UBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program
Student Research Report

# Replacement of the Spiral Drain at the North End of Campus


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**CIVL445 – Engineering Design and Analysis**

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**Executive Summary**

Vanguard Engineering was contracted by the University of British Columbia to review and assess the available options to replace the spiral drain at the north end of the campus. The existing spiral drain handles all stormwater runoff north of Agronomy Road, which is a considerable amount of water and it is undersized. This presents a flooding hazard, which is a significant concern along the northern cliffs as they have been found to be excessively unstable. Furthermore, the drain was installed in the early 20th century and is expected to have approximately thirty to one hundred years of life remaining.

Reports from Piteau Associates Ltd, Northwest Hydraulic Consultants, UBC, and GeoAdvice were reviewed for general design criteria such as 100-year storm capacities and soil conditions, as well as information regarding the aquifers under the Point Grey Peninsula and future campus development. With this information three conceptual designs were created with a holding tank system being deemed to be the most desirable.

Several items were analyzed for the design of the proposed holding tank. In terms of construction, erosion along the cliffs needed to be held paramount due to their sensitivity and must be protected throughout the entire duration of construction. It is for this reason that the spiral drain and existing drainage system were not to be disturbed until the new system was in place, thus limiting the potential locations for the tanks. In addition, construction of the new outfall needs to consider the requirements of both Metro Vancouver and the Musqueam Indian Band, which both have vested interest in the region.

The proposed design consists of a 35.6 metre by 35.6 metre holding tank 2.25 metres in height, capable of retaining 2,450 $m^3$ of stormwater. This is sufficient to withstand a 100-year storm. Due to the size of the holding tank the most economical location is the space between Cecil Green Road and the Anthropology & Sociology Building. This location is close enough to the ocean to make direction drilling for a new outfall feasible, however this would require the removal of a few trees and bushes in the area. A new green space can be constructed overtop the holding tanks once construction is complete.

The entire project is expected to take approximately six months to complete, thus if construction were started in May 2017 the tank would be in place mid-October. The cost of the project is estimated to be $3,664,833.09.

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# 1.0 - Introduction

## 1.1 - Objective of Report

Vanguard Engineering (Vanguard) has been contracted by the University of British Columbia (UBC) to analyze, plan and design a replacement for the Spiral Drain located at the northern end of the UBC campus. This final design report contains finalized design details as well as required construction practices including a finalized schedule and cost breakdown.

## 1.2 - Project Background

UBC's existing stormwater drainage system is divided into four separate catchment areas labelled North, 16th Avenue, West and South (see Appendix A). The system includes storm sewers of varying size and type, some drainage channels, multiple outfalls and the spiral drain itself which is owned by Metro Vancouver. The entirety of the North Catchment is serviced by this drain, which diverts flows via four trunk sewers, each about 30 inches in diameter, to a 4-foot diameter concrete outfall passing underneath the nearby Point Grey cliffs. There are considerable concerns regarding the erosion of these cliffs, and an overland flood presents the possibility of washout.

The spiral drain, built in 1938, is the last structure of its kind in North America. It is composed of a concrete lined shaft 6.1 metres (20 feet) across with a 2.44 metre (8 feet) diameter center column, and descends roughly 60 metres below surface elevation. In function, it allows stormwater to flow through a spiral water chase to avoid the consequences of such a large vertical drop. A pipe constriction at the bottom of the shaft limits the outflow to approximately 4 $m^3/s$, and as such a more conservative 3.5 $m^3/s$ has been assumed for the purposes of design. Figure 1 provides a sectional view of the spiral drain, inlets and outfall. Figure 2 shows the interior photographs of the spiral drain.

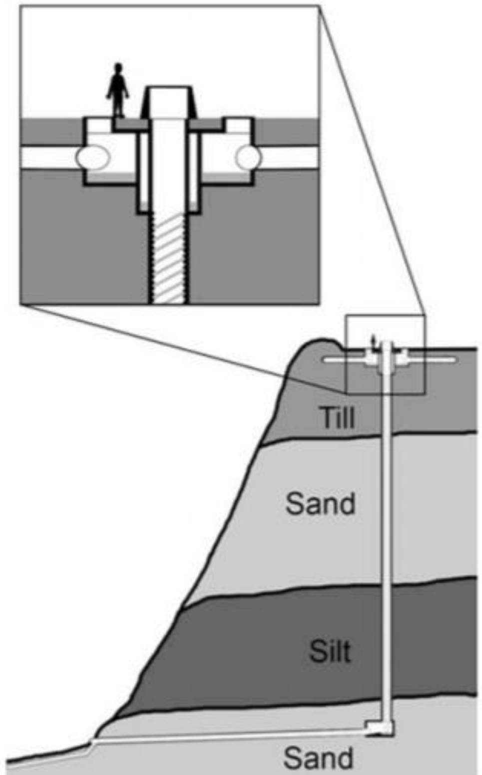


*Figure 1: Sectional Diagram of Spiral Drain, Outfall and Inlets*

*Figure 2: View of Spiral Drain shaft and Trunk Sewer Inlets*

The aging spiral drain is estimated to have 30 to 100 years of service life remaining; for the purposes of design a 50-year timeframe has been assumed. During recent years, both the ongoing development of the campus and the consistently limited capacity of the spiral drain to meet large flow volumes has resulted in overall capacity dropping below that of the expected 100-year and 200-year storms. In the event of such a large flow event, floods are expected to take place across the entire north catchment and at the spiral drain itself. Key to any replacement design would be to increase capacity and avoid localized flooding.

### 1.3 - Team Work Distribution

*Table 1: Team Work Distribution*

| ***Team Member*** | **Contribution to Preliminary Design Report** |
|---|---|
| *Antonio Castro* | Executive Summary, Hydrotechnical Calculations, Review |
| *Matt Sze* | Cost Estimate, Construction Schedule, Review |
| *Osama Moin* | Background Information, Geotechnical Calculations, Review |
| *Robert Ngai* | Geotechnical Calculations, Review |
| *Shane Duke* | Hydrotechnical Calculations, Review |
| *Thomas Bekenn* | Structural Calculations, Review |

## 2.0 - Summary of Conceptual Design

### 2.1 - Background Research and Information

The conceptual design process was undertaken in three separate stages. In the first stage, Vanguard conducted background research in order to identify all of the site constraints and regulations governing the design of a new drainage system. Previous studies were used to determine the hydrotechnical and geological performance of the existing spiral drain and surrounding area.

The *Hydrogeological and Geotechnical Assessment of Northwest Area UBC Campus* (Piteau, 2002) and the *U.E.L. Drainage and Shaft Tunnel Hydraulic Model Study* (Northwest Hydraulic, 1999) reports both assessed the performance of various elements of the existing infrastructure in the event of extreme weather conditions up to a 100-year storm event. Furthermore, the *UBC Stormwater Model System Analysis, Detention Analysis and System Optimization Report* (GeoAdvice, 2013) provided additional information as to which elements in the UBC north catchment drainage system pose the greatest risk of flooding in an extreme weather event. This report also identified potential upgrades to allow the system to meet the 100-year and 200-year storm capacities. As a part of the conceptual design, Vanguard considered incorporating some of the upgrades recommended in the report in order to produce an optimal and cost effective solution.

The key design constraints and parameters that were identified by Vanguard based on this information, as well as observations made during site investigations, have been summarized in Section 3.0 of this report.

## 3.0 - Key Issues for Design

The primary design challenges for the spiral drain replacement fall into three categories: geology, land use, and as-built conditions of the spiral drain itself. Each of the three categories are discussed in detail below.

The Point Grey cliffs are located at the northern end of the campus and are particularly sensitive to erosion. The Point Grey Peninsula primarily consists of glacial till and gravel with some minor silt deposits down to approximately 45 metres below the surface. Towards the lower elevations of the geological profile of the cliff, two aquifers are present; the upper and lower aquifers located at approximately 26 metres and 2.6 metres above sea level respectively. As water falls onto the surface near the cliff, it is either absorbed by plants, seeps into the ground and eventually to the upper aquifer or flows over the cliff face. Observational parameters, such as the state of existing trees and lack of seepage along the cliff face, suggests that the former is likely more probable route for water than the latter. The remaining water is suggested to be seeped into the ground and into the upper aquifer (Piteau Associates 2002; 16).

It has been observed through a study of wells installed in various areas that some portion of the water in the upper aquifer seeps through the cliff face due to its porous nature and intermittent silt deposits, which could contribute to local slope instability. The lower aquifer, being close to sea level, discharges in an acceptable manner to the beach and does not cause concern for local slope instability. With the considerations of both the aquifers, this results in unstable cliffs on the north end of campus, which saw a few massive washout events over the past century. The pictures in Figure 3 show a comparison of the cliffs in January 1967 to March 1975.

*Figure 3: Comparison of Point Grey Cliffs from January 1967 (left) to March 1975 (right)*

*(UBC, retrieved 2016)*

As seen above, over a span of 8 years the cliffs eroded significantly and thus, the cliff face is considered to be very unstable and construction on the cliff face should be avoided in a best-case scenario. A further detailed hydro-geological study was completed by Piteau Associates Ltd. in 2002 and they had conducted a "simulated earthquake loading conditions on [a] generalized cliff profile… to develop a setback line from the crest for major developments or construction of underground utilities" (Piteau Associates 2002; 21). The results of the cliff stability analysis yielded a setback of approximately 25 metres or a 35° line taken from the toe of the cliff would be safe for construction for buildings and/or underground utilities, as per Appendix E of the Piteau Associates Ltd. hydro-geological study. Although the recommended scenario is to avoid construction near the Point Grey cliffs, if a 25 metre setback is maintained, construction is feasible with the proper stakeholders engaged and in agreement with the work to be completed.

Land management of the Point Grey Peninsula is shared amongst three parties: Metro Vancouver and UBC, which are directly in the affected areas of the project, and the Musqueam Indian Band, which owns land near the south end of campus. Metro Vancouver oversees the Pacific Spirit National Park which covers the cliffs along the north end of the campus and UBC cooperates with the Musqueam on land development in the region. This relationship must be carefully managed. Figure 4 and Figure 5 below represent the boundaries where each of the three parties' lands are located regarding the spiral drain.

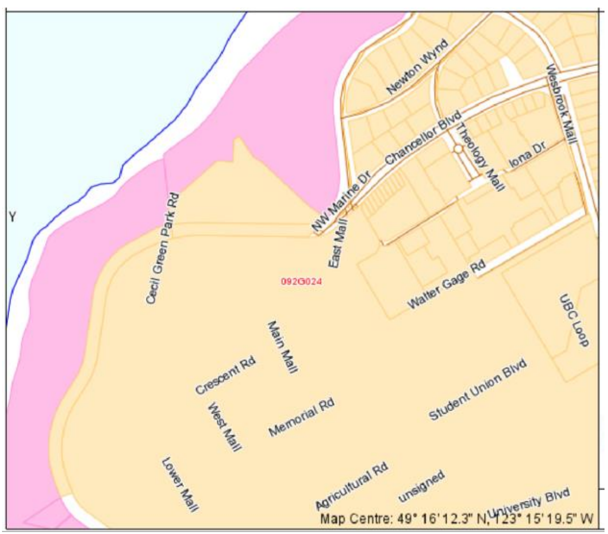


*Figure 4: Metro Vancouver (pink) vs UBC Land (beige)*

*(B.C. Map Services, 2016)*


*Figure 5: Musqueam Reserve Boundaries (purple)*

*(Musqueam Community Profile, n.d)*

Other areas of concern also include the BC Water Quality Guidelines (BCWQG) and associated requirements for particulate matter and future development in the north end of the campus. With the BCWQG, the water leaving the system from the outfall of the proposed structure must be within the appropriate concentrations listed in the document to allow for the protection of aquatic life in this case. With the development of the north end of campus, non-permeable areas will see an increase in area as buildings, paved roads and sidewalks are installed which will directly impact the 100-year and 200-year storms.

