University of British Columbia

Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

UBC Groundwater Emergency Water Supply Final Design Report

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Prepared for:

Course Code: CIVL 446

University of British Columbia

Date: 16 April 2021

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Executive Summary

The objective is to establish a method in providing emergency potable water to the University Endowment Lands (UEL) by accessing groundwater from the Quadra Sand Layer.The UEL includes the University of British Columbia (UBC) campus and the population is estimated to be 55,000 people per day. Water is currently supplied by Metro Vancouver through two water mains. If these water mains become unusable due to a natural disaster, UBC would be unable to provide clean potable water to residents. Key constraints considered are total water demand, water quality, water volume, and method of distribution. The desired outcome of this project is to prepare UBC to be self-sufficient in an emergency situation.

Team 20 created a five-day demand cycle using the given data. The per capita and UBC hospital demand were established as approximately 10 L/Cap-Day and 190k L/Day, respectively. The total required emergency potable water for this project is approximately 3.7 million liters over five days. These figures are the minimum potable water required as per the Government of Canada's Drinking Water Quantity Guideline. In addition, a groundwater feasibility study estimated 4.9 million liters of available water via ground infiltration within the UEL.

The final design was established by analyzing and segmenting the UBC population by location. Team 20 chose six development locations on the UEL using population density. At each location, a groundwater well and pumphouse will be constructed. In an emergency, UBC personnel will shut off compromised sections of water distribution infrastructure and the pumphouse will connect to and pressurize the existing and intact UBC water distribution infrastructure forming a "closed loop" network. In the event that disaster damages the entire water distribution network, each pumphouse has the ability to serve as a manual water distribution-site. The estimated cost of this project, including a 5% consulting fee, a 20% contingency fund, and a 12% tax rate, is $1,486,300 CAD.

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1.0 Introduction

1.1 Project Objectives

Team 20 has been contracted by UBC SEEDS to provide a potable water system to the University of British Columbia (UBC) and the University Endowment Lands (UEL) during an emergency. The current potable water system supplying this area relies on a main connection along W16 avenue which is supplied by the City of Vancouver. In the event of this line rupturing, this would leave approximately 55,000 people and the UBC hospital without any potable water. We aim to provide a minimum of 5 days of drinking water so that the water mains can be repaired within that time frame. The proposed UBC Groundwater Emergency Water Supply plan includes establishing UBC's drinking water demand and needs, drawing upon UBC's Quadra Sand Layer to establish a suitable supply rate, determining water treatment where applicable, and finally delivering a design of the proposed system and needed infrastructure to disburse water throughout UBC's campus and surrounding areas.

1.2 Site Overview

UBC campus and the surrounding UEL is an isolated region separated from Metro Vancouver by Pacific Spirit Park. This isolation provides particular challenges to the university and surrounding population and residents in this area. In the event of damages to water distribution infrastructure, the UEL is required to develop its own backup plans and contingencies. Calculating future water demands for the UEL is extremely difficult due to the exceptional work population fluctuation during the weekdays. The permanent resident population was estimated to be 25,000 during the school year. While the influx of additional weekday population includes commuting students and UBC staff which is estimated to be 30,000 people. The permanent population is spread out among the UBC residences with a minority residing along the west and southern ends of campus - see figure 1 for permanent population density distribution.

Figure 1: Population Density of UBC

1.3 Member Contributions

Table 1: Summary of member contributions

Member Initials	Contribution
AH	Sections: 3.1, 5.3, 5.3.1, 5.3.2, 5.3.3, 5.3.4, 5.3.5, 5.3.6, 5.3.7, 5.3.8, 10, 11.1, & 11.3. Figures: 1, 2, 3, 4, 5, 6, 7, & 8 Technical Contribution: - Population density analyses - Architectural Well Schematics - Site Layouts - Isolation Valve Install - Storage Tank Access & Venting
EH	Sections: Executive Summary, 5.4, 7.0 Technical Contributions: - Conducted site investigations - Created process flow diagram for emergency system - Revised, edited, and approved all IFC drawings - Assembled PDF package of IFC drawings

	- Extensive Report Editing & Formatting
IS	Sections: 1.2, 3.0, 3.1, 3.2, 5.2, 5.2.1, 5.2.2, 5.2.2.1, 5.2.2.2, 5.2.3, 5.2.4, 5.3, 5.4.2, 5.5, 6.0, 9.0, 9.1, 9.2, & 11.2 Appendix: A, B, C, D, & E Technical Contributions: - Conducted Site Investigations. - Structural Analysis and Design of Site Components. - Hydrotechnical and Groundwater Analysis. - Site Consumption and Supply Analysis for All Sites. - EPANET Modelling Demand and System Drawings / Layout. - Designed Entire System for All Sites. - Drew all Issued for Construction Drawings. - 3-Dimensional Architectural Renderings used in Figures 3-8. - Report Editing & Formatting.
KM	Sections: 5.1, 5.4.1, 5.4.2 , 5.8, 6.0, 12, 12.1, 12.3, 12.4 Appendix: F, G, H Technical Considerations: - System design - EPAnet Model - Cost analysis - Treatment calculations - Maintenance plan - Report Editing & Formatting
KC	Sections: 5.6, 5.7, 8.0, 8.1, 8.2, 13 Appendix: I Technical Considerations: - Gantt Chart - Well Installation - Sustainability Plan - Report Editing & Formatting
SG	Sections: 2, 2.1, 2.2, 4.1, 4.2, 4.3, 12.2, 14 - Extensive Report Editing & Formatting - Reviewed Calculations

2.0 Technical Design Considerations

Team 20 focused on the following technical aspects: 1) Hydrotechnical 2) Geotechnical 3) Structural Loading in order to determine the feasibility of the well and site locations. The following sections will outline the important features considered in the system.

2.1 Procedure and Methodology

Team 20 aimed to provide a resilient and adaptive system, while being able to minimize the total associated costs. We propose to use the existing water infrastructure network to minimize costs and rely on the resiliency of using the “closed loop” networks to distribute the water. Using this approach ensures that construction costs and required hardware are minimized.

Team 20 first analysed the UEL area based on the hydrogeological report from Piteau and Associates. A preliminary replenish rate and draw-down rate were examined in order to assess the feasibility of drawing groundwater. After ensuring viability, Team 20 assessed splitting the population area of UBC into more manageable sizes to place potential well locations. By grouping the permanent residence population by density, well locations were decided by searching for key buildings in each density segment.

From here, site specific replenish rates, hydraulic conductivity, daily demand, and assumed ground porosity were determined for each well location. Furthermore, geotechnical conditions were assessed simultaneously. Due to this system being an emergency backup, a site/soil assessment for an 8.0 magnitude earthquake was analyzed in a “worst case” scenario and primarily for liquefaction. These demand values were also confirmed with modelling software discussed in the latter sections of this report.

In addition to the geotechnical/hydrotechnical analyses, a structural analysis was also performed under the worst case scenario conditions. The system consists of a pump house, well/shaft, and a prefabricated water tank complete with a disinfection system. Using the 8.0 magnitude earthquake, the structural system was analyzed for lateral stability confirming the design is able to uphold the associated vertical loads.

2.2 Design Requirements

The design requirements of the system were split into two categories: negotiable and non-negotiable. The constraints are as follows:

Non Negotiable:

- 3 day potable water supply
- Service a population of 55,000 using residential base daily demand
- Supply emergency water to UBC Hospital
- Sufficient water quality against bacteria/viruses (Log 4 disinfection)
- Sustainable/adaptable system
- Post-disaster serviceability

Negotiable:

- Non-consumption water use (ie. bathing)
- Maintain UBC campus operations
- Mitigate disruption to campus activity post construction
- Noise and pollution considerations
- Design life of 30 years.

From these constraints Team 20 decided to alot the minimum daily recommended water allowance of 10 L/person/day as per Canadian Drinking Water Guidelines [11]. However, to add a factor of resiliency, the system is aimed to provide at least five days of freshwater as the soil was analyzed in the latter sections of this report to have enough supply to do so. This plan is not meant to replace the current system, but will be enacted for emergency purposes on the assumption that the current mainlines supplying the UEL will be fixed within those five days of supply. To meet the non-negotiable constraints, a filtration system for sediments and chlorination system will ensure that there is protection in accordance with the 4-3-2-1-0 log disinfection method. To make the design adaptable and resilient, the design will tie into the existing water network at UBC and supply key buildings on campus. If this system fails the pre-disbursement check, the pumphouse itself will act as a disbursement point as it will be outfitted with water taps.

3.0 Design Standards and Software

3.1 Design Standards

In the hydrotechnical analysis and design of the proposed system, the following regulations were taken into consideration. The Province of British Columbia's Groundwater Protection Regulation [22], and The Province's 2016 Water Sustainability Act [10] guided well design and withdrawal rates. During design, the American Water Works Association (AWWA) [23] guidelines were used to ensure the design meets proper hydrotechnical requirements. To provide acceptable drinking water qualities the treatment design was set forth to meet standards outlined in BC's Drinking Water Protection Act [8] .

The system's structural elements adhere to the necessary regulatory bodies. Design Loads were developed in accordance with the National Building Code of Canada (NBCC) (2015) [14], and Division B Part 4 of the Building Code of British Columbia (BCBC) (2018) [24]. These standards were used to derive the dead, live, snow, wind, and earthquake load combinations affecting the super-structure. The light-frame wood design adhered to the Engineering Design in Wood (CSA O86-14) [6] guidelines, which incorporated methods described in the Wood Design Manual by Canadian Wood Council (2017) [1]. The main use of these standards was to determine the lateral stability of the light-frame structure under critical loading (earthquake lateral loads). Concrete foundation and reinforcement design follow the codes set forth in Design of Concrete Structures (CSA A23.3-14) [5] guidelines, which is further explained in Concrete Design Handbook Canada (2016) [2].

The design is also in compliance with relevant UBC Board of Governors Policies such as the Environmental Protection Policy SC4 [26], and the Land Use Policy UP12. All work performed on-site will adhere to Work Safe BC [19] regulations and guidelines as well as all applicable UBC Technical Guidelines [27].

3.2 Design Software

To perform hydrotechnical analysis, EPANET was employed to model system pressure and flow rates within all four proposed isolated networks with the designed storage tanks, booster pump, and distribution water mains. Microsoft Excel 2019 was used to determine the campus wide and site specific water consumption, which developed values for sizing and designing the submersible pump, storage tank, pumphouse, and supply rate. AutoCAD 2020 was utilized to develop accurate Issued For Construction (IFC) design drawings, including site, utility, pumphouse layout, floor plan and elevation views. Sketchup was used to provide 3-dimensional renderings of the site design including pumphouse, perimeter fencing, storage tank, propane tank, backup generator, well shaft, and internal workings of pump station shown in Section 5.3. Material and labour cost estimates were obtained from RS Means, and local supplier/contractor quotes were used when RS Means data was unavailable.

4.0 Geotechnical Assessment

4.1 Subsurface Conditions

In general, the upper strata sequence is made up of Glacio-marine sediments followed by a Vashon drift. While UBC is a well developed area, these sediment layers are of particular concern as they are vulnerable to erosion liquefaction mechanisms. The lower strata layers consist of thick Quadra Sand units overlaying a fine-grained silty sand layer. For analysis purposes, stratigraphy layers from ground surface to a depth of 30m were examined. Below a depth of 30m, stratigraphy layers were deemed safe due to increasing overburden pressures.

4.2 Liquefaction Potential

The top 30m of soil of all sites was examined. Due to the lack of data, Team 20 was required to make the following assumptions: soil stratigraphy is consistent across sites; correlations were used in determining the FOS (no direct testing for parameters); any layer with a depth greater than 30 m was deemed safe due to overburden pressure; and an 8.0 magnitude earthquake is assumed to occur. The FOS against liquefaction for a magnitude 8.0 earthquake is determined to be 0.22. The well sites are extremely prone to liquefaction. As a result, site remediation prior to construction is required. Detailed calculations can be found in Appendix C - Liquefaction Assessment.

4.3 Ground Improvement

It has been determined that the upper layers of the site are made up of loose-medium dense glacio-marine sediments and a vashon layer. UBC is well developed and it is assumed that this area has experienced a degree of virgin compression. To further compact the surrounding soil around the well sites, Team 20 proposes using a Vibro-compaction method to achieve the required densification. Vibro-compaction has been shown to be effective in sandy soils (non-cohesive) and is able to penetrate to the required depth. Additionally, Vibro-compaction does not disturb the surrounding environment and minimizes the disruption to the neighbourhood. This method also allows Team 20 to precisely compact the critical soil areas around the well shaft, footings/pads, and other structural components.

5.0 Key Design Components

5.1 Design Overview

This design consists of six individual well sites situated in key areas across the UBC campus selected using a metric of population density and institutional importance. Each site will perform under the water system seen in Appendix A - T20-DWG05 or 06 and is described as follows. A 50mm diameter, 7.5hp submersible pump is used to pump water up the 200mm PVC well shaft, lined with a 250mm gravel screen on its exterior, through a sediment filter, and into a storage tank where it is disinfected via an automatic chlorination system. The 58,673L (58.7cu.m.) storage tank provides a baffle for site consumption demand. A 7.5hp centrifugal booster pump then delivers water from the tank into the existing mainline system via a 250mm diameter ductile iron service connection. All system components are connected to UBC's power grid, as well as a 22kWh standby generator to ensure the system remains operational if UBC's power grid becomes compromised. Each site is connected to UBC's power grid via a pumphouse constructed adjacent to it, which serves as shelter for the mechanical and chlorination equipment, and storage for system consumables such as filters and chlorine. These pumphouses also serve as distribution points in a worst case scenario where all of UBC's water infrastructure is damaged from an earthquake.

In the event of a water service disruption, identified valves will be shut off by UBC maintenance crews in order to create isolated "loops" of water main connecting to the groundwater wells. Buildings connected to these loops will retain full, potable water service. The loops service multiple buildings as shown in Appendix A - T20-DWG02. Buildings serviced by these loops will retain complete water service and pressure, meaning much of UBC's vital buildings and residences will remain viable in the event of a natural disaster.

5.2 Structural Analysis and Design

The structural design is divided into five components: vertical stability of light-frame wood walls, lateral stability of light-frame wood walls, mat foundation, foundation walls, and soil bearing capacity. All structural components were designed in accordance with either Engineering Design in Wood (CSA-O86-14) or Design of Concrete Structures (CSA A23.3-14) to provide axial, flexural and shear resistance of the worst loading cases acting on the structure. See Appendix B for sample calculations and a summary of structural capacity and design loading.

5.2.1 Loads Acting on Sub-Structure and Super-Structure

To properly analyze and design the super-structure, the imposed unfactored loads needed to be determined. These loads were developed in accordance with the Wood Design Manual, National Building Code of Canada (NBCC), and Building Code of British Columbia (BCBC) standards and regulations.

Table 2: Unfactored Design Loading

Structural Load	Unfactored Load	Structural Component	Unfactored Load
Roof Dead Load (D_r)	0.65 kPa	Roof Live Load (L_r)	1.0 kPa
Wall Dead Load (D_s)	0.55 kPa	Floor Live Load (L_s)	3.6 kPa
Wind Load (+P) (W)	0.45 kPa	Wind Load (-P) (W)	-0.32 kPa
Snow Load (S)	2.275 kPa	Earthquake Load (E)	38.18 kN

5.2.2 Super-Structure (Pumphouse) Structural Analysis

The superstructure (pumphouse) is designed as a light-frame D.Fir-L timber building on a shallow concrete strip footing, which is a sustainable means of construction. Due to the structure being a post-disaster facility the overall stability of this structure needs to meet ultimate vertical and lateral loading, which is determined to be induced by earthquake loading. The structural checks completed on the superstructure are as follows: compression resistance of shearwalls, sheathing buckling failure, sheathing-to-frame failure, chord stud requirements, lateral deflection, hold-down requirements, and blocking requirements. All four perimeter walls act as shear walls and are made of 1200 x 2400mm, 18.5mm thick Douglas Fir plywood (DFP) sheathing panels nailed to both sides of 38 x 140mm No. 2 D. Fir-L studs spaced 300mm on centre. Nails are 3.25mm in diameter and 63.5mm in length, and have a sheathing fastener spacing of 100mm. The shearwalls are held-down, blocked and are expected to get wet. See Appendix A- T20-DWG08 for design of structural components.

5.2.2.1 Vertical Stability of Light-Frame Timber

Compression resistance was determined by CSA O86-14 clause 6.5.6.2.4. After considering all relevant parameters and assumptions, the factored compression resistance per meter of wall was determined to be 142kN/m. Which takes into account the spacing of the studs and individual stud compression resistance taken about the strong axis, due to lateral stability in the weak axis.

5.2.2.2 Lateral Stability of Light-Frame Timber

The super-structure lateral stability was determined by evaluating the shearwall capacity under earthquake loading. An identical analysis was conducted on both wall section 1 & 2 and A & B separately, as these wall segments may have the same assembly but they do not provide the same support.

To determine the number of chord studs required, an evaluation of lateral load on the structure was performed. This lateral load induces a rotation on the shearwalls, thus creating a larger load on one side. The increase of loading needs to be resisted by the chord compression strength, therefore the compression resistance was taken from Section 5.2.2.1. It was found that only one stud is needed in each compression chord. However, the tension chord requires Simpson Strong-Tie (Model HD5B) hold-downs to prevent uplift - shearwall A & B has four and shearwall 1 & 2 has two (see Appendix A - T20-DWG08).

Shearwalls rely on the sheathing panel strength to resist lateral force. Thus, sheathing buckling and sheathing-to-frame capacities are required. CSA O86-14 Clause 11.5.1.2 was used to determine these capacities. The sheathing buckling capacity relies on panel stiffness and rigidity, while sheathing-to-frame capacity relies more on the fastener capacity. Consequently, the fastener lateral resistance is needed to be calculated in accordance with CSA O86-14 Clause 12.9.4.1. Due to the high stiffness of the assembly, a decreased deflection occurs and is found to be within the allowable limit. To ensure adequate blocking, eight Simpson Strong-Tie (Model: MASA) concrete anchors (blocking) are required in each wall.

5.2.3 Concrete Superstructure Foundations

An adequate foundation is required to withstand lateral and bearing loads imposed on the soil. This foundation consists of a foundation wall to carry load from structural walls into the ground and an on-grade pad footing that transfers load from the floor directly into the soil. These components can be seen in Appendix A - T20-DWG08.

The foundation wall was designed to meet CSA A23.3-14 requirements, by providing minimum steel reinforcements at adequate spacing. A bending moment resistance check was performed by using an equivalent rectangular concrete stress distribution in relation to the reinforcing steel within the member. Shear resistance was determined by evaluating the shear resistance of the concrete and neglecting the steel. To determine if this footing will be supported by the soil strata, a soil bearing analysis was conducted using information provided by Piteau [13] on the clay/silty sand layer, and the theory from *Theoretical Soil Mechanics* by Terzaghi, K. (1943) [17] and *Foundation design principles and practices (2nd ed.)* by Coduto, D. P. (2000) [4].

On-grade pad footing is designed to have minimum thickness and reinforcing steel, to ensure appropriate concrete cover and spacing. As all the load gets directly transferred into the soil strata, thus no bending moment or shear propagates in the concrete.

5.2.4 Storage Tank Bearing Load

After analyzing liquefaction potential in Section 4.2, it was determined the bearing capacity of the soil has a high failure potential. Thus, ground improvement is required prior to storage tank installation, as the bearing load is approximately 80.0kPa. The expected bearing capacity post improvements is to be approximately 252.6kPa. Ensure this capacity is reached prior to installation by performing a standard soil penetration test. For further details see sample calculations in Appendix B - Soil Bearing Capacity Under Storage Tank.

5.3 Site Layout and Water Consumption Analysis

Due to the large spread of residents within the UEL, it was difficult to determine adequate site locations to reach the entire population. Another critical factor that played the role of deciding where to locate wells was finding an open area that can fit a large storage tank, pumphouse, and the physical well itself. Team 20 chose not to use vacant lots or open spaces near parks and gardens to minimize negative effects on the surrounding environment and constructability of potential developments in the future. Team 20 was also conscious of not taking away from the nature and green space on campus.

Site locations considered were close to higher permanent populations and emergency service buildings, including student and staff housing and the UBC Hospital. A major deciding factor for site locations depended on the influx of students, staff, and facility employees from off campus and how this population might be distributed throughout campus. As mentioned in section 1.3, the permanent residential population is approximately 25,00 people, while the influx of population for a weekday would be approximately an additional 30,000 people. To determine how this higher weekday population is distributed across campus, a distribution map was created based on a 2016 census conducted on *UBC Residence Population and Non-resident Population* [16, 20, 21]. As seen on Figure 2, the distribution map depicts an appropriate demand population density distribution that the well sites need to coincide with.

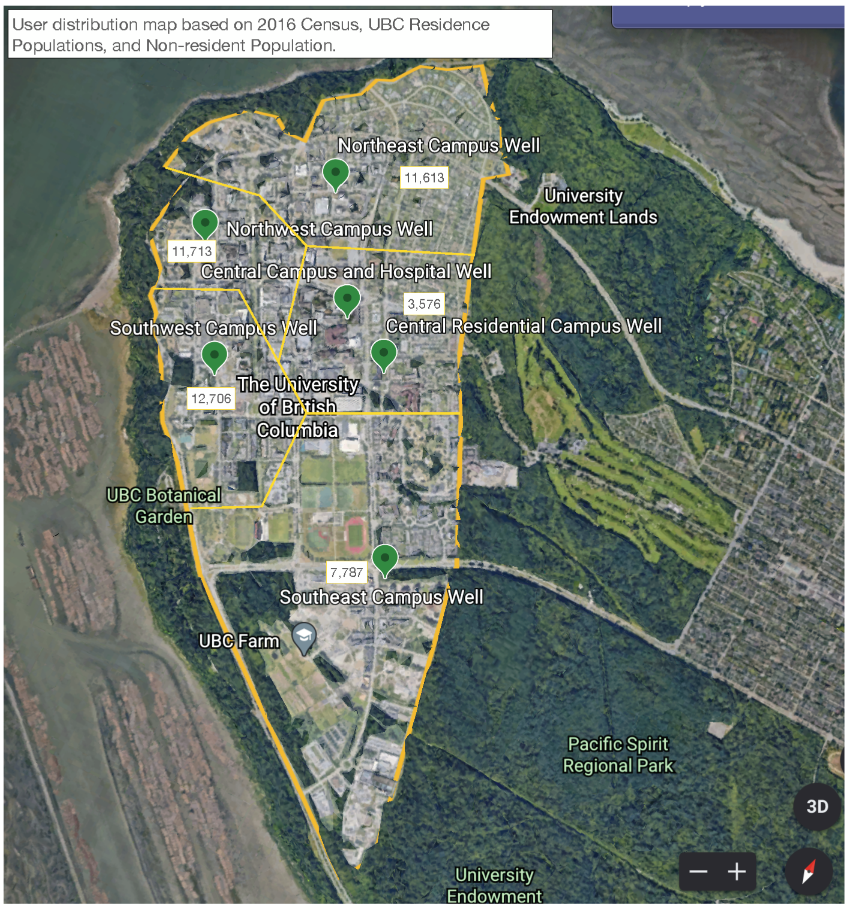

Figure 2: Site Population Distribution Density

To provide equal distribution to users and attempting to maintain regular campus operations, it was determined that six well and distribution-sites be set up across UEL. By using a network of different sites, the emergency system can easily tie into the pre-existing water distribution infrastructure, while minimizing pressure loss, leakage, user wait time, and emergency response time.

In an emergency, each site distributes water through the local surviving pipe network, with valves isolated as indicated in the isolation plan in Appendix A - T20-DWG02. By dividing up total water storage required for the service population into six separate tanks this design greatly reduces soil bearing point loads and hydrogeological demand at site. Soil bearing load reduction results in fewer structural needs and minimal soil densification requirements at all reservoir locations, while lower hydrogeological demands allow for a higher contingency on the well location.

To perform water consumption analysis and determine the well withdrawal rate and tank sizing, the HydroGeo Study [13] conducted by Piteau and Associates was useful in determining expected soil and aquifer properties on UBC Campus. As stated in this study, the soil strata on campus mostly consists of glacial till which overlays an extremely deep glaciofluvial sand unit (Quadra sand). Within the Quadra sand layer there is an upper aquifer suspended on a low permeability silty-clay layer. This has an average elevation and depth of approximately 18.5 m above sea level (asl) and 12 m-asl, respectively. Restrained below this low permeability aquitard, is a lower aquifer which our design will draw its water from as there are less safety hazards associated. Through the course of this study, four soil analyses were conducted on the boreholes with the data found on the lower aquifer being tabulated on Table 3 of Piteau [13]. Unfortunately, a majority of data was not determined within the initial study by Piteau [13], such as the bottom of the lower aquifer layer, porosity, and hydraulic conductivity. From the borehole analysis Team 20 was able to conclude the average elevation from the base of the lower aquifer to be -5.87 m-asl. The respective soil porosity of each borehole location was determined using the soil classification descriptions. From the Piteau [13] study, the provided range of hydraulic conductivity was stated as 0.00005 - 0.0001 m/s. Therefore when determining the missing hydraulic conductivity data for the borehole locations, these values were used alongside the soil classification descriptions.

Table 3: Piteau Borehole Analysis Summary [13]

Borehole	TH01-01	TH01-02	TH01-03	TH01-04
Latitude	49⁰ 16' 11" N	49⁰ 15' 57" N	49⁰ 15' 51" N	49⁰ 15' 43" N
Longitude	123⁰ 15' 25" W	123⁰ 14' 56" W	123⁰ 15' 19" W	123⁰ 14' 17" W
Ground Elevation	77.5 m-asl	87.1 m-asl	85.1 m-asl	98.5 m-asl
Lower Aquifer Elevation	4.96 m-asl	7.5 m-asl	4.33 m-asl	-1.5 m-asl
Lower Aquifer Depth	> 3.05 m	13.37 m	> 9.76 m	> 3.6 m
Aquifer Soil Type	Fine to medium sand with depth	Medium sand, medium/ coarse with depth, trace silt	Fine-medium sand, trace silt and gravel	Coarse Sand, trace silt
Typical Porosity	0.29-0.46	0.26-0.43	0.29-0.46	0.26-0.43
Expected Hydraulic Conductivity	5×10^{-5} m/s	7.5×10^{-4} m/s	7.5×10^{-5} m/s	1×10^{-4} m/s

However, as this report provides geotechnical data on particular test boreholes, the site locations do not correspond to these test locations. Thus, prior to construction, it is recommended that a hydrogeological test be conducted for each site to ensure that soil parameters assumed and discussed in this report match that which is on-site. The values and soil characteristics used in analysis of each site were determined via linear approximation and interpolation between provided borehole analysis, contour maps of the area for corresponding soil strata, lower aquifer elevations, and the provided cross-section drawings of the Quadra Sand Layer. To conduct a 3-dimensional seepage analysis, methods provided by Linghui Liu, Mingfeng Lei, Chengyong Cao, and Chenghua Shi on "*Dewatering Characteristics and Inflow Prediction of Deep Foundations Pits with Partial Penetrating Curtains in Sand and Gravel Strats*" [12] were used to determine allowable well replenish and withdrawal rates. Refer to Appendix D - Site and Soil Characteristics from Piteau

Hydrogeological Study for values associated with site characteristics and well replenishment rates.

