UBC Social Ecological Economic Development Studies (SEEDS) Student Report

UBC Botanical Garden Redevelopment: Constructed Wetland

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Executive Summary

Following approval of our proposal to provide sustainable community amenities for the University of British Columbia's Botanical Gardens, Group 9 provides the following design of a constructed wetland (CW) providing details for elements of the forebay section. Adhering to the garden's mission of maintaining the integrity of the plant collections and to its status as a research and conservation facility, CW design also serves as a living laboratory in accordance with the UBC BOG 2011 goals. The CW is designed within the footprint of the existing cattail marsh. Comprised of three weir separated sections, each with several depth pools, the wetland will be cultivated with cleansing plants for contaminant removal, making it suitable for non-potable use – notably irrigation. Incorporating shallow slopes (0.5%), sheet flow is attained which allows laminar flow conditions and contaminant removal via physical and biological processes. By maintaining plant based water treatment our design creates an opportunity to draw attention to the botanical garden, highlighting initiatives in plant filtration technology and striving towards the UBC Water Action Plan (2013) goal of a water neutral campus.

Detailed design will focus on the first section of the wetland, the forebay, which acts as a settling basin, and the first concrete weir, functioning as a flow control. Comprised of four depth pools the forebay is contained by the inlet and an adjustable transition weir on the upstream and downstream ends respectively. Maintaining a shallow slope within each pool, the transition between pools will be specified as 1H: 1V.

Specific elements focused on, in detail, for our design will be hydrotechnical and water quality, key structural components, and project management. Each of these sections will consist of the following items, described below.

<u>Hydrotechnical and Environmental</u>:
This section will focus on hydraulic retention times, plant selection, contaminant removal and regulations, water quality and maintenance. In addition, a cost benefit analysis on the selection of either a clay or geosynthetic clay liner (GCL) will be provided, allowing the priority of benefits to be weighed by the client before a final decision is reached. Recommendation is for the clay liner.

<u>Structural Elements</u>:
Focusing on the typical design of the separation weirs this section will specify capacity requirements, necessary foundations and embedment, flow distribution capacity, as well as ancillary structures for safety and maintenance. Design load cases and potential failure mechanisms are assessed and compared to material and structural capacities with reference to relevant safety factors

<u>Construction Management</u>:
By outlining scheduling, materials, costs, and labour requirements this section will allow us to create the most efficient design through optimization. This organizational system will create a project with the inherent benefit of minimal cost and construction time, two key concerns for the UBC Botanical Garden. Minimizing construction time as well as cost will cause minimal disruptions for the gardens. The project is scheduled during the least impacting season, thus allowing a return to status-quo garden condition for optimal patron satisfaction.

1.0 Introduction

1.1 Purpose and Scope

In accordance with UBC's commitment to innovation and sustainability, and the request by the Botanical Garden for Sustainable Community Amenities, Group 9 has developed a detailed design for the construction and management of a surface flow constructed wetland (CW). This project will be located within the current footprint of the Cattail Marsh. The CW will help to manage stormwater runoff within UBC while minimizing biological adverse impacts downstream in Rock Creek by biologically removing high concentrations of contaminants. The filtered water will be available for irrigating the gardens on the east side of SW Marine Dr.

Detailed design of the forebay and first weir are presented with future works proposed for the remaining sections of the wetland. The forebay of the CW is the first permanent pool where stormwater flow enters the system and the majority of the physical settling of suspended solids takes place under relatively quiescent conditions. The detailed aspects of the hydrological, structural analysis, and project management aspects of the forebay and weir will be discussed, along with the general outline of the entire CW. The CW will provide a new research opportunity for the gardens and for UBC faculty/students with respect to the contaminant removal and water treatment capacity of aquatic plants.

The full CW will be comprised of three zones: forebay, wetland, and outlet pool. Each of these zones serves a distinct function that will holistically achieve settlement and contaminant removal within the CW. Each section is separated by a flow control structure consisting of a weir and baffle structure. In addition there are ancillary features of the CW, such as inlet and outlet structures, trash racks, reservoir connections, as well as pumping and mechanical systems. These elements have been identified as required for full functionality of the wetland; however detailed designs of these latter elements are proposed as future works.

Elements of the detailed design for the hydrological element will include the hydraulic retention times, contaminant levels and anticipated removal, varying seasonal flows, planting selection and layout, as well as maintenance requirements. All quantitative parameters are compared to current levels and literature values, yielding a reasonable estimate of potential removal for contaminants. Each of these elements is designed with environment, habitat, wetland and riparian area, and prevention of invasive species in mind.

Structural analysis will consist of the comparison of design average and extreme cases, with capacity to resist driving forces within acceptable safety factors. This will include analysis against sliding, rotation, and bearing failure as compared to the capacity of the aluminum stop logs themselves.

Project management will consist of cost and schedule analysis for maximum efficiency. Schedule will be analyzed through critical path and labour allocation methods. The project cost is estimated using RS means.

1.2 Design Components

Upon request of the client, design documents herein focus on detailed design of elements of the forebay. Subsequent design stages involve generating a detailed design report inclusive of a similar level of detail for each remaining section of the wetland. For completeness and context an overall plan of the wetland is provided in preliminary detail, showing the footprint and general geometry. Detailed design of the forebay includes:

- Detailed drawings and geometric specifications
- Stratigraphy of below grade elements
- Hydraulic retention times and flow conditions
- Water quality, contaminant removal efficiencies, and expected performance
- Plant selection and general landscaping plan
- Maintenance requirements
- Separation weir design including foundation embedment and related bedding considerations
- Material quantities and costs
- Scheduling and organizational chart

2.0 Hydrological and Environmental Design Components

2.1 General Design

The constructed wetland will be comprised of 3 main sections, the forebay, wetland, and outlet pool, each separated by a weir for flow control. Each pool has different depth zones providing appropriate flow through the channel. Laminar sheet flow is maintained by a shallow 0.5% slope for even distribution and settlement of suspended solids throughout the wetland. The functions of each section are described in detail in section 2.6. With respect to hydrotechnical and environmental engineering, our design addresses the following issues:

1. Estimating the influent flows and pollutant load to the CW
2. Estimating the constructed wetland performance
3. Determining the area and volume required to satisfy water quality treatment goals outlined by the Approved Water Quality Guidelines for British Columbia
4. Specifying wetland hydrology, hydraulic design, and operating criteria that meet performance comparable to systems for which empirical rate constants were derived and
5. Maintaining the physical, chemical, and biological systems to attain desired pollutant-processing rates

2.2 Preliminary Analysis

Preliminary analysis of this project has involved an extensive review of the provincial, federal, and local laws, regulations and BMPs that govern activities in or near wetlands (shown in Table 1 below). All required permits and approvals will be obtained prior to commencing all proposed activities. Consultations with First Nations will also be undertaken to ensure land-use activities adhere to their vision and protocols.

Table 1:Regulations, legislation, & BMPs applicable to project (including permits, authorizations & applications).

Water Act (S.9) and Water Act Regulations (S.7)	Governs all works in and about a stream, including wetlands.
	"Approval Application or Notification for Changes in and About a Stream"
Wildlife Act	Protects most vertebrates from direct harm/harassment (Refer to Sections 9 and 34)
Wildlife Amendment Act	Lists specific "species at risk"(SAR). This prohibits killing, harming, and handling of these species on crown/private land except if authorized by regulation/permit/agreement.
Environmental Management Act	Provides protection for wetlands impacted by deposit of waste into the Environment
Municipal Sewage Regulation	Controls use of reclaimed water and identifies permitted uses
Canada Species at Risk Act (SARA) & Migratory Birds Convention Act	Legal protection of federally listed wildlife species & conservation of their diversity on federal/private land includes aquatic species &migratory birds listed under SARA).
BMPs for Amphibians & Reptiles in Urban and Rural Environments in B.C.	Least-risk work windows for instream works in BC. Region-specific timing windows: outlines prescribed timing windows for construction in and about wetlands. Refer to "Conservation Data Center" MOE Website and the "Conservation Framework".