# 4.0 - Preliminary Design

## 4.1 - Design Description

It was decided that a below grade concrete holding tank system is the preferred design to replace the spiral drain. The 100-year storm flows could be accommodated through retention of excess flooding water, and at the end of the spiral drain's service life it could be replaced with a new, high capacity outfall. Further analysis and design was conducted for the detailed design, described in the following sections.

## 4.2 - Key Parameters

Various key components and parameters were considered for the design of the underground storage tank and new drainage infrastructure. One of the limiting factors includes the underground utility conflicts within the vicinity of the storage tank area. The location and depth of the holding tanks is required to be constructed so as to minimize conflicts with existing infrastructure. Breaching underground utility boundaries may lead to large relocation costs and increased risk if construction takes place too close to existing lines. Figure 6 below outlines all existing underground utilities around the existing spiral drain as well as a proposed area outlining the new location of the storage tanks.

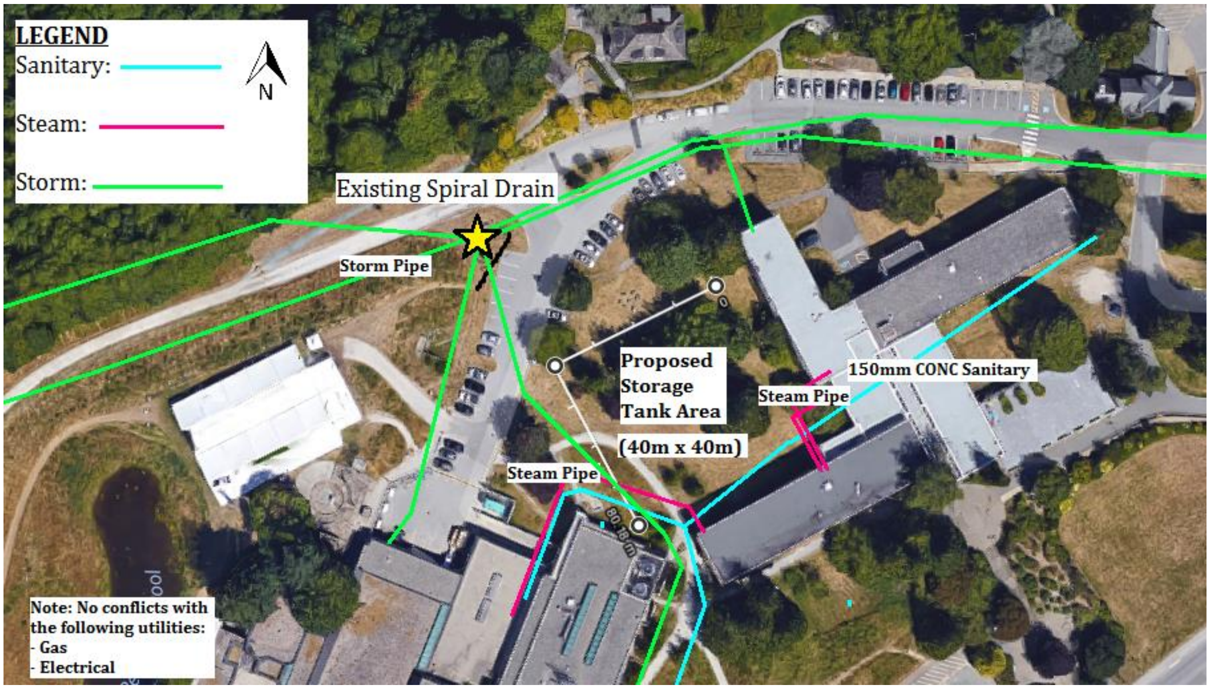


*Figure 6: Existing Utilities and Proposed Site Area*

*(Google Earth, 2016)*

Geotechnical and environmental concerns may also limit the constructability, and are thus considered as vital criteria. Cliff side erosion can be prevented as the tanks would be located away from any sensitive soil.

It is also worth noting that for the design Vanguard analyzed both the 100-year and 200-year storm events. For the 200-year storm, it is found that the amount of storage volume required to prevent flooding around the drainage structure is extremely large. Due to the large amounts of holding tanks that would be required, the utility lines would likely need to be rerouted in order to create enough space for the detention tanks to be placed. This leads to a very large increase in the cost of the project. The risk of a flood during a 200-year storm does not pose an immediate danger to the public and though there are concerns of erosion around the cliffs the risk is relatively low. Coupled with the extremely low probability of a 200-year event occurring Vanguard has determined that it is most practical to only design for the 100-year storm event. All of the design parameters discussed for the design have been created considering a 100-year storm event.

### 4.2.1 - Materials

The material choice for the storage tank will be cast in place reinforced concrete. When comparing lifecycle cost analysis, the approximate 50-year lifecycle and maintenance costs illustrates that concrete storage tanks are five times more expensive than steel tanks due to high installation costs and leak repairs. Since concrete does not hold flexible properties, subjecting constant expansion and contraction due to freeze thaw cycles may weaken the integrity of concrete, eventually leading to leaks. However, given the requirements of Civil 446 Vanguard has moved forward with a cast-in-place concrete reservoir in order to meet the design requirements of the course.

The area between the Museum of Anthropology, Cecil Green Park Road, and the Anthropology & Sociology Building was found to be the most feasible location for the holding tank system due to its proximity to the spiral drain, space available, and lack of underground services. See section 4.3.7 for details about the tank orientation.

Furthermore, the proposed location featured little in terms of underground services, which is particularly important when considering the stormwater drainage system as it should remain in service during construction. As seen in Figure 6 previously, the only services to be dealt with are the steam pipe heating system the sanitary pipe for the Anthropology & Sociology Building, and the storm pipe to the west. The sanitary and steam services are located close to the south wing of the building while the storm is well away from the proposed construction area, therefore none of these services would be impacted significantly by any excavation. However, the drawings that were provided likely reflect as-designed rather than as-built conditions and so the exact location of the pipes will have to be determined prior to construction.

### 4.2.2 - Environmental

The chosen location has a significant impact on the environment. A number of trees and bushes are located in the field and will have to be removed during the excavation. This is an unfortunate result of optimizing the project to minimize costs and disruption to people in the area: while there are other locations that would preserve the trees, these locations would require extensive amounts of excavation, directional drilling, and infrastructure repairs to complete the necessary work. Furthermore, this location is well suited to reduce the impact of the project on the cliff erosion as it is far enough away to avoid any direct impact from the construction, yet close enough to make directional drilling for the outfall feasible. To rebuild the green space that will be affected by the installation of the holding tank, a park feature will be implemented. No designs have been made at this stage, however such features as new trees, benches, pathways and potentially a pond could be designed.

It was determined that a sump would not be required for the storage tank. Stormwater is typically collected in a sump to remove sediment prior to leaving a building's vicinity, thus little to no sediment should reach the tank. It was also determined that there likely would have been significant drainage problems with the existing system if sumps were absent from the buildings in the north catchment, so it is reasonable to assume this is not a concern.

Prior to the construction of the project, it is recommended to produce an Environmental Impact Assessment (EIA), ensuring that the land of interest is compatible with the primary aim of protecting natural and historic resources. More specifically, performance indicators are proposed to measure the anticipated effects of the project, measuring the possible unacceptable design criteria or mitigation measures to reduce those effects. Thus, Table 2 on the following page provides adverse effects and mitigation solutions for the replacement of the spiral drain.

*Table 2: Environmental Impacts & Mitigation Strategies*

| VALUES | POTENTIAL/ADVERSE EFFECTS | EXAMPLES OF MITIGATION MEASURES |
|---|---|---|
| Terrestrial | Clearance, disturbance, destruction or modification of any vegetation in the natural habit of interest | • If impact cannot be avoided, restoration or vegetation of the area is necessary<br>• Educate staff, clients, and students why they should keep clear of the sensitive Cliffside area |
| Aquatic and Marine Values | Damage, disturbance, or modification to aquatic life or stream habitat | • Ensure outflow rate into the outfall is protected by a form of rip rap to conserve aquatic habitat downstream of outfall<br>• Provide a slower outflow volume that reduces the danger to aquatic life |
| Aquatic and Marine Values | Discharge of pollutants; such as sediment and oil spills | • Can be avoided - sump would not be required for the storage tanks as storm water typically collected in a sump to remove sediment prior to leaving a building's vicinity |
| Aquatic and Marine Values | Erosion, scouring or deposition of riverbeds | • Ensure exit flow rates are within Vancouver hydro technical standards<br>• If unavoidable, provide sufficient native vegetation to riverbanks in addition to riprap covering at the outfall |
| Landscape Values | Damage to geological features | • Identify alternative locations outside of the UBC Cliffside area<br>• Can storage tank be utilized in a neighbouring building or facility? |

## 4.3 - Final Design

### *4.3.1 - Holding Tank Sizing*

The holding tank was designed to increase the current capacity of the spiral drain to meet the 100-year storm flows. Overall runoff values were obtained via GeoAdvice Engineering Ltd.'s *Model Update and Calibration of the University of British Columbia Stormwater Collection System* Technical Memorandum 2 and are summarized in Table 3 below. As part of that analysis, the 100-year storm was modeled as an SCS Type 1A Curve. It was assumed that the runoff flow curve would match this exactly, as shown in Figure 7.

*Table 3: GeoAdvice TM#2 Information*

| | | |
|---|---|---|
| **North Catchment Area** | 138.69 | ha |
| **10yr Storm Runoff (North Catchment)** | 601 | $m^3$/ha |
| **Total Runoff** | 83353 | $m^3$ |
| **100yr Storm Runoff (North Catchment)** | 884 | $m^3$/ha |
| **Total Runoff** | 122602 | $m^3$ |

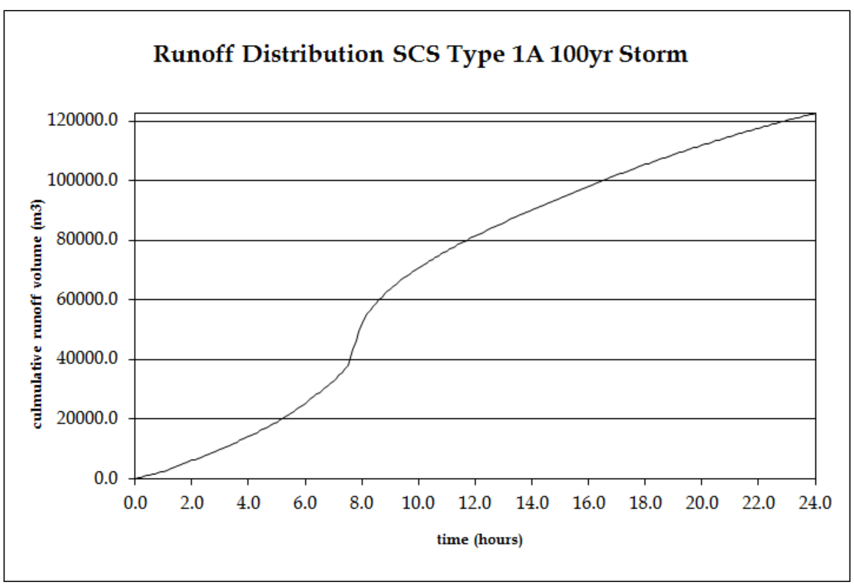


*Figure 7: 24-hr North Catchment Runoff Curve (100-year storm)*

It was also assumed that the spiral drain has a maximum outflow of 3.5 $m^3/s$, a more conservative value when compared to the approximately 4 $m^3/s$ assumed in UBC's *Integrated Stormwater Management Plan* report. Using the known inflow and outflow flow rates allows for calculation of total flooding:

*Equation 1: Total Flooding Calculation*

$$Total\ Flooding\ = \sum (Inflow - Outflow) \times timestep$$

However, not all runoff will reach the spiral drain as localized flooding occurs across the north catchment due to insufficient pipe sizes (local pipe constrictions). GeoAdvice has estimated the flooding volume to be approximately 6,000 $m^3$ using their model. Thus, the holding tanks would only need to account for flooding of the spiral drain itself per Equation 2:

*Equation 2: Modified Flooding Calculation*

$$Spiral\ Drain\ Flooding\ = Total\ Flooding\ -\ Localized\ Flooding$$

Through these calculations, presented in Appendix B, it has been determined that the holding tank should be capable of retaining 2,450 $m^3$ of storm water to increase the capacity of the spiral drain to meet the 100-year storm. Additional holding tanks would likely need to be constructed across the north catchment to accommodate localized flooding, but this was outside the scope of work of the project.