All water consumption analyses were carried out based on 2016 Canadian Census Data [16], UBC Residences' bed numbers [20], and UBC enrollment numbers [21]. Campus population analyses across all six of the key service areas identified can be seen in Figure 2: Site Population Distribution Density using the following equation seen below.

$$Service\ Population = 2016\ Census\ Population + SUM[Bed\ Numbers\ of\ Residence(s)] + Estimated\ Commuter\ Population$$

$$Estimated\ Commuter\ Population = [(Total\ enrollment - residence\ beds)\ /\ Total\ Campus\ Area] * Trafficked\ Service\ Area$$

Per site water consumption analyses and site descriptions are detailed in the following subsections and are summarized in Appendix D.

5.3.1 Site 1: Northwest Campus Well (49° 15' 54" N, 123° 15' 24" W)

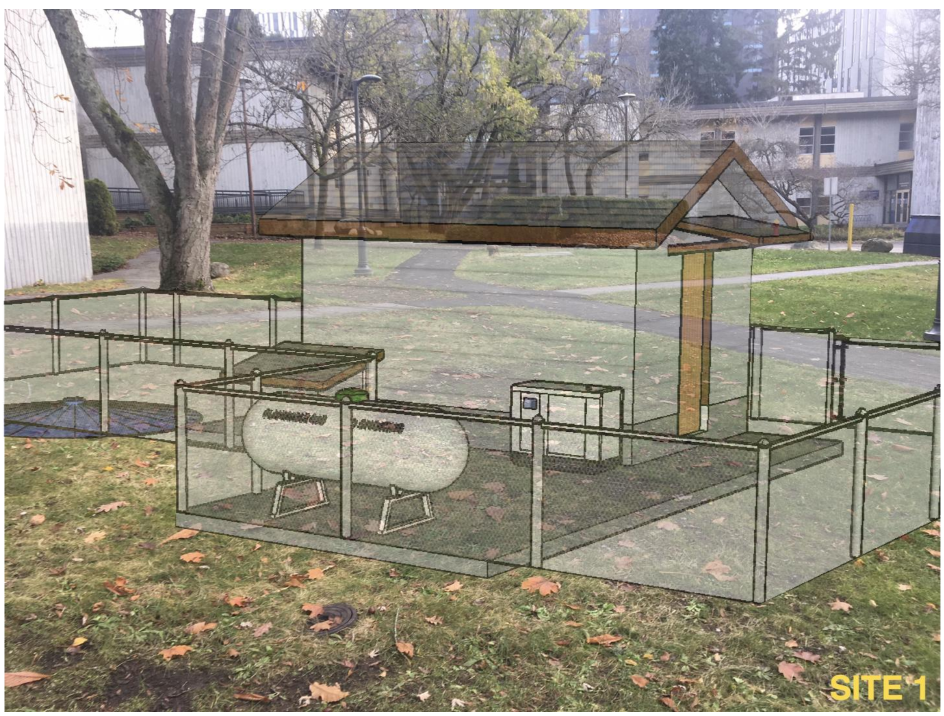

Figure 3: Site 1 - Design Service Population: 11,713 residents

Design Daily Water per capita: 10L

This site is located in a grassy courtyard between Ponderosa A, C, E, and F, south of the Ponderosa Commons residence. The site is level, with some larger trees around the perimeter, but not in the direct path of construction. The site is accessible from a small parking/loading area off Lower Mall. A concrete footpath will need to be demolished in order to complete the build, and the southern portion of the grassy courtyard would become inaccessible for pedestrians.

Well site 1 serves the northeast corner of campus between Main Mall and NW Marine Drive. This area includes UBC residences: Marine Drive, Ponderosa Commons, and Place Vanier. Estimated resident population in this small area is 11,713 people, generating a 5,080L/hr average hourly demand.

5.3.2 Site 2: Northeast Campus Well (49° 16' 10" N, 123° 15' 01" W)

Figure 4: Site 2 -Design Service Population: 11,613 residents

Design Daily Water per capita: 10L

Site 2 is tucked west of the northernmost tower in the Walter Gage Residence complex. This area is an open grassy area in front of the residence complex's visitor parking lot. The site is clear of trees, existing structures, and does not immediately appear to have a complex network of utilities below ground. Site is easily accessible straight from the parking lot, but attention should be paid to how much of the residences' parking lot is taped off during construction. This parking lot sees large amounts of inflow and outflow, so it is imperative traffic and parking impacts at this site be kept to a minimum.

Well site 2 serves an area north of College Highroad and east of Main Mall. This service area includes large UBC residences such as Gage Towers and Brock Commons, as well as Green College, and most of the single-family housing stock in the University Hill neighbourhood. An estimated 11,613 area residents generate a 5,149L/hr average hourly demand during an emergency.

5.3.3 Site 3: Southwest Campus Well (49° 15' 34" N, 123° 15' 06" W)

Figure 5: Site 3 - Design Service Population: 12,706 residents

Design Daily Water per capita: 10L

Site 3 is located North of Totem Park 4 - q̓ələχən House and south of Ritsumeikan - UBC House, in a green area west of West Mall. Site area appears level from Google earth imagery, and road access is easy off of West Mall. There are some old-growth trees around the site, as well as a light pole, and some stormwater manholes. These will likely pose some additional challenges during construction, other utilities will need to be planned around, and the presence of large tree roots would delay excavation times.

The southwest campus service area houses a few of UBC's largest student residences, notably Totem Park, Orchard Commons, and Thunderbird Residences. In addition to these residences this service area also includes a few low-rise multi-family developments. Per the population estimates, this area would house the 12,706 people during an emergency, generating a 5,494L/hr average hourly demand. This is the most populous service area within the design's area of concern.

5.3.4 Site 4: Southeast Campus Well (49° 15' 19" N, 123° 14' 07" W)

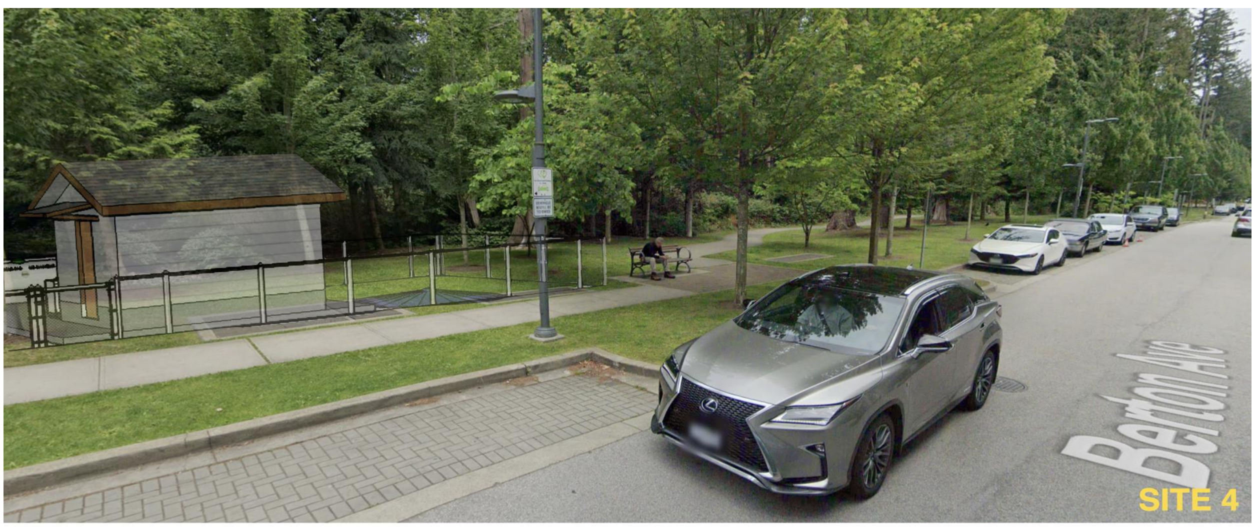

Figure 6: Site 4 - Design Service Population: 7,787 residents

Design Daily Water per capita: 10L

Well site 4 shall be located on the stretch of greenspace parallel to Berton Ave near the Berton Ave & Westbrook Mall intersection. Google Earth imagery of the site shows some trees that may need to be relocated depending on the exact mechanics of site access for construction machinery. Current elevations on-site appear to be near level. A nearby electrical transformer and metal duct bank covers indicate that this site has significant electrical utilities below ground.

Pre-construction location of all utilities in the area and extra caution during pad excavation and well drilling will be necessary.

Site 4's service area encompasses most of the south campus between West 16th, Marine Drive and Binning Road. Permanent residents in Westbrook Village make up the vast majority of this service area's population. Estimated service population for the southeast campus well is 7,787, resulting in a 3,725L/hr average hourly supply demand.

5.3.5 Site 5: Central Campus Hospital Well (49° 15' 54" N, 123° 14' 44" W)

Figure 7: Site 5 - Design Service Population: 332 hospital beds

Design Daily Water per bed: 561L

Well site 5 is located on a small grassy knoll just northeast of the campus parking off Westbrook Mall and south of the UBC faculty of dentistry. The knoll slopes westward at about 6.25%, therefore earthwork removal is required to place the pumphouse slab foundation on level grade. Well site 5 currently has some shrub and small tree landscaping, which will need to be removed, and in the case of the few trees relocated per campus policy UP12.

In the event of an emergency the UBC Hospital is an essential service that should be kept open to ensure the safety of the patients inside and any who may arrive during the disaster aftermath. This emergency water system design prioritises maintaining necessary hospital function for a 3-day post-disaster period. The design allocates UBC hospital a dedicated reservoir and pumphouse to deliver necessary water to the 332 beds inside. During the emergency, it is expected that hospital operations be limited to critical care only - non-essential hospital services and their water demands were not included in this project's design scope. Site 5's reservoir and pump system was based on a 561L/hospital bed/day demand, with a 7,787L/hr average hourly demand. While this site appears to share a service area with well site 6, this water main connection is if the hospital needs additional water from site 6. All residential populations in this service area shall receive supply water from well site 6.

5.3.6 Site 6: Central Residence Campus Well (49° 15' 48" N, 123° 14' 30" W)

Figure 8: Site 6 - Design Service Population: 3,576 residents

Design Daily Water per Capita: 10L

Well site 6 is located on the south east corner of a 15m wide green strip that runs parallel to southbound traffic on Western Parkway between Dalhousie Road and Agronomy Road. Well site 6 already appears to be level with only grass covering the area. This site has one large tree in the area, which can easily be avoided during construction, so university tree retention and relocation measures do not need to be considered at this site. Above ground conditions pose little issue for site 6 construction, however below ground site utilities will need to be carefully coordinated with new subgrade construction. Based on a site visit and google earth imagery this area has below grade electrical runs, fire water pipes, and storm or sanitary sewers for the apartment buildings directly west of the site.

This site serves the largest area of all sites, but with the least dense population distribution. Well site 6's service area spans south from Agronomy road to West 16th. Acadia Road and Wesbrook Mall serve as the service area's east and west boundaries, respectively. This area contains many single-family homes, mostly low-rise apartments east of Westbrook Mall, as well as Fairview, Frazer, and Acadia university residents. It is estimated that about 3,576 people would likely shelter in this area during an emergency, generating a 4,501L/hr average hourly demand.

5.3.7 Level Control

All well sites have the same storage tank volume, but slightly different hydrotechnical conditions, and different service populations. Due to differing service populations average hourly demand at well sites vary from 3,725L/hr to 7,763L/hr, meaning the approximately 10,000L design ballast in each tank makes up a slightly different percentage of each site's average daily withdrawal rate. Minimum storage tank volumes are required not only to guarantee the system can always provide water to residents, but also to ensure pumps can provide adequate water pressure to local distribution fixtures and outflow mains. Appendix D - Site Consumption and Supply Analysis, lists all exact tank level minimums under designed operations. While also providing the max allowable demand to ensure the tank volume does not fall below 1000L, at this volume the tank can no longer supply water to the system. Thus, see Appendix - Consumption Analysis Summary Table for specific details on the system flow rates, design demands, maximum allowable demands, and total volumes consumed. In order to maintain designed tank minimums and keep from overflowing the storage tanks, each site's pumps shall be modulated to provide a volume of water between minimum demand and maximum pump capacity as appropriate. This system assumes end users have an infinite need for water beyond their allotted 10L/day that would easily consume any excess groundwater inflows (for example in a flood or heavy storm situation).

5.3.8 Storage Tank Access and Ventilation

All storage tanks shall be outfitted with a 560mm manhole access hatch for non-routine inspection, maintenance, and system upgrades. Routine storage tank maintenance shall be done through sanitation flushes, without the need for technicians to drain and enter the confined tank space. In addition to an access hatch, each tank shall also have a downturned vent to allow for pressure equilibrium between the interior and exterior of the tank regardless of internal water level. All storage tank vents shall be outfitted with a #24 mesh screen to keep out insects, rodents, birds, and other animate hazards. The base of the downturned vent shall be at least 600mm above grade to prevent contaminant inhalation from the ground such as dirt, dust, dried animal feces, etc. Reservoir tank vents shall be distinct from each tank's manufactured overflow spigot.

5.4 Pumphouse Station

The Pumphouse Stations act as housing for the mechanical components for the emergency distribution system. In addition, if the current infrastructure is deemed completely unusable, the pumphouses at each well location have the ability to act as a distribution point with outfitted water faucets serving three people simultaneously. This is an undesirable situation, however it creates a reliable contingency plan in the event of complete disaster.

In addition, water testing will be completed through the emergency water distribution faucets inside the pumphouse mentioned above. The chlorine feeder and sediment filter components are also accessed from inside the pumphouse. In the following sections, the mechanical components inside the pumphouse will be discussed.

5.4.1 Pump Specification

Submersible well pumps were determined by selecting a pump that could meet the required head and flow rates, the head requirement was the determining factor of pump selection due to the depth of the well. Booster pumps were selected based on demand values; and since the water has already been pumped into a storage tank at approximately surface level, pumps with high flows were considered. The booster pump chosen for the design is a 7.5 hp centrifugal pump manufactured by Goulds water technology (model # 6BF1K1E0). This pump is constructed out of cast iron and has bronze fittings for durability. At its most efficient operating point, running at 3500 rpm, it can deliver 19 L/s at 30 psi through it's 75mm diameter outlet. Using one of these pumps is sufficient to supply sites 1,2,3,4; however for sites 5 & 6, two of these pumps are used in series to generate the required system pressure. Refer to Appendix E for the complete technical specifications and the associated pump curve for both submersible and booster pumps..

5.4.2 Piping, Fittings and Valves

The arrangement of piping, valves and fitting are standard across sites, however, due to various system pressure demands two different setups are required as shown in the details of Appendix A - T20-DWG05 and Appendix A - T20-DWG06. It should be noted that each site requires a unique length of service feeder main to tie into the existing water distribution system seen in Table 4 and all systems adhere to the American Water Works Association (AWWA) [23] guidelines.

The components of the design distribution system are illustrated as follows:

- Approximately 13.9m of 75mm black steel piping.
- 2 - 50mm gasket.
- 1 - 50to75mm adapter.
- 35 - 75mm gaskets.
- 9 - 75mm 90 degree elbow connections.
- 2 - 75mm Tee connection.
- 8 - 75to100mm adapter.
- 12 - 100mm groove gaskets.
- 4 - 100mm gate valves.
- 4 - 100mm check valve.
- 26 - 75mm flanges (sites 1-4) and 22 - 75mm flanges (sites 5-6).
- 1 - 75to250mm adapter.
- 2 - 250mm gaskets.
- 1 - 250mm 90 degree elbow connections.
- 2 - Goulds pump model # 6BF1K1E0 (site 1-4) and 4 - Goulds pump model # 6BF1K1E0 (site 5-6)
- 2 - pump stand (site 1-4) and 2 - pump stand (site 5-6)
- 404 - 10mm stainless steel hex bolts, washers and hex nuts.

5.5 Service Feeder Main Requirements

To supply water to the existing UBC infrastructure, a 250mm service feeder main connects the site design water distribution network to the existing water distribution infrastructure. The implementation and connection of these feeder mains will be contracted to an experienced municipal water main excavation in installation contractor. However, this contractor must follow the following design and implementation requirements. Service mains will be constructed from 250mm ductile iron bell and spigot piping. These mains must be locally restrained across all connections via tie-rods with wedge action coupling restraints. Adequate thrust blocks will be implemented at all tie-in locations and bends in the main. Pressure test of 150psi must be conducted on the system prior to operation. All components must be non-corrosive materials, such as stainless steel nuts and bolts and coated retraining couplers and pipes. Proper pipe bedding and topping will be used in accordance with installation guidelines. All trench work and construction will adhere to Work Safe BC [19] requirements. The associated feeder mains distances and excavation requirements area as seen in Table 4.

Table 4: Service Feeder Main Excavation and Installation

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Length of Pipe (m)	66.1	24.5	13.2	25.0	68.8	31.1
Excavation Volume (cu.m.)	57.58	21.35	11.41	21.78	59.94	27.09
Number of Pipes	12	5	3	5	13	6
Number of Restraints	24	10	6	10	26	12

5.6 Distribution System

The key feature of this design is the usage of the existing water main lines. Each service location will pump directly into the existing water main infrastructure. The existing water mains have a cover of 0.9m and range in diameter from 200mm to 250mm with the exception of the lines on University Boulevard and Main Mall from Thunderbird to Agricultural Road, which have a range of 450mm to 600mm. Using the existing system will provide a smooth distribution network that does not need to be constructed and greatly reduces the overall cost. However, this system has the potential to lose potable water through leakage either through pre or post disaster breaks, and the time/resources associated with system setup. To mitigate leakage, sections of the water main will be isolated using pre-existing network isolation valves thereby forming a “closed service loop” - see Appendix A - T20-DWG02. This will be achieved via pressure monitoring by UBC maintenance staff and the manual closing of isolation valves by UBC’s emergency response team. Isolating segments can prevent overconsumption of potable water, as non essential buildings and network segments can be shut off from the supply network. This makes the system more efficient, user friendly, and resilient.

The isolation loops depicted in blue within the Appendix A - T20-DWG02 drawing will service key buildings, namely residences such as Walter Gage Residence and Ponderosa Commons and UBC hub buildings such as UBC Hospital and University Hill Secondary School. These isolation loops are the expected service loops under emergency situations. Each one will meet the expected consumption based on the permanent population and weekday influx population related to the site and loop location, these populations are discussed in Section 5.3 Figure 2 and Appendix D - Consumption Analysis Summary Table. However, under the scenario that a service loop is compromised, the segments of that loop can be isolated further. If all water mains are compromised, the pumphouse at the well site will act as a secondary distribution point, serving at least three people at once.

5.7 Well Installation and Design

Water will be drawn out of a 200mm borehole well with depths and well screens lengths depending on the determined aquifer conditions at each site - see Appendix A - T20-DWG04 for details of bore lengths. The well will be drilled with a dual rotary drill as it is able to meet the size and depth requirements for the wells. To provide adequate earthquake resilience the well is lined with a PVC sleeve. The water will then be pumped from the aquifer by a 50mm submersible pump and up the 200mm shaft and immediately passes through a sediment filter just before entering the pumphouse. The submersible pump selected for the design is a 7.5 hp pump manufactured by Grundfos (model # 98924583). The pump, impeller and motor are made of stainless steel which is ideal for use in water. At the operating point, the pump will run at a speed of 3450 rpm and it will deliver the water at a flow of 2.21 L/s as detailed in Appendix E.

5.8 Treatment / Disinfection (Filtration and Disinfection)

Disinfection is achieved through an automatic chlorination system, which treats the water for pathogens and viruses. After the water passes through the sediment filter, the chlorination system injects the flow with a chlorine solution before the water enters the storage tank. The largest storage tank and shortest distance from tank to first distribution point was used to determine the contact time and residual concentration of free chlorine required; a 58.7 cu.m volume and 14m distance, respectively. Using these variables with the method outlined in appendix H, a contact time of 52 minutes is needed to achieve the required 0.12mg/L concentration of free chlorine residual. The amount of NSF powdered chlorine needed for this volume at peak flow is approximately 6.8g.

6.0 Epanet Modelling

Four EPANET models of the proposed water distribution networks were developed to ensure that the system complies with UBC's water main pressure distribution requirement. These models are identical to the isolated sections depicted in Appendix A - T20-DWG02, which incorporate the existing isolated network and additional feeder mains associated with demand. The system was modelled using the Peak Hour Demand (PHD) established by predicting residential hourly consumption discussed by Pei ru Chao et al. (2015) [3] and hourly hospital demand by Justo Garcia-Sanz-Calcedo et al. (2017) [7]. These demands were explained in Section 5.3 and tabulated in Appendix D - Consumption Analysis Summary Table.

Due to the lack of data on the pre-existing water main network, assumptions on the system were required to accurately analyze the system. It was assumed that the pipe diameter and buried depth throughout the network were 250mm and 900mm, respectively. To determine an accurate leakage in the system, the average length of service connections was assumed to be 20m and the active system pressure was 30psi. To simplify the demand in the system it was assumed that it was equally distributed across all serviced buildings. A field test should be conducted prior to construction to determine if the model is accurate. To properly simulate the consumption used in the model, this test should be done during a time of predicted minimum demand with minimal users on campus. If the outcome of this field test does not meet requirements, resize the booster pump to ensure minimum system pressure and flow is met.

The system layout and pressure distributions for the EPANET analysis, are depicted in Appendix F. Based on modelling results, pressure within all systems range between 30.68psi (21.58m) and 73.25psi (51.51m), with an average system pressure of 50psi (35m); which meets the required minimum pressure of 30psi (21.09m).

It should be noted that for sites 5 & 6, two booster pumps are applied in series to meet the system pressure demands; in all other sites using one booster pump was sufficient.

7.0 Serviceability and Maintenance Plan

In designing the system, serviceability was taken into consideration to ensure that different components can be replaced and serviced easily. The submersible pump is accessed through a removable top plate cover (see Appendix A - T20-DWG05 and T20-DWG06). Testing the water will be done through the emergency water distribution faucets inside the pumphouse. The chlorine feeder and sediment filter components are also accessed from inside the pumphouse. Overall, the serviceability of the design and being able to isolate individual parts creates a robust and easily maintained system.

The design requires regular maintenance to ensure water quality and ease of distribution throughout the whole system. Due to buildup of organic materials, the storage tank requires regular cleaning. This is achieved by complete flushing of water and removal of sludge and other buildups of contaminants. Ambient water quality will be tested for compliance to BC Approved Water Quality Guidelines on a regular basis. Sediment filters will be regularly cleaned out to ensure minimum head loss through the system. Water pipeline integrity will be regularly checked for leaks or signs of degradation such as rust. Valves that are essential to the deployment of the system should be checked regularly for valve seizure. See Table 5 for a summary of maintenance workers' tasks and frequency.

Table 5: Maintenance Task List

Task	Frequency	Purpose
Tank Cleaning	Quarterly	Removal of organic buildup
Water Quality Testing	Monthly	Ensure treatment is sufficient
Valve Exercise	Monthly	Ensure valves remain functioning
Sediment Filter Replacement	Yearly	Ensure sediment stays out of system
Pumphouse Check	Monthly	Ensure equipment is functioning properly

Another key responsibility for the emergency response would be to implement the isolation process when required under emergency situations. In the event that the existing water infrastructure is damaged, compromised water mains are required to be shut off to minimize pressure drops and contamination of water in the existing system. The more detailed plan of emergency valve shutoff will be designed alongside the University of British Columbia Operations team to ensure efficient integration with their other emergency response operations.

8.0 Sustainability

Environmental sustainability is a key aspect of this project and measures were taken to ensure that the design and construction follow guidelines from UBC's sustainability plans and BC's Environmental Management Act [9].

8.1 Design

During the design phase, sustainability was considered by ensuring that the project was economically viable, served the target population efficiently and had little impact on the environment. The project uses the existing pipe distribution network as this is less costly than constructing a new system and it also has lower impact on the environment as greenhouse gas emissions will only be associated with the construction of the pipehouse, well an storage tank, and no addition from installation. This also limits the disruption to the campus' environment as construction will be limited to the six well sites. Additionally, the storage tank will be placed underground, allowing for grass to be planted on top of it to maintain the existing green environment.

8.2 Construction

Construction contributes largely to greenhouse gas emissions, ecosystem damage, and waste production and it is important to ensure that this impact is mitigated. To minimize the risk of contaminating the groundwater during construction, BC's Groundwater Protection Regulation will be complied with during construction and maintenance of the well as detailed in Section 5.7 and site construction further discussed in Section 11. In addition, the construction material used for the pumphouse and the storage tank will be prefabricated to reduce waste and soil and air pollution that occurs on the construction-site. The excavated soil will be reused on the project or in coordination with other projects on the UBC campus. Transport vehicles will be under a no-idle policy as this is a large contribution to greenhouse gas emissions. Any waste produced during construction will be disposed of according to Part 2.6 of BC's Environmental Management Act [9] to eliminate any possible contamination and maintain a healthy ecosystem.

9.0 Technical Design Outputs

9.1 Supply System and Feeder Mains

Issued For Construction drawings showing the designed supply system within the pumphouse as seen in Appendix A - T20-DWG05, T20-DWG06 and T20-DWG07. These drawings show the required booster pump and valve arrangement for different sites due to the change in pressure demand. Details outlined in IFC drawings Appendix A - T20-DWG03 and Appendix A - T20-DWG07, depict the horizontal and vertical alignment of designed service feeder main. These drawings indicate the required ground elevation, pipe sizing, water main cover, tie-in, and restraining types.

9.2 Structural Reinforcement Details and Requirements

Details showing the structural reinforcement design for vertical stability of light-frame wood walls, lateral stability of light-frame wood walls, mat foundation, and foundation walls are included in Appendix A - T20-DWG08. The construction contractor must follow these drawings to ensure the design can tolerate the design loading and structural requirements determined in Appendix B and Section 5.2.

10.0 Construction Specifications

Construction shall take place over the course of approximately six months, and be compliant with specifications from the federal, provincial, municipal, and UBC Campus policy. Site safety protocol shall be in compliance with WorksafeBC guidelines. Tree and Green Edge maintenance are specifically considered in accordance with *Section 4.1.2* of *UBC's Land Use Policy - UP12*. The proposed timeline suggests one to three well and pumphouse sites will be cordoned off at a time to which full access for construction activities will be required.

Team 20 will design, procure, and install all components necessary to complete the design. The design and construction of the system's wells, pump sizing & arrangement, filtration sequence, isolation segments, pumphouses, and pumphouse foundations shall be within the project scope. Design of specialty items such as storage tanks, pumps, and filtration technology shall be excluded from scope. Team 20 shall purchase and install specialty equipment with vendor support if required. Included in the proposal is the purchase and installation at all six well locations of:

- 50mm submersible pumps
- 200mm diameter wells with shaft casing bored to each site's aquifer depth per the report's groundwater analysis, see in Appendix B - T20-DWG04.
- Systems needed to bring water up to drinking quality such as a chlorination system, sediment filters, and secondary filters.
- Booster pumps as needed to maintain adequate service flow and/or pressure
- Valves, reducers, pipe fittings, gaskets, flanges, nuts, and bolts necessary to connect each site's submersible pump, booster pumps, valves, sediment filter, and chlorination system, to outflow through on-site distribution (sinks) and a feeder main.

    - Installation of the feeder main and attachment to campus existing water distribution infrastructure shall be contracted out to others.
- Electrical equipment necessary to run the system during a power outage such as a generator, and filled propane tanks.
- Valves, reducers, pipe fittings, gaskets, flanges, nuts, and bolts necessary to carry out the proposed branch isolation of UBC's existing pipe infrastructure should existing infrastructure be missing or in disrepair.
    - If necessary, modifications to existing pipe infrastructure shall be done via hot tap
- Construction of a pumphouse and foundation
- 24 Pump Flow Test following installation of all new pump systems, valves, reducers, and pipe fittings.