(Cox, Cullington & Associates, 2009)

Our analysis also involved extensive review of water quality and quantity regulations, as well as the intended features and functions of the wetland with respect to re-establishing a diverse ecosystem and wildlife habitat. This included analyzing potential pressures on the wetland system, such as likely impacts from development activities, climate change, invasive species, wetland succession, and sedimentation. A site-specific mapping and inventory survey will be conducted prior to initiating any activities. The four main stages of this survey are:

1. **Preliminary Site Survey:** Involves identification of wetland area, analysis of exiting data, consult with Botanical Garden and First Nations stakeholders, and general site inspections
2. **Bio-Inventory Survey:** Performed by qualified professional; detailed site investigations, evaluation of environmental resources and concerns; outline of mitigation and development enhancement opportunities
3. **Conservation Evaluation:** Comprehensive review of bio-inventory data and a comparison with other local sites. This will assist in designing plans to preserve features of highest conservation value.
4. **Impact Assessment:** Scientific review to set practices which will minimize ecological degradation.

(Cox, Cullington & Associates, 2009)

The proposed construction period avoids sensitive nesting, mating, migrating and denning times for wildlife, as well as flowering and seed-set periods for plant communities. Most species are more tolerant to disruption during specific "timing windows" (established for many ecosystems and species in British Columbia), however, it is still necessary to perform a comprehensive bio-inventory survey. BC MOE provides known locations of species and ecological communities at risk in each regional district. A qualified professional will be hired to assess if the project will have any potentially adverse effects on SAR.

In order to prevent the introduction of invasive species, all equipment, packs, and shoes must be cleaned and free of seeds and plant material prior to entering the botanical gardens. If any invasive species are observed, they will be removed immediately following consultation with the Botanical Garden. Disturbed areas will be stabilized with mulch/grass and re-vegetated with native plants (Cox, Cullington & Associates, 2009).

2.3 Stormwater Quality Analysis

There is a high variability in runoff quality during and between each rainfall event due to differences in length of dry period between events, total runoff volume, storm duration, and/or storm intensity. Long term changes in runoff quality are generally due to changes in rainfall cycles and land-use changes. Stormwater quantity and quality are highly dependent on local conditions (terrain, land-use, % impervious area, runoff from highways, rainfall cycles, etc) (BCRCWMG, 1992). The site-specific nature of stormwater runoff and the spatial and temporal dynamics of urban environments make long-term characterization of runoff difficult. Although the proposed CW system is designed to meet current demands on the system in terms of biologically filtering water, it will be necessary to design a comprehensive long-term study of the urban stormwater from this catchment area. Widely accepted design criteria for treatment BMPs remain a focus for R&D (BCRCWMG, 1992).

The effects of stormwater on water quality are usually assessed by comparing the concentrations of designated pollutants in the water against accepted provincial or federal water quality criteria. However, such criteria may not be entirely appropriate for urban runoff considerations because of its intermittent nature (not addressed by these guidelines). Also, the total pollutant concentrations measured do not equal the bioavailable portions and thus measured values may be misleading in determining acute toxicity (BCRCWMG, 1992). Nevertheless, the Approved Water Quality Guidelines for the Province of B.C. provide us with credible target values to consider in our initial assessment of the efficiency of treatment. These criteria include those for freshwater aquatic life, wildlife, irrigation, and recreation as applicable to the CW for the UBC Botanical Garden ([GBCMOE], 2013). Site-specific goals and objectives are defined based on using effluent from the wetland for irrigation purposes.

2.3.1 Background Analysis: Available Flow and Stormwater Constituents

Understanding of stormwater influent characteristics is gained via comprehensive quantitative and qualitative analyses. Parameters investigated include daily volume, peak recorded flows in Rock Creek, as well as concentration of suspended solids, heavy metals, temperature, and pH. Unfortunately accurate information on many contaminants, including organic materials, oils, pesticides, nutrients, COD, trace elements, indicator micro-organisms and pathogens is not currently available. The contributing drainage area was investigated to identify and map potential contamination sources, including: oil from roads/parking lots, fertilizer residue, building/driveway wash-down, and runoff from stored material, debris, or bare soil areas ([GBCMEM], 2002).

2.3.1.1 Available Flow

A 2013 study of Rock Creek indicated that summer base flow, including tributary flows, is approximately 2.4 L/s (207 m^3/day). Fluctuations due to storm events were omitted in calculations (Shen & Wong, 2013).

2.3.1.2 Stormwater Constituents and Potential Environmental Effects

Table 2 below shows a list of contaminants and water quality parameters and their range of concentrations measured in stormwater in the Trail 7 outfall in February – March, 2005.

Table 2: Contaminants and Water Quality Parameters for the Trail 7 Outfall at UBC.

Stormwater Constituent	Concentration Range	Water Quality Parameter	Level Range
Aluminum	0.05 – 0.2 mg/L	**Turbidity**	2.52 – 8.4 NTU (large variation)
Arsenic	0.001 – 0.008 mg/L	**Specific Conductivity**	258.1 – 469.1 µS/cm
Cadmium	0.00008 – 0.00012 mg/L	**pH**	7.28 – 8.22
Copper	0.125 – 0.2 mg/L	**Temperature**	10.4 – 12.3 ^{o}C
Iron	0.25 – 0.45 mg/L		
Lead	0 – 0.0005 mg/L		
Mercury	0 – 0.0001 mg/L		
Zinc	0.01 – 0.02 mg/L		

(Fowler, Robinson, & Phillips, 2005)

Contaminants in stormwater runoff can pose acute and/or chronic toxic effects to aquatic life, plant life, organisms, and wildlife. Long-term effects are augmented by re-suspension and mobilization of contaminated sediment deposits (can make concentrated toxic substances more bio-available). Several pollutants (ie. metals, organic compounds, pathogens) persist in sediments where they can be released into the water and/or incorporated into the food chain via consumption by benthic organisms. Left untreated, pollutants can have the following effects in the Rock Creek system:

1. Potentially kill organisms and decrease species diversity
2. Have sub-lethal effects that affect the reproduction, growth, and survival of organisms, weakening them over the long-term and making them more susceptible to disease and environmental stresses
3. Increase turbidity and sedimentation rates and
4. Increase nuisance vegetation and algae growth

2.4 Treatability

Ranges of reported pollutant removal efficiencies from field studies for CWs and the expected performance targets for the proposed project are shown in Table 3. Green highlighted constituents we expect to remove to levels that exceed approved guidelines for irrigation. Red highlighted values may require further attention. Initial contaminant concentrations were measured directly in Rock Creek; however, the inflow for the forebay is taken from a retention facility where some primary settling occurs. An in-situ study, following construction, to determine actual influent concentrations, site-specific removal rates, and treatment capacities is recommended. Subsequent design alterations (geometry, planting arrangement) can increase capacity if necessary.