### *4.3.2 - Geotechnical Design*

In order to provide an appropriate location for the new underground storage tank, an investigation of the subsurface conditions was undertaken to ensure that the mechanical and chemical properties of the soils were adequate under long term loading. Additionally, a stability analysis provided by Trow Geotechnical was considered moving forward in the design. According to the "UBC Cliff Slope Stability Analysis" report, a maximum cut slope of 35 degrees was reflected in the geotechnical consideration.

Existing sonic drill hole data provided by Piteau Associates explored the ground surface data approximately 200 meters from the existing spiral drain location. As the excavation is to be constructed to a depth of 3 meters, an analysis of the first 12 meters of the subsurface soil was considered. The results indicated variable compact sand to silty sand with minor firm silt zones in the first 3 meters below ground. The following meter depth below consists of very silty coarse sand with traces of coarse gravel. Approximately 4 meters to 7 meters in depth comprises of grey, compact coarse sand with well graded trace silt and gravels. It is to be noted that the sand in this region becomes coarser with depth. Finally, the depth from 7 meters to 10 meters outlines a loose to compact, medium grained sand with trace silt. The following Figure 8 outlines the test hole data provided by Piteau Associates.

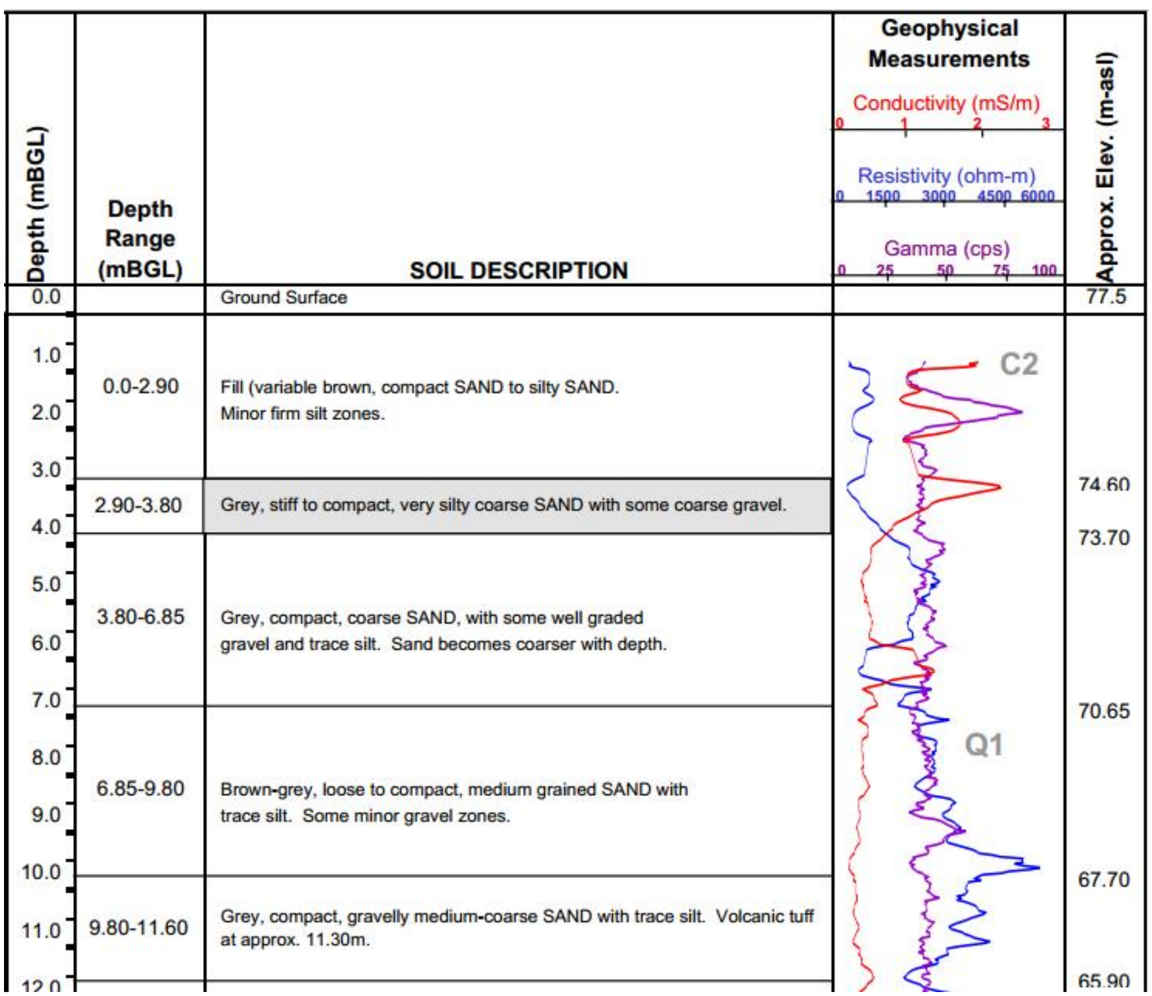


*Figure 8: Piteau Associates test hole data – 200m offset to existing spiral drain location*

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Additionally, a sectional view is also provided; illustrating the test hole of interest (TH01) as well as the ground water table located approximately 22m above sea level.

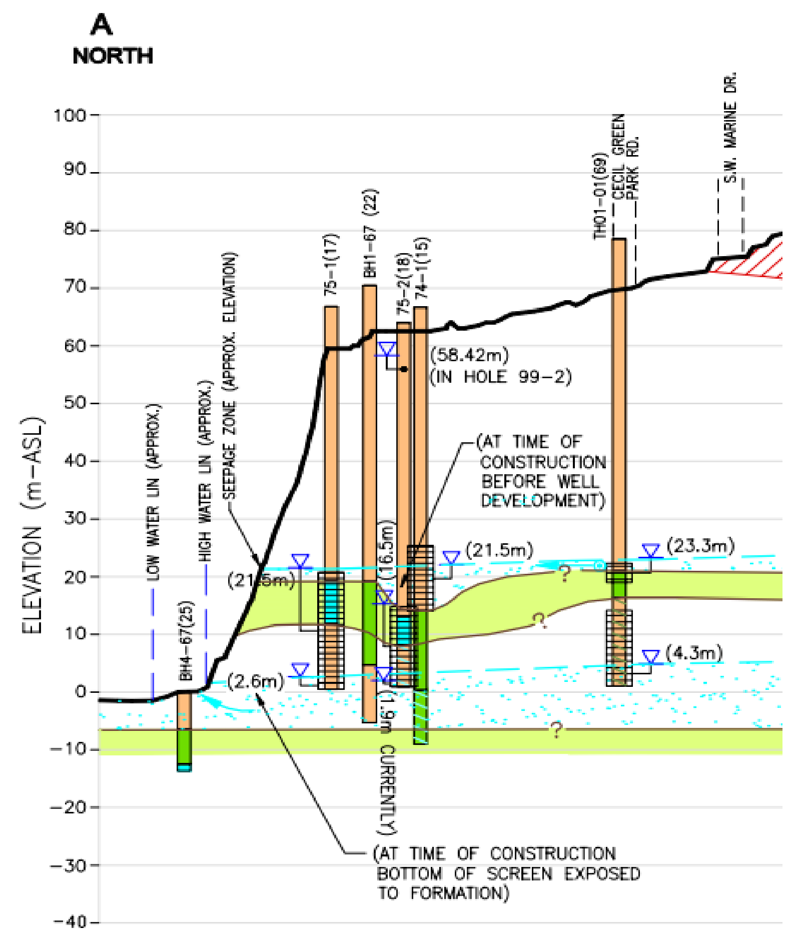


*Figure 9: Section view of the test hole (TH01)*

From the collected data, a unit weight of 19kN/m³ is anticipated for the area of interest and is utilized for the loading calculations. Additionally, the storage tank location closest to the Cliffside was chosen due to reduced lineal meters of pipe required to reach the outlet of the UBC Cliffside. To deem this area appropriate, the soil corrosiveness was identified given the results from the Piteau report. Firstly, the resistivity parameter was recognized to be approximately 2000 ohm-m, which correlates to a highly severe corrosion potential. Despite this corrosive nature, the moisture content of the soil was deemed to be extremely low in the first 3 meters due to the water table approximately located 40 meters below the area of interest. Due to the negligible moisture content, the geotechnical design considers a dry soil, thus indicating marginal corrosive effect with the outside surface of the concrete tank.

### *4.3.3 - Structural Design*

The water detention tank used in the system is to be made of reinforced concrete and is to be designed in accordance with CSA A23.3. The structure is to have the capacity to be able to withstand gravity loads caused by soil surcharge as well as lateral loads caused by lateral soil pressure. The structure is also designed to withstand seismic loads and is analyzed using an equivalent static analysis. The entire holding tank system is to be cast-in-place and constructed on site. Detailed structural calculations are found in Appendix F.

#### 4.3.3.1 - Loads

The detention tank used to temporarily store excess flow in the system is to be constructed below ground. As a result, gravity loads are calculated using an assumed soil unit weight of $19kN/m^3$. The soil also exerts lateral pressure on the sides of the reservoir. This lateral earth pressure is calculated based on an active condition using a factor of 0.33. An equivalent static load is also calculated for earthquake design and is considered as a distinct load case. All loads and load combinations are factored and are determined in accordance with NBCC 2010. The calculated loads can be found in Appendix F.

#### 4.3.3.2 - Structural Components

The roof of the concrete detention tank is designed as an elevated slab system. The slab is supported by concrete columns in the interior of the tank and by concrete walls along the perimeter. The slab is designed as a slab-beam-girder system. The purpose of the beam system is to reduce the span lengths of the slab so as to increase the shear and bending resistance. The beams are also arranged in such a way that the span of the slab is double in one direction. This allows for the slab to be designed as a one-way system which simplifies the design process. A plan layout of the slab system is shown in the following Figure .