This proposal details a suggested maintenance and flushing schedule for the emergency groundwater system. Within the project scope is providing knowledge necessary to educate future system operators. Carrying out routine system maintenance shall be the responsibility of the client (UBC). The salaries of the facilities staff needed to test, and maintain the system shall also be the responsibility of the client (UBC).

11.0 Draft Plan of Construction Work

11.1 Site Excavation

At each of the six sites a reservoir tank, groundwater well, and pumphouse foundation must be placed entirely or partially below grade. Thus, an excavator with a drill attachment and a dump truck to haul excavated material are necessary pieces of equipment during the construction of all well site locations. Following permit approval and geological site investigation, earthwork at sites can begin. In order to expedite project completion without dramatically increasing project cost Team 20 recommends two excavators be deployed to two different well sites, each with their own dump truck to off-haul material. Should backfill be needed, a sand and gravel mixture (pea gravel) shall be used as typical. Once on-site, the excavators should drill and case wells 1 & 2 in one day, then wells 3 & 4, then finally 5 & 6. It is assumed the crews get more efficient as they drill and case wells so that on days 2 and 3 of on-site activity extra time in the work day can be allotted to pumphouse foundation and reservoir tank excavation. Team 20 projects nine days of drilling and excavation work.

11.2 Pumphouse Construction

The pumphouse is the only required superstructure on-site. However, this building must withstand a magnitude 8.0 earthquake. Thus, the contractor issued for construction must follow the structural design laid out in Section 5.2, Appendix A, and Appendix B. Once site excavation and borehole drilling has concluded, the feeder main and other underground piping will be implemented on-site to allow for undisrupted erection of the superstructure. Pumphouse construction will start by pouring the required steel reinforced concrete foundation walls and footing pad. The super-structure will be constructed in segments off site to increase productivity on-site. Once the building is erected, implementation of the designed water distribution network will commence by the contractor performing the task. In completion of the distribution network, other components will be installed in the structure, such as, electrical components, filtration and chlorination, on-site distribution system, and pumphouse finishing. Lastly, all other site components will be installed to allow for pre-operation checks to be conducted on the site and local system.

11.3 Isolation Valve Install

Per the design's Main Isolation Plan 22, pre-existing gate valves shall be utilized in the event of an emergency to isolate six "closed service loops" of existing campus water main. The presence and adequate operational status of these existing valves are assumed from a campus utility plan provided to Team 20. A pre-construction survey of the existing valves and their operational/maintenance status should be conducted to ensure all assumed valves are in fact existing and all valves are in good operating condition. Costs, delays, and design changes related to missing and/or inoperable valves shall be the responsibility of the client, and are out of the scope of this proposal. 100mm gate and check valves shall isolate booster pumps in each pumphouse for maintenance purposes. These booster pump isolation valves shall be installed when pumps are installed at each well site. The feeder main from each pumphouse and its connection to existing campus water distribution infrastructure shall be designed and installed by others, thus any system isolation necessary is out of the design scope. Requirements for subcontracted feeder main design are as follows: feeder mains shall be constructed with 250mm ductile iron bell and spigot piping, and these mains must be locally restrained across all connections via tie-rods with wedge action coupling restraints. An estimated cost of this subcontracted work is included in the cost estimate.

12.0 Cost Estimate

Through performing a class 'A' cost analysis, the estimated cost of this project, including a 5% consulting fee, a 20% contingency, and a 12% tax rate, is $1,486,300 CAD; equivalent to approximately $250,000 CAD per well. The total cost estimate, summarized in Table 6 below, is approximately $294,000 higher than the total cost estimated in the preliminary report. The significant discrepancy is due to the addition of the piping required within the pumphouses to connect the storage tank to the existing system which was not accounted for in the previous estimate. Another factor which increased costs was the addition of several redundancies to the system; however, the tradeoff between costs and system resilience was deemed to be a net benefit. Given the scope of the project, and anticipated efficacy of the design, the total amount is considered to be a reasonable estimate for this emergency groundwater system. Please refer to Appendix G for the fully sourced tables for reference.

Table 6: High Level Cost Summary

Final Cost			
Materials & Construction Total			$854,564.05
Permits Total			$58,906.91
Management & Maintenance			$148,200.00
Subtotal			**$1,061,670.95**
Consultant Fees	Subtotal x	5%	$53,083.55
20% Contingency Fund	Subtotal x	20%	$212,334.19
Tax (Contingency & Consultant Fees Incl.)	Subtotal x	12%	$159,250.64
Total (CAD)			**$1,486,339.71**

12.1 Detailed Design Costs

This section contains a fully itemized list of materials, services, and labour for the installation of the system. Table 7 below gives a detailed account of the components used and services required for the pumps to be operational, but does not go into detail with respect to pumphouse construction or permitting costs; these are explained further in the following sections. Price references have been provided for each item in Appendix G - Material Construction Cost References.

Table 7: Detailed Design Costs

Materials Construction			
Item	Price (CAD)	Amount	Totals (CAD)
Submersible Pump - 50mm	$16,000.00	6	$96,000.00
Well Drilling & Shaft Casing	$30,000.00	6	$180,000.00
Filtration Housing	$1,437.00	6	$8,622.00
Sediment Filter	$146.00	6	$876.00
Chlorination System	$1,540.92	6	$9,245.50
Booster Pump	$4,418.82	16	$70,701.12
Generator	$6,479.00	6	$38,874.00
Propane Tank & Liquid	$2,890.00	6	$17,340.00
Storage tanks	$20,160.00	6	$120,960.00
24 Hr Pump Flow Test	$17,000.00	6	$102,000.00
Hot Tap Into Water System	$15,120.00	6	$90,720.00
Construction Labour	$22.00	90	$1,980.00
Skilled Labour	$150.00	36	$5,400.00
Excavation / Soil Removal	$670.00	6	$4,020.00
Pumphouse	$3,691.00	6	$22,147.35
Stainless Steel Sink	$837.90	6	$5,027.40
Stainless Steel Check Valve - 65mm	560.1078	6	3360.6468
Pumphouse Door	$285.00	12	$3,420.00
Gate Valves - 100mm	$721.22	12	$8,654.69
Check Valves - 100mm	$521.98	12	$6,263.76
Iron Tee Connection - 75mm	$122.89	12	$1,474.65
Black Steel 90 Deg. Elbow - 75mm	$182.70	54	$9,865.80
Black Steel Reducer - 75mm x 50mm	$187.71	6	$1,126.29
Black Steel Reducer - 10c0mm x 75mm	$116.42	48	$5,588.35
Black Steel Piping (10ft) - 75mm	$344.66	30	$10,339.81
Ductile Iron Reducer - 250mm x 75mm	$1,260.00	6	$7,560.00
Ductile Iron 90 Deg. Elbow	$1,260.00	6	$7,560.00
Gaskets - 250mm	$92.99	12	$1,115.86

Gaskets - 50mm	$2.14	12	$25.70
Gasket - 75mm	$3.20	210	$672.08
Groove Gaskets - 100mm	$41.83	72	$3,011.90
Flanges - 75mm	$66.24	148	$9,803.25
Flange Bolts (200 Count)	$167.58	3	$502.74
Flange Nuts (100 Count)	$51.08	6	$306.48
Total (CAD)			**$854,564.05**

12.2 Permitting

Team 20 compiled a list of all relevant permits needed in order to construct the system and have it operational. The following table names the permits needed and a description of what it entails.

Table 8: Relevant Permits Needed

Permit Name	Description and Details
UBC Development Form	Needed for any new building construction and permission to develop on campus. Includes changes to UBC environment, changes to existing buildings, change of land use. Also ensures correct development permit sign layout for public engagement
UBC Building Application	Ensures BCBC code complacency (Schedule A and B) and UBC Development/Building Regulations code complacency.
UBC SLP (Street and Landscape Permit)	Required for any project that involves change, excavation, or construction in the public realm, such as sidewalks, landscapes, or any related construction activity outside a development project boundary as defined by the Development Permit
Crown Land use Application	Permission to use and access crown owned land including land covered by water.
Crown Groundwater Rental	Annual payments on the diversion of water use. Ensures complacency with respect to the Water Sustainability Act and fees relevant to non-domestic groundwater usage and rental fees pertaining to surface water use.

Given the above, the associated costs for obtaining these permits is listed below. Note that the permits are based on estimated quantity and usage - the total pricing in the table below reflects the usage calculations.

Table 9: Total Permit Costs

Permits			
Item	**Rate ($)**	**Quantity**	**Total (CAD)**
UBC Development Fee	0.3	1000	$300.00
UBC Building Application Fee	98	1	$98.00
	14	15	$210.00
	8.25	30	$247.50
	8.4	857	$7,198.80
UBC SLP Damage Deposit	0.08	250000	$20,000.00
	0.04	250000	$10,000.00
	0.02	407008	$8,140.17
UBC SLP Costs	0.015	250000	$3,750.00
	0.01	250000	$2,500.00
	0.005	407008	$2,035.04
Crown Land use Application Fee	263	1	$262.50
Crown Groundwater Rental Fee (Annual)	4165	1	$4,164.90
Total (CAD)			$58,906.91

Acquiring the proper permits and submitting relevant applications is a significant cost to this project, totalling approximately $60,000CAD. However, going through all proper application and permitting procedures will ensure that delays are mitigated which translates to cost savings during construction of the pumphouses and installation of the wells.

UBC's required fees for applications and permits are the majority of the total permitting costs, approximately 92.5%. However, approximately $38,000 of the permitting fees are in the form of a damage deposit, making 65% of the total cost recoverable. It should be noted that the fee for "provincial water use" is built into the "Crown groundwater rental" annual fee. Appendix G - Permitting Cost Information and Requirements offers the above table with the associated permitting cost referenced.

12.3 Construction Costs

Construction costs associated with the building of the pumphouse are detailed in the table below, the values shown are the total costs for all 6 pumphouses. These costs do not represent the groundwater well system, but specifically the construction of the shelter and foundation. Estimated costs for the items listed in the following table were found using Bluebeam Software.

Table 10: Construction Costs Breakdown

Pumphouse Construction Item	Cost (CAD)
Excavate slab area	$1,000.00
Off-Haul	$1,000.00
Backfill	$660.00
Concrete	$5,398.70
Wall Framing	$680.00
Sheathing + Layer	$4,510.00
Gypsum	$3,166.25
Vinyl Siding	$5,732.40
Total (CAD)	$22,147.35

12.4 Annual Operating and Maintenance Costs

Table 11: Annual Project Management & Maintenance Costs

Operating & Maintenance Costs			
Item	Price (CAD)	Amount	Totals (CAD)
Training Hours	$35.00	240	$8400.00
Maintenance Salary	$50,000.00	2	$100,000.00
Facility Costs	$100,000.00	0.05	$5,000.00
Total			**$113,400.00**

Maintenance costs were calculated assuming UBC would need to hire two additional full time employees, whose routine responsibilities would include: tank cleaning, filter cleaning, water quality checks, valve exercising, and checking integrity of components within the pumphouse.

Another key responsibility for these two positions would be to implement the isolation process when required. These new staff members are responsible for training existing staff, and organizing teams within UBC operations to aid them in implementing the isolation processes.

Initially, the two new staff members would require training to learn their responsibilities; thus, training hours was consequently based on one supervisor and two workers training for a period of two work weeks. Facility costs are assumed to include costs associated with vehicle use, cleaning supplies, and various small hardware, and was taken to be 5% of the annual maintenance cost. For a list of references, please see Appendix G - Annual Management, Maintenance and Operation Cost Reference.

13.0 Schedule

The construction schedule in Appendix I displays the tasks that will be carried out beginning May 2021 until completion of the project. The duration of the tasks is shown in work days where a work day consists of eight hours, with five days in a work week. The schedule was designed to have some tasks overlapping each other to minimize the project time. As shown, the excavation of site 1 and site 2 will begin after the well has been drilled. This will occur at the same time as the drilling of wells 3 and 4. The key milestones include obtaining all permits, installation of the filtration system at each individual well site and connecting the well system to the existing infrastructure.

14.0 Conclusion

To meet the needs of UBC SEEDS and theUEL, six groundwater well sites are being proposed. Site locations were determined using a weighted metric of population density and institutional importance. Each location will feature a pumphouse and well shaft that feeds into the existing water infrastructure and will be further isolated into "closed loops" to distribute the treated water. The groundwater wells will be servicing the key buildings outlined in this report. In the event of a total system failure, the pump houses are outfitted with faucets and sinks for distribution. Each pumphouse will contain the the following components:

- Submersible pump to draw water up
- Reinforced/grouted well shaft
- Tank under the pumphouse
- A disinfection system (sediment filter and chlorination)
- A secondary booster pump to charge the mainlines
- Sinks for distribution at pumphouse.

The total cost of this system is $1.49 million CAD. This figure includes consultant's fee, applicable taxes, materials, excavation, construction, permits, maintenance, and a contingency. Pending a construction start date of early May 2021, the project is expected to be completed by the end of August 2021.

15.0 References

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Appendix A - IFC Drawings

TEAM 20
CIVL 446

UNIVERSITY OF BRITISH COLUMBIA

GROUNDWATER EMERGENCY WATER SUPPLY

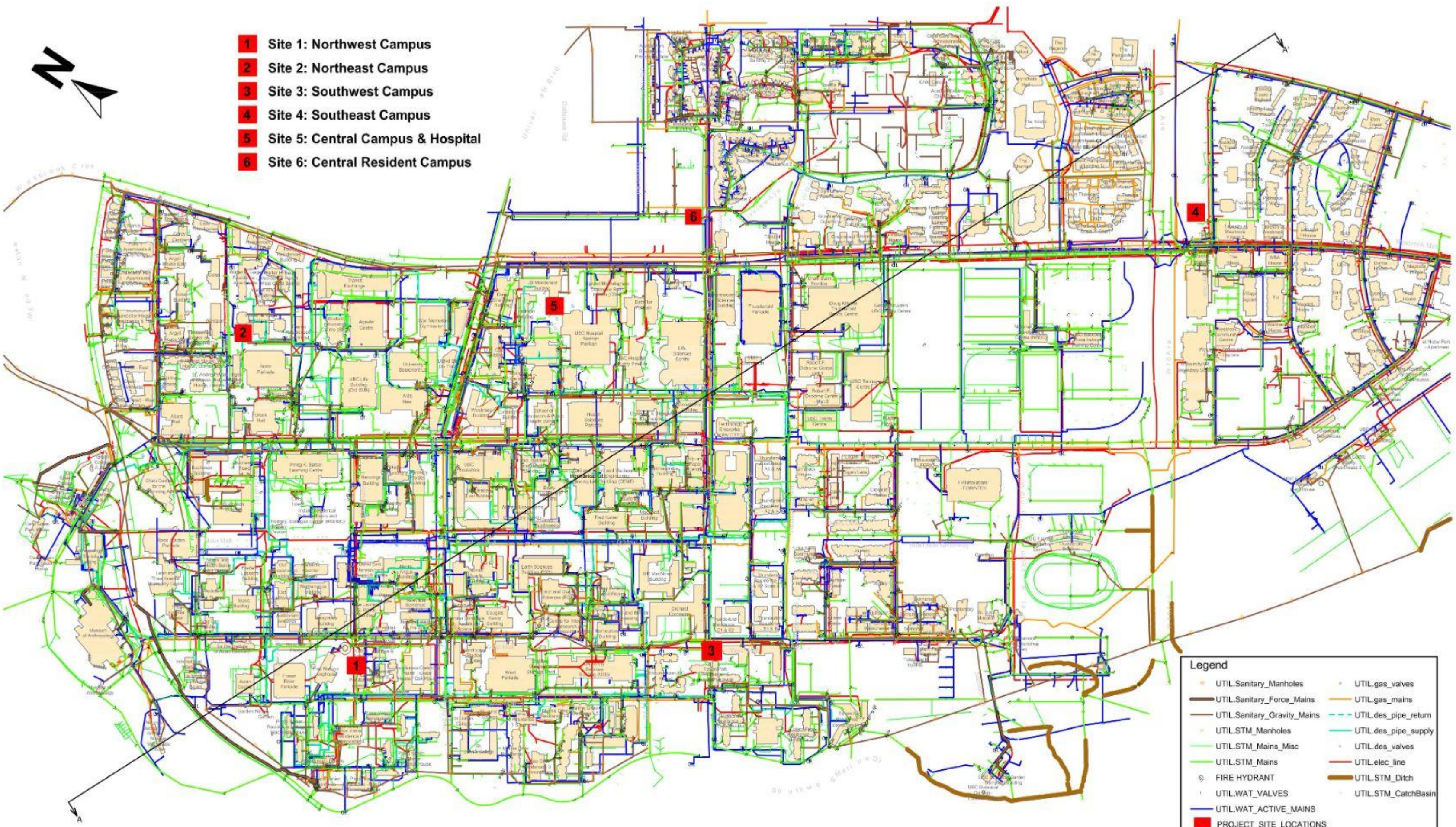
UBC CAMPUS

LOCATION OF PROJECT

DRAWING INDEX

T20-DWG01	CAMPUS WIDE SITE & UTILITIES PLAN VIEW
T20-DWG02	PRE-EXISTING WATER MAIN UTILIZATION AND BUILDINGS SERVED
T20-DWG03	BASE PLAN FOR SITE 1-6 C/W EXISTING UTILITIES
T20-DWG04	SITE WELL BOREHOLES RELATIVE TO AQUIFER DEPTHS AND WATER TABLE
T20-DWG05	SITE LAYOUT AND WATER NETWORK FOR SITE 1 - 4
T20-DWG06	SITE LAYOUT AND WATER NETWORK FOR SITE 5 - 6
T20-DWG07	SITE ELEVATION
T20-DWG08	REINFORCEMENT DETAILS SUPER AND SUB-STRUCTURE

ISSUED FOR CONSTRUCTION
APRIL 16, 2021



PROJECT:
UBC GROUNDWATER EMERGENCY WATER SUPPLY

ISSUED FOR CONSTRUCTION

DRAWING NAME:
CAMPUS WIDE SITE & UTILITIES PLAN VIEW

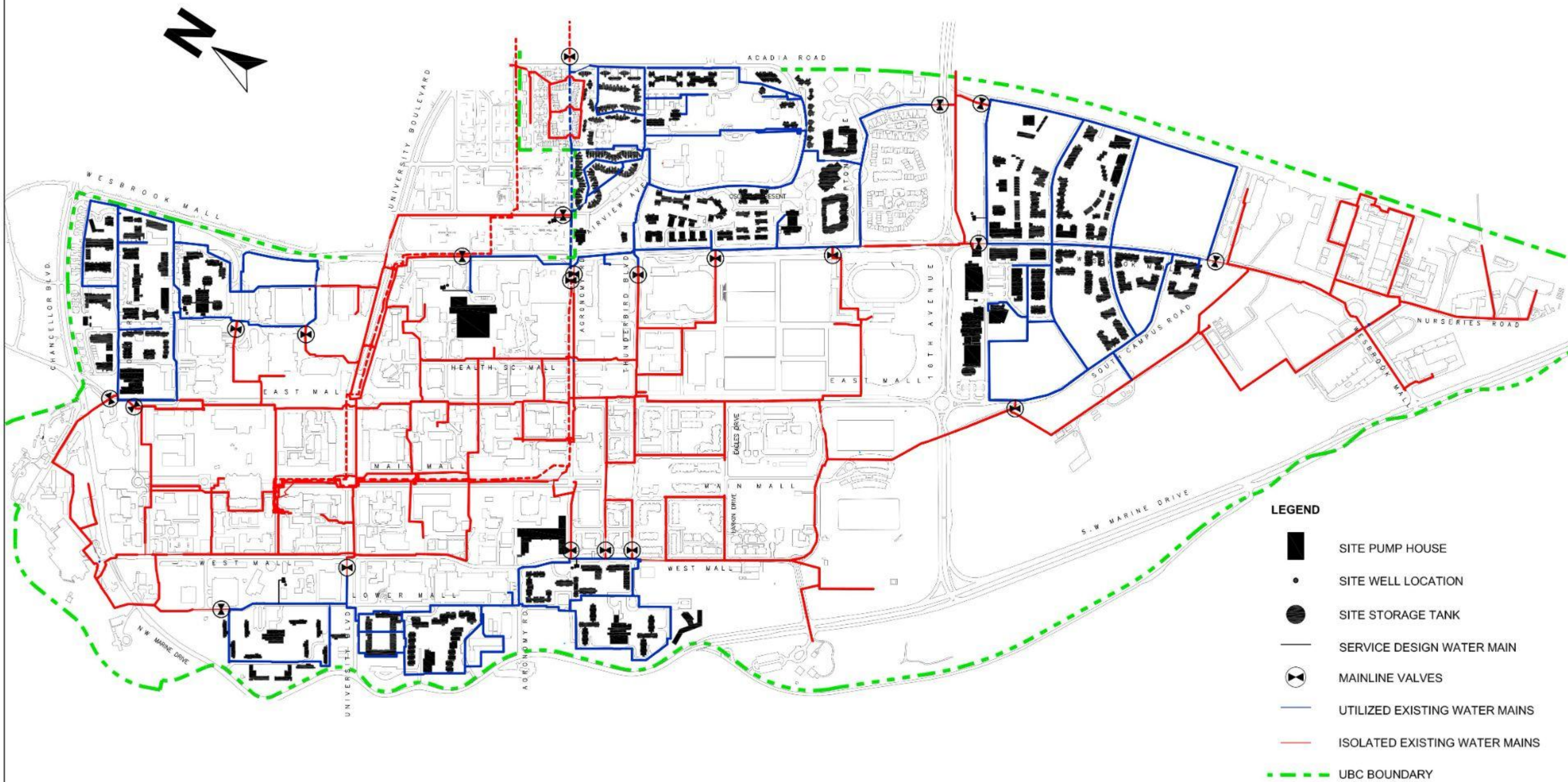
DRAWING NUMBER: T20-DWG01

NOTE:
- UBC CAMPUS UTILITIES PROVIDED BY DR. NAZHAT IS THE ORIGINAL DRAWING
- DRAWING EDITED TO SHOW THE PROJECT UTILIZATION IN RELATION TO CAMPUS UTILITIES
- GROUP 20 ASSUMES NO RESPONSIBILITY FOR THE CORRECTNESS AND ACCURACY OF ORIGINAL UTILITIES SHOWN
- SUB AND SUPER-STRUCTURES MIGHT HAVE BEEN ADDED SINCE DRAWING WAS ESTABLISHED AND PROVIDED

REV NO.	DATE	Dwg.	Chk.	DESCRIPTION
0	2020-11-27	IS	AH	ISSUED FOR TENDERING
1	2021-02-19	IS	AH	RECORD DRAWING
2	2021-04-08	EH	EH	ADDITIONAL NOTES

SEAL

DESIGNED: IS	SCALE: N/A
CHECKED: EH	DATE: 2020-04-08
DRAWN: IS	REV: 2
APPROVED: EH	SHEET: 1 OF 8



PROJECT:
UBC GROUNDWATER EMERGENCY WATER SUPPLY

ISSUED FOR CONSTRUCTION

DRAWING NAME:
PRE-EXISTING WATER MAIN UTILIZATION AND BUILDINGS SERVED

DRAWING NUMBER: T20-DWG02

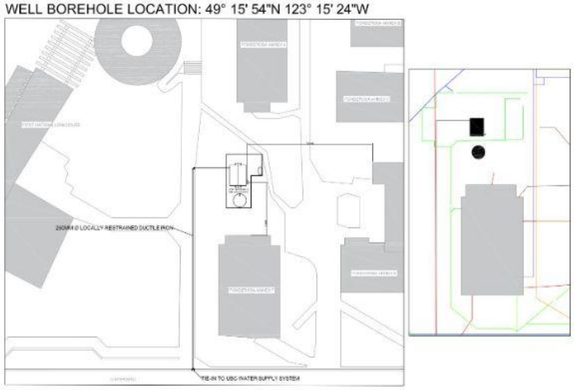
NOTE:
- UBC CAMPUS UTILITIES PROVIDED BY DR. NAZHAT IS THE ORIGINAL DRAWING
- DRAWING EDITED TO SHOW THE PROJECT UTILIZATION IN RELATION TO CAMPUS UTILITIES
- GROUP 20 ASSUMES NO RESPONSIBILITY FOR THE CORRECTNESS AND ACCURACY OF ORIGINAL UTILITIES SHOWN
- SUB AND SUPER-STRUCTURES MIGHT HAVE BEEN ADDED SINCE DRAWING WAS ESTABLISHED AND PROVIDED

REV NO.	DATE	Dwg.	Chk.	DESCRIPTION
0	2021-02-20	IS	EH	RECORD DRAWING

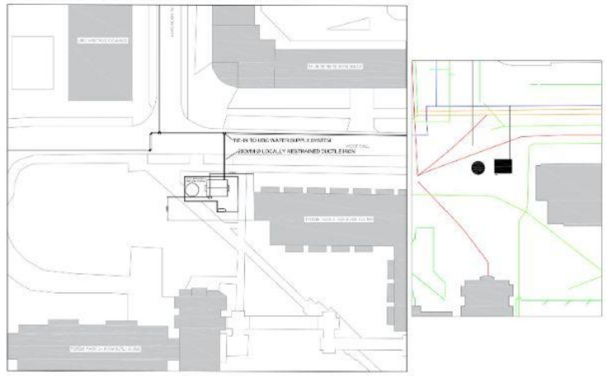
SEAL

DESIGNED: IS	SCALE: N/A
CHECKED: EH	DATE: 2021-02-20
DRAWN: IS	REV: 0
APPROVED: EH	SHEET: 2 OF 8

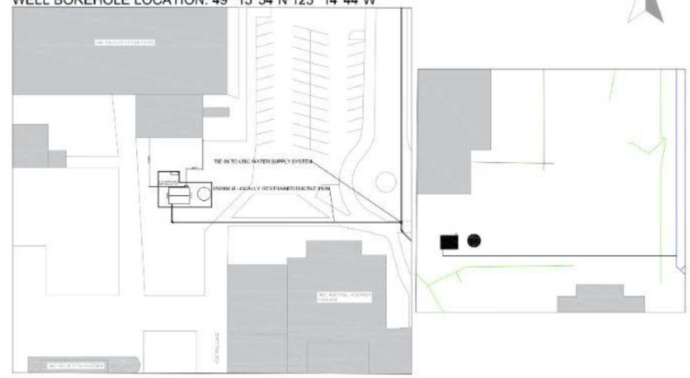
SITE 1: NORTHWEST CAMPUS
WELL BOREHOLE LOCATION: 49° 15' 54"N 123° 15' 24"W



