$

(c) Select amount of vertical reinforcement in terms of size and spacing.

Use 30M bars:

$$s = A_b \frac{1000}{A_s} = 700 \times \frac{1000}{4741} = 148\ mm$$

(d) Find maximum permitted bar spacing (Cl 14.1.8.4).

$$s_{max} = min \begin{cases} 3t = 3 \times 300 = 900\ mm \\ 500\ mm \end{cases}$$

$$s_{max} = 500\ mm$$

$$s = 148\ mm\ < s_{max} = 500\ mm$$

$$\Rightarrow Use\ s = 150\ mm\ \Rightarrow\ use\ 30M@150.$$

(e) Check that the maximum tension reinforcement requirement is satisfied (Cl 10.5.2).

$$A_s = A_b \frac{1000}{s} = 700 \times \frac{1000}{150} = 4667 \frac{mm^2}{m}$$

$$\rho = \frac{A_s}{bd} = \frac{4667}{1000 \times 215} = 0.0217$$

$$\rho = 0.0217 < \rho_b \approx \frac{f_c'}{1100} = 0.0227 \ \Rightarrow \text{properly reinforced}$$

(f) Check the minimum area of distributed vertical reinforcement (Cl 14.1.8.5).

$$A_g = 1000t = 1000 \times 300 = 300 \times 10^3 \ mm^2$$

$$A_{v,min} = 0.0015 A_g = 0.0015 \times (300 \times 10^3) = 450 \frac{mm^2}{m}$$

Since

$$A_v = 4667 \frac{mm^2}{m} > A_{v,min} = 450 \ \frac{mm^2}{m}$$

The vertical reinforcement is adequate.

Design walls for shear.

(a) Determine the concrete shear resistance, V_c.

Find effective shear depth:

$$d_v = max \begin{cases} 0.9d = 0.9 \times 210 = 189 \ mm \\ 0.72t = 0.72 \times 300 = 216 \ mm \end{cases}$$

$$d_v = 216 \ mm \approx 220 \ mm$$

Use $b_w = 1000 \ mm$ as the width of the unit strip.

Find β (Cl 11.3.6.3b):

$$\beta = \frac{230}{1000 + d_v} = \frac{230}{1000 + 220} = 0.189 \approx 0.19$$

Find V_c:

$$\begin{aligned} V_c &= \phi_c \lambda \beta \sqrt{f_c'} b_w d_v \\ &= 0.65 \times 1.0 \times 0.19 \times \sqrt{25} \times 1000 \times 220 = 136 \ kN \end{aligned}$$

$$V_f = 234 \frac{kN}{m} > V_c = 136 \frac{kN}{m} \Rightarrow \text{Shear reinforcement needed}$$

(b) Find shear resistance of steel, V_c.

$$V_s = V_f - V_c = 234 - 136 = 98\frac{kN}{m}$$

Use 15M shear reinforcement ⇒ $A_v = A_b = 200\ mm^2$

$$s = \frac{\phi_s A_v f_y d_v cot(35°)}{V_s} = \frac{0.85 \times 200 \times 400 \times 220 \times 1.43}{98 \times 10^3} = 218\ mm$$

$$s = 218\ mm\ \Rightarrow use\ s = 200\ mm \Rightarrow use\ 15M@200.$$

(c) Check maximum shear resistance (Cl 11.3.3).

$$V_{r,max} = 0.25\phi_c f_c' b_w d_v = 0.25 \times 0.65 \times 25 \times 1000 \times 220 = 894\ kN$$

$$V_r = V_c + V_s$$

$$V_s = \frac{\phi_s A_v f_y d_v cot(35°)}{s} = \frac{0.85 \times 200 \times 400 \times 220 \times 1.43}{200} = 107\ kN$$

$$V_c = 136\ kN$$

$$\Rightarrow V_r = 243\ kN < V_{r,max} = 894\ kN$$

(d) Check the minimum area of distributed horizontal reinforcement (Cl 14.1.8.6).

$$A_g = 1000t = 1000 \times 300 = 300 \times 10^3\ mm^2$$

$$A_{h,min} = 0.002A_g = 0.002 \times (300 \times 10^3) = 600\frac{mm^2}{m}$$

$$A_h = \frac{1000A_v}{s} = \frac{1000 \times 200}{200} = 1000\ mm^2$$

$$A_h = 1000\frac{mm^2}{m} > A_{h,min} = 600\ \frac{mm^2}{m}$$

(e) Check maximum permitted spacing (Cl 14.1.8.4).

$$s_{max} = min\begin{cases} 3t = 3 \times 300 = 900\ mm \\ 500\ mm \end{cases}$$

$$s_{max} = 500\ mm$$

$$s = 200\ mm\ < s_{max} = 500\ mm$$

Check if 1 layer is adequate.

Since $t = 200\ mm > 310\ mm$ ⇒ Use 2 layers of reinforcement. For the side facing water, use a 60 mm cover, corresponding to exposure class C.

Mat Foundation

Design mat foundation using the finite element method (a type of non-rigid method) in SAFE 2016. Consider loading cases with the reservoir empty and full.

- Use a modulus of subgrade reaction, k, of $27100\ kN/m$ for silts and clays of low compressibility.
- Start with 10M bars.
- For side exposed to soil (concrete is cast against and permanently exposed to earth) ⇒ $\text{cover} = 75\ mm$
- For side exposed to water, use exposure class C ⇒ $\text{cover} = 60\ mm$
- Coduto, 2006 recommends a mat thickness of 1-2 m for buildings and tower structures. Since the reservoirs have a smaller load compared to larger multi-storey buildings, a 500 mm thickness was initially tested and verified in SAFE 2016.
- No temperature or shrinkage reinforcement is required for two-way slabs.

Model outputs: all designed reinforcement is less than the minimum reinforcement requirement. Therefore, the minimum reinforcement requirement governs:

(a) Minimum reinforcement requirement (governs from model, Cl 7.8.1).

$$A_{s,min} = 0.001A_g\ (\text{per direction}) = 0.001 \times (1000 \times 500) = 500\ mm^2$$

(b) Check the minimum bar spacing requirement (Cl 7.4.1.2).

$$s = 100 \times \frac{1000}{250\ (\text{per layer per direction})} = 400\ mm$$

$$\Rightarrow use\ 10M@400.$$

(c) Check maximum bar spacing requirement (Cl 7.4.1.2).

$$s_{max} = min\begin{cases} 3t = 3 \times 500 = 1500\ mm \\ 500\ mm \end{cases}$$

$$s_{max} = 500\ mm$$

$$s = 400\ mm\ < s_{max} = 500\ mm$$

(d) Check maximum reinforcement requirement (Cl 10.5.2).

$$\rho = \frac{A_s}{bd} = \frac{1000 \text{ (both directions)}}{500 \times 925} = 0.0022$$

$$\rho = 0.0022 < \rho_b \approx \frac{f_c'}{1100} = 0.0227 \; \Rightarrow \text{properly reinforced}$$

Design Roof Load Calculations

North Reservoir Dimensions

length, l	72	m
width, w	45	m
area, A	3240	m^2

Dead Load

		Unit	Equation
Self weight, w	25	kN/m^3	
Slab Thickness, t_c	0.3	m	
Concrete Load, D_c	7.5	kPa	=w*t_s
Soil weight, γ	16.7	kN/m^3	
Soil layer, t_s	0.3	m	
Soil load, D_s	5.01	kPa	=γ*t_s
Dead Load, D	15.015		=D_c+1.5*D_s
Live Load			
Assembly Area load, L_A	4.8	kPa	from UBC Technical Guidelines
Reduction factor, f	0.578567		=0.5+SQRT(20/A)
Live Load, L	2.777124	kPa	=L_A*f
Snow/Rain Load			
I_s	1.25		Importance factor for post-disaster structurre
S_s	1.9	kPa	Climatic data from Jabacus Roof and Snow Load Calculator (Vancouver Granville & 41st Ave)
l_c	61.875		=2w-w^2/l
C_b	0.8		for l_c < 70
C_w	1		
C_s	1		
C_a	1		
S_r	0.3	kPa	Climatic data from Jabacus Roof and Snow Load Calculator (Vancouver Granville & 41st Ave)
S	2.275	kPa	=I_s*[S_s*(C_b*C_w*C_s*C_a)+S_r]

	Load Factors			
Case	D	L	S	Combination
1	1.4	0	0	18.015
2	1.25	1.5	0	21.05568542
2+comp	1.25	1.5	1	23.33068542
3	1.25	0	1.5	20.3025
3+comp	1.25	1	1.5	23.07962362