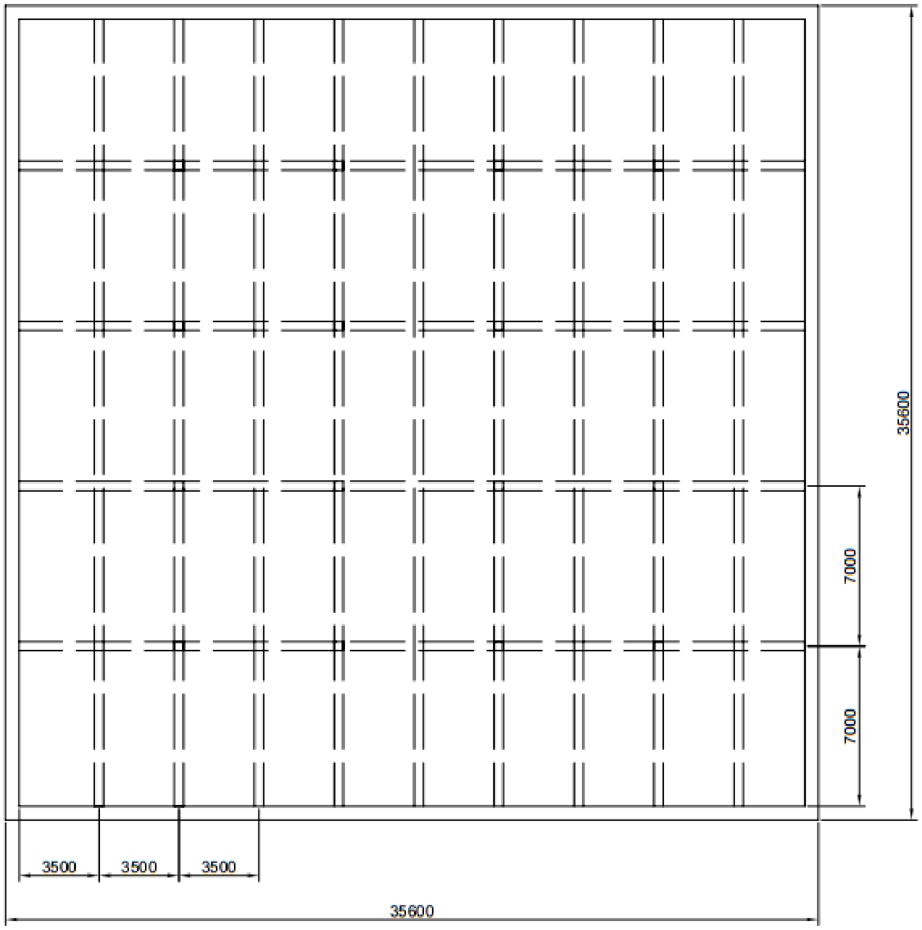


*Figure 10: Plan layout of the beam system*

Each slab is designed for both shear and bending. The shear resistance is calculated using the following equation:

*Equation 3: Total Shear Resistance*

$$V_r = V_c + V_s$$

Where $V_c$ is the shear resistance of the concrete and $V_s$ is the shear resistance of the steel reinforcement. In order to minimize the amount of steel reinforcement required, the entire calculated shear force in the slab is considered to be taken by the concrete. As a result, $V_s$ is equal to zero. $V_c$ is then calculated using the following equation:

*Equation 4: Concrete Shear Resistance*

$$V_c = \varphi_c \beta f_c' b_w d_v$$

Where $\varphi_c$ is the concrete material resistance factor, β is the shear resistance factor for cracked concrete, $f_c$' is the compressive strength of concrete, $b_w$ is the width and $d_v$ is the effective shear depth. The thickness of the slab is determined based upon this calculation. A slab of thickness of 350mm is to be used for each slab.

The bending resistance of the slab determines the amount and spacing of reinforcement required. All tensile forces created due to bending are assumed to be taken by the steel reinforcement. The bending resistance of the slab is calculated using the following equation:

*Equation 5: Slab Bending Resistance*

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

Where $\varphi_s$ is the steel material resistance factor, $f_y$ is the yield strength of steel, $A_s$ is the area of steel reinforcement, d is the effective depth and a is the location of the resultant compression block. All spacing requirements for the steel reinforcement, along with minimum and maximum allowed reinforcement, are determined based on the requirements in CSA A23.3. The detailed calculation for determining the shear and bending resistance of the slab is found in Appendix F.

The T-beams in the system are also designed using the same equations for shear and bending resistance. The beam depth is determined based on the effective depth necessary to achieve the required shear and bending resistance. It is also worth noting that the beams have additional shear capacity carried by the steel ties. A design summary of each T-beam is shown in the following Figure . The calculations for the design of the beams are found in Appendix F.

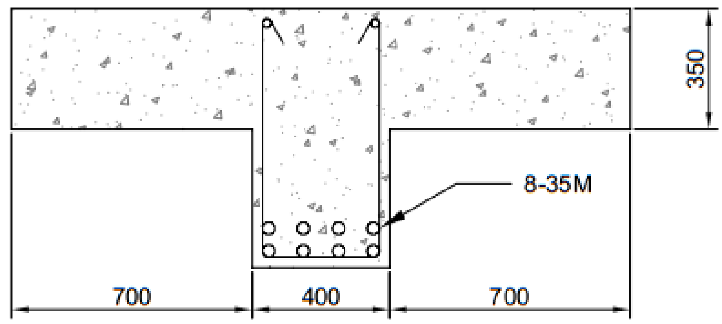


*Figure 11: Typical cross-section of the T-beam*

As a part of the gravity support system, 16 columns are to be constructed within the interior of the tank. The columns are designed with the consideration of slenderness effects as well as eccentricities created by unbalanced loading conditions. The compressive resistance of the columns can be found through the utilization of interaction diagrams that relate the compressive and bending resistances of the column based upon the desired steel ratio.

The columns are all 400mm x 400mm x 2100mm and have 8-25M bars for flexural reinforcement. The ties for the columns are all 10M. The detailed calculations for the column sizing can be found in Appendix F.

The perimeter walls for the tank serve two functions in the structural system; to assist the interior columns with gravity loads and to resist lateral loads caused by the soil. As a result, the walls have to be designed as both bearing and retaining walls. The bearing system requires the walls to have the capacity to resist axial loading from the elevated slab. CSA A23.3 sets out requirements that determine the amount of steel reinforcement required in both the vertical and horizontal directions for a wall under an axial load. The wall thickness determined in part due to the axial loading conditions but is also dependent on the lateral loads as well.

The lateral earth pressure acting on the wall creates bending and shear stresses in the wall that need to be considered in the design. The calculation of the shear and bending resistances is done in a similar manner to how they are calculated for the elevated slab. The wall thickness and steel reinforcement arrangement is designed to have the capacity to accommodate the factored axial and shear forces as well as the factored bending moment. The walls are all designed to have a 300mm thickness and will have one layer of 25M rebar at 500mm spacing in both the vertical and horizontal directions.

The final component of the reinforced concrete detention tank is the slab on grade at the base of the structure. Designs of slabs on grade often employ empirical methods. A typical thickness for a slab to be used for a detention tank is 150mm which is used as the design thickness. The amount of steel reinforcement required is determined based on the following equation:

$$A_s f_s = \left(w \times \frac{L}{2}\right) F$$

Where $A_s$ is the area of steel reinforcement required, $f_s$ is the allowable steel stress of the reinforcement, w is the weight of the slab, L is the length of the slab between joints, and F is a coefficient of friction between the granular base and the slab on grade. The reinforcing arrangement for the slab on grade is found to be 25M at 100mm. Detailed calculations can be found in Appendix F.

#### *4.3.4 - Hydrotechnical Design*

Aside from the sizing of the holding tank, refer to Section 4.3.1, additional design was done to account for rerouting of storm mains to flow through the tank to the spiral drain as shown in Figure 12 below. Adequate slopes needed to be maintained such that the inlets would reach a proper depth and flows would proceed at a velocity such that the holding tank would be unaffected. To this end, slopes of 1% to 7% were used. Where possible, pipes were designed to reroute from an existing manhole, otherwise joints and elbows were specified.

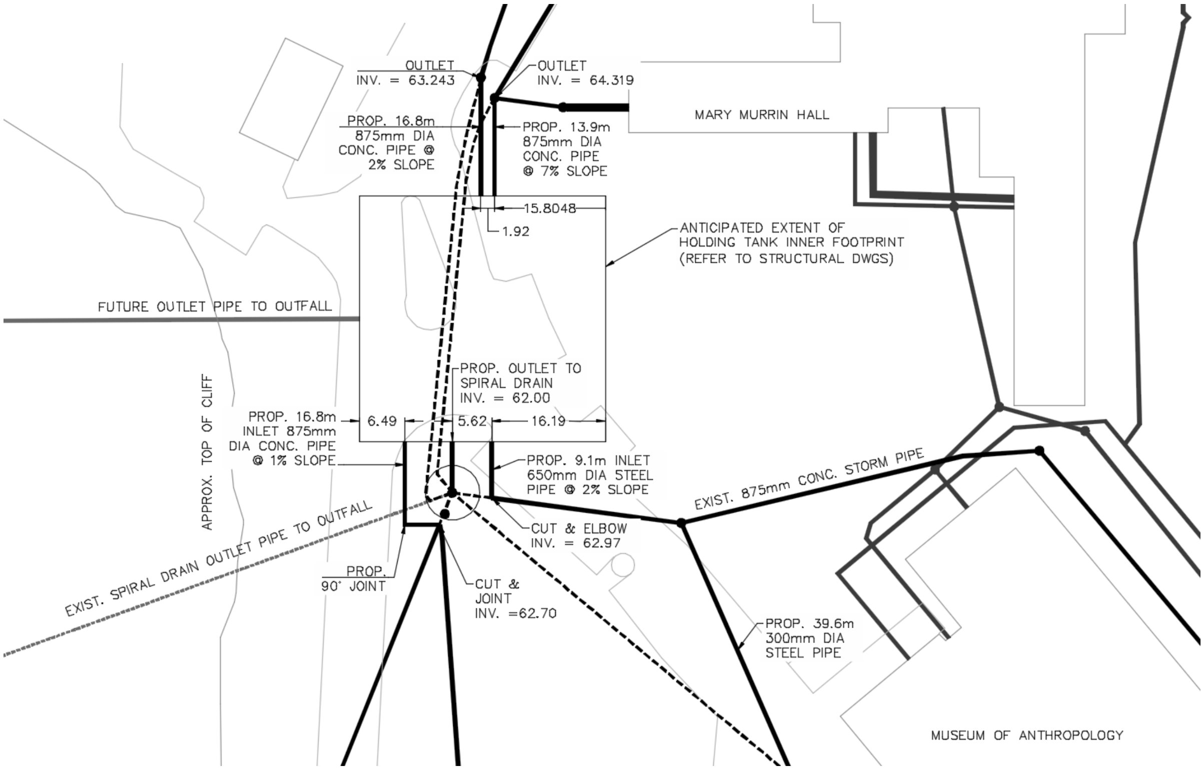


*Figure 12: Rerouting of Storm Pipes to Holding Tank*

### *4.3.5 - Concrete Mix Design*

A concrete mix design was determined using the ACI Mix Design process. The following table describes the quantity of material required to obtain the desired concrete mix design:

*Table 4: Concrete Mix Design*

| ***Material*** | **Quantity per 1m$^3$ of concrete** | **Quantity required for holding tank (2500m$^3$)** |
|---|---|---|
| *Water* | 377.94kg | 944,850kg |
| *Cement* | 675.93kg | 1,689,825kg |
| *Fine Aggregate* | 184.92kg | 462,300kg |
| *Coarse Aggregate* | 948.6kg | 2,371,500kg |

### *4.3.6 - Holding Tank Location*

The water detention tank's location has been chosen near the existing spiral drain so as to simplify the construction process by making the implementation easier for construction crews. This will also help to reduce costs associated with construction. The proposed location minimizes the rerouting of the existing trunk sewers as it is mostly located along their existing paths. This will reduce the amount of excavation required on site and will ultimately shorten the amount of time it takes to complete the project. The location also minimizes conflicts with other existing buildings, roadways and utilities in the area. The location of the tank is shown in the following Figure 13.