SITE 3: SOUTHWEST CAMPUS
WELL BOREHOLE LOCATION: 49° 15' 34"N 123° 15' 06"W

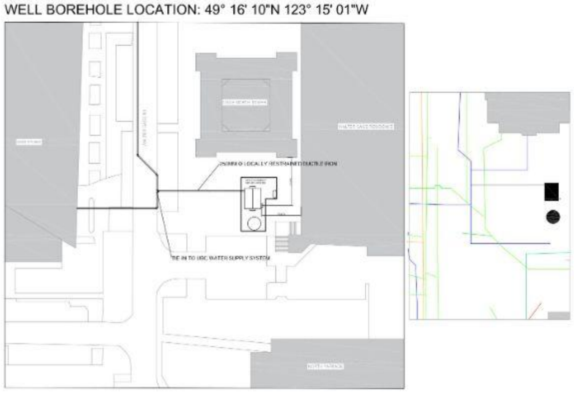


SITE 5: CENTRAL CAMPUS & HOSPITAL
WELL BOREHOLE LOCATION: 49° 15' 54"N 123° 14' 44"W

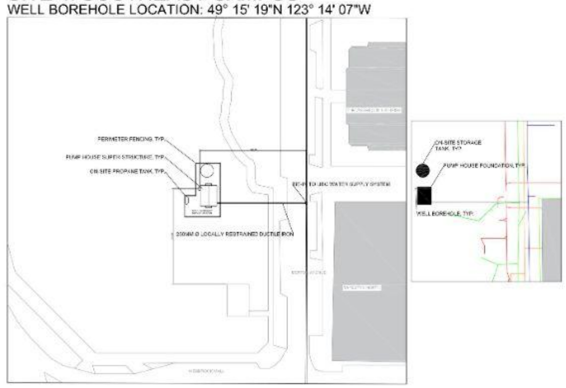


N

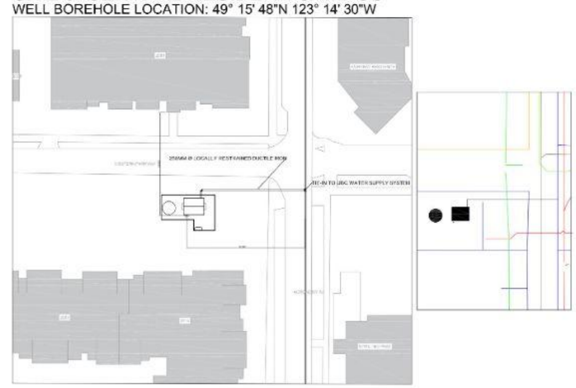
SITE 2: NORTHEAST CAMPUS
WELL BOREHOLE LOCATION: 49° 16' 10"N 123° 15' 01"W



SITE 4: SOUTHEAST CAMPUS
WELL BOREHOLE LOCATION: 49° 15' 19"N 123° 14' 07"W



SITE 6: CENTRAL RESIDENT CAMPUS
WELL BOREHOLE LOCATION: 49° 15' 48"N 123° 14' 30"W



NOTE:
- GENERAL LAYOUT OF SITE AND SURROUNDING INFRASTRUCTURE, ONLY USE AS REFERENCE MATERIAL
- DIMENSIONS AVAILABLE IN DRAWING ARE REFERENCE DISTANCES FOR WELL BOREHOLE LOCATION
- CONSULT WITH ENGINEER PRIOR TO DRILLING BOREHOLE
- PRIOR TO DRILLING BOREHOLE SEE SHEET 5: DWG21-04-03-02 TO ENSURE ADEQUATE SPACE FOR DESIGN ON SITE.
- SEE SHEET 1: DWG20-11-27-01 FOR DESCRIPTION OF UTILITIES
- SITE 4 DESCRIBES THE COMPONENTS FEATURED IN THESE DRAWINGS
  - ONLY SUB-STRUCTURE IS SHOWN IN THE EXISTING UTILITY DRAWINGS
  - ONLY SUPER-STRUCTURE COMPONENTS ARE SEEN IN THE BASE PLAN DRAWINGS

PROJECT:
UBC GROUNDWATER EMERGENCY WATER SUPPLY

ISSUED FOR CONSTRUCTION

DRAWING NAME:
BASE PLAN FOR SITE 1-6 C/W EXISTING UTILITIES

DRAWING NUMBER: T20-DWG03

NOTE:
- UBC CAMPUS UTILITIES PROVIDED BY DR. NAZHAT HAS BEEN EDITED TO DEPICT EACH SITE LOCATION AND SHOW THE PROJECT UTILIZATION IN RELATION TO CAMPUS UTILITIES
- GROUP 20 ASSUMES NO RESPONSIBILITY FOR THE CORRECTNESS AND ACCURACY OF ORIGINAL UTILITIES SHOWN
- SUB AND SUPER-STRUCTURES MAY HAVE BEEN ADDED SINCE DRAWING WAS ESTABLISHED AND PROVIDED - CONSULT WITH UBC SERVICES
- GENERAL LAYOUT OF SITE AND SURROUNDING INFRASTRUCTURE - ONLY USE AS REFERENCE MATERIAL

REV NO.	DATE	Dwg.	Chk.	DESCRIPTION
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1	2021-04-08	EH	EH	ADDITIONAL NOTES

SEAL

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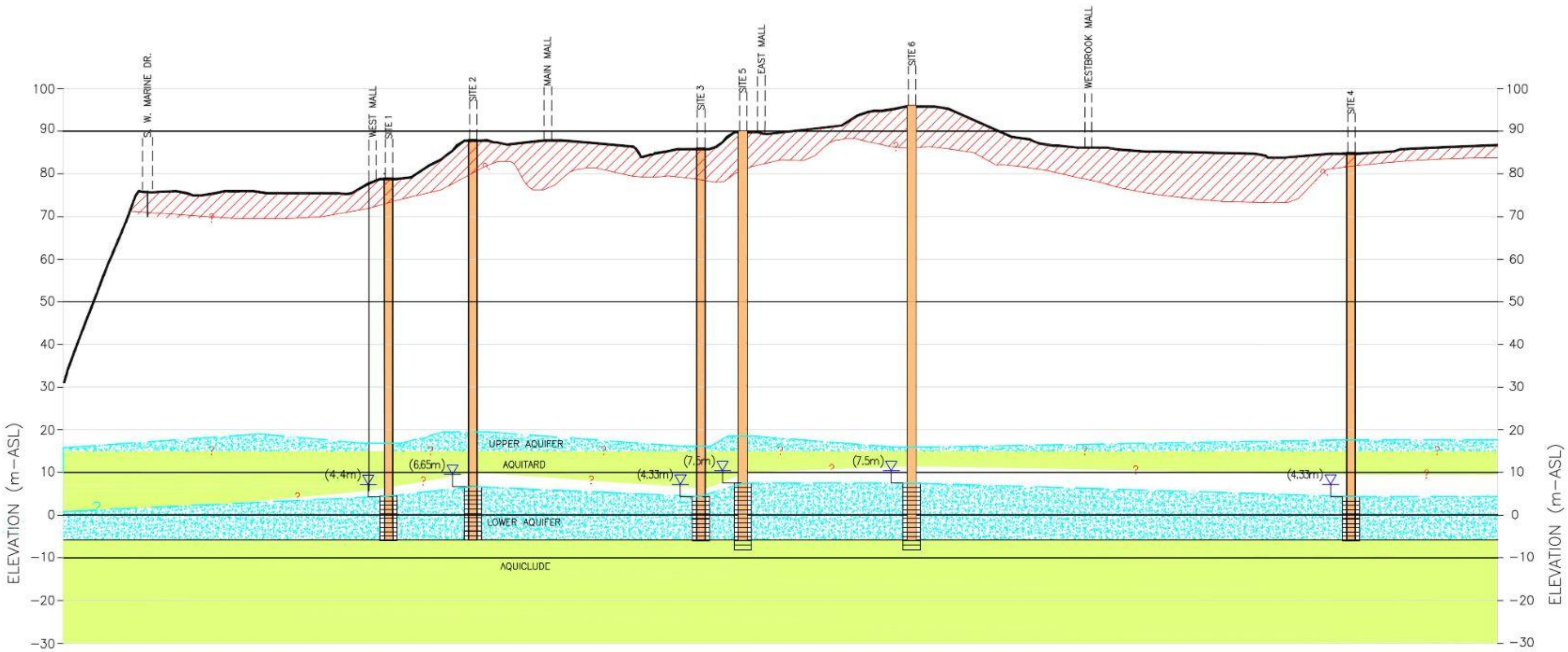
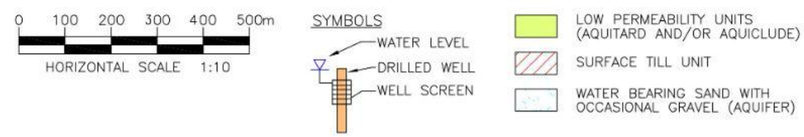
APPROVED: EH	SHEET: 3 OF 8



WELL ID	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6
GROUND ELEVATION (M-ASL)	79	88	86	85	90	96
WATER TABLE ELEVATION (M-ASL)	4.40	6.65	4.33	4.33	7.50	7.50
AQUICLUDE ELEVATION (M-ASL)	-5.87	-5.87	-5.87	-5.87	-5.87	-5.87
WELL SCREEN HEIGHT (M)	10.27	12.52	10.20	10.20	13.37	13.37
SITE TOTAL BORE DEPTH (M)	84.87	93.87	91.87	90.87	95.87	101.87



UPPER AQUIFER

- ELEVATION ABOVE SEA LEVEL CHANGES ACROSS ALL SITES
- NOT ACCURATELY DEFINED
- WAS NOT OF INTEREST DURING STRATA ANALYSIS
- ASSUMED ELEVATION CAMPUS WIDE: 22.4M-ASL (PITEAU 2001)

AQUITARD

- ELEVATION ABOVE SEA LEVEL CHANGES ACROSS ALL SITES
- NOT ACCURATELY DEFINED
- WAS NOT OF INTEREST DURING STRATA ANALYSIS

LOWER AQUIFER

- ELEVATION ABOVE SEA LEVEL CHANGES ACROSS ALL SITES
- NOT ACCURATELY DEFINED AT PROJECT SITES, REASONABLE ASSUMPTIONS MADE FROM DATA PROVIDED BY PITEAU 2001

AQUICLUDE

- ELEVATION ABOVE SEA LEVEL CHANGES ACROSS ALL SITES
- NOT ACCURATELY DEFINED
- WAS OF INTEREST DURING STRATA ANALYSIS
- ASSUMED ELEVATION CAMPUS WIDE: -5.87M-ASL (PITEAU 2001)

WELL LOCATION

- ELEVATION ABOVE SEA LEVEL CHANGES ACROSS ALL SITES
- NOT ACCURATELY DEFINED AT PROJECT SITES, REASONABLE ASSUMPTIONS MADE FROM DATA PROVIDED BY PITEAU 2001
- BOREHOLE HAS SLEEVE REINFORCING WALL
- SCREEN OVER THE WHOLE DEPTH OF LOWER AQUIFER

PROJECT:
UBC GROUNDWATER EMERGENCY WATER SUPPLY

ISSUED FOR CONSTRUCTION

DRAWING NAME:
SITE WELL BOREHOLES RELATIVE TO AQUIFER DEPTHS AND WATER TABLE

DRAWING NUMBER: T20-DWG04

NOTE:
- UBC CAMPUS GROUND WATER AND SOIL DATA PROVIDED BY DR. NAZHAT HAS BEEN INTERPRETED AS SEEN ABOVE
- DRAWING EDITED TO SHOW THE PROJECT UTILIZATION IN RELATION TO SITE LOCATIONS AND WELL BOREHOLE ANALYSIS
- GROUP 20 ASSUMES NO RESPONSIBILITY FOR THE CORRECTNESS AND ACCURACY OF ORIGINAL SOIL STRATA AS SHOWN
- WATER TABLE COULD HAVE CHANGED SINCE DRAWING WAS ESTABLISHED AND PROVIDED

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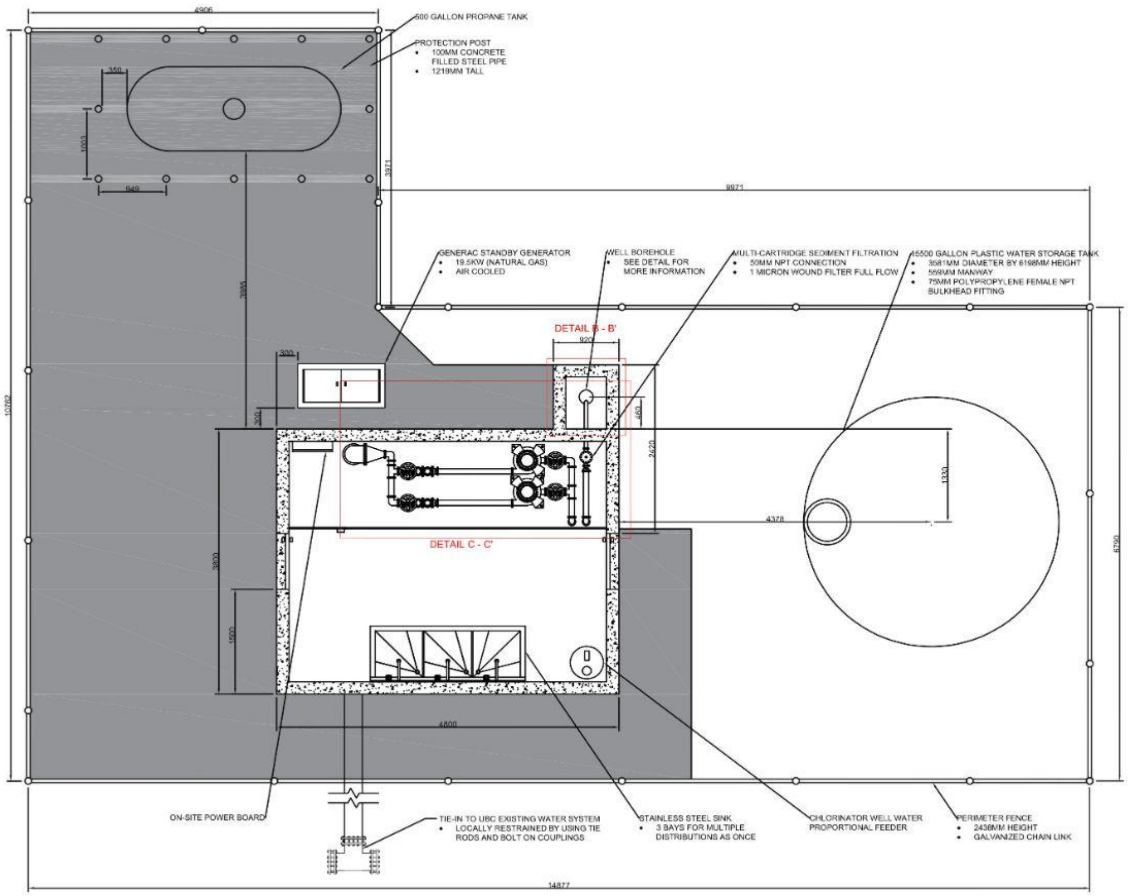

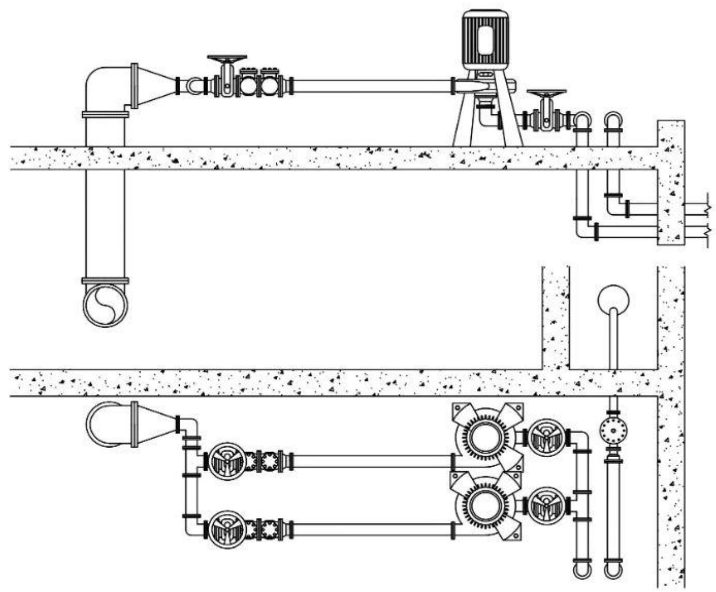

DETAIL C - C'
BOOSTER STATION (SITE 1 - 4)

PROJECT:
UBC GROUNDWATER EMERGENCY WATER SUPPLY

ISSUED FOR CONSTRUCTION

DRAWING NAME:
SITE LAYOUT AND WATER NETWORK FOR SITE 1 - 4

DRAWING NUMBER: T20-DWG05

NOTE:
- UBC CAMPUS UTILITIES PROVIDED BY DR. NAZHAT HAS BEEN EDITED TO DEPICT EACH SITE LOCATION AND SHOW THE PROJECT UTILIZATION IN RELATION TO CAMPUS UTILITIES
- GROUP 20 ASSUMES NO RESPONSIBILITY FOR THE CORRECTNESS AND ACCURACY OF ORIGINAL UTILITIES SHOWN
- SUB AND SUPER-STRUCTURES MIGHT HAVE BEEN ADDED SINCE DRAWING WAS ESTABLISHED AND PROVIDED
- GENERAL LAYOUT OF SITE AND SURROUNDING INFRASTRUCTURE, ONLY USE AS REFERENCE MATERIAL

REV NO.	DATE	Dwg.	Chk.	DESCRIPTION
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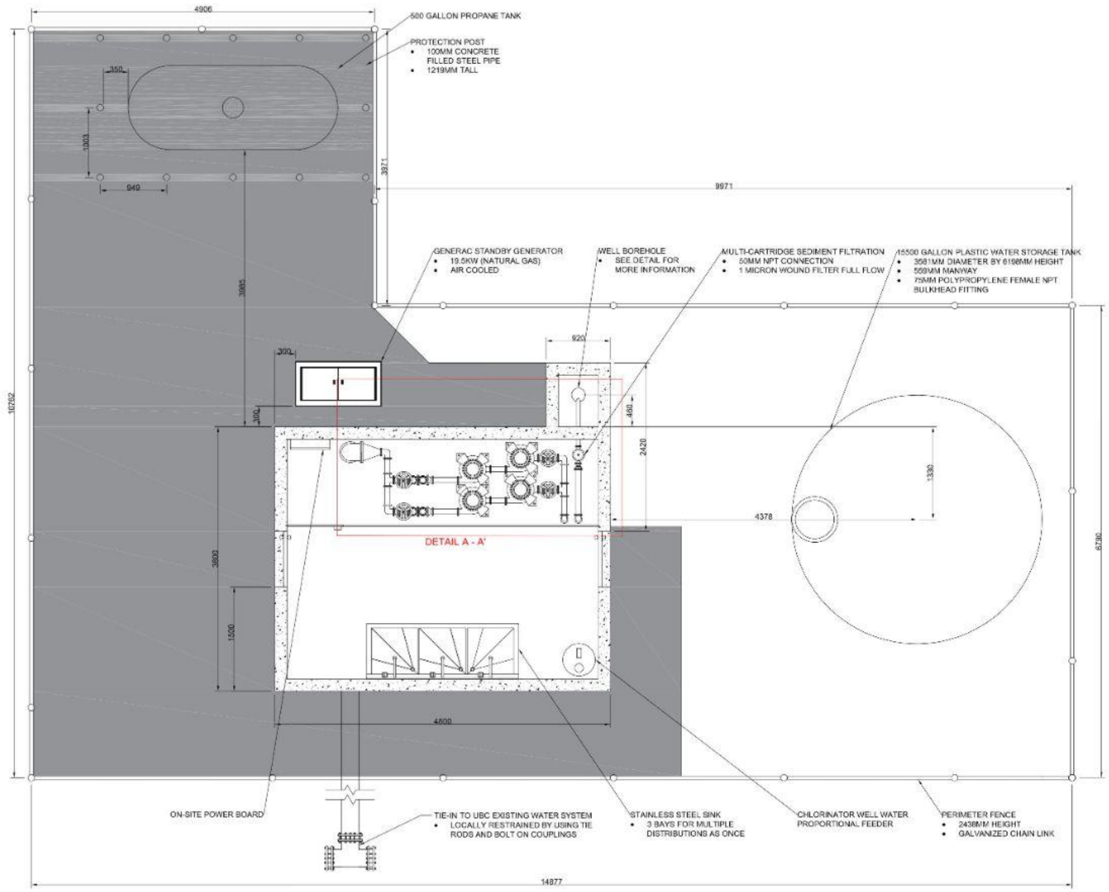
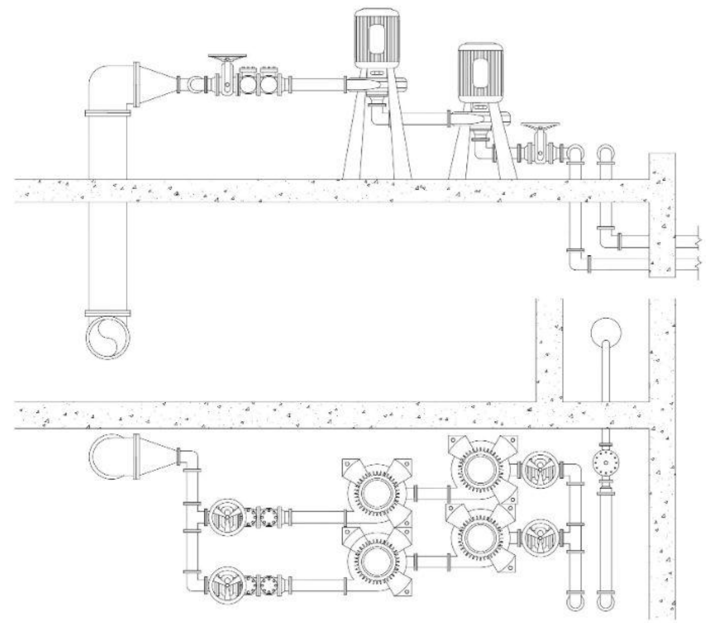
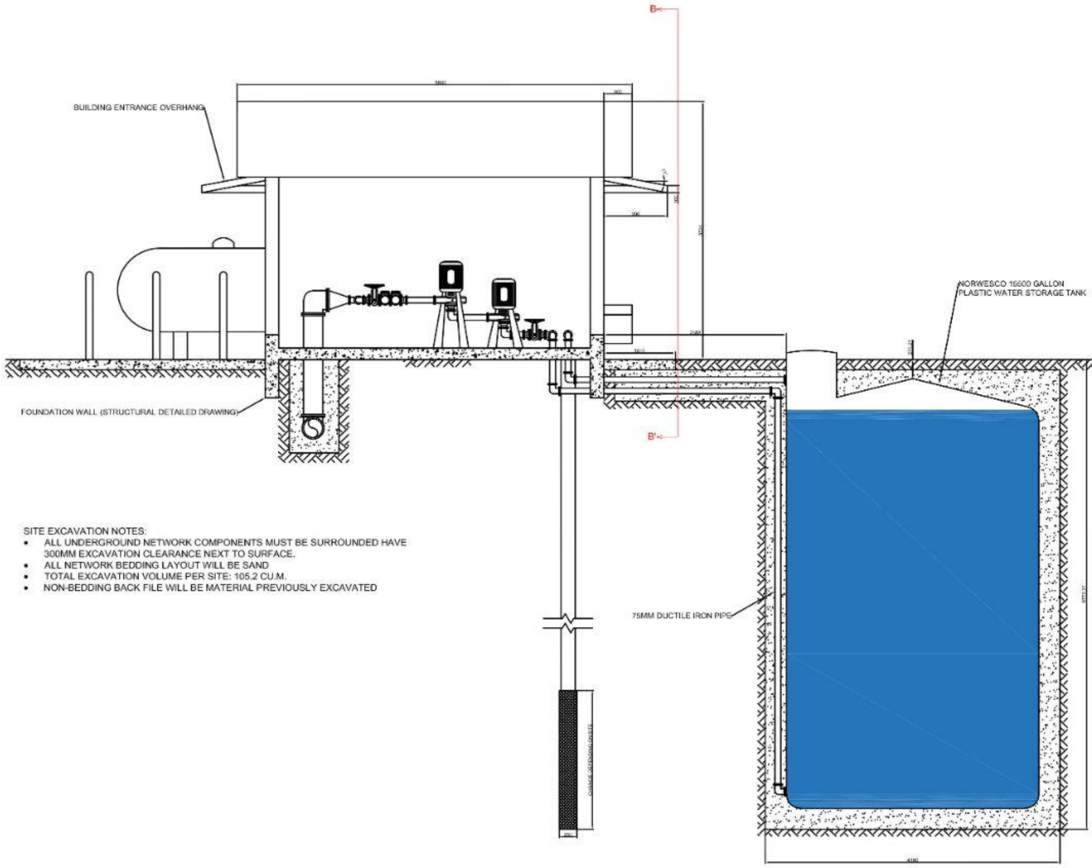




DETAIL A - A'
BOOSTER STATION (SITE 5-6)

PROJECT:	DRAWING NAME:	NOTE:	REV NO.	DATE	Dwg.	Chk.	DESCRIPTION			
UBC GROUNDWATER EMERGENCY WATER SUPPLY	**SITE LAYOUT AND WATER NETWORK FOR SITE 5 - 6**	• UBC CAMPUS UTILITIES PROVIDED BY DR. NAZHAT HAS BEEN EDITED TO DEPICT EACH SITE LOCATION AND SHOW THE PROJECT UTILIZATION IN RELATION TO CAMPUS UTILITIES • GROUP 20 ASSUMES NO RESPONSIBILITY FOR THE CORRECTNESS AND ACCURACY OF ORIGINAL UTILITIES SHOWN • SUB AND SUPER-STRUCTURES MIGHT HAVE BEEN ADDED SINCE DRAWING WAS ESTABLISHED AND PROVIDED • GENERAL LAYOUT OF SITE AND SURROUNDING INFRASTRUCTURE, ONLY USE AS REFERENCE MATERIAL	0	2021-04-03	IS	EH	RECORD DRAWING		DESIGNED: IS	SCALE: N/A
									CHECKED: EH	DATE: 2021-04-03
ISSUED FOR CONSTRUCTION									DRAWN: IS	REV: 0
	DRAWING NUMBER: T20-DWG06							SEAL	APPROVED: EH	SHEET: 6 OF 8

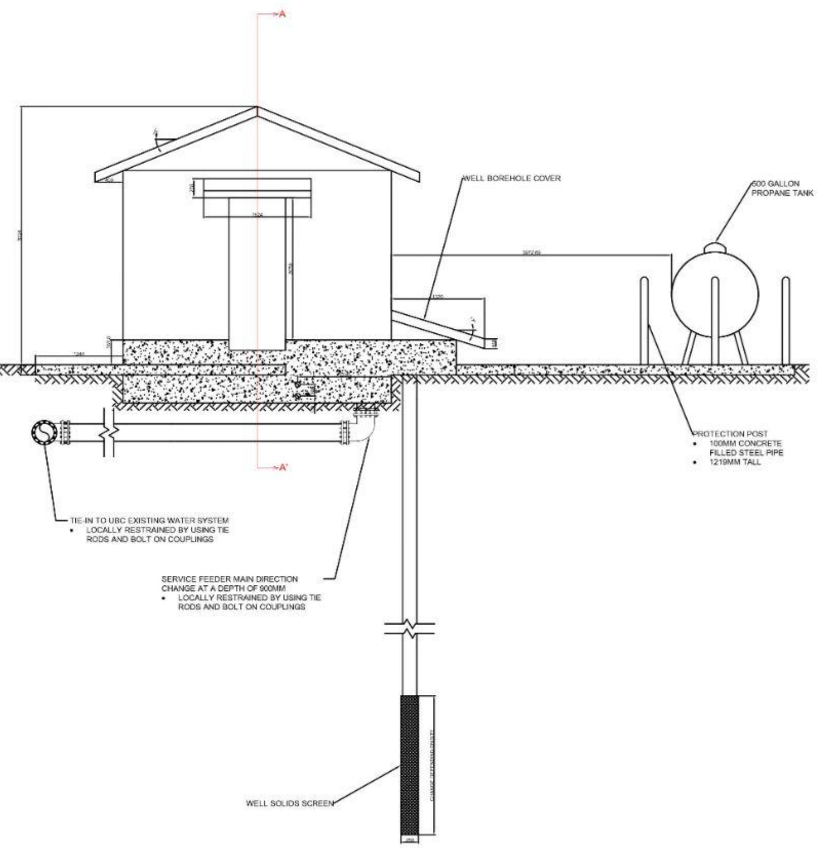
STREET ELEVATION VIEW
(SECTION A - A')



