South Campus Stormwater Detention Facility

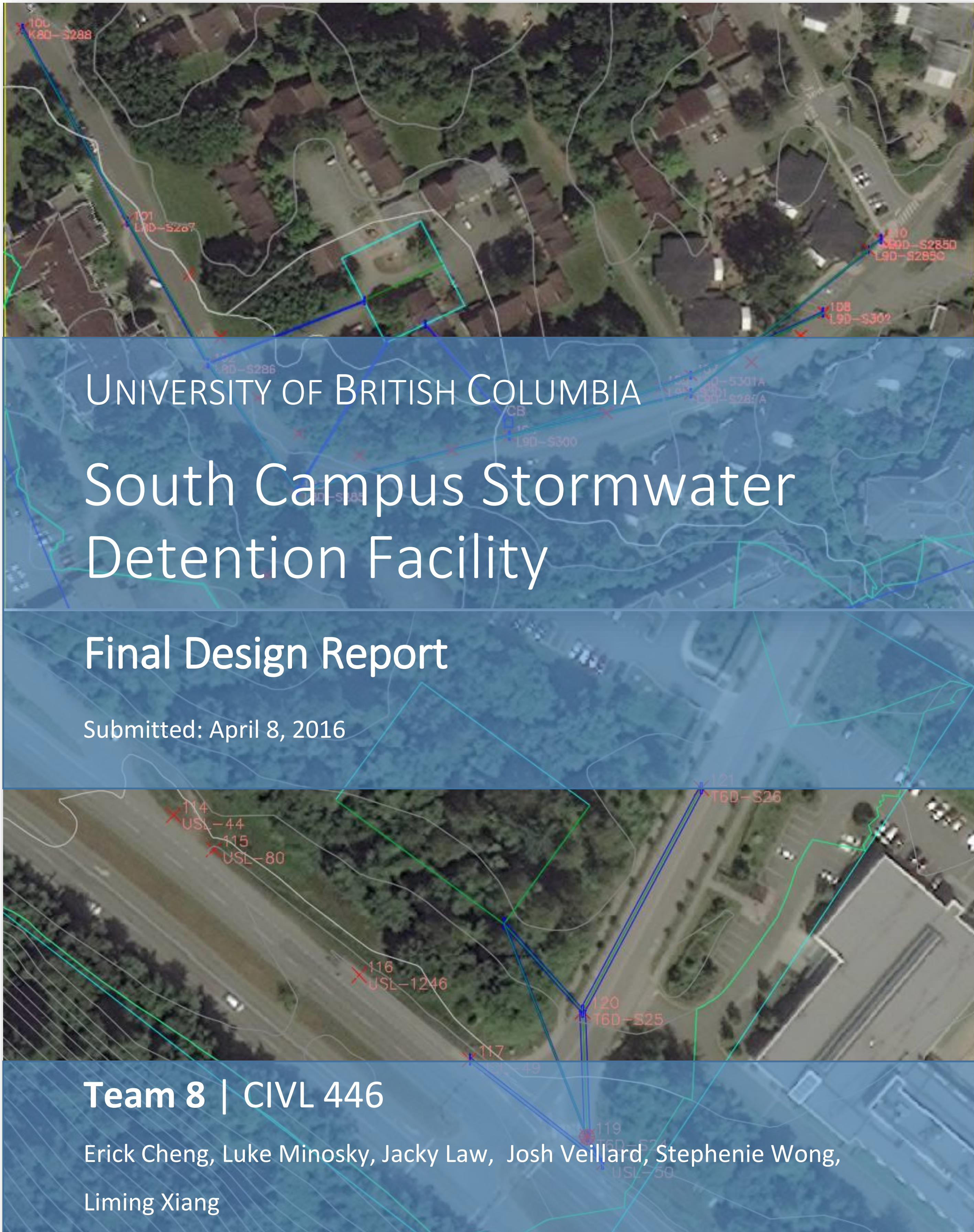
Final Design Report

Erick Cheng, Jacky Law, Josh Veillard, Li Ming Xiang, Luke Minosky, Stephenie Wong

University of British Columbia

CIVL 446

April 08, 2016



UNIVERSITY OF BRITISH COLUMBIA

South Campus Stormwater Detention Facility

Final Design Report

Submitted: April 8, 2016

Team 8 | CIVL 446

Erick Cheng, Luke Minosky, Jacky Law, Josh Veillard, Stephenie Wong, Liming Xiang

Executive Summary

The purpose of this report is to present a detailed design solution for controlling and eliminating flood damage at vulnerable locations in University of British Columbia (UBC). Through hydraulic modeling data, it has been shown that UBC currently does not have adequate infrastructure to manage extreme flood events; in particular, the South Campus may experience extensive flood damage such as property damage, riparian habitat deterioration, cliff erosion, and ultimately cliff failure.

The design process consists of an overview of regulatory guidelines, technical standards, and stormwater model simulation results to identify requirements and constraints of the detailed design. The design solution is comprised of two separate stormwater management systems located at Hampton Place and Southwest (SW) Marine Drive. The selected design for both systems is underground, pre-cast concrete stormwater detention tanks connected to the existing stormwater system using gravity mains. This report discusses the design configuration, elevation profiles of storm mains, and the structural and hydraulic capacity of the design.

The proposed storm mains are designed based on the locations of the existing stormwater infrastructure and requirements defined by the UBC Technical Guidelines, including velocity and slope restrictions. The reinforced concrete tanks are sized to withstand lateral and surface loading. Finally, the target design lives of the facilities are determined based on the estimated lifetime of facility components, maintenance requirements, and the probability that it will be in use. Several iterations were undertaken to ensure the final design is an optimal solution, meeting all identified requirements.

At the Hampton Place facility, stormwater will enter the 1,200 cubic metre detention facility to prevent flooding and protect emergency services in the case of a storm. At the SW Marine Drive facility, a large volume of flooding is anticipated, hence the detention facility has a storage capacity of 3,226 cubic metres. Stormwater collected from an existing storm main running along Wesbrook Mall will be diverted into this facility. When the rainfall intensity decreases, the water will gradually be released back into an existing storm main, eliminating flooding while minimizing pollution.

Table of Contents

List of Illustrations

1.0 Introduction

Stormwater modeling results suggests that extensive and costly damages can occur if an extreme rainfall event occurred at University of British Columbia (UBC) today. UBC currently does not have adequate infrastructure to manage extreme flood events. This project aims to find a stormwater detention facility design solution to reduce the impact of such events to acceptable levels.

As part of the design process, the team utilizes technical reports provided by the client, stormwater modeling results, technical standards, regulatory information and data gathered from site visits. The implications gathered from these sources include water quality requirements, detention capacity estimates, pipe capacity estimates and structural capacity estimates. All factors were considered while selecting various configurations. Several iterations were undertaken to reduce the impact on the existing environment, cost, and overall construction effort required to complete the facilities.

This report will provide a thorough discussion of the design process and the resulting design outputs, starting with an overview of design criteria, technical standards and relevant software packages. Next, the report will analyze the hydraulic capacity, structural capacity, and environment requirements. The resulting design outputs, construction plans and cost estimates for detention facilities at Hampton Place and the intersection of Wesbrook and SW Marine Drive are detailed. Finally, several recommendations will be made regarding items required to improve the design and progress on the project.

1.1 Project Objectives

The objective of this project is to design on-campus stormwater detention systems at high risk locations to eliminate floods with a 10 year return period and control floods with a 100 year return period to protect against property damage, harm to riparian habitat, and cliff erosion. This will support the ongoing implementation of UBC's Integrated Stormwater Management Plan and reduce negative impact to acceptable levels.

The key components of the design include the detention facility and the pipework required to connect the facility to the existing stormwater system. This design will require structural stability under lateral and surface loading conditions as well as providing sufficient hydraulic capacity to meet technical guidelines. The detention facility will also aim to lower the sediment, oil and contaminant loading in the resulting stormwater discharge.

1.2 Site Overview

The scope of work of this project is restricted to the South Campus of UBC. The area adjacent to Hampton Place and the intersection of SW Marine Drive and Wesbrook Mall are predicted to experience unacceptable levels of negative impact in the case of a 100-year flood event. These locations are indicated using yellow stars in Figure 2.

Figure 2: Proposed project locations on the UBC South Campus

Source: (Google Maps, 2015)

The location at SW Marine Drive is situated near institutional buildings such as TRIUMF, National Research Council Canada, and UBC Animal Care Services. The SW Marine Drive Corridor is owned and operated by BC Ministry of Transportation and Infrastructure. Vehicular traffic is limited and pedestrian traffic is rare. The site is selected primarily due to the high flood volume predicted by stormwater modelling, caused by the adjacent stormwater trunk main running along Wesbrook Mall. As shown in Figure 1, the proposed project location is currently a wooded area next to large stormwater ditches; the arterial road, SW Marine Drive is located on the left.

Figure 1: Proposed detention facility location at SW Marine Drive and Wesbrook Mall

The Hampton Place location is situated nearby the Hampton Place and Acadia Park residences. It is surrounded by low-rise residential buildings and is separated from Wesbrook Mall by the Fraternity Village and the RCMP building. The location of the detention tank installation is free of trees and the relatively flat, albeit at a higher ground elevation than the nearby roads. The two roads that are closest to this location, Osoyoos Crescent and Acadia Park Lane, typically have low traffic volume. This site is selected to protect the Fire Hall and Royal Canadian Mounted Police (RCMP) building from being located directly in the flood path. These facilities need to be protected to ensure emergency services are able to operate without delay during severe rainfall events. The proposed location for the detention tank, as shown in Figure 3, is currently a small parking lot surrounded by a vacant grass field.

Figure 3: Proposed detention facility location at Hampton Place

1.3 Task Allocation Summary

In fulfillment of the requirements specified for the final design report, Table 1 is included to summarize each team member's contributions to this report.

Table 1: Task Allocation Summary

	Erick Cheng	Jacky Law	Luke Minosky	Josh Veillard	Stephenie Wong	Liming Xiang
General Tasks						
Project Management & Scheduling		✓				
Report Compilation & Formatting					✓	
Drafting				✓		
Stormwater Modelling & Hydraulic Calculations					✓	
Structural Calculations		✓				
Final Design Report						
Letter of Transmittal	✓					
Executive Summary	✓					
1. Introduction	✓					
1.1 Project Objectives	✓					
1.2 Site Overview	✓					
1.3 Task Allocation Summary	✓					
2. Design Criteria and Tools						✓
2.1 Regulatory Requirements						✓
2.2 Technical Standards					✓	
2.3 Adopted Design Life						✓
2.4 Design Loadings					✓	
2.5 Software Packages				✓		
3. Hampton Place - Design Outputs			✓			
3.1 Components			✓			
3.2 Design Layout				✓		
4. Wesbrook - Design Outputs			✓			
4.1 Components			✓			
4.2 Design Layout				✓		
5. Technical Considerations					✓	
5.1 Hydraulic and Storage Capacity					✓	
5.2 Structural Capacity		✓				
5.3 Environmental Accomodations			✓			
6. Construction Planning		✓				
6.1 Hampton Place - Construction Schedule		✓				
6.2 Wesbrook - Construction Schedule		✓				

	Erick Cheng	Jacky Law	Luke Minosky	Josh Veillard	Stephenie Wong	Liming Xiang
Final Design Report (cont'd)						
6.3 Cost Estimate	✓					
7. Recommendations for Design Improvement						✓
7.1 Additional Data						✓
7.2 Field Tests						✓
7.3 Next Phases						✓
8. Conclusion	✓					
Appendix A - Rainfall Intensity-Duration-Frequency Curve					✓	
Appendix B - EPA-SWMM Results					✓	
Appendix C - Pipe Capacity Calculation					✓	
Appendix D - Structural Calculations		✓				
Appendix E - Construction Schedule		✓				
Appendix F - Cost Estimate	✓					

✓ indicates contribution to task

2.0 Design Criteria and Tools

The constraints of the project sites have been evaluated in detail to develop the preliminary design into a detailed design. These constraints include regulatory requirements, technical standards, neighbourhood outlook and existing conditions such as elevations and underground services. Based on the project objectives, the intended design life and loadings were selected for use in the design process. All of these items dictate the functional capacity, aesthetic appeal, and construction planning of the projects. Once the constraints at each of the two project site are satisfied, further design considerations and standards are imposed on the proposed designs.

AutoCAD, Civil 3D, SAP 2000 and EPA-SWMM were used to support the design process. A full model of the projects is drafted in AutoDesk Civil 3D to include elevations, pipe sizes, storage tank layout, and tie-in locations to existing services. This detailed model is then used as an input baseline for EPA-SWMM, a storm water management modeling software. The outputs of these two programs are then compared to the initial constraint definitions to ensure that the projects indeed satisfy those constraints.

2.1 Regulatory Requirements

Regulatory requirements are the first item to be assessed; the proposed designs must support any regulations governing this area. The most prominent regulations are those imposed by UBC, as summarized in the *UBC Integrated Stormwater Management Plan*. These include the preferred design life, priority locations, land zoning requirements and discharge water quality.

Technical guidelines are then considered, taking into account design standards for underground storage units and piping systems. These are imposed by local governmental bodies such as UBC and Metro Vancouver.

The final technical consideration was an environmental requirement specified by the client: a tree buffer must be maintained along Southwest Marine Drive to maintain the surrounding forestry and ecosystem.

2.2 Technical Standards

Both project locations fall under the UBC Campus jurisdiction, thus, the *UBC Technical Guidelines* are the predominant standards which are used to develop the detailed design. The standards define hydraulic capacity and configuration requirements, to be discussed in Sections 3.2, 4.2, and 5.1. The Guidelines also provide goals to which each structural design must conform. One such goal is to provide minimum lifecycle cost of ownership including design, construction, operating and maintenance costs. As a result, careful consideration of lifecycle efficiency and cost are key criteria in our designs.

While the projects are located on the UBC Campus, the stormwater system is closely connected to British Columbia Ministry of Transportation and Metro Vancouver jurisdictions; the SW Marine Drive project location borders on Ministry of Transportation land and the stormwater discharges through Metro Vancouver owned and operated outfalls. Consequently, the *Ministry of Transportation Association of Canada Geometric Design Guide* and *GVRD Bylaws* are also referred to.

The detention facilities consist of underground concrete tanks which must withstand all lateral loading, surface loading and seismic loading. The *Canadian Concrete Design Standard* is used to determine sizing of the concrete tanks and pipes, as described in Section 5.2.

Finally, water quality and cliff erosion is a concern whenever implementing new additions to storm drainage, as described in the *Fisheries Act, the Water Act*, and the *GVRD Sewer Use Bylaw No 164*. The requirements found in these guidelines are compared to the expected levels of contaminants, sediment, debris and oil at the project location. Where necessary, sediment filters and oil separators will be considered in the design to ensure stormwater discharge meets water quality guidelines. Outfall discharge and surface runoff rates will be monitored and controlled to minimize cliff erosion.

