South Campus Stormwater Detention Facility

Detailed Design Report

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University of British Columbia

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UBC SOUTH CAMPUS STORMWATER MANAGEMENT

DETAILED DESIGN REPORT

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EXECUTIVE SUMMARY

SMC Engineering has prepared a detailed design report, as requested by UBC Social, Ecological, Economic Development Studies (SEEDS), of the UBC South Campus Stormwater Management System that intends to mitigate the key risks associated with the 1 in 10 and 1 in 100-year storm event. The detailed design report, further developed on the preliminary design report, provides the methodology and reasoning utilized for designing the optimal solution that curtails the risk of cliff erosion along Foreshore Trail and mitigates overland flow on the UBC campus. The report intends to provide UBC SEEDS with an understanding of the design, cost, schedule, and construction practices required to complete the methods of risk mitigation associated with the 1 in 10 and 1 in 100-year storm events.

An overall site assessment confirms the physical aspects of the site such as topography, land usage, and the key constraints. A set of six studies are commissioned, which analyze the technical, economic, regulatory, environmental, societal, and constructability performance of the design solution. In particular, the environmental considerations regarding turbidity, infiltration, and long-term sustainability are detailed and cross-referenced with anticipated design performances. Engineering solutions component to the mitigation system that are not common in the UBC region have been researched thoroughly; the documented performances have been scrutinized with practicing engineering judgment in order to provide reasonable benefits with regards to the six commissioned studies.

SMC Engineering has designed a system that consists of four detention tanks, a dry pond, and a system of permeable asphalt to manage, the 1 in 10 and 1 in 100-year storm events. The cost estimate and project schedule indicate that this system is estimated to have a total initial direct and indirect construction cost of $5,573,000 with construction slated to start on May 2, 2016 with substantial completion on October 14, 2016. The system is anticipated to have a 90-year design life, and a life-cycle analysis determines the maintenance and repair costs throughout its lifespan.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1.0 INTRODUCTION

UBC Social, Ecological, Economic Development Studies (SEEDS) has requested a design report that addresses the current concerns of the South Campus Stormwater Management System, specifically, the 1 in 10 and 1 in 100-year storm events. The project objectives are to manage the factors of overland flooding, damage to UBC assets, harm to the riparian habitats, and cliff erosion along the Wreck Beach region. This detailed design report represents an final step before the forthcoming construction phase. The report will provide information on the design and a detailed understanding of the recommended solution from SMC Engineering.

In determining a solution, past information, including both client provided and self researched, has been studied to prepare a solution designed to mitigate the risks of large stormwater events. An investigation into site, design criteria, key issues, and precedent studies were made to ensure due diligence concerning existing conditions and situations.

The technical analysis (hydrotechnical, geotechnical, and structural analyses) undertaken provides an understanding of how the stormwater flooding is mitigated. The solution analysis results in a complete mitigation of the 1 in 100-year storm event. These analyses provide the insight utilized to complete a description of the selected solution, materials required for construction and the overall functionality of the design.

A regulatory analysis provides a framework of the various applicable forms of regulations that have the ability to govern the timeline, design, and success of this project.

The environmental analysis details the current environmental risks, the environmental impact assessment that will take place during the construction phase of the project, and the benefits of the solution post-construction.

The societal study outlines the benefits and risks to stakeholders before the implementation of the solution, the impacts of construction to stakeholders, and the overall benefits of implementing the solution.

The constructability analysis is developed to ensure that the design, with aspects governed by the other studies, is constructible; potential areas of concern regarding certain methodologies are outlined as well. A cost estimate and construction schedule are prepared in relation to the aforementioned studies and are included in the appendices.

As a conclusion to the design process, the design rationale summarizes the entire design process and methodology. It is intended to give the reader an understanding of how the solution was developed and improved upon in a concise summarized section.

The team allocated to the preparation of this report consists of six engineering students with differing areas of expertise ranging from structural and geotechnical consulting, construction to material testing. Each member has been responsible for varying tasks for the completion of the design and their roles are assigned based on their specialties. The roles for the development of this report are as follows:

Table 1: Team responsibilities

Team Member	Responsibilities
Joshua Deans	Overview of Design, Stakeholder Impact Analysis,
Hermanpreet Gill	Executive Summary, Scope of Work, Design Rationale, Geotechnical Technical and Regulatory Analysis, and Lead Reviewer.
David Grant	Economical and Constructability Analysis, Cost Estimate and Construction Schedule.
Cliff Huang	Hydrotechnical Analysis of Design, Design Rationale
Asad Ijaz	Schematic drawings, Structural Analysis of design and Environmental Impact.
Jack Liu	Introduction, Project Overview, Design Development and Recommendation.

Source: Table. Jack Liu. March 31, 2016.

2.0 SCOPE OF WORK

This report entails a comprehensive review of a detailed design that functions to mitigate risks for 1 in 10 and 1 in 100-year storm events as outlined in Section 3.0 – Project Overview. The findings and the level of effort are outlined by the scope of work. This scope of work for the detailed design intends to give the reader a summary of the work undertaken to ensure an efficient and functional design is in. This section is intended to be a follow up of the scope of work completed for the preliminary design report and has been built forward from that document. The work was approached in three phases as follows: Phase I – Technical and Economic Analysis, Phase II – Associated Studies and Phase III – Construction. The following is a summary of the scope of work:

Phase I – Technical and Economic Analysis

- Technical Analysis

    Task 1: Refine solution sizing

    Task 2: Confirm SWMM analysis for solution

    Task 3: Confirm building code reference studies to ensure design requirements

    Task 4: Detail material specifications of solution

    Task 5: Create a detailed drawing set

- Economic Analysis (In conjunction with Phase III)

    Task 6: Analyze solution benefits in conjunction with cost estimate

    Task 7: Determine secondary and tertiary monetary benefits to UBC campus

    Task 8: Detail risk mitigation costs

Phase II – Associated Studies

- Environmental Study

  Task 9: Re-evaluate current environmental concerns

  Task 10: Establish an environmental impact assessment

  Task 11: Re-evaluate post construction environmental benefits and concerns

  Task 12: Detail environmental monitoring plan during construction

- Stakeholder Impact Study

  Task 13: Confirm development of design based on stakeholder input

  Task 14: Detail stakeholder benefits with detailed design

- Constructability and Regulatory Study

  Task 15: Analyze difficulties in construction methodology

  Task 16: Cross-reference affecting regulations

Phase III – Construction

- Cost

  Task 17: Establish a refined cost estimate for direct costs

  Task 18: Re-assess indirect costs and contingency values

- Schedule

  Task 19: Refine construction schedule based on new methodologies

  Task 20: Establish a construction risk contingency in days

3.0 PROJECT OVERVIEW

The following sections intend to provide a brief background of past and present issues and concerns with regards to the UBC stormwater system capacity. An overview of the site alongside a description of the goals, constraints, and key issues is summarized to ensure a fundamental understanding of the basis of this report is established.

3.1 Project Background

With the current stormwater system, the quantity of overland flow and flooding during extreme events can cause damage to the University of British Columbia's assets, riparian habitats and local businesses, and can result in cliff erosion leading to cliff failure. The existing UBC stormwater system contains a series of storm sewers, open drainage channels, and stream outfalls serving the majority of the developed areas of UBC's campus. Through recent studies, such as the Integrated Stormwater Management Plan (ISMP) and Overland Flow Route Assessment (OFRA), it is illustrated that Wesbrook Village and Marine Drive at Wesbrook are specifically at risk to high floods and the effects of the run-offs can damage the existing infrastructure. Therefore, UBC currently faces challenges to withstand both 1 in 10 and 1 in 100-year storm events. Ignoring these challenges could ultimately lead to the damaging of important structures such as the TRIUMF nuclear research facility. To mitigate these potential risks, UBC Infrastructure and Services Planning has suggested implementing a stormwater system that upgrades the overall capacity of the system, and has the ability to deal with 1 in 10 and 1 in 100-year storm events.

3.2 Site Overview and Constraints

The site is located at the south end of the UBC campus and an aerial view can be seen in the Figure 1. The size of Wesbrook Village is roughly 250 acres, mostly surrounded by varying deciduous and evergreen tree specimens and is adjacent to the Pacific Spirit Regional Park and Musqueam First Nation Lands. Since 2005, this area has seen significant development due to an increasing demand for housing and Wesbrook Village is now considered the largest neighborhood – comprising of 40,000 people – on the UBC campus. Wesbrook Village consists of six parks, community centres, commercial, residential, and institutional buildings. As highlighted in blue in Figure 2, TRIUMF, Canada's national laboratory for particle and nuclear physics, is part of this region and the institute consists of many valuable library books archived from the Irving K. Barber Library.

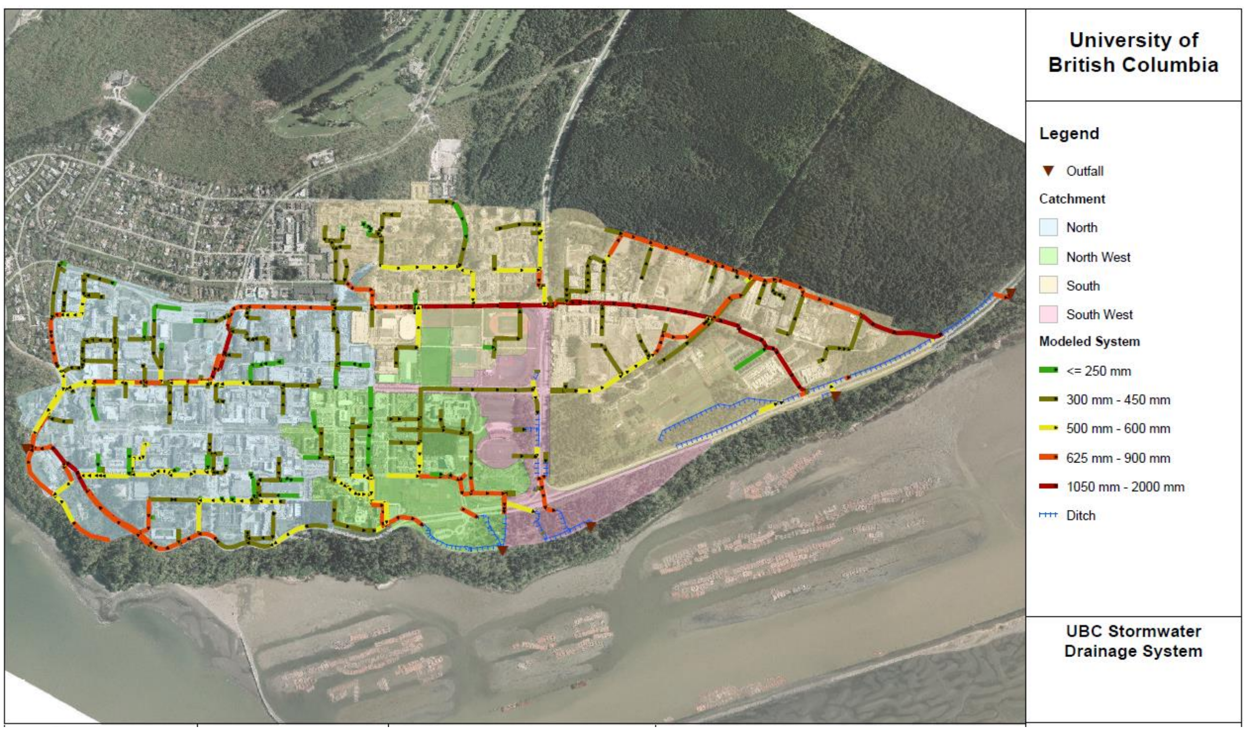

Figure 1: UBC catchment areas

Source: *UBC Stormwater Model System Analysis, Detention Analysis and System Optimization*, p.9. Technical Report. GeoAdvice Engineering Inc. 2013.

Figure 2: Main site locations

Source: Digital Image. Jack Liu. Oct 18, 2015. Adapted from <www.google.ca/maps>.

The cliff region of UBC is currently owned and operated by Metro Vancouver. Figure 1 can also provide visual aid that the majority of the flood loss will migrate from Wesbrook Village towards the cliff along SW Marine Drive. UBC is encompassed in four different catchments and is significantly isolated in terms of stormwater capacity from the surrounding region; this, in part, is associated with the terrain which includes steep slopes favoring a UBC isolated catchment area. The project itself falls into two UBC catchments, the UBC South and UBC South West catchments; an illustration of the various catchments can be seen in Figure 1.

Large inflows of water can impact the ground conditions due to the characteristics of the site's soil stratigraphy. The geological composition of this region consists largely of a surface layer of glacial till followed by a thin layer of porous Quadra sand. The combination of the layers can accumulate groundwater that seeps out the cliff face leading to cliff face erosion. Cliff erosion can also happen through construction developments. In the year 2004, UBC experienced a cliff failure when three landslides occurred during the Phase 1 construction of the Marine Drive residential building.

3.3 Design Criteria

The stormwater system design criteria will be divided into primary and secondary criteria. The items in the primary criteria contain the key elements to develop a functioning solution that will mitigate flooding and cliff erosion in the situation of a 1 in 10 or 1 in 100-year storm event. The secondary criteria contain aspects that are highly desirable for the client and stakeholders but are not essential to the solution solving the key issues.

The stormwater management system primary criteria are as follows:

- Reduce the amount of overland water flow during extreme events
- Ensure the safeguarding of human life in extreme events occurring over the lifetime of the system
- Improve the current environmental conditions of the natural hydrological cycle and the stream runoff from engineered systems

The primary criteria that this report attempts to address, as listed above, are specific to the success of the recommended design and project goals. The main objective of the design is to reduce the amount of overland flow and flooding caused in the south campus as described in Section 3.1 – Project Background. Component to this criterion is the necessity to safeguard human life; the design needs to ensure the safety of occupants both directly as a result of the design and indirectly as a result of construction or potential outcomes of natural disasters (i.e. the design needs not to create an additive risk in the event of high risk disasters). Lastly, the design should not only maintain but attempt to improve on current environmental aspects, this is something that is crucial to the longevity of the ecosystem in the UBC South Campus and is discussed in detail in Section 6.4 – Environmental Impact Analysis.

The secondary criteria focus on aspects of the design, which are component to the primary criteria but not necessarily critical to achieving a functioning design. These criteria are studied for value engineering purposes and are as follow:

- Minimize capital and long term maintenance costs of the project
- Efficient space usage
- Ensure future development and expansion can be incorporated

The list above contains features that are highly desirable for the client but are not required for the completion of the stormwater facility design. To ensure the project payback periods are reasonable over the life of the project, the design will consider and analyze both initial capital and long term maintenance costs. This will be a significant portion of the analysis as UBC needs to approve budgetary allocations for project funding at various stages. Understanding that existing UBC land has the potential to be developed into high density occupational buildings in a short period of time has led to the prioritization within the secondary criteria for efficient space usage. The design needs to ensure current space usage is minimized and future development will be minimally impacted. The intention of this criteria is to ensure the design does not create a barrier which future developers and owners must work around, rather it be a design that is incorporated into the community development plan.

3.4 Key Issues

There are two key issues that need to be addressed based on the current information available through UBC SEEDS and research done by SMC Engineering. The first key issue is the increase in stormwater run-off resulting in cliff erosion along Wreck Beach and the second issue is the potential damage to existing infrastructures and severe flooding on SW Marine Drive.

The effects of a major storm event with the current management system will saturate the ground causing an increase in runoff along SW Marine Drive and lead to high risk cliff erosion along Wreck Beach. The results of this erosion can be severe in the sense an immediate cliff failure could occur, endangering all occupants of the beach. The majority of the surface runoff will be sourced from Wesbrook Village. According to the OFRA report, during a 1 in 100-year storm the magnitude of flooding ranges from 145 to 1470 m^3 of water. Moreover, the surface runoff will eventually infiltrate through the soil to the lower aquifer, polluting the groundwater. Infiltration is an effective way to mitigate soil erosion and surface run-off, however, UBC only permits infiltration in certain regions throughout the campus. As seen in Figure 3, the green region is where infiltration is permitted, whereas, the red region cannot be infiltrated. Furthermore, as per UBC's Integrated Stormwater Management Plan, infiltration cannot occur within 300 m from the face of the cliff. Direct mitigation of the cliff erosion is not feasible because the entirety of the Wreck Beach region is owned and maintained by Metro Vancouver. Therefore, the solution needs to ensure the mitigation of this runoff by attempting to reduce overland flow prior to the cliff location by means of storage, infiltration, and evaporation.

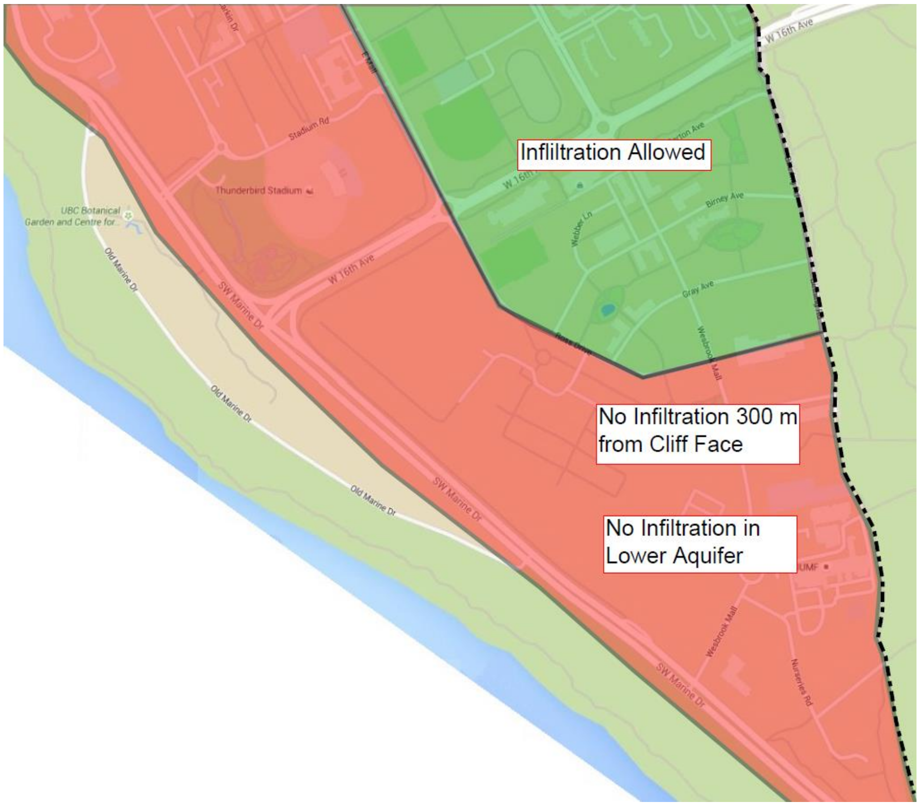

Figure 3: Infiltration limits

Source: Digital Image. Asad Ijaz. Oct 18, 2015. Adapted from <www.google.ca/maps>.

The second key issue is protecting the assets in the south end of the campus from the severe surface runoffs from the 1 in 10 and 1 in 100-year storm events. In addition to the residential and commercial neighborhoods, the south end campus region contains other important structures such as TRIUMF, Canada's leading nuclear science research institute. This facility also archives a substantial amount of historic texts from the UBC library. The solution will need to ensure that the extreme stormwater events will not impact the buildings such that the structures become incapable of performing their intended purpose.

The combination of cliff erosion and potential severe flooding of UBC assets leads to an increase in risk and potentially severe financial consequences for UBC and its surrounding neighbours. This report incorporates the key issues mentioned above throughout the entire design process and ensures they are a fundamental basis of all decisions made with regards to project solution.

3.5 Precedent Studies

Multiple documents have been reviewed prior to the development of the initial solutions for the UBCSouth Campus Stormwater Management System. These documents provided an overview of site and project constraints, further documentation and literature to study, as well as the technical findings of engineering firms commissioned to study the UBC South Campus region.

The primary reports reviewed were the UBC Integrated Stormwater Management Plan (ISMP), the UBC Stormwater Model System Analysis, and the Overland Flow Route Assessment. The ISMP is a UBC document which outlines UBC's plan and goals for stormwater management on campus and provides some basic site constraints. GeoAdvice Engineering Inc. developed the Stormwater Model System analysis; this report discusses potential solutions to the stormwater management issue at UBC. The Overland Flow Route Assessment report is a study completed by Urban Systems that provides an in-depth analysis of flood and water flow routes on the campus.

The above mentioned documents are the initial basis of what the detailed design was developed on. The majority of the research was completed during a previous phase of study and is simply restated for background purposes.

3.5.1 UBC Integrated Stormwater Management Plan (ISMP)

UBC's Integrated Stormwater Management Plan is a document from 2015 that outlines the plan for UBC to manage the multiple facets of the stormwater system in the future. Several facets of this report, such as objectives and existing policy to study, are imperative in the consideration and design of a stormwater management system for UBC's South Campus. These facets from the ISMP are integral in the applications of the top-down approach, as they relate to the client objectives, project objectives, and design constraints.

The ISMP outlines the main objectives of stormwater management design to be:

1. Protection of campus assets from flooding, safeguard human life, prevention of overland flooding and downstream erosion across the cliffs.
2. Meet or exceed existing provincial and federal policies and standards. Protect the campus environmental values and minimise the impact of campus discharge on neighbouring watercourses.
3. Maintain or preferably enhance water quality at its boundaries at a level that meets or exceeds best practices for urbanized municipalities.
4. Incorporate the natural hydrologic cycle and natural systems approach into the long term planning and design of the stormwater system.

Excerpts from the ISMP that are relevant to the project can be found in Appendix A. Details in this appendix include:

- UBC stormwater policy content to consider,
- Regulatory acts and laws that need to be adhered to,
- Actions that are recommended for the creation of a stormwater management system,
- Information and guidance on current conditions of the South Campus Region, and
- Project constraints.

3.5.2 UBC Stormwater Model System Analysis

The UBC Stormwater Model System Analysis report is an optimization analysis of the UBC stormwater system prepared by GeoAdvice Engineering Inc. for UBC. The objective of the document is to determine the stormwater system upgrades needed in order to minimize flooding volumes at key locations in the case of a 1 in 100 or 1 in 200-year storm event. In achieving this goal, it considers three potential improvement scenarios for each location. These include:

- Option 1: Offline detention only
- Option 2: System optimization with inline storage
- Option 3: System optimization with inline and offline storage

In determining the initial conditions, the results of the 1 in 10, 1 in 100 and 1 in 200-year storm events were simulated, which identified the locations and volume of surface flooding in the four catchments (Figure 4). After this was determined, thirteen different project locations were identified based on the previous simulated results (Figure 5). The individual flood-loss volumes and locations were simulated in these thirteen different locations as well.

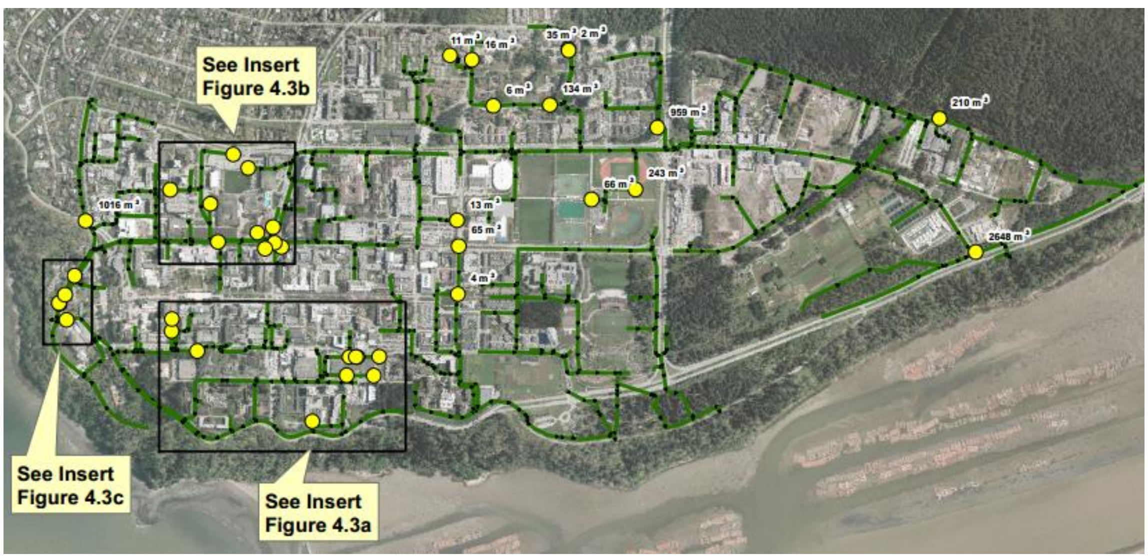

Figure 4: Existing system performance

Source: *UBC Stormwater Model System Analysis, Detention Analysis and System Optimization*, p.11. Technical Report. GeoAdvice Engineering Inc. 2013.

Figure 5: Project locations

Source: *UBC Stormwater Model System Analysis, Detention Analysis and System Optimization*, p.21. Technical Report. GeoAdvice Engineering Inc. 2013.

Once these values were found, the three potential improvement scenarios listed above were analyzed. Beginning with offline detention storage only, the detention tank volumes and locations were determined. Next, the system upgrades required to eliminate surface flooding were found, considering pipe upsize, pipe diversion, or when neither worked, the use of detention tanks. Lastly, for each chosen location, the optimal solution was identified by comparing relative cost of each solution. Based on the final optimization analysis it was found that for all but four locations the use of detention tanks would be more cost effective and thus more efficient.

Following the optimization analysis, another analysis was conducted to assess the impact of the 1 in 100 and 1 in 200-year volumes in the future. This took into account current development site boundaries and projected future impervious area through to 2030. Using this information, the development areas were divided into 18 different development impact groups. In each of these areas, the different in current and future projected impervious area. Using this difference, once again, the increase in 1 in 100 and 1 in 200-year peak flows were found.

The results of this study were closely referenced in the development of the conceptual designs. However, for the level of preliminary design, the aforementioned report has been utilized as a consistency check with the various forms of studies undertaken to achieve the successful solution.

3.5.3 Overland Flow Route Assessment (OFRA)

UBC has previously hired Urban Systems to complete an Overland Flow Route Assessment (OFRA) which resulted in an integrated water management plan that reviews and assesses the current drainage system. The findings of this report have determined the long term feasibility of the current stormwater system and identifies locations where high volumes of anticipated overland flow will occur under major storm events. The findings outlined in this section were relied upon to determine areas of flood mitigation requirements and analysis of post construction reduction in overland flooding.

Urban System uses the data from LiDAR, a remote sensing technology, to generate a 3-D ground surface which assess area of potential risk due to overland flow. In conjunction with the 2-D flow analysis, a risk assessment and magnitude of impact of each location were made available. The ranking of the sequence of occurrence and magnitude of impact can be found in Table 2, as seen below.

Table 2: Risk assessment parameter

Risk Assessment Parameter			
Sequence of Occurrence		**Magnitude of Impact**	
Rank 1	Very Likely to Occur	Rank 1	Least Significant
Rank 2	Likely to Occur	Rank 2	Less Significant
Rank 3	Less Likely Occur	Rank 3	Significant
Rank 4	Rarely Occur	Rank 4	Most Significant

Source: Table. Jack Liu. Nov 30, 2015. Adapted from *Overland Flow Route Assessment*.

An overview of the flood loss area in UBC South Campus can be seen in the figure below. Figure 6 shows that Area 7 to Area 10 are areas to be considered when a major storm event occurs. The magnitude of flood loss in Area 7 is the largest with roughly 1270 m^3 of water in a 1 in 100-year event. Area 8 contains the lowest magnitude of flood loss with 150 m^3. The report notes that the highest risk for flooding occurs in Area 10, where the potential for a cease in traffic flow could occur. For a detailed list of all the areas and associated risks refer to Appendix B.

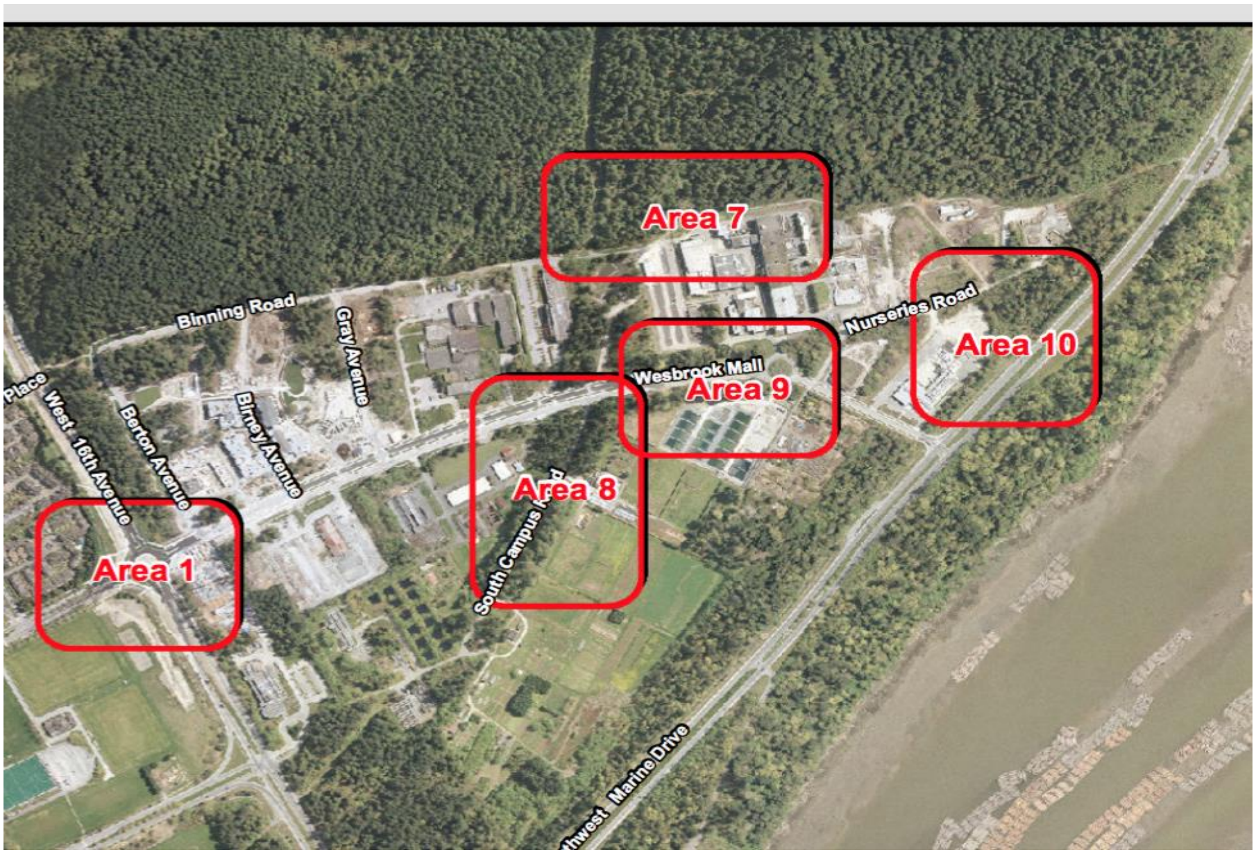

Figure 6: Overview of flood loss area in UBC South Campus

Source*: Overland Flow Route Assessment,* p.9. Technical Report. Urban Systems. 2011.

4.0 OVERVIEW OF DESIGN

The design solution integrates multiple stormwater management elements, including the use of detention tanks, permeable asphalt and multi-use dry ponds. This section provides a general overview of the design, specifying the arrangement of the components, a description of the key components, the materials to be used, and how the components will function.

4.1 Layout

The design spans between Hampton Place to SW Marine Drive in the south portion of UBC campus. The overall layout of the design components (and their respective volume capacities) are shown in Figure 7 below. Detention tanks are shown in red and the dry pond is shown in green. The orange dotted lines portray that sections of road that are to be replaced with permeable asphalt. For reference, permeable asphalt cannot be used within the 300 m of the cliffs, as mandated in the UBC ISMP. In total, there are four detention tanks and one dry pond to be added to UBC South Campus. They are located where the likelihood of flood mitigation is highest as determined by SWMM analysis.