SITE EXCAVATION NOTES:

- ALL UNDERGROUND NETWORK COMPONENTS MUST BE SURROUNDED HAVE 300MM EXCAVATION CLEARANCE NEXT TO SURFACE.
- ALL NETWORK BEDDING LAYOUT WILL BE SAND
- TOTAL EXCAVATION VOLUME PER SITE: 105.2 CU.M.
- NON-BEDDING BACK FILE WILL BE MATERIAL PREVIOUSLY EXCAVATED

SIDE ELEVATION VIEW
(SECTION B - B')



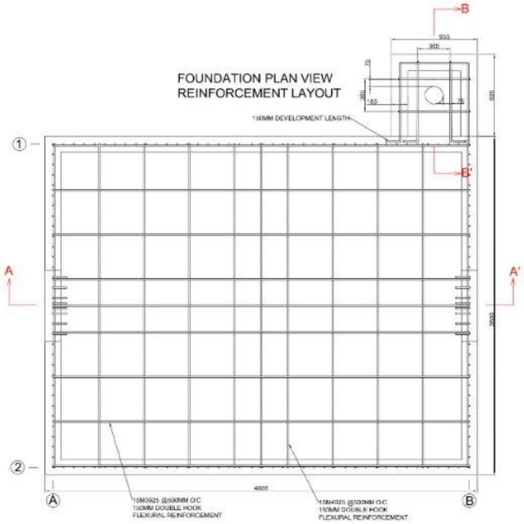
PROJECT:	DRAWING NAME:	NOTE:
UBC GROUNDWATER EMERGENCY WATER SUPPLY	**SITE ELEVATION**	
ISSUED FOR CONSTRUCTION	DRAWING NUMBER: T20-DWG07	

REV NO.	DATE	Dwg.	Chk.	DESCRIPTION
0	2021-04-08	IS	EH	RECORD DRAWING

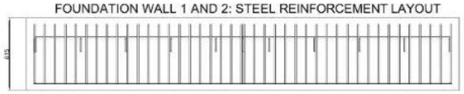
SEAL

DESIGNED: IS	SCALE: SEE DWG
CHECKED: EH	DATE: 2021-04-08
DRAWN: IS	REV: 0
APPROVED: EH	SHEET: 7 of 8

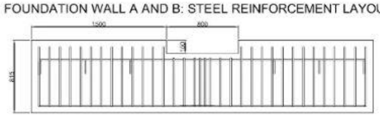
FOUNDATION PLAN VIEW
REINFORCEMENT LAYOUT



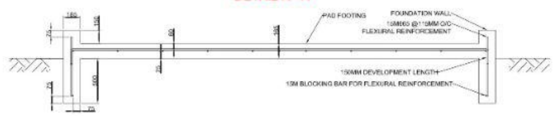
FOUNDATION WALL 1 AND 2: STEEL REINFORCEMENT LAYOUT



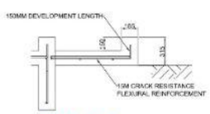
FOUNDATION WALL A AND B: STEEL REINFORCEMENT LAYOUT



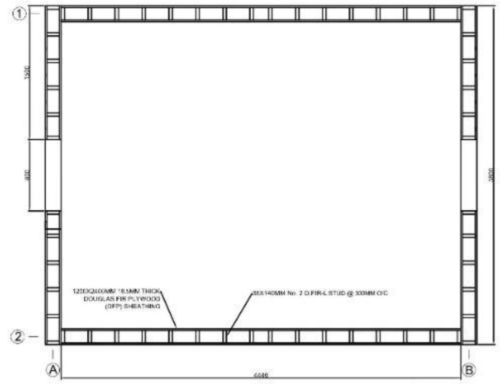
DETAIL A - A'



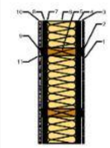
CONCRETE REINFORCEMENT AND FOUNDATION NOTES:
- SPECIFIC STEEL REINFORCEMENT YIELD STRENGTH: 400MPA
- 15M IS THE ONLY BAR SIZE USED IN CONSTRUCTION
- TOTAL LENGTH OF REINFORCEMENT FOUNDATION: 213M
- SPECIFIC CONCRETE STRENGTH: 25MPA
- TOTAL VOLUME OF CONCRETE PER STRUCTURE: 5.27CU.M.
- TOTAL VOLUME OF CONCRETE PER SITE: 10.83CU.M.



DETAIL B - B'



PROPOSED WALL ASSEMBLY

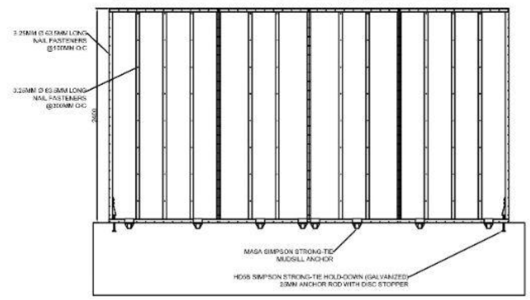


LEGEND
1. 8MM HARDIE PLANK CLADDING
2. 7.5MM D.FIR-L STRAPPING, AIR GAP IN THE ASSEMBLY
3. ASPHALT-SATURATED HEAVY FELT MOISTURE BARRIER
4. 1200X2400MM 18.5MM D.FIR-L 6PLY SHEATHING PANEL
5. 38X140MM NO. 2 D.FIR-L STUDS SPACED 300MM ON CENTER
6. 140MM FIBERGLASS BATTS INSULATION
7. 0.15MM POLYETHYLENE VAPOUR BARRIER
8. 1200X2400MM 18.5MM D.FIR-L 6PLY SHEATHING PANEL
9. 7.5MM D.FIR-L STRAPPING, AIR GAP IN THE ASSEMBLY
10. 1200X2400MM 12MM LIGHT-WEIGHT GYPSUM PANEL
11. INTERIOR FINISHING PAINT

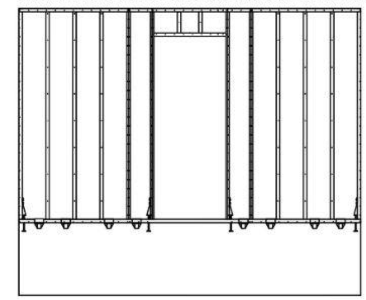
CONSULT BUILDING ENCLOSURE ENGINEER TO CONFIRM ASSEMBLY

SCALE: NTS

SHEARWALL 1 AND 2 LATERAL REINFORCEMENT LAYOUT



SHEARWALL A AND B LATERAL REINFORCEMENT LAYOUT



SHEARWALL AND LATERAL REINFORCEMENT NOTES:
- SHEATHING FASTENERS ALONG EDGE OF PANEL ARE SPACED 100MM O/C WHILE IN PANEL FASTENERS ARE SPACES 300MM O/C
- BLOCKING REQUIREMENTS PER WALL: 8 SIMPSON STRONG-TIE (MODEL: MASA)
- HOLD-DOWN REQUIREMENTS WALL: 1 SIMPSON STRONG-TIE (MODEL: HD5B) PER CHORD STUD
- WALLS DOUBLE SHEATHED (PANEL ON EACH SIDE OF STUD) TO PROVIDE BUCKLING STABILITY
- TOTAL NUMBER OF D.FIR-L STUDS PER STRUCTURE: 56
- TOTAL D.FIR-L PLYWOOD PANEL AREA PER STRUCTURE: 72.18 SQ.M.

PROJECT:
UBC GROUNDWATER EMERGENCY WATER SUPPLY

ISSUED FOR CONSTRUCTION

DRAWING NAME:
REINFORCEMENT DETAILS SUPER AND SUB-STRUCTURE

DRAWING NUMBER: T20-DWG08

NOTES:

REV NO.	DATE	Dwg.	Chk.	DESCRIPTION
0	2021-04-07	IS	AH	RECORD DRAWING
1	2021-04-08	EH	EH	EDITS AND ADDITIONAL NOTES

SEAL

DESIGNED: IS	SCALE: SEE DWG
CHECKED: EH	DATE: 2021-04-08
DRAWN: IS	REV: 1
APPROVED: EH	SHEET: 8 of 8

Appendix B - Structural Design of Site Components

Unfactored Design Loading

Roof Dead Load: 586Pa ~ 0.65kPa

Asphalt Shingles	120/cos(18)=126Pa
18.5mm D.Fir-L Sheathing	92/cos(18)=105Pa
38x140mm D.Fir-L Truss (300mm Space)	2.5*(90)=225Pa
150mm Fiberglass Batts Insulation	150*(0.2)=30Pa
12mm Gypsum Panel	100Pa

*CSA O86-14 Table 11.25-11.27

Wall Dead Load: 540Pa ~ 0.55kPa

8mm Hardie Plank Cladding (150mm space)	135Pa
18.5mm D.Fir-L Sheathing	2*(18.5)(5)=185Pa
38x140mm D.Fir-L Stud (300mm Spacing)	135Pa
140mm Fiberglass Batts Insulation	150*(0.2)=30Pa
12mm Gypsum Pane	100Pa

*CSA O86-14 Table 11.25-11.27

Roof Live Load: 1.0 kPa
*NBCC Table 4.1.5.3

Floor Live Load: 3.6 kPa
*NBCC Table 4.1.5.3

Snow Load: 2.2 kPa

$S = I_s[S_S(C_b C_w C_s C_a) + S_r]$	NBCC Clause 4.1.6.2
Importance Factor, I_s = 1.25	NBCC Clause 4.1.6.2-A
1in50 year ground snow load, S_S=1.9kPa	BCBC Div. B A.C Table C-2
1in50 year associated rain load, S_r=0.3kPa	BCBC Div. B A.C Table C-2
Wind Exposure, C_w = 1.0	NBCC Clause 4.1.6.2
Basic Roof Snow Load Factor, C_p=0.8	NBCC Clause 4.1.6.2
Slope Factor, C_s=1.0	NBCC Clause 4.1.6.2
Accumulation Factor, C_a=1.0	NBCC Clause 4.1.6.5

Wind Load: +0.45kPA or -0.32kPa

$W = I_w q C_e C_t C_g C_p$	NBCC Clause 4.1.7.3
Importance Factor, I_w = 1.25	NBCC Clause 4.1.7.3
Reference Velocity Pressure, q=0.45kPA	BCBC Div. B A.C Table C-2
Exposure Factor, C_e = 0.7	NBCC Clause 4.1.7.3
Topography Factor, C_t=1.0	NBCC Clause 4.1.7.4
Gust Effect & External Pressure, $C_g C_p$	NBCC Clause 4.1.7.6

- Positive Pressure, $C_g C_p$ = 1.15
- Negative Pressure, $C_g C_p$ = -0.8

Earthquake Load: 38.18kN

$V = I_E F_s S(T_s) W_t / (R_s)$	NBCC Clause 4.1.8.1
Importance Factor, I_s = 1.5	NBCC Clause 4.1.6.2-A
Total Weight, $W_t = 25\%S + DL$= 49.97kN	
Site Coefficient, F_s=1.6	NBCC Clause 4.1.8.1(2)
Seismic Force Resistant, R_s=1.5	NBCC Clause 4.1.8.1(7)
Fundamental Lateral Period, T_s=1	NBCC Clause 4.1.8.1(7)
Spectral Acceleration, $S(T_s)$=0.441	NBCC SHV

Vertical Stability of Light-Frame Timber

Determine Compression Resistance of Single Stud:

Compression Resistance, $P_r = \phi F_c A_g K_{zc-d} K_{c-d}$	CSA O86 Clause 6.5.6.2.4
Compressive Strength, $F_c = f_c(K_D K_H K_{Sc} K_T) = 10.6MPa$	
Specific Strength, $f_c = 14MPa$	CSA O86 Table 6.3.1A
Load Duration Factor, $K_D = 1.0$	CSA O86 Table 5.3.2.2
System Factor, $K_H = 1.1$	CSA O86 Table 6.4.4
Service Condition Factor, $K_{Sc} = 0.69$	CSA O86 Table 6.4.3
Gross Area, $A_g = b * d = 5320mm^2$	

Size Factor, $K_{zc-d} = 6.3(dL)^{-0.13} < 1.3 = 1.205$

Slenderness Factor, $K_{c-d} = [1 + \frac{F_C K_{zc-d} C_C^{\ 3}}{35 E_{05} K_{SE} K_T}]^{-1} = 0.781$ CSA O86 Clause 6.5.6.2.4

$E_{05} = 7000MPa$ CSA O86 Clause 6.3.1A

$K_{SE} = 0.94$ CSA O86 Table 6.4.2

Slenderness Ratio, $C_C = \frac{Effective\ Length}{d} = 17.14$ CSA O86 Clause 6.5.6.2.2

Compression Resistance, $P_r = 0.8(10.6)(5320)(1.205)(0.781) = 42.6N$

Compression Resistance per Meter of Wall, $P_r/m = 42.5kN(\frac{1000mm}{300mm}) = 142kN/m$

Shearwall Section 1 & 2:

<u>Ultimate Limit State Load</u> CSA O86 Table 5.2.4.1

Case 1: 1.4D = 17.3kN

Case 2: 1.25D+1.5L+1.0S = 50.4kN

Case 3: 1.25D+1.5S+1.0L = 56.4kN

Case 4: 1.25D+1.4W+0.5S = 33.3kN

Critical Case:

$P_f/m = 56.4kN/4.8m = 11.7kN/m < P_r/m = 14$

Shearwall Section A & B: (Critical Load)

<u>Ultimate Limit State Load</u> CSA O86 Table 5.2.4.1

Case 1: 1.4D = 10.3kN

Case 2: 1.25D+1.5L+1.0S = 22.8kN

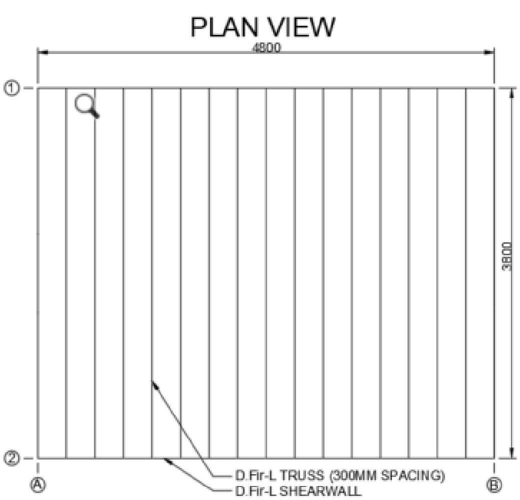
Case 3: 1.25D+1.5S+1.0L = 25.1kN

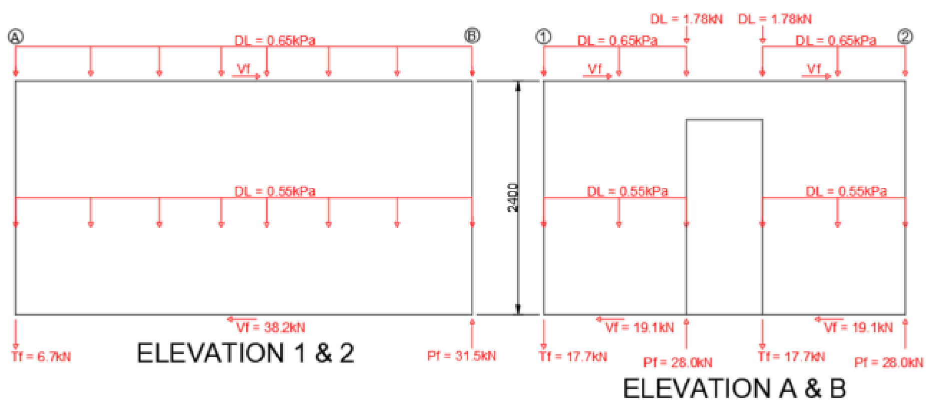
Case 4: 1.25D+1.4W+0.5S = 19.1kN

Critical Case:

$P_f/m = 25.1kN/4.8m = 5.2kN/m < P_r/m = 142$

Lateral Stability for Light-Frame Timber





<u>Determine the Maximum Lateral Load and Chord Loads on Structure:</u>

Factored Earthquake Load, 1.0E = 1.0(38.18kN) = 38.18kN

Factored Wind Load, 1.4W = 1.4(Largest Area)(+W & -W) = 1.4(4.8m)(2.4m)(0.45kPa+0.32kPa) = 12.4kN

Shearwall Section 1 & 2:

Tension Chord Load, $T_f = \frac{V_{fs}*H}{h} - 0.9 * DL = 6.7kN$ Compression Chord Load, $T_f = \frac{V_{fs}*H}{h} + 1.25 * DL = 31.4kN$

Shearwall Section A & B:

Tension Chord Load, $T_f = \frac{V_{fs}*H}{h} - 0.9 * DL = 17.7kN$ Compression Chord Load,

$T_f = \frac{V_{fs}*H}{h} + 1.25 * DL = 28.0kN$

*Section A & B are identical with two Identical shearwall segments that equally carry the lateral loads

Determine Sheathing Buckling Capacity of Shearwall:

Shear Buckling Resistance, $V_{rs} = \phi v_{pd} K_D K_s K_T L_s$ CSA O86 Clause 11.5.1.2

Load Duration Factor, $K_D = 1.15$ CSA O86 Clause 5.3.2.2

Service Condition Factor, $K_S = 0.85$ CSA O86 Clause 9.4.2

Treatment Factor, $K_T = 1.0$ CSA O86 Clause 9.4.3

Panel Buckling Strength, $v_{pb} = K_{pb} \frac{\pi^2 t^2}{3000*b} (B_{a,o} B_{a,90})^{1/4} = 81.00$

Panel Buckling Factor, $K_{pd} = 1.7(\eta + 1)exp(\frac{-\alpha}{0.05\eta+0.75}) + (0.5\eta + 0.8) = 1.11$

$\alpha = \frac{a}{b} (\frac{B_{a.90}}{B_{a,0}})^{1/4} = 1.78$

$\eta = \frac{2B_v}{\sqrt{B_{a,0} B_{a,90}}} = 0.22$

$B_{a,0} = 110000N/mm$ $B_{a,90} = 69000N/mm$ $B_v = 4600N/mm$ CSA O86 Table 9.3A

Shearwall Section 1 & 2:

Shear Buckling Resistance, $V_{rs} = 0.8(81)(1.15)(0.85)(1.0)(4.8) = 304kN > 38.2kN$

Shearwall Section A & B:

Shear Buckling Resistance, $V_{rs} = 0.8(81)(1.15)(0.85)(1.0)(1.5) = 95kN > 19.1kN$

Determine Sheathing-To-Frame Capacity of Shearwall:

Shear Sheathing-to-Frame Resistance, $V_{rs} = \phi v_d J_D n_s J_{us} J_s J_{hd} L_s$ CSA O86 Clause 11.5.1.2

$v_d = N_u/s = 6.53N/mm$ - Lateral strength resistance divided by fastener spacing (s = 100mm)

Shearwall Factor, $J_D = 1.3$ CSA O86 Clause 12.9.4.1

Number of Shear Plans, $n_s = 2$

Fastener Spacing Factor, $J_s = 1 - (\frac{150-s}{150})^{4.2} = 0.9901$ CSA O86 Clause 11.4.1

Unblocked Factor, $J_{us} = 1.0$ CSA O86 Clause 11.4.4

Hold-Down Factor, $J_{hd} = 1.0$ CSA O86 Clause 11.4.5

Lateral Strength Resistance, $N_u = n_u * (K_D K_{SF} K_T) = 653.2N$ CSA O86 Clause 12.9.4.1

Service Condition Factor, $K_{SF} = 0.67$ CSA O86 Clause 12.2.1.6

Johanson Model, $n_u = Min(a, b, d, e, f, g) = 847N$

$t_1 = 18.5mm$ $t_2 = 45mm$

$f_y = 50(16 - d_F) = 637.5MPa$

$f_1 = 51(1 - 0.1d_F) = 34MPa$

$f_2 = 50G(1 - 0.01d_F) = 23.7MPa$ $G = 0.49$ CSA O86 Table A.12.1

Shearwall Section 1 & 2:
Shear Sheathing-to-Frame Resistance,
$V_{rs} = 0.8(6.53)(1.3)(2)(1.0)(1.0)(1.0)(4.8) = 64.6kN > 38.2kN$
Shearwall Section A & B:
Shear Sheathing-to-Frame Resistance,
$V_{rs} = 0.8(6.53)(1.3)(2)(1.0)(1.0)(1.0)(1.5) = 20.2kN > 19.1kN$

Determine Chord Stud Requirements:

The compression resistance of a single stud was determined in the "Vertical Stability of Light-Frame Wood Wall'' portion of the sample calculations. However, due to lateral loading being a different loading case than vertical, parameters in the calculation have changed. These changes are seen below.

Compression Resistance, $P_r = \phi F_c A_g K_{zc-d} K_{c-d}$ CSA O86 Clause 6.5.6.2.4

Compressive Strength, $F_c = f_c(K_D K_H K_{Sc} K_T) = 12.2MPa$

Load Duration Factor, $K_D = 1.15$ CSA O86 Clause 5.3.2.2

Slenderness Factor, $K_{c-d} = [1 + \frac{F_c K_{zc-d} C_c^{3}}{35E_{05} K_{SE} K_T}]^{-1} = 0.756$ CSA O86 Clause 6.5.6.2.4

Compression Resistance, $P_r = 0.8(12.2)(5320)(1.205)(0.756) = 47.4kN$

Shearwall Section 1 & 2:
Compression Resistance, $P_r = 47.4kN > P_f = 31.5kN$ - Therefore, 1 stud needed
Shearwall Section A & B:
Compression Resistance, $P_r = 47.4kN > P_f = 28.0kN$ - Therefore, 1 stud needed

Determine Lateral Deflection During Earthquake Load:

Deflection, $\Delta_{sw} = \frac{2vH_s}{3EAL_s} + \frac{vH_s}{B_V} + 0.0025H_s e_n + \frac{H_s}{L_s} d_a$ CSA O86 Clause 11.7.1.2

Max Shear due to specified load, $v = 38.2kN/L_s$

Elastic Modulus, $E = 11000MPa$ CSA O86 Clause 6.3.1A

Nail Deformation, $e_n = 2(\frac{0.013vs}{d_f^{2}})^2$ CSA O86 Clause A.11.7

Total Vertical Elongation of Anchorage, $d_a = 0mm$

Shearwall Section 1 & 2:
Deflection, $\Delta_{sw} = 5.44 * 10^{-5} + 4.15 + 11.5 + 0 = 15.6mm$
Shearwall Section A & B:
Deflection, $\Delta_{sw} = 8.67 * 10^{-5} + 5.24 + 18.4 + 0 = 23.6mm$

Determine Blocking Requirements:

Chosen concrete connector/anchor (Blocking) is the Simpson Strong-Ties Model No. MASA, which has a allowable lateral load of 5.5kN per connector that is connected to a 38mm thick stud. Therefore, there is more than one connector needed along each shear wall.

Blocking Anchors Required, # $= V_f/V_r = 38.18kN/5.49kN = 6.95 = 7connectors$

Shearwall Section 1 & 2:

Spacing of Anchors Along Shear Wall, $S = 4800mm/6 = 800mm$

- One at each end, than divide the length of the wall into 6 segments

Shearwall Section A & B:

Spacing of Anchors Along Shear Wall, $S = 1500mm/3 = 500mm$

- One at each end, than divide the length of the wall into 3 segments

Determine Hold-Down Requirements:

Chosen Hold-Down is the Simpson Strong-Ties Model No. HD5B, which has a allowable tension loading of 10.7kN per hold-down that is connected to a 38mm thick stud. Hold-down connections in shearwall section 1 & 2 will have one placed at each chord. Hold-down connections in shearwall section A & B will have two placed at each chord.

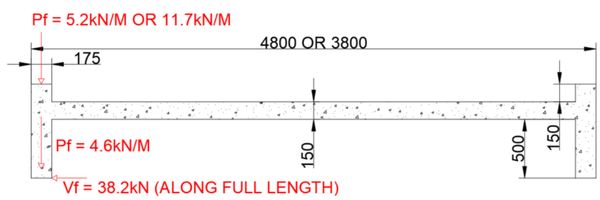
Shearwall Section 1 & 2:

Hold-down Resistance, $Tr = 10.9kN > 1.2T_f = 1.2(6.7) = 8.04kN$ CSA O86 Clause 11.8.2

Shearwall Section A & B:

Hold-down Resistance, $Tr = 2 * 10.9kN = 21.8kN > 1.2T_f = 1.2(17.7) = 21.24kN$ CSA O86 Clause 11.8.2

Super-structure Foundation



Determine Loading on the Footing

Shearwall Section 1 & 2:

Shear Load, $V_f = 38.2kN/4.8m = 7.96kN/m$ Bending Moment, $M_f = V_f D = 3.98kNm/m$

Bearing Load, $B_f = [DL(structure) + DL(Footing)]/(width\ of\ footing) = 56.0kPa$

Shearwall Section A & B:

Shear Load, $V_f = 38.2kN/3.8m = 10.05kN/m$ Bending Moment, $M_f = V_f D = 5.02kNm/m$

Bearing Load, $B_f = [DL(structure) + DL(Footing)]/(width\ of\ footing) = 93.2kPa$

Analysis/Design of Footing Wall

Assumed Parameters: $f'_c = 25MPa$ $f_y = 400MPa$ $d_{Bar} = 15mm$ $Concrete\ Cover = 75mm$

Minimum Wall Thickness, $t = 165mm$ Use Thickness, $t = 175mm$

Minimum Steel, $A_s = 1\%A_g = 1750mm^2$ CSA A23.3 Clause 10.9.1

Minimum Bar Spacing, $s = 1000/(A_s/A_{Bar}) = 115mm\ (o/c)$

Moment Resistance, $M_r = \phi_s f_y A_s (d - \frac{\phi_s f_y A_s}{2\alpha_1 \phi_c f_c b}) = 38.6kNm\ per\ m$ CSA A23.3 Clause 10.1.7

$\alpha_1 = 0.85 - 0.0015f'_c$ CSA A23.3 Clause 10.1.7

Effective Depth, $d = 175/2 = 87.5mm$ $\phi_s = 0.85$ $\phi_c = 0.65$

Shear Resistance, $V_R = V_C = \phi_C \lambda \beta \sqrt{f_C} b_w d_v = 53.8 kN\ per\ m$ CSA A23.3 Clause 11.3.4

$\beta = 0.21$ ("Slab" Thickness <350mm) CSA A23.3 Clause 11.3.6.2

Shear Depth, $d_V = 0.9d = 78.75mm$ $\lambda = 1.0$ $b_w = 1000mm$

Bearing Resistance of Soil, $B_r = \sigma'_D N_q + 0.5\gamma' B N_\gamma = 464.5kPa$ Coduto Eqn.15.5

Bearing Capacity Factors, $\theta = 35^o$ $N_q = 41.4$ $N_\gamma = 47.3$ Terzaghi Chapter 8

Effective Unit Weight, $\gamma' = 18.7kPa$ (soil description: clay/silty sand)

Strip Footing Width, $B = 0.175m$

Analysis/Design of Pad Footing (Floor Slab)

- Cover exposed to Earth: 75mm
- Cover Exposed to Air: 60mm
- Using 15M Bars
- No temperature or shrinkage reinforcement required
- Forces transfer directly into soil, no bending moment or shear is carried in slab

Minimum Slab Thickness, $h_S = \frac{L_n(0.6+f_y/1000)}{30} = 160mm$ CSA A23.3 Clause 13.2.3

Clear Span, c

Minimum Slab Thickness for Appropriate Cover, $H_S = 75 + 2 * 15 + 60 = 175mm$

Minimum Steel, $A_S = 0.2\% A_g = 0.002(175)(1000) = 350mm^2$ CSA A23.3 Clause 7.8.1

Minimum Bar Spacing, $s = \frac{1000mm}{A_S/A_b} = 571mm$

Maximum Bar Spacing, $s = min(3t,\ 500mm) = 500mm\ (o/c)$ CSA A23.3 Clause 7.4.1.2

Soil Bearing Capacity Under Storage Tank

Bearing Load of Largest Storage Tank, $B_f = 1.4[(58.673m^3) * (9810N/m^3)]/(\frac{\pi}{4}(3.581m)^2) = 80.0kPa$

Bearing Resistance of Soil, $B_r = \sigma'_D N_q + 0.3\gamma' B N_\gamma = 252.6kPa$ Coduto Eqn.15.5

Bearing Capacity Factors, $\theta = 7^o$ $N_q = 2.0$ $N_\gamma = 0.6$ Terzaghi Chapter 8

Effective Unit Weight, $\gamma' = 21kPa$ (soil description: Glacial Till)

Strip Footing Width, $B = 3.581m$

Structural Analysis Capacity and Loading Summary

Shearwalls	Shearwall 1 & 2	Shearwall A & B

Compression Capacity	$P_f = 11.7kN/m$	$P_r = 142kN/m$	$P_f = 5.2kN/m$	$P_r = 142kN/m$
Chord Load	$T_f = 6.7kN$	$P_f = 31.4kN$	$T_f = 17.7kN$	$P_f = 28.0kN$
Chord Stud($P_r = 47.4kN$)	$1\ stud$		$1\ stud$	
Sheathing Buckling Capacity	$V_f = 38.2kN$	$V_{rs} = 304kN$	$V_f = 19.1kN$	$V_{rs} = 95kN$
Sheathing-to-Frame Capacity	$V_f = 38.2kN$	$V_{rs} = 64.6kN$	$V_f = 19.1kN$	$V_{rs} = 20.2kN$
Lateral Deflection	$\Delta_{sw} = 15.6mm$		$\Delta_{sw} = 23.6mm$	
Blocking Requirements	$7\ Connectors,\ Spacing = 800mm$		$4\ Connectors,\ Spacing = 500mm$	
Hold-Down Requirements	$T_f = 21.24kN$	$T_r = 21.8kN$	$T_f = 8.04kN$	$T_r = 10.9kN$
Foundation Wall				
Foundation Wall Thickness	$175mm$			
15M Bars Spacing	$115mm\ (o/c)$			
Concrete Moment Resistance	$M_f = 3.98kNm/$	$M_R = 38.6kNm/$	$M_f = 5.02kNm/$	$M_R = 38.6kNm/$
Concrete Shear Resistance	$V_f = 7.96kN/m$	$V_R = 53.8kN/m$	$V_f = 10.05kN/m$	$V_R = 53.8kN/m$
Soil Bearing Resistance	$B_f = 56.0kPa$	$B_R = 464.5kPa$	$B_f = 93.2kPa$	$B_R = 464.5kPa$
Pad Footing (Floor Slab)				
Slab Thickness	$160mm$			
15M Bars Spacing	$480mm\ (o/c)\quad (Both\ Directions)$			
Storage Tank Bearing Load				
Soil Capacity	$B_f = 80.0kPa$		$B_R = 252.6kPa$	

Appendix C: Hydrotechnical and Geotechnical Analysis

Groundwater Replenish Rate Analysis

Assumed site well seepage was determined using the findings of Linghui Liu, Mingfeng Lei, Chengyong Cao, and Chenghua Shi on "*Dewatering Characteristics and Inflow Prediction of Deep Foundations Pits with Partial Penetrating Curtains in Sand and Gravel Strats*". Who were discussed prior in the preliminary design report, see that report for reference details.