2.3 Adopted Design Life

The expected service life of the projects is 100 years, as the project is being designed to control a 100-year flood event. Beyond 100 years, potential flood volumes may exceed the designed storage capacity of the projects, and further upgrades will need to be considered. At Hampton Place, the detention facility is only in operation during a 100-year event, corresponding to an encounter probability of 63%, given the 100-year service life. However, the SW Marine Drive facility is expected to divert water at a 10-year event, corresponding to a 100% encounter probability.

For the project to be serviceable for this 100-year period, regular maintenance of the project will be required. The maintenance of the project can be divided in to the concrete storage structure, the water filtration system, and inflow and outflow piping.

The concrete storage structure when properly built, will last the full 100-year design life of the project, as the structural loading on the concrete is low. As the tanks are designed to act as a settling pond and oil separator, these tanks will require maintenance after severe rainfall events to remove oil and sediment buildup. The interiors of the tanks need to be regularly cleaned and inspected for cracks and seepage. The inspection process applies to the inflow and outflow piping as well to prevent sediment build up in the pipes and control deterioration of the pipes.

2.4 Design Loadings

The stormwater model provided by the client is used to determine the capacity of each stormwater detention system. As the objective of this project is to reduce flooding to acceptable levels for 100-year rainfall events, the design capacity is based on the results of the 100-year rainfall simulation, as shown in Figure 4. As recommended for coastal British Columbia, the SCS Type 1A curve was used to develop a 24-hour rainfall distribution for a 10- and 100-year return period rainfall (BC Ministry of Transportation, 2007). The rainfall intensity for the selected return periods were determined using an Intensity-Duration-Frequency (IDF) curve supplied by the client, shown in Appendix A. The intensity for a 24-hour duration rainfall event for a 10 and 100 year return period are 80.9 and 113 mm/h respectively.

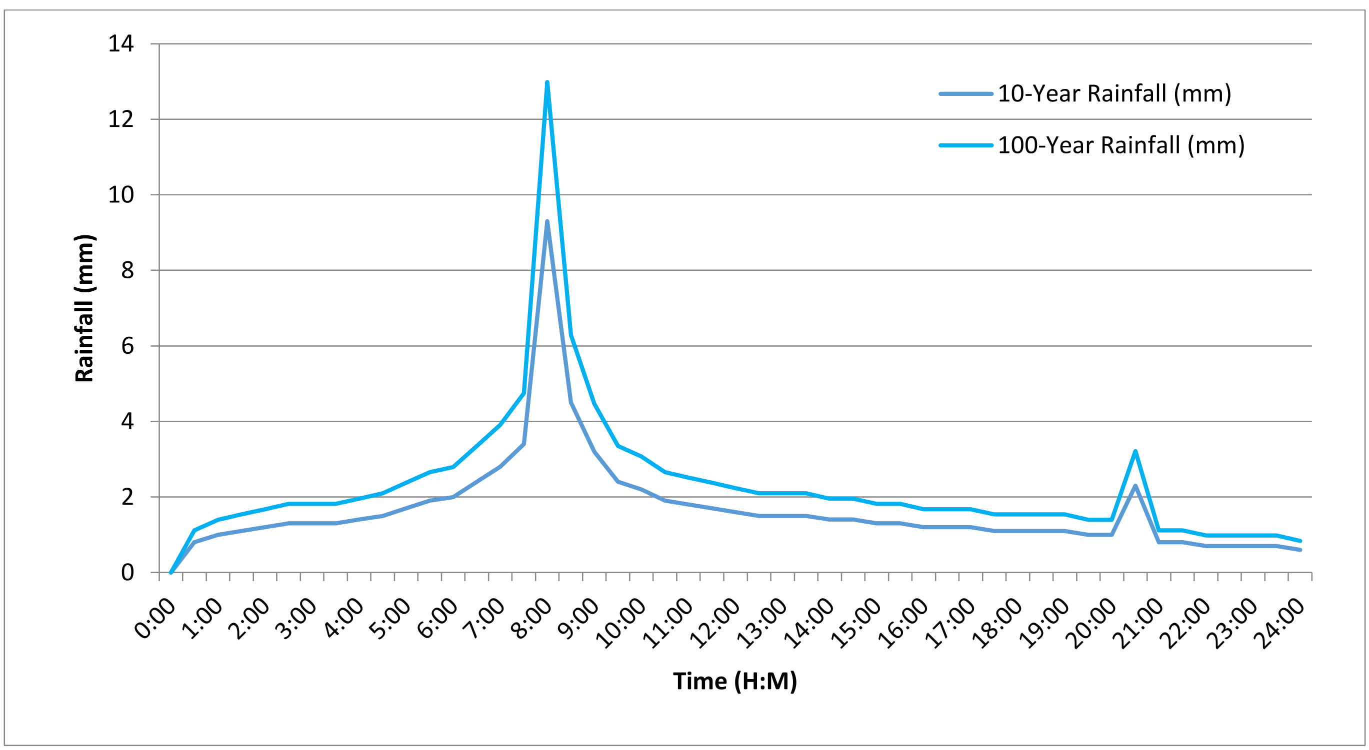


Figure 4: SCS Time Series

The flood volumes affecting high priority locations identified in the conceptual design phase of the project are determined using the results of a 100-year rainfall event simulation on EPA-SWMM, shown in detail in Appendix B. All nodes predicted to flood at Hampton Place and SW Marine Drive are shown in Figure 5 and Figure 6. At Hampton Place, a total of 206 cubic metres are expected to impact the emergency services buildings; nodes L89-286 and L9D-285C, indicated in Figure 5 by callout boxes, are the source of this flooding. At SW Marine Drive, 2926 cubic metres of flooding is expected to occur at a constriction located at node T6D-S24, shown in Figure 6. Further calculations are carried out in Section 5.1 to determine the required storage capacity and hydraulic capacity.

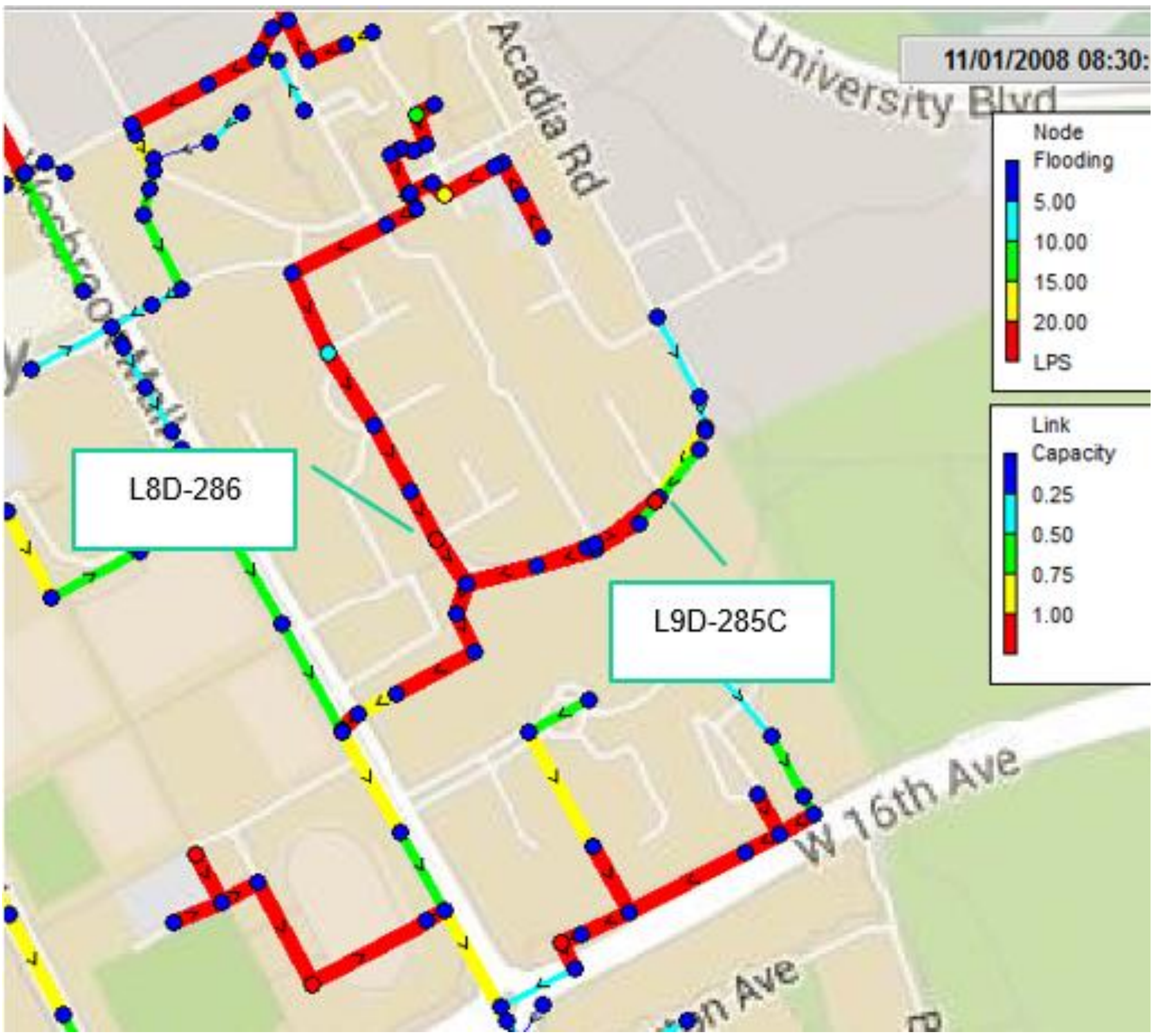


Figure 5: Hampton Place EPA-SWMM high flow results

Figure 6: SW Marine Dr EPA-SWMM high flow results

2.5 Software Packages

Several software packages were used in the preparation of this design, including AutoCAD, Civil 3D, SAP2000 and EPA-SWMM. Specific outputs used in this design project are included as illustrations in this report. While the files used to generate these outputs were not required as part of this deliverable, they are available upon request. A brief overview of the software and their purpose is described in the following sections.

2.5.1 AutoCAD and Civil 3D

A free student version of these programs were acquired from the Autodesk website. The programs were used for pipe system design and the creation of plan view drawings in typical urban systems. Civil 3D also enabled the creation of surfaces for the current ground elevation from VanMap, a City of Vancouver maintained site. Using this surface, elevation profiles were created to show pipe elevation, slope, and diameter relative to the existing and proposed ground elevations. These profiles illustrate the installation depth, predict the cost of excavation, and ensure sufficient ground cover will be installed over the proposed pipes and detention facilities. With the coordinates of certain tie-ins with the existing pipe system, Civil 3D was used to overlay an aerial image of the region to the plan view.

2.5.2 Sap 2000

A license for the structural analysis program SAP2000 was provided for academic use in the civil engineering undergraduate program. It was used to determine the forces acting on the individual cells of our detention tank. The magnitude of the forces were then used to design the walls of the cell.

2.5.3 EPA-SWMM

The client provided an EPA-SWMM model of the stormwater system on the UBC Campus. The configuration data found on the model were assumed to be an accurate representation of the system behaviour at the project location. The model was adjusted to simulate rainfall conditions in a 10-year and 100-year event. The results of the simulation were used to determine the design capacity of the detention facilities. The stormwater model was also used in conjunction with manual calculations to determine the optimal sizing of the detention facility components. The final detailed design of the detention facilities was implemented in the model; the model confirmed the designs are able to eliminate high risk flooding in a 100-year rainfall event.

3.0 Hampton Place – Design Outputs

An underground detention tank will be installed in the vacant area adjacent to Hampton Place and Acadia Park residences. The configuration of the facility is designed to capture excess stormwater volumes from nearby catchments. While the region is not expected to undergo flooding in a 10-year rainfall event, 100-year rain fall events will result in flooding that will likely impact the Fire Hall and RCMP building. The detention facility is designed to eliminate this risk of flooding these high importance buildings. The construction schedule estimates the construction phase will require 85 days to complete. The design, construction and implementation of the facility are expected to cost approximately $1,824,671. The following sections will discuss in greater detail the key components of the design and the design layout. Later sections will provide and in-depth discussion of the construction schedule and cost estimate of the design.

3.1 Components

Two new storm mains will be installed to divert high volumes of stormwater into the detention facility. In addition, an outlet pipe will tie into the existing stormwater system to gradually return the stormwater into the system. With the exception of 100-year rainfall events, the detention facility is expected to be dry. The detention facility will consist of precast concrete units placed side by side. A total of 96 units will be placed in a rectangular grid to provide up to 1200 m^3 of capacity. Figure 7 below provides several views of the design.

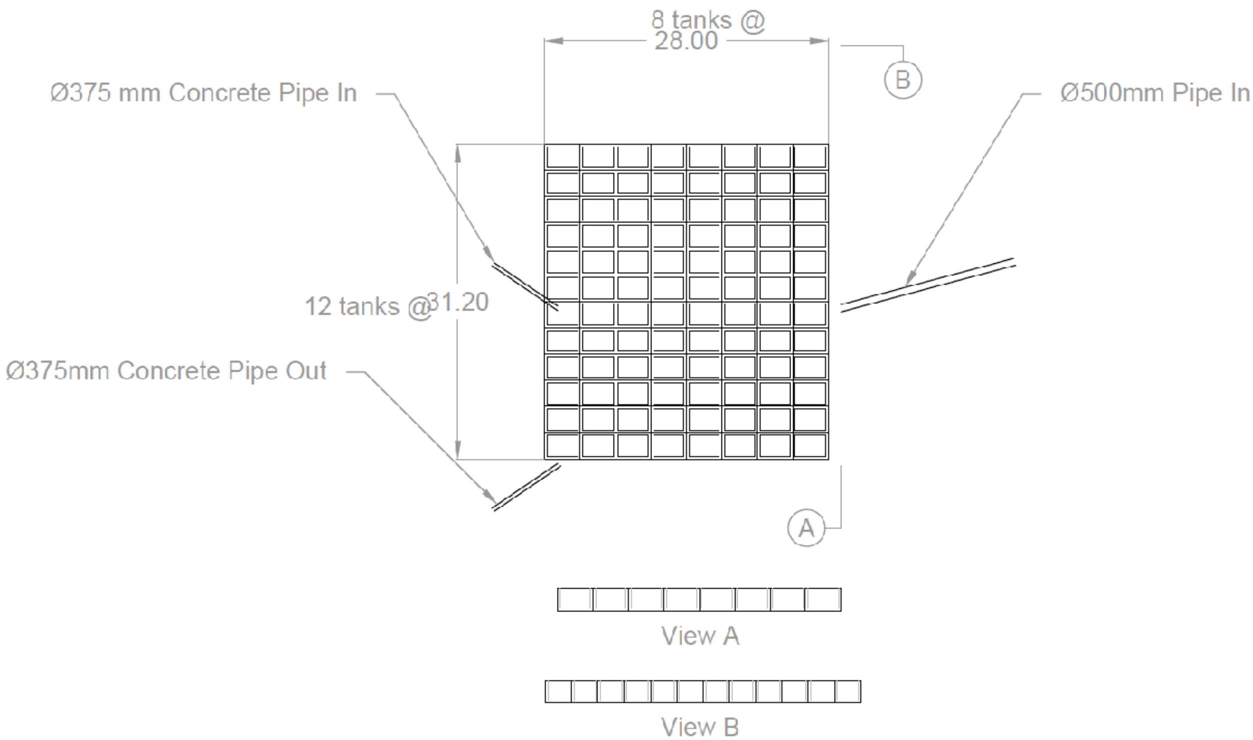


Figure 7: Hampton Place Detention Facility Layout

The following list provides a description of the individual components:

- **Pre-Cast Concrete Units** – A total of 96 pre-cast concrete units are arranged in an 8 by 12 rectangular grid. The pre-cast concrete was selected to reduce the construction time of the detention facility. Additionally, its durability, longevity, ease of installation and minimal maintenance requirements make it the ideal choice. While concrete is not entirely impermeable, it is expected to be capable of containing the water in extreme events given the 250 mm thickness of each wall of each unit. Rectangular slots are placed at the bottom of each unit to allow stormwater to distribute across the units while preventing the movement of oil that has risen to the water surface.