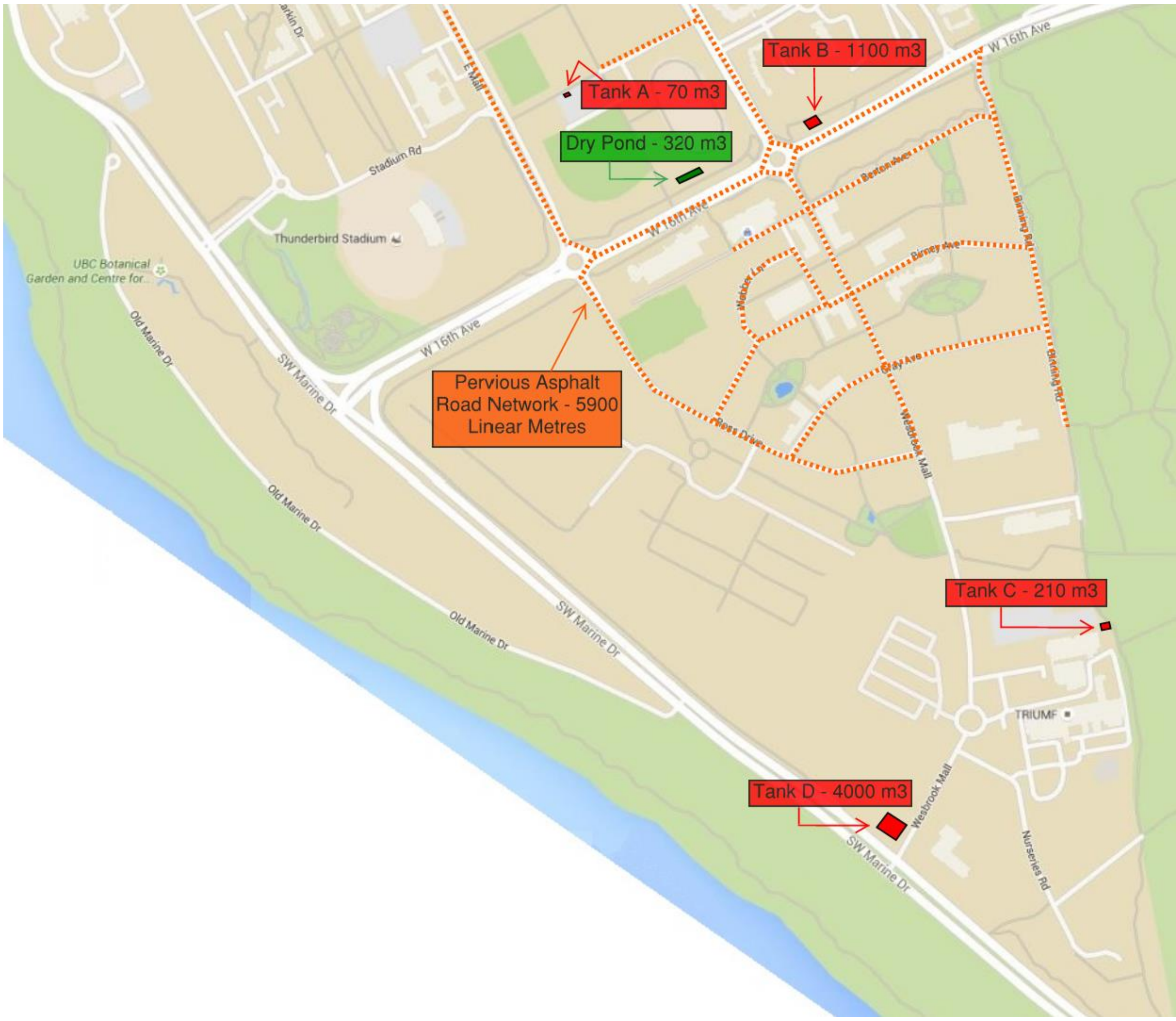

Figure 7: Design feature locations

Source: Digital Image. Asad Ijaz. Dec 1, 2015. Adapted from <www.google.ca/maps>.

4.2 Key Components

There are three key components to design of the project – detention tanks, a dry pond, and permeable asphalt. The sections below describe each component in detail.

4.2.1 Detention Tanks

Detention tanks are the primary mode of flood mitigation for this design solution (see Appendix C for detention tank schematics). They are intended to handle the majority of the volume capacity in the event of a major stormwater event. The individual tank capacities and dimensions are listed in Table 3 below, with locations in reference to Figure 7.

Table 3: Detention tank capacities and dimensions

Tank	Capacity (m^3)	Length (m)	Width (m)	Height (m)
A	70	6	5	3
B	1,100	16	16	5
C	210	9	9	3
D	4,000	30	30	4.5

Source: Table. Joshua Deans. February 20, 2016.

For each tank, there will be Armtec VortClarex oil and grit (O/G) separators equipped upstream. These serve to increase effluent quality and reduce maintenance costs on the detention tanks (product details in Appendix E). The tanks have been set up as an on-line system, meaning that the benefits of filtration will be present throughout the local water system as the system will be consistently online.

4.2.2 Dry Pond

A multi-use dry pond will be placed between West 16th Avenue and the Track & Field Oval in lieu of a small detention tank. Overall, the dry pond has a total capacity of 320 m^3, with a base of 10 m by 32 m and a height of 1 m. Although the dry pond can withstand a small percentage of the total capacity needed, it promotes maintenance of the natural water cycle. It also adds aesthetic value and can be used as a community social hub when it is not being utilized during storm events. See Appendix C for dry pond details.

4.2.3 Permeable Asphalt

The third component of the design is permeable asphalt. Its imperviousness allows water to infiltrate at a faster, more natural rate than traditional asphalt. The asphalt will be installed within the infiltration limits set by the UBC ISMP. The permeable asphalt would need to be installed only once the current paved roads need replacing. For the purposes of this study, it is assumed that the remaining design life on all roads is less than two years, and therefore the replacement will begin as soon as construction is approved. A cross section of the permeable asphalt can be found in Appendix D.

Nilex RoaDrain, a geotextile material, will be placed in the sublayer of pavement, particularly where oil and grease are most likely to collect (see Appendix F for Nilex RoaDrain product details). This will stimulate the flow of heavily contaminated water towards existing pipes, therefore leading to O/G separators.

4.3 Materials

The following sections are intended to detail the materials required to construct each of the key components of the proposed design.

4.3.1 Detention Tanks

The detention tanks are made up of a combination of shotcrete shoring walls with soil anchors, a cast-in-place concrete slab, and a pre-cast lid. The tanks also utilize an impervious interior liner. The methodology behind this construction is outlined in Section 6.6 – Constructability Analysis. The numerous O/G separators will be made of precast concrete and contain a pre assembled O/G separation mechanism. Piping in immediate connection between the O/G separators and detention tanks will be comprised of pre-cast C76 Concrete piping, readily available in the lower mainland. Piping associated with connecting the tanks to the existing system will consist of SDR 35 PVC piping for all diameters less than 600 mm. Concrete was chosen as the primary construction material for the tanks, in large part due to the relatively low increase in cost when designed to support above ground loads in comparison to precast or prefabricated tanks. However, cast-in-place concrete is very rigid and is prone to cracking, particularly in clay predominant soils. At this stage of study, it is unknown whether any of the detention tank locations will be situated in clay and therefore an allowance has been made to waterproof the exterior each tank. The waterproof membrane on the tanks will ensure water does not create an environment for corrosion on the reinforcement of the cast-in-place concrete. This exterior waterproof membrane is in addition for the interior lining of the tank.

4.3.2 Dry Pond

As the dry pond is quite simple, it will be the least demanding component in terms of material use. Underneath the top layer, three-inch drainage rocks will be placed to promote water infiltration through the top layer. The top layer will consist of soil and vegetation, primarily being grass and smaller plants. Storm water will be routed into the dry pond with a pre-cast concrete spillway, equipped with concrete blocks to reduce the speed of flood water.

4.3.3 Permeable Asphalt

Permeable asphalt will replace a large percent of standard asphalt road surfaces. It works quite similar to standard asphalt, but contains less fine aggregates. Overall, porosity is increased and water is allowed to infiltrate at a much greater flow rate. The typical lifespan of permeable asphalt is typically greater than fifteen years in standard conditions (“Porous Asphalt Pavement”, 2014). Air voids in the material allow it to be more durable by alleviating cracking and freeze/thaw stress. The pores in the asphalt can clog over time, and can be maintained with the use of a vacuum truck.

Nilex RoaDrain is a geotextile subsurface drainage system that distributes water collected under paved road surfaces. This material will be placed underneath the permeable asphalt layer, primarily where contaminants are most likely to gather. RoaDrain prevents potholes, cracking and freeze-thaw damage that can occur in a heavy storm event. This will also prevent clogging of the permeable asphalt and support consistent drainage, decreasing water damage over the long term.

4.4 Function

During a large stormwater event, the detention tanks will retain the majority of the surge flow. Figure 8 showcases the components within the tank. The tank is made up of cast-in-place concrete and has a waterproof membrane to prevent seepage into the reinforcement or ground. Stormwater is contained within the tank and is slowly released over the period of 24 hours. The tanks have been positioned not only for maximum utilization, but also in regions close to existing piping infrastructure, effectively allowing the filtered stormwater to exit through the existing pipe network. In addition, Armtec Vortclarex O/G separators or equivalent will be installed upstream of the detention tank and will be housed in durable pre-cast concrete structures. Water flows enter through the inlet pipe, which contains a non-clog diffuser, and those flows are spread out. The O/G separator contains a solids baffle wall that captures sizeable solid waste. Further, a coalescing media provides a secondary form of remediation, collecting smaller oily contaminants and accumulating them into larger, and more buoyant, groups. These combined droplets float up to the water surface, where they are trapped above the outflow pipe, allowing for treated water to exit the system. A manhole above allows for cleanup via vacuum truck and water hose when needed. This system is only intended to be used during normal flows, and in the case of 1 in 10 or 1 in 100-year storm events, there will be a bypass valve to route the stormwater directly into the detention tank. Stormwater enters the detention tank either through the oil and grit separator outflow, or through the bypass pipe.

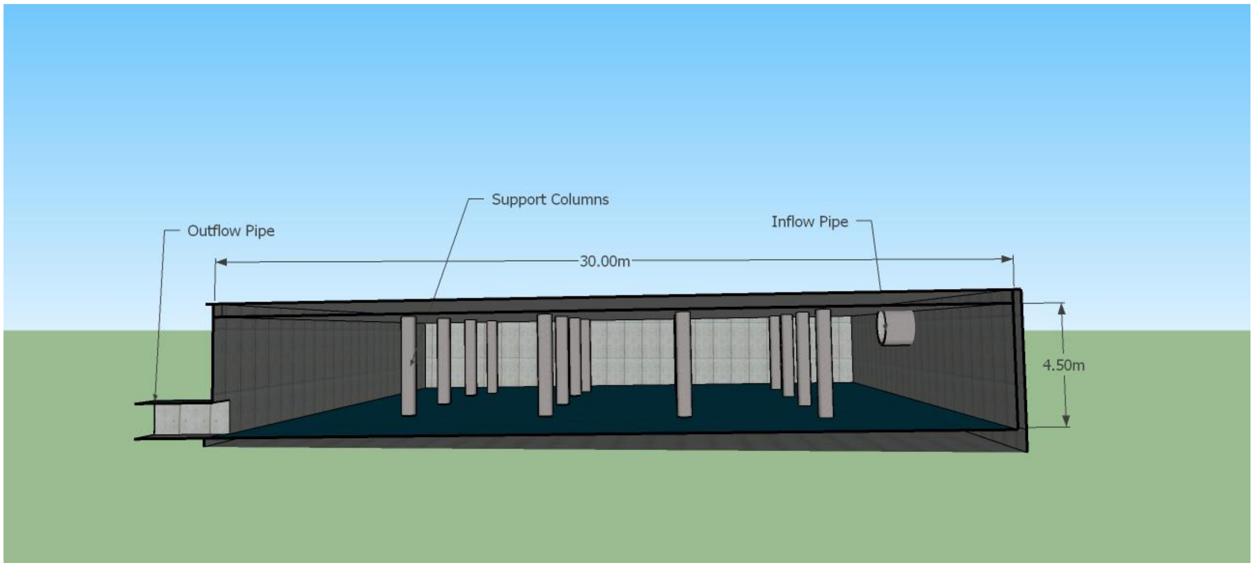

Figure 8: Detention tank overview

Source: Digital Image. Asad Ijaz. Dec 1, 2015.

The dry pond is a large basin that is intended to be empty during normal operation, allowing for more useable space in the area. In major stormwater events, however, it will capture excess stormwater run-off and retain the water until the natural hydrologic cycle will facilitate evaporation into the atmosphere and, more importantly, infiltration into the ground water. As a precautionary measure, if the dry pond reaches a certain depth of water, an outflow pipe will direct water back into the stormwater system.

Permeable asphalt contributes to the maintenance of the natural hydrological cycle at UBC. It has an inherently high infiltration rate due to the open graded-ness of the aggregate that even when clogged the infiltration rate resides above 1 inch per hour of infiltration ("Porous Asphalt Pavement", 2014). This asphalt system creates extremely favourable conditions for infiltration. Areas where a high likelihood of build oil and grease build up will have the Nilex RoaDrain leading into catch basins that will also have similar O/G separation apparatuses. The remainder of the Nilex RoaDrain will be placed in areas where the ground is likely to become saturated quicker and It will divert the infiltration to areas of lower saturation likelihood. This infiltration relocation technique will prevent over-infiltration of the groundwater and help balance the geohydrology.

4.5 Design Life

In this project solution, optimally assessing costs over the component design lives was a greater priority than focusing on upfront costs. The design life of the detention tanks and oil water separators is estimated to be 90 years (National Precast Concrete Association, 2011). As the detention tanks are most significant component of the system in terms of storm water management, their design life represents the overall design life of the entire stormwater management system. The design life of the dry pond was found to be to have an effective lifespan of approximately 25 years (Davenport, 2006). After this 25-year period, the area will need to be cleared of the accumulated sediment. A design life of twenty years is typical of permeable asphalt (Credit Valley Conservation, 2010), as compared to a lifespan of fifteen years for traditional asphalt (Boyer & Hensley, 1999).

The design life of the permeable asphalt is one sixth of the overall project design life, meaning that the permeable asphalt will be replaced five times throughout the lifespan of the stormwater system. Likewise, the dry pond will need to be replaced four times through the lifespan of the stormwater system. The design life of permeable asphalt has a five-year advantage to that of traditional asphalt.

5.0 DESIGN RATIONALE

The current design incorporates multiple different components, each with their own rationale. In order to detail the design, each component has been carefully reasoned to ensure the most beneficial decisions are made in regards to stormwater mitigation and valued engineering. The following section will outline the design rationale for the detention tanks, dry pond, and the use of permeable asphalts.

5.1 Detention Tanks

Utilizing cast-in-place concrete storage detention tanks is a traditional method in mitigating stormwater flooding. These tanks are capable of storing large volumes of excess water, and are relatively easy to construct. The locations of each tank is selected such that the underground structures would be efficiently used, convenient to construct, and constructed in location where the below grade land would not have been used otherwise. In addition, the implementation of a network of O/G separators upstream of the detention tanks would allow for a higher quality water being detained, but in addition, could also be bypassed in the event of a large flood. Overall, this design not only allows for efficient storage of excess stormwater, the O/G separators will allow the stored water to be released with higher quality, thus providing an environmentally sustainable solution.

The reasoning behind the use of O/G separators is to allow for the stored water to be reused in other applications. Adding this component will lower the flow rate into the detention tanks as it takes time to separate the oil and grit from the water. Realizing this limitation, a bypass route is also implemented to ensure that the system will function at the maximum flow rate during a large rainfall event. Finally, the costs of implementing O/G separators to the system are small in comparison to the returned benefit of reduced turbidity and toxin content in the released water.

As the tanks will be underground, the land above can be repurposed and will be an added benefit to students and the public in general. Examples of this are seen on campus already, such as the plaza in front of the AMS Nest, a small basketball court, and even a baseball arena. Creating a space that benefits the public will in turn also be a benefit to UBC.

5.2 Dry Pond

The implementation of a dry pond is a creative solution that promotes the return of the natural hydrological cycle. UBC is a leader in sustainability, and such it is in UBC's interest to explore alternative solutions. A dry pond functions similarly to a detention tank, but it is a more natural way of storing water. In short, it is a basin above ground that has a network of pipes to divert the water stored. In the case of a large stormwater event, the dry pond will fill up gradually while diverting the excess water into the upgraded stormwater system detention tanks.

Unlike the detention tanks, the dry pond is only expected to have significant amounts of water stored during larger stormwater events. As the dry pond is open, it would be unacceptable to have it flood in any circumstance. The location has been picked based off historical rainfall data to ensure it does not overflow, as that would be counter-productive. As a result, the addition of O/G separators will not be efficient and is therefore not included with a dry pond.

The land used to construct a dry pond is not as versatile as one used to construct a detention tank, but it can be repurposed as a scenic park. Dry ponds are quite rare in the lower mainland and this could be a unique viewpoint for the public - once again, benefitting the public is in UBC's best interest.

5.3 Permeable Asphalt

The rationale behind the permeable asphalt use stems from the value added to UBC with regards to the primary criteria of restoring the natural hydrological cycle. The permeable asphalt replaces existing asphalt for an initial capital premium cost but an overall cost savings over the design life of the entire project as detailed in the Section 6.2 – Economic Analysis. This design will promote the return of infiltration into areas where infiltration was not accessible and provide several benefits to the users of the infrastructure.

In detail, the permeable asphalt in combination with the use of Nilex RoaDrain will promote the flow of surface run-off into the groundwater table. The Nilex RoaDrain is traditionally used as a facilitator of water flow below the asphalt surface, guiding it to catch basins and increasing permeability rates of the asphalt. However, SMC engineering understands that this concept of guiding the water to catch basins can be altered so that the surface water, once permeated to the road drain, can be guided to regions of traditionally lower infiltration. One of the identified concerns of the the current asphalt system at UBC is the differing levels of groundwater saturation occurring due to dominating surface flows and localized ponding. The permeable asphalt will provide an overall increase to the infiltration in the region, while the Nilex RoaDrain will aid in providing an even distribution of that infiltration - helping move forward with the restoration of the natural hydrological cycle.

There are distinct user benefits of the permeable asphalt over traditional asphalt. The open grade of the asphaltic concrete allows for better sound absorption and rut prevention. The latter of the two also promotes longevity in life and user satisfaction through smoother surfaces over a longer duration – a problem UBC commuters face all too often.

The combination of the benefits for the stakeholders and the increase in distributed infiltration make the permeable asphalt option feasible. The issue for implementation lies in the increase in upfront capital expenditures. However, if owners can recognize the long term cost savings based on design life research of the asphalts, it is almost undeniable that this aspect of the solution adds only value to the UBC stormwater management system.

6.0 ANALYSIS OF DESIGN

A multitude of items were analyzed in order to develop a design that meets all functional, safety, and regulatory needs. Analyses involved a technical component (hydrotechnical, geotechnical, and structural), an economic investigation, investigation into regulations, an environmental impact assessment, and a review of constructability.

6.1 Technical Analysis

Detailed analyses have been completed in order to ensure safety and constructability of the design. There are three main technical analyses that are critically relevant to the project. This section details the hydrotechnical, geotechnical and structural analysis that have been completed while referencing appropriate appendices for calculation backups.

6.1.1 Hydrotechnical

This portion of analysis relied on the use of the modelling software “Storm Water Management Model” (SWMM) developed by the United States Environmental Protection Agency (EPA). Using EPA SWMM, the rainfall parameters inputted were based off of Environment Canada’s 100-year precipitation data to simulate an extreme event that would be considered a 100-year event (Environment Canada, 2014). Below in Figure 9 is a visual representation of the rainfall modelled.

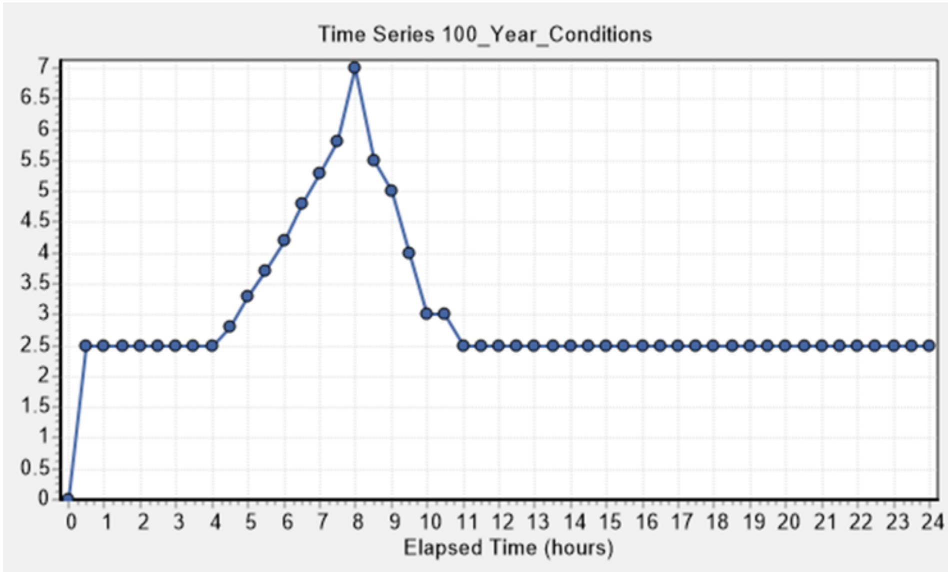

Figure 9: 100-year rainfall event model

Source: Digital Image. Cliff Huang. Oct 12, 2015.

The rainfall is consistently 2.5 mm (vertical axis in the rainfall intensity, mm/h) throughout the day, which is a large rainfall event by itself. There is a peak rainfall of 7 mm/h to simulate an extreme during the event. The rainfall input is the most crucial part of the modelling as all the pipe and detention tank parameters were made to match the existing SWMM model provided by UBC SEEDS. Using this as the primary rainfall pattern, the detention tanks are being utilized to a high percentage and there is no water backup occurring in the system.

Apart from the detention tanks, the dry pond is also incorporated into the model as a small storage tank at grade. As it was not requested by the client, the permeable asphalt was not incorporated into the model. Permeable asphalt has a lot more variance than a detention tank, but due to specific features of the Nilex RoaDrain, it will undoubtedly improve performance of the system. With the road drain placed under the permeable assault, water in high flow regions can be rerouted to other low flow regions to relieve the stress in certain junctions.

Overall, the primary parameter that controls the model is rainfall. Experimenting with different rainfall patterns led to similar usages of the detention tanks and dry pond, so the system is in fact capable of taking on a large storm event without failure. Gradual increases in rainfall work best when using SWMM as the software discretizes the rainfall intervals, and having sudden spikes in rainfall would lead to inadequate results. The summary report from the SWMM simulation, as well as additional results, are available for examination in Appendix G.

6.1.2 Geotechnical

With the available geotechnical information centered around Wesbrook Mall and Agronomy Road, significant interpolation had to be completed to make an attempt at understanding the anticipated ground conditions at the tank locations. Based on the Wesbrook Mall Geotechnical Report, the anticipated subsurface geology contains fluvial deposits and, to interpolate from the borehole data, layers of silts 3m below the surface elevation. The extent of the load will be transferred to the subsurface geology through a slab footing. For the purpose of this explanation, this report will look into what was completed for the largest tank located across the NSERC facility.

Input parameters for the required bearing capacity were calculated to be approximately 100 kPa. However, this 100 kPa factored load will only last for a short period of time as it is when the detention tank has reached full capacity. Analysis of immediate elastic and consolidation settlement are not considered in the design because the soil is overly consolidated. At full tank capacity the weight of the tanks will be less than the current anticipated soil weight by approximately 50%. Therefore, settlement will be in the recompression zone and be minimal such that the accuracy of either this assumption or an analysis with the available information will be of equivalent accuracy. Bearing capacity calculations can be reviewed in Appendix H, it is important to note that without further testing an undrained shear strength of 30 kPa has been assumed based on experience of clayey and silty materials of consulted contractors in the point grey area of the Lower Mainland.

Anchor designs have been completed using a 2 anchor system following Peck's lateral earth pressure theories. The first row of anchors is 1.25 m below the surface and the following row of anchors is 1.875 m below the first row. The anchors are situated at 15 degrees below the horizontal and extend up to lengths of 12.5 m with bond lengths of 1.5 and 2 m for the top and bottom rows respectively. Bond lengths were determined utilizing typical anchor bond strengths in stiff silty-clays and an average friction angle of 25 degrees has been utilized. However, this analysis should be reviewed with great scrutiny as the geotechnical parameters have been estimated off of boreholes more than a kilometer away, and soil properties have been estimated by averaging historical ranges of silty-clay like deposits.

An accompanying seismic analysis was to be completed, however there has been a lack of relevant additional information provided between the issuance of the preliminary design report and detailed design report. The analysis, if undertaken with the available information, will provide no relevant guidance to the performance of the design. Further information on recommended steps to ensure design performance are outlined in Section 10.0 – Design Development and Recommendations.

6.1.3 Structural

The four proposed stormwater detention tanks utilize the construction of both precast and cast-in-place concrete sections. The concrete structure is designed in accordance with CSA A23.3-04 code standards and in recommendation with the design guidelines listed in "Reinforced Concrete Design: A Practical Guideline" (Brzev and Pao, 2006). The precast concrete sections are designed at an expected 28-day compressive strength of 30 MPa. The compressive tests are to be conducted in accordance with testing standards ASTM C39/C39M. The unit weight of the concrete structures is assumed to be at a conservative 22 kN/m^3. The factored live and dead loads are determined according to the National Building Code 2005 (NBC 2005) clause C1.4.1.3.2.

The structure of the detention tanks consists of a ceiling slab, square tied-eccentrically loaded columns and a floor slab. The steel rebar in the ceiling/floor slab will also be designed for shrinkage and temperature reinforcement requirements as per clause 7.8.1 and 7.8.3. The walls of the tank are to be substituted by a system of rock anchors and shotcrete walls, as discussed in Section 6.1.2 above. As such, the dead/live loads of the overburden soil and the weight of the ceiling slab will be carried solely by the concrete columns. Column designs are completed using the influence diagram method and the ceiling/floor slabs are designed in accordance with one-way slabs as outlined in Brzev & Pao and can be found in Appendix I. The shotcrete walls will be waterproofed to prevent leakage of soil contaminants into the tanks that would result in potential concrete deterioration.

Additional seismic designs of the structural tanks are dismissed on the reasoning that the soil analyses are lacking relevance. However, as described in the design development section, for UBC SEEDS to minimize the design uncertainty, additional seismic loading analyses are recommended to model the structural response of the detention tank with varying water levels within.

6.2 Economic Analysis

Economic factors dictate the design of the UBC South Campus Stormwater Management System. A specific budget was not detailed by UBC SEEDS, but the notion that the budget for this project is limited was conveyed. SMC Engineering took the approach of combining a common stormwater management approach combined with a low-premium cost innovative solution to meet the client's economic objectives and commitment to the environment.

The UBC South Campus Stormwater Management System comprises of two main facets – detention tanks, dry pond, and permeable asphalt – with each having varying economic impacts in both the short and long term. The detention tanks and dry ponds are a conventional stormwater management approach and are grouped together, for the purposes of this project, as detention facilities. The innovative solution, permeable asphalt, is referred to as roadworks. An emphasis was placed on reducing the overall economic expenditures with the project rather than the initial capital costs or future costs alone. Factors considered in detail were the design life and maintenance costs of the system. An outline of the economic considerations for each aspect of the proposed design is discussed in the following paragraphs along with an analysis of storm event exceedance probabilities.

The detention facilities were found to a have cost of $4,292,000 in total initial capital (construction; Engineering, Procurement, and Construction Management (EPCM); and owner costs) for the tanks, dry pond, and associated infrastructure required. As the oil/grit separators filter sediment and other particulates that may accumulate in the tank, maintenance of the tank itself will be negligible. Maintenance costs will be incurred with the oil/grit separators as they need to cleaned out when at capacity for holding oil or sediment. There is a minimal impact of maintenance costs with the dry pond due to the requirement of clearing only once every 25 years. The design life of the detention facilities system is estimated to be 90 years. As the most significant portion of the system in regards to stormwater mitigation, the design life of the detention facilities serves as the design life of the UBC South Campus Stormwater Management System as a whole.

The permeable asphalt component is judged to have a total initial capital cost (construction, EPCM, and owner) of $5,846,000 with maintenance totalling $75,000 per. An average design life of 15 years is anticipated. The design life of the permeable asphalt is only a portion of the overall project design life, meaning that the permeable asphalt will be replaced five times in order for the system to operate at optimum efficiency during storm events. The existing asphalt network, that the permeable system is replacing, is nearing the end of its life span meaning that the implementation of the permeable system should be seamless. A breakdown of costs comparing permeable asphalt to conventional asphalt can be seen below.

Table 4: Permeable asphalt vs. conventional asphalt costs

Item	Design Life of Asphalt (Years)	Initial Capital Costs (C, EPCM, O)	Replacements Over 90-Year System Life	Future Capital Costs (C, EPCM, O)	Maintenance Costs (M)	Total 90-Year System Cost (C, EPCM, O, M)
Permeable Asphalt	15	$5,846,000	5	$29,230,000	$75,000/Year	$41,826,000
Conventional Asphalt	10	$4,447,000	8	$35,576,000	$30,000/Year	$42,723,000
Roadworks Premium	5	$1,399,000	-3	-$6,346,000	$45,000/Year	-$897,000

<All dollar values are in 2016 CAD.>

Source: Table. David Grant. March 31, 2016.

As seen in the table above, the premium costs over the system design results in cost savings for the permeable asphalt, and as such permeable asphalt serves as a cost effective solution. While the permeable asphalt incurs significantly higher capital costs relative to the detention facilities, it is still believed to be a monetarily sustainable option due to cost savings premium, with respect to the regular replacement cycle of the conventional asphalt, over the 90-year design life. The permeable asphalt allows UBC SEEDS to implement an economically friendly solution while also promoting UBC's commitment towards greener solutions on campus.

Due to the premium cost savings of the roadworks system, permeable asphalt was implemented wherever possible over the design area. This was to reduce the capacity burden on the detention facilities, and therefore lower costs for that section of the South Campus Stormwater Management System.

The total initial capital costs, future capital costs of components, and total system cost incurred over the lifetime of each facet of the South Campus Stormwater Management System is summarised below in Table 5. For the entire project over the design life of 90 years, the present day value of all costs incurred over lifetime is estimated to be $46,838,000. A more accurate depiction of the project costs, factoring in that permeable asphalt will only be a premium expense over conventional asphalt to UBC, can be see in Table 6. The total system cost over the 90-year design life, based on premium, is $4,115,000; this value provides a good representation of the financial commitment that UBC must allocate for the project.

Table 5: Total South Campus Stormwater Management Project cost to UBC

Item	Initial Capital Costs (C, EPCM, O)	Future Capital Costs (C, EPCM, O)	Maintenance Costs (M)	Total 90-Year System Cost (C, EPCM, O, M)
Detention Facilities	$4,292,000	$0	$8,000/Year	$5,012,000
Roadworks	$5,846,000	$29,230,000	$75,000/Year	$41,826,000
Complete System	$10,138,000	$29,230,000	$81,000/Year	$46,838,000

<All dollar values are in 2016 CAD.>

Source: Table. David Grant. March 31, 2016.

Table 6: Total premium South Campus Stormwater Management Project cost to UBC

Item	Initial Capital Costs (C, EPCM, O)	Future Capital Costs (C, EPCM, O)	Maintenance Costs (M)	Total Premium 90-Year System Cost (C, EPCM, O, M)
Detention Facilities	$4,292,000	$0	$8,000/Year	$5,012,000
Roadworks Premium	$1,399,000	-$6,346,000	$45,000/Year	-$897,000
Complete System	$5,691,000	-$6,346,000	$53,000/Year	$4,115,000

<All dollar values are in 2016 CAD.>

Source: Table. David Grant. March 31, 2016.

A comparison of the total estimated premium system cost over the design life relative to the expected value of damage to assets under present conditions is illustrated in Table 7. These values outline the 1 in 10 and 1 in 100-year stormwater events and the effects of a singular occurrence; these expected damage values are preliminary and will be further explored in the detailed design phase. Also listed is the probability of exceedance – the percentage chance that the event occurs at least once over the lifespan. The estimated damage values provided are a conservative estimate based on surveys of campus assets; true damages are likely to be within an error range of 50% of the utilized values.