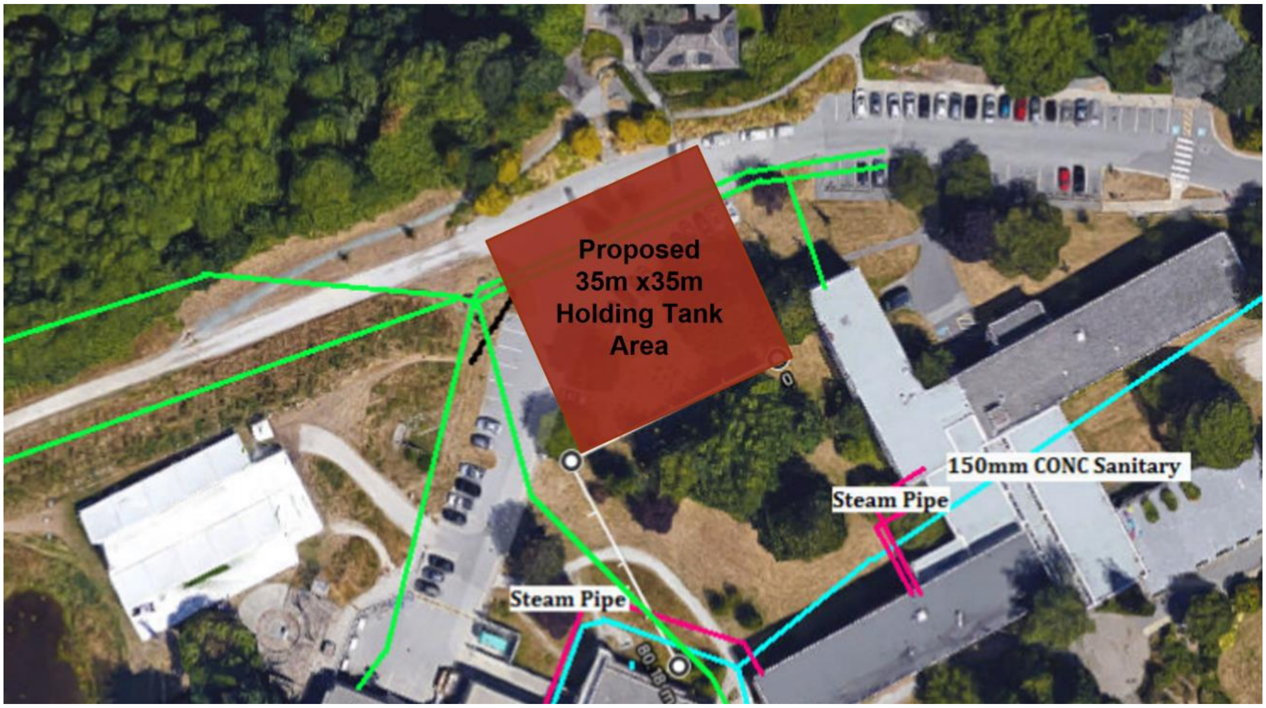


*Figure 13: Proposed holding tank location*

A second proposed location was considered further offset from the cliffs near Marine Drive. The purpose behind this location was to minimize interaction with the cliff face in order to prevent erosion. However the Marine Drive location complicates construction because of its close proximity to roadways and existing buildings. Furthermore, all the trunk sewers have to be majorly rerouted away from their existing locations to get to the Marine Drive location. This would be extremely challenging due to the large amount of conflicting existing buildings, roadways and utilities in the area. As a result, Vanguard has concluded that it would be easier to implement slope stability and erosion control measures on the cliffs and to place the tank closer to the cliff face than at the Marine Drive location.

### *4.3.7 - Outfall Details and Orientation*

The orientation of the storage tanks will be five rows of two laid out to fit within an approximate 40 metre by 40 metre footprint. This area, as seen in Figure 14 below, is preferable as no utilities are present. From the location of the existing spiral drain, a 1 metre diameter concrete pipe is to be tied into the storage tanks at the required minimum depth. The storage tank tying into the outlet pipe shall be equipped with a control valve to adjust the flow exiting the system. For the outlet pipe structure, the method of pipe jacking shall be utilized over a sloped distance of 194 metres with a concurrent grade of 31°.


*Figure 14: Orientation of Storage Tanks*

*(Google Earth, 2016)*

The outfall was sized based on the most extreme conditions expected for the storage tank, where the tank is nearly full and the exit orifice is submerged. A detailed calculation of the sizing can be found in **Appendix E – Culvert Design**, and it was found that the pipe diameter required was 1000 mm for the discharge of 3.5 $m^3$/s.

## 5.0 - Construction Schedule

The schedule for implementation of the chosen design option can be seen in Appendix C, assuming a start date of May 2017 with a concluding date in October 2017. The following assumptions regarding scheduling have been made to complete the schedule:

- Assumption 1: The activity "pipe jacking" accounts for assembly of pipe sections and boring the assembled sections into the desired location. Each pipe section is 3 metres in length and will be bored in with 6 pieces assembled at a time (ie. pipes will be bored in 18 metre sections).
- Assumption 2: Backfilling will take two-thirds of the time as excavation.

## 6.0 - Cost Estimate

The cost estimate is summarized in  below with a detailed breakdown located in Appendix D. This engineer's estimate was completed using RS Means. This budget is subject to change depending on input from the contractor's estimate.

*Table 5: Cost Estimate*

| **Item:** | **Cost:** |
|---|---:|
| **Engineering** | $351,000 |
| **Site Works** | $1,264,000 |
| **Concrete** | $457,000 |
| **Pipe Jacking** | $1,592,000 |
| **Total** | $3,665,000 |

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# Appendices

## Appendix A – Catchment Areas

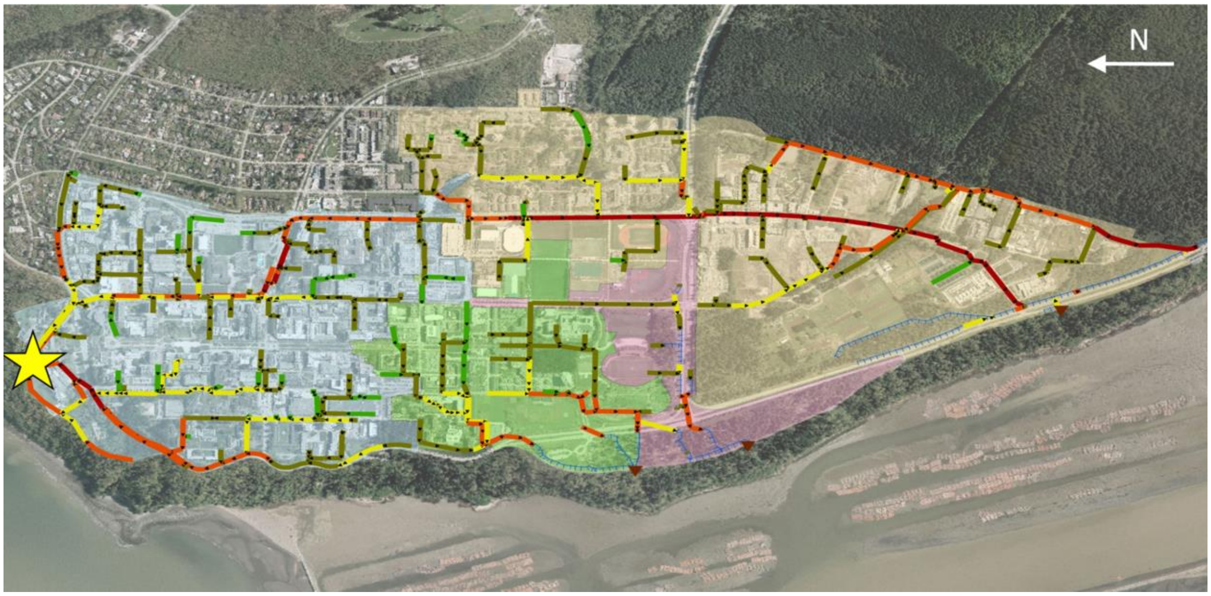


Figure 15: Overview of Catchment Areas

(GeoAdvice Engineering Inc., 2013)