Assumptions taken:

- Continuous soil characteristics across the whole influenced area of the aquifer
- Replenish rate stays constant the whole time of emergency
- For safety purposes and judgment error, drawdown is only 50% of the total depth

Here is an example calculation for Site 1:

Population Demand (P)	11713	**Drawdown (s)**	5.135m
Hydraulic Conductivity (k)	0.0001m/s	**Radius of Influence (R)**	151m
Total Depth of Aquifer (M)	10.27m	**Radius of Well (r)**	0.1m

Radius of Influence, $R = 10s\sqrt{k * 3600 * 24} = 151m$

Groundwater Replenishment Rate, $Q_T = \frac{2\pi kMs}{ln(R/r)} = 0.0045m^3/s = 4.45L/s$

Site Consumption, Non-Revenue Water, Well Withdraw Rate Demand

Due to the uncertainty of the soil characteristics, we determined the allowable water seepage we can assume will be equal to that of the Base Daily Demand plus Non-Revenue Water (NRW) under 30psi. The sample calculations for BDD pertain to Site 1 and the non-revenue water (system leakage) calculations are for Epanet Model 1 (site 1&2).

Base Daily Demand, $BDD = P * 10L/day = (11713) * 10L/day = 1.36L/s$

Non-Revenue Water (NRW), $NRW(L/s) = 5 * (0.4704 * L_m + 0.0303 * N_c + 0.8 * L_c) * (\frac{P}{49.26})^{1.5} = 0.109L/s$

Total Length of Watermains, $L_m = 3.924km$

Total Number of Service Connections, $Nc = 38$

Total Length of Service Connections, $L_C = 0.76km$

System Pressure, $P = 30psi$

Well Withdraw Rate (WWR), $WWR = BDD + NRW = 1.469L/s$

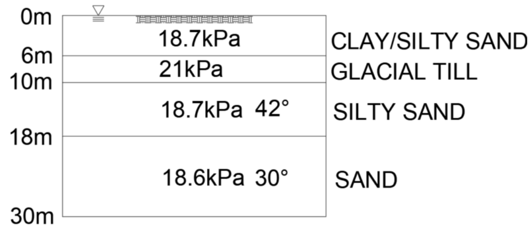
- The required well withdrawal rate is 33% of the well replenishment rate, this provides substantial contingency for climate change and seasonal fluctuations in water table levels.

Liquefaction Assessment

The data for the following analysis was provided by Piteau and Associates, and the assessment is conducted on borehole THo1-02.

- Max Assessment Depth = 30m

- Assume fully saturated soil for worst case scenario



Vertical Effective Stress at 30m,

$\sigma'_{vo} = (6)(18.7) + (4)(21) + (8)(18.7) + (12)(18.6) - (9.81)(30) = 274.7kPa$

Cyclic Shear Stress Ratio, $CSR = 0.65 * r_d(\frac{\sigma_{vo}}{\sigma'_{vo}})(\frac{a_m}{g}) = 0.65(0.61)(\frac{569}{274.7})(0.45) = 0.3696$

$r_d = 1 - 0.015(30m - 4m) = 0.61 > 0.6$

$a_m = 0.45g$

$\sigma_{vo} = 569kPa$

Cyclic Resistance Ratio, $CRR = 8.33(\frac{(N_1)_{60}}{Pa}) + 0.05 = 0.1179$

Kulhawy (1990)

$Pa = 100kPa$

Critical Cyclic Resistance Ratio, $CRR_{crit.} = k_m k_\alpha k_\sigma CRR$

Assume 8.0 Magnitude Earthquake

$k_m = (\frac{8.0}{7.5})^{-2.56} = 0.848$

$k_\alpha = 1.0$ - Assume relatively flat ground

$k_\sigma = (\frac{\sigma'_{vo}}{100})^{F-1} = 0.815$

$F = 1 - 0.005D_r = 0.798$

$D_r = \sqrt{\frac{(N_1)_{60}}{17+24(\frac{\sigma'_{vo}}{Pa})}} = 0.404$

$(N_1)_{60} = \sqrt{\frac{Pa}{\sigma'_{vo}}}N_{60} = 8.15kPa$

$N_{60} = (12.2 + 20.3(\frac{\sigma'_{vo}}{Pa}))Tan(\sqrt[0.34]{\phi}) = 13.51kPa$

$\phi = 30degrees$

Factor of Safety, $FOS = \frac{CRR_{Crit.}}{CSR} = 0.22 < 1.0$

- Extremely prone to liquefaction

Appendix D: Site Consumption and Supply Analysis

Consumption Analysis Summary Table

	Site 1: Northwest Campus Well	Site 2: Northeast Campus Well	Site 3: Southwest Campus Well	Site 4: Southeast Campus Well	Site 5: Central Campus Hospital	Site 6: Central Campus Residential
Population Associated With Site	11,713	11,613	12,706	7,787	0	3,576
Number of Hospital Beds	0	0	0	0	332	0
Average Hourly Demand (L/hr)	5,080	5,149	5,494	3,725	7,763	4,501
Volume in Tanks Required (L)	58,673	58,673	58,673	58,673	58,673	58,673
Well Replenish Rate at 50% Depth (L/hr)	16,333	12,388	16,126	16,126	20,425	20,425
Well Withdraw Rate (L/hr)	4,850	4,920	5,280	3,430	7,720	4,200
Well Withdraw Rate (US GPM)	21.35	21.66	23.25	15.10	33.99	18.49
Well Pump Pressure Head (m)	84.87	93.87	91.87	90.87	95.87	101.87
Well Pump Efficiency (%)	56.9	58.7	57.6	56.9	69.8	62.5
Designed Demand						
Daily Consumption (L/Cap)	10	10	10	10	561	10
Total 5-day Site Consumption (L)	609,650	617,850	659,300	446,950	931,507	540,077
Base Daily Demand (L/s)	1.41	1.43	1.53	1.03	2.16	1.25
Peak Hourly Demand (L/s)	2.87	2.88	3.11	2.01	3.98	1.87
Total 5-day Well Withdrawal Volume (L)	582,000	585,480	628,320	408,170	931,507	499,800
Minimum Volume in Tank (L)	10,385	10,764	10,299	10,734	10,319	11,072
Maximum Allowable Demand						
Daily Consumption (L/Cap)	10.16	10.17	10.15	10.25	567.00	10.58
Total 5-day Site Consumption (L)	619,020	627,721	668,830	456,684	941,220	550,447
Base Daily Demand (L/s)	1.43	1.45	1.55	1.06	2.18	1.27
Peak Hourly Demand (L/s)	2.92	2.92	3.15	2.05	4.03	1.91
Total 5-day Well Withdrawal Volume (L)	582,000	585,480	628,320	408,170	931,507	499,800
Minimum Volume in Tank (L)	1,280	1,172	1,039	1,275	1,282	1,123
Total 5-day Allowable Demand Float (L)	37,020	42,241	40,510	48,514	9,713	50,647

Total Allowable Demand Float (%)	6.36%	7.21%	6.45%	11.89%	1.04%	10.13%

Site and Soil Characteristics for Piteau Hydrogeological Study

Site 1: Northwest Campus Well		Site 2: Northeast Campus Well	
Elevation of Water Table (m-asl)	4.4	Elevation of Water Table (m-asl)	6.65
Elevation of Aquiclude (m-asl)	-5.87	Elevation of Aquiclude (m-asl)	-5.87
Elevation of Ground Surface (m-asl)	79	Elevation of Ground Surface (m-asl)	88
Porosity (n)	0.36	Porosity (n)	0.38
Hydraulic Conductivity (m/s)	0.0001	Hydraulic Conductivity (m/s)	0.00005
Diameter of Well (m)	0.2	Diameter of Well (m)	0.2
Radius of Well (m)	0.1	Radius of Well (m)	0.1
Drawdown(m)	5.135	Drawdown(m)	6.26
Radius of Influence (m)	150.94	Radius of Influence (m)	130.11
Inflow (m^3/s)	0.0045	Inflow (m^3/s)	0.0034
Inflow (L/hr)	16333	Inflow (L/hr)	12,388
Site 3: Southwest Campus Well		**Site 4: Southeast Campus Well**	
Elevation of Water Table (m-asl)	4.33	Elevation of Water Table (m-asl)	4.33
Elevation of Aquiclude (m-asl)	-5.87	Elevation of Aquiclude (m-asl)	-5.87
Elevation of Ground Surface (m-asl)	86	Elevation of Ground Surface (m-asl)	85
Porosity (n)	0.35	Porosity (n)	0.345
Hydraulic Conductivity (m/s)	0.0001	Hydraulic Conductivity (m/s)	0.0001
Diameter of Well (m)	0.2	Diameter of Well (m)	0.20
Radius of Well (m)	0.1	Radius of Well (m)	0.10
Drawdown(m)	5.1	Drawdown(m)	5.1
Radius of Influence (m)	149.91	Radius of Influence (m)	149.91
Inflow (m^3/s)	0.0045	Inflow (m^3/s)	0.0045
Inflow (L/hr)	16126	Inflow (L/hr)	16126
Site 5: Central Campus Hospital		**Site 6: Central Campus Residential**	
Elevation of Water Table (m-asl)	7.5	Elevation of Water Table (m-asl)	7.50
Elevation of Aquiclude (m-asl)	-5.9	Elevation of Aquiclude (m-asl)	-5.87
Elevation of Ground Surface (m-asl)	90.0	Elevation of Ground Surface (m-asl)	96

Porosity (n)	0.3	Porosity (n)	0.35
Hydraulic Conductivity (m/s)	0.000075	Hydraulic Conductivity (m/s)	0.000075
Diameter of Well (m)	0.2	Diameter of Well (m)	0.2
Radius of Well (m)	0.1	Radius of Well (m)	0.1
Drawdown(m)	6.685	Drawdown(m)	6.685
Radius of Influence (m)	170.17	Radius of Influence (m)	170.17
Inflow (m^3/s)	0.0057	Inflow (m^3/s)	0.0057
Inflow (L/hr)	20425	Inflow (L/hr)	20425

Site1, Site 2, and Site 3 Consumption Analysis Data Table

		Site 1: Northwest Campus				Site 2: Northeast Campus				Site 3: Southwest Campus			
		Designed Demand		Maximum Demand		Designed Demand		Maximum Demand		Designed Demand		Maximum Demand	
Time	Hourly Demand	Design Demand (L)	Tank Volume (L)	Max Demand (L)	Tank Volume (L)	Design Demand (L)	Tank Volume (L)	Max Demand (L)	Tank Volume (L)	Design Demand (L)	Tank Volume (L)	Max Demand (L)	Tank Volume (L)
0:00	1.22%	1,629	58,673	1,652	58,673	1,727	58,673	1,751	58,673	1,750	58,673	1,773	58,673
1:00	1.08%	1,465	58,673	1,485	58,673	1,564	58,673	1,586	58,673	1,572	58,673	1,593	58,673
2:00	0.95%	1,313	58,673	1,331	58,673	1,413	58,673	1,432	58,673	1,407	58,673	1,425	58,673
3:00	1.30%	1,723	58,673	1,747	58,673	1,820	58,673	1,845	58,673	1,852	58,673	1,877	58,673
4:00	1.54%	2,004	58,673	2,033	58,673	2,098	58,673	2,129	58,673	2,157	58,673	2,186	58,673
5:00	2.70%	3,363	58,673	3,413	58,673	3,446	58,673	3,499	58,673	3,631	58,673	3,682	58,673
6:00	6.75%	8,106	55,417	8,233	55,290	8,149	55,444	8,282	55,311	8,777	55,176	8,905	55,048
7:00	8.65%	10,332	49,935	10,494	49,646	10,355	50,009	10,526	49,705	11,191	49,266	11,356	48,972
8:00	7.84%	9,383	45,402	9,530	44,966	9,415	45,514	9,569	45,056	10,162	44,384	10,311	43,941
9:00	6.75%	8,106	42,146	8,233	41,584	8,149	42,286	8,282	41,694	8,777	40,888	8,905	40,316
10:00	5.62%	6,783	40,213	6,888	39,546	6,837	40,369	6,947	39,666	7,341	38,827	7,448	38,148
11:00	4.59%	5,576	39,487	5,662	38,733	5,640	39,649	5,731	38,855	6,032	38,075	6,120	37,309
12:00	4.05%	4,944	39,393	5,020	38,564	5,013	39,555	5,093	38,682	5,346	38,009	5,423	37,166
13:00	3.78%	4,628	39,615	4,698	38,715	4,700	39,776	4,774	38,828	5,003	38,286	5,075	37,371
14:00	3.24%	3,995	40,470	4,056	39,510	4,073	40,623	4,137	39,611	4,317	39,249	4,378	38,272
15:00	3.38%	4,159	41,161	4,222	40,137	4,235	41,308	4,302	40,229	4,495	40,035	4,559	38,993
16:00	4.11%	5,014	40,997	5,091	39,896	5,083	41,145	5,164	39,985	5,422	39,893	5,500	38,773
17:00	5.46%	6,595	39,252	6,698	38,049	6,651	39,414	6,758	38,146	7,137	38,035	7,242	36,811
18:00	6.73%	8,083	36,019	8,209	34,690	8,126	36,209	8,258	34,808	8,751	34,564	8,879	33,212
19:00	5.67%	6,841	34,028	6,948	32,592	6,895	34,234	7,007	32,722	7,404	32,440	7,512	30,979
20:00	5.13%	6,209	32,669	6,305	31,137	6,267	32,887	6,369	31,273	6,718	31,001	6,816	29,443
21:00	4.11%	5,014	32,505	5,091	30,896	5,083	32,724	5,164	31,029	5,422	30,859	5,500	29,223
22:00	3.38%	4,159	33,196	4,222	31,524	4,235	33,409	4,302	31,647	4,495	31,645	4,559	29,944
23:00	1.97%	2,507	35,539	2,544	33,829	2,598	35,731	2,637	33,930	2,703	34,222	2,741	32,483
0:00	1.22%	1,629	38,760	1,652	37,028	1,727	38,924	1,751	37,099	1,750	37,751	1,773	35,990
1:00	1.08%	1,465	42,145	1,485	40,392	1,564	42,280	1,586	40,434	1,572	41,459	1,593	39,677
2:00	0.95%	1,313	45,682	1,331	43,912	1,413	45,787	1,432	43,922	1,407	45,332	1,425	43,532
3:00	1.30%	1,723	48,809	1,747	47,015	1,820	48,887	1,845	46,996	1,852	48,760	1,877	46,935
4:00	1.54%	2,004	51,656	2,033	49,832	2,098	51,709	2,129	49,788	2,157	51,884	2,186	50,029
5:00	2.70%	3,363	53,143	3,413	51,269	3,446	53,183	3,499	51,209	3,631	53,533	3,682	51,627
6:00	6.75%	8,106	49,887	8,233	47,886	8,149	49,954	8,282	47,847	8,777	50,036	8,905	48,002
7:00	8.65%	10,332	44,405	10,494	42,242	10,355	44,519	10,526	42,241	11,191	44,126	11,356	41,926
8:00	7.84%	9,383	39,872	9,530	37,562	9,415	40,024	9,569	37,591	10,162	39,244	10,311	36,895
9:00	6.75%	8,106	36,616	8,233	34,180	8,149	36,796	8,282	34,229	8,777	35,748	8,905	33,270
10:00	5.62%	6,783	34,683	6,888	32,142	6,837	34,879	6,947	32,202	7,341	33,687	7,448	31,102
11:00	4.59%	5,576	33,957	5,662	31,329	5,640	34,159	5,731	31,391	6,032	32,935	6,120	30,263
12:00	4.05%	4,944	33,863	5,020	31,160	5,013	34,065	5,093	31,218	5,346	32,869	5,423	30,120
13:00	3.78%	4,628	34,085	4,698	31,311	4,700	34,286	4,774	31,363	5,003	33,146	5,075	30,325
14:00	3.24%	3,995	34,940	4,056	32,106	4,073	35,133	4,137	32,147	4,317	34,109	4,378	31,226
15:00	3.38%	4,159	35,631	4,222	32,733	4,235	35,818	4,302	32,765	4,495	34,895	4,559	31,947
16:00	4.11%	5,014	35,467	5,091	32,492	5,083	35,655	5,164	32,521	5,422	34,753	5,500	31,727
17:00	5.46%	6,595	33,722	6,698	30,644	6,651	33,924	6,758	30,682	7,137	32,895	7,242	29,765
18:00	6.73%	8,083	30,489	8,209	27,286	8,126	30,719	8,258	27,344	8,751	29,424	8,879	26,166

19:00	5.67%	6,841	28,498	6,948	25,188	6,895	28,744	7,007	25,257	7,404	27,300	7,512	23,933
20:00	5.13%	6,209	27,139	6,305	23,733	6,267	27,397	6,369	23,809	6,718	25,861	6,816	22,397
21:00	4.11%	5,014	26,975	5,091	23,492	5,083	27,234	5,164	23,565	5,422	25,719	5,500	22,177
22:00	3.38%	4,159	27,666	4,222	24,120	4,235	27,919	4,302	24,183	4,495	26,505	4,559	22,898
23:00	1.97%	2,507	30,009	2,544	26,425	2,598	30,241	2,637	26,466	2,703	29,082	2,741	25,437
0:00	1.22%	1,629	33,230	1,652	29,623	1,727	33,434	1,751	29,635	1,750	32,611	1,773	28,944
1:00	1.08%	1,465	36,615	1,485	32,988	1,564	36,790	1,586	32,970	1,572	36,319	1,593	32,631
2:00	0.95%	1,313	40,152	1,331	36,508	1,413	40,297	1,432	36,458	1,407	40,192	1,425	36,486
3:00	1.30%	1,723	43,279	1,747	39,611	1,820	43,397	1,845	39,532	1,852	43,620	1,877	39,889
4:00	1.54%	2,004	46,126	2,033	42,428	2,098	46,219	2,129	42,323	2,157	46,744	2,186	42,983
5:00	2.70%	3,363	47,613	3,413	43,865	3,446	47,693	3,499	43,745	3,631	48,393	3,682	44,581
6:00	6.75%	8,106	44,357	8,233	40,482	8,149	44,464	8,282	40,383	8,777	44,896	8,905	40,956
7:00	8.65%	10,332	38,875	10,494	34,838	10,355	39,029	10,526	34,777	11,191	38,986	11,356	34,880
8:00	7.84%	9,383	34,342	9,530	30,158	9,415	34,534	9,569	30,127	10,162	34,104	10,311	29,850
9:00	6.75%	8,106	31,086	8,233	26,776	8,149	31,306	8,282	26,765	8,777	30,608	8,905	26,224
10:00	5.62%	6,783	29,153	6,888	24,737	6,837	29,389	6,947	24,738	7,341	28,547	7,448	24,056
11:00	4.59%	5,576	28,427	5,662	23,925	5,640	28,669	5,731	23,927	6,032	27,795	6,120	23,217
12:00	4.05%	4,944	28,333	5,020	23,756	5,013	28,575	5,093	23,753	5,346	27,729	5,423	23,074
13:00	3.78%	4,628	28,555	4,698	23,907	4,700	28,796	4,774	23,899	5,003	28,006	5,075	23,279
14:00	3.24%	3,995	29,410	4,056	24,701	4,073	29,643	4,137	24,683	4,317	28,969	4,378	24,180
15:00	3.38%	4,159	30,101	4,222	25,329	4,235	30,328	4,302	25,301	4,495	29,755	4,559	24,901
16:00	4.11%	5,014	29,937	5,091	25,088	5,083	30,165	5,164	25,057	5,422	29,613	5,500	24,681
17:00	5.46%	6,595	28,192	6,698	23,240	6,651	28,434	6,758	23,218	7,137	27,755	7,242	22,719
18:00	6.73%	8,083	24,959	8,209	19,881	8,126	25,229	8,258	19,880	8,751	24,284	8,879	19,120
19:00	5.67%	6,841	22,968	6,948	17,784	6,895	23,254	7,007	17,793	7,404	22,160	7,512	16,888
20:00	5.13%	6,209	21,609	6,305	16,329	6,267	21,907	6,369	16,344	6,718	20,721	6,816	15,352
21:00	4.11%	5,014	21,445	5,091	16,088	5,083	21,744	5,164	16,100	5,422	20,579	5,500	15,131
22:00	3.38%	4,159	22,136	4,222	16,716	4,235	22,429	4,302	16,718	4,495	21,365	4,559	15,852
23:00	1.97%	2,507	24,479	2,544	19,021	2,598	24,751	2,637	19,002	2,703	23,942	2,741	18,391
0:00	1.22%	1,629	27,700	1,652	22,219	1,727	27,944	1,751	22,171	1,750	27,471	1,773	21,898
1:00	1.08%	1,465	31,085	1,485	25,584	1,564	31,300	1,586	25,505	1,572	31,179	1,593	25,585
2:00	0.95%	1,313	34,622	1,331	29,104	1,413	34,807	1,432	28,993	1,407	35,052	1,425	29,440
3:00	1.30%	1,723	37,749	1,747	32,207	1,820	37,907	1,845	32,068	1,852	38,480	1,877	32,843
4:00	1.54%	2,004	40,596	2,033	35,024	2,098	40,729	2,129	34,859	2,157	41,604	2,186	35,937
5:00	2.70%	3,363	42,083	3,413	36,461	3,446	42,203	3,499	36,280	3,631	43,253	3,682	37,535
6:00	6.75%	8,106	38,827	8,233	33,078	8,149	38,974	8,282	32,918	8,777	39,756	8,905	33,910
7:00	8.65%	10,332	33,345	10,494	27,434	10,355	33,539	10,526	27,312	11,191	33,846	11,356	27,835
8:00	7.84%	9,383	28,812	9,530	22,754	9,415	29,044	9,569	22,663	10,162	28,964	10,311	22,804
9:00	6.75%	8,106	25,556	8,233	19,371	8,149	25,816	8,282	19,301	8,777	25,468	8,905	19,178
10:00	5.62%	6,783	23,623	6,888	17,333	6,837	23,899	6,947	17,273	7,341	23,407	7,448	17,011
11:00	4.59%	5,576	22,897	5,662	16,521	5,640	23,179	5,731	16,462	6,032	22,655	6,120	16,171
12:00	4.05%	4,944	22,803	5,020	16,351	5,013	23,085	5,093	16,289	5,346	22,589	5,423	16,028
13:00	3.78%	4,628	23,025	4,698	16,503	4,700	23,306	4,774	16,435	5,003	22,866	5,075	16,233
14:00	3.24%	3,995	23,880	4,056	17,297	4,073	24,153	4,137	17,218	4,317	23,829	4,378	17,134
15:00	3.38%	4,159	24,571	4,222	17,925	4,235	24,838	4,302	17,836	4,495	24,615	4,559	17,855
16:00	4.11%	5,014	24,407	5,091	17,684	5,083	24,675	5,164	17,592	5,422	24,473	5,500	17,635
17:00	5.46%	6,595	22,662	6,698	15,836	6,651	22,944	6,758	15,754	7,137	22,615	7,242	15,673
18:00	6.73%	8,083	19,429	8,209	12,477	8,126	19,739	8,258	12,415	8,751	19,144	8,879	12,074
19:00	5.67%	6,841	17,438	6,948	10,380	6,895	17,764	7,007	10,329	7,404	17,020	7,512	9,842
20:00	5.13%	6,209	16,079	6,305	8,925	6,267	16,417	6,369	8,880	6,718	15,581	6,816	8,306
21:00	4.11%	5,014	15,915	5,091	8,684	5,083	16,254	5,164	8,636	5,422	15,439	5,500	8,085
22:00	3.38%	4,159	16,606	4,222	9,312	4,235	16,939	4,302	9,254	4,495	16,225	4,559	8,806
23:00	1.97%	2,507	18,949	2,544	11,617	2,598	19,261	2,637	11,538	2,703	18,802	2,741	11,346
0:00	1.22%	1,629	22,170	1,652	14,815	1,727	22,454	1,751	14,707	1,750	22,331	1,773	14,852
1:00	1.08%	1,465	25,555	1,485	18,180	1,564	25,810	1,586	18,041	1,572	26,039	1,593	18,539
2:00	0.95%	1,313	29,092	1,331	21,700	1,413	29,317	1,432	21,529	1,407	29,912	1,425	22,394
3:00	1.30%	1,723	32,219	1,747	24,802	1,820	32,417	1,845	24,604	1,852	33,340	1,877	25,798
4:00	1.54%	2,004	35,066	2,033	27,620	2,098	35,239	2,129	27,395	2,157	36,464	2,186	28,891
5:00	2.70%	3,363	36,553	3,413	29,057	3,446	36,713	3,499	28,816	3,631	38,113	3,682	30,489
6:00	6.75%	8,106	33,297	8,233	25,674	8,149	33,484	8,282	25,454	8,777	34,616	8,905	26,864
7:00	8.65%	10,332	27,815	10,494	20,030	10,355	28,049	10,526	19,848	11,191	28,706	11,356	20,789
8:00	7.84%	9,383	23,282	9,530	15,350	9,415	23,554	9,569	15,199	10,162	23,824	10,311	15,758
9:00	6.75%	8,106	20,026	8,233	11,967	8,149	20,326	8,282	11,837	8,777	20,328	8,905	12,133
10:00	5.62%	6,783	18,093	6,888	9,929	6,837	18,409	6,947	9,809	7,341	18,267	7,448	9,965
11:00	4.59%	5,576	17,367	5,662	9,117	5,640	17,689	5,731	8,998	6,032	17,515	6,120	9,125