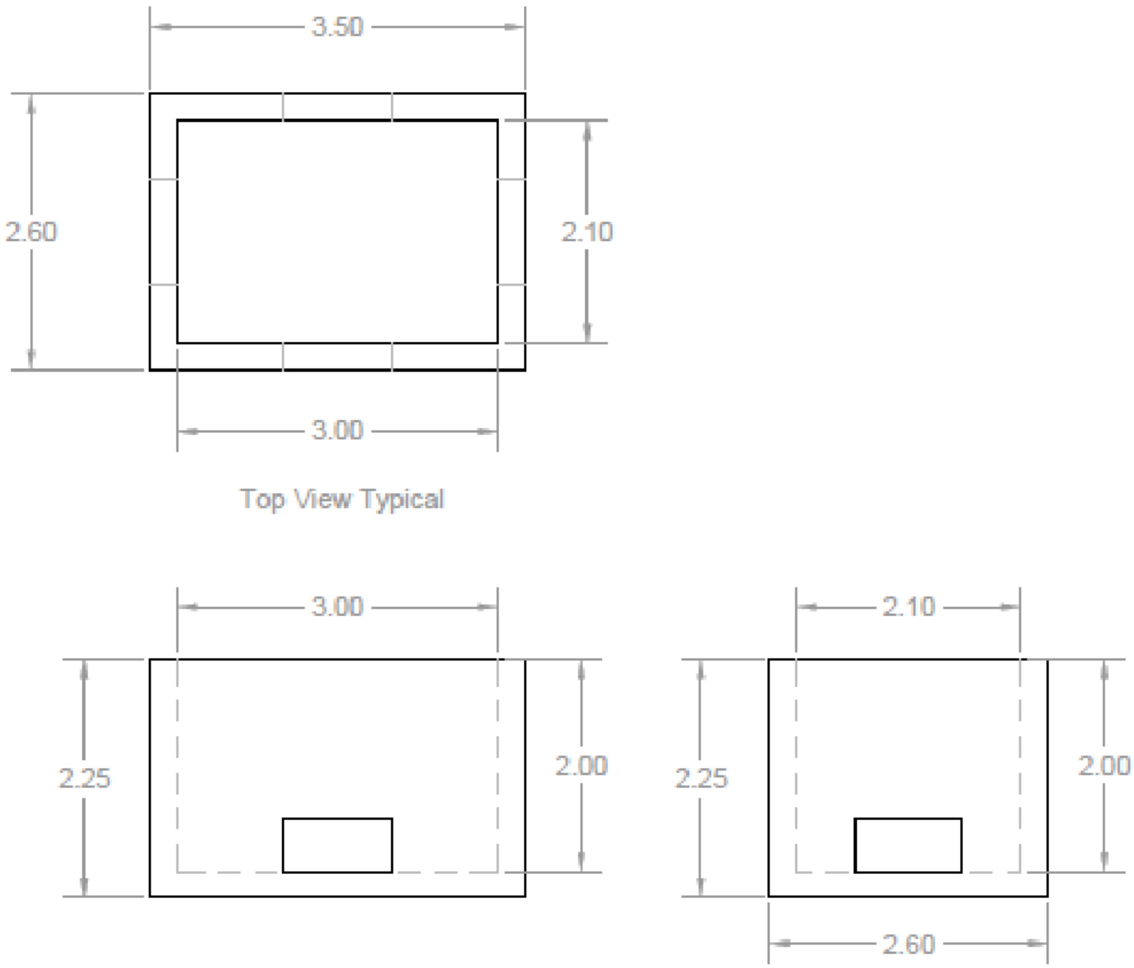


Figure 8: Cross sections of individual precast concrete tanks

- **Gravity Mains In and Out** – The detention tanks are placed at an elevation that allows for inflow and outflow to and from the existing system. The flow will be driven by gravity, caused by placing the inlet of the pipe at a higher elevation than the outlet. The purpose of this is to avoid the use of pumps; pumps require continual maintenance throughout the life of the system and would have to be on standby at all times. Using gravity flows avoids the cost of pumps and their associated running requirements. Due to the technical parameters discussed previously, 375 mm and 500 mm diameter pipes will lead into the detention facility and a 375 mm diameter pipe will exit the facility. Based on the sizes of the pipes, they must be constructed of concrete (UBC Technical Guidelines, 2015). The elevation profiles shown in the following figures show the downhill slope of the proposed pipes and the amount of ground cover above the pipes.

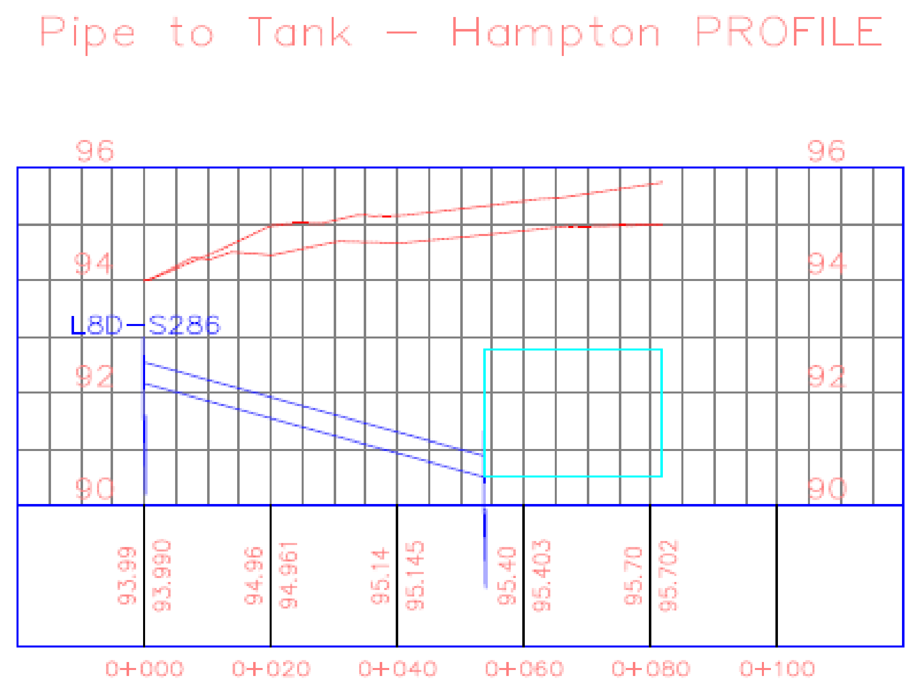


Figure 9: Elevation Profile of 500 mm Intake Pipe at Hampton Place

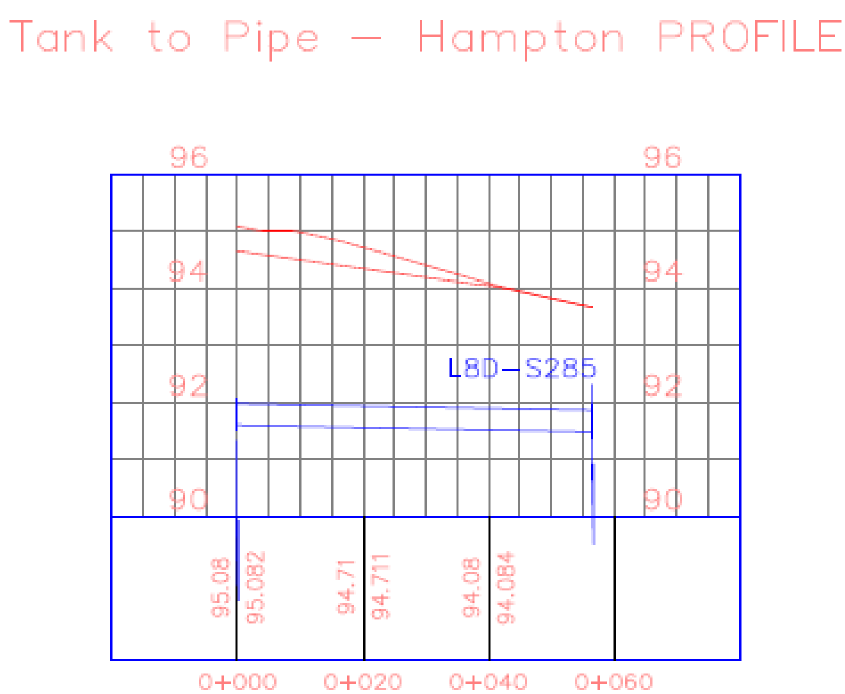


Figure 10: Elevation Profile of 375 mm Outtake Pipe at Hampton Place

3.2 Design Layout

This location was chosen due to the fire hall and police station being at this location. These buildings are of high importance especially in the event of a major flood. We are proposing to put a detention tank at the corner just uphill of these two buildings. The tank is made up of 8 by 12 cells which has a total volume of approximately 1210 m^3 and is made up of 96 individual cells. It ties into the existing pipe system at three locations with two pipes in and one pipe out. The west inflow pipe and outflow pipe have a diameter of 375mm and is concrete and the east inflow pipe is a 150mm diameter concrete pipe. At the south pipe inflow a catch basin will be installed. The current ground elevation will be lowered by approximately 1m up construction.

Figure 11: Hampton Place Plan View

4.0 Southwest Marine Drive – Design Outputs

The stormwater management system being installed at the corner of SW Marine Drive and Wesbrook Mall is an underground detention tank. This will supplement the existing infrastructure, which lacks the capacity to handle a 100-year storm condition, by providing additional storage capacity. This is to be done by tying into the existing culvert and pipes and diverting excess flow into modular concrete detention tanks. The construction schedule estimates the construction phase will require 65 days to complete. The design, construction and implementation of the facility are expected to cost approximately $4,221,404. The following sections will discuss in greater detail the key components of the design and the design layout. Later sections will provide and in-depth discussion of the construction schedule and cost estimate of the design.

4.1 Components

The stormwater management system features three key components. This includes components that are required for functionality as well as components that serve public interest, such as the environment. The key components are concrete tanks, gravity mains leading in and out of the tank, and membrane filters in the outlet pipe. The components are shown in Figure 12.

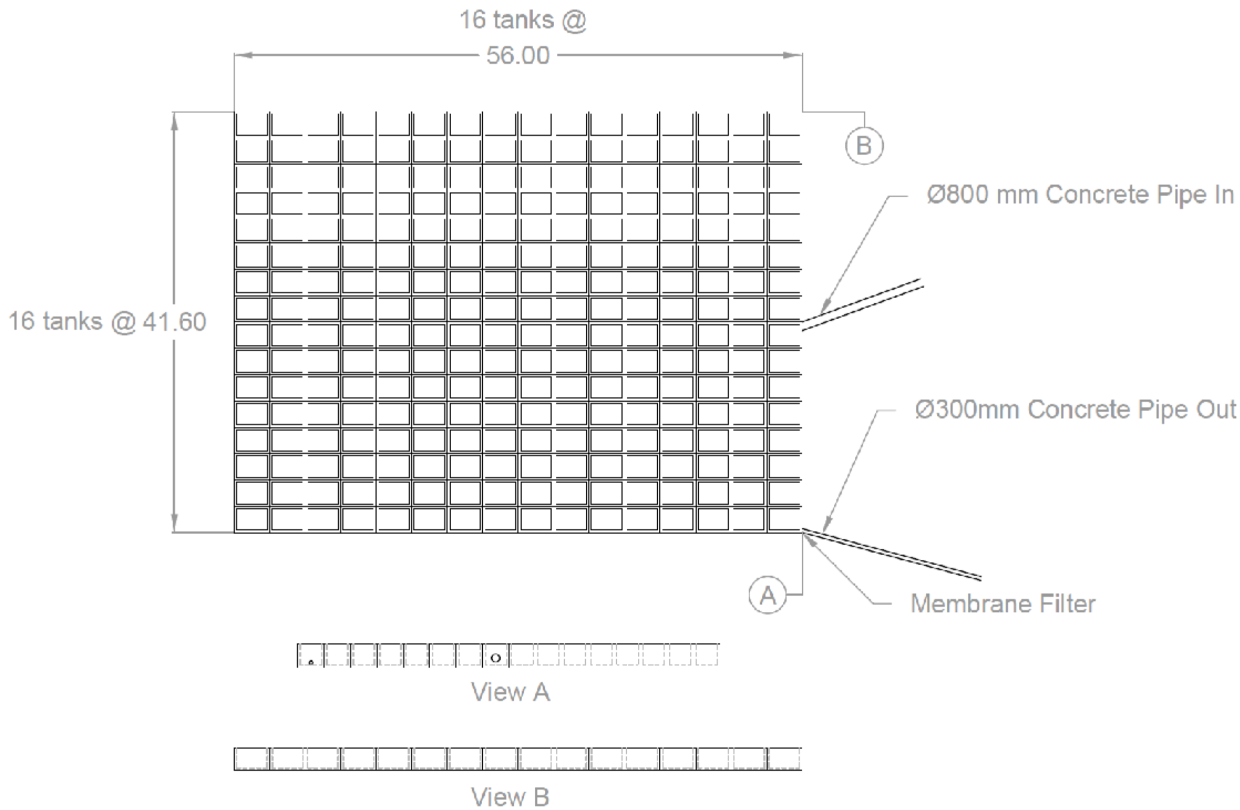


Figure 12: Dimensions of Hampton Place Detention Facility

The following is a detailed description of the design components:

- **Pre-Cast Concrete Units** – Instead of using a singular cast in place tank, which would be very difficult to pour and finish, modular pre-cast concrete tanks are being used. This will increase construction speeds, decrease construction costs, and increase the quality of the tank. The use of individual tanks also allows for future expansion and repair as tanks can be added or removed. A total of 256 pre-cast concrete units are arranged in a 16 by 16 rectangular grid. Rectangular slots are placed at the bottom of each unit to allow stormwater to distribute across the units. These units are shown in Figure 13.