# Appendix B – Storm Water Detention Calculations

standard 24-hour NRCS rainfall distributions

6-minute interval

| time (hours) | type Ia 24-hour | 10yr (Runoff volumes m3) | 100yr (Runoff volumes m3) | 100yr flow rates (m3/s) over a 6 min | Backup m3 |
|---|---|---|---|---|---|
| 0.0 | 0.00000 | 0.0 | 0.0 | 0.000 | 0.0 |
| 0.1 | 0.00224 | 186.7 | 274.6 | 0.763 | 0.0 |
| 0.2 | 0.00432 | 360.1 | 529.6 | 0.708 | 0.0 |
| 0.3 | 0.00628 | 523.5 | 769.9 | 0.667 | 0.0 |
| 0.4 | 0.00816 | 680.2 | 1000.4 | 0.640 | 0.0 |
| 0.5 | 0.01000 | 833.5 | 1226.0 | 0.627 | 0.0 |
| 0.6 | 0.01184 | 986.9 | 1451.6 | 0.627 | 0.0 |
| 0.7 | 0.01372 | 1143.6 | 1682.1 | 0.640 | 0.0 |
| 0.8 | 0.01568 | 1307.0 | 1922.4 | 0.667 | 0.0 |
| 0.9 | 0.01776 | 1480.3 | 2177.4 | 0.708 | 0.0 |
| 1.0 | 0.02000 | 1667.1 | 2452.0 | 0.763 | 0.0 |
| 1.1 | 0.02276 | 1897.1 | 2790.4 | 0.940 | 0.0 |
| 1.2 | 0.02568 | 2140.5 | 3148.4 | 0.994 | 0.0 |
| 1.3 | 0.02872 | 2393.9 | 3521.1 | 1.035 | 0.0 |
| 1.4 | 0.03184 | 2653.9 | 3903.6 | 1.063 | 0.0 |
| 1.5 | 0.03500 | 2917.3 | 4291.1 | 1.076 | 0.0 |
| 1.6 | 0.03797 | 3164.9 | 4655.2 | 1.011 | 0.0 |
| 1.7 | 0.04095 | 3413.3 | 5020.6 | 1.015 | 0.0 |
| 1.8 | 0.04394 | 3662.5 | 5387.1 | 1.018 | 0.0 |
| 1.9 | 0.04695 | 3913.4 | 5756.2 | 1.025 | 0.0 |
| 2.0 | 0.05000 | 4167.6 | 6130.1 | 1.039 | 0.0 |
| 2.1 | 0.05315 | 4430.2 | 6516.3 | 1.073 | 0.0 |
| 2.2 | 0.05633 | 4695.3 | 6906.2 | 1.083 | 0.0 |
| 2.3 | 0.05954 | 4962.8 | 7299.7 | 1.093 | 0.0 |
| 2.4 | 0.06276 | 5231.2 | 7694.5 | 1.097 | 0.0 |
| 2.5 | 0.06600 | 5501.3 | 8091.7 | 1.103 | 0.0 |
| 2.6 | 0.06920 | 5768.0 | 8484.1 | 1.090 | 0.0 |
| 2.7 | 0.07240 | 6034.7 | 8876.4 | 1.090 | 0.0 |
| 2.8 | 0.07560 | 6301.5 | 9268.7 | 1.090 | 0.0 |
| 2.9 | 0.07880 | 6568.2 | 9661.0 | 1.090 | 0.0 |
| 3.0 | 0.08200 | 6834.9 | 10053.4 | 1.090 | 0.0 |
| 3.1 | 0.08514 | 7096.6 | 10438.3 | 1.069 | 0.0 |
| 3.2 | 0.08829 | 7359.2 | 10824.5 | 1.073 | 0.0 |
| 3.3 | 0.09147 | 7624.3 | 11214.4 | 1.083 | 0.0 |
| 3.4 | 0.09471 | 7894.3 | 11611.6 | 1.103 | 0.0 |
| 3.5 | 0.09800 | 8168.6 | 12015.0 | 1.120 | 0.0 |
| 3.6 | 0.10147 | 8457.8 | 12440.4 | 1.182 | 0.0 |
| 3.7 | 0.10502 | 8753.7 | 12875.7 | 1.209 | 0.0 |
| 3.8 | 0.10862 | 9053.8 | 13317.0 | 1.226 | 0.0 |
| 3.9 | 0.11229 | 9359.7 | 13767.0 | 1.250 | 0.0 |
| 4.0 | 0.11600 | 9668.9 | 14221.8 | 1.263 | 0.0 |
| 4.1 | 0.11969 | 9976.5 | 14674.2 | 1.257 | 0.0 |
| 4.2 | 0.12342 | 10287.4 | 15131.5 | 1.270 | 0.0 |
| 4.3 | 0.12721 | 10603.3 | 15596.2 | 1.291 | 0.0 |
| 4.4 | 0.13107 | 10925.0 | 16069.4 | 1.315 | 0.0 |
| 4.5 | 0.13500 | 11252.6 | 16551.3 | 1.338 | 0.0 |
| 4.6 | 0.13901 | 11586.9 | 17042.9 | 1.366 | 0.0 |
| 4.7 | 0.14310 | 11927.8 | 17544.3 | 1.393 | 0.0 |
| 4.8 | 0.14729 | 12277.0 | 18058.0 | 1.427 | 0.0 |
| 4.9 | 0.15159 | 12635.4 | 18585.2 | 1.464 | 0.0 |
| 5.0 | 0.15600 | 13003.0 | 19125.9 | 1.502 | 0.0 |
| 5.1 | 0.16059 | 13385.6 | 19688.6 | 1.563 | 0.0 |
| 5.2 | 0.16530 | 13778.2 | 20266.1 | 1.604 | 0.0 |
| 5.3 | 0.17011 | 14179.1 | 20855.8 | 1.638 | 0.0 |
| 5.4 | 0.17501 | 14587.6 | 21456.6 | 1.669 | 0.0 |
| 5.5 | 0.18000 | 15003.5 | 22068.4 | 1.699 | 0.0 |
| 5.6 | 0.18494 | 15415.2 | 22674.0 | 1.682 | 0.0 |
| 5.7 | 0.18999 | 15836.2 | 23293.1 | 1.720 | 0.0 |
| 5.8 | 0.19517 | 16267.9 | 23928.2 | 1.764 | 0.0 |
| 5.9 | 0.20049 | 16711.4 | 24580.5 | 1.812 | 0.0 |
| 6.0 | 0.20600 | 17170.7 | 25256.0 | 1.876 | 0.0 |
| 6.1 | 0.21196 | 17667.4 | 25986.7 | 2.030 | 0.0 |
| 6.2 | 0.21808 | 18177.6 | 26737.0 | 2.084 | 0.0 |
| 6.3 | 0.22432 | 18697.7 | 27502.1 | 2.125 | 0.0 |
| 6.4 | 0.23064 | 19224.5 | 28276.9 | 2.152 | 0.0 |
| 6.5 | 0.23700 | 19754.6 | 29056.7 | 2.166 | 0.0 |
| 6.6 | 0.24285 | 20242.2 | 29773.9 | 1.992 | 0.0 |
| 6.7 | 0.24878 | 20736.5 | 30500.9 | 2.020 | 0.0 |
| 6.8 | 0.25490 | 21246.6 | 31251.2 | 2.084 | 0.0 |
| 6.9 | 0.26127 | 21777.6 | 32032.2 | 2.169 | 0.0 |
| 7.0 | 0.26800 | 22338.5 | 32857.3 | 2.292 | 0.0 |
| 7.1 | 0.27517 | 22936.2 | 33736.4 | 2.442 | 0.0 |
| 7.2 | 0.28287 | 23578.0 | 34680.4 | 2.622 | 0.0 |
| 7.3 | 0.29118 | 24270.6 | 35699.2 | 2.830 | 0.0 |
| 7.4 | 0.30019 | 25021.6 | 36803.9 | 3.068 | 0.0 |
| 7.5 | 0.31000 | 25839.3 | 38006.6 | 3.341 | 0.0 |
| 7.6 | 0.33142 | 27624.7 | 40632.7 | 7.295 | 1348.1 |
| 7.7 | 0.35469 | 29564.4 | 43485.7 | 7.925 | 1574.9 |
| 7.8 | 0.37876 | 31570.7 | 46436.7 | 8.197 | 1673.0 |
| 7.9 | 0.40255 | 33553.6 | 49353.4 | 8.102 | 1638.7 |
| 8.0 | 0.42500 | 35424.9 | 52105.8 | 7.646 | 1474.4 |
| 8.1 | 0.43936 | 36621.8 | 53866.4 | 4.890 | 482.6 |
| 8.2 | 0.45168 | 37648.7 | 55376.9 | 4.196 | 232.5 |
| 8.3 | 0.46232 | 38535.6 | 56681.3 | 3.624 | 26.5 |
| 8.4 | 0.47164 | 39312.5 | 57824.0 | 3.174 | 0.0 |
| 8.5 | 0.48000 | 40009.3 | 58848.9 | 2.847 | 0.0 |
| 8.6 | 0.48904 | 40762.8 | 59957.3 | 3.079 | 0.0 |
| 8.7 | 0.49752 | 41469.6 | 60996.9 | 2.888 | 0.0 |
| 8.8 | 0.50548 | 42133.1 | 61972.8 | 2.711 | 0.0 |
| 8.9 | 0.51296 | 42756.6 | 62889.9 | 2.547 | 0.0 |
| 9.0 | 0.52000 | 43343.4 | 63753.0 | 2.398 | 0.0 |
| 9.1 | 0.52664 | 43896.9 | 64567.1 | 2.261 | 0.0 |
| 9.2 | 0.53292 | 44420.3 | 65337.0 | 2.139 | 0.0 |
| 9.3 | 0.53888 | 44917.1 | 66067.7 | 2.030 | 0.0 |
| 9.4 | 0.54456 | 45390.5 | 66764.1 | 1.934 | 0.0 |
| 9.5 | 0.55000 | 45844.0 | 67431.1 | 1.853 | 0.0 |
| 9.6 | 0.55564 | 46314.1 | 68122.6 | 1.921 | 0.0 |
| 9.7 | 0.56116 | 46774.2 | 68799.3 | 1.880 | 0.0 |
| 9.8 | 0.56656 | 47224.3 | 69461.4 | 1.839 | 0.0 |
| 9.9 | 0.57184 | 47664.4 | 70108.7 | 1.798 | 0.0 |
| 10.0 | 0.57700 | 48094.5 | 70741.3 | 1.757 | 0.0 |
| 10.1 | 0.58198 | 48509.6 | 71351.9 | 1.696 | 0.0 |
| 10.2 | 0.58685 | 48915.5 | 71949.0 | 1.659 | 0.0 |
| 10.3 | 0.59163 | 49314.0 | 72535.0 | 1.628 | 0.0 |
| 10.4 | 0.59635 | 49707.4 | 73113.7 | 1.607 | 0.0 |
| 10.5 | 0.60100 | 50095.0 | 73683.8 | 1.584 | 0.0 |
| 10.6 | 0.60576 | 50491.7 | 74267.4 | 1.621 | 0.0 |
| 10.7 | 0.61044 | 50881.8 | 74841.1 | 1.594 | 0.0 |
| 10.8 | 0.61504 | 51265.2 | 75405.1 | 1.567 | 0.0 |
| 10.9 | 0.61956 | 51642.0 | 75959.3 | 1.539 | 0.0 |
| 11.0 | 0.62400 | 52012.1 | 76503.6 | 1.512 | 0.0 |
| 11.1 | 0.62836 | 52375.5 | 77038.2 | 1.485 | 0.0 |
| 11.2 | 0.63264 | 52732.2 | 77562.9 | 1.458 | 0.0 |
| 11.3 | 0.63684 | 53082.3 | 78077.8 | 1.430 | 0.0 |
| 11.4 | 0.64096 | 53425.7 | 78583.0 | 1.403 | 0.0 |
| 11.5 | 0.64500 | 53762.5 | 79078.3 | 1.376 | 0.0 |
| 11.6 | 0.64889 | 54086.7 | 79555.2 | 1.325 | 0.0 |
| 11.7 | 0.65272 | 54406.0 | 80024.8 | 1.304 | 0.0 |
| 11.8 | 0.65651 | 54721.9 | 80489.4 | 1.291 | 0.0 |
| 11.9 | 0.66026 | 55034.4 | 80949.2 | 1.277 | 0.0 |
| 12.0 | 0.66400 | 55346.2 | 81407.7 | 1.274 | 0.0 |
| 12.1 | 0.66773 | 55657.1 | 81865.0 | 1.270 | 0.0 |
| 12.2 | 0.67148 | 55969.7 | 82324.8 | 1.277 | 0.0 |
| 12.3 | 0.67527 | 56285.6 | 82789.4 | 1.291 | 0.0 |
| 12.4 | 0.67910 | 56604.8 | 83259.0 | 1.304 | 0.0 |
| 12.5 | 0.68300 | 56929.9 | 83737.1 | 1.328 | 0.0 |
| 12.6 | 0.68665 | 57234.1 | 84184.6 | 1.243 | 0.0 |
| 12.7 | 0.69027 | 57535.9 | 84628.5 | 1.233 | 0.0 |
| 12.8 | 0.69386 | 57835.1 | 85068.6 | 1.223 | 0.0 |
| 12.9 | 0.69744 | 58133.5 | 85507.5 | 1.219 | 0.0 |
| 13.0 | 0.70100 | 58430.2 | 85944.0 | 1.212 | 0.0 |
| 13.1 | 0.70473 | 58741.1 | 86401.3 | 1.270 | 0.0 |
| 13.2 | 0.70838 | 59045.4 | 86848.8 | 1.243 | 0.0 |
| 13.3 | 0.71198 | 59345.4 | 87290.1 | 1.226 | 0.0 |
| 13.4 | 0.71551 | 59639.7 | 87722.9 | 1.202 | 0.0 |
| 13.5 | 0.71900 | 59930.6 | 88150.8 | 1.189 | 0.0 |
| 13.6 | 0.72245 | 60218.2 | 88573.8 | 1.175 | 0.0 |
| 13.7 | 0.72586 | 60502.4 | 88991.9 | 1.161 | 0.0 |
| 13.8 | 0.72926 | 60785.8 | 89408.7 | 1.158 | 0.0 |
| 13.9 | 0.73263 | 61066.7 | 89821.9 | 1.148 | 0.0 |
| 14.0 | 0.73600 | 61347.6 | 90235.0 | 1.148 | 0.0 |
| 14.1 | 0.73939 | 61630.1 | 90650.7 | 1.155 | 0.0 |
| 14.2 | 0.74277 | 61911.9 | 91065.1 | 1.151 | 0.0 |
| 14.3 | 0.74613 | 62191.9 | 91477.0 | 1.144 | 0.0 |
| 14.4 | 0.74948 | 62471.2 | 91887.7 | 1.141 | 0.0 |
| 14.5 | 0.75281 | 62748.7 | 92296.0 | 1.134 | 0.0 |
| 14.6 | 0.75613 | 63025.5 | 92703.0 | 1.131 | 0.0 |
| 14.7 | 0.75943 | 63300.5 | 93107.6 | 1.124 | 0.0 |
| 14.8 | 0.76271 | 63573.9 | 93509.7 | 1.117 | 0.0 |
| 14.9 | 0.76598 | 63846.5 | 93910.6 | 1.114 | 0.0 |
| 15.0 | 0.76924 | 64118.2 | 94310.3 | 1.110 | 0.0 |
| 15.1 | 0.77248 | 64388.3 | 94707.6 | 1.103 | 0.0 |
| 15.2 | 0.77571 | 64657.5 | 95103.6 | 1.100 | 0.0 |
| 15.3 | 0.77892 | 64925.1 | 95497.1 | 1.093 | 0.0 |
| 15.4 | 0.78211 | 65191.0 | 95888.2 | 1.086 | 0.0 |
| 15.5 | 0.78529 | 65456.0 | 96278.1 | 1.083 | 0.0 |
| 15.6 | 0.78845 | 65719.4 | 96665.5 | 1.076 | 0.0 |
| 15.7 | 0.79160 | 65982.0 | 97051.7 | 1.073 | 0.0 |
| 15.8 | 0.79474 | 66243.7 | 97436.7 | 1.069 | 0.0 |
| 15.9 | 0.79786 | 66503.8 | 97819.2 | 1.063 | 0.0 |
| 16.0 | 0.80096 | 66762.2 | 98199.3 | 1.056 | 0.0 |
| 16.1 | 0.80405 | 67019.7 | 98578.1 | 1.052 | 0.0 |
| 16.2 | 0.80712 | 67275.6 | 98954.5 | 1.046 | 0.0 |
| 16.3 | 0.81018 | 67530.7 | 99329.7 | 1.042 | 0.0 |
| 16.4 | 0.81322 | 67784.1 | 99702.4 | 1.035 | 0.0 |
| 16.5 | 0.81625 | 68036.6 | 100073.8 | 1.032 | 0.0 |
| 16.6 | 0.81926 | 68287.5 | 100442.9 | 1.025 | 0.0 |
| 16.7 | 0.82226 | 68537.6 | 100810.7 | 1.022 | 0.0 |
| 16.8 | 0.82524 | 68786.0 | 101176.0 | 1.015 | 0.0 |
| 16.9 | 0.82821 | 69033.5 | 101540.2 | 1.011 | 0.0 |
| 17.0 | 0.83116 | 69279.4 | 101901.8 | 1.005 | 0.0 |
| 17.1 | 0.83410 | 69524.5 | 102262.3 | 1.001 | 0.0 |
| 17.2 | 0.83702 | 69767.9 | 102620.3 | 0.994 | 0.0 |
| 17.3 | 0.83992 | 70009.6 | 102975.8 | 0.988 | 0.0 |
| 17.4 | 0.84281 | 70250.5 | 103330.2 | 0.984 | 0.0 |
| 17.5 | 0.84569 | 70490.5 | 103683.3 | 0.981 | 0.0 |
| 17.6 | 0.84855 | 70728.9 | 104033.9 | 0.974 | 0.0 |
| 17.7 | 0.85140 | 70966.5 | 104383.3 | 0.971 | 0.0 |
| 17.8 | 0.85423 | 71202.4 | 104730.3 | 0.964 | 0.0 |
| 17.9 | 0.85704 | 71436.6 | 105074.8 | 0.957 | 0.0 |
| 18.0 | 0.85984 | 71670.0 | 105418.1 | 0.954 | 0.0 |
| 18.1 | 0.86262 | 71901.7 | 105758.9 | 0.947 | 0.0 |
| 18.2 | 0.86539 | 72132.6 | 106098.5 | 0.943 | 0.0 |
| 18.3 | 0.86815 | 72362.6 | 106436.9 | 0.940 | 0.0 |
| 18.4 | 0.87089 | 72591.0 | 106772.8 | 0.933 | 0.0 |
| 18.5 | 0.87361 | 72817.7 | 107106.3 | 0.926 | 0.0 |
| 18.6 | 0.87632 | 73043.6 | 107438.5 | 0.923 | 0.0 |
| 18.7 | 0.87901 | 73267.8 | 107768.3 | 0.916 | 0.0 |
| 18.8 | 0.88169 | 73491.2 | 108096.9 | 0.913 | 0.0 |
| 18.9 | 0.88435 | 73713.0 | 108423.0 | 0.906 | 0.0 |
| 19.0 | 0.88700 | 73933.8 | 108747.9 | 0.902 | 0.0 |
| 19.1 | 0.88963 | 74153.1 | 109070.4 | 0.896 | 0.0 |
| 19.2 | 0.89225 | 74371.4 | 109391.6 | 0.892 | 0.0 |
| 19.3 | 0.89485 | 74588.2 | 109710.4 | 0.885 | 0.0 |
| 19.4 | 0.89744 | 74804.0 | 110027.9 | 0.882 | 0.0 |
| 19.5 | 0.90001 | 75018.3 | 110343.0 | 0.875 | 0.0 |
| 19.6 | 0.90257 | 75231.6 | 110656.9 | 0.872 | 0.0 |
| 19.7 | 0.90511 | 75443.4 | 110968.3 | 0.865 | 0.0 |
| 19.8 | 0.90763 | 75653.4 | 111277.2 | 0.858 | 0.0 |
| 19.9 | 0.91014 | 75862.6 | 111584.9 | 0.855 | 0.0 |
| 20.0 | 0.91264 | 76071.0 | 111891.5 | 0.851 | 0.0 |
| 20.1 | 0.91512 | 76277.7 | 112195.5 | 0.845 | 0.0 |
| 20.2 | 0.91759 | 76483.6 | 112498.3 | 0.841 | 0.0 |
| 20.3 | 0.92004 | 76687.8 | 112798.7 | 0.834 | 0.0 |
| 20.4 | 0.92247 | 76890.4 | 113096.6 | 0.828 | 0.0 |
| 20.5 | 0.92489 | 77092.1 | 113393.3 | 0.824 | 0.0 |
| 20.6 | 0.92729 | 77292.1 | 113687.6 | 0.817 | 0.0 |
| 20.7 | 0.92968 | 77491.3 | 113980.6 | 0.814 | 0.0 |
| 20.8 | 0.93206 | 77689.7 | 114272.4 | 0.811 | 0.0 |
| 20.9 | 0.93442 | 77886.4 | 114561.7 | 0.804 | 0.0 |
| 21.0 | 0.93676 | 78081.5 | 114848.6 | 0.797 | 0.0 |
| 21.1 | 0.93909 | 78275.7 | 115134.3 | 0.794 | 0.0 |
| 21.2 | 0.94140 | 78468.2 | 115417.5 | 0.787 | 0.0 |
| 21.3 | 0.94370 | 78659.9 | 115699.5 | 0.783 | 0.0 |
| 21.4 | 0.94598 | 78850.0 | 115979.0 | 0.776 | 0.0 |
| 21.5 | 0.94825 | 79039.2 | 116257.3 | 0.773 | 0.0 |
| 21.6 | 0.95050 | 79226.7 | 116533.2 | 0.766 | 0.0 |
| 21.7 | 0.95274 | 79413.4 | 116807.8 | 0.763 | 0.0 |
| 21.8 | 0.95496 | 79598.5 | 117080.0 | 0.756 | 0.0 |
| 21.9 | 0.95717 | 79782.7 | 117350.9 | 0.753 | 0.0 |
| 22.0 | 0.95936 | 79965.2 | 117619.4 | 0.746 | 0.0 |
| 22.1 | 0.96154 | 80146.9 | 117886.7 | 0.742 | 0.0 |
| 22.2 | 0.96370 | 80327.0 | 118151.5 | 0.736 | 0.0 |
| 22.3 | 0.96584 | 80505.4 | 118413.9 | 0.729 | 0.0 |
| 22.4 | 0.96797 | 80682.9 | 118675.0 | 0.725 | 0.0 |
| 22.5 | 0.97009 | 80859.6 | 118934.9 | 0.722 | 0.0 |
| 22.6 | 0.97219 | 81034.7 | 119192.4 | 0.715 | 0.0 |
| 22.7 | 0.97428 | 81208.9 | 119448.6 | 0.712 | 0.0 |
| 22.8 | 0.97635 | 81381.4 | 119702.4 | 0.705 | 0.0 |
| 22.9 | 0.97840 | 81552.3 | 119953.8 | 0.698 | 0.0 |
| 23.0 | 0.98044 | 81722.3 | 120203.9 | 0.695 | 0.0 |
| 23.1 | 0.98246 | 81890.7 | 120451.5 | 0.688 | 0.0 |
| 23.2 | 0.98447 | 82058.2 | 120698.0 | 0.685 | 0.0 |
| 23.3 | 0.98647 | 82224.9 | 120943.2 | 0.681 | 0.0 |
| 23.4 | 0.98845 | 82390.0 | 121185.9 | 0.674 | 0.0 |
| 23.5 | 0.99041 | 82553.3 | 121426.2 | 0.667 | 0.0 |
| 23.6 | 0.99236 | 82715.9 | 121665.3 | 0.664 | 0.0 |
| 23.7 | 0.99429 | 82876.7 | 121901.9 | 0.657 | 0.0 |
| 23.8 | 0.99621 | 83036.8 | 122137.3 | 0.654 | 0.0 |
| 23.9 | 0.99811 | 83195.2 | 122370.2 | 0.647 | 0.0 |
| 24.0 | 1.0000 | 83352.7 | 122602.0 | 0.644 | 0.0 |