12:00	4.05%	4,944	17,273	5,020	8,947	5,013	17,595	5,093	8,825	5,346	17,449	5,423	8,982
13:00	3.78%	4,628	17,495	4,698	9,099	4,700	17,816	4,774	8,971	5,003	17,726	5,075	9,187
14:00	3.24%	3,995	18,350	4,056	9,893	4,073	18,663	4,137	9,754	4,317	18,689	4,378	10,089
15:00	3.38%	4,159	19,041	4,222	10,521	4,235	19,348	4,302	10,372	4,495	19,475	4,559	10,810
16:00	4.11%	5,014	18,877	5,091	10,280	5,083	19,185	5,164	10,128	5,422	19,333	5,500	10,589
17:00	5.46%	6,595	17,132	6,698	8,432	6,651	17,454	6,758	8,290	7,137	17,475	7,242	8,627
18:00	6.73%	8,083	13,899	8,209	5,073	8,126	14,249	8,258	4,951	8,751	14,004	8,879	5,028
19:00	5.67%	6,841	11,908	6,948	2,976	6,895	12,274	7,007	2,865	7,404	11,880	7,512	2,796
20:00	5.13%	6,209	10,549	6,305	1,521	6,267	10,927	6,369	1,416	6,718	10,441	6,816	1,260
21:00	4.11%	5,014	10,385	5,091	1,280	5,083	10,764	5,164	1,172	5,422	10,299	5,500	1,039
22:00	3.38%	4,159	11,076	4,222	1,907	4,235	11,449	4,302	1,790	4,495	11,085	4,559	1,760
23:00	1.97%	2,507	13,419	2,544	4,213	2,598	13,771	2,637	4,073	2,703	13,662	2,741	4,300

Site 4, Site 5, and Site 6 Consumption Analysis Data Table

			Site 4: Southeast Campus				Site 5: Central Campus Hospital				Site 6: Central Campus Residential			
			Designed Demand		Maximum Demand		Designed Demand		Maximum Demand		Designed Demand		Maximum Demand	
Time	Hourly Demand	Hospital Hourly Demand	Design Demand (L)	Tank Volume (L)	Max Demand (L)	Tank Volume (L)	Design Demand (L)	Tank Volume (L)	Max Demand (L)	Tank Volume (L)	Design Demand (L)	Tank Volume (L)	Max Demand (L)	Tank Volume (L)
0:00	1.22%	3.75%	1,430	58,673	1,454	58,673	6,986	58,673	7,059	58,673	3,253	58,673	3,278	58,673
1:00	1.08%	2.00%	1,321	58,673	1,342	58,673	3,726	58,673	3,765	58,673	2,388	58,673	2,410	58,673
2:00	0.95%	2.00%	1,220	58,673	1,238	58,673	3,726	58,673	3,765	58,673	2,341	58,673	2,361	58,673
3:00	1.30%	1.10%	1,492	58,673	1,518	58,673	2,049	58,673	2,071	58,673	2,047	58,673	2,074	58,673
4:00	1.54%	1.10%	1,679	58,673	1,709	58,673	2,049	58,673	2,071	58,673	2,133	58,673	2,165	58,673
5:00	2.70%	1.00%	2,582	58,673	2,635	58,673	1,863	58,673	1,882	58,673	2,501	58,673	2,557	58,673
6:00	6.75%	1.00%	5,736	56,367	5,868	56,235	1,863	58,673	1,882	58,673	3,950	58,673	4,090	58,673
7:00	8.65%	1.80%	7,216	52,581	7,384	52,281	3,353	58,673	3,388	58,673	5,002	57,871	5,181	57,692
8:00	7.84%	1.80%	6,585	49,426	6,738	48,974	3,353	58,673	3,388	58,673	4,712	57,359	4,875	57,017
9:00	6.75%	3.75%	5,736	47,120	5,868	46,536	6,986	58,673	7,059	58,673	5,230	56,329	5,370	55,847
10:00	5.62%	3.75%	4,856	45,693	4,966	45,000	6,986	58,673	7,059	58,673	4,826	55,703	4,943	55,104
11:00	4.59%	5.45%	4,054	45,069	4,144	44,287	10,153	56,240	10,259	56,134	5,250	54,653	5,345	53,959
12:00	4.05%	5.45%	3,634	44,866	3,713	44,004	10,153	53,806	10,259	53,594	5,057	53,796	5,141	53,019
13:00	3.78%	7.00%	3,423	44,872	3,497	43,937	13,041	48,485	13,177	48,137	5,682	52,314	5,760	51,458
14:00	3.24%	7.00%	3,003	45,299	3,066	44,301	13,041	43,164	13,177	42,680	5,489	51,026	5,556	50,102
15:00	3.38%	7.70%	3,112	45,617	3,178	44,553	14,345	36,539	14,495	35,905	5,865	49,361	5,935	48,367
16:00	4.11%	7.70%	3,680	45,367	3,760	44,223	14,345	29,914	14,495	29,131	6,126	47,434	6,211	46,356
17:00	5.46%	7.00%	4,732	44,065	4,838	42,815	13,041	24,592	13,177	23,674	6,283	45,352	6,396	44,160
18:00	6.73%	7.00%	5,721	41,774	5,852	40,393	13,041	19,271	13,177	18,217	6,737	42,815	6,877	41,483
19:00	5.67%	5.45%	4,895	40,309	5,006	38,817	10,153	16,838	10,259	15,677	5,636	41,379	5,754	39,930
20:00	5.13%	5.45%	4,475	39,264	4,575	37,673	10,153	14,405	10,259	13,138	5,443	40,136	5,549	38,580
21:00	4.11%	4.00%	3,680	39,014	3,760	37,342	7,452	14,672	7,530	13,328	4,403	39,933	4,488	38,292
22:00	3.38%	4.00%	3,112	39,332	3,178	37,595	7,452	14,940	7,530	13,518	4,142	39,992	4,212	38,281
23:00	1.97%	3.75%	2,014	40,748	2,052	38,972	6,986	15,674	7,059	14,179	3,521	40,671	3,562	38,919
0:00	1.22%	3.75%	1,430	42,748	1,454	40,948	6,986	16,408	7,059	14,840	3,253	41,618	3,278	39,841
1:00	1.08%	2.00%	1,321	44,857	1,342	43,036	3,726	20,402	3,765	18,795	2,388	43,430	2,410	41,630
2:00	0.95%	2.00%	1,220	47,067	1,238	45,228	3,726	24,396	3,765	22,750	2,341	45,289	2,361	43,470
3:00	1.30%	1.10%	1,492	49,005	1,518	47,140	2,049	30,066	2,071	28,400	2,047	47,442	2,074	45,595
4:00	1.54%	1.10%	1,679	50,755	1,709	48,861	2,049	35,737	2,071	34,049	2,133	49,508	2,165	47,630
5:00	2.70%	1.00%	2,582	51,603	2,635	49,656	1,863	41,594	1,882	39,887	2,501	51,207	2,557	49,273
6:00	6.75%	1.00%	5,736	49,297	5,868	47,219	1,863	47,451	1,882	45,724	3,950	51,458	4,090	49,384
7:00	8.65%	1.80%	7,216	45,511	7,384	43,264	3,353	51,818	3,388	50,056	5,002	50,656	5,181	48,403
8:00	7.84%	1.80%	6,585	42,356	6,738	39,957	3,353	56,184	3,388	54,387	4,712	50,144	4,875	47,728
9:00	6.75%	3.75%	5,736	40,050	5,868	37,519	6,986	56,918	7,059	55,048	5,230	49,114	5,370	46,558
10:00	5.62%	3.75%	4,856	38,623	4,966	35,984	6,986	57,652	7,059	55,709	4,826	48,487	4,943	45,815
11:00	4.59%	5.45%	4,054	37,999	4,144	35,270	10,153	55,218	10,259	53,170	5,250	47,438	5,345	44,670
12:00	4.05%	5.45%	3,634	37,796	3,713	34,987	10,153	52,785	10,259	50,630	5,057	46,581	5,141	43,729
13:00	3.78%	7.00%	3,423	37,802	3,497	34,920	13,041	47,464	13,177	45,173	5,682	45,099	5,760	42,169
14:00	3.24%	7.00%	3,003	38,229	3,066	35,284	13,041	42,143	13,177	39,716	5,489	43,810	5,556	40,813
15:00	3.38%	7.70%	3,112	38,547	3,178	35,536	14,345	35,517	14,495	32,941	5,865	42,145	5,935	39,078
16:00	4.11%	7.70%	3,680	38,297	3,760	35,206	14,345	28,892	14,495	26,167	6,126	40,219	6,211	37,066
17:00	5.46%	7.00%	4,732	36,995	4,838	33,798	13,041	23,571	13,177	20,710	6,283	38,136	6,396	34,870
18:00	6.73%	7.00%	5,721	34,704	5,852	31,376	13,041	18,250	13,177	15,253	6,737	35,599	6,877	32,194

19:00	5.67%	5.45%	4,895	33,239	5,006	29,801	10,153	15,817	10,259	12,713	5,636	34,164	5,754	30,640
20:00	5.13%	5.45%	4,475	32,194	4,575	28,656	10,153	13,383	10,259	10,174	5,443	32,921	5,549	29,291
21:00	4.11%	4.00%	3,680	31,944	3,760	28,326	7,452	13,651	7,530	10,364	4,403	32,718	4,488	29,003
22:00	3.38%	4.00%	3,112	32,262	3,178	28,578	7,452	13,919	7,530	10,554	4,142	32,776	4,212	28,991
23:00	1.97%	3.75%	2,014	33,678	2,052	29,955	6,986	14,653	7,059	11,215	3,521	33,455	3,562	29,629
0:00	1.22%	3.75%	1,430	35,678	1,454	31,932	6,986	15,386	7,059	11,876	3,253	34,402	3,278	30,551
1:00	1.08%	2.00%	1,321	37,787	1,342	34,020	3,726	19,380	3,765	15,831	2,388	36,215	2,410	32,341
2:00	0.95%	2.00%	1,220	39,997	1,238	36,211	3,726	23,374	3,765	19,786	2,341	38,073	2,361	34,180
3:00	1.30%	1.10%	1,492	41,935	1,518	38,124	2,049	29,045	2,071	25,436	2,047	40,226	2,074	36,306
4:00	1.54%	1.10%	1,679	43,685	1,709	39,845	2,049	34,716	2,071	31,085	2,133	42,293	2,165	38,341
5:00	2.70%	1.00%	2,582	44,533	2,635	40,640	1,863	40,573	1,882	36,923	2,501	43,992	2,557	39,984
6:00	6.75%	1.00%	5,736	42,227	5,868	38,202	1,863	46,430	1,882	42,760	3,950	44,242	4,090	40,094
7:00	8.65%	1.80%	7,216	38,441	7,384	34,248	3,353	50,796	3,388	47,092	5,002	43,441	5,181	39,113
8:00	7.84%	1.80%	6,585	35,286	6,738	30,940	3,353	55,163	3,388	51,423	4,712	42,929	4,875	38,439
9:00	6.75%	3.75%	5,736	32,980	5,868	28,502	6,986	55,897	7,059	52,084	5,230	41,898	5,370	37,268
10:00	5.62%	3.75%	4,856	31,553	4,966	26,967	6,986	56,630	7,059	52,745	4,826	41,272	4,943	36,525
11:00	4.59%	5.45%	4,054	30,929	4,144	26,253	10,153	54,197	10,259	50,206	5,250	40,222	5,345	35,380
12:00	4.05%	5.45%	3,634	30,726	3,713	25,971	10,153	51,763	10,259	47,666	5,057	39,366	5,141	34,440
13:00	3.78%	7.00%	3,423	30,732	3,497	25,904	13,041	46,442	13,177	42,209	5,682	37,884	5,760	32,879
14:00	3.24%	7.00%	3,003	31,159	3,066	26,267	13,041	41,121	13,177	36,752	5,489	36,595	5,556	31,523
15:00	3.38%	7.70%	3,112	31,477	3,178	26,520	14,345	34,496	14,495	29,977	5,865	34,930	5,935	29,788
16:00	4.11%	7.70%	3,680	31,227	3,760	26,189	14,345	27,871	14,495	23,203	6,126	33,004	6,211	27,777
17:00	5.46%	7.00%	4,732	29,925	4,838	24,781	13,041	22,550	13,177	17,746	6,283	30,921	6,396	25,581
18:00	6.73%	7.00%	5,721	27,634	5,852	22,360	13,041	17,229	13,177	12,289	6,737	28,384	6,877	22,904
19:00	5.67%	5.45%	4,895	26,169	5,006	20,784	10,153	14,795	10,259	9,749	5,636	26,948	5,754	21,351
20:00	5.13%	5.45%	4,475	25,124	4,575	19,639	10,153	12,362	10,259	7,210	5,443	25,705	5,549	20,002
21:00	4.11%	4.00%	3,680	24,874	3,760	19,309	7,452	12,630	7,530	7,400	4,403	25,503	4,488	19,714
22:00	3.38%	4.00%	3,112	25,192	3,178	19,561	7,452	12,898	7,530	7,590	4,142	25,561	4,212	19,702
23:00	1.97%	3.75%	2,014	26,608	2,052	20,939	6,986	13,631	7,059	8,251	3,521	26,240	3,562	20,340
0:00	1.22%	3.75%	1,430	28,608	1,454	22,915	6,986	14,365	7,059	8,912	3,253	27,187	3,278	21,262
1:00	1.08%	2.00%	1,321	30,717	1,342	25,003	3,726	18,359	3,765	12,867	2,388	28,999	2,410	23,052
2:00	0.95%	2.00%	1,220	32,927	1,238	27,195	3,726	22,353	3,765	16,822	2,341	30,858	2,361	24,891
3:00	1.30%	1.10%	1,492	34,865	1,518	29,107	2,049	28,024	2,071	22,472	2,047	33,011	2,074	27,017
4:00	1.54%	1.10%	1,679	36,615	1,709	30,828	2,049	33,694	2,071	28,121	2,133	35,078	2,165	29,052
5:00	2.70%	1.00%	2,582	37,463	2,635	31,623	1,863	39,551	1,882	33,959	2,501	36,777	2,557	30,694
6:00	6.75%	1.00%	5,736	35,157	5,868	29,185	1,863	45,408	1,882	39,796	3,950	37,027	4,090	30,805
7:00	8.65%	1.80%	7,216	31,371	7,384	25,231	3,353	49,775	3,388	44,128	5,002	36,225	5,181	29,824
8:00	7.84%	1.80%	6,585	28,216	6,738	21,923	3,353	54,141	3,388	48,459	4,712	35,713	4,875	29,149
9:00	6.75%	3.75%	5,736	25,910	5,868	19,486	6,986	54,875	7,059	49,120	5,230	34,683	5,370	27,979
10:00	5.62%	3.75%	4,856	24,483	4,966	17,950	6,986	55,609	7,059	49,781	4,826	34,057	4,943	27,236
11:00	4.59%	5.45%	4,054	23,859	4,144	17,236	10,153	53,175	10,259	47,242	5,250	33,007	5,345	26,091
12:00	4.05%	5.45%	3,634	23,656	3,713	16,954	10,153	50,742	10,259	44,702	5,057	32,150	5,141	25,150
13:00	3.78%	7.00%	3,423	23,662	3,497	16,887	13,041	45,421	13,177	39,245	5,682	30,668	5,760	23,590
14:00	3.24%	7.00%	3,003	24,089	3,066	17,251	13,041	40,100	13,177	33,788	5,489	29,379	5,556	22,234
15:00	3.38%	7.70%	3,112	24,407	3,178	17,503	14,345	33,475	14,495	27,013	5,865	27,715	5,935	20,499
16:00	4.11%	7.70%	3,680	24,157	3,760	17,172	14,345	26,849	14,495	20,239	6,126	25,788	6,211	18,488
17:00	5.46%	7.00%	4,732	22,855	4,838	15,764	13,041	21,528	13,177	14,782	6,283	23,706	6,396	16,291
18:00	6.73%	7.00%	5,721	20,564	5,852	13,343	13,041	16,207	13,177	9,325	6,737	21,169	6,877	13,615
19:00	5.67%	5.45%	4,895	19,099	5,006	11,767	10,153	13,774	10,259	6,785	5,636	19,733	5,754	12,061
20:00	5.13%	5.45%	4,475	18,054	4,575	10,623	10,153	11,340	10,259	4,246	5,443	18,490	5,549	10,712
21:00	4.11%	4.00%	3,680	17,804	3,760	10,292	7,452	11,608	7,530	4,436	4,403	18,287	4,488	10,424
22:00	3.38%	4.00%	3,112	18,122	3,178	10,544	7,452	11,876	7,530	4,626	4,142	18,346	4,212	10,412
23:00	1.97%	3.75%	2,014	19,538	2,052	11,922	6,986	12,610	7,059	5,287	3,521	19,024	3,562	11,050
0:00	1.22%	3.75%	1,430	21,538	1,454	13,898	6,986	13,344	7,059	5,948	3,253	19,972	3,278	11,972
1:00	1.08%	2.00%	1,321	23,647	1,342	15,986	3,726	17,338	3,765	9,903	2,388	21,784	2,410	13,762
2:00	0.95%	2.00%	1,220	25,857	1,238	18,178	3,726	21,332	3,765	13,858	2,341	23,643	2,361	15,601
3:00	1.30%	1.10%	1,492	27,795	1,518	20,090	2,049	27,002	2,071	19,508	2,047	25,795	2,074	17,727
4:00	1.54%	1.10%	1,679	29,545	1,709	21,811	2,049	32,673	2,071	25,157	2,133	27,862	2,165	19,762
5:00	2.70%	1.00%	2,582	30,393	2,635	22,606	1,863	38,530	1,882	30,995	2,501	29,561	2,557	21,405
6:00	6.75%	1.00%	5,736	28,087	5,868	20,168	1,863	44,387	1,882	36,832	3,950	29,812	4,090	21,515
7:00	8.65%	1.80%	7,216	24,301	7,384	16,214	3,353	48,754	3,388	41,164	5,002	29,010	5,181	20,534
8:00	7.84%	1.80%	6,585	21,146	6,738	12,907	3,353	53,120	3,388	45,495	4,712	28,498	4,875	19,860
9:00	6.75%	3.75%	5,736	18,840	5,868	10,469	6,986	53,854	7,059	46,156	5,230	27,468	5,370	18,689
10:00	5.62%	3.75%	4,856	17,413	4,966	8,933	6,986	54,588	7,059	46,817	4,826	26,841	4,943	17,947
11:00	4.59%	5.45%	4,054	16,789	4,144	8,220	10,153	52,154	10,259	44,278	5,250	25,792	5,345	16,802

12:00	4.05%	5.45%	3,634	16,586	3,713	7,937	10,153	49,721	10,259	41,738	5,057	24,935	5,141	15,861
13:00	3.78%	7.00%	3,423	16,592	3,497	7,870	13,041	44,400	13,177	36,281	5,682	23,453	5,760	14,301
14:00	3.24%	7.00%	3,003	17,019	3,066	8,234	13,041	39,078	13,177	30,824	5,489	22,164	5,556	12,944
15:00	3.38%	7.70%	3,112	17,337	3,178	8,486	14,345	32,453	14,495	24,049	5,865	20,499	5,935	11,209
16:00	4.11%	7.70%	3,680	17,087	3,760	8,156	14,345	25,828	14,495	17,275	6,126	18,573	6,211	9,198
17:00	5.46%	7.00%	4,732	15,785	4,838	6,748	13,041	20,507	13,177	11,818	6,283	16,490	6,396	7,002
18:00	6.73%	7.00%	5,721	13,494	5,852	4,326	13,041	15,186	13,177	6,361	6,737	13,953	6,877	4,326
19:00	5.67%	5.45%	4,895	12,029	5,006	2,750	10,153	12,752	10,259	3,821	5,636	12,517	5,754	2,772
20:00	5.13%	5.45%	4,475	10,984	4,575	1,606	10,153	10,319	10,259	1,282	5,443	11,275	5,549	1,423
21:00	4.11%	4.00%	3,680	10,734	3,760	1,275	7,452	10,587	7,530	1,472	4,403	11,072	4,488	1,135
22:00	3.38%	4.00%	3,112	11,052	3,178	1,528	7,452	10,855	7,530	1,662	4,142	11,130	4,212	1,123
23:00	1.97%	3.75%	2,014	12,468	2,052	2,905	6,986	11,589	7,059	2,323	3,521	11,809	3,562	1,761

Appendix E: Pump Selection and Specifications

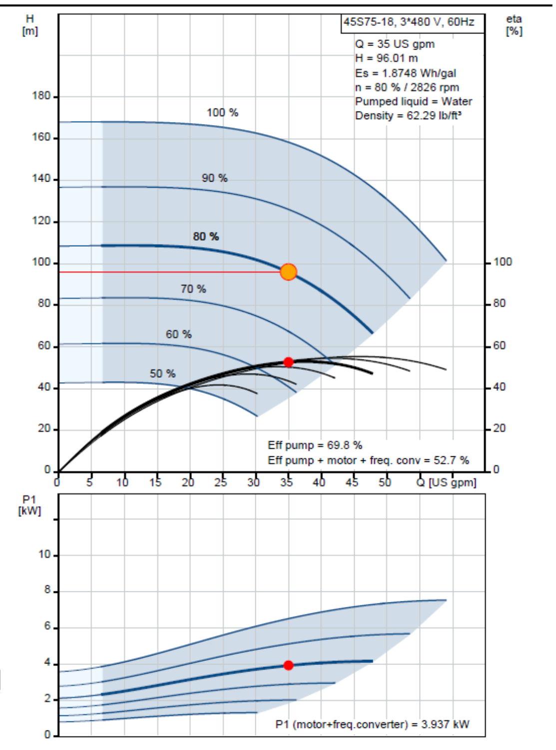
Submersible Well Pump Specification Sheet

GRUNDFOS

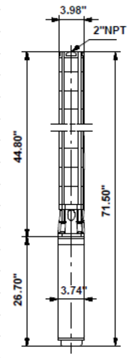
Company name:
Created by:
Phone:

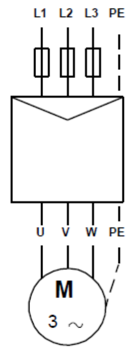
Date:

Description	Value
General information:	
Product name:	45S75-18
Product No.:	98924593
EAN:	5712603665610
Technical:	
Pump speed on which pump data is based:	3450 rpm
Actual calculated flow:	35 US gpm
Resulting head of the pump:	96.01 m
Actual impeller diameter:	2.87 in
Stages:	18
Impeller reduc.:	NONE
Shaft seal for motor:	HM/CER
Approvals on nameplate:	CE,EAC,CSA
Curve tolerance:	ISO9906:2012 3B
Model:	A
Valve:	YES
Motor version:	T40
Materials:	
Pump:	Stainless steel
Pump:	EN 1.4301
Pump:	AISI 304
Impeller:	Stainless steel
Impeller:	EN 1.4301
Impeller:	AISI 304
Motor:	Stainless steel
Motor:	DIN W.-Nr. 1.4301
Motor:	AISI 304
Installation:	
Maximum ambient pressure:	870.23 psi
Pump outlet:	2"NPT
Motor diameter:	4 inch
Liquid:	
Pumped liquid:	Water



Maximum liquid temperature:	104 °F
Electrical data:	
Motor type:	MS4000
Applic. motor:	NEMA
Rated power - P2:	7.5 HP
KVA code:	J
Main frequency:	60 Hz
Rated voltage:	3 x 440-460 V
Service factor:	1.15
Rated current:	12.8-12.6 A
Starting current:	570-620 %
Cos phi - power factor:	0.87-0.82
Rated speed:	3440-3460 rpm
Axial load max:	992 lb
Enclosure class (IEC 34-5):	IP68
Insulation class (IEC 85):	F
Motor protection:	NONE
Thermal protec:	external
Built-in temperature transmitter:	yes
Motor Number:	96405814
Others:	
DOE Pump Energy Index CL:	0.84
ErP status:	EuP Standalone/Prod.
Net weight:	90 lb
Gross weight:	102 lb
Shipping volume:	2.4 ft³