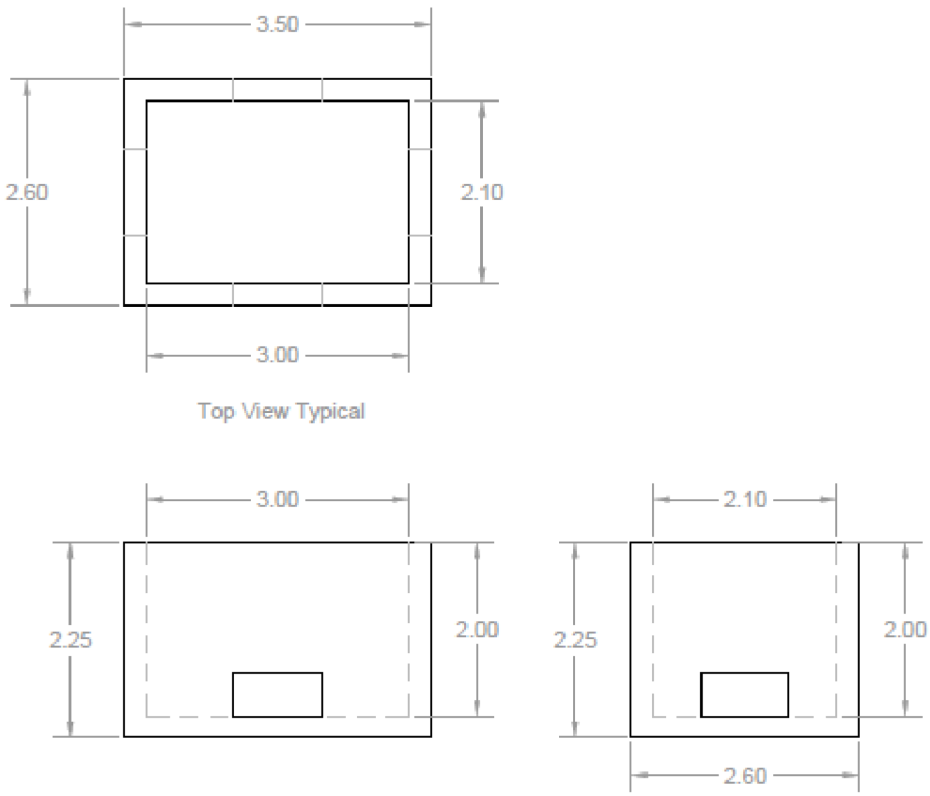


Figure 13: Cross sections of individual precast concrete tanks

- **Gravity Mains In and Out –** The detention tanks are placed at an elevation that allows for gravity flow into the tank, from the existing system, and gravity flow out of the tank, the outflow. The purpose of this was to avoid the use of pumps which would require continual maintenance throughout the life of the system and would have to be on standby at all times. Using gravity flows avoids the cost of pumps and their associated running requirements. Figure 14 and Figure 15 show the elevation profile of the storm mains and existing topography.

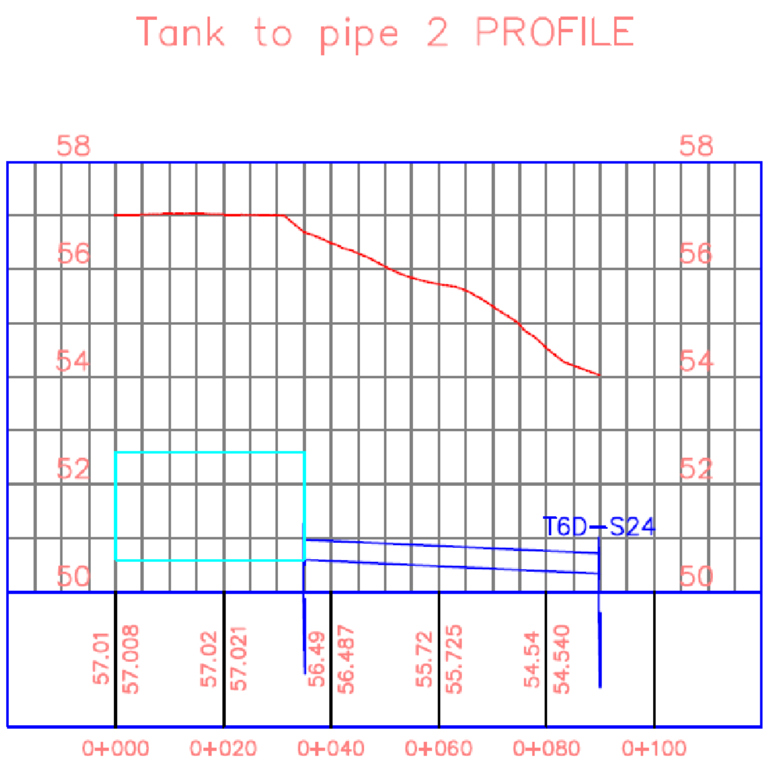


Figure 14: Elevation profile of existing ground, detention tank, and 300 mm diameter storm main

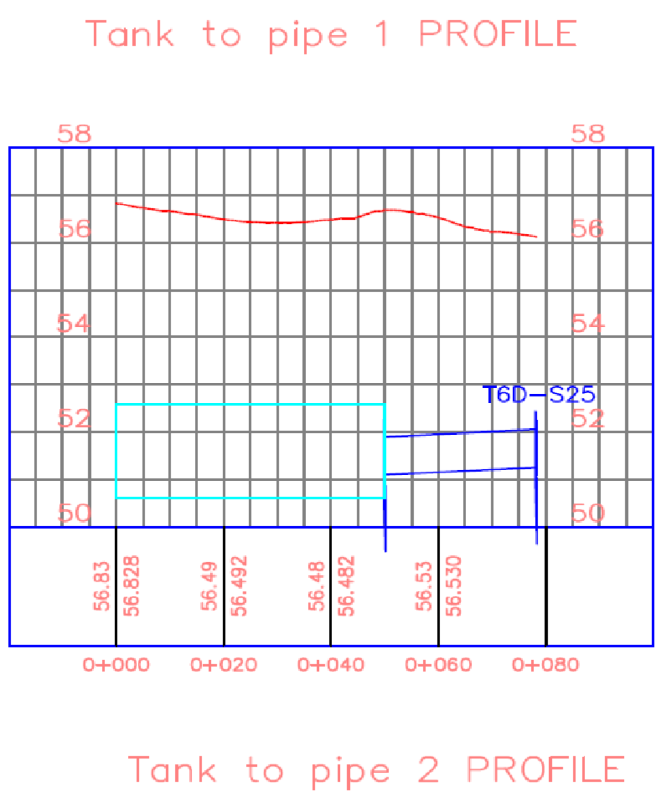


Figure 15: Elevation profile of existing ground, detention tank, and 800 mm diameter storm main

4.2 Design Layout

This location was chosen due to its location near an outfall and its relatively high flood volumes. This area also has several important research facilities. The proposed area of the tank is in the unused plot of land at the northeast corner of the intersection. The tank is made up of 16 cells by 16 and can hold a total volume of 3225m^3. This tanks has one inflow pipe and one outflow pipe that ties into the existing system. The inflow pipe has a diameter of 800mm and is concrete and the outflow pipe has a diameter of 375 mm and is also concrete.

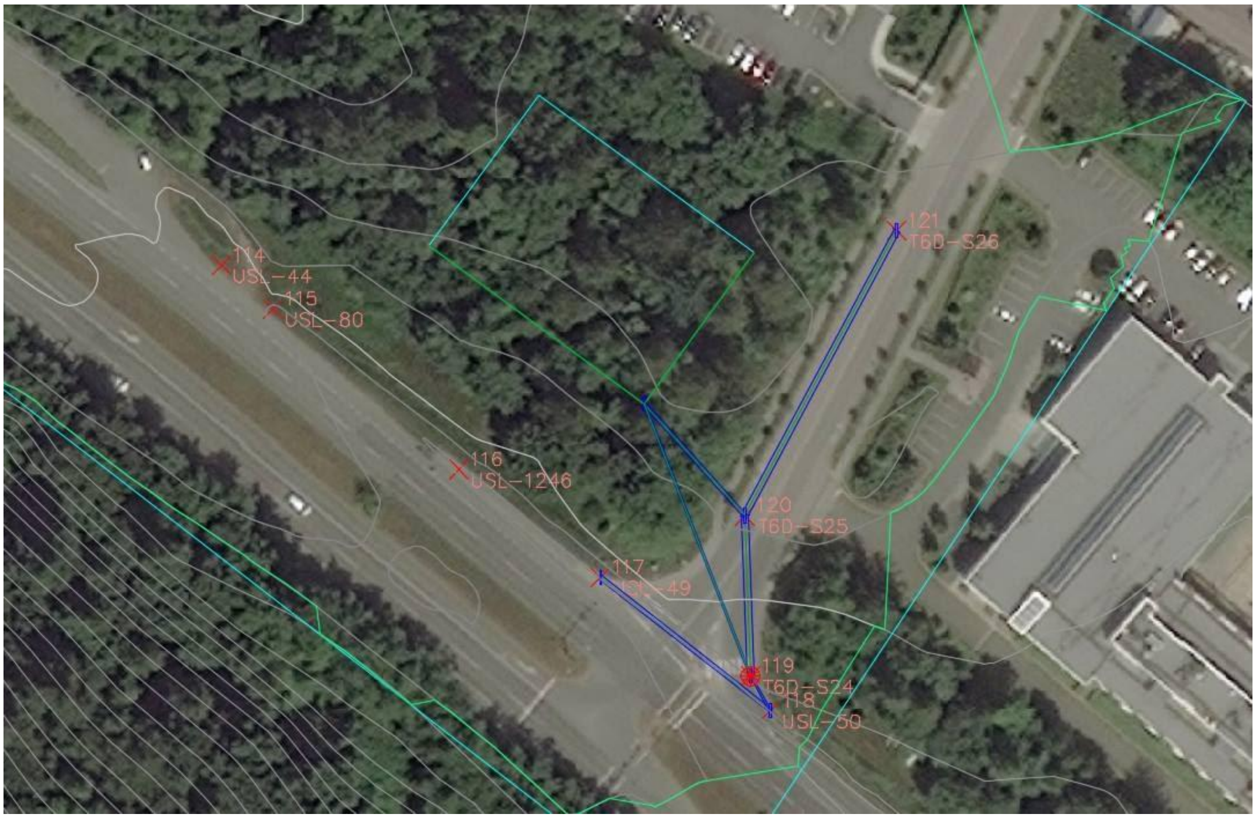


Figure 16: SW Marine Dr Plan View

5.0 Technical Considerations

Both detention facilities were designed to meet technical considerations such as hydraulic capacity, structural capacity and environmental requirements. Hydraulic capacity is defined as the stormwater system's ability to safely convey runoff to the outfall; it is typically governed by pipe slope and diameter. Insufficient hydraulic capacity may result in above ground flooding and damage to pipes. The temporary storage provided by detention facilities is intended to decrease the loading in areas that do not provide sufficient hydraulic capacity. Structural capacity is required to ensure the design is able to withstand external forces without damage. The external forces dictate the dimensions and materials used in the design. Finally, several environmental requirements are met in this design to ensure the protection of ecosystems situated in the vicinity of the detention facility and the discharge waters.

5.1 Hydraulic and Storage Capacity

The storm main diameters are sized to ensure the UBC Technical Guidelines are met. Storm mains must maintain minimum velocities of 0.6 m/s when flowing full or half full and is limited to a maximum velocity of 3.0 m/s (UBC Technical Guidelines, 2015). This design criterion is specified to ensure storm water is adequately conveyed during rainfall events while maintaining structural stability. The resulting storm main dimensions and details of the associated calculations are shown in Table 2 and Appendix C.

Table 2: Pipe Sizing and Placement Calculation Summary

Location	Invert Elevation (m)	Invert Elevation (m)	Pipe Invert Elevation (m)	Length (m)	Pipe Slope	Flow (m3/s)	Diameter, D (m)	Design Diameter (mm)	Velocity (m/s)	Travel Time (min)
SW Marine Drive										
T6D-S24	50.345	0.055	50.400	7.15	-1.4%	0.336	-	375	3.0	0.04
USL-50	50.300		50.300							
T6D-S25	51.260	0.000	51.260	54.00	-0.9%	1.253	0.796	800	2.5	0.36
In_Wesbrook	50.600	0.160	50.760							
Out_Wesbrook	50.600	0.500	51.100	28.00	-2.7%	0.336	0.398	375	3.0	0.15
T6D-S24	50.345	0.000	50.345							
Hampton Place										
L89-S285	91.485	0.005	91.490	29.67	-1.3%	0.598	-	500	3.0	0.16
L8D-S284	91.105	0.010	91.115							
L9D-S301	93.195	0.005	93.200	59.39	-0.4%	0.145	-	250	3.0	0.34
L9D-S300	92.955	0.005	92.960							
L9D-S300	92.955	0.004	92.959	70.00	-0.3%	0.470	-	450	3.0	0.39
L9D-S285	91.485	1.235	92.720							
L8D-S286	92.165	0.005	92.170	50.88	-1.3%	0.354		500	1.8	0.47
L8D-S285	91.485	0.000	91.485							
L8D-S286	92.165		92.165	73.00	-1.2%	0.321	0.456	375	2.9	0.42
In_Hampton1	91.000	0.300	91.300							
CB	92.955		92.955	46.00	-4.3%	0.034	0.154	150	1.9	0.40
In_Hampton2_CBLEAD	91.000		91.000							
Out_Hampton	91.000	0.600	91.600	56.00	-0.2%	0.062	0.341	375	0.6	1.67
L8D-S285	91.485		91.485							

To determine the storage capacity, the maximum allowable flow rate of storm mains immediately downstream of the flood locations are calculated based on the maximum allowable velocity of 3.0 m/s, as shown in the table above. Based on 10- and 100-year rainfall event simulation, the inflow of the nodes at which the flooding occurs are compared to the maximum allowable flow rate. The flow in excess of the maximum allowable velocity will require detention to eliminate flooding. In other words, the storage requirement for a 100-year rainfall event is equal to the area of the shaded polygons in Figure 17 and Figure 18.