| GeoAdvice TM#2 Info: | | |
|---|---|---|
| North Catchment Area | 138.69 | ha |
| 10yr Storm Runoff NC | 601 | m3/ha |
| | 83353 | m3 |
| 100yr Storm Runoff NC | 884 | m3/ha |
| | 122602 | m3 |
| 10yr Avg. Runoff Flow Rate | 0.96 | m3/s |
| 10yr Peak Runoff Flow Rate | 3.55 | m3/s |
| 100yr Avg. Runoff Flow Rate | 1.42 | m3/s |
| 100yr Peak Runoff Flow Rate | 3.55 | m3/s |
| GeoAdvice TM#3 Info: | | |
| Total Flooding 100yr NC | 6000 | m3 |

NC - North Catchment

| Spiral Drain Outflow (m3/s) |
|---|
| 3.55 |
| Total Backup (m3) |
| 8450.7 |
| Spiral Drain Backup (m3) |
| 2450.7 |
| Holding Tank Footprint |
| 1633.8 |

# Appendix C – Preliminary Schedule

## Preliminary Schedule

| ACTIVITY | PLAN START | PLAN DURATION | ACTUAL START | ACTUAL DURATION | PERCENT COMPLETE |
|---|---|---|---|---|---|
| **May, 2017** | | | | | |
| Site Preparation | 1 | 5 | 1 | 5 | 100% |
| Excavation of pipes | 8 | 24 | 8 | 24 | 100% |
| Pipe rerouting | 25 | 7 | 25 | 7 | 100% |
| **June, 2017** | | | | | |
| Excavation of pipes | 1 | 23 | 1 | 23 | 100% |
| Pipe rerouting | 1 | 29 | 1 | 29 | 100% |
| Pipe Jacking | 26 | 6 | 26 | 6 | 100% |
| Excavation of holding tank area | 26 | 6 | 26 | 6 | 100% |
| **July, 2017** | | | | | |
| Pipe Jacking | 1 | 31 | 1 | 31 | 100% |
| Excavation of holding tank area | 1 | 31 | 1 | 31 | 100% |
| **August, 2017** | | | | | |
| Excavation of holding tank area | 1 | 8 | 1 | 8 | 100% |
| Placement of holding tanks | 9 | 22 | 9 | 22 | 100% |
| Backfill of pipe area | 1 | 28 | 1 | 28 | 100% |
| Backfill of holding tank areas | 30 | 2 | 30 | 2 | 100% |
| **September, 2017** | | | | | |
| Backfill of holding tank areas | 1 | 30 | 1 | 30 | 100% |
| Project Closeout | 31 | 1 | 31 | 1 | 100% |
| **October, 2017** | | | | | |
| Project Closeout | 1 | 10 | 1 | 10 | 100% |