Design combination load 23.33069 kPa

Beam Calculations

Tributary width, w_t	5.625	m	=w/8
Vertical Load, q	140.860106	kN/m	=w_t*q_s+q_r
Col Spacing, l_n	9	m	=l/8
f'c	25	MPa	
f_y	400	MPa	
msa	20	mm	
h	700	mm	
min d	428.571429	mm	=ln/21*1000
d	590	mm	=h-110
b	550	mm	
M-	950.805712	kNm	=q*ln^2/12
iteration	a	A_s	
1	250	6013.951	A_s=(M-*10^6)/((d-a/2)*0.85*f_y)
2	285.978107	6255.971	a=0.85*f_y*a/(0.8*0.65*f'c*b)
3	297.486719	6337.553	
4	301.366161	6365.535	
5	302.696787	6375.19	
6	303.155894	6378.528	
7	303.314623	6379.683	
8	303.36954	6380.083	
9	303.388545	6380.221	
10	303.395123	6380.269	
# bars, n	10		
area of bars, A_b	700	mm^2	
diameter of bars, d_b	30	mm	
area of steel, A_s	7000	mm^2	=n*A_b
Clear Cover, C	60	mm	for exposure to chloride, no exposure to earth
n per row, n_r	5		
stirrup diameter, d_s		mm	
Min Steel Requirement			
A_s min	962.5	mm^2	=0.2*SQRT(f'c)*b*h/f_y
Check:	YES		A_s>A_S min
Min Spacing Requirement			
s_min >	42	mm	1.4*d_b
	28	mm	1.4*MSA
	30	mm	
s_available	43.3333333	mm	=(b-n_r*d_b-2*C-2*d_s)/(n_r-1)
Check:	YES		s_available > s_min
d (actual)	579	mm	=h-C-d_s-d_b-d_b-(s_min/2)
ρ	0.02198147		=A_s/d/b
ρ_max	0.02272727		=f'c/1100
Check:	YES		ρ<ρ_max
Crack Control Parameter			
A_e	133100	mm^2	=(h-d)*2*b
z	25007.8815	N/mm	=0.6*f_y*((C+d_s+d_b/2)*A_e/n)^(1/3)
Check:	YES		z<30000
M_r	1016.97566	kNm	
Check:	YES		M_r > M_f
Use:	10-30M		

Load per column			
677.1829748	kN	=q*l_n/2	
Self Weight, q_s			
9.625	kN/m	=l*b*h*w	
h	700	mm	
min d	428.5714	mm	
d	630	mm	
b	550	mm	
M+	475.4029	kNm	
iteration	a	A_s	
1	250	2768.799	
2	131.6632	2478.415	
3	117.8547	2448.452	
4	116.4299	2445.401	
5	116.2848	2445.091	
6	116.27	2445.059	
7	116.2685	2445.056	
8	116.2684	2445.056	
9	116.2684	2445.056	
10	116.2684	2445.056	
n	5		
A_b	700	mm^2	
d_b	30	mm	
A_s	3500	mm^2	
Clear Cover	60	mm	
n per row	5		
		mm	
Min Steel Requirement			
A_s min	962.5	mm^2	
Check:	YES		
Min Spacing Requirement			
s_min	42	mm	
	28	mm	
	30	mm	
s_available	43.33333	mm	
Check:	YES		
d	615	mm	
ρ	0.010101		
ρ_max	0.022727		
Check:	YES		
Crack Control Parameter			
A_e	93500	mm^2	
z	28009.03	N/mm	
Check:	YES		
M_r	662.6703	kNm	
Check:	YES		
Use:	5-30M		

Note: cells in blue are trial and error guesses

Slab Calculations

		Unit	Equation
clear span, l_n	5.625	m	=w/8
Load, q_r	23.3306854	kN/m	
f'c	25	MPa	
f_y	400	MPa	
h_min	281.25	mm	=l_n/20*1000
h	300	mm	
d	225	mm	=h-C-d_b
b	1000	mm	
M_max	92.2746836	kNm	=q_r*l_n^2/8
n	7		=1000/s
A_b	200	mm^2	
d_b	15	mm	=n*A_b
A_s	1429	mm^2	
Clear Cover	60	mm	
Min Steel Requirement			
A_s min	600	mm^2	0.002*h*1000
Check:	YES		A_s > A_s min
Max Spacing Requirement			
s_max <	900	mm	=3*h
	500	mm	
s	140	mm	
d (actual)	232.5	mm	=h-C-d_b/2
ρ	0.00614439		=A_s/d/b
ρ_max	0.02272727		=f'c/1100
Check:	YES		ρ<ρ_max
Crack Control Parameter			
A_e	97500	mm^2	=(h-d)*2*b
z	23353.7548	N/mm	=0.6*f_y*((C+d_s+d_b/2)*A_e/n)^(1/3)
Check:	YES		z<30000
M_r	104.638291	kNm	
Check:	YES		M_r > M_f
Temperature Steel			
A_s min	600	mm^2	0.002*h*1000
n	4		
d_b	15	mm	
A_b	200	mm^2	
A_s	800		n*A_b
Check:	YES	A_s > A_smin	
s_max <	1500		=5*h
	500		
s	250		

iteration	a	A_s
1	250	2713.961
2	70.98052582	1432.096
3	37.45481731	1315.716
4	34.41103123	1306.08
5	34.1590038	1305.288
6	34.13830116	1305.223
7	34.13660167	1305.218
8	34.13646217	1305.217
9	34.13645072	1305.217
10	34.13644978	1305.217
11	34.1364497	1305.217
12	34.13644969	1305.217
13	34.13644969	1305.217
14	34.13644969	1305.217
15	34.13644969	1305.217
16	34.13644969	1305.217
17	34.13644969	1305.217
18	34.13644969	1305.217
19	34.13644969	1305.217
20	34.13644969	1305.217

A_s=(M-*10^6)/((d-a/2)*0.85*f_y)
a=0.85*f_y*a/(0.8*0.65*f'c*b)

Use:	Flexural	15M@140mm
	Temp	15M@250mm

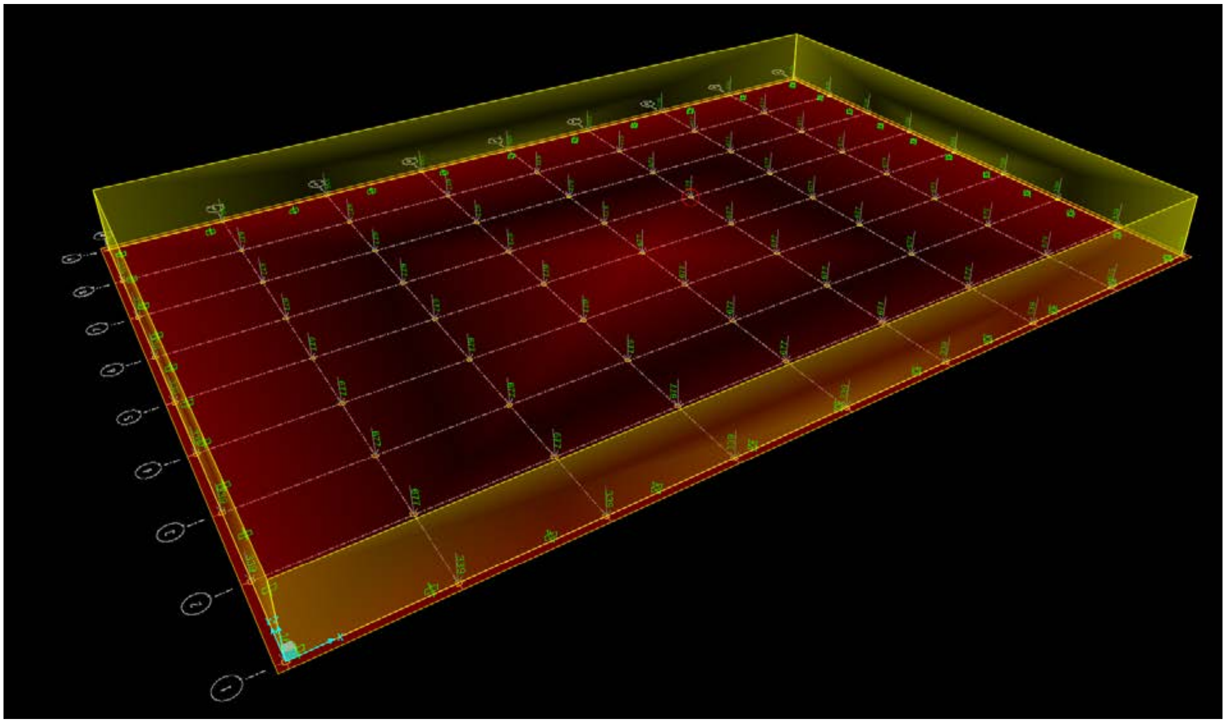
Column Calculations

P_f	677.183	kN	
Clear cover	60	mm	
MSA	20	mm	
b	300	mm	
A_g	90000	mm62	=b^2
n	8		
d_b	20	mm	
A_b	300	mm^2	
A_s	2400	mm^2	=n*A_b
P_ro	1954.8	kN	=(0.8*0.65*f'c*(A_g-A_s)+0.85*f_y*A_b)/1000
P_max	1563.84	kN	=0.8*P_ro
ρ_t	0.026667		=A_g/b
s_min >	28	mm	=1.4*d_b
	28	mm	=1.4*msa
	30	mm	
s_max	500	mm	
s	110	mm	
d_tie	10	mm	
s_tie max <	320	mm	=16*d_b
	480	mm	=48*d_tie
	300	mm	
s_tie	300	mm	