Table 3: Constructed Wetland Pollutant Removal Efficiencies in Field Studies & Expected Performance Targets

Constituent	Range of Reported Removal	Average Removal % (Field Studies)	Maximum Initial [ ] (mg/L)	Expected Final [ ] (mg/L)	Approved Guidelines for Irrigation [5]
Aluminum [1]	0 – 99	50	0.2	0.1	5
Arsenic [2]	99	99	8.0E-03	8E-05	1.0E-04
Cadmium [3]	50 – 98	74	1.2E-04	3.1E-05	-
Copper [3]	55 – 96	75.5	0.2	4.9E-02	2.0E-04
Iron [3]	66 – 97	81.5	0.45	8.3E-02	1
Lead [4]	88 – 97	92.5	5.0E-04	3.8E-08	4.0E-04
Mercury [3]	60 – 70	65	1.0E-04	3.5E-05	2.0E-06
Zinc [4]	33 – 96	64.5	2.0E-02	7.1E-03	5.0E-03
SS [4]	64 – 99	81.5	8.4 NTU	1.6 NTU	*Depends on Background
COD [4]	54 – 89	71.5			None Proposed
Total N & P [4]	0 – 97	48.5			None Proposed
pH			7.28 – 8.22		5.0 – 9.0

[1] (Kadlec & Wallace, 2009) [2] (Duncan, Gould, & Mattes, n.d.) [3] (Humboldt State University, CH2M-HILL, & PBS&J, 1999) [4](BCRCWMG, 1992) [5] (GBCMOE, 2013)

The CW is designed to exploit natural treatment processes by providing sufficient hydraulic retention time (HRT) for settling and maximum stormwater contact of reactive surfaces (plants, sediments, bacteria, etc). Wetlands are capable of removing high concentrations of particulates, dissolved contaminants, sediment, nutrients, heavy metals, toxic materials, floatable materials, oil and grease, while reducing the Chemical Oxygen Demand (VCSQMP, 2001). CWs are very efficient at managing intermittent periods of variable influent flows characteristic of stormwater runoff (Hoban, 2002). Additionally, surface/emergent plants help control flow rates and shade the water surface, facilitating control of algae growth within the wetland. Pollutant removal rates are much greater during the growing season, while poor removal rates have been noted when organic debris is removed from the wetland at the end of the growing season. Stormwater treatability depends on the nature of the pollutants involved, such as density and particle associations. Some constituents, such as hydrocarbons and lead, are largely associated with suspended solids (SS) and can be removed via filtering. However, the majority of pollutants are associated with the smaller particle sizes of SS and are more difficult to remove. If conditions are suitable, they will flocculate. Some pollutants (i.e. nutrients, Cu, Zn, Cd) have a considerable soluble portion that, under certain conditions, will adsorb to the surface of larger particles (sediment) (BCRCWMG, 1992).

2.4.1 Pollutant Removal Efficiency of Forebay

Pollutant removal in the quiescent permanent pool during or between runoff events occurs via: flocculation and sedimentation of particulate-associated pollutants, chemical reactions, adsorption to suspended solids and sediments, and the biological action of bacteria, algae, and aquatic plants. As water flows through the wetland, waste material is strained out by submerged plants, plant stems, roots, leaves, and plant litter, upon which waste-consuming bacteria also becomes attached. Longer residence time in the forebay provides increased settling, facilitated by a flow control weir between the forebay and wetland. After inflow subsides, the water level decreases at a controlled rate to the final design elevation of 73.8 meters amsl. This process dissipates inflow energy (minimizes turbulence induced by filling/emptying the pond), thereby preventing re-suspension of settled particles and reducing scour/erosion of sediments throughout the forebay.

Vegetation and detritus occupy a portion of the volume of the CW, reducing the actual volume occupied by water in the wetland. Research shows a range of porosity values from 0.65 to 0.95 (Humboldt State University et al., 1999). To be conservative, we have estimated a porosity of 0.85 for the forebay, when fully vegetated and after some sediment accumulation, leaving an approximate design volume of 94 m^3. Note that low pollutant removal efficiencies result if the inflow volume exceeds this design volume (BCRCWMG, 1992).

Water flow through the forebay (and CW) is extremely complex, varying temporally and spatially. The hydraulic profile of the water surface is dictated by the gradient and length-to-width ratio, as well as friction from submerged and emergent plants, litter, peat, and channel bottom/sides. Deposition of sediment is inversely proportional to the flow velocity. The following factors dissipate energy (reduce water velocity) leading to laminar flow, thereby producing quiescent conditions that optimize pollutant-removal efficiency:

1. Wide inlet structure design: kinetic energy in the water is dissipated prior to entering the forebay [1]
2. Regulate hydraulic loading [1]
3. Limit the average slope within the wetland to less than 0.5% [1]
4. Regulate the outlet flow from the forebay with an adjustable weir [1]
5. Plant the wetland with persistent submerged and emergent vegetation [1] and
6. Minimize corners or pockets (on surface and along the bed) that may become isolated from the main flow path. These “dead-spaces” often have little or no water exchange occurring. [2]

[1] (Jones, 1997) [2] (Humboldt State University et al., 1999)

2.5 Water Budget and Balance

The water balance evaluation of the CW quantifies the inflows and outflows of water and the storage volume, elucidating contaminant flux and overall system performance. The dynamic water budget for the CW is:

$$\frac{dV}{dt} = Q_i - Q_o + Q_c - Q_b + Q_{sm} + (P - ET - I)A$$

dV/dt = Volumetric rate of change in wetland, (m^3/day)
Q_i = inflow rate (m^3/day)
Q_o = outflow rate (m^3/day)
Q_c = catchment runoff rate (m^3/day)
Q_b = bank loss rate (m^3/day)
Q_{sm} = snowmelt rate (m^3/day)
P = precipitation rate (m/day)
A = Wetland surface area (m^2)
ET = evapotranspiration rate (m/day)
I = infiltration to groundwater (m/day)

{Q_b, Q_c, Q_{sm}, & I} are relatively insignificant and ignored in further analysis; thus, this equation is reduced to:

$$\frac{dV}{dt} = Q_i - Q_o + (P - ET)A$$ (Humboldt State University et al., 1999)

Predominant inflow to the forebay will be controlled by a pump and pipe system taking water from a proposed retention facility installed adjacent to Rock Creek (this component falls outside of wetland specific project scope). Outflow from the constructed wetland will be via a pump and pipe network for distributing irrigation water in the North Garden and Native Garden. This subsequently draws water from the forebay over the exit weir. An additional drainage pipe will be installed to regulate water depth for situations in which the volume of water within the wetland exceeds that required for irrigation and/or for maintenance purposes. Altering weir levels manually changes the water level and storage volume for varying seasonal inflows/outflows. Outflow increases during spring and summer months when water is required for irrigation. Precipitation and evapotranspiration also fluctuate, affecting the seasonal hydrology (Humboldt State University et al., 1999).

2.5.1 Irrigation

This project is designed to meet the peak irrigation demands for the North Garden and Native Garden. Table 4 has been adapted from a UBC SEEDS Report and reveals water consumption in the UBC Botanical Gardens for irrigation purposes in 2011. Maximum demand of 124 m^3 recorded on August 23, 2011 was allocated approximately 70% to the Asian Garden, while the remaining 30% was consumed on the east side of SW Marine Drive (Justice, 2013). These values exclude the requirements for the Native Garden, which is currently connected to a separate municipal source. Assuming the Native Garden is approximately 4500 m^2, and that 75% of this area is irrigated at a peak rate of 5cm/week, the peak flow required for this area is an additional 24m^3/day. Water demand for the North and Native Gardens is the sum of 30% of total irrigation demand for the entire garden plus a fraction of the peak 24 m^3/day for Native Garden. During the months of May and November, given the low water requirements of the entire garden, the demand for the Native Garden was assumed proportional to (month/peak month) demands (see Appendix C sample calculations). The final column shows the average daily water requirements for the North and Native Gardens according to these specifications.

Table 4: Water Consumption for Irrigation Purposes at the UBC Botanical Garden in 2011

Date	Meter Reading (m^3)	Monthly Demand (m^3)	Average Daily Demand (m^3/day)
2011-May-20	550	450	8
2011-Jun-21	3003	2453	49
2011-Jul-21	5840	2837	53
2011-Aug-22	9180	3340	58
2011-Sept-16	12270	3090	55
2011-Oct-24	13785	1515	39
2011-Nov-21	14005	220	4

(Shen & Wong, 2013)

2.5.2 Evapotranspiration (ET)

Evapotranspiration is total water lost due to direct evaporation from the water surface and transpiration from the wetland. ET losses from the forebay are based on potential evapotransipiration (ET_o) values. Data was obtained from an Environment Canada weather station at the Vancouver International Airport (based on the modified Penman Monteith equation). Following consultation with Dr. Chieng at UBC-Vancouver, these values were averaged over 2012 and 2013, adjusted using appropriate parameters, and multiplied by the surface area of the forebay (203 m^2) to provide the information in Table 5. (Sample calculation provided in Appendix C). Note that annual water lost due to ET is overwhelmed by inputs from precipitation throughout the year.