# Appendix D – Cost Estimate

Total Cost Breakdown:

| | | | |
|---|---|---|---|
| **ENGINEERING** | | | |
| *Vanguard Engineering* | | | |
| | Engineering Design | $351,000.00 | |
| | | | |
| **EXCAVATIONS AND PIPE RETROFITTING** | | | |
| *Labour + Equipment* | | | |
| | Excavations | $480,165.60 | |
| | Pipe Retrofits | $293,860.80 | |
| *Materials* | | | **Site Works Cost** |
| | Steel Pipes | $489,600.00 | $1,263,626.40 |
| | | | |
| **CONCRETE HOLDING STRUCTURE** | | | |
| *See Concrete Estimate* | | | |
| | Columns | $16,782.00 | |
| | Beams | $104,988.27 | |
| | Elevated Slab | $115,234.63 | |
| | Slab on Grade | $110,757.85 | |
| | Walls | $18,150.45 | **Concrete Total Cost** |
| | Contingency | $91,478.30 | $457,391.49 |
| | | | |
| **PIPE JACKING AND OUTFALL INSTALLATION** | | | |
| *Labour + Equipment* | | | |
| | Installation | $1,024,015.20 | |
| | | | |
| *Materials* | | | **Pipe Jacking Cost** |
| | Pipe Jacking Pipes | $568,800.00 | $1,592,815.20 |
| | | | |
| **TOTAL** | | **$3,664,833.09** | |

| **COLUMNS** | | | | | | | |
|---|---|---|---|---|---|---|---|
| ***BASE DATA*** | | | ***ACTIVITY*** | ***RATE*** | | ***SUM*** | ***NOTES*** |
| Surface Area | 0.84 | m2 | Forms (4 Use) | 87.5 | per m2 | $22.40 | |
| Number | 16 | | Pour | 2550 | per m3 | $856.80 | |
| | | | Rebar | 2125 | per met ton | $169.72 | 8-25M |
| | | | | | *TOTAL PER COL.* | $1,048.92 | |
| | | | | | | | |
| | | | | | **TOTAL (ALL COLS)** | **$16,782.71** | |

| **WALLS** | | | | | | | |
|---|---|---|---|---|---|---|---|
| ***BASE DATA*** | | | ***ACTIVITY*** | ***RATE*** | | ***SUM*** | ***NOTES*** |
| Area | 78.75 | m2 | Forms (4 Use) Side | 77 | per m2 | $1,847.92 | |
| Number | 4 | | Pour | 46.5 | per m3 | $1,098.56 | |
| | | | Rebar | 2125 | per met ton | $1,591.13 | 25M@500mm |
| | | | | | | | |
| | | | | | TOTAL PER WALL | $4,537.61 | |
| | | | | | | | |
| | | | | | **TOTAL (ALL)** | **$18,150.45** | |

| **BEAMS** | | | | | | | |
|---|---|---|---|---|---|---|---|
| ***BASE DATA*** | | | ***ACTIVITY*** | ***RATE*** | | ***SUM*** | ***NOTES*** |
| Number | 65 | | Forms (4 Use) Bottom | 115 | per m2 | $441.58 | |
| Bottom Web Area | 2.8 | m2 | Forms (4 Use) Side | 82 | per m2 | $262.39 | |
| Bottom Flange Area | 9.8 | m2 | Pour | 84.5 | per m3 | $569.62 | |
| Side Web | 5.6 | m2 | Rebar | 2125 | per met ton | $341.62 | 8-35M |
| Side Flange | 4.9 | m2 | | | TOTAL PER BEAM | $1,615.21 | |
| | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | **TOTAL (ALL)** | **$104,988.41** | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **ONE WAY SLAB** | | | | | | | |
| ***BASE DATA*** | | | ***ACTIVITY*** | ***RATE*** | | ***SUM*** | ***NOTES*** |
| Number | 1 | | Forms (4 Use) Side | 62.5 | per m2 | $93,329.26 | |
| Area | 1225 | m2 | Pour | 28 | per m3 | $12,005.00 | |
| | | | Rebar | 2125 | per met ton | $9,900.37 | 35M@250mm |
| | | | | | **TOTAL** | **$115,234.63** | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **SLAB ON GRADE** | | | | | | | |
| ***BASE DATA*** | | | ***ACTIVITY*** | ***RATE*** | | ***SUM*** | ***NOTES*** |
| Number | 1 | | Forms (4 Use) Side | 62.5 | per m2 | $93,329.26 | |
| Area | 1225 | m2 | Pour | 27.5 | per m3 | $5,053.13 | |
| | | | Rebar | 2125 | per met ton | $12,375.46 | 10-25M/meter |
| | | | | | **TOTAL** | **$110,757.85** | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **SUM OF WORK** | | | | | | **$365,914.05** | |
| | | | | | **CONTINGENCY** | $91,478.51 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **TOTAL** | | | | | | **$457,392.56** | |

## C. Orifice Flow Control

Figure C.1 illustrates the orifice flow condition. The flow condition persists when the culvert is especially steep or short and is sometimes referred to as "hydraulically short."

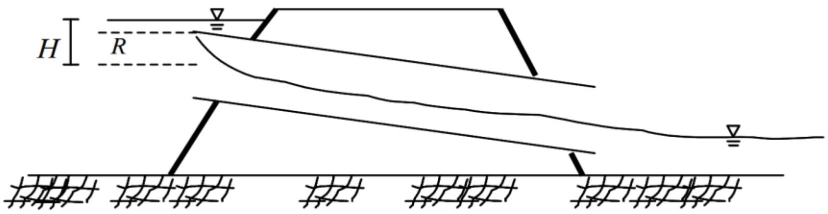


**Figure C.1**: Schematic of the orifice flow culvert design condition

$$q = aC\sqrt{2gH} \qquad \text{(A.1)}$$

where $q$ is the flow rate, $a$ is the pipe cross-sectional area, $H$ is the energy head (defined in Fig. C.1), $C$ is a head loss coefficient; for sharp inlets this is called the *vena contracta* and can be determined from first principles $C = 0.611$.

| | | | |
|---|---|---|---|
| C | 0.611 | | |
| g | 9.81 | m^2/s | |
| h (reservior) | 4 | m | |
| | | | |
| D (mm) | a (m^2) | H (m) | q (m^3/s) |
| 100 | 0.00785 | 3.95 | 0.0422 |
| 150 | 0.01767 | 3.925 | 0.0948 |
| 200 | 0.03142 | 3.9 | 0.1679 |
| 250 | 0.04909 | 3.875 | 0.2615 |
| 300 | 0.07069 | 3.85 | 0.3754 |
| 350 | 0.09621 | 3.825 | 0.5093 |
| 400 | 0.12566 | 3.8 | 0.6630 |
| 450 | 0.15904 | 3.775 | 0.8363 |
| 500 | 0.19635 | 3.75 | 1.0290 |
| 550 | 0.23758 | 3.725 | 1.2410 |
| 600 | 0.28274 | 3.7 | 1.4719 |
| 650 | 0.33183 | 3.675 | 1.7216 |
| 700 | 0.38485 | 3.65 | 1.9899 |
| 750 | 0.44179 | 3.625 | 2.2764 |
| 800 | 0.50265 | 3.6 | 2.5811 |
| 850 | 0.56745 | 3.575 | 2.9037 |
| 900 | 0.63617 | 3.55 | 3.2440 |
| 950 | 0.70882 | 3.525 | 3.6017 |
| 1000 | 0.78540 | 3.5 | 3.9766 |

# Appendix F – Structural Design Calculations

| | | | | | | |
|---|---|---|---|---|---|---|
| Soil | 19 | kn/m^3 | | Depth at top | 2.9 | m |
| Dead | 25.23675 | kpa | | Depth at bottom | 5.15 | m |
| Live | 0 | | | Load at top | 18.183 | kpa |
| Snow | 0 | | | Load at Bottom | 32.2905 | kpa |
| Wind | 0 | | | Length | 35 | m |
| Seismic | 9.44 | | | Height | 2 | m |
| | | | | Area of Wall | 70 | m^2 |
| | | | | Ka | 0.33 | |
| | | | | | | |
| **ULTIMATE** | **Principal Load** | **Companion Loa** | **Total (kpa)** | | | |
| 1 | 1.4D | - | 35.33 | | | |
| 2 | 1.25D+1.5L | 0.5S or 0.5W | 31.55 | | | |
| 3 | 1.25D+1.5S | 0.5L or 0.5W | 31.55 | | | |
| 4 | 1.25D+1.4W | 0.5L or 0.5S | 31.55 | | | |
| 5 | 1.0D+1.0E | 0.5L+0.25S | 34.67675 | | | |
| | | | | | | |
| | | | | | | |
| | | | Total | 2473.2015 | kN | |

*Table 6: Lateral Load Calculations*

| | | | | | | |
|---|---|---|---|---|---|---|
| Soil | 19 | kn/m^3 | | Depth to Top | 2.9 | m |
| Dead | 35.815 | kpa | | Length | 35 | m |
| Live | 0 | | | Width | 35 | m |
| Snow | 0 | | | Area of Slab | 1225 | m^2 |
| Wind | 0 | | | K | 0.65 | |
| Seismic | 0 | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| **ULTIMATE** | **Principal Load** | **Companion Loa** | **Total (kpa)** | | | |
| 1 | 1.4D | - | 50.14 | | | |
| 2 | 1.25D+1.5L | 0.5S or 0.5W | 44.77 | | | |
| 3 | 1.25D+1.5S | 0.5L or 0.5W | 44.77 | | | |
| 4 | 1.25D+1.4W | 0.5L or 0.5S | 44.77 | | | |
| 5 | 1.0D+1.0E | 0.5L+0.25S | 35.815 | | | |
| | | | | | | |
| | | | | | | |
| | | | Total | 61422.725 | kN | |

*Table 7: Vertical Load Calculations*

| | | | | | |
|---|---|---|---|---|---|
| Concrete | 23.6 | kn/m^3 | | | |
| Length | 35 | m | | | |
| Height | 2 | m | | | |
| Thickness | 0.5 | m | ASSUMED VALUE | | |
| | | | | | |
| Number of Walls | 4 | | | | |
| Total Weight | 3304 | kn | | | |
| | | | | | |
| S(4.0) | 0.1 | Approximated | | | |
| Mv | 1 | | Formula | S(4.0)*Mv*Ie*W/(Rd*Ro) | |
| Ie | 2 | | | | |
| Rd | 1 | | | | |
| Ro | 1 | | | | |
| | | | | | |
| Base Shear | 660.8 | Kn | | | |
| | | | | | |
| Area | 70 | m2 | | | |
| Stress | 9.44 | kpa | | | |

*Table 8: Seismic Load Calculations*

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Columns | | | | | | | | | | |
| | f'c (MPa) | 30 | | h | 1200 | | φm | 0.75 | | |
| | fy (Mpa) | 400 | | b | 1200 | | cm | 1 | | |
| | Es (Mpa) | 200000 | | Lu | 2100 | | I | 1.728E+11 | | |
| | φc | 0.65 | | r | 360 | | E | 24647.51509 | | |
| | φs | 0.85 | | K*Lu/r | 5.833333333 | | β | 1 | | |
| | K | 1 | | Pc | 1.91E+09 | | EI | 8.52E+14 | | |
| | | | | | | | | | | |
| | Pf | Mf | Check | δ | Mc | | Pr | Mr | Pr/Ag | Mr/Agh |
| | 2456.909 | 0 | GOOD | 1.00E+00 | 0.00E+00 | | 2456.909 | 0 | 1.706186806 | 0 |
| | 3685.3635 | 6449.386125 | GOOD | 1.00E+00 | 6.47E+03 | | 3685.3635 | 6449.386125 | 2.559280208 | 3.732283637 |
| | 5528.04525 | 9674.079188 | GOOD | 1.00E+00 | 9.71E+03 | | 5528.04525 | 9674.079188 | 3.838920313 | 5.598425456 |
| | | | | | | | | | | |
| | Quantity | b | h | Steel Ratio | Steel Area Required | Arrangement | | | | |
| | 16 | 400 | 400 | 0.02 | 3200 | 8-25M | 2100 | | | |

*Table 9: Column Calculations*