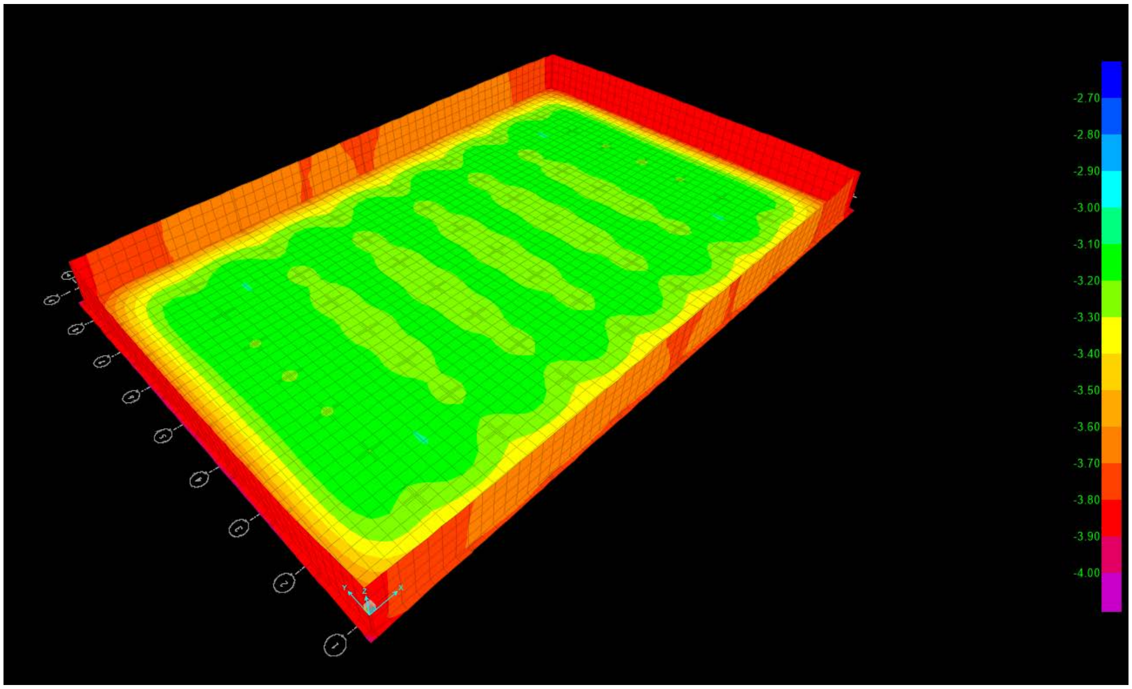
Appendix C – SAFE 2016 Outputs

North Reservoir

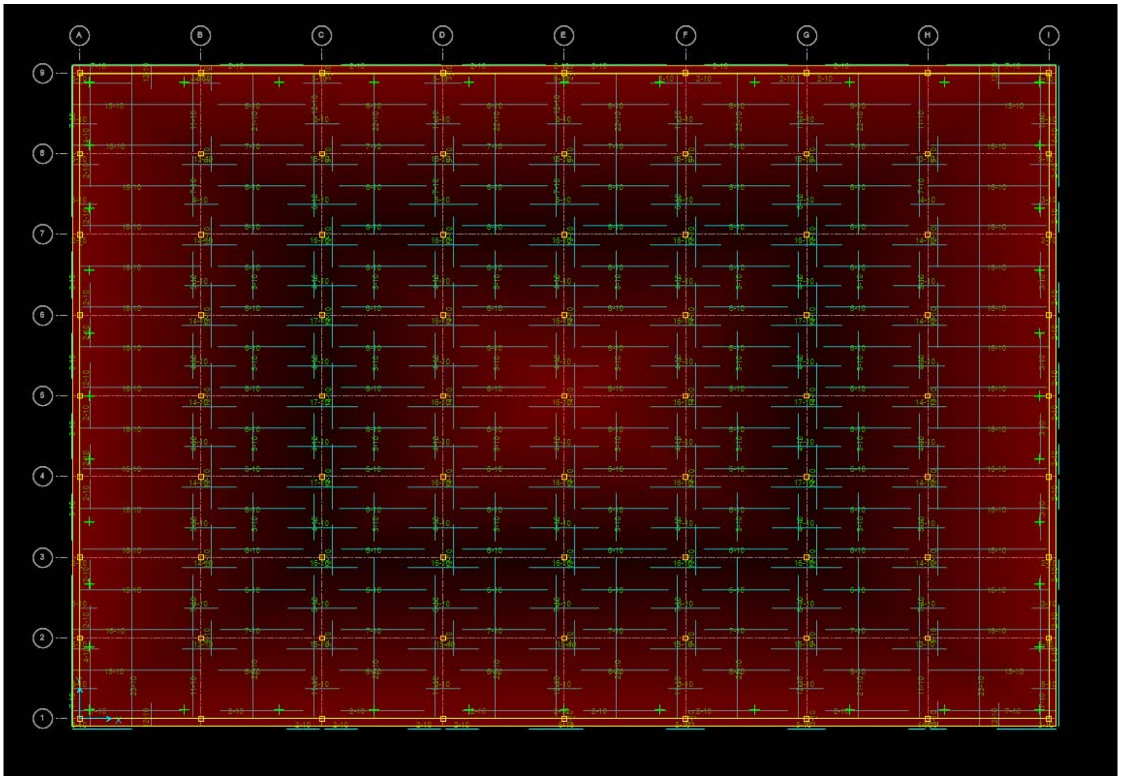
Point Loads



Deflections

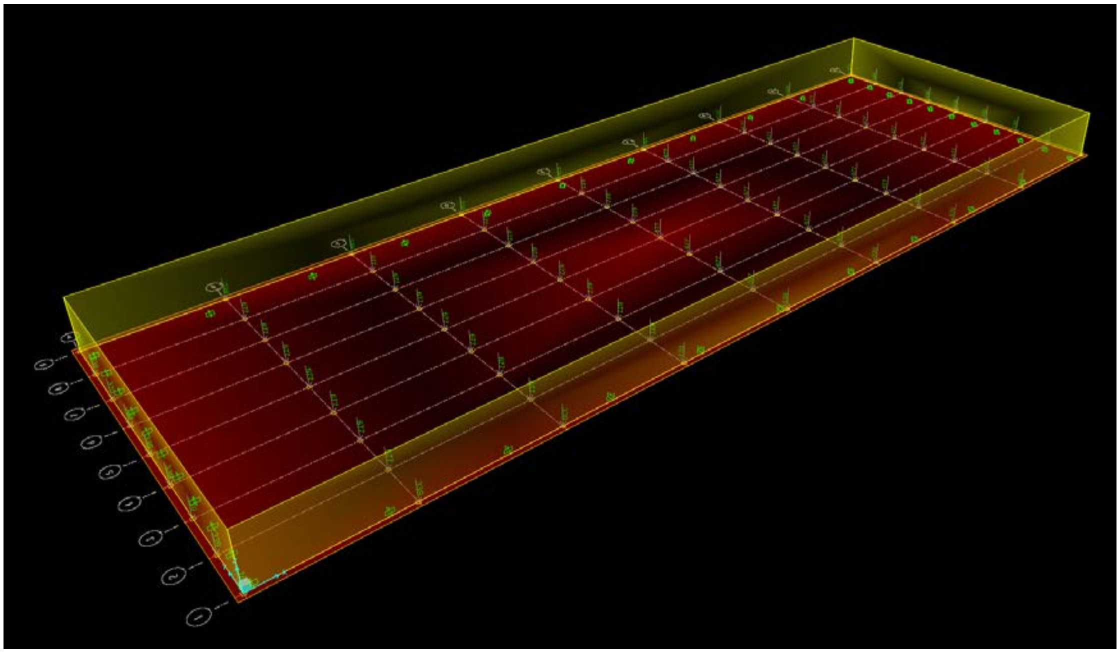


Flexural Reinforcement Layout

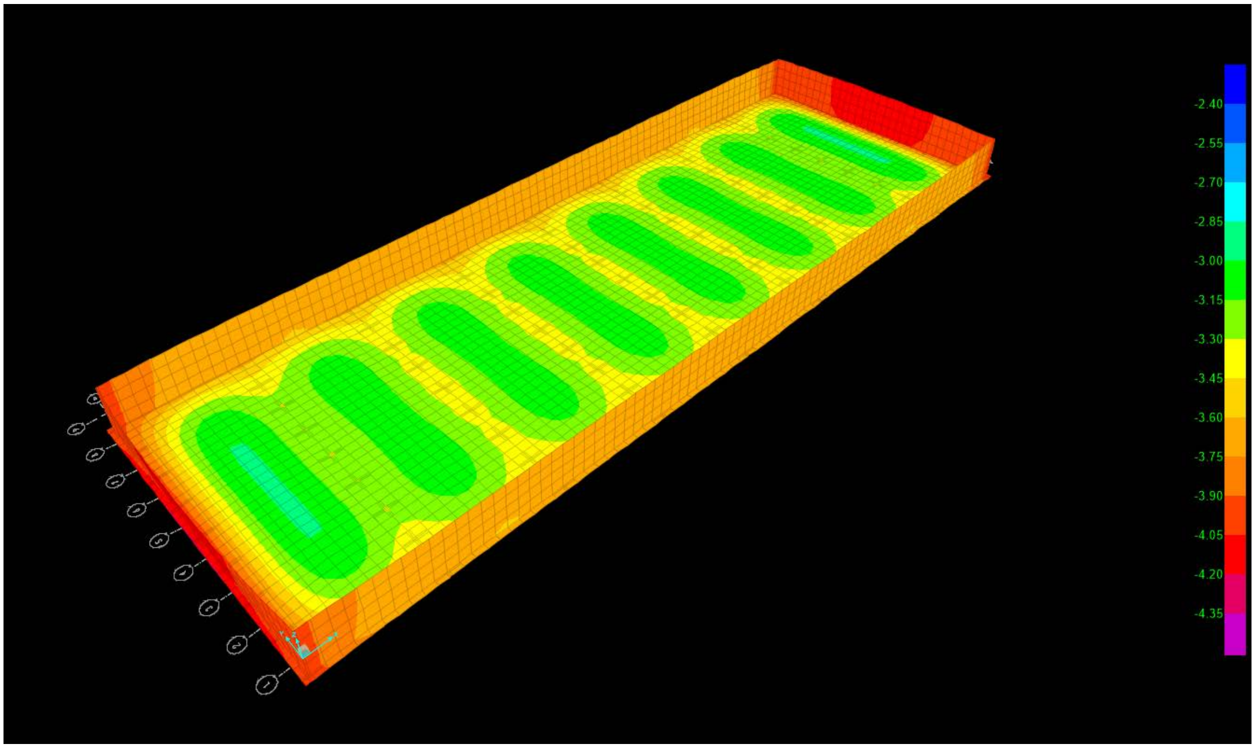


South Reservoir

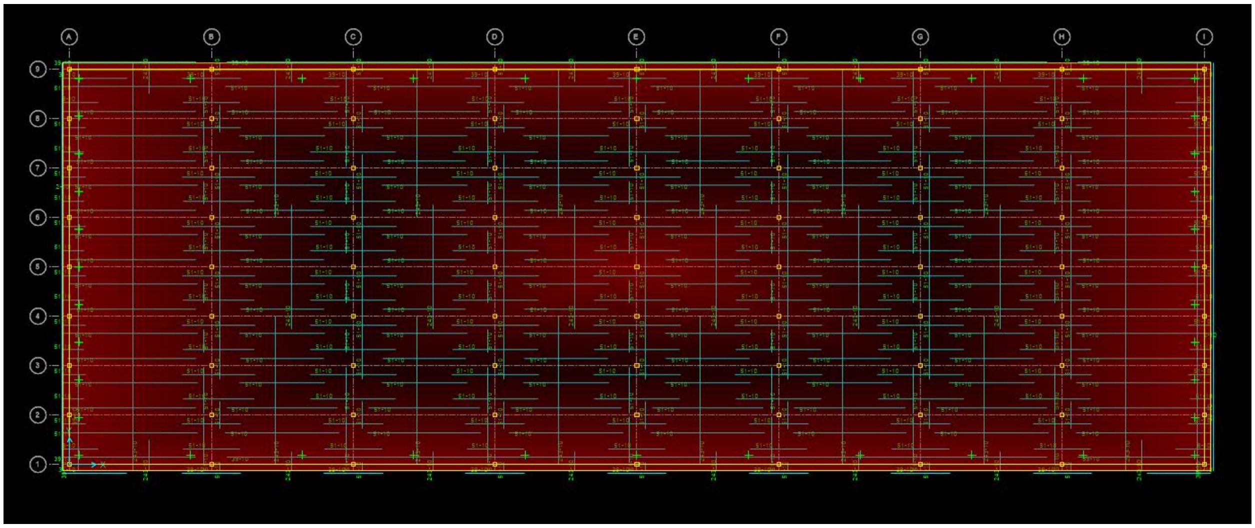
Point Loads



Deflections



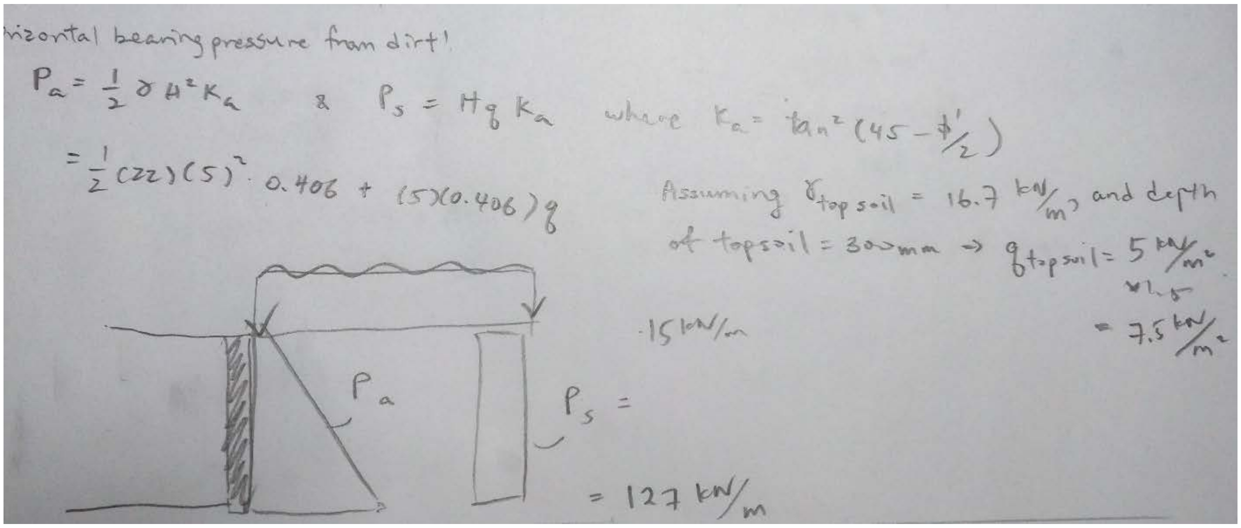
Flexural Reinforcement Layout



Appendix D – Cost Estimate

Appendix E – Schedule

Appendix F – Geotechnical Analysis



rizontal bearing pressure from dirt!

$P_a = \frac{1}{2}\gamma H^2 K_a$ & $P_s = H q K_a$ where $K_a = \tan^2(45 - \phi'/2)$

$= \frac{1}{2}(22)(5)^2 \cdot 0.406 + (5)(0.406) q$

Assuming $\gamma_{top\ soil} = 16.7\ kN/m^3$ and depth of topsoil = 300mm → $q_{topsoil} = 5\ kN/m^2$

$\times 1.5$

$= 7.5\ kN/m^2$

$\cdot 15\ kN/m$

$P_s =$

$= 127\ kN/m$

Item #	Item Description	Unit	Qty	Unit Price	Amount
1.0	General				$130,000.00
	Mobilization / Demobilization	L.Sum	1	$30,000.00	$30,000.00
	Bonding and Insurance	L.Sum	1	$30,000.00	$30,000.00
	General Conditions	L.Sum	1	$70,000.00	$70,000.00
2.0	Civil				$3,726,200.00
	Clearing and grubbing	Sq. M.	6500	$2.00	$13,000.00
	Topsoil Stripping and Replacement	Sq.M.	6500	$10.00	$65,000.00
	Ground excavation	Cu.M.	36000	$60.00	$2,160,000.00
	Fill to grade (with native)	Cu.M.	4100	$20.00	$82,000.00
	Road Granular subbase	Cu.M.	1300	$40.00	$52,000.00
	Road Granular base	Cu.M.	150	$45.00	$6,750.00
	Hot mix asphalt paving	Sq.M.	3150	$35.00	$110,250.00
	Fencing and gates	Lin.M.	500	$175.00	$87,500.00