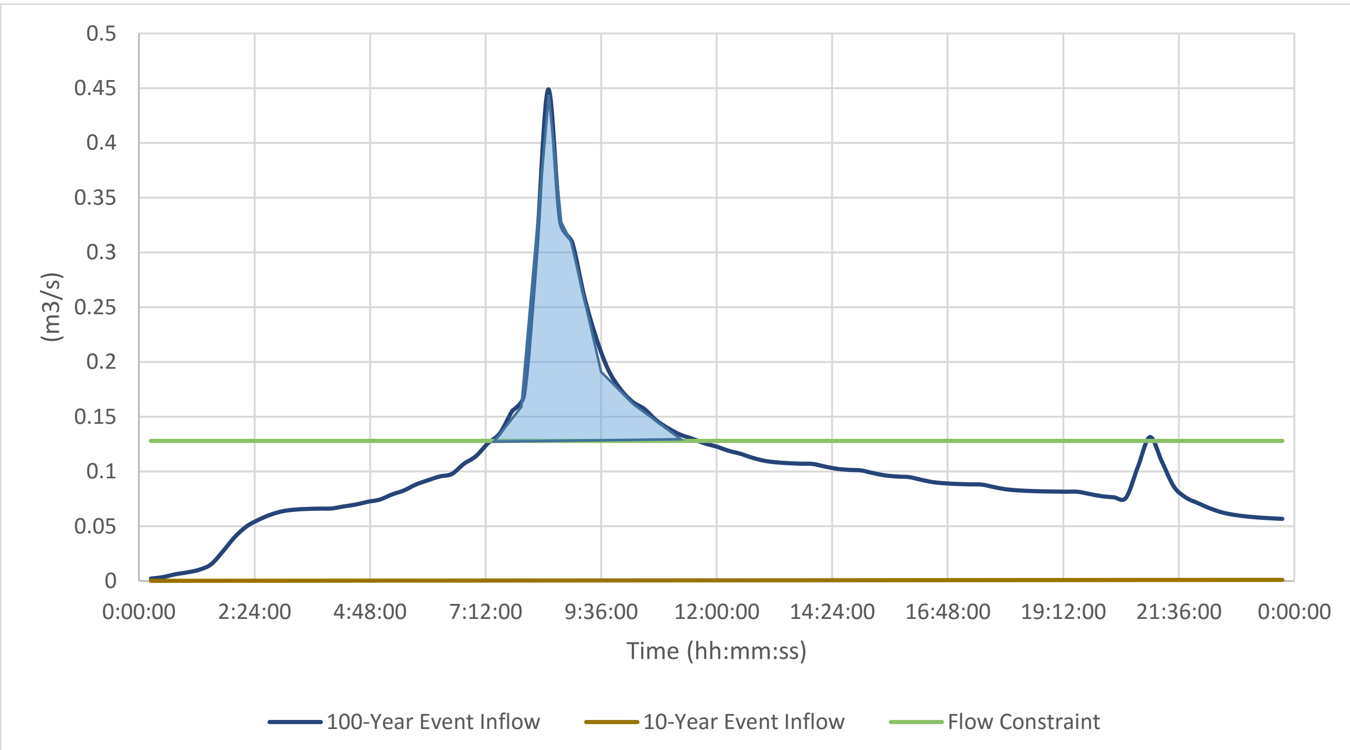


Figure 17: Hampton Place Storage Requirement Calculation Based on EPA-SWMM Node L8D-S286

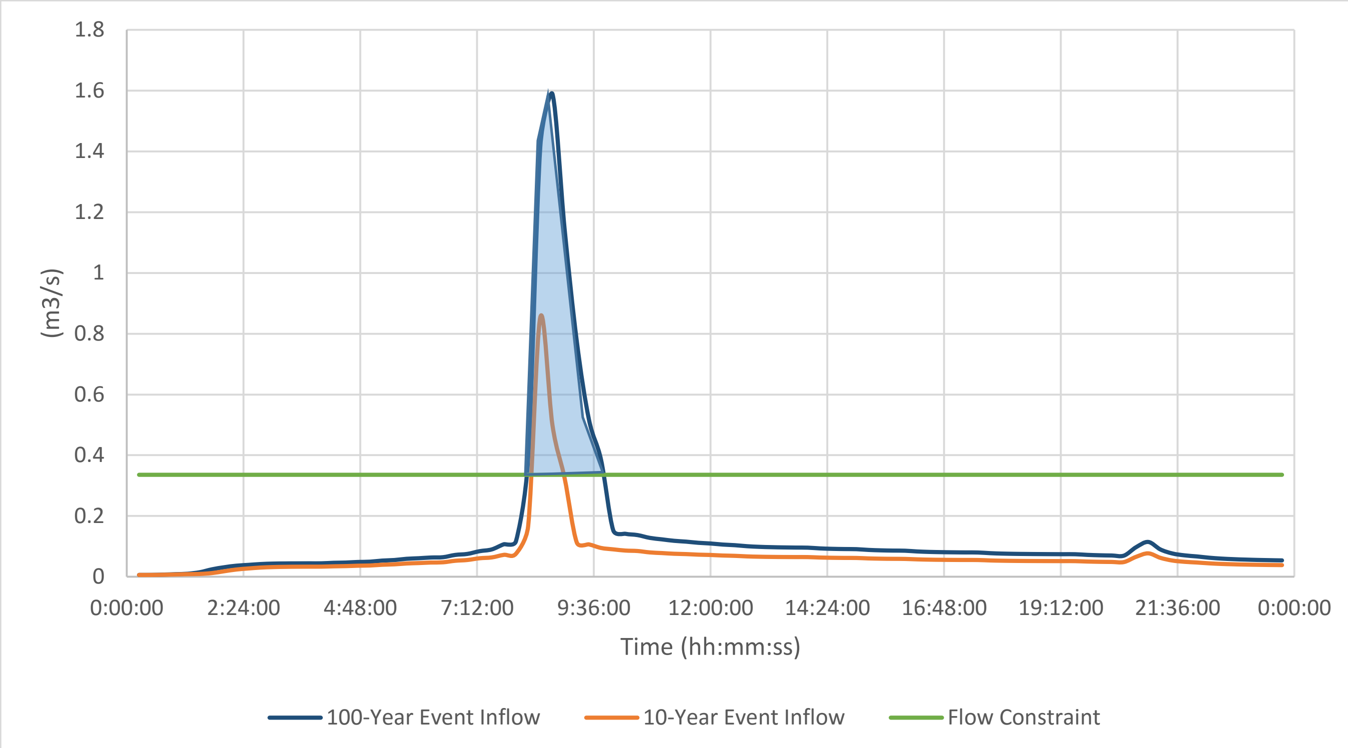


Figure 18: SW Marine Drive Storage Requirement Calculation Based on EPA-SWM Node T6D-S24

The design parameters and resulting storage requirement are summarized in Table 3. The required storage capacities correspond to the design volumes with an approximate factor of safety of 1.0. This factor was selected as the probability of exceedance and the impact of exceedance results in an acceptable level of risk. In a 100-year storm event, minor amounts of ponding and safe overland flow is allowable by regulation.

Table 3: Storage Requirements

Location	Limiting Flow (m/s)	100-Year Return Period		10-Year Return Period	
		Excess Flow (m3/s)	Required Storage (m3)	Excess Flow (m3/s)	Required Storage (m3)
Hampton Place	0.128	1.310	**1179**	0.000	0
SW Marine Drive	0.336	3.862	**3476**	0.681	613

5.2 Structural Capacity

Because the water storage tanks are buried, they are under the effects of external earth pressures that will compress the tanks. It is of critical importance of the tanks do not fail due to these vertical or lateral earth pressures. As such, the tanks are designed to withstand the loads created by these earth pressures.

Based on geotechnical reports, the composition of the soil at the Hampton and SW Marine locations are likely to be sand or silt (EBA Consulting Engineers & Scientists, 2013), which have a unit weight of 20.42 kN/m^3 and 18 kN/m^3, a friction angle of 38^o and 35^o, and a passive soil factor (Ko) of 0.384 and 0.426 respectively. Using Rakine's method, lateral earth forces were determined at both locations.

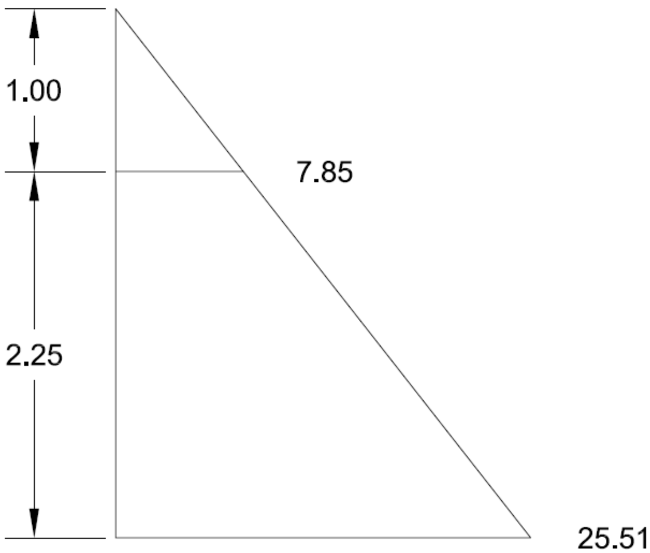


Figure 19: Hampton Sand Pressure Distribution

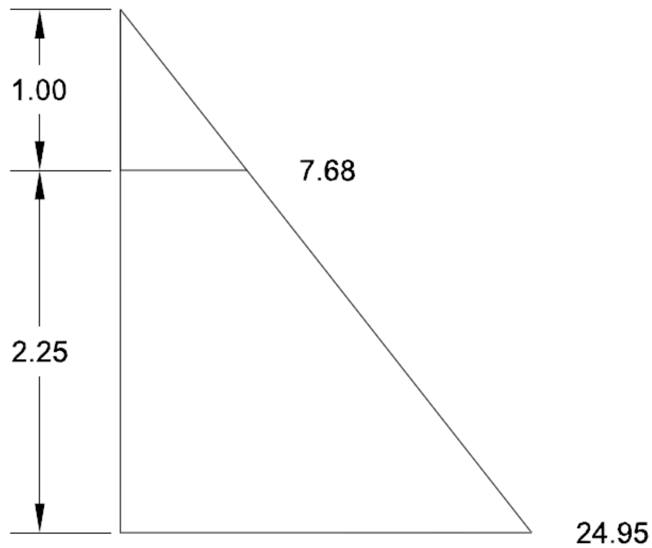


Figure 20: Hampton Silt Pressure Distribution

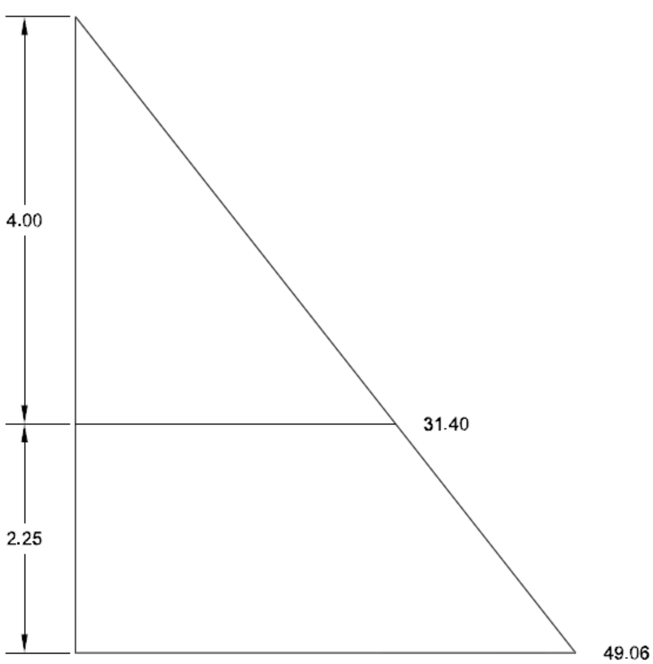


Figure 21: SW Marine Sand Pressure Distribution

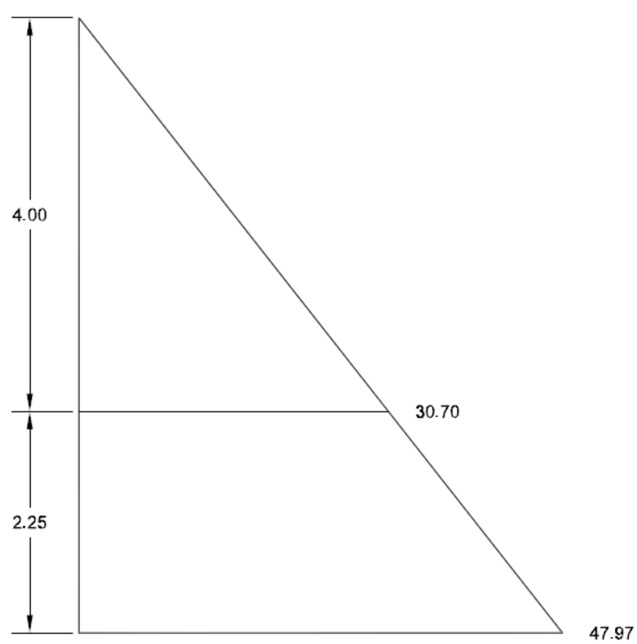


Figure 22: SW Marine Silt Pressure Distribution

Looking firstly at the Hampton location, the tanks are to be buried at a depth of 1 meter and reach a final depth of 3.25 meters. The lateral load will be 7.84 kN/m at the top of the tank and 25.51 kN/m at the bottom for sand and 7.68 kN/m and 24.95 kN/m for silt. The maximum moment in the wall of the tank is 34.09 kNm.

Following the same procedure for the SW Marine location, the maximum moment experienced by the wall of the tank is 80.6 kNm. Following design procedures from the Canadian concrete design manual, the minimum moment resistance of the 250mm thick reinforced concrete tank wall is 145.45 kNm.

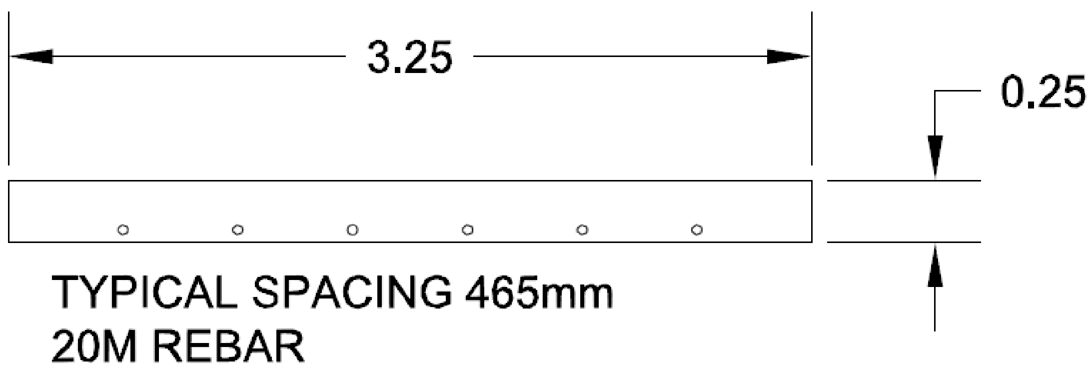


Figure 23: Typical Rebar Spacing for Vertical Concrete Walls

The roof of the tank, however, will experience larger moments than the side walls in the SW Marine location. The expected moment is 161.25 kNm which will require the roof of the tank to have a modified design from the rest of the tank. Increasing the amount of reinforcement raises the moment resistance to 191.11 kNm. The need for a higher resistance is unfound as there should not be any reason for additional surface loading in the SW Marine area. Following the same design in the Hampton area is sufficient as the tanks will be buried much closer to the surface, and similar to SW Marine, there is no reason for additional surface loading.