Table 5: Expected Mean Daily Evapotranspiration Outflow from the Forebay for Each Month

	J	F	M	A	M	J	J	A	S	O	N	D
Mean Daily ET (mm/day) [1]	0.41	0.63	1.17	1.89	2.75	3.15	3.42	3.15	2.03	1.04	0.50	0.32
Mean Daily Outflow (m^3/day)	0.08	0.13	0.24	0.38	0.56	0.64	0.70	0.64	0.41	0.21	0.10	0.06

(Farmwest.com, 2014)

2.5.3 Precipitation

Precipitation inflows result from direct precipitation onto the wetland surface area and runoff from the surrounding wetland catchment. In the lower mainland region, the addition of precipitation into the water balance is critical; it can dilute pollutant concentrations and must be considered in the pollutant mass balance. Average precipitation input to the forebay is estimated from a sampling period of 30 years of historical monthly average precipitation for the Vancouver region. The second row outlines the average daily volume input to the wetland from precipitation falling within the forebay and surrounding buffer zone (Surface Area: 424.5 m^2).

Table 6: Expected Mean Daily Precipitation Inflow to the Forebay for Each Month

	J	F	M	A	M	J	J	A	S	O	N	D
Mean Daily Precip. (mm/day) [1]	5.77	6.57	5.03	3.93	2.81	2.33	1.71	1.65	2.43	4.77	7.97	7.45
Mean Daily Input (m^3/day)	2.45	2.79	2.14	1.67	1.19	0.99	0.73	0.70	1.03	2.03	3.38	3.16

[1] (The Weather Network, 2014)

2.5.4 Hydraulic Retention Time (HRT) for the Forebay

The required HRT of the wastewater in the entire wetland depends on the strength of the influent, the specified permissible treatment level, as well as climatic factors (Hoban, 2002). Irrigation outflow from the wetland is ceased from December through April, and given the precipitation inputs and evaporative losses during these months, inlet and outlet flows were determined to maintain an ideal HRT of at least 36 hours (and an absolute minimum of 6 hours) for the forebay. Settling column analyses suggest that a minimum of 6 hours of flocculation and sedimentation under quiescent conditions is required to remove particulate pollutants from urban stormwater runoff. (BCRCWMG, 1992) Shutes et. al. (2005) suggest ensuring a HRT of greater than 36 hours for adequate removal of total suspended solids (TSS), heavy metals, petroleum, Polycyclic Aromatic Hydrocarbons (PAHs), and herbicides (Jayaratne et al., 2010). Theoretical HRT is the ratio between the effective volume (accounting for reduction due to vegetative porosity) and the flow-rate:

$$HRT = \frac{Effective\ Volume}{Inflow\ Rate\ (Q_i)}$$

This theoretical HRT value is highly dependent on the estimated surface area, volume, and porosity. Studies show that the theoretical HRT is always much higher than the actual HRT as water often flows at increased velocities through preferential flow paths (Knight & Ferda, 1989). Once the wetland is constructed, a tracer study will determine the actual HRT and we can then modify the planting regime to optimize this value.

The forebay has been designed with a theoretical HRT of between 39 and 45 hours, shown in Table 7: Monthly Water Balance and Average Daily Inflow Rates each Month Required to Maintain Design HRT.. This provides a 10 – 25% surplus HRT over the specified ideal theoretical HRT of 36 hours. The following table outlines the Monthly Water Balance and average daily inflow rates required to maintain the forebay volume and minimum HRT. The inlet flow should not exceed the effective design volume of the permanent pool (94m^3). Similar analysis is proposed for HRT determination of the wetland and outlet pool in future works.

Table 7: Monthly Water Balance and Average Daily Inflow Rates each Month Required to Maintain Design HRT.

Month	Precipitation Inputs (m^3/day)	Evaporation Losses (m^3/day)	Irrigation Outflow (m^3/day)	Drain Outflow (m^3/day)	Required Inflow (m^3/day)	HRT (hours)
January	2.5	0.1	-	53	50	45
February	2.8	0.1	-	53	50	45
March	2.1	0.2	-	52	50	45
April	1.7	0.4	-	51	50	45
May	1.2	0.6	8	43	50	45
June	1.0	0.6	49	2	50	45
July	0.7	0.7	52	0	52	43
August	0.7	0.6	58	0	57	39
September	1.0	0.4	55	0	54	42
October	2.0	0.2	39	13	50	45
November	3.4	0.1	4	50	50	45
December	3.2	0.1	-	53	50	45

2.5.5 Forebay Expected Flow Velocities

The expected flow velocity in the forebay can be calculated using Manning's Equation, $V = \frac{1}{n} * R^{\frac{2}{3}} * S^{1/2}$ (Finnemore & Franzini, 2002) where V is the average velocity (m/s), n is Manning's roughness coefficient, R is the hydraulic radius (m), and S is the slope (m/m). The value for Manning's n is dependent on vegetation selected, planting arrangement, channel design, season, and sediment accumulation, amongst other factors. The US Geological Survey specifies a value of up to 0.132 for a natural channel with dense vegetation (Hall & Freeman, 1994). Yet further studies indicate that a value of approximately 0.75 may be more appropriate for the given forebay (Kadlec & Wallace, 2009). The resulting estimates of upper and lower bound flow velocities for the forebay shown in Table 8 are based on these minimum and maximum Manning's n estimates respectively. All velocities fall below the specified upper design value of 0.46 m/s (ideally below 0.18 m/s) (Humboldt State University et al., 1999). This procedure is proposed for each depth zone within the CW.

Table 8: Expected Flow Velocities in Each Pool of the Forebay at Design Depth and Volume.

Pool	Average Depth (m)	Hydraulic Radius (m)	Upper Bound Velocity (m/s)	Lower Bound Velocity (m/s)
DP1	0.15	0.07	0.09	0.02
DP2	0.4	0.19	0.18	0.03
DP3	0.65	0.31	0.24	0.04
DP4	1.05	0.49	0.33	0.06

2.6 Layout and Design

The wetland consists of three distinct hydraulic zones: forebay, wetland, and outlet micro pool. The forebay facilitates sediment removal while the wetland and outlet micropool focus on pollutant removal and promoting plant diversity. See Figure 7 in Appendix A for a general plan view of each hydraulic zone. The plan view dimensions are described in the following table:

Table 9 - Constructed Wetland Sections and Dimensions

Section	Width x Length (m)	Design Volume (m^3)	# depth pools	Average pool Depth (mm)	Bottom width (m)
Forebay	10.75 x 36	135	4	700	3
Wetland	10 x 30	110	7	300 [1]	3
Outlet pool	8.5 x 20	160	6	600 [2]	3

Notes: 1. Wetland depth zones alternate from deep to shallow, ranging from 200mm to 600mm in depth
2. Outlet pool depth zones become progressively deeper, ranging from 300mm to 900mm in depth.

The forebay inlet is proposed near the northernmost extent of the existing cattail marsh. The approximate centreline length of the forebay is 36m, coinciding as closely as possible with the centreline of the existing cattail marsh. Because the forebay comprises four pools with different depths, the top-of-bank to top-of bank widths vary between 9m and 13.5m. An adjustable weir acts as a flow control structure between the forebay and wetland. See Figure 7 and Figure 8 in Appendix A for details.