Table 7: Potential damage to UBC assets

Event	Value
10-Year Event: Potential Damage Under Present Conditions	$2,000,000
10-Year Event: Probability of Exceedance over 90-Year Design Life	99.992%
100-Year Event: Potential Damage Under Present Conditions	$16,000,000
100-Year Event: Probability of Exceedance over 90-Year Design Life	59.527%

<All dollar values are in 2016 CAD.>

Source: Table. David Grant. March 31, 2016.

The overall premium costs of the system ($4,115,000) over the design life is considered a budget minded solution when compared to the potential damages of a 100-year storm event. The significant reduction of the overland flow and flooding from 10 and 100-year storm events resulting from the implementation of the South Campus Stormwater System delivers extensive value to the stakeholders of this project. In short, stakeholders are receiving asset protection and potential reduction in insurance costs from the implementation of the environmentally sensitive system.

6.3 Regulatory Analysis

The site location, as described in Section 3.2 - Site Overview and Constraints, consists primarily of UBC South Campus which is governed by multiple different regulating bodies. This section is intended to outline the codes and regulations that are both followed and taken into consideration during the current design phase and proposed construction phase. The specific regulating bodies are listed below in alphabetical order.

6.3.1 ASTM International

Standardized material testing must be completed prior to and during the construction phase. According to ASTM International geotechnical material testing standards, the ground conditions have been analyzed in accordance with ASTM standards to ensure an accurate geotechnical model of the proposed sites prior to construction and acceptable quality control during construction.

6.3.2 Canadian Standards Association (CSA)

The Canadian Standards Association provides a regulating guide code authority throughout Canada for many aspects of construction. The governing CSA standards pertaining to the detailed design consist of the following:

- CSA Sustainable Stormwater Practices: Fundamentals
- CSA Sustainable Stormwater Practices: Designing Road & Parking Lot Infiltration Systems
- CSA CAN/CSA-A23.3-04 Concrete Design Standards

The stormwater tank structural and seismic design, porous asphalt road section design and rainwater storage will be completed by complying with the CSA standards listed above.

6.3.3 Master Municipal Construction Documents Association (MMCD)

The detailed design is to comply with the associated requirements in the Master Municipal Construction Documents (MMCD), which provides a standardized set of guidelines for design and construction in British Columbia. Components that must be designed abiding to the MMCD are structural and seismic designs, excavation, rock anchoring, asphalt milling, paving, storm drain piping, instrumentation, backfill and compaction are to be adopted in the form of supplementary design guidelines. In addition, the design will be incorporating the Green Design Guidelines found within the MMCD to explore potential factors to enhance the sustainability of the preliminary design. At the federal level, the same capacity of design guidelines is available in the National Building Code of Canada (NBCC). In the case of a design specification conflict, priority will be given to the NBCC.

6.3.4 Metro Vancouver

Metro Vancouver Regulations and Guidelines indirectly govern the UBC South Campus site location, as such, the Integrated Liquid Waste and Resource Management Plan (ILWRMP) regulates liquid waste management at UBC. The primary purpose of this report is to (1) provide guidelines for recycling liquid waste to use as a resource and (2) protect the environment and public by overseeing sewage and stormwater management (Metro Vancouver, 2010). The ILWRMP provides a comprehensive framework for stormwater management, and was used in creating the structure for the UBC ISMP as described in Section 4.2 – Key Components.

As per the UBC Technical Guidelines outlined in Section 6.3.8 below, Metro Vancouver (GVRD) Sewer Use Bylaw No. 299 is also to be applied to design and implementation of stormwater practices. Bylaw No. 299 provides the framework to protect human health, safety and environment and restricting the discharge of stormwater in sewage channels (Metro Vancouver, 2007).

6.3.5 Ministry of Transportation (MoTI)

For the scope of the proposed design and the associated constructability issues, the Ministry of Transportation and Infrastructure (MoTI) Traffic Control Manual for Work on Roadways (MoTI, 1999) has been followed. This guideline suggests minimizing the traffic disturbance at the proposed site of the Wesbrook Village community during construction phase with the use of flaggers and traffic signage. MoTI has set out traffic control layouts for short duration work zones which are to be implemented as necessary. For purposes of the preliminary design, existing road infrastructure to be removed and replaced is considered to follow the Standard Specifications for Highway Construction and associated highway sign standards.

6.3.6 Occupation Health & Safety (OH&S) Regulations

According to Occupational Health and Safety (OH&S) Regulation and Regulated Materials, the construction process must adhere to all applicable safety guidelines. For the scope of the proposed design, the OH&S regulations must apply for all excavating and shoring work, work done with heavy equipment and tools as well as confined space for the installation and maintenance of the detention tanks and accompanying oil and grit separators. Further regulations governing excavation requirements are provided by the Oil & Gas Activities ACT (OGAA) to regulate safety and excavation planning for the construction phase. All excavations are required to be obeyed by OGAA to ensure that existing nearby utilities are not affected.

OH&S guidelines are enforced by WorkSafeBC, which administers the Workers Compensation Act for the BC Ministry of Labour. OH&S consists of the legal requirements that must be met as necessary under the inspection of WorkSafeBC. As such, for the duration of the construction phase, OH&S and WorkSafeBC BC are both to be followed.

6.3.7 Stormwater Quality

Stormwater quality at UBC is governed and protected by federal and provincial regulations and legislatures. The federal regulations regulating stormwater management are the Fisheries Act and the Canadian Environmental Protection Act. At the provincial level in British Columbia, the Water Act and the Environmental Management Act are applicable for managing stormwater runoff.

The federal regulations overseeing water quality consist of the Fisheries Act which mandates what is permitted to be discharged into a body of water containing fish and aquatic life. It also regulates human activity in areas of close proximity to fish habitats ensuring toxic substances are not released into a fish habitat. Likewise, the Canadian Environmental Protection Act regulates the disposal of solid waste into the environment.

At the provincial level, the Water Act prohibits polluting water bodies within the provincial boundary. The BC Water Quality Guidelines contains recommended levels of various substances and materials for the protection of varied water uses in order to maintain an acceptable level of water quality. Additionally, the Environmental Management Act regulates waste management from municipal sources including planning for air contaminants, water resource management and solid waste management.

6.3.8 University of British Columbia Guidelines

The primary governing body at the UBC South Campus location is the UBC Board of Governors which has imposed three primary guidelines to adhere to for stormwater design; Sustainable Development, Environmental Protection Compliance and UBC Technical Guidelines.

Policy #5 – Sustainable Development is created by the Board of Governors to develop an environmentally safe campus and ensure ecologic, economic and social benefits of UBC operations. As such, the procedures laid out in Policy #5 will be conformed with as per the clients' guidelines.

The Environmental Protection Compliance (Policy #6) provides a formal framework to ensure compliance with all applicable environmental regulations of UBC operations and is taken into consideration to account for the environmental processes of the preliminary designs.

UBC Technical Guidelines provides a site specific technical framework for each specific construction division and describing all governing regulations for each construction division. UBC Technical Guidelines – Division 02 Section 02720 lists describes the technical guidelines governing UBC storm drainage practices and is to be taken into account for the design and construction (permitting) phase.

6.3.9 University Neighbourhood Association (UNA)

Adhering to the University Neighbourhoods Association Construction Noise Control Bylaw, hours between 0730 hours to 1900 hours on any weekday that is not a holiday and between 0900 hours to 1700 hours on any Saturday that is not a holiday are permitted to allow for acceptable levels of construction noise (UBC, 2012). All other times, any and all construction noise is not permitted thereby affecting the construction scheduling.

6.4 Environmental Impact Analysis

An assessment of environmental impacts of the project are not only important in the short term, but the long term as well. Effects from construction, as well as post-construction, are considered and analyzed.

6.4.1 Environmental Impact Assessment (EIA)

An Environmental Impact Assessment (EIA) conducted on the effects of implementing the proposed stormwater management plan has been completed for the detailed design. The EIA analyzes the potential environmental, health, and social impacts as a result of the construction phase by evaluating the impact of air quality and water quality discharged by construction and effects of site clearing and deforesting. The EIA has been administered in adherence to the Environmentally Responsible Construction and Renovation Handbook's recommended regulations as well as UBC's Land Use and Permitting Policy #92. The EIA conducted is not in accordance with the Canadian Environmental Assessment Act 2012 (CEAA2012) as the project boundaries are defined within UBC property lines.

The air quality index in the immediate vicinity of the construction is expected to be reduced, primarily due to dust generated by bulk soil excavation, asphalt milling, and final grading. The effects of airborne dust will be mitigated by implementing the Best Management Practice's associated with dust control.

The water quality affected by the construction methods can include highly turbid water entering the streams, potential mechanical spillage of machines and equipment's as well as concrete washouts. This will result in an impact on the water quality downstream of the construction sites as the water will be drained into the existing stormwater system in place. The negative impact of the construction on the water quality is to be mitigated by adhering to the water quality guidelines enforced by the Fisheries Act and the Canadian Environmental Management Act.

Lastly, the potential removal of trees for excavation purposes at Tanks B, C and D will result in approximately 1200 m^2 of deforestation. The possibility of replanting uprooted trees in UBC's existing urban forest is rejected due to the high cost of said solution. Instead, tree retention will be practiced according to UBC's Tree Removal and Replacement Policy and a notice of tree removal will be conducted for said locations.

6.4.2 Environmental Benefits

The cast-in-place concrete stormwater tank facility provides minimal environmental impact benefits alone, and as such, they will be used in a treatment-train type system in conjunction with an oil and grit (O/G) separator. This treatment-train system will consist of a series of catch basins upstream to filter out large scale debris and an O/G separator to filter suspended particles and water insoluble contaminants prior to water being detained in the storage tank. The detention tank will also be designed to be completely drained following a storm event to avoid water stagnation and prevent potential insect and microorganism breeding (PUB, n.d.).

The roadway upgrade to a system of permeable asphalt roadways will increase groundwater infiltration and will be the subject of high levels of water infiltration into the water table. Permeable asphalt provides a significant filtration benefit in repressing sediment, however, there is difficulty for the system to separate oil and grease retention prior to infiltration. The majority of the filtration will be provided by the absorption, filtration and microbial decomposition at the base-subgrade interface as well as the subgrade filtration (“2004 Connecticut Stormwater Quality Manual”, 2004). A layer of impermeable road drain fabric where oil and grease buildup is likely will allow for water to be re-routed to catch basins and O/G separators with a higher volume capacity. This diversion will allow for the separation of oil from the water prior to percolation into the water table.

The installation of a dry pond is intended to provide a low impact detention facility that can improve water quality and reduce overland flooding in less desirable areas. In practice, dry detention ponds have detention times of less than 24 hours and lack the time required for sufficient settling of suspended particles in the flood stream (“2004 Connecticut Stormwater Quality Manual”, 2004). As such, the dry pond will also employ a treatment-train approach to be able to mitigate the effects of suspended sediments. This will be achieved by placing a system of fine particle screens at the outflow pipe and small precast O/G separators downstream of the dry pond to maintain an acceptable quality of discharge water. Alternatively, the amount of water that will be contained in the dry pond for extended periods of time will allow for suspended particulates to settle and will be filtered by the subgrade soil layers to deliver an improved quality of water into the subsoil layers.

6.4.3 Environmental Hazard Monitoring

Monitoring of environmental factors should be maintained throughout the lifespan of the design to analyze the environmental factors to ascertain if they are within an acceptable range as required by environmental regulations. The factors that are to be monitored are as follows:

Table 8: Factors to be monitored

Factor to be Monitored	Indicator Used to Monitor
Hydrogeology	Groundwater levels
Water Quality	Measuring water turbidity and amount of fecal matter present in water as per the Canada Water Act
Aquatic Biology	Index of biotic integrity

Source: Table. Asad Ijaz. Nov 29, 2015. Adapted from <*http://laws-lois.justice.gc.ca/eng/acts/C-11/page-8.html#h-12*>.

Using the factors and indicators mentioned in Table 8, a lifetime assessment of the environmental impacts can be monitored allowing for potential risks to be reduced in a timely manner. For example, an increase in turbidity of discharged water could indicate potential maintenance required for the existing infrastructure. The results of the hazard monitoring would also provide beneficial cost analysis data for future impact studies and is highly recommended to be maintained over the life cycle of the system.

6.5 Stakeholder Impact Analysis

In the process of this project, mitigating the potential impact on stakeholders and the community at large has been essential to the overall success. Many stakeholder studies have been performed to confirm that the preliminary design optimally meets their needs and addresses potential concerns. The stakeholders that are impacted by the design solution, either directly or indirectly include:

- Metro Vancouver
- Ministry of Transportation and Infrastructure
- Musqueam Indian Band
- Pacific Spirit Park Society
- TransLink
- TRIUMF

- UBC Neighborhood Association
- UBC Properties Trust
- UBC Students, Faculty, and Staff
- Wreck Beach Preservation Society

It is imperative that the values and opinions of the stakeholders listed above are considered in the design of the project. Numerous studies have been executed to better understand from the public's point of view: the issues and risks associated with the existing system and construction of the new design, and the advantages received post construction. With these points, a comparison between the potential impacts and the stakeholders' values and opinions can be made.

Initially, study evaluated current risks for stakeholders if the updated system were not employed. The first issue is that a 1 in 100-year storm event is very likely to damage campus assets, harming many of the previously listed stakeholders. Also, flooding on the roads can prevent multiple modes of transportation (walking, biking, vehicle or transit) from safely and efficiently travelling to campus. Finally, the irreparable erosion concerns to the Wreck Beach cliff can impair many of the stakeholders dependent on its environmental assets.

There are very few benefits for stakeholders if the design solution is not implemented, as the risks of flooding and cliff erosion are detrimental on all stakeholders involved. The primary benefit would be the lack of inconvenience due to construction. This would prevent temporary traffic and pedestrian detours, and most profoundly noise. Also, although the design solution hopes to maximize potential space for future expansion, it still uses space and will provide some minor conflict with expansions on campus. However, these are both quite minor compared to the previously mentioned risks incurred.

The primary benefits of the employment of the design is the mitigation of flooding and cliff erosion risks, which already provides immense value to stakeholders. As flooding of the south campus inherently increases the risk for severe damage, the reduction of risk could cause a possible tangible reduction on insurance premiums. Another benefit to the system is the use of O/G separators which allow for higher quality stormwater released from the tanks to the online system. This will greatly benefit the Pacific Spirit Park Society and Metro Vancouver, as well as the public in general, by providing a cleaner and healthier environment.

This solution serves to maintain the hydrological cycle on campus with the use of permeable asphalt and dry pond, achieving the goals expressed in the Vancouver Campus Plan. The installation of permeable asphalt will likely have the greatest direct impact on stakeholders during construction phase. As paving occurs, the effected roads will need to be detoured or managed. Regardless of how much delays are mitigated, the traffic congestion will be the greatest source of stakeholder disturbance.

The dry pond is not linked to any major roadways or walkways and its construction is quite short in comparison with other component. The dry pond also benefits the community, as it acts as a social hub in dry weather, attracts students and visitors to an outdoor environment and provides more business to Wesbrook Village. Therefore, the dry pond is considered to be a low impact solution.

6.6 Constructability Analysis

This section analyzes the constructability of the proposed stormwater management system. Topics covered include aspects of the design, construction schedule, site inspection, drawings and plans, as well as the process for clarifications and changes to design during the construction process.

6.6.1 Design

For the purposes of this constructability review the design has been broken down into four components – the four detention tanks, the dry pond, pipe network infrastructure, and the permeable asphalt roadworks.

6.6.1.1 Detention Tanks

The four detention tanks in the system range from a depth of 3 m to 5 m, while their footprints range from 30 m^2 to 900 m^2. As these tanks are located underground they require significant excavation and installation of numerous soil anchors, it is highly recommended that an experienced civil contractor handles this facet.

Walls of the tanks are proposed to be placed with shotcrete rather than conventional cast-in-place concrete. This enables a reduction to the amount of excavation required and allows for a smaller work site, which is beneficial considering fewer trees and other vegetation will need to be disturbed in the construction process due to the smaller footprint.

The base of the tanks and columns will be conventional cast-in place. The tank lids, as well as the oil/grit separator tanks will be pre-cast for ease of installation purposes. The sizing of the pre-cast segments has been determined to ensure they can be transported on provincial roads with 53-foot tri-axle trailers without any special permits or pilot vehicle requirements.

With the extensive amount of trucks and associated machinery involved in the construction of the detention tanks, it is recommended that the general contractor retains the services of a traffic management company. This is to ensure proper traffic flow and safety regulations are met. SMC engineering has not put forward a traffic management plan and has recommended that the contractor furthers on this aspect as it provides flexibility in terms of construction sequencing.

6.6.1.2 Dry Pond

The construction of the dry pond presents limited issues. The area in which the dry pond is to be constructed is clear of trees with adequate area around for the staging of equipment. The largest concern would likely be traffic management. However, with the proposed size of the pond being relatively small in comparison to the larger detention tanks, the traffic management should be typical of projects of similar nature.

6.6.1.3 Pipe Network Infrastructure

Pipe network tie-ins are required to connect the detention tanks and dry pond to the existing stormwater system. Due to the sensitive and detailed nature of connecting to existing systems it is recommended a contractor with significant experience with this scope of work is selected to perform the work. Comprehensive coordination with the contractor will be required to convey information regarding existing utilities along where the new pipe is slated to be installed. Possible wet-tap connections will be required and the contractor will need to prepare a methodology statement that be approved by the client engineer at the time of construction.

6.6.1.4 Permeable Asphalt

The permeable asphalt covers an extensive portion of UBC South Campus and will need to be performed in phases to minimise disruptions to regular traffic flow. The use of multiple phases will allow traffic management to be conducted in a more efficient manner, and reduce the amount of congestion during construction. A traffic management plan prepared by an engineer needs to be submitted and approved prior to construction.

6.6.2 Construction Schedule

Breaking down the South Campus Stormwater Management System into the detention facilities system (detention tanks, dry pond, and pipe network infrastructure) and roadworks (permeable asphalt) enables an aggressive approach with construction. Work on the detention facilities and the roadworks are both slated at the same time at the start of May. The resources and expertise required in the construction of the permeable asphalt is independent of that needed in the other processes required in the construction of the detention facilities; this facilitates the splitting of overall project scope and the multi-aspect start.

For the detention facilities, items relating to the excavation and shoring relate to critical path. Delays in excavation of the sites will invariably lead to delays in the project. Emphasis during construction will be placed on the productivity of the excavation and shoring by potentially allocating a bonus % amount for finishing the excavation and concrete prior to a certain date.

The critical path for the roadworks is the milling of the old asphalt. This means that although permeable asphalt may have a high learning curve for construction for a general contractor, there is room in the schedule to allow for this extension to work activities related to learning new methods for the permeable asphalt placing.

6.6.3 Drawings and Plans

The detailed design drawings provide adequate instructions and guidance as to the construction of all facets of the South Campus Stormwater Management System. Relevant codes and standards have been followed to ensure construction processes, materials, and structures are to code. Should any issues arise in the plans from the client or contractors, the clarification and change process outlined in the next section should be followed.

6.6.4 Clarifications and Changes

All queries regarding the design and drawings of the South Campus Stormwater Management from the selected general contracts and owners should be sent to the primary engineer (to be determined) from SMC Engineering assigned to the project. Queries should be submitted as formal

Requests for Information (RFI), and it is the responsibility of all parties to keep a log to track these documents. SMC Engineering will respond to all queries within a timely manner and notify all parties with the answered RFI.

In the event of a change to design, SMC Engineering will issue a formal Construction Change Order (CCO) for review and signing of all parties. All parties must agree to, and sign off on the CCO before work that has been scheduled for change can proceed. The same process for keeping track of and notifying parties as used for RFIs will be used for CCOs.

7.0 CONSTRUCTION DRAWINGS AND PLANS

A full compliment of construction drawings are readily available in the appendices. The drawings for detention facilities can be found in Appendix C and the drawings for the roadworks can be found in Appendix D. All construction drawings are based off the design work outlined in Section 6.0 – Analysis of Design.

8.0 COST ESTIMATE

The following section is intended to be read in conjunction with the cost estimates provided in Appendix J and Appendix K. Outlined is the general methodology, assumptions and parameters used to create the estimate for the identified solution. Table 9 summarizes the direct and indirect costs itemized by the Master Format 1995 divisions applicable to the project.

Table 9: Direct and indirect construction costs

Description	Detention Facilities Cost ($)	Roadworks Cost ($)	Total Projects Cost ($)
Division 1: General Conditions	517,000	317,000	834,000
Division 2: Sitework	1,466,000	2,896,000	4,362,000
Division 3: Concrete	309,000	0	309,000
Division 7: Thermal and Moisture Protection	68,000	0	68,000
Total Construction Direct & Indirect	2,360,000	3,213,000	5,573,000

<All dollar values are in 2016 CAD.>

Source: Table. David Grant. March 31, 2016.

Table 10 summarizes the construction; contractor; engineering, procurement, and project management (EPCM); and owner and contingency costs for the South Campus Stormwater Management Project.

Table 10: Direct and indirect construction costs

Description	Detention Facilities Cost ($)	Roadworks Cost ($)	Total Projects Cost ($)
Total Construction Direct & Indirect	2,360,000	3,213,000	5,573,000
Additional Contractor Direct & Indirect	248,000	337,000	585,000
Contractor Overhead & Profit	521,000	711,000	1,232,000
Engineering, Procurement, and Project Management (EPCM)	375,000	511,000	886,000
Total Owner and Contingency	788,000	1,074,000	1,862,000
Total Initial Capital: Unescalated	4,292,000	5,846,000	10,138,000

<All dollar values are in 2016 CAD.>

Source: Table. David Grant. March 31, 2016.

8.1 Contracting Strategy

Due the vast differences in scopes of work between the detention facilities (detention tanks and dry pond) and the roadworks (permeable asphalt), it is in recommended that UBC SEEDS tenders the two scopes of work as separate packages. Each contract is to be issued as a design-bid-build type and the entirety of the project work with respect to construction is deemed to be awarded to one general contractor per contract through an open tender system. Splitting the tenders allows for a more competitive bidding process due to the specialisations of general contractors in different fields of work.

The dollar value of these proposed tenders are referred to as the “Total Project Direct and Indirect” value in the estimate summaries. The contractor direct and indirect costs have been calculated using a detailed bottom-up estimate. The estimate was developed using crews, equipment, supervision, and material specific to each of the construction tasks. Other associated costs with the project such as design engineering and site investigations have been estimated using percentages of the total project direct and indirect costs. These Engineering, Procurement, and Construction Management (EPCM) percentages were based on historical cost relations between project direct and indirect costs and overall owner cost. Lastly, an allowance for owners cost and contingency has been established. The owner's costs have been set to 7.5% of the total project costs and this is based on relative market rates for owners' costs on similar scope projects in Canada. SMC Engineering recommends an owner's contingency of 15% for covering scope risk and quantity growth that is allocated based on unknown information beyond the control of SMC Engineering.

8.2 Estimate Methodology

The goal of this cost estimate is to provide the client with a reasonable dollar value of expected capital expenditure in the year 2016. Therefore, the estimate was developed in a manner which simulated a contractor bidding on the proposed project in an organized, experienced, and competitive environment. The majority of the estimate was developed from the bottom up, also known as "first principles". However, allowances have been made for items such as small tools consumption, first aid supplies, traffic management, and general personal protective equipment (PPE) costs. The following is a summary of the labour rates utilized in developing the estimate; an assumed 50-minute effective working hour factor has been included in these rates.

Table 11: Summary of labour rates

Title	Base Rate ($/hr)	Benefits (%)	WCB (%)	Vacation (%)	EI + CPP + Government (%)	Total Rate ($/hr)
Labour 1	22.00	10	4	4	6.5	32.87
Labour 2	24.20	10	4	4	6.5	36.15
Labour 3	26.62	10	4	4	6.5	39.77
Skilled Labour 1	27.00	10	4	4	6.5	40.34
Skilled Labour 2	29.70	10	4	4	6.5	44.37
Skilled Labour 3	32.67	10	4	4	6.5	48.81
Operator 1	30.00	10	4	4	6.5	44.82
Operator 2	33.00	10	4	4	6.5	49.30
Operator 3	36.30	10	4	4	6.5	54.23

<All dollar values are in 2016 CAD.>

Source: Table. Herman Gill. Dec 2, 2015.

Material rates have been verified by quotations from previous projects of similar size and scope. Equipment rates have been calculated using information provided by contractors and cannot be released due to confidentiality reasons. Rental rates for equipment not owned by the typical general contractor in the Lower Mainland, such as concrete pump trucks, have been taken from the B.C. Road Builders & Heavy Construction Association's Blue Book Equipment Rental Rate Guide. GST and PST has been excluded from this estimate.

8.3 Quantities

All quantities taken for the estimate are based on the construction drawings and detailed engineering calculations included within this document. Consideration has been made to standardized construction practices and is reflected within the quantities surveyed.

9.0 CONSTRUCTION SCHEDULE

This section on the construction schedule is intended to be read in conjunction with the schedules provided in Appendix L and Appendix M. Provided are the details on the documents, assumptions and methods utilized to produce the schedules for the detention facilities (detention tanks and dry pond) and roadworks (permeable asphalt). The projects' construction milestones are summarized below in Table 12 and Table 13.

Table 12: Detention facilities construction milestones

Detention Facilities	
Description of Task	**Date**
Construction Start Date	May 2, 2016
Project Completion (No Contingency)	October 24, 2016
Contingency Duration	10 Working Days
Project Completion Including Contingency	November 7, 2016

Source: Table. David Grant. March 31, 2016.

Table 13: Roadworks construction milestones

Roadworks	
Description of Task	**Date**
Construction Start Date	May 2, 2016
Project Completion (No Contingency)	July 14, 2016
Contingency Duration	5 Working Days
Project Completion Including Contingency	July 21, 2016

Source: Table. David Grant. March 31, 2016.

9.1 Development and Background

The provided schedules outline the estimated duration and sequencing of construction for the recommended solution. The schedule was developed based in part on the productivities which calculated the cost of construction as shown in Appendix J and Appendix K. Line items which did not have productivities to reference from were based on construction experience of both Herman Gill and

David Grant who have worked extensively with roadwork, excavations, and concrete structures in the past four years.

The project schedule is broken into two packages (detention facilities and roadworks) due to the conclusion that the scopes of work in each package are different enough for the work to be bid on and constructed separately. Further discussion on this can be reviewed Section 8.1 – Contracting Strategy.

9.2 Work Breakdown Structure and Construction Sequencing

The work breakdown structure (WBS) of the schedule is reflective of all the significant components required to complete the construction of the project. Due care was taken to ensure that the WBS was reflective of the scope of work during construction to assist in the client in visualization of the construction process.

The WBS for the overall project indicates two separate streams of construction, (1) the detention facilities and (2) the roadworks. The two streams are independent of one another and delays in one will not affect the timeline of completion for the other. However, because the detention tanks and dry pond comprise of a significantly longer duration, it is evidently the critical path for the South Campus Stormwater Management Project.

9.2.1 Detention Facilities

The WBS for the detention facilities splits the project down into main components and phases consisting of Phase 1 - Tank A, Phase 2 - Tank B, Phase 3 - Dry Pond, Phase 4 - Tank C, and Phase 5 - Tank D. The associated start and end dates can be seen in the table below, and a visualisation can be viewed in Appendix L.

Table 14: Detention facilities phasing dates

Detention Facilities - Phases		
Description of Task	**Start Date**	**End Date**
Total Project (No Contingency)	May 2, 2016	October 24, 2016
Total Project Including Contingency	May 2, 2016	November 7, 2016
Phase 1 - Tank A	May 2, 2016	May 17, 2016
Phase 2 - Tank B	May 18, 2016	June 29, 2016
Phase 3 - Dry Pond	June 8, 2016	June 23, 2016
Phase 4 - Tank C	June 27, 2016	July 20, 2016
Phase 5 - Tank D	July 11, 2016	October 21, 2016

Source: Table. David Grant. March 31, 2016.

These phases were chosen based on the work cycles and repetitive systems within each section, and based on a critical path following excavation activities.

9.2.2 Roadworks

The roadworks portion of work has a WBS that reflects five different phases. These phases were selected to distribute the work intro manageable and logical sequence packages. Critical path to these phases is the milling of existing asphalt. The start and end dates of the phases can be seen in Table 15; the visual representation of the phases are in Appendix M.

Table 15: Roadworks phasing dates

Roadworks - Phases		
Description of Task	**Start Date**	**End Date**
Total Project (No Contingency)	May 2, 2016	July 14, 2016
Total Project Including Contingency	May 2, 2016	July 21, 2016
Phase 1	May 3, 2016	May 26, 2016
Phase 2	May 18, 2016	June 10, 2016
Phase 3	June 3, 2016	June 27, 2016
Phase 4	June 20, 2016	July 13, 2016

Source: Table. David Grant. March 31, 2016.

9.3 Efficiencies and Contingencies

The schedules, at this detailed stage of design, are deemed accurate and representative as to the planning and coordination of work activities based on the evaluation of SMC Engineering. However, upon discussions with general contractors in the bidding process, further efficiencies may arise and time may be saved on the schedules due to the experience of the contractors in this type of work. For the purposes of the SMC Engineering schedules it has been assumed that the contractor(s) will be working sequentially on all tasks, and as per the UBC guidelines stated in Section 6.3 – Regulatory Analysis, from Monday to Friday 7:30 am to 5:00 pm excluding holidays.

While every reasonable effort has been made to mitigate risk, uncertainties are unavoidable and the potential for risk has been built into the schedule. In an attempt to include the uncertainties within the schedule, a schedule contingency was derived. First, a total dollar per day cost for the construction work was established based on the total direct and indirect costs of the project. Next, it was assumed that 50% of the owners' contingency would be allocated toward schedule risk. Finally, the dollar value of the schedule contingency was divided by the dollar per day cost of construction to establish an estimated schedule contingency accounted for in the total initial capital cost. The resulting contingencies for the detention facilities and roadworks can be seen below in Table 16.

Table 16: Project schedule contingencies

Schedule Contingency		
Item Description	**Detention Facilities**	**Roadworks**
Dollar Per Day Construction Cost	October 18, 1970	May 6, 2124
Schedule Contingency Cost	July 9, 2619	November 22, 2879
Schedule Contingency Duration	10 Days	5 Days

Source: Table. David Grant. March 31, 2016.

These contingencies have been reflected in the schedules and, conservatively, added to the total duration of the critical paths.

It is important to note that this schedule was developed based on the assumption that work would begin at the start of May, 2016. The schedule does not account for delays associated with a change in start date. It should be noted that the delay of the start of construction could move the roadworks and prolong completion due to restrictions on paving in cold or wet weather and restrictions on traffic management during months where the fall and winter semesters are in session.

10.0 DESIGN DEVELOPMENT AND RECOMMENDATIONS

In order to come up with a further refined solution, the proposed design can be further developed with additional geotechnical and seismic information either through site investigations approved by the owner or previous documented analysis that has yet to be released to SMC Engineering. Prior to commencement of design of any project, a geotechnical investigation is normally carried to interpret the surface conditions for design purposes. However, a lack of relevant geotechnical information has been provided by the client and hence it is difficult to ensure that assumed design values are accurate enough for a typical detailed design level study. Component to the geotechnical analysis would be the seismic analysis of the support columns. Once again, because of difficulties ensuring the assumed design values for the geotechnical parameters are accurate, it is of little value to attempt a seismic analysis on how the columns will behave during large subduction earthquakes.

It is in the client’s best interest, and a serious recommendation of SMC Engineering, to perform a geotechnical evaluation of the locations where the proposed tanks are to be placed. The geotechnical study conducted in this report has been heavily based on the available geotechnical information centered around Wesbrook Mall and Agronomy Road, which required significant interpolation. The data collected from the interpolation may cause the stormwater retention tanks to be over or under designed. information surrounding the soil conditions, loading histories and water table locations will undoubtedly enhance the planning and development of the design.

UBC South Campus is prone to earthquake activities and the lack of seismic soil interaction information has hindered the seismic safety analysis which plays a role in the design life of the project as well. Seismic loading analysis need to be considered to ensure the longevity of the detention tanks. Excessive ground movements overtime can damage the underground detention tanks and could potentially crack the precast concrete panels or result in columns failing in flexure. When the tanks are near capacity, the cracks have the potential of further expanding and weakening the structural integrity of the tanks such that the factor of safety falls below 1, resulting in a collapse. SMC Engineering recommends conducting field vibration measurements that would allow the correlation of seismic activity to the structural parameters for the detention tank material. In addition, an appropriate soil-detention tank modeling experiment is recommended to study the effects of seismic activity on tanks in empty and half-capacity situations. The combination of the described recommendations for the seismic design would assist in determining whether the design is capable of continued performance after a large seismic event.