	300mm PVC Watermain	Lin. M.	140	$500.00	$70,000.00
	610mm PVC Watermain	Lin. M.	1000	$600.00	$600,000.00
	Tie-ins	L.Sum	2	$10,000.00	$20,000.00
	Installation of fittings	L.Sum	1	$26,400.00	$26,400.00
	300mm HxH PVC Gate Valve	Each	18	$3,400.00	$61,200.00
	300mm Robar Coupling	Each	2	$700.00	$1,400.00
	300mm PVC WYE	Each	1	$1,000.00	$1,000.00
	350 x 300mm PVC Reducer	Each	2	$300.00	$600.00
	300mm 45 degree PVC Bend	Each	7	$300.00	$2,100.00
	350mm 22.5 degree PVC Vert. Bend	Each	2	$300.00	$600.00
	300mm Robar Coupling	Each	35	$500.00	$17,500.00
	300mm PVC SDR35 Drain	Lin. M.	50	$600.00	$30,000.00
	300mm Perforated PVC DR35 Perim Drain	Lin. M.	50	$360.00	$18,000.00
	Hydroseeding	Sq. M.	6500	$3.00	$900.00
	Ground Improvement	L.Sum	1	$300,000.00	$300,000.00
3.0	Structural				$17,235,000.00
	Concrete	Cu.M.	9200	$1,800.00	$16,560,000.00
	Rebar	Cu.M.	135	$5,000.00	$675,000.00
4.0	Mechanical/HVAC				$370,800.00
	Pumps	Each	2	$100,000.00	$200,000.00
	300 mm Butterfly Valve	Each	6	$3,500.00	$21,000.00
	Pressure Gauges	Each	2	$700.00	$1,400.00
	50mm Air release Valve	Each	2	$5,000.00	$10,000.00
	200mm Check Valve	Each	8	$3,000.00	$24,000.00
	Weir Gate	Each	8	$8,000.00	$64,000.00
	Sluice Gate	Each	8	$6,300.00	$50,400.00
5.0	Electrical and Instrumentation				$437,000.00
	MCC	EA.	1	$150,000	$150,000.00
	Instrumentation (Chlorine)	LS	1	$30,000	$30,000.00
	Control Panel	EA.	1	$20,000	$20,000.00
	Building Electrical Install	L.S.	1	$95,000	$95,000.00
	Power Service	L.S.	1	$5,000	$5,000.00
	Genset	L.S.	1	$115,000	$115,000.00
	Genset Pad	L.S.	1	$4,000	$4,000.00
	Program, startup, commissioning	L.S.	1	$18,000	$18,000.00