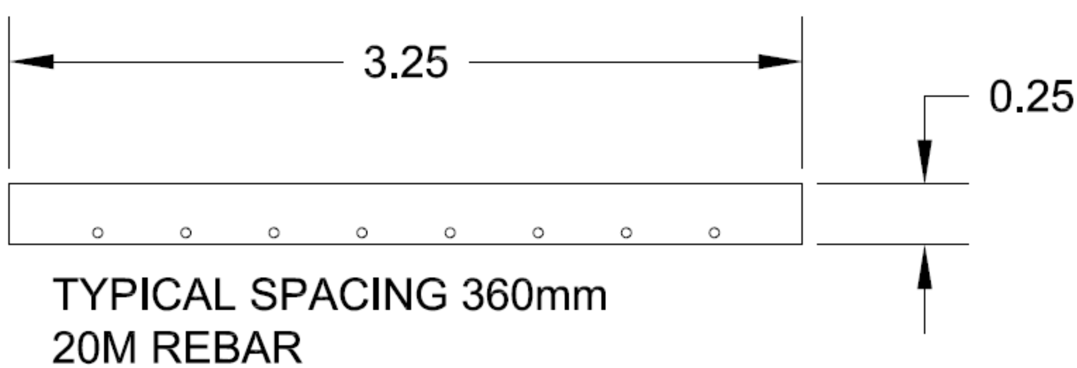


Figure 24: Typical Rebar Spacing for Horizontal Concrete Slabs

5.3 Environmental Requirements

Reducing the risks of environmental impact is of high importance in the design process. The preliminary design must conform to UBC's 20 Year Sustainability Strategy. As noted in the strategy, the second strategic goal for operations and infrastructure is "the integration of campus-scale energy, water, waste, and food systems is linked to improved quality of life for students, staff, faculty and campus community and to enhanced ecological integrity" (UBC Sustainability and Engineering, n.d.).

Because of the high importance of students, faculty, and ecological integrity it is important that the designs further the progress made towards enhancing the sustainability of the campus. To be sustainable, the designs are focused on lowering carbon dioxide emissions and minimizing impact on all existing ecosystems.

Both the Hampton Area and the SW Marine Drive location are forested areas where ecosystems and carbon dioxide-reducing vegetation exist. As a result, minimizing the surface area of land usage correlates with minimizing environmental impact. Thus, there is a focus on minimizing the clear-cut area and incorporating new vegetation. Thus, our designs focused on reducing transported materials and minimizing truck shipments to reduce carbon dioxide emissions during the construction phases. Furthermore, our designs incorporate recyclable materials such as concrete with recycled aggregate to avoid issues with deconstruction and replacement at the end of the life cycles.

Finally, to increase the quality of stormwater discharge, sediment, contaminants and oil carried by the runoff are to be reduced when detained in the detention facility. The detained stormwater will have an hydraulic resonance time of 4 hours, allowing for sediment and debris to settle at the base of the tank while oil and grease rise to the water surface. The inflow pipes are sized to limit the inflow rate to avoid turbulent mixing, preventing the sediment and oil from being mixed into the discharge. Each detention tank unit is designed to act as an oil separator; the slots located at the base of unit allow for stormwater to travel from the inflow location to the outflow location gradually while the walls of the units at a higher elevation prevent the movement of oil and grease. The outflow pipe is located at a minimum of 0.5 m above the base of the tank to prevent settled particles from being discharged.

6.0 Construction Planning

The construction process will be able to begin after the completion of the following items:

- Funding Approval
- Permitting
- Construction Tendering
- Construction Award

After the completion of these items, the construction process will begin. Currently, the process is estimated to begin in May 2016 and will require less than two months to complete. The construction schedules for both locations can be found in Appendix E. As previously mentioned, the implementation of these projects are subject to budgetary approval. To facilitate this process, a cost estimate is also included below, estimating a total construction cost of $6 million Canadian.

6.1 Hampton Place - Construction Schedule

Construction will begin on May 2nd with a site preparation survey. They will mark out utilities and cut and fill locations. This will be followed up on May 9th with full site mobilization, setting up perimeter fencing, and material excavation. Upon completion of the material excavation on, pipes will be delivered and pipe installation locations will be marked. Installation of pipes and tanks will begin on May 26rd and will be completed on June 1st. Infill and compaction will follow, but unlike Hampton, there is no need for landscaping activities. Site demobilization and site cleanup will follow.

Being on UBC grounds, the scheduling of construction activities for the Hampton Place water management facility must follow the Noise Control Bylaws set forth by the University Neighbourhoods Association (University Neighbourhoods Association, 2012). Work hours are to be between 7:30am and 7:00pm on weekdays and 9:00am to 5:00pm on weekends and, because the work site is within 50 meters of residential boundaries, power equipment can only be used between 8:00am and 6:00pm on weekdays and 10:00am and 5:00pm on weekdays.

In addition to time constraints, there are also environmental constraints. According to (Holiday Weather, 2015) there is an average rainfall in Vancouver of 70mm over 14 days in May. Soil compaction cannot be performed when the ground conditions are wet and given that compaction is a critical activity, will increase the construction time required for completion. The road required for transportation of materials and equipment is a small 2 lane residential road with car parking on the side of the road. This will limit the size of the vehicles used for mobilizing equipment and materials to and from site.

Before construction can begin, there are several permits that must be acquired; the first being a Streets and Landscaping permit and the second being an Excavation and Backfill permit. This will require the submission of a development permit application, public notification, review by the Advisory Urban Design Panel and the Development Review Committee, a public open house, project amendments if necessary, and consideration by the UBC Development Permit Board.

Construction will begin on May 2nd with a site preparation survey. They will mark out utilities and cut and fill locations. This will be followed up on May 9th with full site mobilization, setting up perimeter fencing, and material excavation. Upon completion of the material excavation on, pipes will be delivered and pipe installation locations will be marked. Installation of pipes and tanks will begin on May 23rd and will be completed on May 27th. Infill and compaction will follow and landscaping will begin on May 7th which will include the installation of playground equipment. Site demobilization and site cleanup will follow.

6.1 Southwest Marine Drive - Construction Schedule

The SW Marine water management facility is similar to Hampton with regards to constraints. As it is on UBC grounds, it must follow the Noise Control Bylaws limiting the work hours from 7:30am to 7:00pm on weekdays and 9:00am to 5:00pm on weekends. There are no limitations on power equipment use as the construction site is far from residential boundaries.

Delays to the schedule could occur due to environmental factors such as rain. Compaction, a critical schedule activity, cannot be performed if there are wet soil conditions. In May, there is an expected 70mm of rainfall over the course of 14 days according to (Holiday Weather, 2015). There will not be any need to close any roads due to the size of SW Marine and the space available to hold equipment and materials that are delivered to site. A flag person will still be required to direct traffic when material and equipment trucks arrive or depart.

Before construction can begin, there are several permits that must be acquired; the first being a Streets and Landscaping permit and the second being an Excavation and Backfill permit. This will require the submission of a development permit application, public notification, review by the Advisory Urban Design Panel and the

Development Review Committee, a public open house, project amendments if necessary, and consideration by the UBC Development Permit Board.

6.2 Cost Estimate

The cost estimate provided corresponds with the construction schedule above as well as accounting for indirect costs such as operations and maintenance, stakeholder engagement, and engineering services. This estimate is based on our preliminary design and assumptions made. Major elements in this design are assessed and priced at fair market value in 2015 Canadian dollars. Some items will be in form of lump sum and some based on unit costs. All prices are retrieved are from North American sources to better reflect actual costs. Users of this estimate should carefully read the inclusion list. For the purpose of this estimate, indirect cost is estimated at 30% of direct costs, Contingency is estimated at 10% of total costs, and profit estimated at 7% of total costs.

The Hampton Place and SW Marine Drive designs are estimated to cost $1,824,671 and $4,221,404 respectively. The detailed cost estimate is provided in Appendix F.

7.0 Recommendations for Design Improvement

This design process is based mostly on a theoretical approach; the flood models are idealized and simplified, the proposed budget is based on estimates, and the design itself has yet to be physically modeled and tested. As the project moves forward, further steps will be required to ensure that the theoretical approach used in this report can accurately describe scaled physical models. The budget and construction plan of the project will also need to be verified with contractors and stakeholders.

7.1 Additional Data

For the purpose of this design process, the expected rainfall volumes and return periods for the Greater Vancouver area are used, and the permeability and run-off rates in the project areas are assumed based on guideline values. However, these values may not accurately reflect the specific soil conditions or rainfall conditions at the capture areas for our project sites. Therefore, detailed rainfall data at the UBC campus and information regarding earth conditions will be required to improve the accuracy of this report.

7.2 Field Tests

The soil conditions at the project locations will also affect whether further structural support will be required for the detention tank complexes and may hinder the construction process as shoring may also be required. These conditions cannot be estimated by examining surface conditions. Therefore, field tests for soil conditions, such as grain size, saturation, and bearing capacity, should be conducted prior to construction.

7.3 Next Phases

Prior to the commencement of the project, stakeholders should be consulted regarding the final outlook of the design. These stakeholders will include the residences of Acadia Park and Hampton Place, UBC, the University Endowment Land Administration Office, and First Nations peoples. This can be achieved through public consultation sessions and design reviews. Field tests and further data should also be analyzed, prior to bidding and construction.

As these two projects are constructed, the rainfall and flooding patterns in the two areas should be closely monitored. These two projects may serve as a baseline test as to whether this type of stormwater detention system is indeed efficient and effective, and future projects using this type of detention system may be considered at other flooding risk locations on the UBC campus. Monitoring of flooding patterns will also reflect the actual capacities of these two projects. Although the projects at both Hampton Place and Wesbrook-Marine Drive locations have been designed for 100-year rainfall events, future expansions can be considered.

8.0 Conclusion

Through thorough considerations of stormwater modelling predictions, environmental impacts, design constraints, design budget, ease of construction, UBC stormwater guidelines, regulatory standards and requirements, and stakeholder implications, detailed stormwater facility design has been produced to control the impact of a 100-year flood event. The design minimizes damage to UBC facilities, reduces harm to riparian habitat, and prevents cliff erosion by providing a diversion for the stormwater. The storage tanks are carefully designed to account for lateral forces of the earth where they will be installed. Pipe networks are designed with the considerations of flood locations obtained from stormwater model analyses. The design is simple yet effective, and is easily scalable to virtually accommodate any amount of wastewater. It will cost 6 million Canadian dollars and two weeks of construction, but the value of damage reduction, the peace of mind it provides, and the protection of the safety of students, faculties, workers, and residents of UBC far outweighs this cost.

References

BC Ministry of Transportation. (2007). *Supplement to TAC Geometric Design Guide.* BC Ministry of Transportation.

EBA Consulting Engineers & Scientists. (2013). *Pavement Evaluation and Options Development - Agronomy Road to Chancellor Boulevard.* Vancouver: EBA Consulting Engineers & Scientists.

Environment Canada. (2012, February 9). *Short Duration Rainfal Intensity-Duration-Frequency Data, Vancouver, UBC.* Retrieved October 10, 2015, from UBC Technical Guidelines: http://www.technicalguidelines.ubc.ca/Division_2/dwg_files/2015/Div_2_Combined_pdf_files.pdf

Google Maps. (2015, November 30). *Google*. Retrieved November 30, 2015, from Google Maps: University of British Columbia: https://www.google.ca/maps/place/The+University+of+British+Columbia/

Holiday Weather. (2015, November 15). *Vancouver: Annual Weather Averages*. Retrieved from Holiday Weather: http://www.holiday-weather.com/vancouver/averages/

Houghtalen, R. J., Akan, A., & Hwang, N. H. (2010). *Fundamental of Hydraulic Engineering Systems.* New Jersey: Prentice Hall.

UBC Sustainability and Engineering. (n.d.). *20-Year Sustainability*. Retrieved April 1, 2016, from Sustain UBC: https://sustain.ubc.ca/sites/sustain.ubc.ca/files/uploads/CampusSustainability/CS_PDFs/PlansReports/Plans/20-Year-Sustainability-Strategy-UBC.pdf

UBC Technical Guidelines. (2015). *02720-2015 Storm Drainage.* Retrieved November 30, 2015, from UBC Technical Guidelines: http://www.technicalguidelines.ubc.ca/technical/divisional_specs.html

University Neighbourhoods Association. (2012, August 8). *Noise Control Bylaw ("Bylaw").* Retrieved November 15, 2015, from University Neighbourhoods Association: http://www.myuna.ca/wp-content/uploads/2010/04/UNA-Noise-Bylaw_Approved_Aug-2012.pdf

Appendix A: Rainfall Intensity-Duration-Frequency Curve

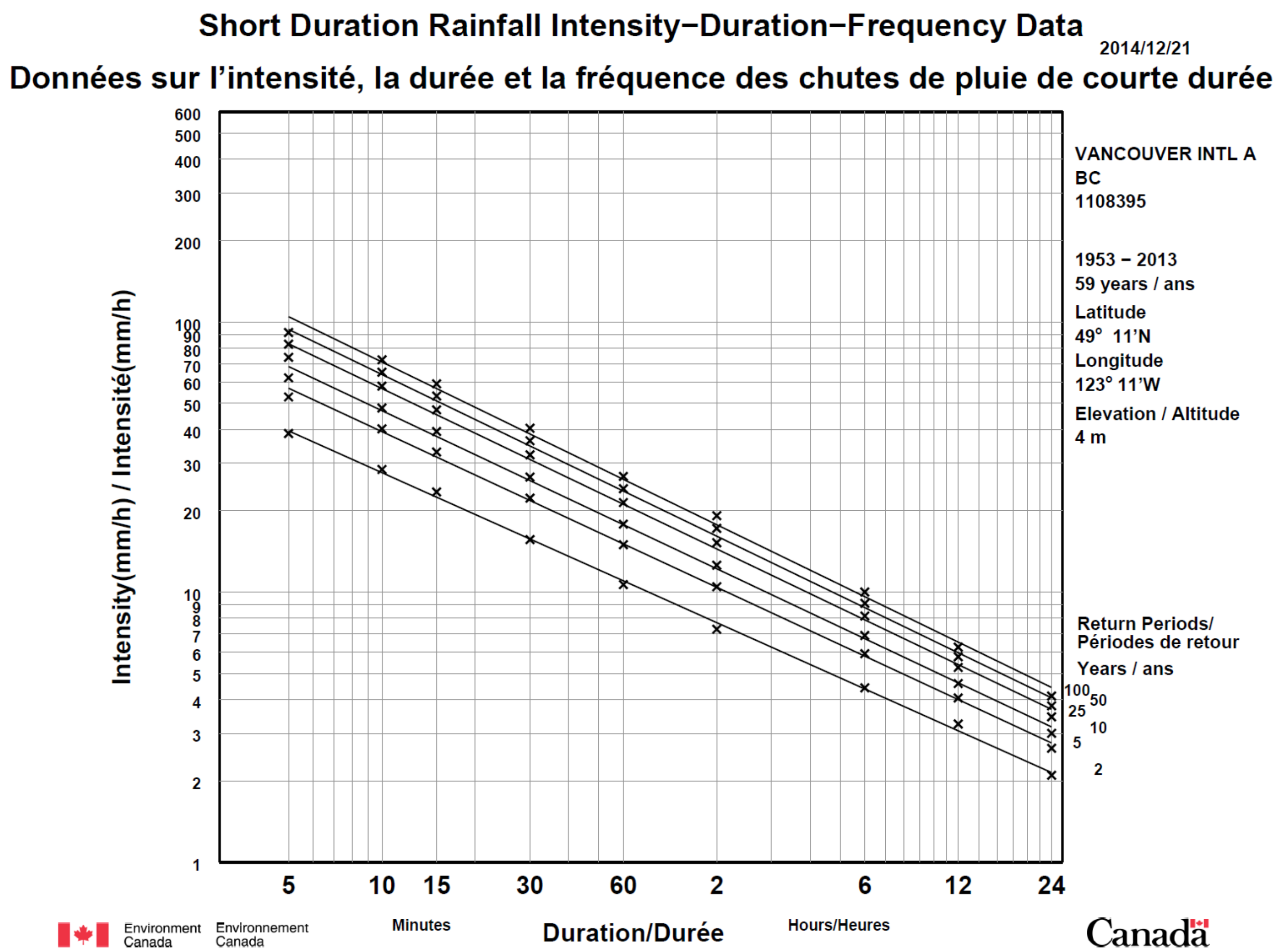


Figure 25: Intensity-Duration-Frequency Curve

Source: (Environment Canada, 2012)