11.0 CONCLUSION

The level of effort put into this study results in a sophisticated multi-faceted design solution completed to a level of detail that allows the tendering process to be undertaken. The design mitigates the risks regarding the 1 in 10 and 1 in 100-year storm event while providing added benefits by decreasing lifecycle costs for existing infrastructure and rehabilitating the natural hydrological cycle. The design solution consists of underground detention tanks A, B, C and D, a dry pond, and a system of road upgrades with use of permeable asphalt. The total project direct and indirect costs are estimated to be $5,573,000 and the construction is estimated to take 121 days.

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APPENDIX A – UBC INTEGRATED STORMWATER MANAGEMENT PLAN (2015) DOCUMENT SUMMARY

UBC INTEGRATED STORMWATER MANAGEMENT PLAN

UBC ISMP (2015) REPORT SUMMARY

SMC Engineering has reviewed UBC's Integrated Stormwater Management Plan (2015) for information pertinent to the design of the South Campus Stormwater Management System. Excerpts of information from the report that are relevant are as follows:

The ISMP outlines the main objectives of stormwater management design to be:

1. Protection of campus assets from flooding, safeguard human life, prevention of overland flooding and downstream erosion across the cliffs.
2. Meet or exceed existing provincial and federal policies and standards. Protect the campus environmental values and minimise the impact of campus discharge on neighbouring watercourses.
3. Maintain or preferably enhance water quality at its boundaries at a level that meets or exceeds best practices for urbanized municipalities.
4. Incorporate the natural hydrologic cycle and natural systems approach into the long term planning and design of the stormwater system.

Existing stormwater policy content from UBC to review, study, and implement:

- Sustainable Development Policy #6
- OCP (1997)
- The Comprehensive Community Plan (2000)
- Vancouver Campus Plan (2008)
- 20-year Sustainability Strategy

The ISMP requires the implementation of the following laws and regulations:

- Water Act and the Environmental Management Act (BC Government)
- Integrated Liquid Waste Management and Resource Plan (Metro Van)

Multiple actions are recommended for implementation of new stormwater management systems:

- Build detention facilities with capacities to manage the 100-year storm event adjacent to the discharge locations: Chancellor/Marine Intersection, South Campus, spot locations within campus.
- Include oil/grit separators to minimize particulate matter released into the environment
- Ensure developments minimize the stormwater that leaves the site and manage the outflow rates to lower levels in order to minimise the erosive forces on the discharges

- Re-establish monitoring of the discharges for quantity and quality through the installation of data recording equipment and periodic water sampling/testing.

Information and guidance on the current conditions are also provided:

- Catchment areas
    - The 16th Avenue catchment: Catchment collects the stormwater from Main Mall, south of Agronomy Road, 16th Avenue, west of Wesbrook, a portion of the sports fields (including Thunderbird Stadium) and the Botanical Gardens. The primary discharge point is a seasonal creek located at the cliffs, within Pacific Spirit Park. Some of the drainage from the Botanical Gardens discharges through an adjacent creek.
    - West or Trail 7 Catchment: Catchment includes Thunderbird Park, Hawthorn Place, Totem Park Residence, and the UBC Botanical Gardens; The West Catchment outfall is the stream at Trail 7.
    - South Campus catchment: Catchment drains most the area south of 16th Avenue, as well as a portion of the Athletics Fields and the Hampton and Acadia neighbourhoods. A portion of the residential system component drains into a detention facility in Nobel Park before being released into the UBC storm system. The storm drainage is collected into a single pipe that leaves the campus boundary and discharges to the ditch that runs along the east side of the Ministry of Transportation Infrastructure Marine Drive corridor. The ditch has a culvert that crosses the driving lanes of the road and discharges the water into Booming Ground Creek. In the event of higher storm flows, approximately 20% of the flows will discharge to an unnamed creek to the north of Booming Ground creek. A detention facility may need to be sized in such a way that the release rate for a larger storm is limited to the culvert limit. The tank will need to detain 2500 to 3000 cubic meters of water, while limiting the release rate to approximately 1.2 cubic meters per second.

The ISMP provides additional constraints and guidance in the development of solutions:

- For natural creeks the measures to mitigate the effects of large flows through them should occur on campus rather than on Metro Vancouver or MOTI lands
- No infiltration within 300m of the top of the cliffs
- Wells into lower aquifer not plausible due to contamination and reactions with heavy metals leading to maintenance
- Outfalls not preferred due to extra stakeholder engagement and legal issues
- Roads are primary source of stormwater contaminants
- Stormwater re-use systems not feasible due to unreasonable payback costs

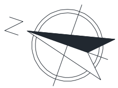
APPENDIX B – CALCULATED FLOOD LOCATION DATA

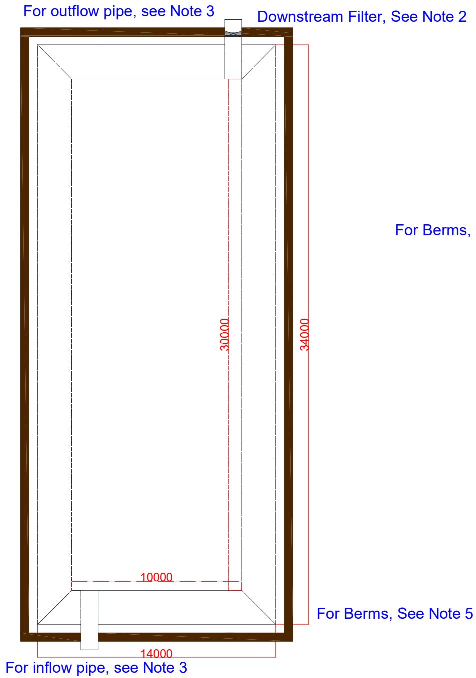
Calculated Flood Location Data

Flood Loss Area	Magnitude of Flood Loss (m^3)		Item No.	Description - *Consequence*	Picture No.	Magnitude of Impact	Sequence of Occurrence	Risk
	100y	200y						
7	1270	1720	7-A	**South Nodes:**				
			7-1	Flow east into Pacific Sprit park	7.01	1	1	Low
			7-B	**North Nodes:**				
			7-2	Flow east into Pacific Sprit park	7.02	1	1	Low
			7-3	Potential for flow to overtop the crest of the embankment and flow down the paved access	7.03	1	3	Very low
			7-4	Potential flooding of paved areas - *buildings protected by curbs and gutter*	7.04	2	4	Low
8	150	380	8-1	Contained within roadside ditch	8.01	1	1	Low
			8-2	Potential for culverts to overtop and flow across access - *Reduced level of service and potential culvert washout*	8.02-8.03	2	2	Moderate
			8-3	Flooding at Botanical Garden access - *Reduced level of service*	8.04-8.05	2	2	Moderate
			8-4	Potential for flooding to overtop ditch and flow towards green house building - *Property damage to green house*	8.05	3	3	Moderate
			8-B	**North-Eastern Ditch:**				
			8-5	Flooding of ditch, overtop and flow across roadways before entering downstream ditch - *Reduced level of service*	8.06	2	2	Moderate
			8-6	Contained within roadside ditch	8.07	1	3	Very Low
9	580	790	9-1	Ongoing road and stormmain construction; construction may resolve the identified flood loss issues. System will need to be re-evaluated under a separate cover.				
10	145	170	10-1	Flow across paved access - *Reduced level of service and potential culvert washout*	10.01-10.02	2	1	High

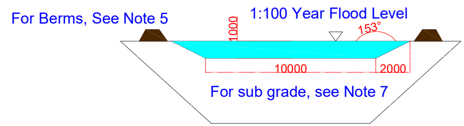
Summary of Flood Locations with Calculated Data

APPENDIX C – DESIGN SCHEMATICS: DETENTION FACILITIES

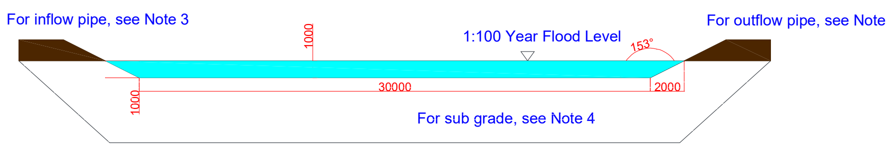




Dry Pond Site Plan



Dry Pond Elevation - West Face



Dry Pond Elevation - South Face

General Notes

Note 1: Dimension are in milimetres

Note 2: Outflow filter details TBD

Note 3: Inflow and outflow channels dimensions TBD

Note 4: Grade elevation for dry pond to be levelled by landscaping

Note 5: Berms dimensions TBD

Note 6: Drawing is issued for tender

Note 7: Retain existing subgrade

No.	Revision/Issue	Date

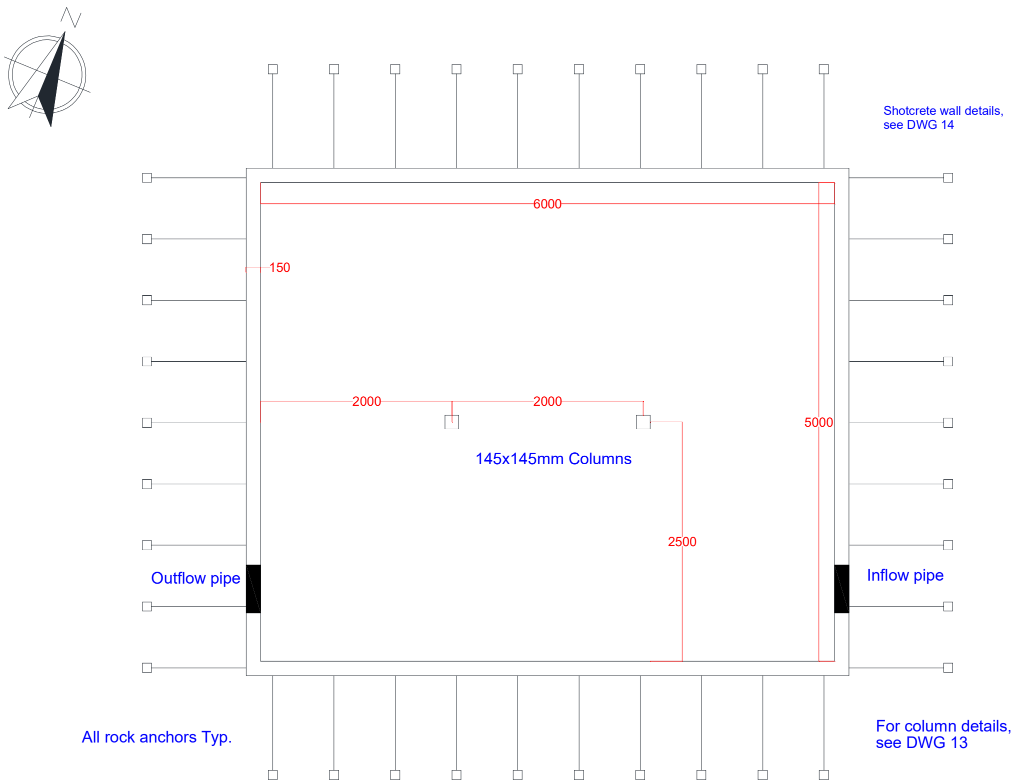
Firm Name and Address

SMC ENGINEERING

Project Name and Address

DRY POND ELEVATION AND SITE PLAN

Project SEEDS	Sheet D1
Date 2016-04-05	
Scale N/A	



General Notes

Note 1: Dimension are in milimetres

Note 2: Rock anchors grout specs TBD

Note 3: Drawing is issued for tender

No.	Revision/Issue	Date

Firm Name and Address

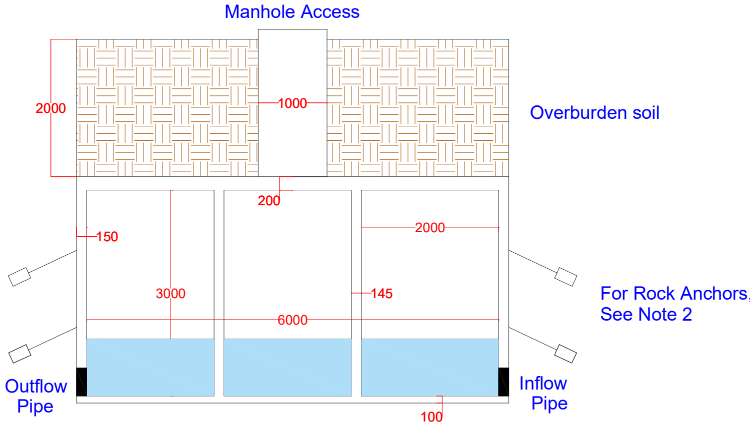
SMC ENGINEERING

Project Name and Address

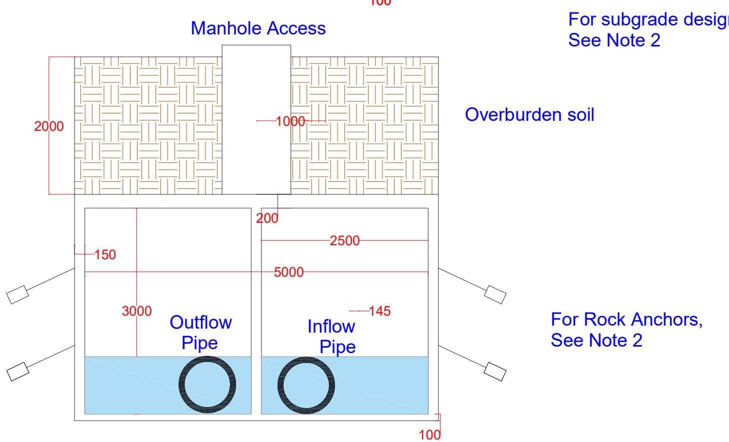
TANK A
SITE PLAN

Project: SEEDS	Sheet: D2
Date: 2016-04-05	
Scale: N/A	

ELEVATION DRAWING
(SOUTH FACE OF TANK)



ELEVATION DRAWING
(EAST FACE OF TANK)



General Notes

Note 1: Dimension are in milimetres

Note 2: Anchor details are shown in D14

Note 3: Rock anchors grout specs TBD

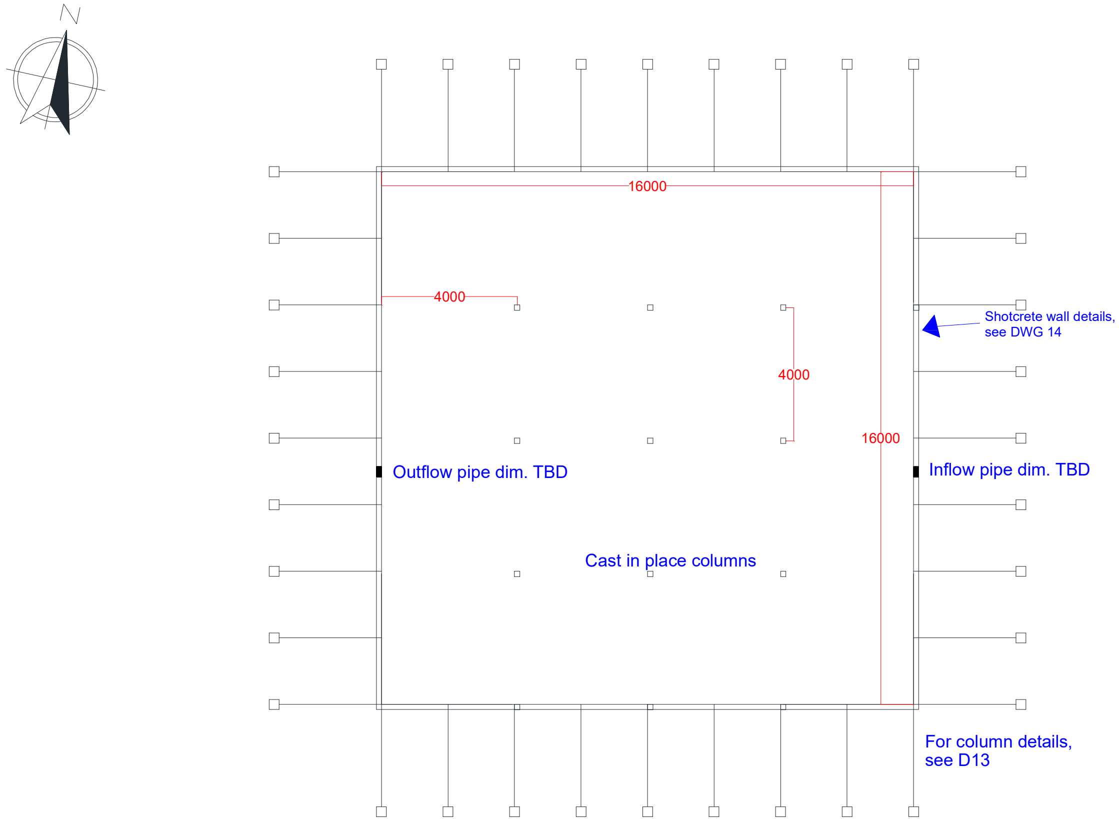
Note 4: Drawing is issued for tender

No.	Revision/Issue	Date

Firm Name and Address
SMC ENGINEERING

Project Name and Address
TANK A
Elevation

Project SEEDS	Sheet D3
Date 2016-04-05	
Scale N/A	



General Notes

Note 1: Dimension are in milimetres

Note 2: Anchor details are shown in DWG14

Note 3: Rock anchors grout specs TBD

Note 4: Drawing is issued for tender

No.	Revision/Issue	Date

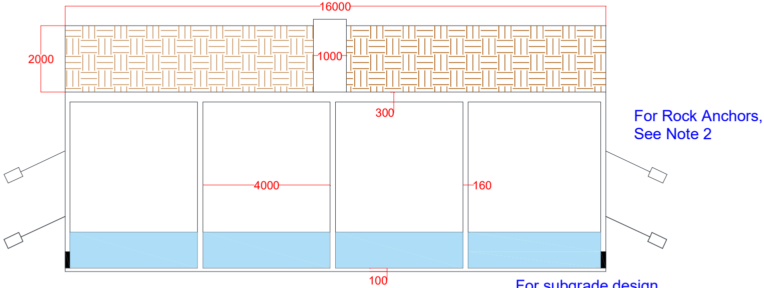
Firm Name and Address

SMC ENGINEERING

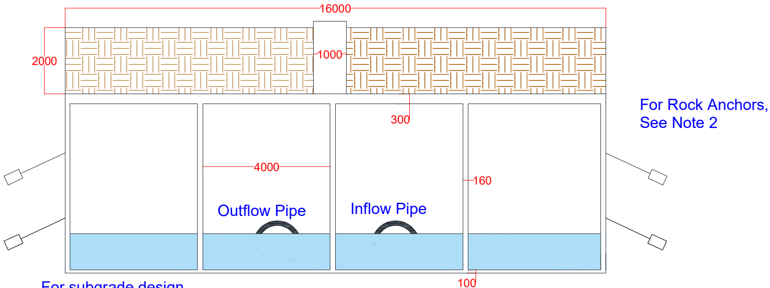
Project Name and Address

TANK B
SITE PLAN

Project: SEEDS	Sheet: D4
Date: 2016-04-05	
Scale: N/A	



ELEVATION DRAWING (WEST FACE OF TANK)



ELEVATION DRAWING (SOUTH FACE OF TANK)

General Notes

Note 1: Dimension are in milimetres

Note 2: Anchor details are shown in DWG14

Note 3: Rock anchors grout specs TBD

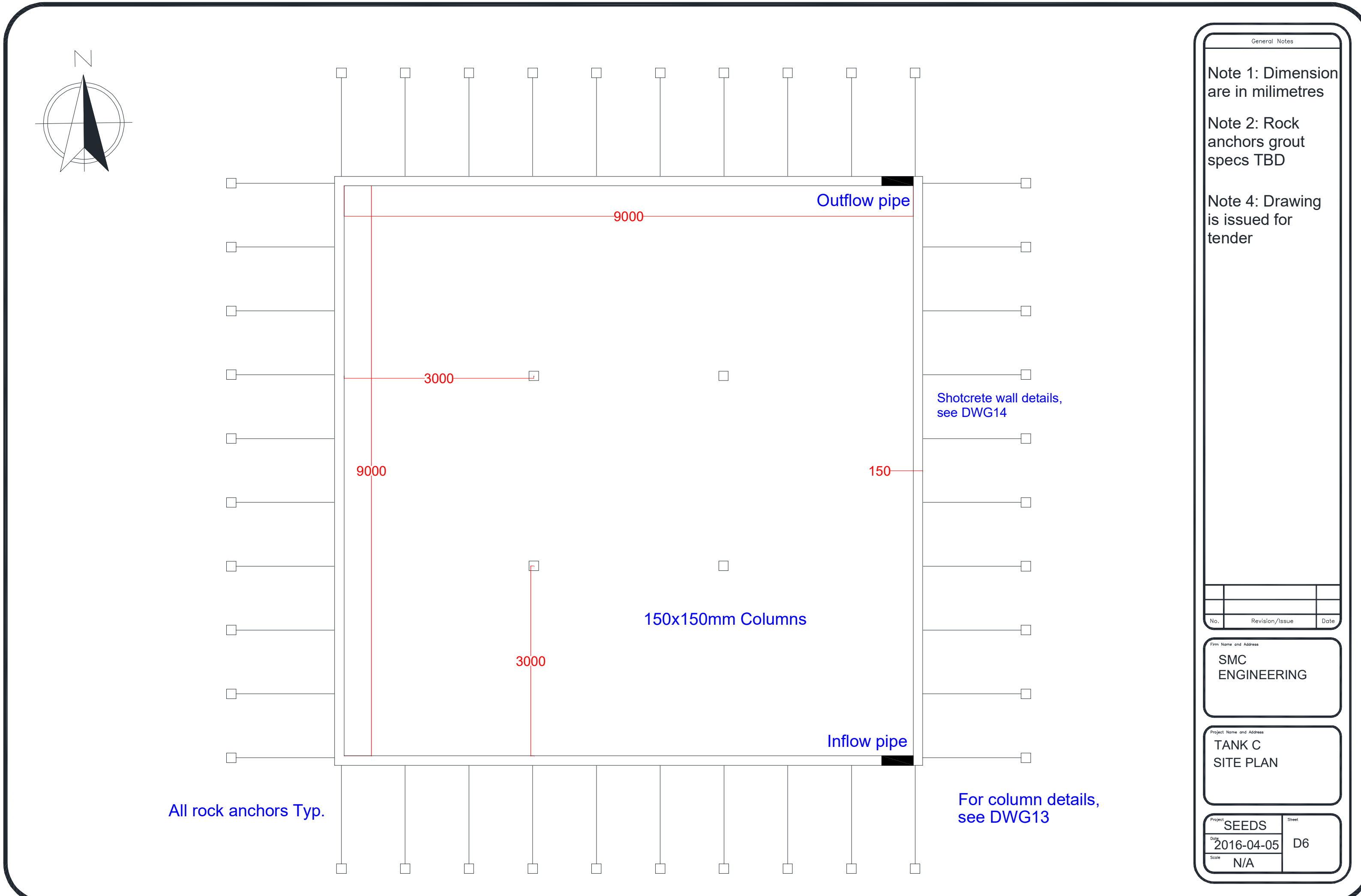
Note 4: Drawing is issued for tender

No.	Revision/Issue	Date

Firm Name and Address
SMC ENGINEERING

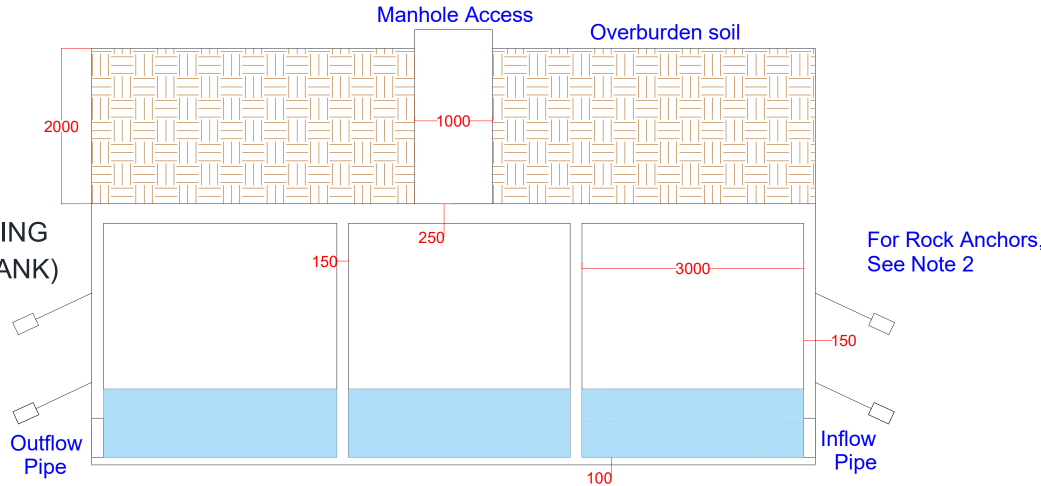
Project Name and Address
TANK B
Elevation

Project SEEDS	Sheet D5
Date 2016-04-05	
Scale N/A	



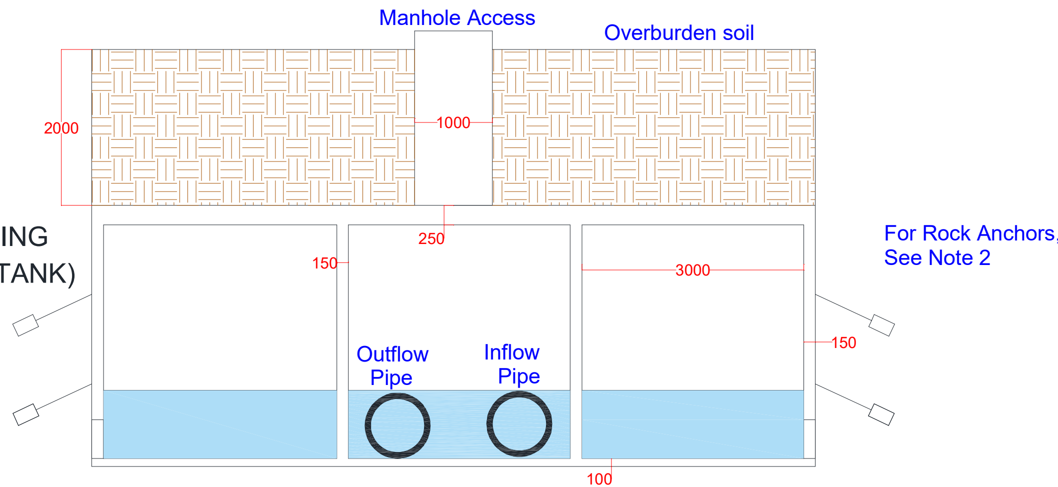
N
Outflow pipe
9000
3000
9000
150
Shotcrete wall details,
see DWG14
150x150mm Columns
3000
Inflow pipe
All rock anchors Typ.
For column details,
see DWG13
General Notes
Note 1: Dimension are in milimetres
Note 2: Rock anchors grout specs TBD
Note 4: Drawing is issued for tender
No.
Revision/Issue
Date
Firm Name and Address
SMC ENGINEERING
Project Name and Address
TANK C
SITE PLAN
Project
SEEDS
Sheet
D6
Date
2016-04-05
Scale
N/A

ELEVATION DRAWING
(WEST FACE OF TANK)



For subgrade design
See Note 2

ELEVATION DRAWING
(SOUTH FACE OF TANK)



General Notes

Note 1: Dimension are in milimetres

Note 2: Anchor details are shown in DWG14

Note 3: Rock anchors grout specs TBD

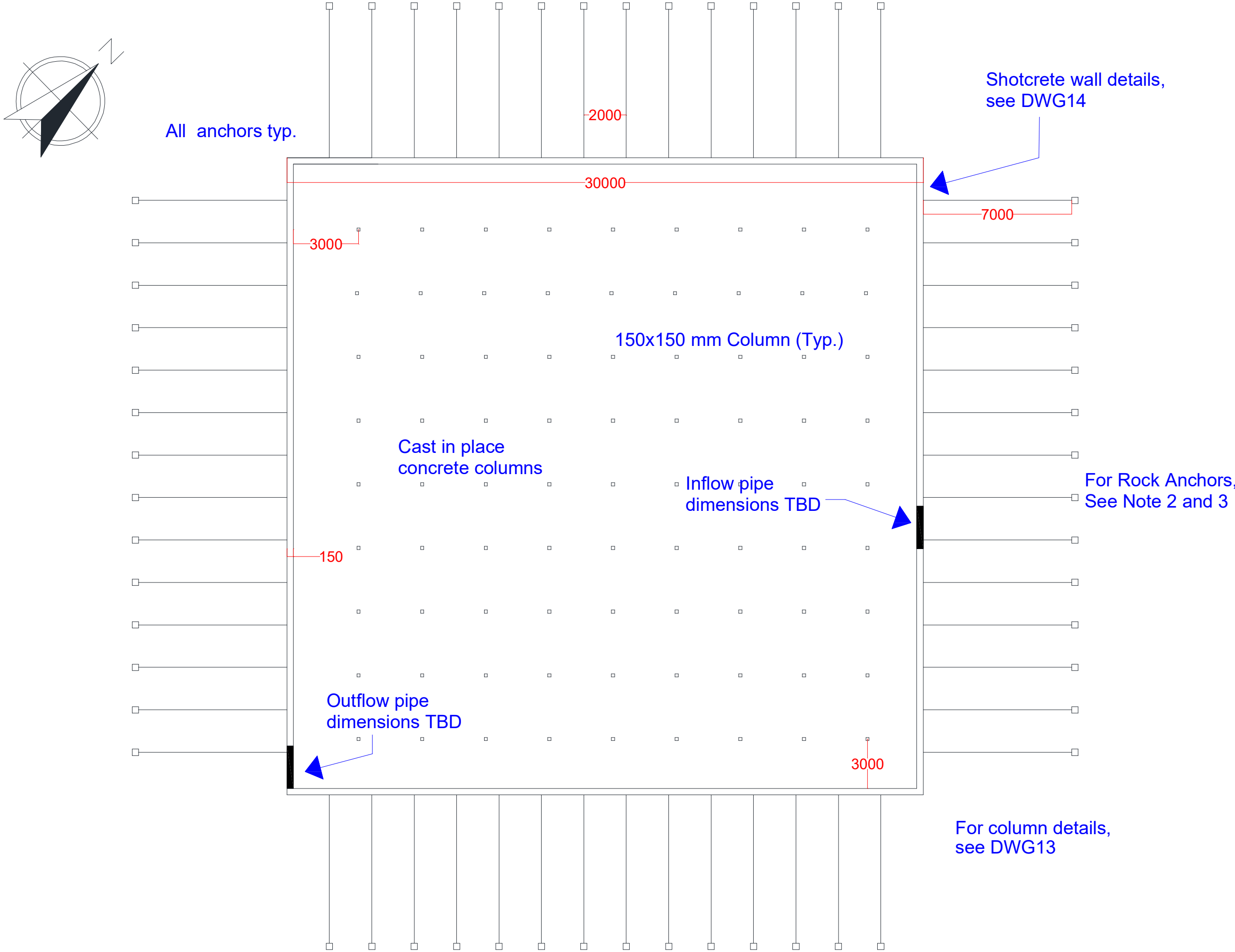
Note 4: Drawing is issued for tender

No.	Revision/Issue	Date

Firm Name and Address
SMC ENGINEERING

Project Name and Address
TANK C
Elevation

Project: SEEDS	Sheet: D7
Date: 2016-04-05	
Scale: N/A	



General Notes

Note 1: Dimension are in milimetres

Note 2: Anchor details are shown in DWG14

Note 3: Rock anchors grout specs TBD

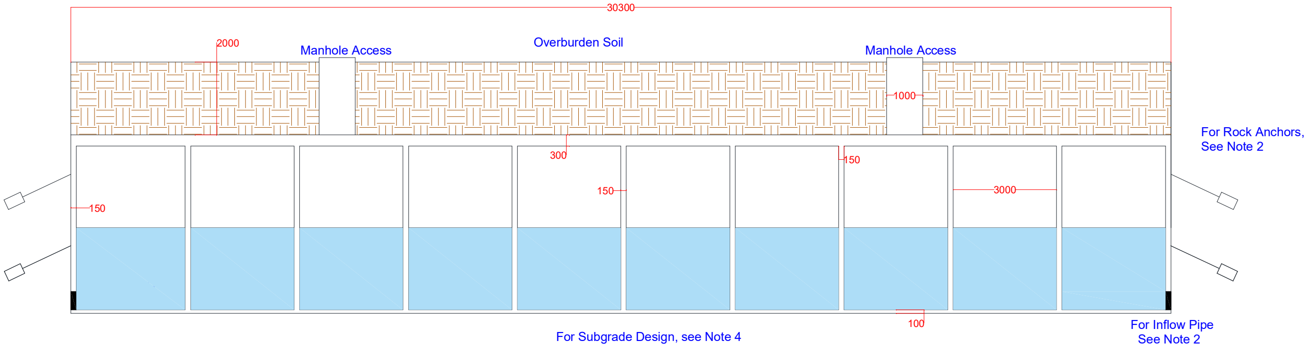
Note 4: Drawing is issued for tender

No.	Revision/Issue	Date

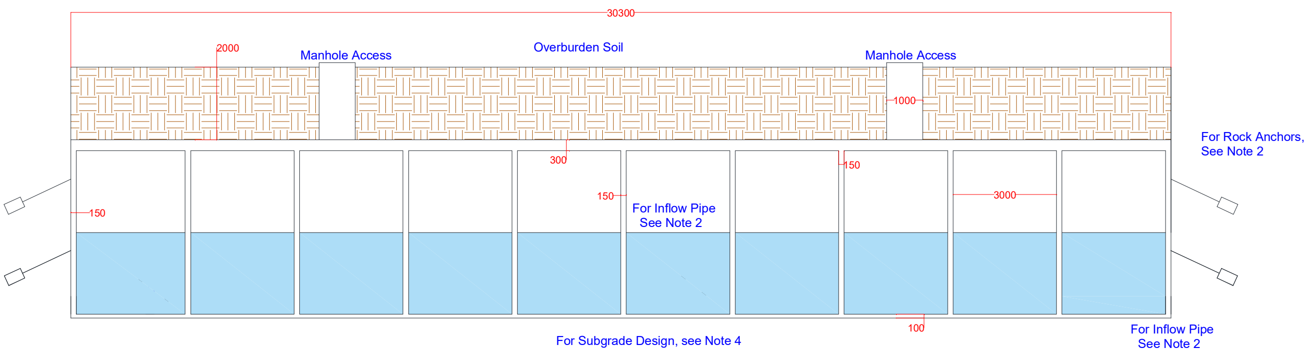
Firm Name and Address
SMC ENGINEERING

Project Name and Address
TANK D SITE PLAN

Project: SEEDS	Sheet: D8
Date: 2016-04-05	
Scale: N/A	



ELEVATION DRAWING (EAST FACE OF TANK)