Subtotal $21,899,000.00

Power Consumption Cost	kWh
Chlorine Booster	
Sodium Hypochlorite system (x4)	100
Instrumentation (x4)	40
Ventilation Fans (x4)	20
Lighting, Auxiliary Power, Utilities etc. (x4)	20
Booster Station	
Distribution Pumps (2x100 HP)	150
Building Heater	15
Lighting, Auxiliary Power, Utilities etc.	10
Ventilation Fans	5
Motor Control Centre	15
Reservoir	
Lighting and Utilities etc. (x2)	15
Flow Controls (Valve and Gates) (x2)	10

Sum (kWh)	400
Electricity Costs ($/kWh)	0.12
Electrical Cost ($ per year)	420,480

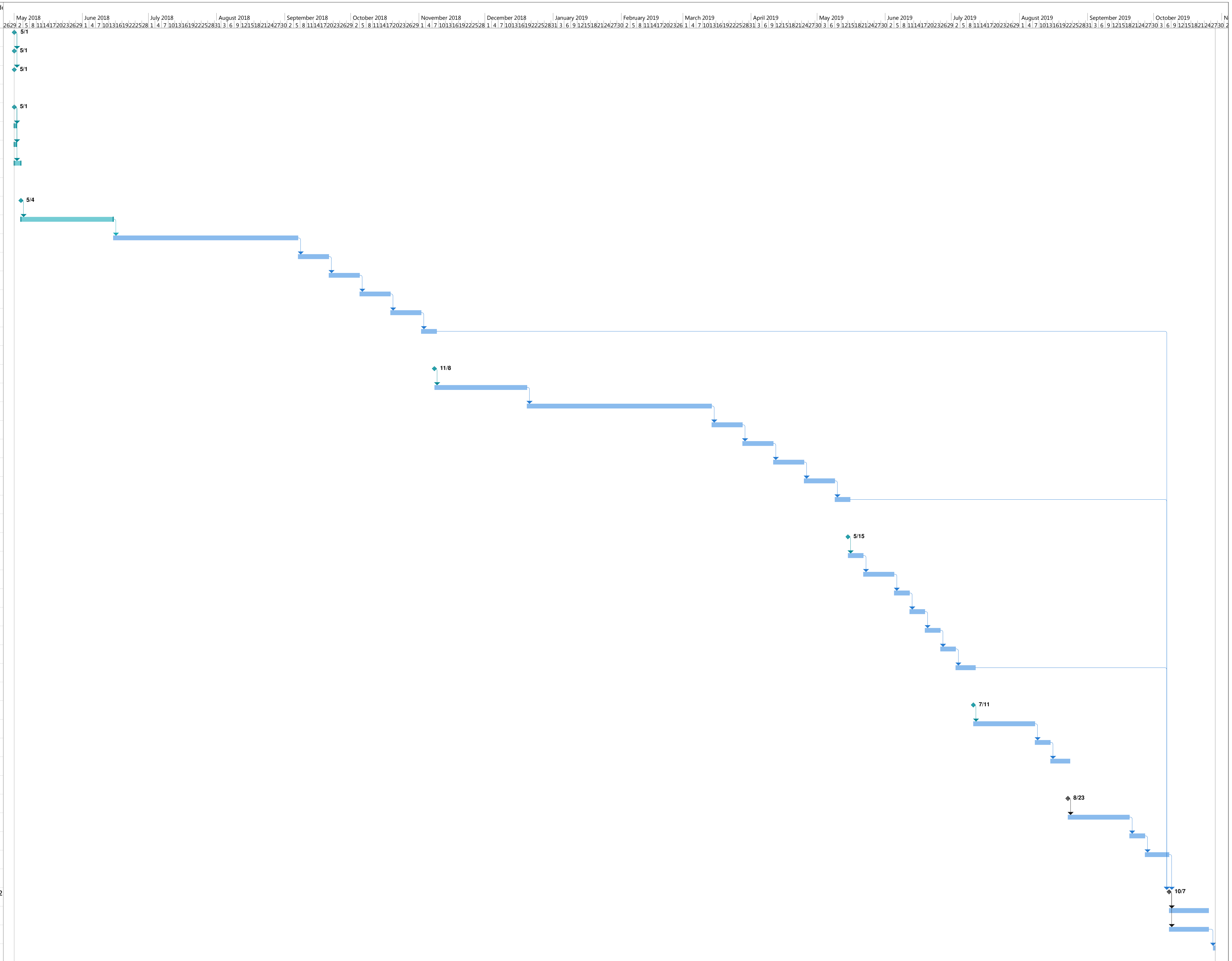
Treatment Cost ($ per year)	
Water Quality Testing Biweekly	7200
Cost of Chemical (Sodium Hypochlorite)	10000
Drained Water Treatment and Disposal	5000

Maintenance Cost ($ per year)	
Pump Maintenance	3000
Major and Minor Pipe Leaks	10000
Programming	2000
Valve Replacement	5000

Operations Cost ($ per year at $50/hr for staff)	
Chlorine Booster Station (1 hour per day by staff)	18250
Booster Station (1 hour per day by staff)	18250
Reservoir (1 hour per day by staff)	18250

Yearly Maintenance and Operational Costs	517,430

ID	Task Name	Duration	Start	Finish	Prede
1	**1.0 Pre-Construction**	0 days	Tue 5/1/18	Tue 5/1/18	
2	Alert Public of Construction	0 days	Tue 5/1/18	Tue 5/1/18	1
3	Obtain Necessary Permits	0 days	Tue 5/1/18	Tue 5/1/18	1
4					
5	**2.0 Site Mobilization**	0 days	Tue 5/1/18	Tue 5/1/18	
6	Setup Site Office	1 day	Tue 5/1/18	Tue 5/1/18	5
7	Install Temporary Fencing	1 day	Tue 5/1/18	Tue 5/1/18	5
8	Clear and Grub Site	3 days	Tue 5/1/18	Thu 5/3/18	5
9					
10	**3.0 North Reservoir Construction**	0 days	Fri 5/4/18	Fri 5/4/18	
11	Excavation of North Reservoir	30 days	Fri 5/4/18	Thu 6/14/18	10
12	Install Formwork and Pour Concrete for North Reservoir	60 days	Fri 6/15/18	Thu 9/6/18	11
13	Install Pipes and Valves	10 days	Fri 9/7/18	Thu 9/20/18	12
14	Programming of Valves	10 days	Fri 9/21/18	Thu 10/4/18	13
15	Testing of North Reservoir	10 days	Fri 10/5/18	Thu 10/18/18	14
16	Backfilling of North Reservoir	10 days	Fri 10/19/18	Thu 11/1/18	15
17	Disinfection Testing of North Reservoir	5 days	Fri 11/2/18	Thu 11/8/18	16
18					
19	**4.0 South Reservoir Construction**	0 days	Thu 11/8/18	Thu 11/8/18	
20	Excavation of South Reservoir	30 days	Thu 11/8/18	Wed 12/19/18	19
21	Install Formwork and Pour Concrete for South Reservoir	60 days	Thu 12/20/18	Wed 3/13/19	20
22	Install Pipes and Valves	10 days	Thu 3/14/19	Wed 3/27/19	21
23	Programming of Valves	10 days	Thu 3/28/19	Wed 4/10/19	22
24	Testing of South Reservoir	10 days	Thu 4/11/19	Wed 4/24/19	23
25	Backfilling of South Reservoir	10 days	Thu 4/25/19	Wed 5/8/19	24
26	Disinfection Testing of South Reservoir	5 days	Thu 5/9/19	Wed 5/15/19	25
27					
28	**5.0 Booster Station Construction**	0 days	Wed 5/15/19	Wed 5/15/19	
29	Booster Station Excavation	5 days	Wed 5/15/19	Tue 5/21/19	28
30	Install Formwork and Pour Concrete for Booster Station	10 days	Wed 5/22/19	Tue 6/4/19	29
31	Install Pumps and Valves	5 days	Wed 6/5/19	Tue 6/11/19	30
32	Programming of Pumps and Valves	5 days	Wed 6/12/19	Tue 6/18/19	31
33	Testing of Booster Station	5 days	Wed 6/19/19	Tue 6/25/19	32
34	Backfilling of Booster Station	5 days	Wed 6/26/19	Tue 7/2/19	33
35	Disinfection Testing of Booster Station	7 days	Wed 7/3/19	Thu 7/11/19	34
36					
37	**6.0 Supply Main Alignment**	0 days	Thu 7/11/19	Thu 7/11/19	
38	Trench Excavation, Pipe Laydown and Backfilling	20 days	Thu 7/11/19	Wed 8/7/19	37
39	Tie In to Existing Connections and Testing	5 days	Thu 8/8/19	Wed 8/14/19	38
40	Disinfection Testing of Supply Main Alignment	7 days	Thu 8/15/19	Fri 8/23/19	39
41					
42	**7.0 Discharge Main Alignment**	0 days	Fri 8/23/19	Fri 8/23/19	
43	Trench Excavation, Pipe Laydown and Backfilling	20 days	Fri 8/23/19	Thu 9/19/19	42
44	Tie In to Existing Connections and Testing	5 days	Fri 9/20/19	Thu 9/26/19	43
45	Disinfection Testing of Discharge Main Alignment	7 days	Fri 9/27/19	Mon 10/7/19	44
46					
47	**8.0 Post-Construction**	0 days	Mon 10/7/19	Mon 10/7/19	17,2
48	Commissioning of New System	14 days	Tue 10/8/19	Fri 10/25/19	47
49	Resurfacing of Excavated Areas	14 days	Tue 10/8/19	Fri 10/25/19	47
50	Remove Site Office and Temporary Fencing	1 day	Mon 10/28/19	Mon 10/28/19	49