Appendix B: EPA-SWMM Results

Figure 26: Southwest Marine Drive and Wesbrook Mall Capacity:

Node	Hours Flooded	Maximum Rate LPS	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr
T6D-S24	1.18	1395.03	8:42	2.926
Total:				**2.926**

Figure 27: Hampton Place Capacity

Node	Hours Flooded	Maximum Rate LPS	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr
K8D-S289	0.13	6.28	8:30	0.001
L8D-S282	0.02	473.66	8:16	0.023
L8D-S286	0.46	150.48	8:30	0.172
L9D-S285A	0.01	2.73	8:16	0
L9D-S285C	0.47	33.53	8:29	0.034
L9D-S285D	0.1	2.09	8:30	0
Total:				**0.230**

Table 4: Hampton Place Excess Flow Determination Based on Existing Node L8D-S286

Days	Hours	100-Year Event		10-Year Event	
		Inflow (m3/s)	Excess (m3/s)	Inflow (m3/s)	Excess (m3/s)
0	0:15:00	0.00221		1.04E-05	
0	0:30:00	0.00355		2.08E-05	
0	0:45:00	0.00606		3.13E-05	
0	1:00:00	0.00786		4.17E-05	
0	1:15:00	0.01023		5.21E-05	
0	1:30:00	0.01521		6.25E-05	
0	1:45:00	0.02731		7.29E-05	
0	2:00:00	0.04054		8.33E-05	
0	2:15:00	0.05023		9.38E-05	
0	2:30:00	0.05618		0.000104	
0	2:45:00	0.06077		0.000115	
0	3:00:00	0.06382		0.000125	
0	3:15:00	0.06519		0.000135	
0	3:30:00	0.0658		0.000146	
0	3:45:00	0.06608		0.000156	
0	4:00:00	0.06621		0.000167	
0	4:15:00	0.06806		0.000177	
0	4:30:00	0.06976		0.000188	
0	4:45:00	0.0723		0.000198	
0	5:00:00	0.07426		0.000208	
0	5:15:00	0.07888		0.000219	
0	5:30:00	0.08258		0.000229	
0	5:45:00	0.08798		0.00024	
0	6:00:00	0.09191		0.00025	
0	6:15:00	0.09545		0.00026	
0	6:30:00	0.0977		0.000271	
0	6:45:00	0.10692		0.000281	
0	7:00:00	0.11392		0.000292	
0	7:15:00	0.1257		0.000302	
0	7:30:00	0.13491	0	0.000313	
0	7:45:00	0.1549	0.02	0.000323	
0	8:00:00	0.1698	0.04	0.000333	
0	8:15:00	0.29517	0.16	0.000344	
0	8:30:00	0.44862	0.32	0.000354	
0	8:45:00	0.32836	0.2	0.000365	
0	9:00:00	0.30917	0.18	0.000375	
0	9:15:00	0.2599	0.13	0.000385	
0	9:30:00	0.2218	0.09	0.000396	
0	9:45:00	0.19278	0.06	0.000406	

Days	Hours	100-Year Event		10-Year Event	
		Inflow (m3/s)	Excess (m3/s)	Inflow (m3/s)	Excess (m3/s)
0	10:00:00	0.17531	0.04	0.000417	
0	10:15:00	0.16371	0.03	0.000427	
0	10:30:00	0.15703	0.02	0.000438	
0	10:45:00	0.1466	0.01	0.000448	
0	11:00:00	0.13926	0.01	0.000458	
0	11:15:00	0.13353	0	0.000469	
0	11:30:00	0.12985	0	0.000479	
0	11:45:00	0.12567		0.00049	
0	12:00:00	0.12268		0.0005	
0	12:15:00	0.11887		0.00051	
0	12:30:00	0.11607		0.000521	
0	12:45:00	0.11242		0.000531	
0	13:00:00	0.10967		0.000542	
0	13:15:00	0.1083		0.000552	
0	13:30:00	0.10756		0.000563	
0	13:45:00	0.10711		0.000573	
0	14:00:00	0.10685		0.000583	
0	14:15:00	0.10447		0.000594	
0	14:30:00	0.10242		0.000604	
0	14:45:00	0.10145		0.000615	
0	15:00:00	0.10095		0.000625	
0	15:15:00	0.09851		0.000635	
0	15:30:00	0.09639		0.000646	
0	15:45:00	0.09536		0.000656	
0	16:00:00	0.09482		0.000667	
0	16:15:00	0.09239		0.000677	
0	16:30:00	0.09023		0.000688	
0	16:45:00	0.08917		0.000698	
0	17:00:00	0.08859		0.000708	
0	17:15:00	0.08825		0.000719	
0	17:30:00	0.08805		0.000729	
0	17:45:00	0.08584		0.00074	
0	18:00:00	0.0838		0.00075	
0	18:15:00	0.08276		0.00076	
0	18:30:00	0.0822		0.000771	
0	18:45:00	0.08187		0.000781	
0	19:00:00	0.08167		0.000792	
0	19:15:00	0.08154		0.000802	
0	19:30:00	0.08146		0.000813	
0	19:45:00	0.0794		0.000823	
0	20:00:00	0.07743		0.000833	

Days	Hours	100-Year Event		10-Year Event	
		Inflow (m3/s)	Excess (m3/s)	Inflow (m3/s)	Excess (m3/s)
0	20:15:00	0.07641		0.000844	
0	20:30:00	0.07586		0.000854	
0	20:45:00	0.10419		0.000865	
0	21:00:00	0.13133	0	0.000875	
0	21:15:00	0.10878		0.000885	
0	21:30:00	0.08603		0.000896	
0	21:45:00	0.07611		0.000906	
0	22:00:00	0.07102		0.000917	
0	22:15:00	0.06629		0.000927	
0	22:30:00	0.0626		0.000938	
0	22:45:00	0.06039		0.000948	
0	23:00:00	0.05896		0.000958	
0	23:15:00	0.05798		0.000969	
0	23:30:00	0.05728		0.000979	
0	23:45:00	0.05675		0.00099	
1	0:00:00	0.05634		0	
Total Excess Flow (m3/s)			**1.31**		**0**

Table 5: SW Marine Drive Excess Flow Determination Based on Existing Node T6D-S24

		100-Year Event		10-Year Event	
Days	**Hours**	**Inflow (m3/s)**	**Excess (m3/s)**	**Inflow (m3/s)**	**Excess (m3/s)**
0	0:15:00	0.00605		0.00605	
0	0:30:00	0.0061		0.0061	
0	0:45:00	0.00705		0.00667	
0	1:00:00	0.0085		0.00762	
0	1:15:00	0.01		0.00865	
0	1:30:00	0.01499		0.00939	
0	1:45:00	0.02453		0.0122	
0	2:00:00	0.03132		0.01821	
0	2:15:00	0.03642		0.02393	
0	2:30:00	0.03909		0.02741	
0	2:45:00	0.04186		0.03027	
0	3:00:00	0.0433		0.03191	
0	3:15:00	0.04389		0.0327	
0	3:30:00	0.04415		0.03309	
0	3:45:00	0.04426		0.03329	
0	4:00:00	0.04432		0.03339	
0	4:15:00	0.04592		0.03446	
0	4:30:00	0.04678		0.03511	
0	4:45:00	0.04868		0.03643	
0	5:00:00	0.04965		0.03716	
0	5:15:00	0.05328		0.03961	
0	5:30:00	0.05511		0.04098	
0	5:45:00	0.05911		0.04372	
0	6:00:00	0.061		0.04518	
0	6:15:00	0.06335		0.04686	
0	6:30:00	0.06441		0.04769	
0	6:45:00	0.07186		0.05267	
0	7:00:00	0.07519		0.05522	
0	7:15:00	0.08415		0.06097	
0	7:30:00	0.0899		0.06367	
0	7:45:00	0.10696		0.07221	
0	8:00:00	0.11743		0.07597	
0	8:15:00	0.3888	0.0528	0.1665	
0	8:30:00	1.41618	1.08018	0.85419	0.51819
0	8:45:00	1.58902	1.25302	0.4989	0.1629
0	9:00:00	1.14432	0.80832	0.32453	
0	9:15:00	0.77462	0.43862	0.11284	
0	9:30:00	0.51737	0.18137	0.10664	
0	9:45:00	0.38411	0.04811	0.09481	

		100-Year Event		10-Year Event	
Days	Hours	Inflow (m3/s)	Excess (m3/s)	Inflow (m3/s)	Excess (m3/s)
0	10:00:00	0.1528		0.09022	
0	10:15:00	0.14148		0.08631	
0	10:30:00	0.13714		0.0848	
0	10:45:00	0.12803		0.08025	
0	11:00:00	0.12313		0.07801	
0	11:15:00	0.11834		0.07578	
0	11:30:00	0.11559		0.07465	
0	11:45:00	0.11176		0.0728	
0	12:00:00	0.10951		0.07179	
0	12:15:00	0.10599		0.06997	
0	12:30:00	0.10391		0.06893	
0	12:45:00	0.10054		0.06708	
0	13:00:00	0.09852		0.06599	
0	13:15:00	0.09736		0.06542	
0	13:30:00	0.0966		0.06509	
0	13:45:00	0.09608		0.06489	
0	14:00:00	0.09572		0.06477	
0	14:15:00	0.09335		0.06339	
0	14:30:00	0.09195		0.06254	
0	14:45:00	0.09122		0.06212	
0	15:00:00	0.09078		0.06188	
0	15:15:00	0.08837		0.06044	
0	15:30:00	0.08693		0.05953	
0	15:45:00	0.08616		0.05905	
0	16:00:00	0.08568		0.05877	
0	16:15:00	0.08328		0.0573	
0	16:30:00	0.0818		0.05635	
0	16:45:00	0.08098		0.05582	
0	17:00:00	0.08046		0.0555	
0	17:15:00	0.08011		0.05528	
0	17:30:00	0.07986		0.05512	
0	17:45:00	0.07764		0.05376	
0	18:00:00	0.07625		0.05284	
0	18:15:00	0.07548		0.05234	
0	18:30:00	0.07499		0.05202	
0	18:45:00	0.07466		0.0518	
0	19:00:00	0.07442		0.05165	
0	19:15:00	0.07425		0.05154	
0	19:30:00	0.07413		0.05146	
0	19:45:00	0.07205		0.05017	
0	20:00:00	0.07071		0.04929	

		100-Year Event		10-Year Event	
Days	Hours	Inflow (m3/s)	Excess (m3/s)	Inflow (m3/s)	Excess (m3/s)
0	20:15:00	0.07		0.0488	
0	20:30:00	0.06954		0.04849	
0	20:45:00	0.09729		0.06566	
0	21:00:00	0.11458		0.0771	
0	21:15:00	0.08985		0.06223	
0	21:30:00	0.07649		0.05336	
0	21:45:00	0.07042		0.0493	
0	22:00:00	0.06691		0.04696	
0	22:15:00	0.06273		0.04426	
0	22:30:00	0.05982		0.04235	
0	22:45:00	0.05788		0.04107	
0	23:00:00	0.05647		0.04014	
0	23:15:00	0.05539		0.03943	
0	23:30:00	0.05453		0.03886	
0	23:45:00	0.05385		0.0384	
1	0:00:00	0.05329		0.03802	
Total Excess Flow (m3/s)			**3.86242**		**0.68109**

Appendix C: Pipe Capacity Calculation

Peak Flow:

$$Q_p = i * \sum C_n A_n$$

Where:

- Q_p is peak flow
- i is rainfall intensity for a 100 year return period
- C_n is runoff coefficient for area A_n
- A_n is total area with runoff coefficient C_n

Minimum Required Pipe Diameter - Intake (Houghtalen, Akan, & Hwang, 2010):

$$D_{intake} = \left[\frac{nQ_p}{0.463\sqrt{S_o}}\right]^{3/8}$$

Where:

- D_{intake} is required pipe diameter
- n is Mannings roughness coefficient
- S_o is pipe slope

Full Flow Velocity:

$$V_f = \left(\frac{1.49}{n}\right) R_f^{2/3} S_0^{1/2}$$

Where:

- V_f is full flow velocity
- R_f is full flow hydraulic radius, D/4

Minimum Required Pipe Diameter – Outtake:

$$D_{outake} = \frac{fL}{\frac{H}{V^2} - \frac{1}{2g}}$$

Where:

- D_{outake} is minimum required outtake pipe diameter
- f is friction factor for the pipe material (concrete)
- H is the total elevation difference between the top of the tank and the bottom of the outtake pipe
- V is the maximum allowable velocity
- g is the acceleration of gravity

Note that the headloss occurring from the pipe entrance is negligible when compared to frictional headloss and therefore not included.