ELEVATION DRAWING (NORTH FACE OF TANK)

General Notes

Note 1: Dimension are in milimetres

Note 2: Design Dimensions are to be decided

Note 3: Drawing is issued for tender

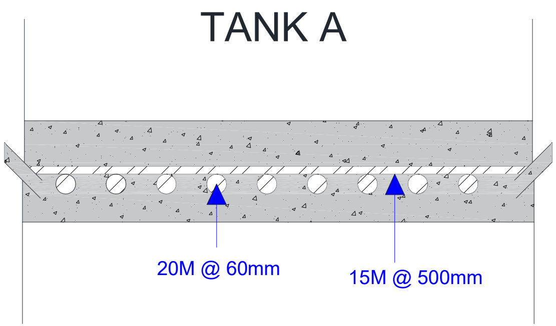
Note 4: Subgrade compaction TBD

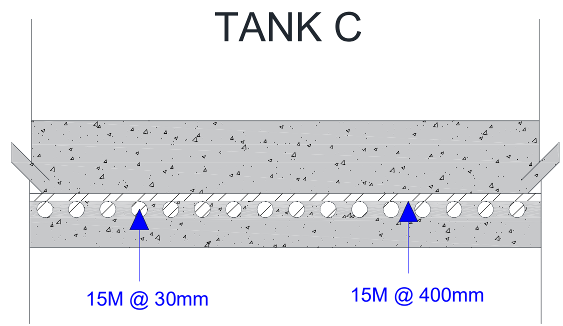
No.	Revision/Issue	Date

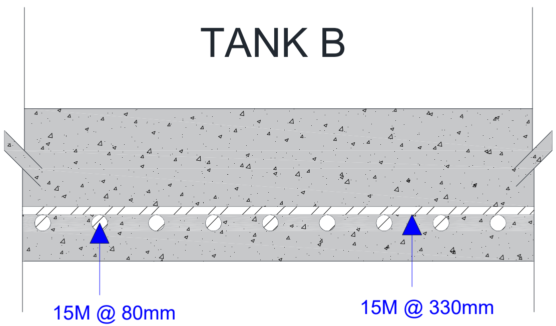
Firm Name and Address
SMC ENGINEERING

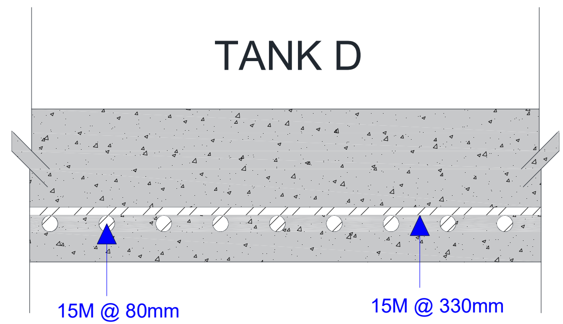
Project Name and Address
TANK D
ELEVATION PLAN

Project: SEEDS	Sheet: D9
Date: 2016-04-05	
Scale: N/A	









General Notes

Note 1: Dimension are in milimetres

Note 2: Drawing is issued for tender

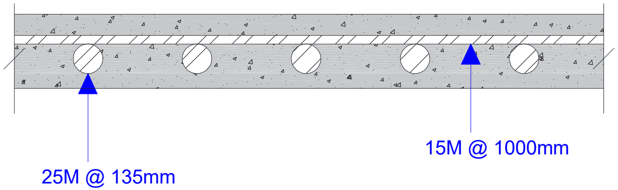
No.	Revision/Issue	Date

Firm Name and Address
SMC ENGINEERING

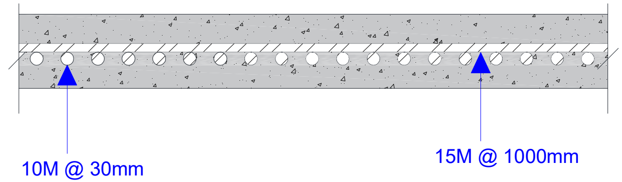
Project Name and Address
CEILING SLAB CROSS SECTIONS

Project: SEEDS
Date: 2016-04-05
Scale: N/A
Sheet: D11

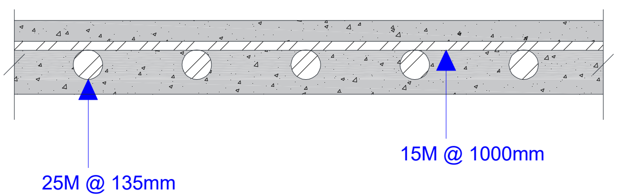
TANK A



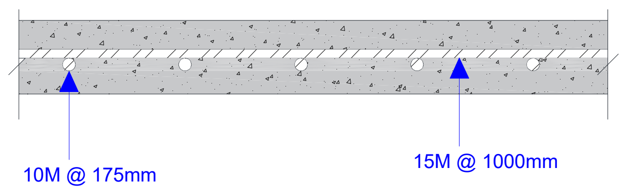
TANK C



TANK B



TANK D



General Notes

Note 1: Dimension are in milimetres

Note 2: Drawing is issued for tender

No.	Revision/Issue	Date

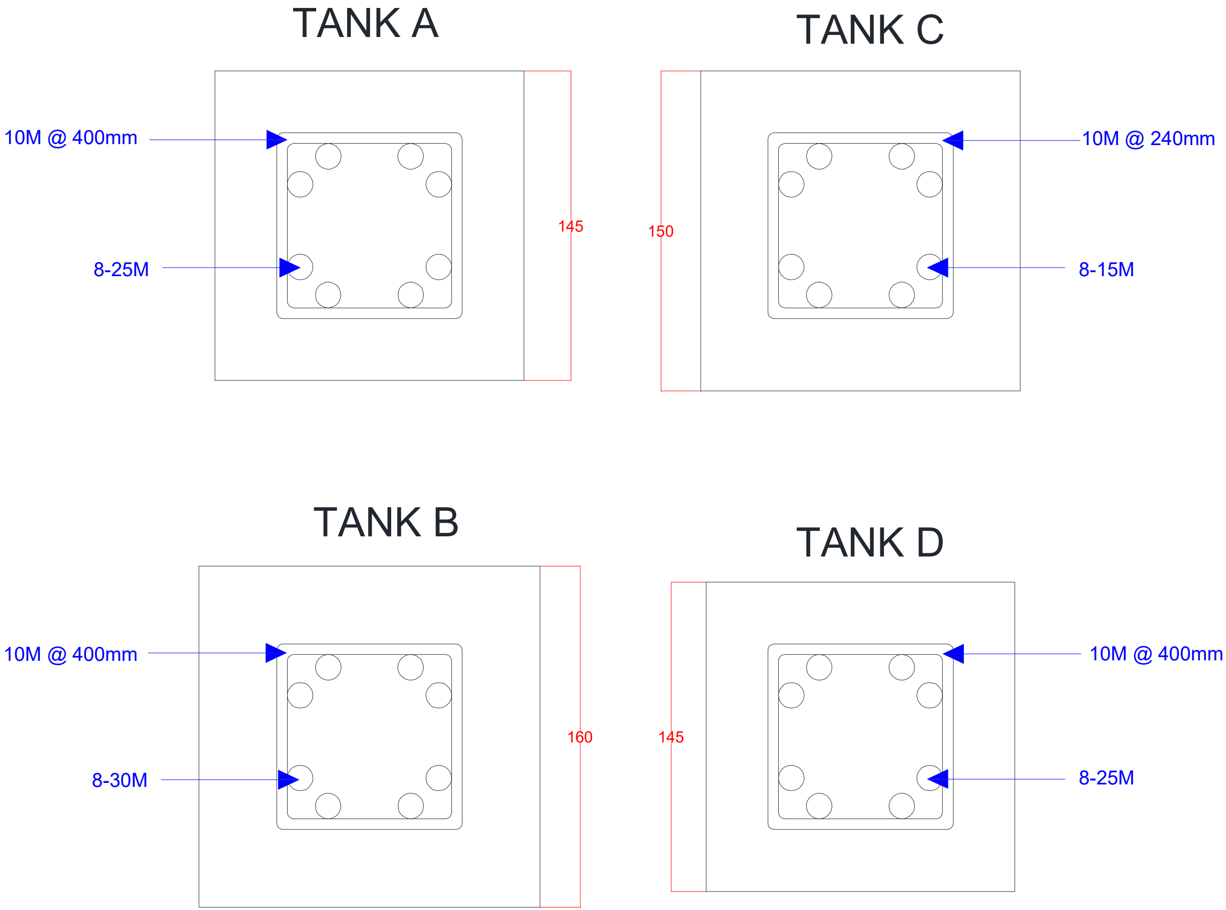
Firm Name and Address

SMC ENGINEERING

Project Name and Address

FLOOR SLAB CROSS SECTIONS

Project	SEEDS	Sheet D12
Date	2016-04-05	
Scale	N/A	



Cross sections are typical for all tank columns

General Notes

Note 1: Dimension are in milimetres

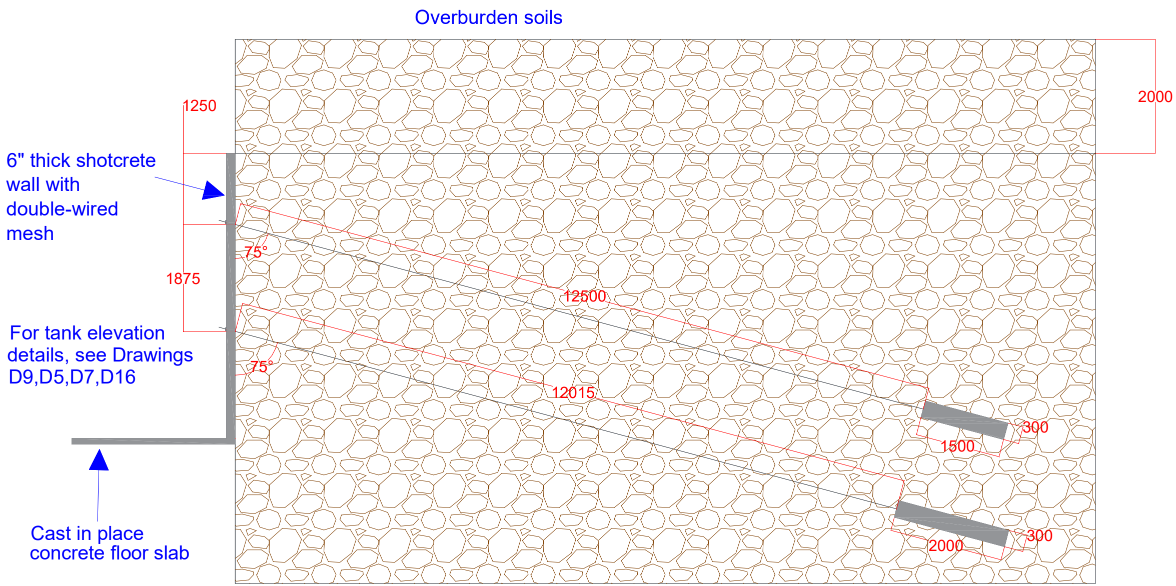
Note 2: Drawing is issued for tender

No.	Revision/Issue	Date

Firm Name and Address
SMC ENGINEERING

Project Name and Address
CONCRETE COLUMN CROSS SECTIONS

Project SEEDS	Sheet D13
Date 2016-04-05	
Scale N/A	



Section typical
for all rock anchors
on Tank B

General Notes

Note 1: Dimension are in milimetres

Note 2: Drawing is issued for tender

Note 3: Grout specification are TBD

No.	Revision/Issue	Date

Firm Name and Address

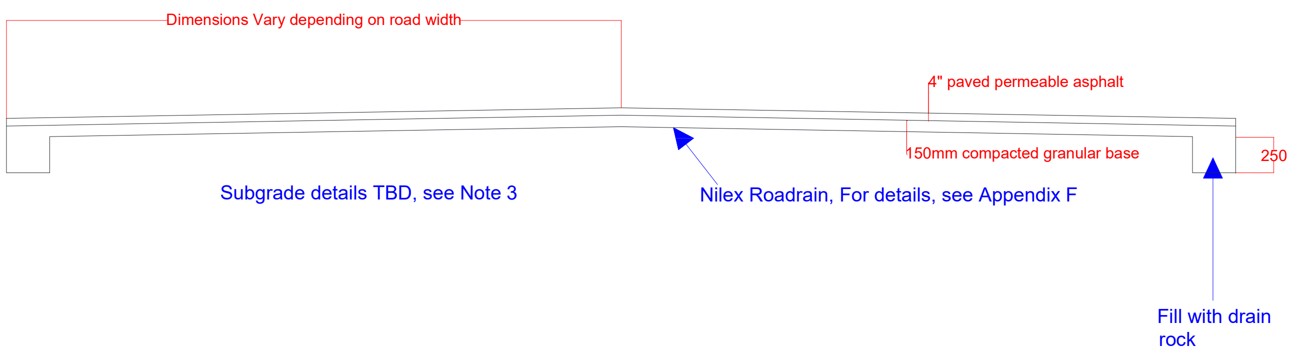
SMC ENGINEERING

Project Name and Address

ROCK ANCHOR DETAILS

Project SEEDS	Sheet D14
Date 2016-04-05	
Scale N/A	

APPENDIX D – DESIGN SCHEMATICS: ROADWORKS



General Notes

Note 1: Dimension are in milimetres

Note 2: Road section is typical

Note 3: Subgrade dimensions and details TBD

Note 4: Drawing is not Issued for Construction

Note 5: For Nilex Roadrain detail, see Appendix F

No.	Revision/Issue	Date

Firm Name and Address

SMC ENGINEERING

Project Name and Address

ROADWAY SECTION

Project	SEEDS	Sheet: D1
Date	2016-04-05	
Scale	N/A	

APPENDIX E – ARMTEC OIL/WATER SEPARATOR PRODUCT INFORMATION

ARMTEC.COM

armtec
VISION | BUILT

DRAINAGE SOLUTIONS AND WATER TREATMENT/ STORMWATER TREATMENT - DETENTION SYSTEMS

OIL/WATER SEPARATION PRODUCTS

OUR DEDICATED, TEAM OF ENGINEERS AND TECHNICAL EXPERTS WILL HELP YOU SELECT THE RIGHT TECHNOLOGY TO MEET YOUR REGULATIONS. WE ARE COMMITTED TO PRESERVING WATER RESOURCES BY PROVIDING CUSTOM, SITE-SPECIFIC STORMWATER TREATMENT SOLUTIONS.

Improved performance

Low cost

Easy maintenance

Durable

Armtec's stormwater management product line includes a variety of effective oil/water separation systems. Oil exists on impervious surfaces in a variety of forms: emulsified, free, attached to solids, or soluble. CONTECH Stormwater Solutions by Armtec help you meet regulations by capturing oil in stormwater and keep it on-site, away from the environment

Treatment systems remove trash, oil, heavy metals and other contaminants from surface drainage. Systems are installed in conjunction with a stormwater collection system, and are designed to meet site-specific flow, removal efficiency and target particle size requirements.

Why Oil/Water Separation?

- Oil spill risk management
- Meets secondary containment requirements
- Effective NPDES stormwater BMP
- Oil spill prevention, control and countermeasure (SPCC) technology

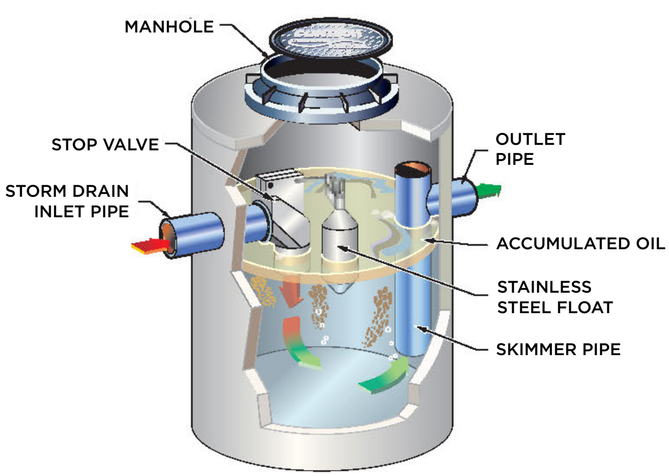
TYPICAL APPLICATIONS

- Utilities
- Transformer yards
- Bulk oil tank farms
- Oil pipeline facilities
- Truck loading racks
- Locomotive fueling areas
- Commercial filling stations
- Maintenance facilities

TARGET POLLUTANTS

- Oil and grease
- Fuel

OIL STOP VALVES



The Oil Stop Valve reduces the risk of catastrophic oil spills being released from your site. The fully adjustable float accommodates any oil type, oil depth, or alarm condition. A simple mechanism, few moving parts, and corrosion resistant stainless steel construction ensure long product life.

How does it work?

In a spill situation, free oil and stormwater flow into the manhole containment structure through the storm drain pipe inlet and stop valve. While the floating oil accumulates on the water surface in the structure, clean water exits through the skimmer pipe. As the layer of oil gets thicker, the stainless steel float, calibrated to the density of water, begins to sink in the lighter oil.

When the accumulated oil reaches a predetermined depth, the float sinks, which triggers the lever and closes the stop valve. The closed valve prevents additional oil or stormwater from flowing through the structure and leaving the site until the unit is reset.

KEY FACTS - OIL STOP VALVES

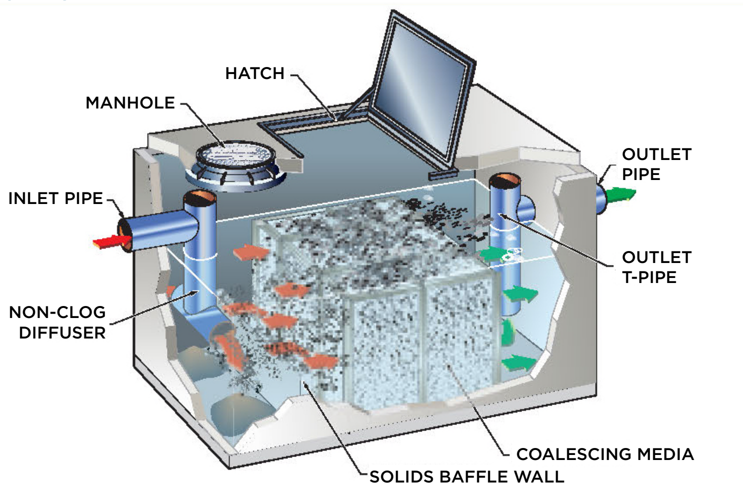
- Uses existing storm drains and pipes as secondary containment modular manhold design simplifies installation
- Requires no electrical power to operate, and only periodic inspection
- Stainless steel materials and passive design with only one moving part ensures reliability
- Acts as a standalone structure or works well in conjunction with an upstream oil/water separator such as the VortClarex™ featured on the opposite page
- Needs no operator adjustment or monitoring
- Is virtually maintenance free

Oil Stop Valve

Vortclarex™

Vortclarex™ installation in progress

VORTCLAREX™



VortClarex™ employs innovative coalescing media to remove free oil from contaminated stormwater flows and help site owners comply with regulations. The system is ideally suited for sites where specific effluent targets are specified, or for sites where removal of oil and grease is the greatest concern.

Conventional oil/water separators provide gravity separation by using baffles or T-sections, but are only effective on oil droplets greater than 150 microns. The VortClarex™ coalescing media maximizes surface area, increasing performance and effluent quality. It is typically sized to remove oil droplets as small as 60 microns, and achieve an effluent concentration of 10 mg/L or less.

The VortClarex™ coalescing media is housed within a precast concrete vault. Unlike other oil/water separators constructed of fiberglass or steel, it does not require anti-floatation hold down straps or concrete traffic collars. Maintaining the system is easy using a standard water hose and vacuum truck, and the media can be cleaned either inside or outside the structure.

How does it work?
Flows enter the VortClarex™ system via a non-clog diffuser and are distributed across the chamber width. The influent passes over a solids baffle wall where settleable solids drop out, reducing the amount of solids in the flow as it enters the coalescing media. As the flow passes through the media, oily pollutants accumulate on the surface and come into contact with others to form larger, more buoyant droplets. These buoyant droplets rise upward through the media and are released near the water surface. The oil is trapped behind the outlet T-pipe, and treated water exits the system.

KEY FACTS - VORTCLAREX™

- Removes up to 99.9% of free oil
- Releases effluent with a quality in the range of 10mg/L or less
- Installs and maintains easily
- Non-turbulent flow-through system increases separation
- Minimal site work requires no hold down straps
- Precast concrete structure ensures durability

AVAILABLE MODELS

VortClarex	Dimensions		Typical Sump Depth		Treatment Flow		Recommended Pipe Size Inlet/Outlet	
	ft	m	ft	m	gpm	lps	in	mm
VCL30	6 x 3	1.8 x 0.9	3.75	1.14	110	6.9	6	150
VCL40	8 x 4	2.4 x 1.2	3.75	1.14	150	9.6	6	150
VCL60-1	12 x 6	3.7 x 1.8	3.58	1.09	225	14.2	8	200
VCL60-2	12 x 6	3.7 x 1.8	3.58	1.09	440	27.7	10	250
VCL80-1	16 x 8	4.9 x 2.4	3.25	0.99	300	18.9	12	300
VCL80-2	16 x 8	4.9 x 2.4	3.42	1.03	620	39.1	12	300
VCL80-3	16 x 8	4.6 x 2.4	3.42	1.03	880	55.5	12	300

Oil Stop Valve	Diameter		Typical Depth (Below Invert)		Treatment Capacity		Max Size Inlet/Outlet	
	ft	mm	ft	m	gpm	lps	in	mm
OSV100†	-	-			100	6.3		
OSV148	4	1.22	4	1.22	100	6.3	4	102
OSV160	5	1.52	4	1.22	100	6.3	4	102
OSV300†	-	-			280	17.7		
OSV360	5	1.52	5	1.52	280	17.7	6	152
OSV372	6	1.83	5	1.52	280	17.7	6	152
OSV500†	-	-			500	31.5		
OSV560	5	1.52	5	1.52	500	31.5	8	203
OSV572	6	1.83	5	1.52	500	31.5	8	203

†This model includes valve only, no structure

NOTE
- Use this table to identify the appropriate configuration for your site
- Our engineers are available to assist you with your project

APPENDIX F – NILEX ROADRAIN PRODUCT INFORMATION

RoaDrain™
ROADWAY DRAINAGE SYSTEM

ROADWAY DRAINAGE SYSTEM

SYSTEM OVERVIEW

Tensar®

RoaDrain™ Roadway Drainage System: Enhance Pavement Performance with Synthetic Aggregate

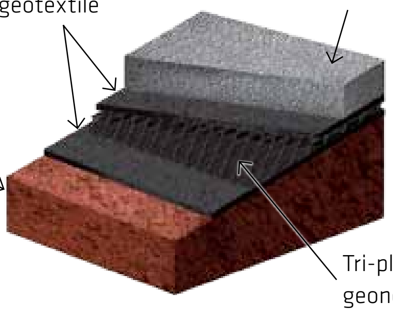
Water retention within a pavement layer is a primary cause of pavement failure. Without adequate underlying drainage, a pavement section is likely to fail prematurely. When an open-graded aggregate base layer is specified, there can be challenges with the migration of fines from the subgrade. The RoaDrain™ Roadway Drainage System from Tensar International Corporation (Tensar) is the engineered solution that consists of a synthetic subsurface drainage layer (SSDL) providing a flow rate up to five times greater than a typical open-graded base layer. The product features a tri-planar geonet core with durable, nonwoven geotextile filters laminated to the top and bottom sides. The result is a SSDL that maintains a flow void and outperforms open-graded base layers in the functions of drainage, longevity, ease of installation and cost.

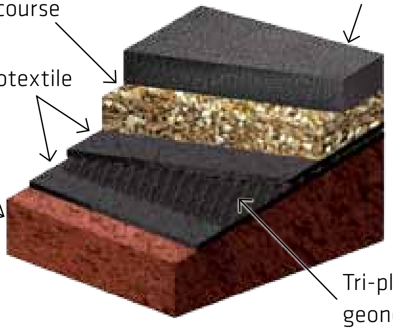
ROADRAIN IS AN INNOVATIVE SUBSURFACE DRAINAGE SYSTEM THAT IS ENGINEERED TO:

- Quickly remove subsurface water
- Provide an economic alternative to open-graded drainage aggregate
- Produce high in-plane flow rates resulting in decreased drainage time
- Successfully control moisture in a weak subgrade
- Provide a void-maintaining structure
- Provide excellent compressive stiffness that resists deformation
- Prevent migration of fines through synthetic separation
- Install quickly and easily to reduce the construction schedule
- Work with less processed structural fill for lower material cost
- Allow for roll installation parallel to center line of the road due to 45° channel orientation.
- Provide a capillary break

ROADRAIN IS AVAILABLE IN DIFFERENT GRADES SUITABLE TO FIT A VARIETY OF APPLICATIONS:

- Roadways, parking lots and paved walkways
  - Under aggregate base course
  - Directly beneath PCC
  - Capillary break (beneficial to Northern climates)
  - PCC joint repair
- Embankments and dike drainage (beneficial in areas with a high water table)
- Alternative to granular blanket drains
- Channel drains
- Detention ponds
- Under concrete slabs
- Airport runways and taxiways
- Railway facilities
- Wherever aggregate drainage material is used



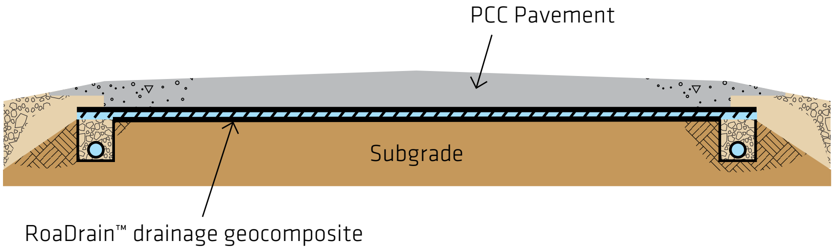


Engineered for Better Drainage

By providing excellent drainage, the RoaDrain™ System is the solution that greatly extends the life of pavements and reduces maintenance costs. Easily installed, the RoaDrain System can be placed under the base course or under Portland Cement Concrete (PCC). Below are illustrations of these various placements:

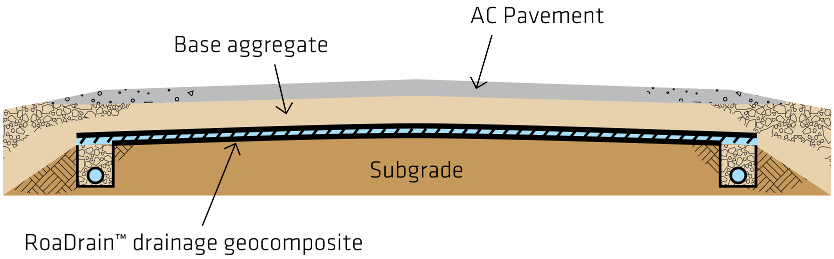
DRAINAGE BENEATH PAVEMENT SURFACE

Placed directly beneath the pavement surface, the RoaDrain System rapidly removes water from the pavement. The RoaDrain System provides excellent drainage as defined by AASHTO, (50% of the water is removed from the pavement structure within two hours.)



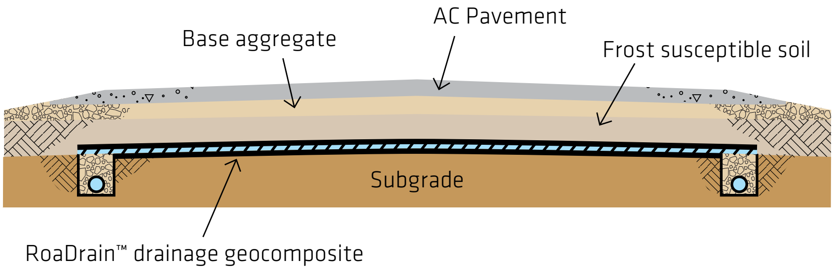
DRAINAGE BENEATH BASE COURSE

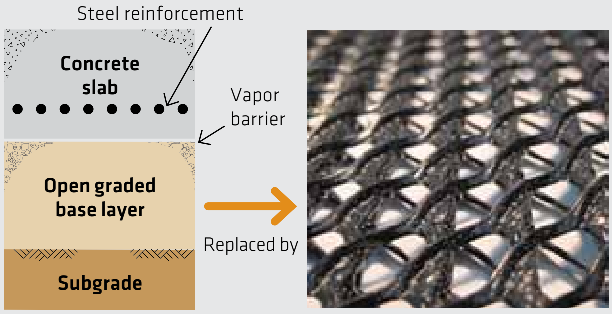
Installed under the base course, the RoaDrain System shortens the drainage path, requiring less select base material. Drainage provided by the RoaDrain System allows for an increase in the structural support design value of the pavement system through modification of the drainage coefficient or "m" values on PCC and asphalt pavement applications.



CAPILLARY BREAK BENEATH FROST-SUSCEPTIBLE SOILS

The RoaDrain Systems acts as a capillary break at lower depths under frost-susceptible soils to help eliminate frost-heave.