The forebay is described by a typical cross section. Each pool in the forebay has a typical bottom width of 3m to accommodate most construction equipment for constructability and maintainability. Storage capacity of the forebay uses a main channel with 2:1 side slopes. An additional 2m buffer zone (for visitor safety and additional storage capacity) utilizes a 5:1 slope. Literature suggests a wide range of buffer distances; the choice of a relatively small buffer zone reflects the controlled inflow/outflow nature of the system and space constraints. (Sheldon et al., 2005). The side slope transition occurs at approximately 350mm below existing grade at the perimeter of the proposed forebay. (*Detail: Section A-A* on Figure 8 of Appendix A)

The forebay comprises of four pools of a typical profile view with depths varying as summarized in Table 10. The pools become progressively deeper and longer to create adequate volumes for suitable HRT, which will be equal to the solids retention time due to no return flow. Additional capacity can be provided by addition of a return line for future expansion. The profile of each pool features a downstream bed slope of 0.5%. This ensures that water continuously flows through the forebay, prevents stagnation at minimal velocities (subcritical flow), and optimizes sediment removal. The transition between two pools features a specified maximum 1:1 slope. This transition is chosen for constructability and enhanced economical design compared to other transition structures, such as weirs or baffles. In addition, this transition allows flow to be continuous within the forebay itself. (Detail: *Section B-B* on Figure 8 in Appendix A)

Table 10: Forebay Pool Dimensions

Pool	Nominal Depth (m)	Average Top Width (m)	Average Length (m)
DP1	0.50	8.92	8.67
DP2	0.75	9.97	7.62
DP3	1.00	10.83	8.27
DP4	1.40	13.31	12.53

2.6.1 Stratigraphy

The base of the forebay comprises of 500mm of native excavated material. This layer functions as growing media to support plant life. Native excavated material reduces capital costs and repurposes this material that would otherwise require disposal. The thickness of this layer is based on typical root establishment depths for selected species. This soil is appropriate growing media for the aquatic plant species being considered. Material from the botanical garden was determined acceptable as a well-graded material that will provide sufficient root establishment for the selected plant species. Below the growing media is 300mm of compacted clay liner. This liner functions as an impermeable barrier to prevent seepage from the system. While other liner options were considered, clay is recommended as it is a natural product reflecting the Botanical Garden's focus on sustainability and environmental stewardship. The thickness of liner is based on industry standards and effective compacted depth requirements to achieve adequate permeability as outlined in CSA standards. Compacted subgrade will underlay the constructed stratigraphy providing stability, reducing settlements, and creating suitable working surfaces for construction. (*Detail: Figure 9 and Figure 10 in Appendix A*)

2.6.2 Planting Species

Plant selection is based on considerations of appropriate temperature, depth, flows, and pH ranges, while targeting specific contaminants (in each zone) and being mindful of aesthetics. Specific species selection is modifiable in order to meet the research and development goals of the botanical garden. Recommended plant species that meet the functionality targets of the various sections of the CW are outlined in Table 11.

Table 11: Plant Selection By Section

Section	Plant Type
Forebay	Rushes (*Juncus*); Reeds (*Poaceae spp.*)
Wetland	Duckweed (*Lemnaeceae*); Pennywort (*Centella asiatica*); Rushes (*Juncus*)
Outlet pool	Duckweed (*Lemnaeceae*); Pennywort (*Centella asiatica*); Reeds (*Poaceae spp.*)
Banks and Flood Plain	Spike Rush (*Eleocharis palustri*); Hyacynth (*Hyacythus*)

Landscaping layout will be in a triangular grid with 18 inch lateral spacing to provide sufficient room for root establishment and plant growth without overcrowding. Linear rows will be oriented perpendicular to flow in order to prevent channelization. First planting should be done 5-6 months prior to intended operational start to allow the plants to establish themselves and acclimatize to the environment.

The main considerations for plant selection are ambient environment and capacity to remove contaminants. By selecting pertinent criteria and judging the performance of different plants in conditions that would likely be experienced at the botanical gardens, appropriate plants were selected and optimal performance ranges were determined. Three environmental criteria were considered to be critical to plant survival: temperature, salinity, and pH. Researched values for appropriate criteria ranges were obtained from a number of pre-existing studies and tabulated for comparison against climatic information relevant to the botanical garden. Removal of all contaminants (previously discussed) were considered in plant selection. The plants selected for the forebay are Rushes (*Juncus*) and Reeds (*Poaceae spp.*). Both of these plant species will have optimal productivity and contaminant removal capacities within a temperature range from 15-30˚C, pH from 4-9, and a maximum salinity of 45ppt. Both plants will offset each other in removal capacities at either end of the spectrum, thus allowing for maximized productivity over a broader range. Note that Cattails were not selected, despite their presence in the existing marsh, as they have a high tendency to become invasive. This invasive nature would result in a higher maintenance requirement, with more frequent removal of organic material build up.

2.7 Maintenance

Four access points have been designed to allow for vehicles, workers, and equipment to enter the wetland riparian area and inundated areas (*noted in Figure 10 in Appendix A*). These access locations are designed to minimize impact to the wetland, re-suspension of sediments and disturbance to vegetation. An emergency drain is installed to allow access for repairs and for sediment control practices. Trash racks and screens are installed at the inlet/outlet and at weirs to minimize litter and debris problems. The following table outlines major routine and non-routine maintenance procedures for the wetland. Overall costs of operation and maintenance are estimated at 3 – 5 % of the base construction cost of the CW. Note that, despite requirements for maintenance and manual weir adjustments, there will be a net decrease in time currently spent by garden staff maintaining the existing cattail marsh according to estimates given by Andy Hill of the Botanical Garden.

Table 12: Routine and Non-Routine Maintenance Procedures for the Forebay and Entire Constructed Wetland

Item	Description
ROUTINE MAINTENANCE	
Mowing [1]	At least twice/year. Surrounding grass maintained as a "meadow", free of woody growth/weeds.
Inspection [1]	1-2/year and during wet weather. Inspect inlet/outlet flow devices for clogging or damage. Evaluate erosion, accumulation of sediment, and nuisance factors (insects, weed growth, algae). Maintain specified depth zones to optimize performance.
Remove Debris [1]	Performed manually in sensitive areas during mowing operation. Remove floatables annually.
Vegetation	Vegetation monitored regularly; invasive/dominating species contained to promote diversity; maintain a minimum of 50% surface area coverage. Remove plants inundated with sediment to reduce further accumulation of sediment/organic matter. [2]
NON-ROUTINE MAINTENANCE	
Vegetation Removal [1]	Wetland vegetation harvested annually to promote nutrient removal & prevent accumulation/flushing of dead vegetation from wetland at the end of the growing season.
Replace inlet/outlet [1]	To be done as required.
Sediment Removal [1]	Forebay should be dredged when accumulated sediment exceeds 25% of the pool's volume; typically every 5-10 years.[3] (Site-specific studies may show solubilization of pollutants from accumulated bottom sediment, requiring **annual** cleaning). Required dredging for wetland section is 10-20 years (site-specific). * Note: disposal of sediment is subject to local waste classification and regulations. The two most cost-effective options are (1) Direct Landfilling or (2) Gravity Thickening and subsequent lime-stabilization and land spreading.
Riparian Vegetation [3]	Maintain riparian vegetation cover (roots of trees/shrubs) to stabilize banks & prevent erosion. *Note: activities in the riparian/buffer regions should only take place when conditions are suitable (dry/frozen ground) to avoid compacting the soil and damaging vegetation.
Shoreline Structure [3]	Maintain structure of shoreline to provide breeding habitat, escape cover, and food.
Tree Canopy [3]	Thin tree branches of understory, but maintain 80-90% of existing canopy. Do not place slash/branches/limbs from cuttings within riparian area or where they may enter wetland.

[1] (BCRCWMG, 1992) [2](South Carolina DHEC, 2005) [3] (Cox, Cullington & Associates, 2009)

It is important to assess the erosion, flow channelling, and sediment accumulation/dispersion immediately following all storm events greater than 2 inches of rainfall. A "sediment cleanout stake" is installed in the forebay to help monitor sediment accumulation and determine when dredging is necessary. Cleaning only half of the basin in one growing season, and the other half the following year minimizes impacts on the wetland as well as maintenance requirements (VCSQMP, 2001). Removal and disposal of dead material is required due to accumulation of metals, nutrients, and other toxic pollutants from the stormwater (Hoban, 2002). Periodic evaluation of wetland performance with potential for upgrade and modification is recommended due to high rates of climate change and community demands of UBC.