Appendix D: Structural Calculations

Soil Properties

Unit Weight of Sand	20.42	KN/m3
Unit Weight of Silt	18	kN/m3
Approximate soil friction angle sand	38	degrees
Approximate soil friction angle silt	35	degrees
Ko sand	0.38	
Ko silt	0.43	

Pressure Distribution

Hampton Sand

Depth	Pressure	
1	0	KN/m
1	7.849891	KN/m
3.25	0	KN/m
3.25	25.51215	KN/m

Hampton Silt

Depth	Pressure	
1	0	KN/m
1	7.675624	KN/m
3.25	0	KN/m
3.25	24.94578	KN/m

SW Marine Sand

Depth		
4	0	KN/m
4	31.39957	KN/m
6.25	0	KN/m
6.25	49.06182	KN/m

SW Marine Silt

Depth		
4	0	KN/m
4	30.7025	KN/m
6.25	0	KN/m
6.25	47.97265	KN/m

Slab Analysis

Hampton Sand Moment

Loading		Moment		Moment over tank	
Start	7.84989145	10.49	KNm/m	34.0925	KNm
End	25.51214721				

Hampton Silt Moment

Loading		Moment		Moment over tank	
Start	7.675624146	10.26	KNm/m	33.345	KNm
End	24.94577847				

SW Marine Sand Moment

Loading		Moment		Moment over tank	
Start	31.3995658	24.8	KNm/m	80.6	KNm
End	49.06182156				

SW Marine Silt Moment

Loading		Moment		Moment over tank	
Start	30.70249658	24.25	KNm/m	78.8125	KNm
End	47.97265091				

Force of Rupture (Tension Failure)

$$\boldsymbol{f_r = \frac{M_{max}C}{I}}$$

$$C = \frac{h}{2}$$

$$I = \frac{bh^3}{12}$$

Relating $\boldsymbol{f'_c}$ and $\boldsymbol{f_r}$

$$\boldsymbol{f_r = 0.6\lambda\sqrt{f'_c}}$$

$\lambda = 1$ for normal concrete

$\lambda = 0.85$ for low density natural sand

$\lambda = 0.75$ for low density concrete (no natural aggregate)

Non-reinforced Concrete

Mmax	0.1015625	KNm
C	0.125	m
I	0.004231771	m^4
fr	3000000	Pa

I	0.004232	m^4
b	3.25	m
h	0.25	m
fr	3	MPa
Lamda	1	
f'c	25	MPa

Finding Moment Resistance $\boldsymbol{M_r}$ Properly Reinforced

$$\boldsymbol{C_r = T_r} \qquad T_r = \phi_s f_y A_s$$

$$C_r = \alpha_, \phi_c f'_c ab$$

$$M_r = T_r\left(d - \frac{a}{2}\right) = \phi_s f_y A_s \left(d - \frac{a}{2}\right)$$

Reinforced Concrete

Rebar Size	20	M
Rebar Count	6	EA
Rows	1	EA
Total Rebar	6	EA

Mr	145.3518144	KNm
Tr	720995.514	N
d	210	mm
a	16.80244439	mm

Tr	720995.5	N
phis	0.85	
fy	450	MPa
As	1884.956	mm^2

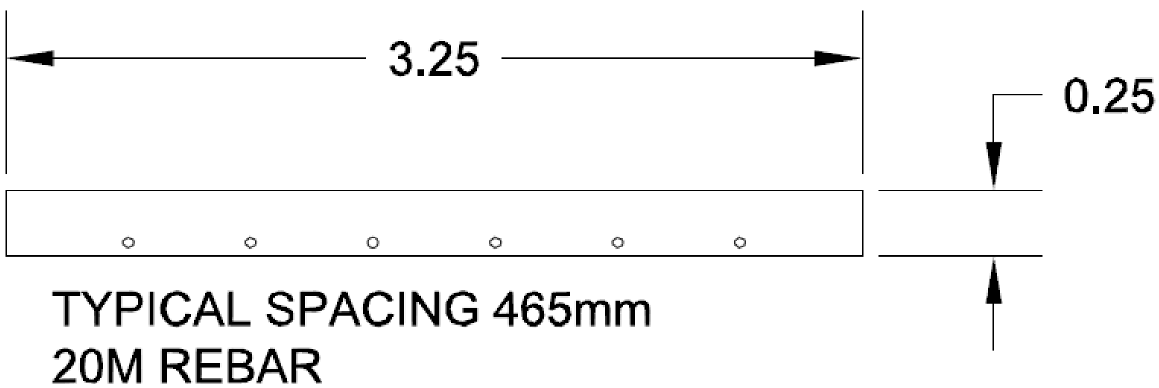
d	210	mm
depth	250	mm
centroid	40	mm

a	16.80244	mm
Tr	720995.5	N

alpha	0.8125	
phic	0.65	
f'c	25	MPa
b	3250	mm

Reinforcement Condition		Properly Reinforced
Steel Yielding	0.00225	
fy	450	MPa
Es	200000	MPa
Strain	0.036197349	
d	210	mm
c	18.51509023	mm

c	18.51509	mm
a	16.80244	mm
B	0.9075	



Appendix E: Construction Schedule

ID	Task Name	Duration	Start	Finish
1	**General**	**34 days**	**Mon 09/05/16**	**Thu 23/06/16**
2	Mobilization	1 day	Mon 09/05/16	Mon 09/05/16
3	Demobilization	1 day	Thu 23/06/16	Thu 23/06/16
4	Site Cleanup	1 day	Thu 23/06/16	Thu 23/06/16
5	**Site Preparation**	**13 days**	**Mon 02/05/16**	**Wed 18/05/16**
6	Site Preparation Survey	5 days	Mon 02/05/16	Fri 06/05/16
7	Fence Installation	1 day	Mon 09/05/16	Mon 09/05/16
8	Material Excavation	8 days	Mon 09/05/16	Wed 18/05/16
9	**Material**	**13 days**	**Thu 19/05/16**	**Mon 06/06/16**
10	Pipe/Tank Delivery	2 days	Thu 19/05/16	Fri 20/05/16
11	Aesthetic Material Delivery	3 days	Thu 02/06/16	Mon 06/06/16
12	**Installation**	**25 days**	**Thu 19/05/16**	**Wed 22/06/16**
13	Pipe/Tank Survey	2 days	Thu 19/05/16	Fri 20/05/16
14	Pipe/Tank Installation	5 days	Mon 23/05/16	Fri 27/05/16
15	Infill	3 days	Mon 30/05/16	Wed 01/06/16
16	Compaction	3 days	Thu 02/06/16	Mon 06/06/16
17	Landscaping	12 days	Tue 07/06/16	Wed 22/06/16

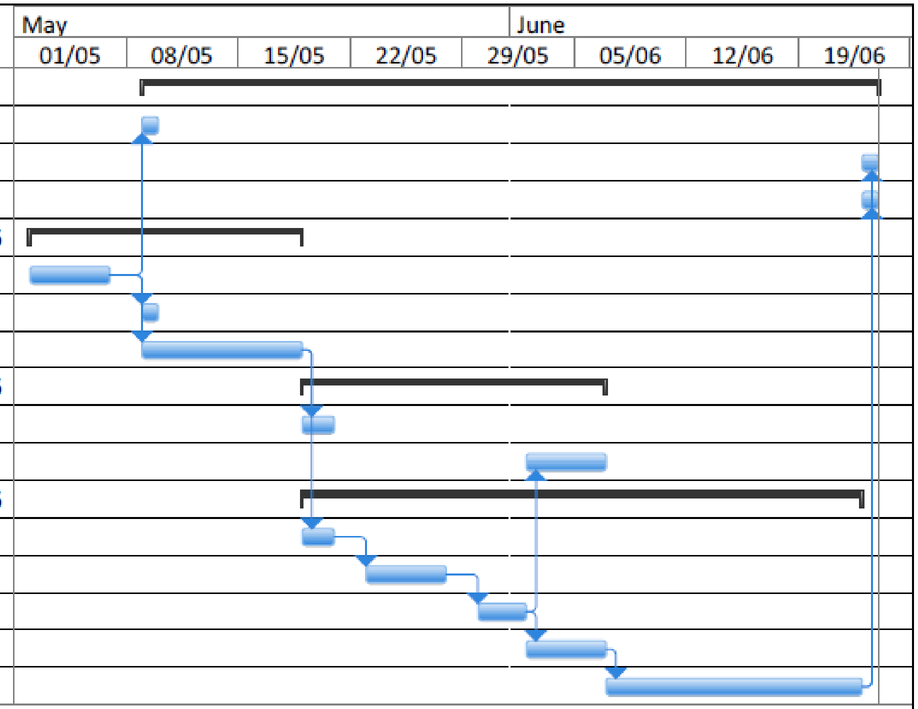


Figure 28: Hampton Place Construction Schedule

ID	Task Name	Duration	Start	Finish
1	**General**	**29 days**	**Mon 5/9/16**	**Thu 6/16/16**
2	Mobilization	1 day	Mon 5/9/16	Mon 5/9/16
3	Demobilization	1 day	Thu 6/16/16	Thu 6/16/16
4	Site Cleanup	1 day	Thu 6/16/16	Thu 6/16/16
5	**Site Preparation**	**15 days**	**Mon 5/2/16**	**Fri 5/20/16**
6	Site Preparation Survey	5 days	Mon 5/2/16	Fri 5/6/16
7	Fence Installation	1 day	Mon 5/9/16	Mon 5/9/16
8	Material Excavation	10 days	Mon 5/9/16	Fri 5/20/16
9	**Material**	**3 days**	**Mon 5/23/16**	**Wed 5/25/16**
10	Pipe/Tank Delivery	3 days	Mon 5/23/16	Wed 5/25/16
11	**Installation**	**18 days**	**Mon 5/23/16**	**Wed 6/15/16**
12	Pipe/Tank Survey	3 days	Mon 5/23/16	Wed 5/25/16
13	Pipe/Tank Installation	5 days	Thu 5/26/16	Wed 6/1/16
14	Infill	5 days	Thu 6/2/16	Wed 6/8/16
15	Compaction	5 days	Thu 6/9/16	Wed 6/15/16

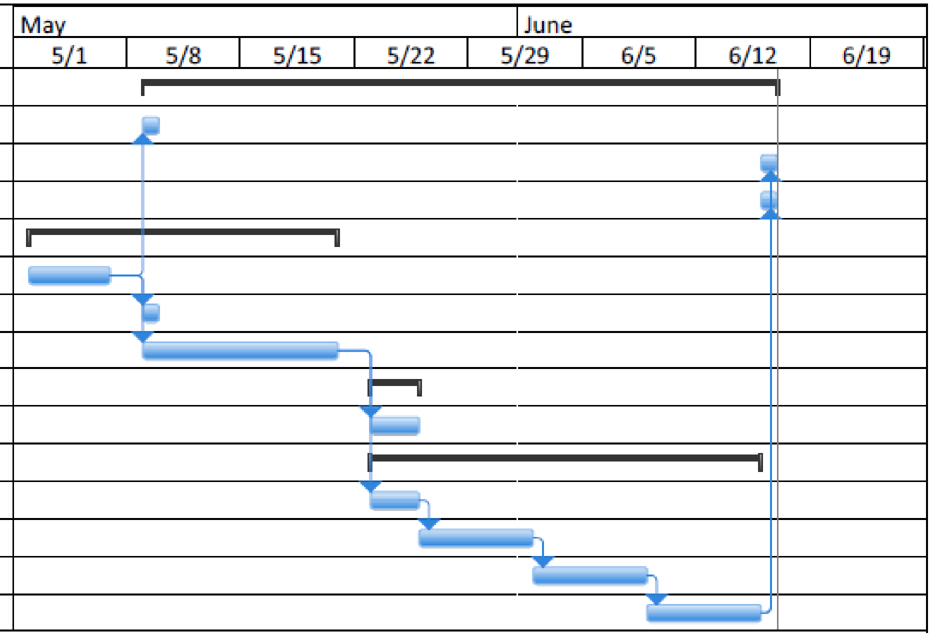


Figure 29: SW Marine Drive Construction Schedule

Appendix F: Cost Estimate

Table 6: Hampton Place Cost Estimate

Description	Quantity		Unit Cost		Cost	Comments
General						
Mobilization/Demobilization	1	LS	$50,000		$50,000	
				Subtotal:	**$50,000**	
Transportation/Shipping						
Shipping of material	1	LS	$50,000		$50,000	
				Subtotal:	**$50,000**	
Site Preparation						
Site preparation survey/Pipe location survey	7	day	$1,500	/day	$10,500	Surveying party of 2-3, including equipment
Fence installation	16	man hr	$60	/man hr	$960	Assume 2 workers working for 8 hours
Site Clearing and Grubbing	896	m^3	$2	/m^3	$1,792	
Strip Topsoil	896	m^2	$1	/m^2	$1,245	
Bulk Excavation (100% Rock)	2,240	m^3	$8	/m^3	$17,920	Includes technician and equipment rental
				Subtotal:	**$50,000**	
Material						
Pre-cast concrete detention tank	96	units	$10,000	ea	$960,000	Based on similar product from Con Cast Pipe
Concrete Pipe 500 OD	105	m	$125	/m	$13,125	Class 100-D from Con Cast Pipe
Concrete Pipe 375 OD	170	m	$95	/m	$16,150	Class 100-D from Con Cast Pipe
Playground Material	1	LS	$50,000		$50,000	50' x 30' Area
				Subtotal:	**$50,000**	
Installation						
Pipe installation/ Concrete detention tank installation	240	man hr	$60	/man hr	$14,400	Assume team of 6 working for 40 hours eachover 5 days
Playground installation	60	man hr	$60	/man hr	$3,600	
				Subtotal:	**$18,000**	
Equipment						
Crane	5	day	$1,000	/day	$5,000	Including crane operator and technician,
Backhoe, wheel-mounted, 65hp	8	day	$380	/day	$3,040	

Description	Quantity	Unit Cost	Cost	Comments
			$8,040	
Site Clean-up	32 man hr	$60 /man hr	$1,920	Assume team of 4 working for 8 hours each
		Subtotal:	**$1,920**	
Total Direct Cost			$1,199,652	
Indirect Cost	30 % of direct costs		$359,895.73	
Total Cost			**$1,559,548**	
Contingency	10% of total cost		$155,954.82	
Profit	7% of total cost		$109,168.37	
Final Cost			**$1,824,671**	

Table 7: SW Marine Drive Cost Estimate

Description	Quantity		Unit Cost		Cost	Comments
General						
Mobilization/Demobilization	1	LS	$50,000		$50,000	
				Subtotal:	**$50,000**	
Transportation/Shipping						
Shipping of material	1	LS	$50,000		$50,000	
				Subtotal:	**$50,000**	
Site Preparation						
Site preparation survey/Pipe location survey	8	day	$1,500	/day	$12,000	Surveying party of 2-3, including equipment
Fence installation	16	man hr	$60	/man hr	$960	Assume 2 workers working for 8 hours
Site Clearing and Grubbing	2,352	m^3	$2	$/m^3$	$4,704	
Strip Topsoil	2,352	m^2	$1	$/m^2$	$3,269	
Bulk Excavation and back fill (Soil)	5,880	m^3	$8	$/m^3$	$47,040	Includes technician and equipment rental
				Subtotal:	**$67,973**	
Material						
Pre-cast concrete detention tank	256	units	$10,000	ea	$2,560,000	Based on similar product from Con Cast Pipe
Concrete pipe 800 OD	30	m	$430	/m	$12,900	Class 100-D from Con Cast Pipe
Concrete pipe 300 OD	60	m	$77	/m	$4,620	Class 100-D from Con Cast Pipe
				Subtotal:	**$2,577,520**	
Installation						
Pipe installation/ Concrete detention tank installation	320	man hr	$60	/man hr	$19,200	Assume team of 8 working for 40 hours each, over 5 days
				Subtotal:	**$19,200**	
Equipment						
Crane	5	day	$1,000	/day	$5,000	Including crane operator and technician,
Backhoe, wheel-mounted, 65hp	10	day	$380	/day	$3,800	
				Subtotal:	**$8,800**	
Site Clean-up	32	man hr	$60	/man hr	$1,920	Assume team of 4 working for 8 hours each
				Subtotal:	**$1,920**	
Total Direct Cost					$2,775,413	

Description	Quantity	Unit Cost	Cost	Comments
Indirect Cost	30 % of direct costs		$832,623.98	
Total Cost			**$3,608,037**	
Contingency	10% of total cost		$360,803.73	
Profit	7% of total cost		$252,562.61	
Final Cost			**$4,221,404**	