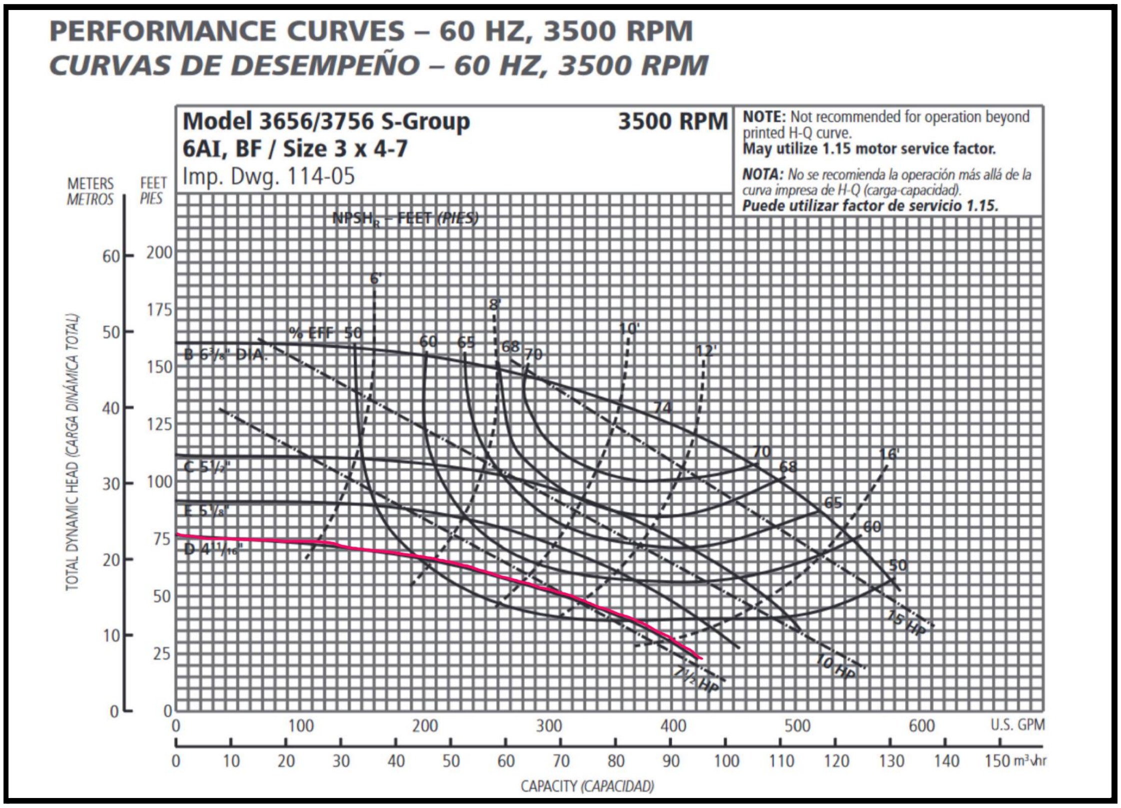


Booster Pump Specification Sheet

Goulds Water Technology

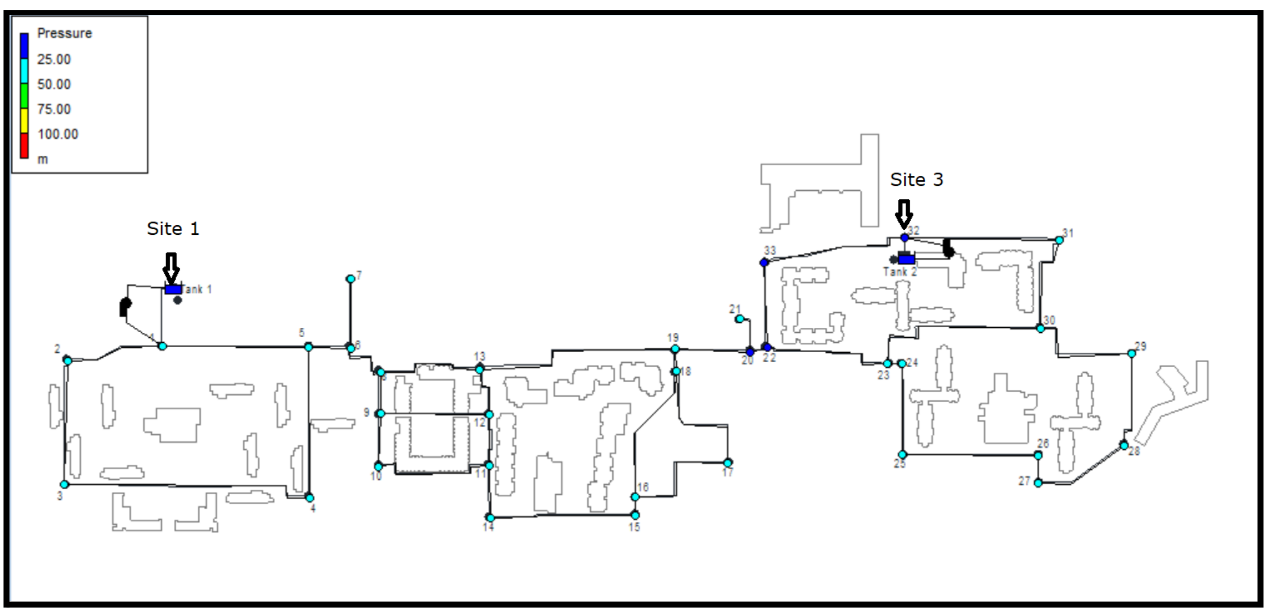
Commercial Water

Item	Centrifugal Pump	Max. Liquid Temp.	212 Degrees F
Item - Straight Centrifugal Pumps	Straight Centrifugal High Head Pump	GPM of Water @ 40 Ft. of Head	420
HP - Pumps	7 1/2 hp	GPM of Water @ 50 Ft. of Head	390
Voltage - Pumps	240V AC	GPM of Water @ 60 Ft. of Head	355
Phase - Pumps	1	GPM of Water @ 70 Ft. of Head	315
Housing Material - Pumps	Cast Iron	GPM of Water @ 80 Ft. of Head	260
Outlet Size - Pumps	3 in Flange	Max. Specific Gravity	1.0
Inlet Size - Pumps	4 in Flange	Wetted Materials	Stainless Steel, Carbon, Cast Iron, Bronze, Ceramic, Buna-N
Max. Head	90 ft	Max. Case Pressure	175 psi
Max. Pressure - Pumps	39 psi	Inlet Pressure	100 psi
Motor Enclosure - Pumps	Totally Enclosed Fan-Cooled	Manufacturers Warranty Length	1 yr
Max. GPM @ Head	260 @ 65 ft	Length	22 7/16 in
Amps	37	Width	16 5/16 in
Hz	60	Height	11 1/4 in
Motor RPM	3,500 RPM	Duty	Continuous
Motor Type	JM	Frame	213JM
Impeller Type	Closed	Port Rotation	90 Increments
Impeller Material	Bronze	Best Efficiency Range GPM @ Head	250 to 350 gpm @ 60 to 83 ft
Max. Dia. Solids	1/2 in	Best Efficiency GPM @ Head	250 @ 70 ft
Seal Material	Buna-N Elastomers, Carbon/Ceramic Face, 316 Stainless Steel Metal Parts	Min. GPM @ Head	180 @ 88 ft



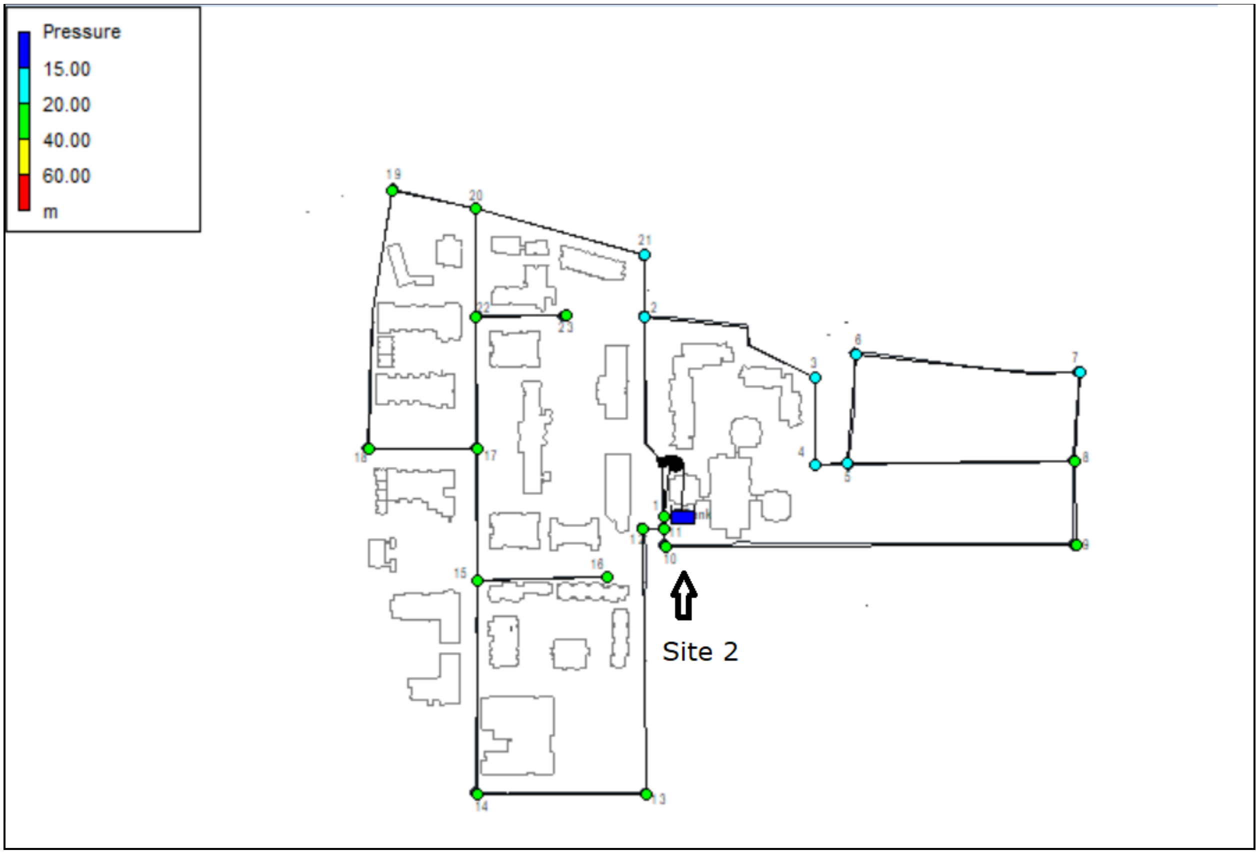
Appendix F: EPANET Models and Results

EPANET Model 1: Site 1 & Site 3



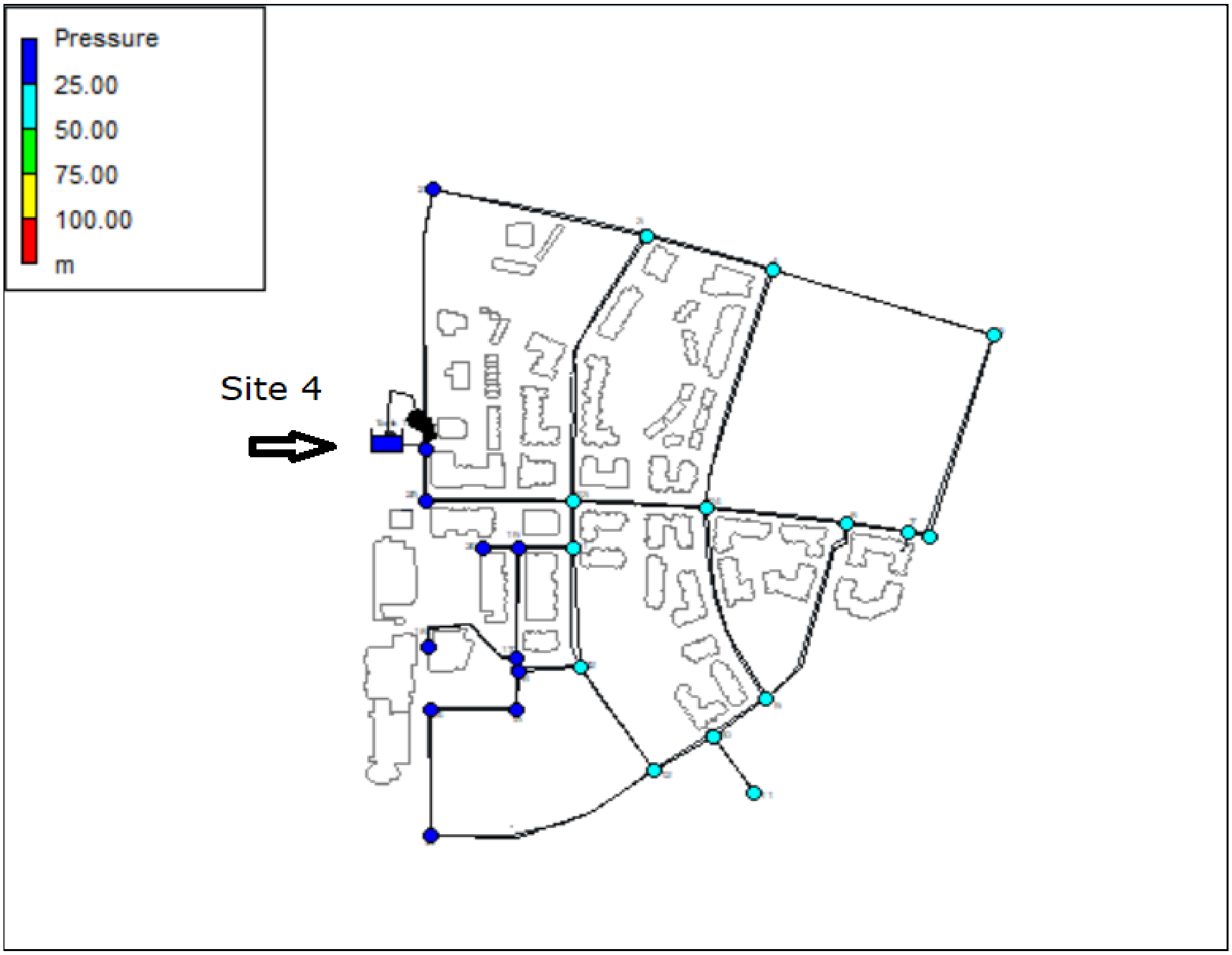
Node ID	Pressure m	Node ID	Pressure m
Junc 1	30.35	Junc 18	26.31
Junc 2	30.34	Junc 19	27.31
Junc 3	32.33	Junc 20	24.31

EPANET Model 2: Site 2



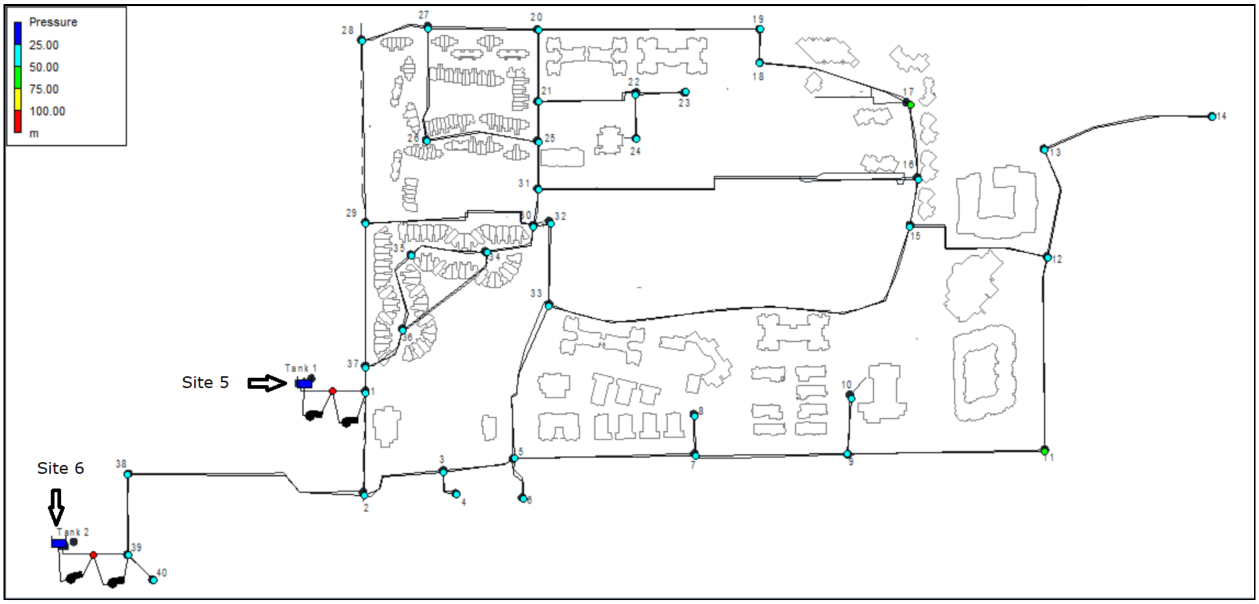
Node ID	Pressure m	Node ID	Pressure m
Junc 1	29.90	Junc 13	34.89
Junc 2	27.90	Junc 14	37.89
Junc 3	28.90	Junc 15	34.89
Junc 4	28.90	Junc 16	32.89
Junc 5	28.90	Junc 17	32.89
Junc 6	26.90	Junc 18	38.89
Junc 7	28.90	Junc 19	36.89
Junc 8	29.90	Junc 20	33.89
Junc 9	29.90	Junc 21	28.89
Junc 10	30.90	Junc 22	33.89
Junc 11	29.90	Junc 23	31.89
Junc 12	30.90		

EPANET Model 3: Site 4



Node ID	Pressure m	Node ID	Pressure m
Junc 1	23.59	Junc 14	23.58
Junc 2	21.58	Junc 15	24.58
Junc 3	29.58	Junc 16	24.58
Junc 4	34.58	Junc 17	24.58
Junc 5	40.58	Junc 18	22.58
Junc 6	35.58	Junc 19	24.58
Junc 7	35.58	Junc 20	23.58
Junc 8	33.58	Junc 21	26.58
Junc 9	31.58	Junc 22	25.58
Junc 10	30.58	Junc 23	26.58
Junc 11	32.58	Junc 24	30.58
Junc 12	27.58	Junc 25	22.58
Junc 13	23.58		

EPANET Model 4: Site 5 & Site 6



Node ID	Pressure m	Node ID	Pressure m
Junc 1	43.52	Junc 21	39.51
Junc 2	44.51	Junc 22	39.51
Junc 3	42.51	Junc 23	40.51
Junc 4	42.51	Junc 24	40.51
Junc 5	43.51	Junc 25	40.51
Junc 6	43.51	Junc 26	39.51
Junc 7	45.51	Junc 27	38.51
Junc 8	44.51	Junc 28	39.51
Junc 9	47.51	Junc 29	41.52
Junc 10	47.51	Junc 30	41.51
Junc 11	50.51	Junc 31	40.51
Junc 12	47.51	Junc 32	40.51
Junc 13	45.51	Junc 33	42.51
Junc 14	49.51	Junc 34	40.52
Junc 15	43.51	Junc 35	41.52
Junc 16	42.51	Junc 36	42.52
Junc 17	51.51	Junc 37	43.52
Junc 18	39.51	Junc 38	47.51
Junc 19	39.51	Junc 39	45.51
Junc 20	38.51	Junc 40	44.51

Appendix G: Cost Estimate and Permit Source

Material Construction Costs

	Materials Construction			
	Item	Price (CAD)	Amount	Totals (CAD)
[1]	Submersible Pump - 150mm	$16,000.00	6	$96,000.00
[2]	Well Drilling & Shaft Casing	$30,000.00	6	$180,000.00
[3]	Filtration Housing	$1,437.00	6	$8,622.00
[4]	Sediment Filter	$146.00	6	$876.00
[5]	Chlorination System	$1,540.92	6	$9,245.50
[6]	Booster Pump	$4,418.82	16	$70,701.12
[7]	Generator	$6,479.00	6	$38,874.00
[8]	Propane Tank & Liquid	$2,890.00	6	$17,340.00
[9]	Storage tanks	$20,160.00	6	$120,960.00
[10]	24 Hr Pump Flow Test	$17,000.00	6	$102,000.00
[11]	Hot Tap Into Water System	$15,120.00	6	$90,720.00
[12]	Construction Labour	$22.00	90	$1,980.00
[13]	Skilled Labour	$150.00	36	$5,400.00
[14]	Excavation / Soil Removal	$670.00	6	$4,020.00
[15]	Pumphouse	$3,691.00	6	$22,146.00
[16]	Stainless Steel Sink	$837.90	6	$5,027.40
[17]	Stainless Steel Check Valve - 65mm	560.1078	6	3360.6468
[18]	Pumphouse Door	$285.00	12	$3,420.00
[19]	Gate Valves - 100mm	$721.22	12	$8,654.69
[20]	Check Valves - 100mm	$521.98	12	$6,263.76
[21]	Iron Tee Connection - 75mm	$122.89	12	$1,474.65
[22]	Black Steel 90 Deg. Elbow - 75mm	$182.70	54	$9,865.80
[23]	Black Steel Reducer - 75mm x 50mm	$187.71	6	$1,126.29
[24]	Black Steel Reducer - 100mm x 75mm	$116.42	48	$5,588.35
[25]	Black Steel Piping (10ft) - 75mm	$344.66	30	$10,339.81
[26]	Ductile Iron Reducer - 250mm x 75mm	$1,260.00	6	$7,560.00
[27]	Ductile Iron 90 Deg. Elbow	$1,260.00	6	$7,560.00
[28]	Gaskets - 250mm	$92.99	12	$1,115.86
[29]	Gaskets - 50mm	$2.14	12	$25.70
[30]	Gasket - 75mm	$3.20	210	$672.08
[31]	Groove Gaskets - 100mm	$41.83	72	$3,011.90
[32]	Flanges - 75mm	$66.24	148	$9,803.25
[33]	Flange Bolts (200 Count)	$167.58	3	$502.74
[34]	Flange Nuts (100 Count)	$51.08	6	$306.48

Material Construction Costs References

Reference [#]	Reference Source
[1]	Direct quote from A&H Drilling
[2]	Direct quote from A&H Drilling
[3]	https://www.globalindustrial.ca/p/plumbing/water-filtration/Filter-Housings/multi-cartridge-housing-5-x-30-w-clamp-closure-2-npt-connections
[4]	https://www.globalindustrial.ca/p/plumbing/water-filtration/sytems-supplies/watts-wound-filter-ff-cartridges-9-34lx4-12od-1-micron
[5]	https://www.cleanwaterstore.com/proportional-flow-chlorinators/chlorinator-well-water-proportional-feed-1-12-j-pro-22-110-240v.html
[6]	https://www.grainger.com/product/GOULDS-WATER-TECHNOLOGY-240V-AC-Totally-Enclosed-Fan-2VRV6
[7]	https://www.homedepot.ca/product/generac-22-000w-lp-19-500w-ng-air-cooled-standby-generator/1001033916
[8]	https://www.kleen-ritecorp.com/p-37895-500-gallon-above-ground-propane-tank-asme.aspx
[9]	https://www.tank-depot.com/productdetails.aspx?part=N-44814
[10]	Direct quote from A&H Drilling
[11]	Isaac Sandri's estimate based on work experience
[12]	https://ca.indeed.com/salaries/construction-worker-Salaries,-Lower-Mainland-BC
[13]	https://www.kcplumb.ca/rates
[14]	https://www.rsmeansonline.com/
[15]	https://www.rsmeansonline.com/
[16]	https://www.zanduco.com/ca/three-tub-sink-18-x18-x11-with-no-drain-board-en-2303prod.html?gclid=Cj0KCQiAh4j-BRCsARIsAGeV12BD3mEjlabyQ2Ot6m7bW3xEXcubYtPX-_2RMSWzpniwE4EDGXQgiPAaAnUjEALw_wcB#.Va6c1_lzeao?utm_source=Google&utm_medium=CPC&utm_campaign=Shopping_SinksAccessories
[17]	https://www.discovervalve.com/mm5/merchant.mvc?Screen=PROD&Product_Code=102244
[18]	https://www.rona.ca/en/masonite-door-ph32lh-6-9-16-sp6p28l6-66605572?viewStore=61740&cq_src=google_ads&cq_cmp=11296616867&cq_con=110854699156&cq_term=&cq_med=&cq_plac=&cq_net=u&cq_pos=&cq_plt=gp&&cm_mmc=shopping_google-_-11296616867-_-110854699156-_-pla-405588308575&gclid=Cj0KCQiAh4j-BRCsARIsAGeV12DyqkzqjNzX4ZIfVnRRTRuKTRub2g86CF-HXbCFGsQZTq_dhZdLJQwaAmPyEALw_wcB&gclsrc=aw.ds
[19]	https://www.grainger.com/product/NIBCO-Gate-Valve-1WPD7
[20]	https://www.grainger.ca/en/product/p/WWG1JNL6?cm_mmc=PPC:+Google+PLA&ef_id=CjwKCAjwpKCDBhBPEiwAFgBzj2bIBU9wHYOJ3JeI1QUxI5J6jWOY06Et_OWYlIGwEAn0AANIDJbUNxoCYLAQAvD_BwE:G:s&s_kwcid=AL!3645!3!483556496832!!!g!305618779148!&gclid=CjwKCAjwKCDBhBPEiwAFgBzj2bIBU9wHYOJ3JeI1QUxI5J6jWOY06Et_OWYlIGwEAn0AANIDJbUNxoCYLAQAvD_BwE
[21]	https://www.grainger.com/product/ANVIL-Tee-4WHA6
[22]	https://www.grainger.com/product/GRAINGER-APPROVED-316-Stainless-Steel-Elbow-2TV75
[23]	https://www.grainger.com/product/ANVIL-Reducer-29JF21
[24]	https://www.grainger.com/product/GRAINGER-APPROVED-Reducer-Coupling-2WU62
[25]	https://www.grainger.com/product/GRAINGER-APPROVED-3-in-Black-Steel-40L309
[26]	Contractor Acquired
[27]	Contractor Acquired
[28]	https://www.grainger.com/product/GRAINGER-APPROVED-SBR-Blend-Gasket-5WLZ5
[29]	https://www.grainger.com/product/GRAINGER-APPROVED-SBR-Blend-Flange-Gasket-1TUV5
[30]	https://www.grainger.com/product/GRAINGER-APPROVED-SBR-Blend-Flange-Gasket-1TUV4
[31]	https://www.grainger.com/product/GRAINGER-APPROVED-SBR-Blend-Flange-Gasket-1TUV2
[32]	https://www.grainger.com/product/GRAINGER-APPROVED-Threaded-Flange-4TXF8
[33]	https://www.grainger.com/product/FABORY-Flange-Bolt-157D60
[34]	https://www.grainger.com/product/FABORY-Hex-Nut-38ZR77

Permitting Cost Information and Requirements

Permit	Reference Source
UBC Development	https://planning.ubc.ca/sites/default/files/2019-11/FORM_UBC_DevPermitApplicationForm_Nov2017.pdf
UBC Building Application	https://planning.ubc.ca/sites/default/files/2020-01/FORM_UBC_BP-AppForm_Jan2020_2_0.pdf
UBC SLP	https://planning.ubc.ca/sites/default/files/2019-11/FORM_UBC_StreetsLandscapesPermitApp.pdf
Crown Land Use	https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-resource-use/land-water-use/crown-land/fees-land.pdf
Crown Groundwater Rental	http://www.env.gov.bc.ca/wsd/water_rights/water_rental_rates/calculator/index.html

Annual Management, Maintenance and Operation Costs

	Management, Maintenance, & Operational			
	Item	Price (CAD)	Amount	Totals (CAD)
[40]	Project Management	$43.50	800	$34,800.00
[41]	Training Hours	$35.00	240	$8,400.00
[41]	Maintenance Salary	$50,000.00	2	$100,000.00
[42]	Facility Costs	$100,000.00	0.05	$5,000.00
	Total (CAD)			**$148,200.00**

Annual Management, Maintenance and Operation Costs References

Management & Maintenance	
Reference [#]	Reference Source
[40]	https://ca.indeed.com/salaries/project-manager-Salaries,-Lower-Mainland-BC
[41]	https://www.glassdoor.ca/Salaries/building-operations-salary-SRCH_KO0,19.htm
[41]	https://www.glassdoor.ca/Salaries/building-operations-salary-SRCH_KO0,19.htm
[42]	Kyle Maxwell's Estimate From Work Experience

Appendix H: Treatment Calculation

Largest tank size = 58673L

Pump Operating Flow = 19 $\frac{L}{s}$

Shortest distance to user = 14m

Required treatment = 6 $\frac{mg*min}{L}$

i) Contact Time:

$$C_t = (\frac{Tank\ size}{Flow\ rate}) + (\frac{Pipe\ volume}{Flow\ rate}) =$$

$$(\frac{58673L}{19\frac{L}{s}}) + (\frac{\frac{\pi}{4}*(0.25m)^2*14m}{19\frac{L}{s}}) = 3124s,\ 3124s * (\frac{1min}{60s}) = 52\ min$$

ii) Free Residual Chlorine:

$$Cl_f = \frac{Required\ treatment}{Contact\ time} = (\frac{6\frac{mg*min}{L}}{52\ min}) = 0.12\ \frac{mg}{L}$$

iii) Required Mass of Chlorine:

$$M_{Cl} = (Tank\ volume) * (Free\ residual\ chlorine) =$$

$$(58763L) * (0.12\frac{mg}{L}) = 6760mg * (\frac{1g}{1000mg}) = 6.8g\ Cl$$

Source referenced:https://www.doh.wa.gov/portals/1/Documents/pubs/331-343.pdf

Appendix I: Construction Schedule