Drainage design featuring open graded base layer (OGBL)

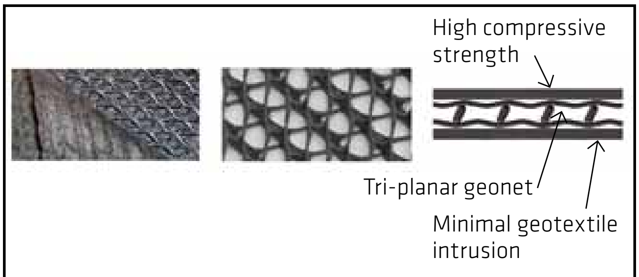
RoaDrain™ net core with tri-planer void-maintaining structure

The RoaDrain™ Roadway Drainage System can replace the open graded stone base layer (OGBL) within a drainage design.

Built for Proven Performance

The RoaDrain product is a synthetic subsurface drainage layer (SSDL) comprised of a tri-planar structure with thermally bonded nonwoven geotextile filters on both sides.

- **Nonwoven geotextile** offers separation and filtration
- **Tri-planar geonet core** ensures a void-maintaining structure with high compressive strength



Drainage Media	Permeability, k (ft/day)	Flow Rate[2] (ft^3/day/ft)
RoaDrain	56,700	30
4 in. OGBL	1,000 – 3,000	6 – 20

[1] *Flow rate at 2% gradient*

[2] *SSDL transmissivity is tested along the primary flow direction with the boundary conditions as follows: steel plate/Ottawa sand/SSDL/Ottawa sand/steel plate, one hour seating period @ 5,000 psf*

Specifications for RoaDrain 5 (RD-5) and RoaDrain 7 (RD-7)

Property	RD-5	RD-7
Net Core Thickness, mil (mm)	280 (7.1) ±10%	300 (7.6) ±10%
Geotextile Weight*	6 oz/sy	8 oz/sy
Geotextile Strength	Exceeds Class 2	Exceeds Class 1
Geotextile AOS, US Std Sieve (mm)	70 (0.212)	80 (0.150)
Permittivity, sec^{-}	1.4	1.1
[1]Water Flow Rate, gpm/ft (l/min/m^2)	110 (4481)	90 (3675)
[2]Transmissivity (loading condition)	5,000 psf	15,000 psf
Pavement Fatigue (# of cycles before cracks propagate)	N/A	3000
Other Details	**RD-5**	**RD-7**
Roll Size	12.75 ft x 200 ft (3.89 m x 61 m)	
Roll Area	283.33 sy (237.29 sm)	
Approximate Roll Weight	1,000 lbs	1,200 lbs

**Typical value measured prior to bonding.*

Experience You Can Rely On

Tensar is the leader for geosynthetic products created especially for roadway improvement. We have developed products and technologies that have been at the forefront of the geotechnical industry for nearly three decades. As a result, you can rely on our systems and design expertise. Our products are backed by the most thorough quality assurance practices in the industry. And, we provide comprehensive design assistance for every Tensar system.

For more information about the RoaDrain™ System, please call **800-TENSAR-1**, visit **www.tensarcorp.com** or e-mail **info@tensarcorp.com**. We are happy to supply you with additional system information, complete installation and design guidelines, product specifications, preliminary cost estimates, summaries of completed projects, and much more.

Featured Projects

SHELL CANADA AIRPORT STRIP, ATHABASCA SANDS, CANADA

The Challenge: The airport strip was built on top of problematic silty soils. Due to the presence of a high groundwater table and low temperatures, frost heave was a significant concern.

The Solution: RoaDrain™ RD-7, a high strength drainage geocomposite with tri-planar structure, was selected for its ability to support heavy loads and its long-term high drainage capacity. The RoaDrain RD-7 benefits were immediately obvious as it removed water from the pavement structure while providing excellent compressive strength. RoaDrain RD-7 also provided a capillary break and separation between the subgrade and base course. The project was completed ahead of schedule and below budget.

HIGHWAY 35 ROAD RECONSTRUCTION, OWATONNA, MINNESOTA

The Challenge: Significant deformation and rutting of the roadway surface was observed shortly after the initial construction of this roadway section. Limited excavation revealed that underground springs and perched water within sand lenses were saturating the subgrade and road base materials, thereby compromising the structural integrity of the roadway.

The Solution: The RoaDrain product was specified due to its ability to efficiently collect water and provide total coverage of the road section. It was determined that the collection capacity and high flow rate of RoaDrain would be sufficient to keep the base aggregates dry and that the compressive strength of RoaDrain would be sufficient for long term serviceability and short-term installation stresses.

BODEGA HIGHWAY, SONOMA COUNTY, CALIFORNIA

The Challenge: Bodega Highway is located half a mile east of the Bohemian Highway in Sonoma County. The roadways in this area are prone to water intrusion. In the winter, the road tends to freeze causing a serious hazard.

The Solution: The Sonoma County Public Works Department elected to use the engineered solution of RoaDrain. The RoaDrain layer between the aggregate base and the silty subgrade soils provided an excellent drainage path. It also provided separation and strength to the pavement section. The RoaDrain product effectively removed the water from the roadway, thus creating a safer road.

SOUTHWEST PARKWAY, AUSTIN, TEXAS

The Challenge: A six lane stretch of Southwest Parkway underwent a major redesign and reconstruction. A 2,940 foot section in the middle of the problematic roadway was exposed to underground water that infiltrated its structural base course. This saturation contributed to premature failure of the pavement.

The Solution: The RoaDrain Roadway Drainage System was specified under the base course as a drainage conduit to channel the groundwater to a collection system. The RoaDrain solution has proven to deliver a valuable performance aspect to the reconstructed highway design section.

Tensar®

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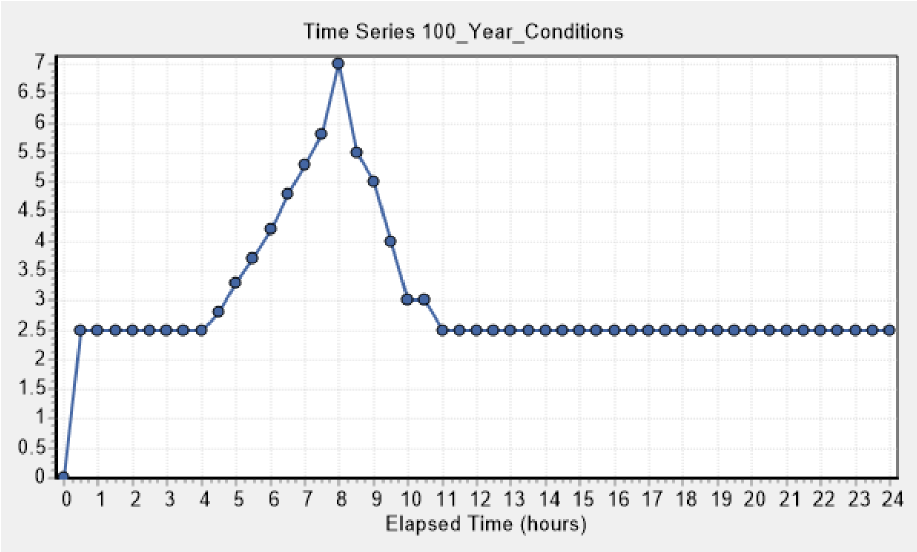
APPENDIX G – STORM WATER MANAGEMENT MODEL (SWMM) ANALYSIS

SWMM Analysis

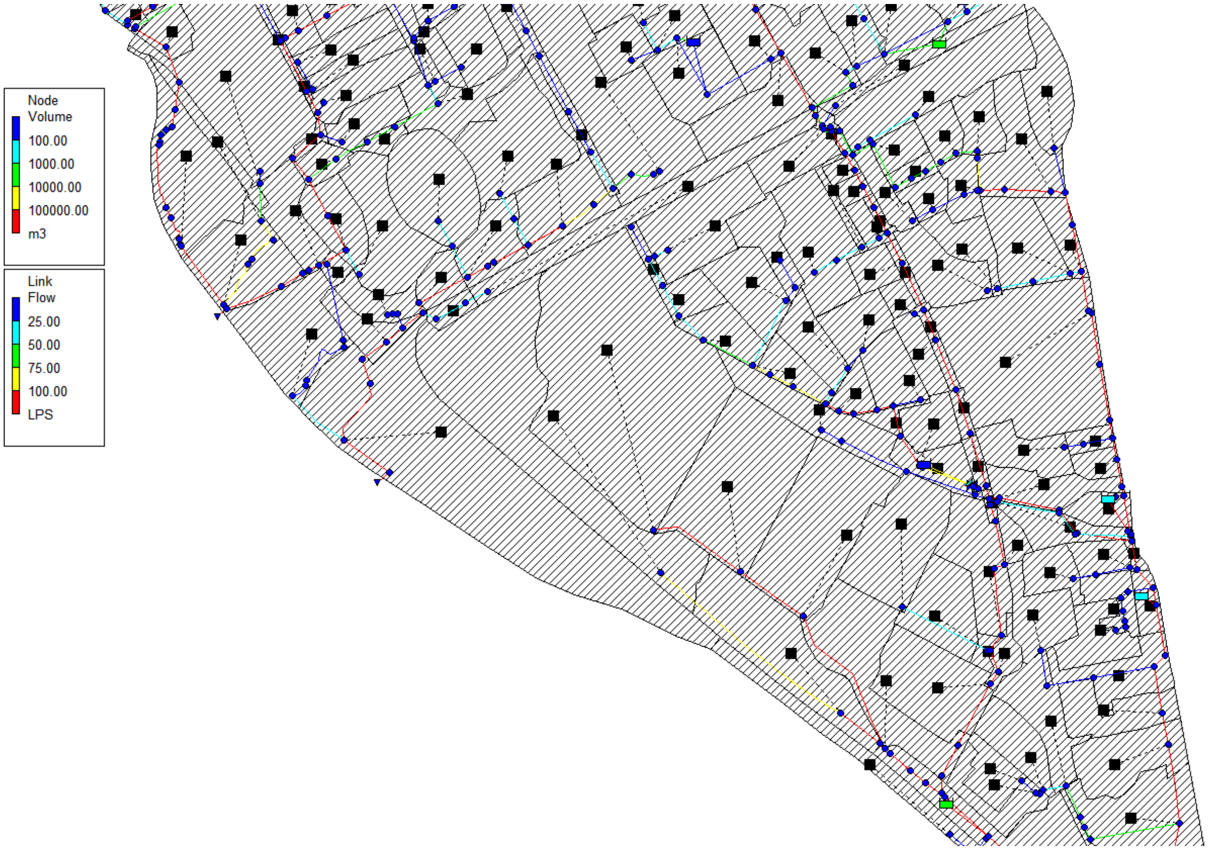
With the SWMM model provided by UBC SEEDS, SMC Engineering implemented storage tanks and ran a simulation. The following images are for additional reference, and is intended for those with experience using SWMM.

Locations of storage tanks

SWMM Analysis

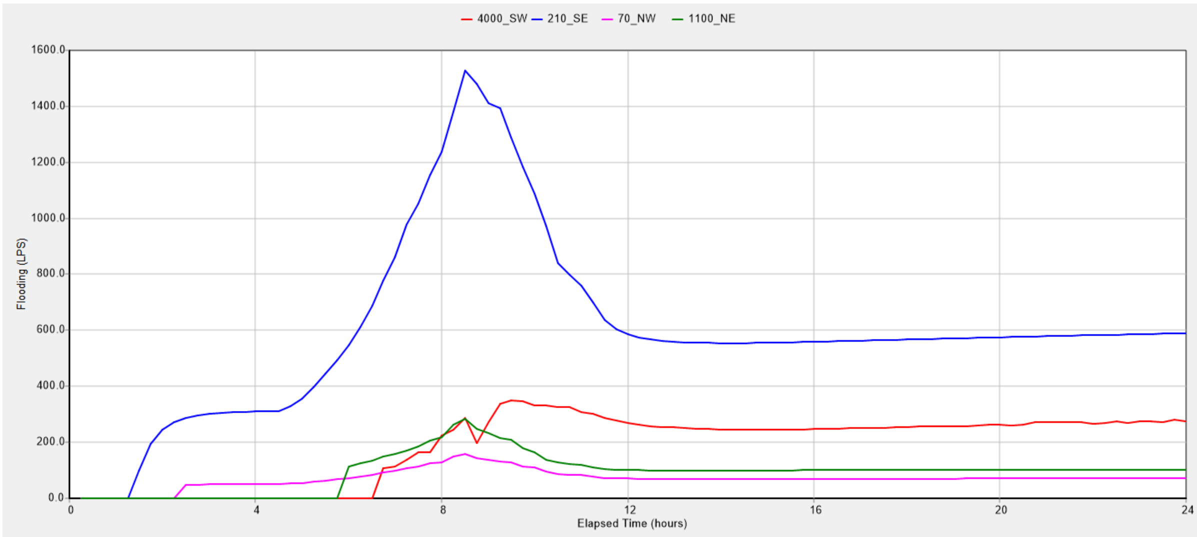


Rain model used to simulate a 100-year event



Volumes and flows of main components after a 24 hour simulation

SWMM Analysis



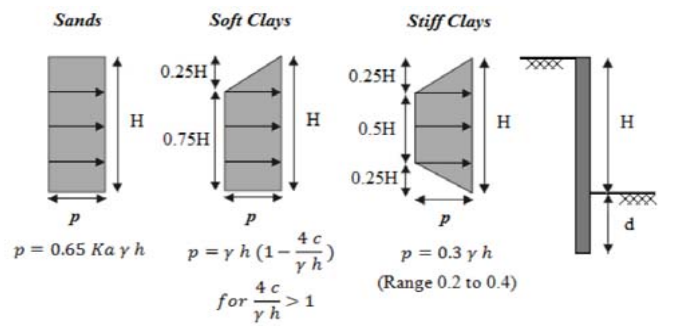
Inflows to the storage tanks after they have reached capacity

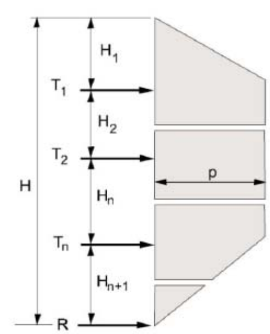
Node	**Hours Flooded**	Maximum Rate LPS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr	Maximum Ponded Depth Meters
210_SE	22.65	1529.53	0	08:31	51.442	0.000
70_NW	21.68	158.61	0	08:30	6.031	0.000
1100_NE	18.03	284.88	0	08:30	8.049	0.000
4000_SW	17.31	362.44	0	09:50	16.212	0.000
T6D-S24	7.22	701.92	0	08:44	2.830	0.000
B6D-N94	3.12	472.66	0	08:31	2.494	0.000
D6D-N106G	1.50	121.16	0	08:31	0.408	0.000
J6D-N127B	1.00	5.36	0	08:30	0.009	0.000
USL-79	0.57	5.13	0	08:30	0.007	0.000
E7D-N108J	0.52	4.91	0	08:30	0.005	0.000
S8D-S210	0.01	1467.71	0	00:00	0.002	0.000
S8D-S299B	0.01	910.97	0	00:00	0.002	0.000

Sub-surface flooding statistics

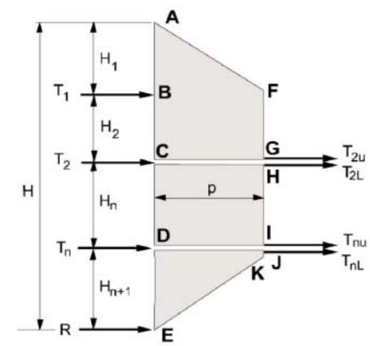
APPENDIX H – GEOTECHNICAL ANALYSIS

Anchor Design





Tributary area method



Hinge method

Assumptions						
Soil Unit Weight, y	18	kN/m^3				
Cohesion, C	0					
Water Table	0	m	Exists below influence zone, ie. Below footing			
H	5	m				
Anchor 1	1.25	m	depth			
Anchor 2	3.125	m	depth			
SPT Range	10-20					
Phi	25					

Soil type	Relative density/Consistency (SPT range)[1]	Estimated ultimate transfer load (kN/m)
Sand and Gravel	Loose (4-10) Medium dense (11-30) Dense (31-50)	145 220 290
Sand	Loose (4-10) Medium dense (11-30) Dense (31-50)	100 145 190
Sand and Silt	Loose (4-10) Medium dense (11-30) Dense (31-50)	70 100 130
Silt-clay mixture with low plasticity or fine micaceous sand or silt mixtures	Stiff (10-20) Hard (21-40)	30 60

Table 1. Presumptive ultimate values of load transfer for preliminary design of small diameter straight shaft gravity-grouted ground anchors in soil.

Calculation			
Pressure, p	27	kN/m^2	0.3*y*H
TH1	47.8125	kN/m	
TH2	59.0625	kN/m	
Transfer Load	30	kN/m	
Bond Length	1.59375	m	TH1
Bond Length	1.96875	m	TH2

Geometry		
Angle	15	Degrees
Length	12.5	m

$$T_{H1} = \left(\frac{2}{3} H_1 + \frac{H_2}{2}\right) p_e \qquad T_{H2} = \left(\frac{H_2}{2} + \frac{2H_3}{3}\right) P_e$$

APPENDIX I – STRUCTURAL ANALYSIS

Structural Design Calculations for Holding Tank A

INPUT	CALCULATION	CONSTANTS

Soil Unit Weight (kN/m3)	18	Concrete Compressive Strength [fc'] (MPa)	30	alpha	0.8	Maximum Steel Strain	0.002
Soil Depth (m)	2	Steel Compressive Strength [fy] (MPa)	400	beta	0.9	Steel Young Modulus (Pa)	2E+11
Length of Tank (m)	6	ϕs	0.85	Maximum Size Aggregate (mm)	20		
Weight of Overburden (kPa)	36	ϕc	0.65	Max Concrete Compressive Strain	0.0035		

Ceiling Slab

Total Tank Width (mm)	6000
Thickness of Slab [h] (mm)	**200**
Approximate Efective Depth [d] (mm)	130
Column-to-Column Width (m)	**3**
Factored Moment [Mf] (kNm)	41
Cover (mm)	75
Efective Depth [d] (mm)	115

Iterative Procedure		
As (mm2)	a (mm)	% Change
1018.10	7.40	-
943.12	6.85	7%
941.09	6.84	0%

Moment Resistance (kNm)	46

Bar Area [Ab] (mm2)	300
Bar Diameter (mm)	20
# of bars	4
Bar Spacing (mm)	60

Min Reinforcement Requirement?	GOOD	Flexural Strength Requirement?	GOOD
Max Bar Spacing Requirement?	GOOD	Crack Control Check?	GOOD
Max Tension Reinforcement Requirement?	GOOD	Max Bar Area Requirement? (TEMP)	GOOD

Temperature Reinforcement

As_min (mm2)	400
S_max (mm)	500
Spacing (mm)	500

Bar Area [TEMP] (mm2)	200
Bar Diameter [TEMP] (mm)	16

SUMMARY	
Tension Rebar	Rebar diameter of 20 mm at 60 mm spacing
Temperature/Shrinkage Rebar	Rebar diameter of 16 mm at 500 mm spacing

Column Design

Unit Weight of Concrete (kN/m3)	22
Weight of Concrete Slab (kN)	66
Number of Columns per Row	**2**
Column Eccentric Load [P] (kN)	141

Column Size (mm2)	**21025**
Side Length (mm)	**145**
Min Reinforcement Ratio	1%
Longitudinal Rebar Area (mm2)	210.25
Bar Diameter (mm)	25
Bar Area (mm)	500
Number of Longitudinal Rebar	**8**
Concrete Cover (mm)	40
Tie Diameter (mm)	11

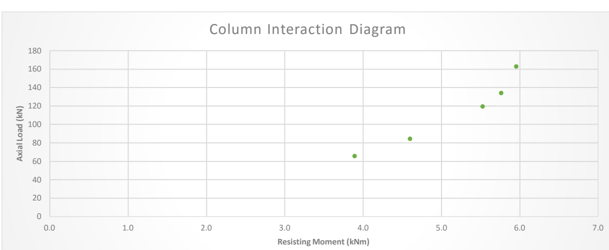
P_r0 (kN)	399
P_rmax (kN)	320
D_1 (mm)	52.5
D_2 (mm)	93
C_b (mm)	59

Transverse Reinforcement

Tie Size Requirement?	GOOD
Tie Spacing (mm)	400

Asad Ijaz: Corner bars bent at 90 degree hooks

Point	1	2	3	4	5
C (mm)	59	66	80	33	42
E_s1	0	0	0	0	0
E_s2	0	0	0	0	0
f_s1 (Pa)	75676	143182	240625	-413636	-175000
f_s2 (Pa)	-400000	-281061	-109375	-1262121	-841667
Cr (N)	119835	134363	162864	67181	85504
Fr_s1 (N)	64	122	205	-352	-149
Fr_s2 (N)	-340	-239	-93	-1073	-715
P_r (kN)	**120**	**134**	**163**	**66**	**85**
Mr_c (Nmm)	5513753	5750728	5944536	3873008	4582993
Mr_s1 (Nmm)	1286	2434	4091	-7032	-2975
Mr_s2 (Nmm)	6800	4778	1859	21456	14308
Mr (kNm)	**5.52**	**5.76**	**5.95**	**3.89**	**4.59**



SUMMARY	
Longitudinal Rebar	Rebar diameter of 25 mm at mm spacing
Transvers Rebar (Tie)	Rebar diameter of 11 mm at 400 mm spacing

Floor Slab

Thickness of Slab [h] (mm)	**100**
Approximate Efective Depth [d] (mm)	30

Weight of Ceiling Slab Per Metre (kN)	11
Weight of Concrete Columns Per Metre (kN)	0.5
Height of Column (m)	3
Total Applied Load Per Metre (kN/m)	47

Factored Moment [Mf] (kNm)	5.9
Cover (mm)	50
Efective Depth [d] (mm)	37.5

Iterative Procedure		
As (mm2)	a (mm)	% Change
646.28	14.09	-
760.09	16.57	18%
803.49	17.51	6%

Moment Resistance (kNm)	10

Bar Area [Ab] (mm2)	500
Bar Diameter (mm)	25
# of bars	2
Bar Spacing (mm)	135
Min Reinforcement Requirement?	GOOD
Max Bar Spacing Requirement?	GOOD
Max Tension Reinforcement Requirement?	GOOD
Flexural Strength Requirement?	GOOD
Crack Control Check?	GOOD
Max Bar Area Requirement? (TEMP)	GOOD

Temperature Reinforcement

As_min (mm2)	200
S_max (mm)	500
Spacing (mm)	1000

Bar Area [TEMP] (mm2)	200
Bar Diameter [TEMP] (mm)	16

SUMMARY	
Tension Rebar	Rebar diameter of 25 mm at 135 mm spacing
Temperature/Shrinkage Rebar	Rebar diameter of 16 mm at 1000 mm spacing

Structural Design Calculations for Holding Tank B

INPUT	CALCULATION	CONSTANTS

Soil Unit Weight (kN/m3)	18	Concrete Compressive Strength [fc'] (MPa)	30	alpha	0.8	Maximum Steel Strain	0.002
Soil Depth (m)	2	Steel Compressive Strength [fy] (MPa)	400	beta	0.9	Steel Young Modulus (Pa)	2E+11
Length of Tank (m)	16	ϕs	0.85	Maximum Size Aggregate (mm)	20		
Weight of Overburden (kPa)	36	ϕc	0.65	Max Concrete Compressive Strain	0.0035		

Ceiling Slab

Total Tank Width (mm)	16000
Thickness of Slab [h] (mm)	300
Approximate Efective Depth [d] (mm)	230
Column-to-Column Width (m)	4
Factored Moment [Mf] (kNm)	72
Cover (mm)	75
Efective Depth [d] (mm)	217

Iterative Procedure		
As (mm2)	a (mm)	% Change
1023.02	5.57	-
932.01	5.08	9%
930.99	5.07	0%

Moment Resistance (kNm)	73

Bar Area [Ab] (mm2)	200		
Bar Diameter (mm)	16		
# of bars	5		
Bar Spacing (mm)	80		
Min Reinforcement Requirement?	GOOD	Flexural Strength Requirement?	GOOD
Max Bar Spacing Requirement?	GOOD	Crack Control Check?	GOOD
Max Tension Reinforcement Requirement?	GOOD	Max Bar Area Requirement? (TEMP)	GOOD

Temperature Reinforcement

As_min (mm2)	600
S_max (mm)	500
Spacing (mm)	333

Bar Area [TEMP] (mm2)	200
Bar Diameter [TEMP] (mm)	16

SUMMARY	
Tension Rebar	Rebar diameter of 16 mm at 80 mm spacing
Temperature/Shrinkage Rebar	Rebar diameter of 16 mm at 333 mm spacing

Column Design

Unit Weight of Concrete (kN/m3)	22
Weight of Concrete Slab (kN)	264
Number of Columns per Row	4
Column Eccentric Load [P] (kN)	210
Column Size (mm2)	25600
Side Length (mm)	160
Min Reinforcement Ratio	1%
Longitudinal Rebar Area (mm2)	256
Bar Diameter (mm)	30
Bar Area (mm)	700
Number of Longitudinal Rebar	8
Concrete Cover (mm)	40
Tie Diameter (mm)	11

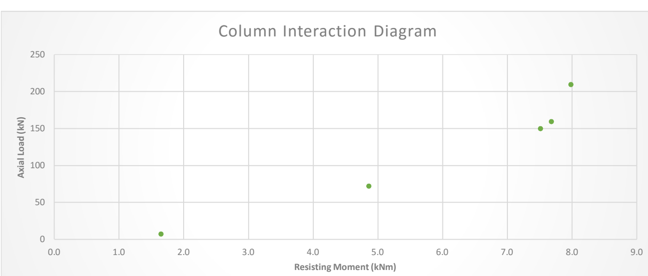
P_r0 (kN)	486
P_rmax (kN)	389
D_1 (mm)	55
D_2 (mm)	105
C_b (mm)	67

Transverse Reinforcement

Tie Size Requirement?	GOOD
Tie Spacing (mm)	400

Asad Ijaz: Corner bars bent at 90 degree hooks

Point	1	2	3	4	5
C (mm)	67	93	71	33	9
E_s1	0	0	0	0	0
E_s2	0	0	0	0	0
f_s1 (Pa)	123810	286022	157746	-466667	-3577778
f_s2 (Pa)	-400000	-90323	-335211	-1527273	-7466667
Cr (N)	150100	208915	159494	74131	20218
Fr_s1 (N)	147	340	188	-555	-4258
Fr_s2 (N)	-476	-107	-399	-1817	-8885
P_r (kN)	150	209	159	72	7
Mr_c (Nmm)	7494784	7970115	7663706	4829648	1535527
Mr_s1 (Nmm)	3683	8509	4693	-13883	-106439
Mr_s2 (Nmm)	11900	2687	9973	45436	222133
Mr (kNm)	7.51	7.98	7.68	4.86	1.65



SUMMARY	
Longitudinal Rebar	Rebar diameter of 30 mm
Transvers Rebar (Tie)	Rebar diameter of 11 mm at 400 mm spacing

Floor Slab

Thickness of Slab [h] (mm)	100
Approximate Efective Depth [d] (mm)	30
Weight of Ceiling Slab Per Metre (kN)	17
Weight of Concrete Columns Per Metre (kN)	0.7
Height of Column (m)	5
Total Applied Load Per Metre (kN/m)	53
Factored Moment [Mf] (kNm)	6.7
Cover (mm)	50
Efective Depth [d] (mm)	37.5

Iterative Procedure		
As (mm2)	a (mm)	% Change
724.46	15.79	-
884.87	19.29	22%
960.85	20.94	9%

Moment Resistance (kNm)	9

Bar Area [Ab] (mm2)	500
Bar Diameter (mm)	25
# of bars	2
Bar Spacing (mm)	135
Min Reinforcement Requirement?	GOOD
Max Bar Spacing Requirement?	GOOD
Max Tension Reinforcement	GOOD
Flexural Strength Requirement?	GOOD
Crack Control Check?	GOOD
Max Bar Area Requirement? (TEMP)	GOOD

Temperature Reinforcement

As_min (mm2)	200
S_max (mm)	500
Spacing (mm)	1000

Bar Area [TEMP] (mm2)	200
Bar Diameter [TEMP] (mm)	16

SUMMARY	
Tension Rebar	Rebar diameter of 25 mm at 135 mm spacing
Temperature/Shrinkage Rebar	Rebar diameter of 16 mm at 1000 mm spacing

Structural Design Calculations for Holding Tank C

INPUT	*CALCULATION*	*CONSTANTS*

Ceiling Slab

Soil Unit Weight (kN/m3)	18	Concrete Compressive Strength [fc'] (MPa)	30	alpha	0.8	Maximum Steel Strain	0.002
Soil Depth (m)	2	Steel Compressive Strength [fy] (MPa)	400	beta	0.9	Steel Young Modulus (Pa)	2E+11
Length of Tank (m)	9	ϕs	0.85	Maximum Size Aggregate (mm)	20		
Weight of Overburden (kPa)	36	ϕc	0.65	Max Concrete Compressive Strain	0.0035		

Total Tank Width (mm)	9000
Thickness of Slab [h] (mm)	**250**
Approximate Efective Depth [d] (mm)	180
Column-to-Column Width (m)	**3**
Factored Moment [Mf] (kNm)	41
Cover (mm)	75
Efective Depth [d] (mm)	167

Iterative Procedure		
As (mm2)	a (mm)	% Change
735.29	5.34	-
671.73	4.88	9%
670.86	4.87	0%

Moment Resistance (kNm)	45

Bar Area [Ab] (mm2)	200		
Bar Diameter (mm)	16		
# of bars	4		
Bar Spacing (mm)	30		
Min Reinforcement Requirement?	**GOOD**	Flexural Strength Requirement?	**GOOD**
Max Bar Spacing Requirement?	**GOOD**	Crack Control Check?	**GOOD**
Max Tension Reinforcement Requirement?	**GOOD**	Max Bar Area Requirement? (TEMP)	**GOOD**

Temperature Reinforcement

As_min (mm2)	500
S_max (mm)	500
Spacing (mm)	400

Bar Area [TEMP] (mm2)	200
Bar Diameter [TEMP] (mm)	16

SUMMARY	
Tension Rebar	Rebar diameter of 16 mm at 30 mm spacing
Temperature/Shrinkage Rebar	Rebar diameter of 16 mm at 400 mm spacing

Column Design

Unit Weight of Concrete (kN/m3)	22
Weight of Concrete Slab (kN)	123.75
Number of Columns per Row	**3**
Column Eccentric Load [P] (kN)	149

Column Size (mm2)	**22500**
Side Length (mm)	**150**
Min Reinforcement Ratio	1%
Longitudinal Rebar Area (mm2)	225
Bar Diameter (mm)	15
Bar Area (mm)	200
Number of Longitudinal Rebar	**8**
Concrete Cover (mm)	20
Tie Diameter (mm)	11

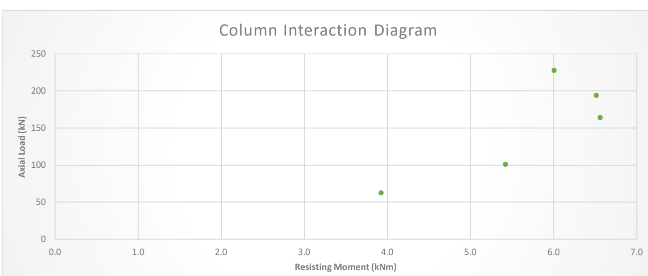
P_r0 (kN)	428
P_rmax (kN)	342
D_1 (mm)	27.5
D_2 (mm)	123
C_b (mm)	78

Transverse Reinforcement

Tie Size Requirement?	GOOD
Tie Spacing (mm)	240

Asad Ijaz:
Corner bars bent at 90 degree hooks

Point	**1**	**2**	**3**	**4**	**5**
C (mm)	78	92	108	48	30
E_s1	0	0	0	0	0
E_s2	0	0	0	0	0
f_s1 (Pa)	0	0	0	298958	58333
f_s2 (Pa)	-400000	-232065	-93981	-1086458	-2158333
Cr (N)	164172	193752	227448	101088	63180
Fr_s1 (N)	0	0	0	102	20
Fr_s2 (N)	-136	-79	-32	-369	-734
P_r (kN)	**164**	**194**	**227**	**101**	**62**
Mr_c (Nmm)	6553832	6510067	6004627	5398099	3885570
Mr_s1 (Nmm)	0	0	0	4828	942
Mr_s2 (Nmm)	6460	3748	1518	17546	34857
Mr (kNm)	**6.56**	**6.51**	**6.01**	**5.42**	**3.92**