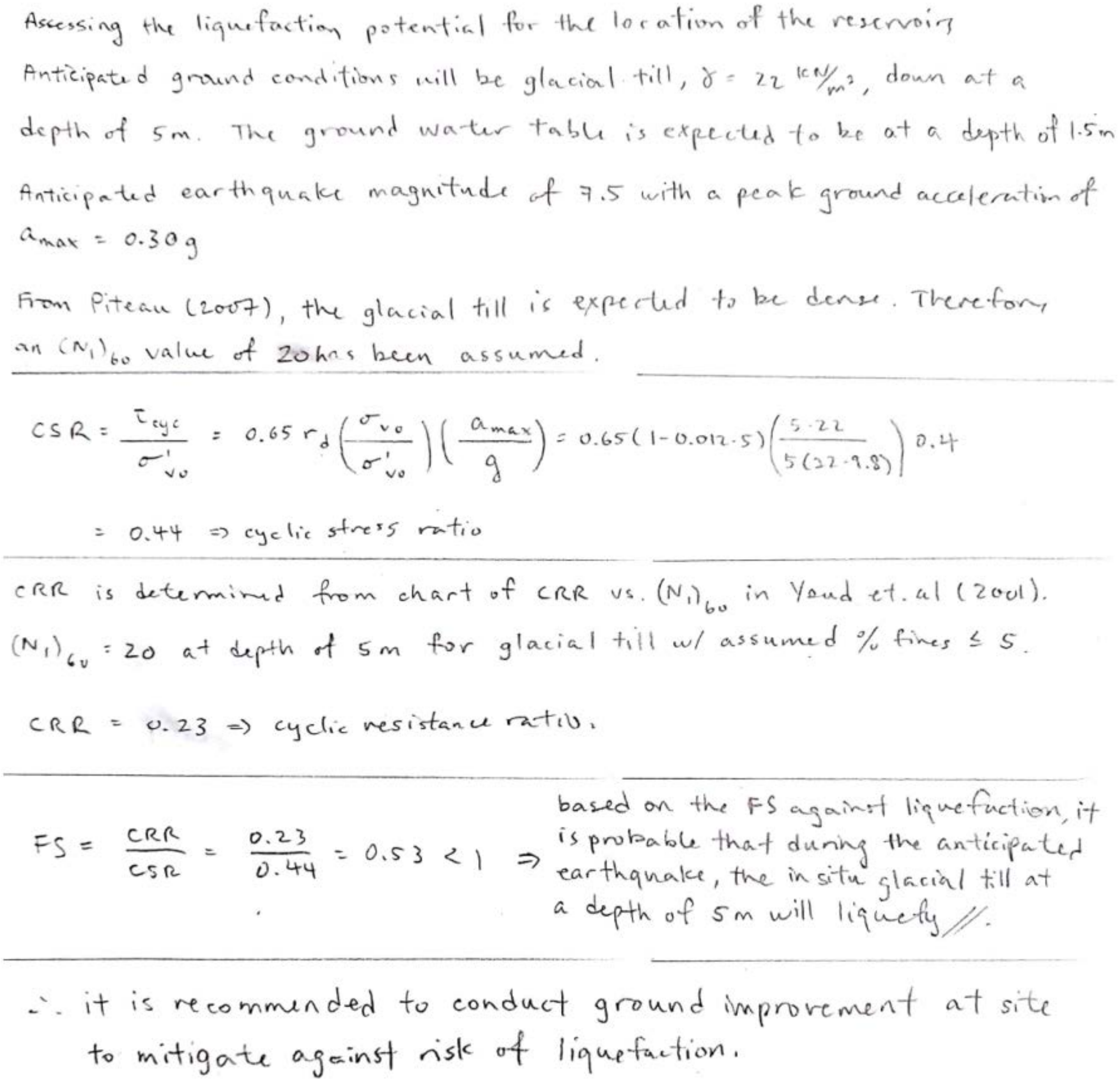


Project: ubcwatersupply
Date: Sat 3/31/18

Task	▬	Milestone	◆	Project Summary	⌐¬	Inactive Milestone	◇	Manual Task	▬	Manual Summary Rollup	▬	Start-only	[	External Tasks	▬
Split	⋯	Summary	⌐¬	Inactive Task	▭	Inactive Summary	⌐¬	Duration-only	▬	Manual Summary	⌐¬	Finish-only	]	External Milestone	◆

Deadline	⇩	Manual Progress	─
Progress	─		

Appendix G – Liquefaction Analysis



Assessing the liquefaction potential for the location of the reservoir

Anticipated ground conditions will be glacial till, $\gamma = 22\ kN/m^3$, down at a depth of 5m. The ground water table is expected to be at a depth of 1.5m

Anticipated earthquake magnitude of 7.5 with a peak ground acceleration of $a_{max} = 0.30g$

From Piteau (2007), the glacial till is expected to be dense. Therefore, an $(N_1)_{60}$ value of 20 has been assumed.

$$CSR = \frac{\tau_{cyc}}{\sigma'_{vo}} = 0.65\, r_d \left(\frac{\sigma_{vo}}{\sigma'_{vo}}\right)\left(\frac{a_{max}}{g}\right) = 0.65(1-0.012\cdot 5)\left(\frac{5\cdot 22}{5(22-9.8)}\right)0.4$$

$= 0.44 \Rightarrow$ cyclic stress ratio

CRR is determined from chart of CRR vs. $(N_1)_{60}$ in Youd et. al (2001).

$(N_1)_{60} = 20$ at depth of 5m for glacial till w/ assumed % fines ≤ 5.

$CRR = 0.23 \Rightarrow$ cyclic resistance ratio.

$FS = \frac{CRR}{CSR} = \frac{0.23}{0.44} = 0.53 < 1 \Rightarrow$ based on the FS against liquefaction, it is probable that during the anticipated earthquake, the in situ glacial till at a depth of 5m will liquefy //.

∴ it is recommended to conduct ground improvement at site to mitigate against risk of liquefaction.

Appendix H – Air Valve Calculations

Pump Sizing Calculation

Pipe Length	1303.59	
Roughness Coeffiecient	110	
Diameter (inches)	26	Use 26" to match existing line