3.0 Structural Design Components

This section details the structural design of the flow control structure between the forebay and wetland zone: the concrete weir and aluminum stop log assembly. The physical design, loading case, and concrete foundation of the weir are discussed. Note that calculations presented can be used to design other weirs in the CW.

3.1 Physical Design of Weir and Aluminum Stop Log Assembly

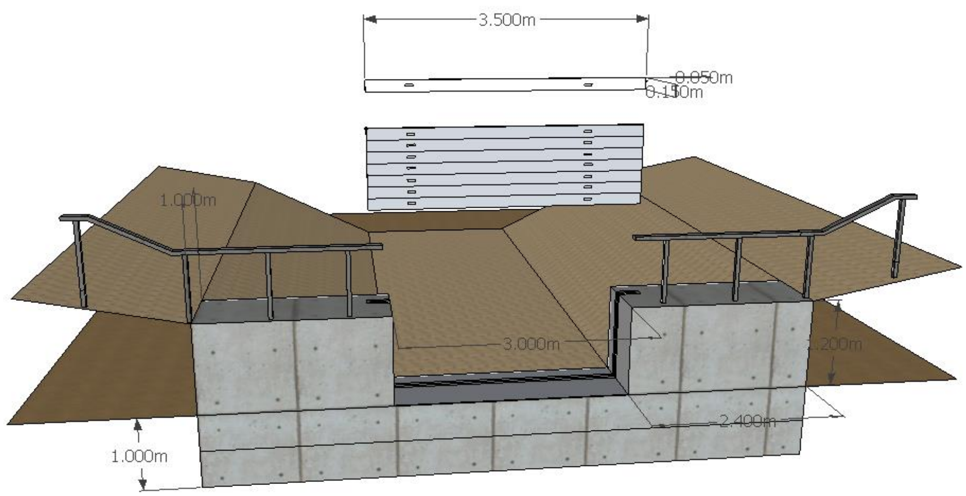


Figure 1: Weir Design

This concrete weir and aluminum stop log assembly, as shown in Figure 1, is intended to control the flow from the forebay to the wetland by changing the number of inserted weir boards. The fabricated weir boards are designed to slide into a steel frame cast integrally into the concrete weir. The weir boards are fabricated with aluminum for its strong, water resistant, and light-weight characteristics. This allows the boards to be easily added or removed by workers. A thin rubber seal is provided between each board to minimize leakage. Hand rails and ladder access rungs are provided to facilitate worker safety and maintenance access during dredging and weir board adjustment activities. The following list contains the relevant dimensions of the design.

- Each aluminum weir board is 3.5 m x 0.15 m x 0.05 m (b x h x t)
- There are 8 weir boards in total and therefore the total maximum height is 1.2 m. This is also equal to the maximum depth of the main channel.
- The weight of each board is approximately 70 kg, which overcomes the buoyancy force, and therefore, a mechanical locking system for securing the stop logs is deemed unnecessary.
- The plan view width of the concrete weir is 1.0 m. This is sufficient clearance to allow workers walk along the structure to access to the weir board and performance maintenance.
- The depth of the foundation below grade is 1.0 m.

3.2 Design Loading Case for Weir

The forces acting on the concrete weir include the hydrostatic force, kinetic force from the flow, and the potential settlement force. However, the forces from flow (subcritical) and settlement are negligible. Therefore, only the hydrostatic force is considered in the design calculation. Figure 2 below displays the hydrostatic pressure profile of the worst design case: forebay flood plain full on one side and wetland empty on the other side. This loading case represents the maximum driving force against the minimum resisting force.

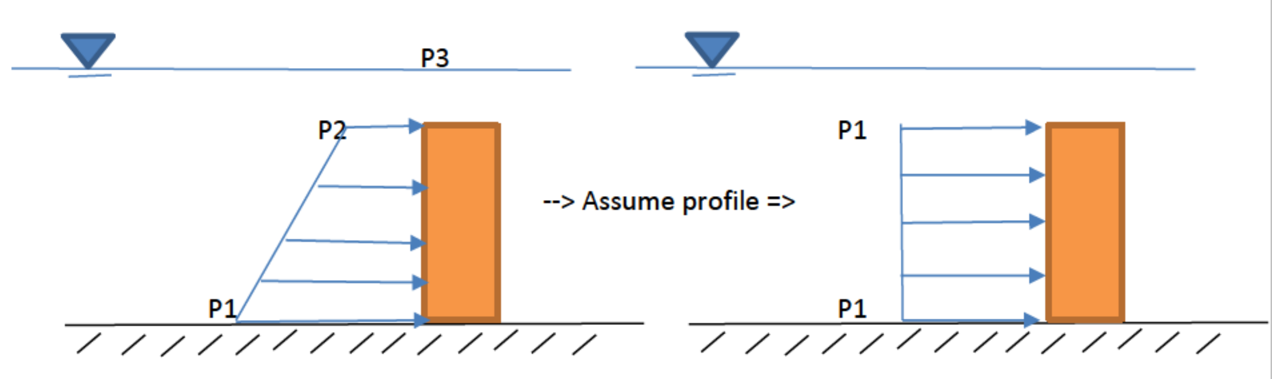


Figure 2: Hydrostatic pressure profile

Table 13: Hydrostatic Pressure Profile

	Depth, z (m)	Hydrostatic Pressure, P (Pa)
P1)	1.62	16000
P2)	0.45	4500
P3)	0	0

Where: $P = \rho g z,$

$\rho = 1000\, kg/m3 \quad g = 9.81\, m/s2$

After consulting with Dr. Haukaas at UBC, the pressure profile was assumed to be uniformly distributed (as shown above) rather than linear. This results in a conservative analysis and also simplifies the design calculations. The weir boards are then analyzed as simply supported beams with maximum stress at the centre of each weir board. Figure 3 and Table 14 summarize the weir board design calculations. The calculated factor of safety is 2.2, which is deemed acceptable.

Figure 3: Stress on weir board calculation

Table 14: Factor of safety of weir board summary

Distributed force, q	$\mathbf{q = \rho gzmax * hw}$	2.38	kN/m
Max Moment, M	$M_{max} = qb^2/8$	2.68	kNm
Max Stress, σ	$\sigma_{max} = M_{max}/I \left(\frac{t}{2}\right)$	42.91	MPa
Aluminum Yield Stress	-	95	MPa
Factor of Safety	FS = yield stress/ σ_{max}	2.21	

3.3 Foundation Design

The weir foundation is designed based on loading calculations presented in Section 3.2 and geologic information obtained from a nearby site investigation at UBC. The geotechnical investigation was completed in October 2013 by GeoPacific Consultants Ltd. near the intersection of Agronomy Road and West Mall for the development of Orchard Commons. This site is located about 720m from the proposed wetland and is the closest site with readily available geotechnical information. For design purposes, the soil layers under the wetland are assumed to be of similar composition and depth as those found in the aforementioned investigation. This information enables determination of values for unit weight and angle of internal friction, shown in Table 15. Due to uncertainties in actual soil composition, conservative values were selected.

Table 15: Soil Layers Characteristics

Composition	Depth	Unit Weight	Angle of Internal Friction
Fill (Sand and Gravel)	0 to 1.6m	17.0 KN/m3	34
Silty Sand and Gravel	1.6 to 3m	19.6 KN/m3	35
Sand and Gravel	3m on	-	38

The weir is 1m wide along the crest in order to enable walking on it for maintenance operations. The total length across the channel is 7.8m, with a gap in the middle where the aluminium stop logs are located. Such large dimensions favour the design of the weir as a gravity wall, which relies mostly on its own weight to resist lateral loads. The proposed design is analysed against three modes of failure: sliding, rotation and soil bearing capacity. Initially, a simple design of a straight wall of uniform width was considered in order to attempt to reduce material costs, but calculations showed that it would likely fail by rotation. Therefore, the design evolved to a cantilever with a 1.5m x 7.8m base, as shown in Figure 9, Appendix A. The following analyses follows procedures described in "Foundations and Earth Retaining Structures" (Budhu , 2007).