SUMMARY	
Longitudinal Rebar	Rebar diameter of 15 mm
Transvers Rebar (Tie)	Rebar diameter of 11 mm at 240 mm spacing

Floor Slab

Thickness of Slab [h] (mm)	**100**
Approximate Efective Depth [d] (mm)	30
Weight of Ceiling Slab Per Metre (kN)	14
Weight of Concrete Columns Per Metre (kN)	0.5
Height of Column (m)	3
Total Applied Load Per Metre (kN/m)	50
Factored Moment [Mf] (kNm)	6.3
Cover (mm)	50
Efective Depth [d] (mm)	44.5

Iterative Procedure		
As (mm2)	a (mm)	% Change
684.16	14.91	-
819.38	17.86	20%
876.68	19.11	7%

Moment Resistance (kNm)	11

Bar Area [Ab] (mm2)	100
Bar Diameter (mm)	11
# of bars	9
Bar Spacing (mm)	30
Min Reinforcement Requirement?	GOOD
Max Bar Spacing Requirement?	GOOD
Max Tension Reinforcement	GOOD
Flexural Strength Requirement?	GOOD
Crack Control Check?	GOOD
Max Bar Area Requirement? (TEMP)	GOOD

Temperature Reinforcement

As_min (mm2)	200
S_max (mm)	500
Spacing (mm)	1000

Bar Area [TEMP] (mm2)	200
Bar Diameter [TEMP] (mm)	16

SUMMARY	
Tension Rebar	Rebar diameter of 11 mm at 30 mm spacing
Temperature/Shrinkage Rebar	Rebar diameter of 16 mm at 1000 mm spacing

Structural Design Calculations for Holding Tank D

INPUT	CALCULATION	CONSTANTS

Soil Unit Weight (kN/m3)	18	Concrete Compressive Strength [fc'] (MPa)	30	alpha	0.8	Maximum Steel Strain	0.002
Soil Depth (m)	2	Steel Compressive Strength [fy] (MPa)	400	beta	0.9	Steel Young Modulus (Pa)	2E+11
Length of Tank (m)	30	ϕs	0.85	Maximum Size Aggregate (mm)	20		
Weight of Overburden (kPa)	36	ϕc	0.65	Max Concrete Compressive Strain	0.0035		

Ceiling Slab

Total Tank Width (mm)	30000
Thickness of Slab [h] (mm)	300
Approximate Efective Depth [d] (mm)	230
Column-to-Column Width (m)	3
Factored Moment [Mf] (kNm)	41
Cover (mm)	75
Efective Depth [d] (mm)	217

Iterative Procedure		
As (mm2)	a (mm)	% Change
575.45	4.18	-
522.65	3.80	9%
522.21	3.79	0%

Moment Resistance (kNm)	44

Bar Area [Ab] (mm2)	200		
Bar Diameter (mm)	16		
# of bars	3		
Bar Spacing (mm)	80		
Min Reinforcement Requirement?	GOOD	Flexural Strength Requirement?	GOOD
Max Bar Spacing Requirement?	GOOD	Crack Control Check?	GOOD
Max Tension Reinforcement Requirement?	GOOD	Max Bar Area Requirement? (TEMP)	GOOD

Temperature Reinforcement

As_min (mm2)	600
S_max (mm)	500
Spacing (mm)	333

Bar Area [TEMP] (mm2)	200
Bar Diameter [TEMP] (mm)	16

SUMMARY	
Tension Rebar	Rebar diameter of 16 mm at 80 mm spacing
Temperature/Shrinkage Rebar	Rebar diameter of 16 mm at 333 mm spacing

Column Design

Unit Weight of Concrete (kN/m3)	22
Weight of Concrete Slab (kN)	495
Number of Columns per Row	10
Column Eccentric Load [P] (kN)	158

Column Size (mm2)	21025
Side Length (mm)	145
Min Reinforcement Ratio	1%
Longitudinal Rebar Area (mm2)	210.25
Bar Diameter (mm)	25
Bar Area (mm)	500
Number of Longitudinal Rebar	8
Concrete Cover (mm)	40
Tie Diameter (mm)	11

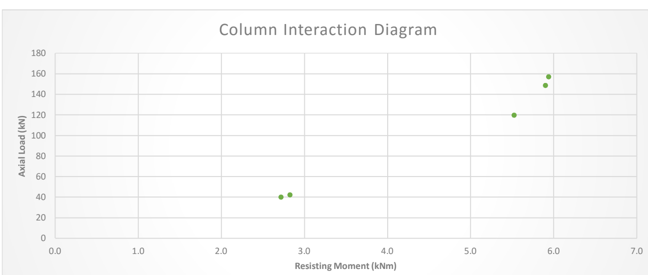
P_r0 (kN)	399
P_rmax (kN)	320
D_1 (mm)	52.5
D_2 (mm)	93
C_b (mm)	59

Transverse Reinforcement

Tie Size Requirement?	GOOD
Tie Spacing (mm)	400

Asad Ijaz: Corner bars bent at 90 degree hooks

Point	1	2	3	4	5
C (mm)	59	77	73	22	21
E_s1	0	0	0	0	0
E_s2	0	0	0	0	0
f_s1 (Pa)	75676	222727	196575	-970455	-1050000
f_s2 (Pa)	-400000	-140909	-186986	-2243182	-2383333
Cr (N)	119835	156757	148613	44788	42752
Fr_s1 (N)	64	189	167	-825	-893
Fr_s2 (N)	-340	-120	-159	-1907	-2026
P_r (kN)	120	157	149	42	40
Mr_c (Nmm)	5513753	5933237	5892521	2803704	2695501
Mr_s1 (Nmm)	1286	3786	3342	-16498	-17850
Mr_s2 (Nmm)	6800	2395	3179	38134	40517
Mr (kNm)	5.52	5.94	5.90	2.83	2.72



SUMMARY	
Longitudinal Rebar	Rebar diameter of 25 mm
Transvers Rebar (Tie)	Rebar diameter of 11 mm at 400 mm spacing

Floor Slab

Thickness of Slab [h] (mm)	100
Approximate Efective Depth [d] (mm)	30

Weight of Ceiling Slab Per Metre (kN)	17
Weight of Concrete Columns Per Metre (kN)	0.7
Height of Column (m)	4.5
Total Applied Load Per Metre (kN/m)	53

Factored Moment [Mf] (kNm)	6.6
Cover (mm)	50
Efective Depth [d] (mm)	44.5

Iterative Procedure		
As (mm2)	a (mm)	% Change
724.32	15.79	-
884.64	19.28	22%
960.55	20.94	9%

Moment Resistance (kNm)	12

Bar Area [Ab] (mm2)	100
Bar Diameter (mm)	11
# of bars	10
Bar Spacing (mm)	175
Min Reinforcement Requirement?	GOOD
Max Bar Spacing Requirement?	GOOD
Max Tension Reinforcement	GOOD
Flexural Strength Requirement?	GOOD
Crack Control Check?	GOOD
Max Bar Area Requirement? (TEMP)	GOOD

Temperature Reinforcement

As_min (mm2)	200
S_max (mm)	500
Spacing (mm)	1000

Bar Area [TEMP] (mm2)	200
Bar Diameter [TEMP] (mm)	16

SUMMARY	
Tension Rebar	Rebar diameter of 11 mm at 175 mm spacing
Temperature/Shrinkage Rebar	Rebar diameter of 16 mm at 1000 mm spacing

Sample Calculations – Structural Designs

Slab Design

Approximate Effective Depth:

$$d_{approx} = h - 70 \text{ [mm]}$$

Factored Load [Clause NBCC2005 C1.4.1.3.2]:

$$w = 1.25\text{DL}+1.5\text{LL}$$

Factored Moment Resistance:

$$M_f = \frac{wl^2}{8}$$

Actual Effective Depth:

$$d = h - c - \frac{d_b}{2}$$

Approximated Area of Steel Rebar:

$$(A_s)_{approx} = \frac{M_f}{f_y \emptyset_s \left(d - \frac{a}{2}\right)}$$

Thickness of Tension Block:

$$a = \frac{f_y \emptyset_s (A_s)_{approx}}{\alpha b \emptyset_c f'_c}$$

Resisting Moment:

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

Rebar Spacing:

$$s = \text{Max}\begin{bmatrix} 1.4d_b \\ 1.4\text{MSA} \\ 30 \text{ mm} \end{bmatrix}$$

Crack Control Parameter:

$$z = 0.6 f_y \sqrt[3]{2s(h-d)^2}$$

Maximum Tension Reinforcement Check [Clause A23.3 C1.10.5.2]:

$$\frac{a/\beta}{d} \leq \frac{700}{700 + f_y}$$

Minimum Reinforcement Required [Clause A23.3 C1.7.8.1]:

$$A_s \geq 0.002bh$$

Maximum Rebar Spacing Required [Clause A23.3 C1.7.4.1.2]:

$$s \leq \text{Min} \begin{bmatrix} 500 \text{ mm} \\ 3h \end{bmatrix}$$

Flexural Strength Requirement [Clause A23.3 C1.8.1.3]:

$$M_r \geq M_f$$

Crack Control Parameter Requirement [Clause A23.3 C1.10.6.1]:

$$z < 25{,}000 \ {}^{\text{N}}/_{\text{mm}} \ \text{(For Exterior Exposure)}$$

Maximum Rebar Area Requirement (For Temperature Rebar)

[Clause A23.3 C1.7.8.1 and C1.7.8.3]:

$$\frac{1000(A_b)_{\text{TEMP}}}{s_{\text{TEMP}}} \geq (A_{min})_{\text{TEMP}}$$

Column Design

Number of Columns/Row

$$n = \frac{\text{Length of Tank}}{\text{Column-to-Column Width}}$$

Column Size

$$A_c = {l_s}^2 \text{ (For Square Columns)}$$

Longitudinal Rebar Area

$$A_l = rA_c$$

Rebar Spacing:

$$s = \text{Max}\begin{bmatrix} 1.4d_b \\ 1.4\text{MSA} \\ 30\text{ mm} \end{bmatrix}$$

Tie Spacing:

$$s_{\text{tie}} = \text{Min}\begin{bmatrix} 16d_b \\ 48d_{\text{tie}} \\ 400\text{ mm} \end{bmatrix}$$

Tie Size Requirement [Clause A23.3 C1.7.6.5.1 and C1.7.6.5.2]:

$$d_{\text{tie}} > 0.3d_b$$

Glossary

h = Height of Slab

DL = Dead Load

LL = Live Load

l = Length of Slab Section (Typically 1 m)

c = Concrete Cover (Typically 75 mm)

f_y = 400 Mpa (Steel Yield Strength)

$\emptyset_s = 0.85$

$\emptyset_c = 0.65$

b = Width of Slab Section

f'_c = 30 MPa (Concrete Compressive Strength)

$\alpha = 0.80$

$\beta = 0.90$

s = Rebar Spacing

A_b = Area of Rebar

d_b = Diameter of Rebar

MSA = Maximum Size Aggregate (Typically 20 mm)

r = Minimum Reinforcement Ratio (Typically 1-4%)

l_s = Side Length (For square columns)

APPENDIX J – COST ESTIMATE: DETENTION FACILITIES

UBC SOUTH CAMPUS STORMWATER MANAGEMENT DETENTION FACILITIES

DETAILED DESIGN

COST ESTIMATE SUMMARY TABLE

	Currency: CAD-Canada-Dollar	March 31, 2016				
	Contractor Direct		$	1,843,021		
	Contractor Indirect		$	517,126		
A	**Contractor Direct and Indirect**		**$**	**2,360,000**	$	2,360,000
% of A	Contractor Escalation (%)	2.5%	$	59,000		
% of A	Contractor Contingency (%)	6.0%	$	141,600		
% of A	Contractor Bonding (%)	1.0%	$	23,600		
% of A	Contractor Insurance (%)	1.0%	$	23,600		
B	**Additional Contractor D & I**		**$**	**248,000**	$	248,000
C	**Project Direct Sub-Total**				**$**	**2,608,000**
% of C	Overhead	5.0%			$	130,000
% of C	Profit	15.0%			$	391,000
D	**Total Project Direct and Indirect**				**$**	**3,129,000**
% of D	Project Management Cost	7.0%	$	219,030		
% of D	Design Engineering Cost	4.0%	$	125,160		
% of D	Site Investigations Cost	1.0%	$	31,290		
E	**EPCM**		**$**	**375,000**	$	375,000
F	**Total Project (Direct, Indirect, & EPCM)**				**$**	**3,504,000**
% of F	Owner Cost	7.5%	$	262,800		
% of F	Owner Contingency	15.0%	$	525,600		
G	**Total Owner and Contingency:**		**$**	**788,000**	$	788,000
H	**Total Initial Capital: Unescalated** (Q2 2016)				**$**	**4,292,000**

Note: Subtotals and Totals rounded to 1,000

UBC SOUTH CAMPUS STORMWATER MANAGEMENT
DETENTION FACILITIES
DETAILED COST ESTIMATE

DATE: 2016-03-31

SUBDIVISION	SUBDIVISION TITLE	ITEM	DESCRIPTION	QUANTITY	SUBTOTAL ($)	TOTAL
		DIVISION 01 – GENERAL CONDITIONS				
01145	Construction Safety					$ 64,506
		First Aid Supplies		0.5 % OF DIR	9,215	
		PPE and General Safety		0.5 % OF DIR	9,215	
		Health and Safety Signage		0.5 % OF DIR	9,215	
		Traffic Management		2.0 % OF DIR	36,860	
01310	Project Management and Coordination					$ 308,000
		Project Manager	One for duration of project	5.6 MONTH	84,000	
		Project Coordinator	One for duration of project	5.6 MONTH	44,800	
		Site Superintendent	One for duration of project	5.6 MONTH	67,200	
		Chief Safety Officer / First Aid	One for duration of project	5.6 MONTH	56,000	
		Foreman	One for duration of project	5.6 MONTH	56,000	
01352	Environmental Procedures					$ 28,000
		Environmental Maintenance	General site maintenance	5.6 MONTH	28,000	
01410	Regulatory Requirements					$ 5,000
		City Permits		1.0 LS	5,000	
01500	Temporary Facilities and Controls					$ 111,621
		Site Office	Mobilization/demobilization	3.0 EA	11,250	
		Site Office	Monthly rental	5.6 MONTH	8,400	
		Tool Shed	Mobilization/demobilization	3.0 EA	6,000	
		Tool Shed	Monthly rental	5.6 MONTH	4,480	
		Temporary Fencing	Monthly rental	5.6 MONTH	5,600	
		Temporary Signage	Allowance	1.0 LS	5,000	
		Temporary Power Setup for Site	Allowance	1.0 LS	10,000	
		Misc. Contractor Facilities and Controls	Allowance	1.0 % OF DIR	18,430	
		Waste Management	Monthly fee	5.6 MONTH	5,600	
		Small Tools	Monthly rental	2.0 % OF DIR	36,860	
DIVISION 01 – TOTAL						$ 517,126
		DIVISION 02 – SITEWORK				
02014	Tree Preservation					$ 10,000
		Tree Preservation		1 LS	10,000	
02100	Site Preparation					$ 110,000
		Layout and Survey	Detention Tanks and Dry Pond	1 LS	110,000	
02300	Earthworks					$ 1,189,642
		Tank A	Soil Removal - Excavation	149 M3	2,099	
			Soil Removal - Trucking	149 M3	3,720	
			Soil Removal - Disposal	149 M3	2,678	
			Soil Anchors	22 EA	22,000	
			Fill Material - Source Material	18 M3	360	
			Fill Material - Trucking	18 M3	203	

UBC SOUTH CAMPUS STORMWATER MANAGEMENT
DETENTION FACILITIES
DETAILED COST ESTIMATE

DATE: 2016-03-31

SUBDIVISION	SUBDIVISION TITLE	ITEM	DESCRIPTION	QUANTITY	SUBTOTAL ($)	TOTAL
			Fill Material - Placing	18 M3	258	
		Tank B	Soil Removal - Excavation	1,743 M3	24,585	
			Soil Removal - Trucking	1,743 M3	43,573	
			Soil Removal - Disposal	1,743 M3	31,372	
			Soil Anchors	128 EA	128,000	
			Fill Material - Source Material	154 M3	3,080	
			Fill Material - Trucking	154 M3	1,733	
			Fill Material - Placing	154 M3	2,207	
		Tank C	Soil Removal - Excavation	371 M3	5,232	
			Soil Removal - Trucking	371 M3	9,273	
			Soil Removal - Disposal	371 M3	6,676	
			Soil Anchors	36 EA	36,000	
			Fill Material - Source Material	49 M3	980	
			Fill Material - Trucking	49 M3	551	
			Fill Material - Placing	49 M3	702	
		Tank D	Soil Removal - Excavation	5,384 M3	75,947	
			Soil Removal - Trucking	5,384 M3	134,603	
			Soil Removal - Disposal	5,384 M3	96,914	
			Soil Anchors	240 EA	240,000	
			Fill Material - Source Material	540 M3	10,800	
			Fill Material - Trucking	540 M3	6,075	
			Fill Material - Placing	540 M3	7,737	
		Dry Pond	Soil Removal - Excavation	360 M3	5,078	
			Soil Removal - Trucking	360 M3	9,000	
			Soil Removal - Disposal	360 M3	6,480	
		Storm Draininage	Soil Removal - Excavation	2,763 M3	38,974	
			Soil Removal - Trucking	2,763 M3	69,075	
			Soil Removal - Disposal	2,763 M3	49,734	
			Fill Material - Source Material	2,500 M3	50,000	
			Fill Material - Trucking	2,500 M3	28,125	
			Fill Material - Placing	2,500 M3	35,820	
02720	Storm Drainage					$ 56,768
		Pipes (Supply)	Tank A	63 M	1,337	
			Tank B	18 M	382	
			Tank C	21 M	446	
			Tank D	60 M	1,273	
			Dry Pond	145 M	3,077	
		Pipes (Installation)	Tank A	63 M	3,130	
			Tank B	18 M	894	
			Tank C	21 M	1,043	
			Tank D	60 M	2,981	

UBC SOUTH CAMPUS STORMWATER MANAGEMENT
DETENTION FACILITIES
DETAILED COST ESTIMATE

DATE: 2016-03-31

SUBDIVISION	SUBDIVISION TITLE	ITEM	DESCRIPTION	QUANTITY	SUBTOTAL ($)	TOTAL
			Dry Pond	145 M	7,204	
		Manholes (Install and Supply)	Tank A	1 EA	5,000	
			Tank B	2 EA	10,000	
			Tank C	1 EA	5,000	
			Tank D	3 EA	15,000	
02920	Clearing and Grubbing					$ 10,000
		Clearing and Grubbing	Entire project	1 LS	10,000	
02930	Planting of Trees, Shrubs and Groundcover					$ 5,000
		Trees, Shrubs, and Groundcover (Supply and Install)	Entire project	1 LS	5,000	
02935	Sodded Lawns					$ 14,010
		Sodded Lawn (Supply and Install)	Tank A	42 M2	315	
			Tank B	289 M2	2,168	
			Tank C	100 M2	750	
			Tank D	900 M2	6,750	
			Dry Pond	537 M2	4,028	
02970	Hard Landscaping					$ 70,000
		Hard Landscaping	Entire project	1 LS	70,000	
DIVISION 02 – TOTAL						$ 1,465,420
DIVISION 03 – CONCRETE						
03100	Concrete Forms and Accessories					$ 9,339
		Formwork	Tank A - Columns	5 EA	146	
			Tank B - Columns	51 EA	1,434	
			Tank C - Columns	16 EA	454	
			Tank D - Columns	261 EA	7,306	
03200	Concrete Reinforcement					$ 97,925
		Rebar (Supply and Install)	Tank A and oil/water separator tank	1,203 KG	3,187	
			Tank B and oil/water separator tank	11,426 KG	30,278	
			Tank C and oil/water separator tank	2,933 KG	7,773	
			Tank D and oil/water separator tank	21,391 KG	56,687	
03300	Cast-In-Place Concrete					$ 35,498
		Tank A	Supply	15 M3	1,088	
			Place/Finish Shotcrete	11 M3	436	
			Place/Finish Base	3 M3	113	
		Tank B	Supply	82 M3	6,140	
			Place/Finish Shotcrete	52 M3	2,074	
			Place/Finish Base	28 M3	983	
		Tank C	Supply	28 M3	2,070	
			Place/Finish Shotcrete	18 M3	724	
			Place/Finish Base	9 M3	310	
			Supply	193 M3	14,496	

UBC SOUTH CAMPUS STORMWATER MANAGEMENT
DETENTION FACILITIES
DETAILED COST ESTIMATE

DATE: 2016-03-31

SUBDIVISION	SUBDIVISION TITLE	ITEM	DESCRIPTION	QUANTITY	SUBTOTAL ($)	TOTAL
		Tank D	Place/Finish Shotcrete	88 M3	3,528	
			Place/Finish Base	99 M3	3,536	
03400	Pre-Cast Concrete					$ 166,530
		Panels for Top of Tanks (Supply and Install)	Tank A	2 EA	5,261	
			Tank B	6 EA	28,750	
			Tank C	3 EA	16,446	
			Tank D	10 EA	101,072	
		Oil/Water Separator Box System (Complete)	Tank A	1 EA	3,750	
			Tank B	1 EA	3,750	
			Tank C	1 EA	3,750	
			Tank D	1 EA	3,750	
DIVISION 03 – TOTAL						$ 309,292
DIVISION 07 – THERMAL AND MOISTURE PROTECTION						
07100	Subgrade Waterproofing					$ 53,520
		Tank Lining / Waterproofing (Supply and Install)	Tank A and oil/water separator tank	126 M2	1,890	
			Tank B and oil/water separator tank	832 M2	12,480	
			Tank C and oil/water separator tank	270 M2	4,050	
			Tank D and oil/water separator tank	2,340 M2	35,100	
07900	Sealants					$ 14,790
		Sealing Precast Concrete Panels (Supply and Install)	Tank A	15 M	450	
			Tank B	112 M	3,360	
			Tank C	36 M	1,080	
			Tank D	330 M	9,900	
DIVISION 07 – TOTAL						$ 50,470

CONTRACTOR DIRECT - TOTAL	$ 1,843,021
CONTRACTOR INDIRECT - TOTAL	$ 517,126

APPENDIX K – COST ESTIMATE: ROADWORKS

SMC ENGINEERING

UBC

UBC SOUTH CAMPUS STORMWATER MANAGEMENT
ROADWORKS (PERMEABLE ASPHALT)
DETAILED DESIGN
COST ESTIMATE SUMMARY TABLE

	Currency: CAD-Canada-Dollar	March 31, 2016				
	Contractor Direct		$	2,896,293		
	Contractor Indirect		$	316,779		
A	**Contractor Direct and Indirect**		**$**	**3,213,000**	$	3,213,000
% of A	Contractor Escalation (%)	2.5%	$	80,325		
% of A	Contractor Contingency (%)	6.0%	$	192,780		
% of A	Contractor Bonding (%)	1.0%	$	32,130		
% of A	Contractor Insurance (%)	1.0%	$	32,130		
B	**Additional Contractor D & I**		**$**	**337,000**	$	337,000
C	**Project Direct Sub-Total**				**$**	**3,550,000**
% of C	Overhead	5.0%			$	178,000
% of C	Profit	15.0%			$	533,000
D	**Total Project Direct and Indirect**				**$**	**4,261,000**
% of D	Project Management Cost	7.0%	$	298,270		
% of D	Design Engineering Cost	4.0%	$	170,440		
% of D	Site Investigations Cost	1.0%	$	42,610		
E	**EPCM**		**$**	**511,000**	$	511,000
F	**Total Project (Direct, Indirect, & EPCM)**				**$**	**4,772,000**
% of F	Owner Cost	7.5%	$	357,900		
% of F	Owner Contingency	15.0%	$	715,800		
G	**Total Owner and Contingency:**		**$**	**1,074,000**	$	1,074,000
H	**Total Initial Capital: Unescalated** (Q2 2016)				**$**	**5,846,000**

Note: Subtotals and Totals rounded to 1,000

UBC SOUTH CAMPUS STORMWATER MANAGEMENT
ROADWORKS (PERMEABLE ASPHALT)
DETAILED COST ESTIMATE
DATE: 2016-03-31

SUBDIVISION	SUBDIVISION TITLE	ITEM	DESCRIPTION	QUANTITY	SUBTOTAL ($)	TOTAL
DIVISION 01 – GENERAL CONDITIONS						
01145	Construction Safety					$ 101,370
		First Aid Supplies		0.5 % OF DIR	14,481	
		PPE and General Safety		0.5 % OF DIR	14,481	
		Health and Safety Signage		0.5 % OF DIR	14,481	
		Traffic Management		2.0 % OF DIR	57,926	
01310	Project Management and Coordination					$ 88,800
		Project Manager	One for duration of project	2.4 MONTH	36,000	
		Site Superintendent	One for duration of project	2.4 MONTH	28,800	
		Foreman / First Aid	One for duration of project	2.4 MONTH	24,000	
01352	Environmental Procedures					$ 8,400
		Environmental Maintenance	General site maintenance	2.4 MONTH	8,400	
01410	Regulatory Requirements					$ 5,000
		City Permits		1.0 LS	5,000	
01500	Temporary Facilities and Controls					$ 113,209
		Site Office	Mobilization/demobilization	2.0 EA	4,800	
		Site Office	Monthly rental	2.4 MONTH	3,600	
		Tool Shed	Mobilization/demobilization	2.0 EA	2,400	
		Tool Shed	Monthly rental	2.4 MONTH	1,920	
		Temporary Fencing	Monthly rental	2.4 MONTH	1,200	
		Temporary Signage	Allowance	1.0 LS	5,000	
		Temporary Power Setup for Site	Allowance	1.0 LS	5,000	
		Misc. Contractor Facilities and Controls	Allowance	1.0 % OF DIR	28,963	
		Waste Management	Monthly fee	2.4 MONTH	2,400	
		Small Tools	Monthly rental	2.0 % OF DIR	57,926	
DIVISION 01 – TOTAL						$ 316,779
DIVISION 02 – SITEWORK						
02005	Road					$ 2,467,253
		Subgrade Layer	Material	12,220 M3	195,520	
			Trucking	12,220 M3	137,475	
			Install/Laydown	12,220 M3	152,493	
		RoaDrain System (Drainage System)	Material	20,000 M2	60,000	
			Install/Laydown	20,000 M2	16,562	
		Asphalt Layer	Supply/Install	12,600 TON	1,890,000	
		Line Painting		19,003 M	15,203	
02100	Site Preparation					$ 50,000
		Layout and Survey	Road	1 LS	50,000	
02200	Demolition					$ 379,041
		Roadway	Milling of Asphalt	42,000 M2	240,441	
			Material Removal (Trucking)	6,300 M3	126,000	

UBC SOUTH CAMPUS STORMWATER MANAGEMENT

ROADWORKS (PERMEABLE ASPHALT)

DETAILED COST ESTIMATE

DATE: 2016-03-31

SUBDIVISION	SUBDIVISION TITLE	ITEM	DESCRIPTION	QUANTITY	SUBTOTAL ($)	TOTAL
			Material Removal (Disposal)	6,300 M3	12,600	
DIVISION 02 – TOTAL						$ 2,896,293

CONTRACTOR DIRECT - TOTAL	$ 2,896,293
CONTRACTOR INDIRECT - TOTAL	$ 316,779

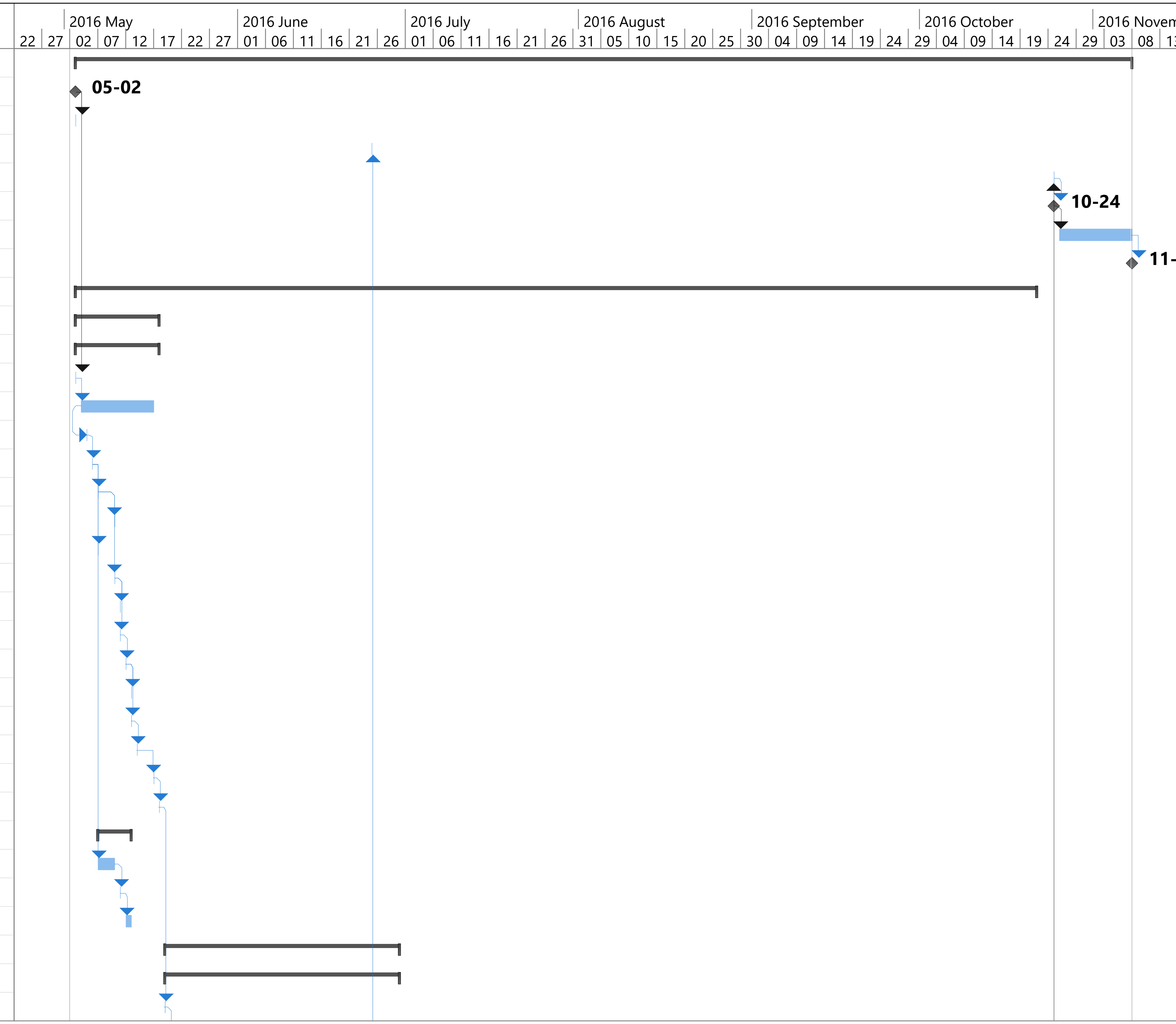
APPENDIX L – CONSTRUCTION SCHEDULE: DETENTION FACILITIES

PHASING SEQUENCE – DETENTION FACILITIES

Figure: Phasing sequence – detention facilities
Source: Digital Image. David Grant. March 31, 2016. Adapted from <www.google.com>.