Operating Point:
System needs a pump that can provide 0.137 m^3/s at 32.83m TDH

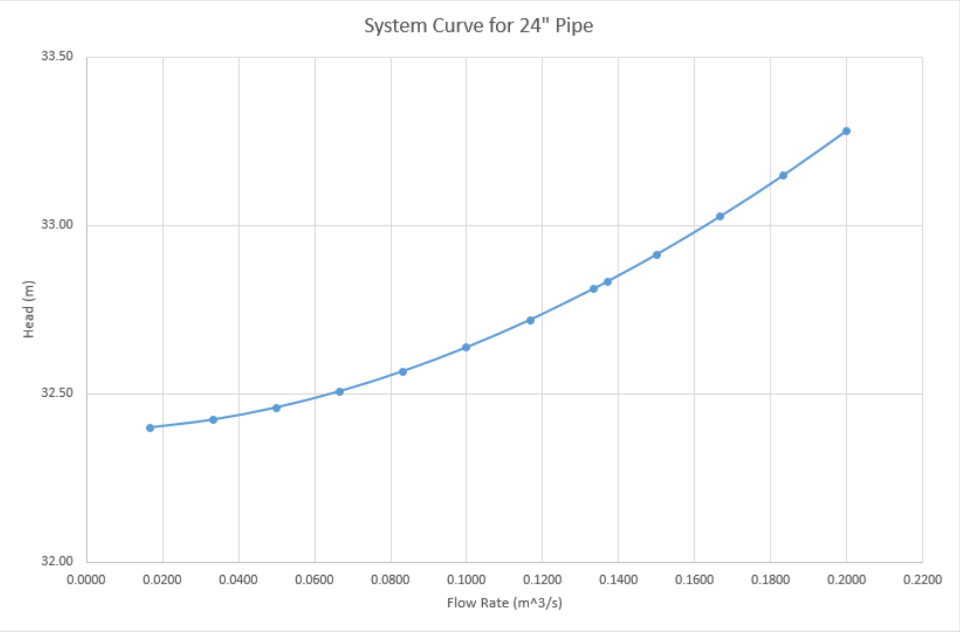
Diameter (inches)	Diameter (m)	Roughness Coefficient	Pipe Length (m)	Flow Rate (m^3/min)	Flow Rate (m^3/s)	Head Loss (m)	PS Elevation (m)	Tie-in Elevation (m)	Static Head (m)	Minimum Press	Pump Head (m)
							From Google Earth				
26	0.6604	110	1303.59	1	0.0167	0.01	88.69	92.96	4.27	28.12	32.40
26	0.6604	110	1303.59	2	0.0333	0.03	88.69	92.96	4.27	28.12	32.42
26	0.6604	110	1303.59	3	0.0500	0.07	88.69	92.96	4.27	28.12	32.46
26	0.6604	110	1303.59	4	0.0667	0.12	88.69	92.96	4.27	28.12	32.51
26	0.6604	110	1303.59	5	0.0833	0.18	88.69	92.96	4.27	28.12	32.57
26	0.6604	110	1303.59	6	0.1000	0.25	88.69	92.96	4.27	28.12	32.64
26	0.6604	110	1303.59	7	0.1167	0.33	88.69	92.96	4.27	28.12	32.72
26	0.6604	110	1303.59	8	0.1333	0.42	88.69	92.96	4.27	28.12	32.81
26	0.6604	110	1303.59	8.22	0.1370	0.44	88.69	92.96	4.27	28.12	32.83
26	0.6604	110	1303.59	9	0.1500	0.52	88.69	92.96	4.27	28.12	32.91
26	0.6604	110	1303.59	10	0.1667	0.64	88.69	92.96	4.27	28.12	33.03
26	0.6604	110	1303.59	11	0.1833	0.76	88.69	92.96	4.27	28.12	33.15
26	0.6604	110	1303.59	12	0.2000	0.89	88.69	92.96	4.27	28.12	33.28

$$H_p = H_s + RQ^{1.85}$$

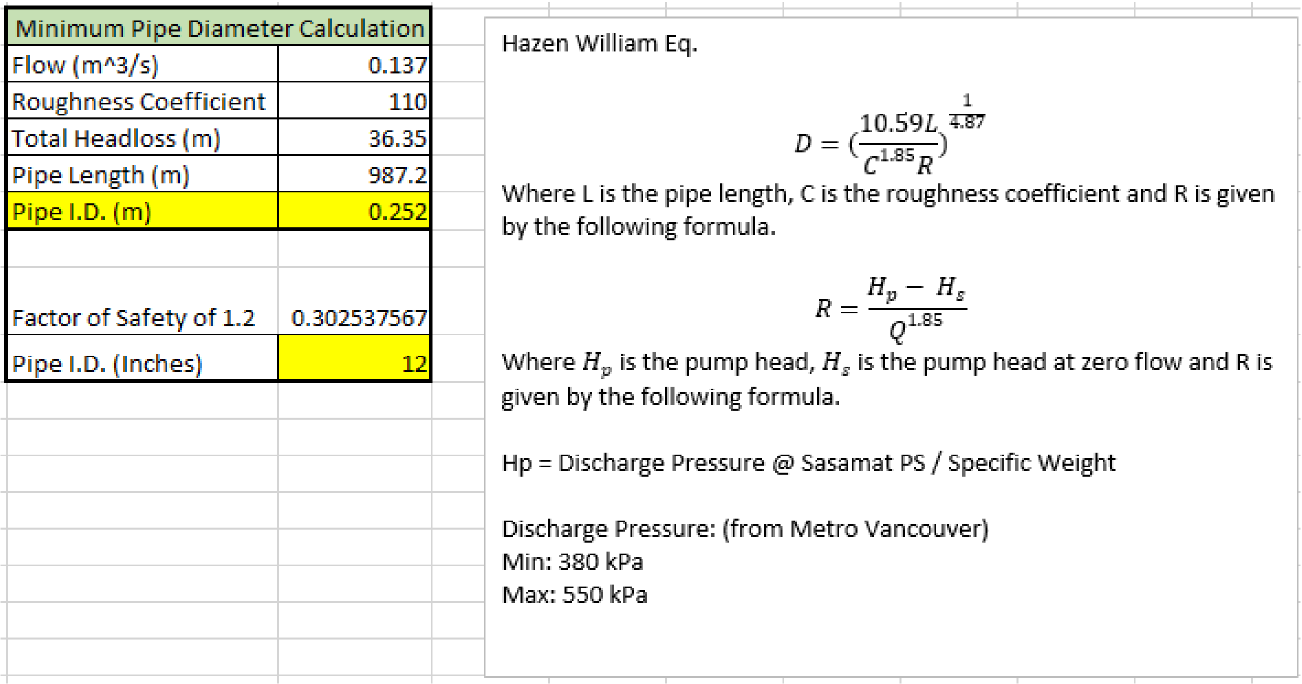
Where H_p is the pump head, H_s is the pump head at zero flow and R is given by the following formula.

$$R = \frac{10.59L}{C^{1.85}D^{4.87}}$$

Where L is the pipe length, C is the roughness coefficient and D is the pipe diameter.



Supply Main Pipe Sizing



Minimum Pipe Diameter Calculation	
Flow (m^3/s)	0.137
Roughness Coefficient	110
Total Headloss (m)	36.35
Pipe Length (m)	987.2
Pipe I.D. (m)	0.252
Factor of Safety of 1.2	0.302537567
Pipe I.D. (Inches)	12

Hazen William Eq.

$$D = \left(\frac{10.59L}{C^{1.85}R}\right)^{\frac{1}{4.87}}$$

Where L is the pipe length, C is the roughness coefficient and R is given by the following formula.

$$R = \frac{H_p - H_s}{Q^{1.85}}$$

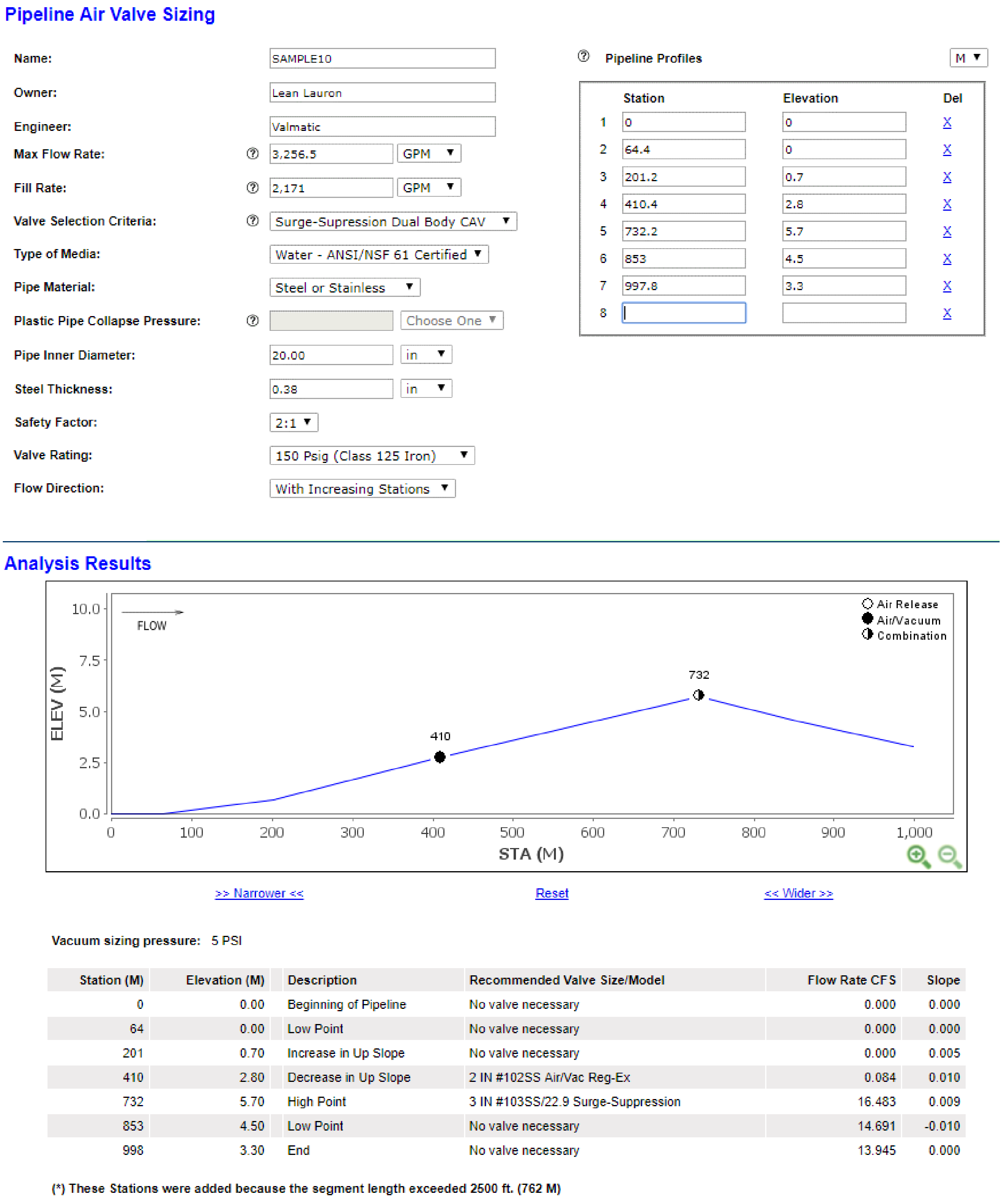
Where H_p is the pump head, H_s is the pump head at zero flow and R is given by the following formula.