3.3.1 Sliding

The sliding failure mode compares the resisting friction force between the base of the structure and the soil with the total horizontal applied force acting on it as shown in Equation (1). FS is the Factor of Safety against sliding; W_w, W_{wa} and Ws are the weight of the weir, the water above the base and the soil above the base respectively; $\emptyset b$ is the interfacial friction between the base of the wall and the soil (obtained from the angle of internal friction); Pp and Pa are the forces from soil passive and active pressures respectively, calculated based on Rankine's method; Pax is the total water force acting against the structure.

$$FS = \frac{(Ww + Ws + Wa) * \tan(\emptyset b) + Pp + Pa}{Pax} \qquad (1)$$

The Factor of Safety of the designed structure against sliding is 3.14; thus considered safe.

3.3.2 Rotation

A structure is considered safe against rotation when its center of gravity [CG] (considering the soil and water above the base and the horizontal forces acting on the weir) is located inside the middle third of the base. Equation (2) is used to find the CG. In this equation, x_w, x_s, x_{wa} represent the CG of the weir, the soil and the water respectively; za_x is the height of application of the resultant water force; x is the CG of the structure.

$$x = \frac{Ww * xw + Ws * xs + Wwa * xwa - Pax * zax}{Ww + Ws + Wwa} \qquad (2)$$

The calculated CG is inside the middle third (6cm away from the limit). The forces due to passive and active pressures of the soil were not considered in this analysis with the objective of being conservative and increasing the safety factor with respect to rotation. In this case, inclusion of these latter components would place the CG nearer to the center of the base; thus to ignore these factors is conservative.

3.3.3 Bearing Capacity

The critical soil parameter for calculating the bearing capacity is the angle of internal friction. The soil is not fine grained, thus an Effective Stress Analysis (ESA) was used, as shown in Equation (3).

$$qu = \gamma * Df * (Nq - 1) * sq * dq * iq * bq * gq * rq * wq + 0.5 * \gamma * B' * N\gamma * s\gamma * d\gamma * i\gamma * b\gamma * g\gamma * r\gamma * w\gamma \qquad (3)$$

γ is the effective unit weight of the soil; Df is the depth of the lower base; Nq is a bearing capacity factor obtained from the angle of internal friction; B' is the effective base width; Nγ is another bearing capacity factor (based on equation proposed by Davis and Booker (1971) for rough soils). The remaining parameters were obtained from Budhu and are in accordance with the Canadian Foundation Engineering Manual: sq and sγ are shape factors obtained based on B' and L' (effective length); dq and dγ are embedment depth factors; iq and iγ are load inclination factors, bq and bγ are base inclination factors and gq and gγ are ground inclination factors (all inclination factors equal 1 for no inclination). Negligible compressibility of the predominantly sand and gravel material on site result in compressibility factors (rg, rγ) to be estimated as 1. For groundwater factors (wq and wγ) groundwater was assumed at grade elevation. The ultimate bearing capacity obtained from Equation (3) is 1015 KN/m^2, giving a Factor of Safety of 14.5.

3.3.4 General Considerations

Although there is a degree of uncertainty in the data used for the analysis, high factors of safety provided and conservative assumptions for loads and soil parameters minimize the risks for all failure modes. In order for the soil passive pressure to be completely mobilized there is normally a small displacement of the structure. Due to the large contact area between the surface of the weir with the soil and the relatively low horizontal force caused by the water pressure, this potential displacement effect is not a significant concern. In addition, the structure is not affixed to other structural elements and thus a very small lateral displacement of the whole structure will not have significant consequences. Possible negative water pressure acting on the soil above the base is also not a concern because even if the soil weight was completely disregarded in the analysis, the FS for sliding is still relatively high and the structure's center of gravity remains in the middle third of the base.

3.4 Soil and Liner

Prior to construction the excavated native material will require compaction to a level no less than 98% Standard Proctor Density in accordance with CSA standards. This will provide sufficient compaction to combat the potential effects of loose coarse-grained material densifying and exhibiting unstable behaviour or settlement of fine-grained material. Generalized specifications are used to account for uncertainties in material properties due to a lack of site-specific investigations.

Consideration of liner material is critical to the design. Two alternatives have been considered in detail; a geosynthetic clay liner (GCL), or a compacted clay liner. GCL is comprised of a layer of bentonite sandwiched between layers of geotextile, thus forming a composite material. Both have benefits and downfalls with respect to cost, maintenance, and synergy with the UBC Botanical Garden's mission. Table 16 compares the pros and cons of both considerations, with ultimate design decision requiring approval from the client depending on the value and priority they place on each component of design.

Table 16 - Benefit analysis of Liner Material

Material	Advantages	Disadvantages
Geosynthetic Clay Liner	• Less expensive (up to \$1.50/ m^3) • Smaller thickness required (approximately 200mm) • Smaller footprint (2H:3V slope) • Predictable water loss when properly installed • Conventional construction equipment	• Require heat-welded seams • Reliant on expertise in construction • Potential for damage with insufficient care in construction and maintenance • Hard to conceal as natural • Increased difficulty of plant establishment • Increased complexity of construction and integrity testing
Compacted Clay Bentonite	• Natural appearance to meet BG mission • Conventional construction equipment • Damage during maintenance and construction not concerning • Ease of plant establishment • Simpler construction testing	• Larger footprint (2H:1V slope) • Reconstituted clays have lower internal friction ability • Uncertainties in long-term stability • Need to import clay for construction – cost, trucking, and potential impacts on garden due to increased truck traffic • Higher cost (up to \$6.50/m^3) • Thicker layer required (up to 500mm)

Following analysis the liner material that is recommended for the UBC Botanical Garden is a bentonite clay liner. Clay material will be a well graded fine clay or till from an appropriate borrow source. Testing will include gradation, atterberg limits, and standard proctor density (SPD) and will adhere to policies as laid out in the provincial guidelines. Compaction will be required to provide conductivity of less than 10^{-9}m/s as per the ASTM guideline for liquid storage facilities.

Overlaying the liner will be a growth media layer which will help to facilitate rooting and establishment of plant heartiness and biodiversity. This layer will be native sand and gravel (USC class SG) material providing optimal growth conditions for the selected cleansing plants. Nominal depth of this layer is specified as 500mm, which will allow adequate root establishment and confinement of selected plant species without damage during vacuum dredging procedures.

4.0 Project Management

Focused on efficient resource allocation, the project management constituent of design will consider design optimization through cost and schedule. Design is optimized to benefit all relevant stake holders. Parameters considered for optimization include, equipment, material, workers, schedule, and budget.

4.1 General Design

Project management is broken down into work plan, construction schedule, cost estimate, and general provisions as outlined below.

4.1.1 Work Plan

Construction will be conducted in many stages, outlined below in Table 17. Elements will be staged such that concurrent construction may occur with minimal interference between appropriate allocation of equipment, materials, and workers.

Table 17: General list of tasks

Task Group	Task	Details
Site Preparation	Site set up	Site trailers, fencing, equipment storage
	Garden collection relocation	Relocate plants from wetland to safe area
	Construction survey boundaries	Survey layout
	Dewatering	Pump out wetland and groundwater for construction
Earthworks	Excavation/stripping	Excavate to grade, stockpile wetland growth media
	Importing/haul away material	Import gravel, clay, and topsoil; haul away unwanted
	Forebay material placement	Grading, clay liner and growth media
	Wetland material placement	Grading, clay liner and growth media
	Outlet micro-pool material placement	Grading, clay liner and growth media
Utilities/ Structures	Inlet structure	Precast headwall, drain rock, PVC pipe
	Forebay/wetland weir	Concrete with aluminum weir boards
	Wetland/outlet micro-pool weir	Concrete with aluminum weir boards
	Outlet structure	Precast headwall, drain rock, PVC pipe
Landscaping and Botany	Planting wetland species	Various submerged and floating plants[1]
	Landscaping and reseeding	Planting in banks and garden area, reseed great lawn
Clean-up/ Commission	Site clean-up and commissioning of wetland	Remove fencing, site trailers and equipment; introduce water to wetland

[1] Landscaping is conducted in accordance with specifications set out in Table 11

Additional provisions have been made for post-construction testing which will provide quality assurance and identify and mitigate any issues prior to final site clean-up and commissioning.