UBC South Campus Stormwater Management
Detention Facilities
Construction Schedule

ID	Task Name	Duration	Start	Finish
1	**UBC SOUTH CAMPUS STORMWATER MANAGEMENT**	**131 days**	**Mon 16-05-02**	**Mon 16-11-07**
2	Project Start	0 days	Mon 16-05-02	Mon 16-05-02
3	Mobilization	1 day	Mon 16-05-02	Mon 16-05-02
4	Secondary Mobilization	1 day	Fri 16-06-24	Fri 16-06-24
5	Demobilization	1 day	Mon 16-10-24	Mon 16-10-24
6	Project Completion (w/o Contingency)	0 days	Mon 16-10-24	Mon 16-10-24
7	Contingency	10 days	Tue 16-10-25	Mon 16-11-07
8	Project Completion (w/ Contingency)	0 days	Mon 16-11-07	Mon 16-11-07
9	**DETENTION FACILITIES**	**120 days**	**Mon 16-05-02**	**Fri 16-10-21**
10	**PHASE 1 - TANK A**	**12 days**	**Mon 16-05-02**	**Tue 16-05-17**
11	**Main Tank Works**	**12 days**	**Mon 16-05-02**	**Tue 16-05-17**
12	Clearing and Grubbing + Tree Protection	1 day	Mon 16-05-02	Mon 16-05-02
13	Site Survey and Layout	10 days	Tue 16-05-03	Mon 16-05-16
14	Excavation	1 day	Wed 16-05-04	Wed 16-05-04
15	Soil Anchor Installation	1 day	Thu 16-05-05	Thu 16-05-05
16	Wall Rebar (North and East)	1 day	Fri 16-05-06	Fri 16-05-06
17	Shotcrete Walls (North and East)	1 day	Mon 16-05-09	Mon 16-05-09
18	Wall Rebar (South and West)	1 day	Fri 16-05-06	Fri 16-05-06
19	Shotcrete Walls (South and West)	1 day	Mon 16-05-09	Mon 16-05-09
20	Pad and Column Rebar	1 day	Tue 16-05-10	Tue 16-05-10
21	Column Forming	1 day	Tue 16-05-10	Tue 16-05-10
22	Pad and Column Pour	1 day	Wed 16-05-11	Wed 16-05-11
23	Oil/Water Separator Install	1 day	Thu 16-05-12	Thu 16-05-12
24	Manhole Install	1 day	Thu 16-05-12	Thu 16-05-12
25	Pre-Cast Cover Install	1 day	Fri 16-05-13	Fri 16-05-13
26	Backfill	1 day	Mon 16-05-16	Mon 16-05-16
27	Landscaping	1 day	Tue 16-05-17	Tue 16-05-17
28	**Pipe Network Tie-In**	**5 days**	**Fri 16-05-06**	**Thu 16-05-12**
29	Pipe Network Excavation	2 days	Fri 16-05-06	Mon 16-05-09
30	Pipe Network Install	1 day	Tue 16-05-10	Tue 16-05-10
31	Pipe Network Backfill	2 days	Wed 16-05-11	Thu 16-05-12
32	**PHASE 2 - TANK B**	**30 days**	**Wed 16-05-18**	**Wed 16-06-29**
33	**Main Tank Works**	**30 days**	**Wed 16-05-18**	**Wed 16-06-29**
34	Clearing and Grubbing + Tree Protection	1 day	Wed 16-05-18	Wed 16-05-18

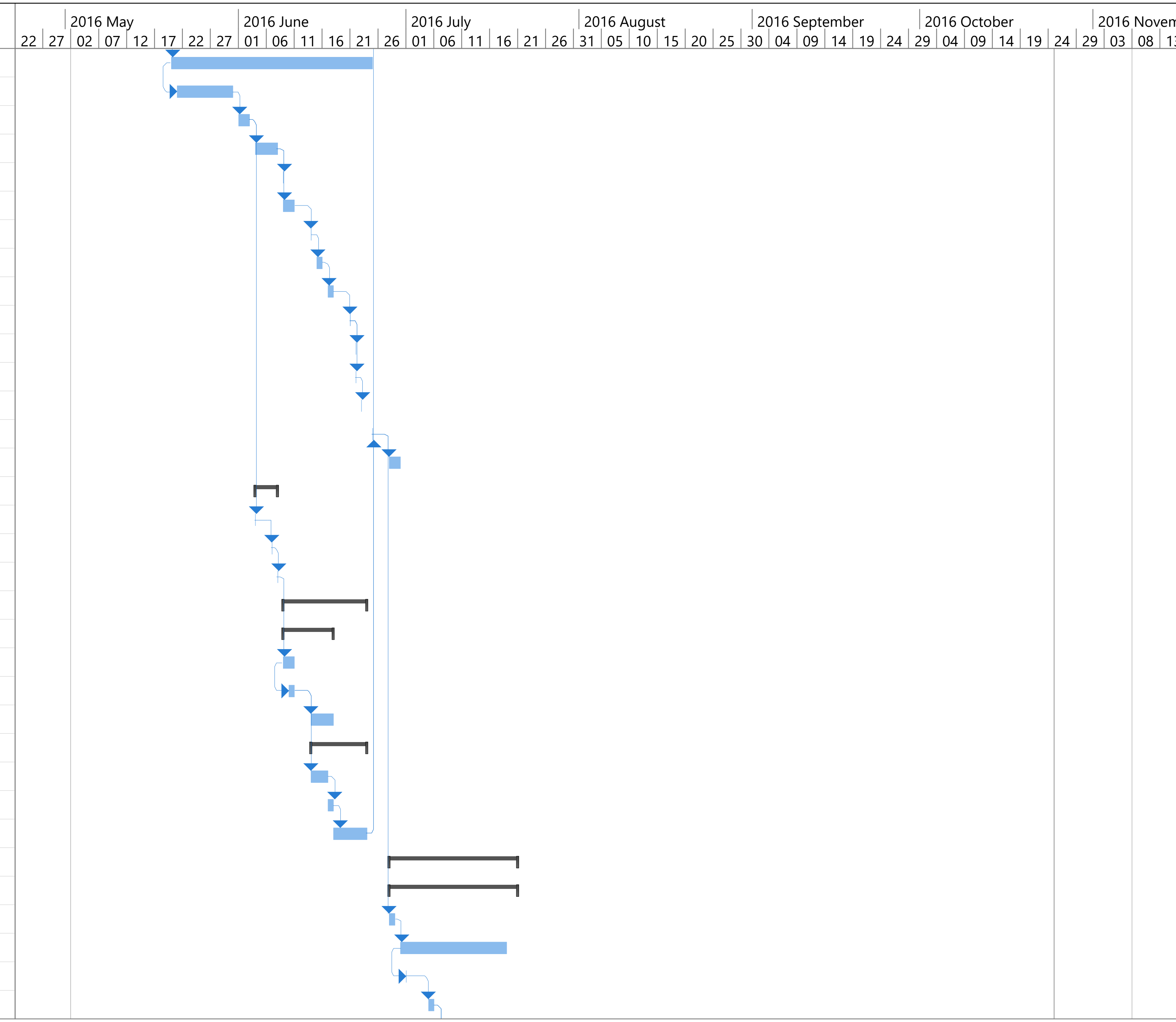


Date: Thu 16-03-31
Reviewed By: HG

Task		Project Summary		Manual Task		Start-only		Deadline	
Split		Inactive Task		Duration-only		Finish-only		Progress	
Milestone		Inactive Milestone		Manual Summary Rollup		External Tasks		Manual Progress	
Summary		Inactive Summary		Manual Summary		External Milestone			

UBC South Campus Stormwater Management
Detention Facilities
Construction Schedule

ID	Task Name	Duration	Start	Finish
35	Site Survey and Layout	26 days	Thu 16-05-19	Fri 16-06-24
36	Excavation	6 days	Fri 16-05-20	Mon 16-05-30
37	Soil Anchor Installation	3 days	Tue 16-05-31	Thu 16-06-02
38	Wall Rebar (North and East)	3 days	Fri 16-06-03	Tue 16-06-07
39	Shotcrete Walls (North and East)	1 day	Wed 16-06-08	Wed 16-06-08
40	Wall Rebar (South and West)	3 days	Wed 16-06-08	Fri 16-06-10
41	Shotcrete Walls (South and West)	1 day	Mon 16-06-13	Mon 16-06-13
42	Pad and Column Rebar	2 days	Tue 16-06-14	Wed 16-06-15
43	Column Forming	2 days	Thu 16-06-16	Fri 16-06-17
44	Pad and Column Pour	1 day	Mon 16-06-20	Mon 16-06-20
45	Oil/Water Separator Install	1 day	Tue 16-06-21	Tue 16-06-21
46	Manhole Install	1 day	Tue 16-06-21	Tue 16-06-21
47	Pre-Cast Cover Install	1 day	Wed 16-06-22	Wed 16-06-22
48	Backfill	1 day	Fri 16-06-24	Fri 16-06-24
49	Landscaping	3 days	Mon 16-06-27	Wed 16-06-29
50	**Pipe Network Tie-In**	**3 days**	**Fri 16-06-03**	**Tue 16-06-07**
51	Pipe Network Excavation	1 day	Fri 16-06-03	Fri 16-06-03
52	Pipe Network Install	1 day	Mon 16-06-06	Mon 16-06-06
53	Pipe Network Backfill	1 day	Tue 16-06-07	Tue 16-06-07
54	**PHASE 3 - DRY POND**	**12 days**	**Wed 16-06-08**	**Thu 16-06-23**
55	**Dry Pond Main Works**	**8 days**	**Wed 16-06-08**	**Fri 16-06-17**
56	Dry Pond Site Survey and Layout	3 days	Wed 16-06-08	Fri 16-06-10
57	Dry Pond Excavation	2 days	Thu 16-06-09	Fri 16-06-10
58	Dry Pond Landscaping	5 days	Mon 16-06-13	Fri 16-06-17
59	**Pipe Network Tie-In**	**9 days**	**Mon 16-06-13**	**Thu 16-06-23**
60	Dry Pond Pipe Network Excavation	4 days	Mon 16-06-13	Thu 16-06-16
61	Dry Pond Pipe Network Install	2 days	Thu 16-06-16	Fri 16-06-17
62	Dry Pond Pipe Network Backfill	5 days	Fri 16-06-17	Thu 16-06-23
63	**PHASE 4 - TANK C**	**17 days**	**Mon 16-06-27**	**Wed 16-07-20**
64	**Main Tank Works**	**17 days**	**Mon 16-06-27**	**Wed 16-07-20**
65	Clearing and Grubbing + Tree Protection	2 days	Mon 16-06-27	Tue 16-06-28
66	Site Survey and Layout	13 days	Wed 16-06-29	Mon 16-07-18
67	Excavation	1 day	Thu 16-06-30	Thu 16-06-30
68	Soil Anchor Installation	2 days	Mon 16-07-04	Tue 16-07-05

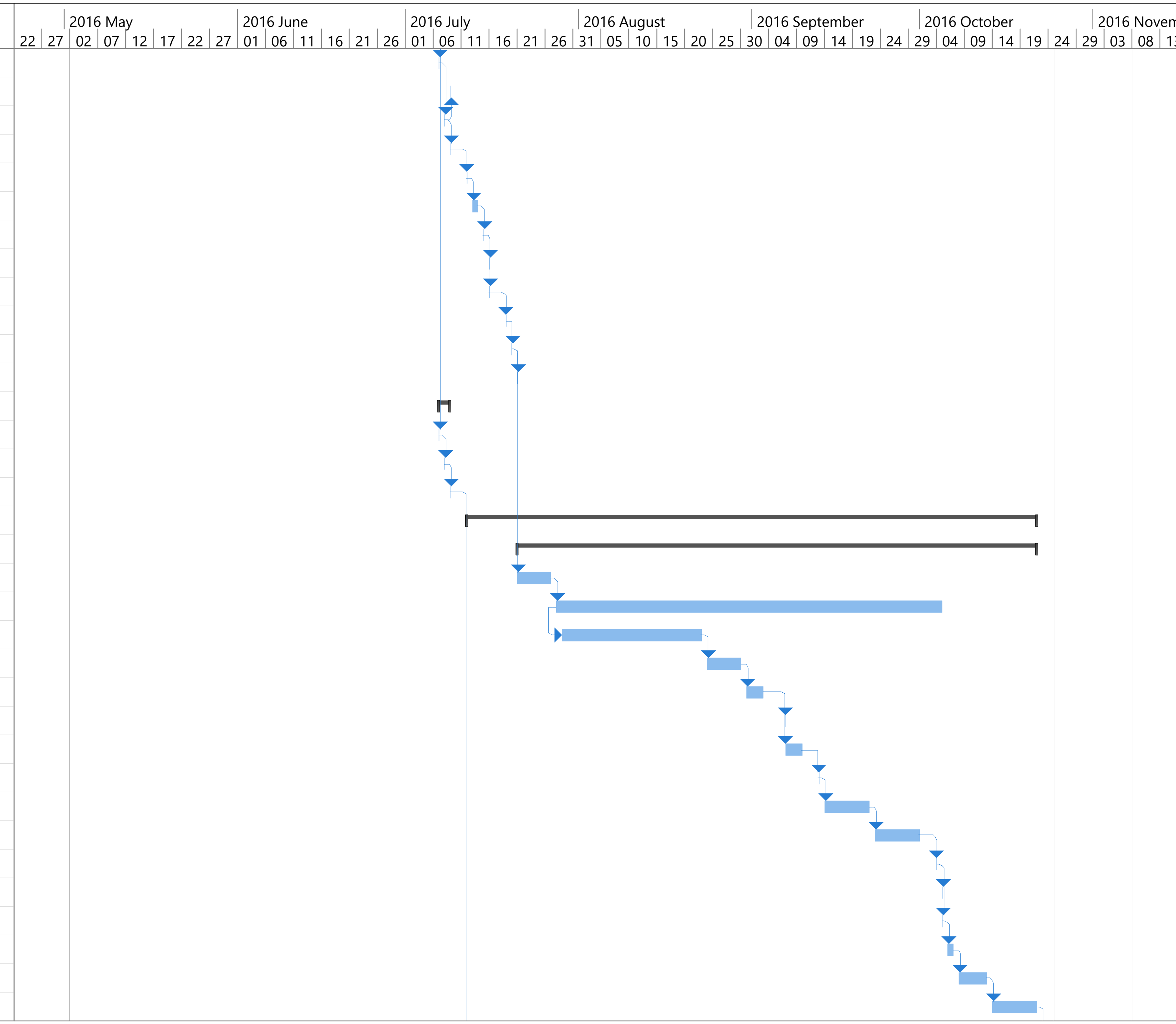


Date: Thu 16-03-31
Reviewed By: HG

Task	Project Summary	Manual Task	Start-only	Deadline
Split	Inactive Task	Duration-only	Finish-only	Progress
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	

UBC South Campus Stormwater Management
Detention Facilities
Construction Schedule

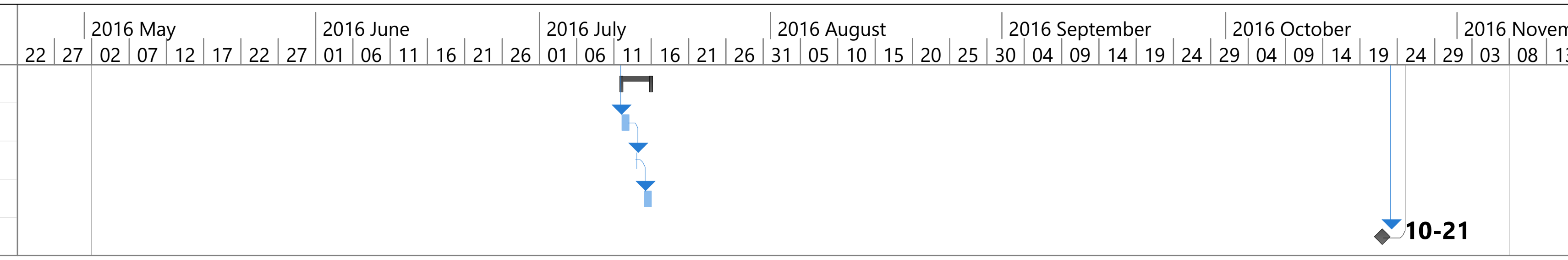
ID	Task Name	Duration	Start	Finish
69	Wall Rebar (North and East)	1 day	Wed 16-07-06	Wed 16-07-06
70	Shotcrete Walls (North and East)	1 day	Fri 16-07-08	Fri 16-07-08
71	Wall Rebar (South and West)	1 day	Thu 16-07-07	Thu 16-07-07
72	Shotcrete Walls (South and West)	1 day	Fri 16-07-08	Fri 16-07-08
73	Pad and Column Rebar	1 day	Mon 16-07-11	Mon 16-07-11
74	Column Forming	2 days	Tue 16-07-12	Wed 16-07-13
75	Pad and Column Pour	1 day	Thu 16-07-14	Thu 16-07-14
76	Oil/Water Separator Install	1 day	Fri 16-07-15	Fri 16-07-15
77	Manhole Install	1 day	Fri 16-07-15	Fri 16-07-15
78	Pre-Cast Cover Install	1 day	Mon 16-07-18	Mon 16-07-18
79	Backfill	1 day	Tue 16-07-19	Tue 16-07-19
80	Landscaping	1 day	Wed 16-07-20	Wed 16-07-20
81	**Pipe Network Tie-In**	**3 days**	**Wed 16-07-06**	**Fri 16-07-08**
82	Pipe Network Excavation	1 day	Wed 16-07-06	Wed 16-07-06
83	Pipe Network Install	1 day	Thu 16-07-07	Thu 16-07-07
84	Pipe Network Backfill	1 day	Fri 16-07-08	Fri 16-07-08
85	**PHASE 5 - TANK D**	**72 days**	**Mon 16-07-11**	**Fri 16-10-21**
86	**Main Tank Works**	**65 days**	**Wed 16-07-20**	**Fri 16-10-21**
87	Clearing and Grubbing + Tree Protection	5 days	Wed 16-07-20	Tue 16-07-26
88	Site Survey and Layout	48 days	Wed 16-07-27	Tue 16-10-04
89	Excavation	17 days	Thu 16-07-28	Mon 16-08-22
90	Soil Anchor Installation	5 days	Tue 16-08-23	Mon 16-08-29
91	Wall Rebar (North and East)	4 days	Tue 16-08-30	Fri 16-09-02
92	Shotcrete Walls (North and East)	1 day	Tue 16-09-06	Tue 16-09-06
93	Wall Rebar (South and West)	4 days	Tue 16-09-06	Fri 16-09-09
94	Shotcrete Walls (South and West)	1 day	Mon 16-09-12	Mon 16-09-12
95	Pad and Column Rebar	7 days	Tue 16-09-13	Wed 16-09-21
96	Column Forming	7 days	Thu 16-09-22	Fri 16-09-30
97	Pad and Column Pour	1 day	Mon 16-10-03	Mon 16-10-03
98	Oil/Water Separator Install	1 day	Tue 16-10-04	Tue 16-10-04
99	Manhole Install	1 day	Tue 16-10-04	Tue 16-10-04
100	Pre-Cast Cover Install	2 days	Wed 16-10-05	Thu 16-10-06
101	Backfill	3 days	Fri 16-10-07	Wed 16-10-12
102	Landscaping	7 days	Thu 16-10-13	Fri 16-10-21



Date: Thu 16-03-31
Reviewed By: HG

Task	Project Summary	Manual Task	Start-only	Deadline
Split	Inactive Task	Duration-only	Finish-only	Progress
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	

ID	Task Name	Duration	Start	Finish
103	**Pipe Network Tie-In**	**5 days**	**Mon 16-07-11**	**Fri 16-07-15**
104	Pipe Network Excavation	2 days	Mon 16-07-11	Tue 16-07-12
105	Pipe Network Install	1 day	Wed 16-07-13	Wed 16-07-13
106	Pipe Network Backfill	2 days	Thu 16-07-14	Fri 16-07-15
107	Detention Tanks and Dry Pond Completion	0 days	Fri 16-10-21	Fri 16-10-21



Date: Thu 16-03-31
Reviewed By: HG

Task		Project Summary		Manual Task		Start-only		Deadline	
Split		Inactive Task		Duration-only		Finish-only		Progress	
Milestone		Inactive Milestone		Manual Summary Rollup		External Tasks		Manual Progress	
Summary		Inactive Summary		Manual Summary		External Milestone			

APPENDIX M – CONSTRUCTION SCHEDULE: ROADWORKS

PHASING SEQUENCE – ROADWORKS

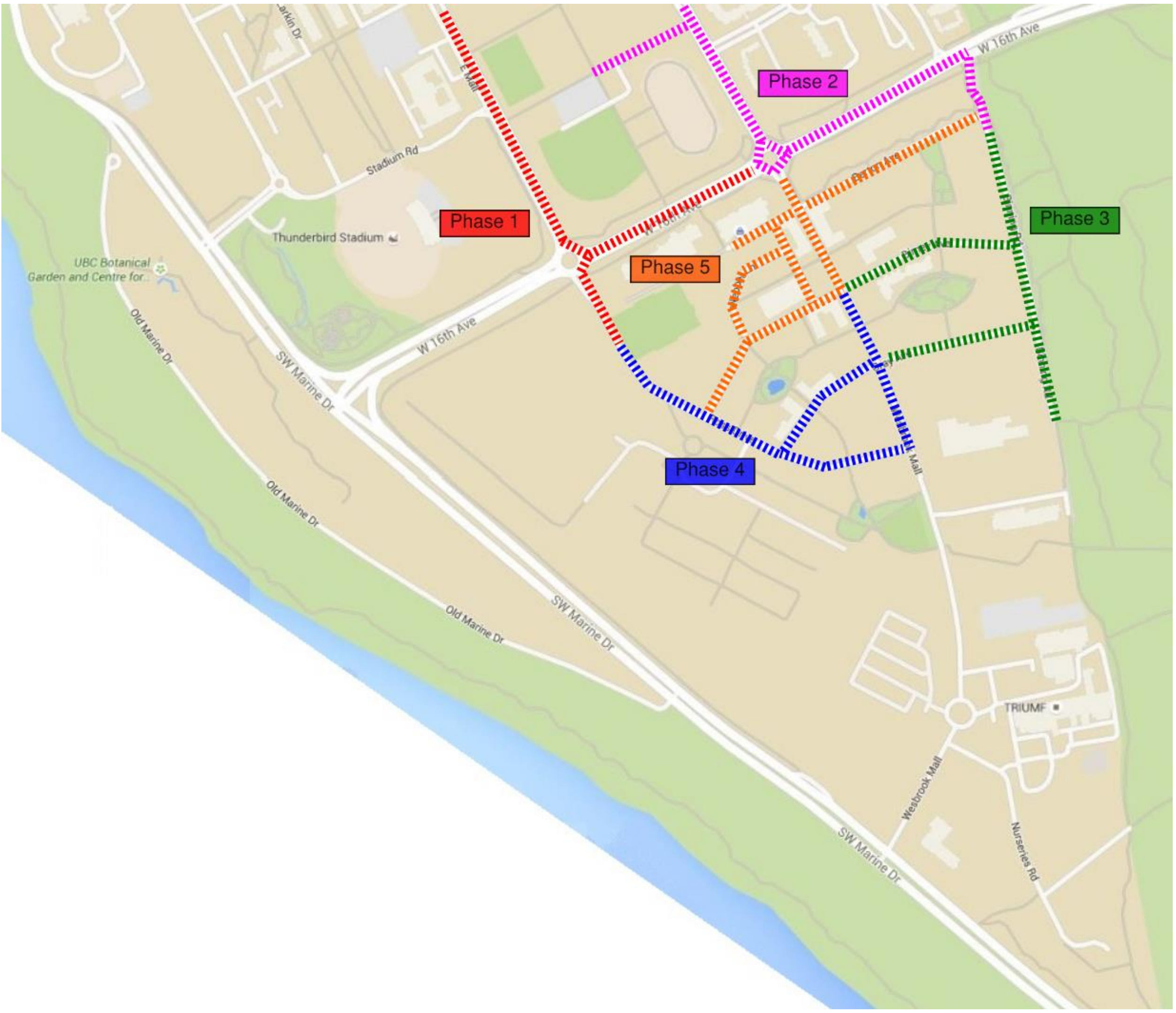


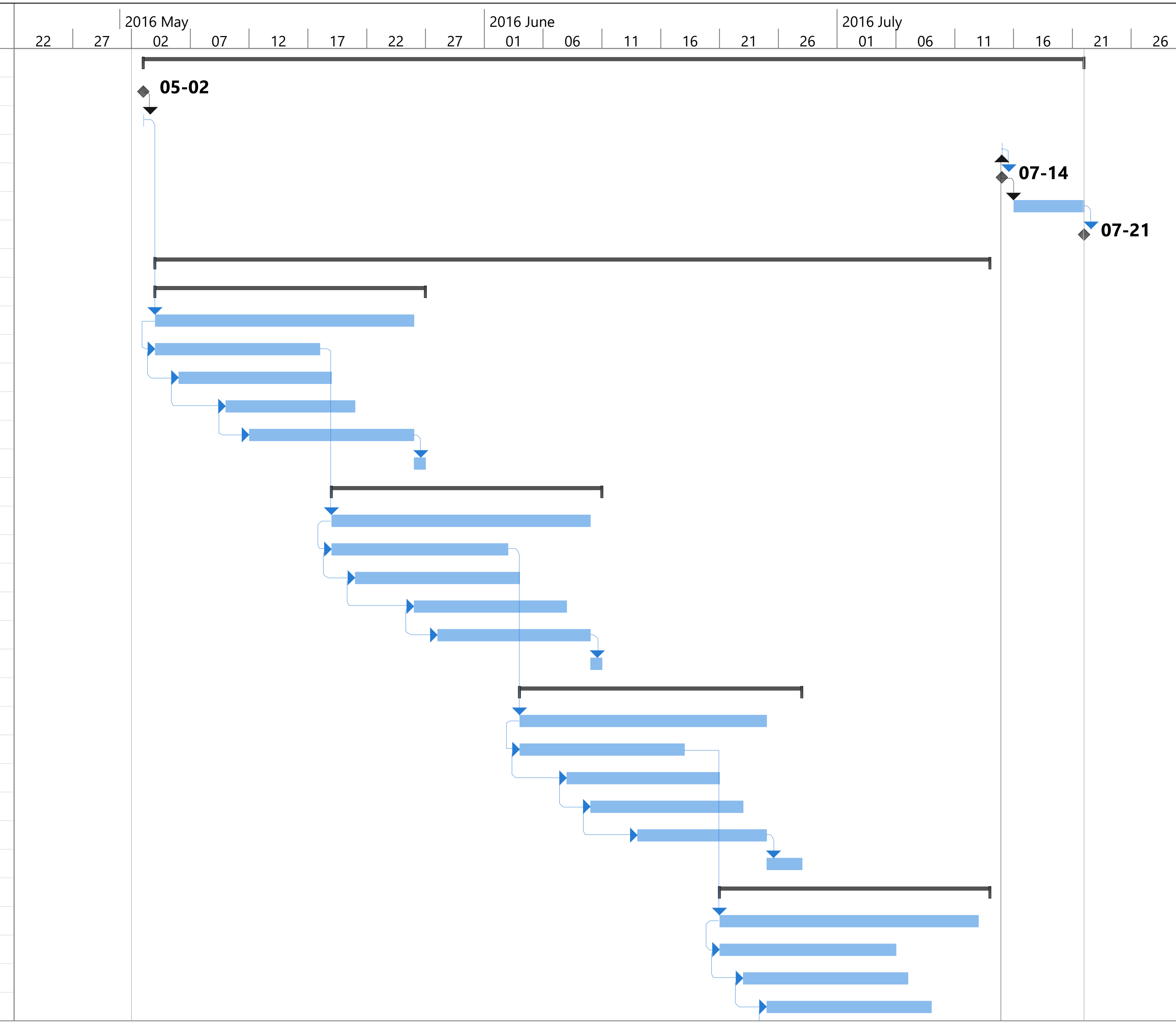
Figure: Phasing sequence – roadworks
Source: Digital Image. David Grant. March 31, 2016. Adapted from <www.google.com>.

SMC ENGINEERING

UBC South Campus Stormwater Management
Roadworks (Permeable Asphalt)
Construction Schedule

UBC

ID	Task Name	Duration	Start	Finish
1	**UBC SOUTH CAMPUS STORMWATER MANAGEMENT**	**57 days**	**Mon 16-05-02**	**Thu 16-07-21**
2	Project Start	0 days	Mon 16-05-02	Mon 16-05-02
3	Mobilization	1 day	Mon 16-05-02	Mon 16-05-02
4	Demobilization	1 day	Thu 16-07-14	Thu 16-07-14
5	Project Completion (w/o Contingency)	0 days	Thu 16-07-14	Thu 16-07-14
6	Contingency	5 days	Fri 16-07-15	Thu 16-07-21
7	Project Completion (w/ Contingency)	0 days	Thu 16-07-21	Thu 16-07-21
8	**ROADWORKS**	**50 days**	**Tue 16-05-03**	**Wed 16-07-13**
9	**Phase 1**	**17 days**	**Tue 16-05-03**	**Thu 16-05-26**
10	Road Survey and Layout	16 days	Tue 16-05-03	Wed 16-05-25
11	Milling of Road	11 days	Tue 16-05-03	Tue 16-05-17
12	Subgrade Layer	10 days	Thu 16-05-05	Wed 16-05-18
13	RoaDrain System Install	10 days	Mon 16-05-09	Fri 16-05-20
14	Asphalt	10 days	Wed 16-05-11	Wed 16-05-25
15	Line Painting	2 days	Wed 16-05-25	Thu 16-05-26
16	**Phase 2**	**17 days**	**Wed 16-05-18**	**Fri 16-06-10**
17	Road Survey and Layout	16 days	Wed 16-05-18	Thu 16-06-09
18	Milling of Road	11 days	Wed 16-05-18	Thu 16-06-02
19	Subgrade Layer	10 days	Fri 16-05-20	Fri 16-06-03
20	RoaDrain System Install	10 days	Wed 16-05-25	Tue 16-06-07
21	Asphalt	10 days	Fri 16-05-27	Thu 16-06-09
22	Line Painting	2 days	Thu 16-06-09	Fri 16-06-10
23	**Phase 3**	**17 days**	**Fri 16-06-03**	**Mon 16-06-27**
24	Road Survey and Layout	16 days	Fri 16-06-03	Fri 16-06-24
25	Milling of Road	11 days	Fri 16-06-03	Fri 16-06-17
26	Subgrade Layer	10 days	Tue 16-06-07	Mon 16-06-20
27	RoaDrain System Install	10 days	Thu 16-06-09	Wed 16-06-22
28	Asphalt	10 days	Mon 16-06-13	Fri 16-06-24
29	Line Painting	2 days	Fri 16-06-24	Mon 16-06-27
30	**Phase 4**	**17 days**	**Mon 16-06-20**	**Wed 16-07-13**
31	Road Survey and Layout	16 days	Mon 16-06-20	Tue 16-07-12
32	Milling of Road	11 days	Mon 16-06-20	Tue 16-07-05
33	Subgrade Layer	10 days	Wed 16-06-22	Wed 16-07-06
34	RoaDrain System Install	10 days	Fri 16-06-24	Fri 16-07-08

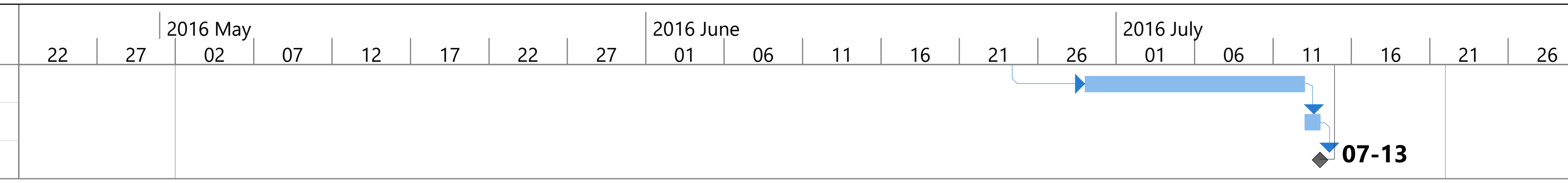


Date: Thu 16-03-31
Reviewed By: HG

Task		Project Summary		Manual Task		Start-only		Deadline	
Split		Inactive Task		Duration-only		Finish-only		Progress	
Milestone		Inactive Milestone		Manual Summary Rollup		External Tasks		Manual Progress	
Summary		Inactive Summary		Manual Summary		External Milestone			

UBC South Campus Stormwater Management
Roadworks (Permeable Asphalt)
Construction Schedule

ID	Task Name	Duration	Start	Finish
35	Asphalt	10 days	Tue 16-06-28	Tue 16-07-12
36	Line Painting	2 days	Tue 16-07-12	Wed 16-07-13
37	Roadworks Completion	0 days	Wed 16-07-13	Wed 16-07-13



Date: Thu 16-03-31
Reviewed By: HG

Task	Project Summary	Manual Task	Start-only	Deadline
Split	Inactive Task	Duration-only	Finish-only	Progress
Milestone	Inactive Milestone	Manual Summary Rollup	External Tasks	Manual Progress
Summary	Inactive Summary	Manual Summary	External Milestone	