Hp = Discharge Pressure @ Sasamat PS / Specific Weight

Discharge Pressure: (from Metro Vancouver)
Min: 380 kPa
Max: 550 kPa

Piping Air Valve Sizing

1. Supply Watermain



Pipeline Air Valve Sizing

Name:	SAMPLE10	
Owner:	Lean Lauron	
Engineer:	Valmatic	
Max Flow Rate:	3,256.5	GPM
Fill Rate:	2,171	GPM
Valve Selection Criteria:	Surge-Supression Dual Body CAV	
Type of Media:	Water - ANSI/NSF 61 Certified	
Pipe Material:	Steel or Stainless	
Plastic Pipe Collapse Pressure:		Choose One
Pipe Inner Diameter:	20.00	in
Steel Thickness:	0.38	in
Safety Factor:	2:1	
Valve Rating:	150 Psig (Class 125 Iron)	
Flow Direction:	With Increasing Stations	

Pipeline Profiles M

	Station	Elevation	Del
1	0	0	X
2	64.4	0	X
3	201.2	0.7	X
4	410.4	2.8	X
5	732.2	5.7	X
6	853	4.5	X
7	997.8	3.3	X
8			X

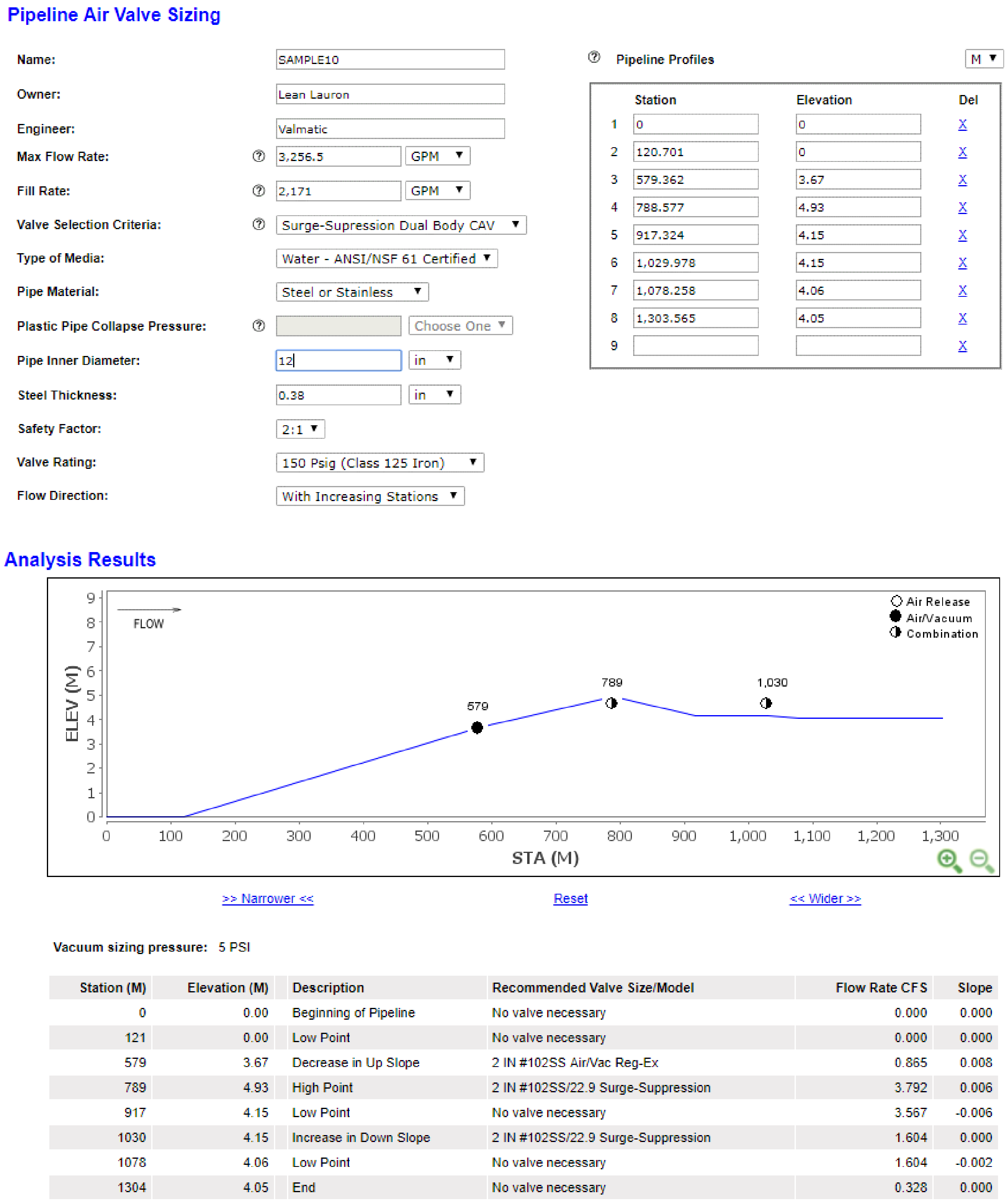
Analysis Results

Vacuum sizing pressure: 5 PSI

Station (M)	Elevation (M)	Description	Recommended Valve Size/Model	Flow Rate CFS	Slope
0	0.00	Beginning of Pipeline	No valve necessary	0.000	0.000
64	0.00	Low Point	No valve necessary	0.000	0.000
201	0.70	Increase in Up Slope	No valve necessary	0.000	0.005
410	2.80	Decrease in Up Slope	2 IN #102SS Air/Vac Reg-Ex	0.084	0.010
732	5.70	High Point	3 IN #103SS/22.9 Surge-Suppression	16.483	0.009
853	4.50	Low Point	No valve necessary	14.691	-0.010
998	3.30	End	No valve necessary	13.945	0.000

(*) These Stations were added because the segment length exceeded 2500 ft. (762 M)

Discharge Watermain



Pipeline Air Valve Sizing

Name:	SAMPLE10
Owner:	Lean Lauron
Engineer:	Valmatic
Max Flow Rate: ⑦	3,256.5 GPM ▼
Fill Rate: ⑦	2,171 GPM ▼
Valve Selection Criteria: ⑦	Surge-Supression Dual Body CAV ▼
Type of Media:	Water - ANSI/NSF 61 Certified ▼
Pipe Material:	Steel or Stainless ▼
Plastic Pipe Collapse Pressure: ⑦	Choose One ▼
Pipe Inner Diameter:	12 in ▼
Steel Thickness:	0.38 in ▼
Safety Factor:	2:1 ▼
Valve Rating:	150 Psig (Class 125 Iron) ▼
Flow Direction:	With Increasing Stations ▼

⑦ **Pipeline Profiles** M ▼

	Station	Elevation	Del
1	0	0	X
2	120.701	0	X
3	579.362	3.67	X
4	788.577	4.93	X
5	917.324	4.15	X
6	1,029.978	4.15	X
7	1,078.258	4.06	X
8	1,303.565	4.05	X
9			X

Analysis Results

>> Narrower <<   Reset   << Wider >>

Vacuum sizing pressure: 5 PSI

Station (M)	Elevation (M)	Description	Recommended Valve Size/Model	Flow Rate CFS	Slope
0	0.00	Beginning of Pipeline	No valve necessary	0.000	0.000
121	0.00	Low Point	No valve necessary	0.000	0.000
579	3.67	Decrease in Up Slope	2 IN #102SS Air/Vac Reg-Ex	0.865	0.008
789	4.93	High Point	2 IN #102SS/22.9 Surge-Suppression	3.792	0.006
917	4.15	Low Point	No valve necessary	3.567	-0.006
1030	4.15	Increase in Down Slope	2 IN #102SS/22.9 Surge-Suppression	1.604	0.000
1078	4.06	Low Point	No valve necessary	1.604	-0.002
1304	4.05	End	No valve necessary	0.328	0.000