Crew labour requirements are outlined below in Table 18.

Table 18: Crew details

Surveying Crew (Crew A-6)	Construction Crew (Crew B-14)	Dirt hauling Crew (B-34A)	Structural Construction crew (C-15)	Landscaping Crew
1 Instrument man	1 Labour foreman	1 Trucks driver (heavy	1 Carpenter foreman	1 Landscape designer/supervisor
1 rodman	4 Labourers	1 Dump truck	2 Carpenters	2 Labourers
1 laser transit and level	1 Equipment operator (light)		3 Labourers	
	1 Backhoe loader (36 kW)		2 Cement finishers	
			1 Rodman (rein.)	

4.1.2 Schedule

Construction start date is set as October 13, 2014 with scheduled completion December 3, 2014. The work schedule consists of five-day work weeks and eight-hour work days throughout the eight weeks of construction. Selection of this construction period is based on minimizing impacts on wildlife such as birds and amphibians that may be present in the gardens (BC Government, 2004). Additionally this schedule avoids construction during peak visitation season to minimize adverse impacts on visitor experience. Special consideration has been made to accommodate the Apple Festival, scheduled for 11-12 October 2014, as this is a critical element of the botanical garden identity. Thus construction commences immediately following the Apple Festival in order to capitalize on weather conditions prior to winter variability.

The schedule is focused around the major tasks of the constructed wetland:

1. Site preparation (3 days)
2. Earthworks & Structures (concurrent for 5 weeks)
3. Landscaping/Botany (2 weeks)
4. Clean-up and commissioning (2 days)

Critical path analysis was undertaken to optimize concurrent construction techniques for the efficient completion. Tasks can then be considered as critical or flexible, depending on their overall impacts of delay and priority can be set on site accordingly. Details can be seen in the Gantt chart provided on the following page.

4.1.3 Cost Estimate

Cost estimates are derived from RSMeans data and through consultations with Dr. Sheryl Staub-French, and are broken down into categories shown in Table 19. Values from the reference guide are adjusted for location and time, and local tax considerations. A detailed breakdown of cost analysis is provided in Appendix B.

Table 19: General cost estimate

Materials	**$106,241.95**
Labour/Equipment/Maintenance	$118,849.70
Engineering/Design	$45,528.67
Taxes (materials sales and unemployment tax)	$14,646.12
Time adjustment	$33,959.02
Location adjustment	$28,415.13
Final	~ **$350,000**

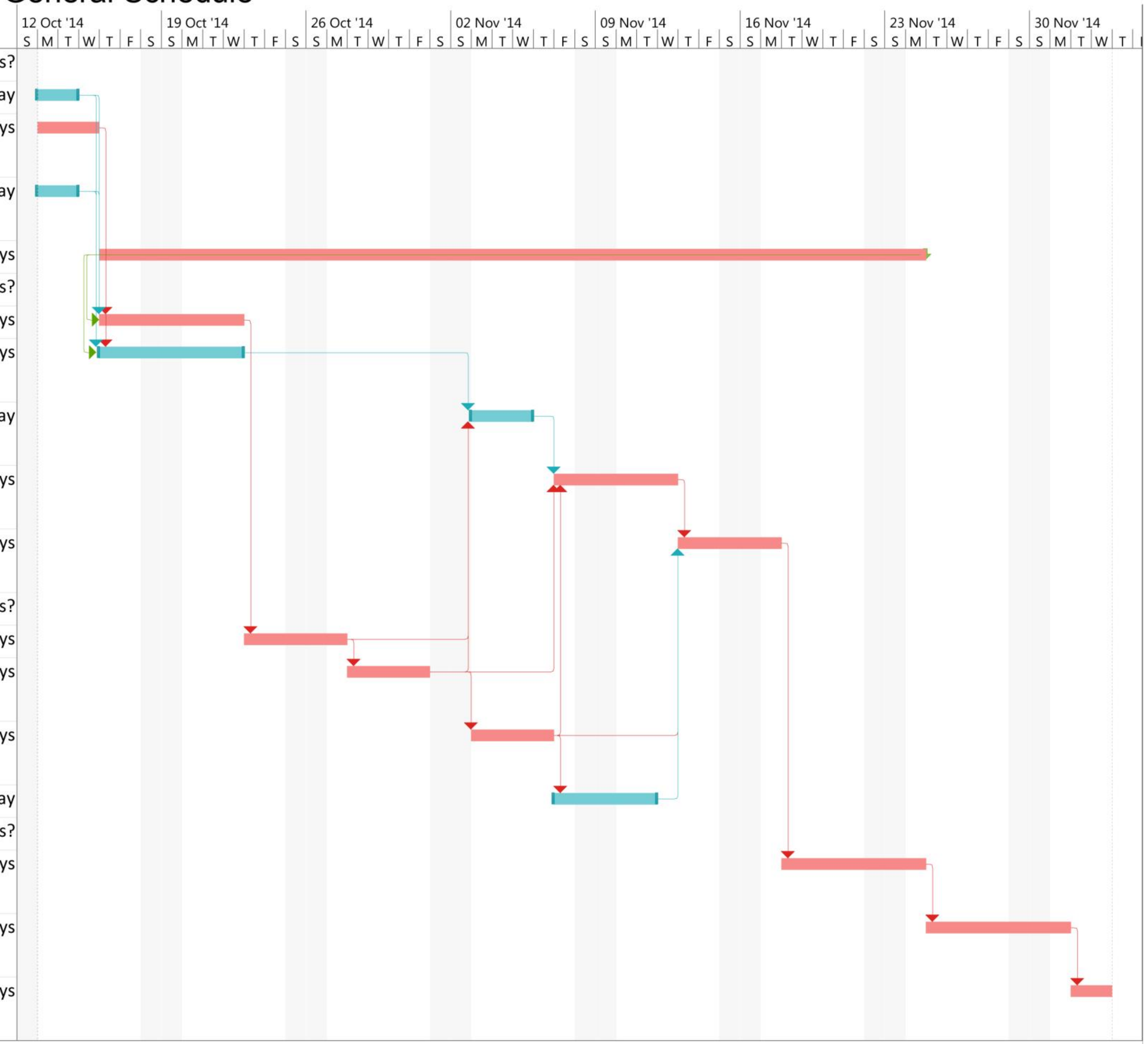
(RSMeans reference guide, 2009)

4.1.4 General Provisions

Construction plan layout, as provided on page 24, consists of access, truck turnaround, equipment storage, material laydown areas, a muster point, and a site office, which will be bound by construction fencing for public safety.

General Schedule

ID		Task Name	Duration	Start	Finish	Predecesso	Total Slack
1		Site Preparation					37 days?
2		Site set up	2 days	Mon 13/10/14	Tue 14/10/14		1 day
3		Garden collection relocation	3 days	Mon 13/10/14	Wed 15/10/14		0 days
4		Construction survey boundaries	2 days	Mon 13/10/14	Tue 14/10/14		1 day
5		Dewatering	28 days	Thu 16/10/14	Mon 24/11/14		0 days
6		Earthworks					37 days?
7		Excavation/stripping	5 days	Thu 16/10/14	Wed 22/10/14	3,5SS,4,2	0 days
8		Importing/hauling away material	5 days	Thu 16/10/14	Wed 22/10/14	2,3,4,5SS	8 days
9		Forebay material placement	3 days	Mon 03/11/14	Wed 05/11/14	8,13,14	1 day
10		Wetland material placement	4 days	Fri 07/11/14	Wed 12/11/14	9,15,14	0 days
11		Oulet micro-pool material placement	3 days	Thu 13/11/14	Mon 17/11/14	10,15,16	0 days
12		Utilities/Structures					37 days?
13		Inlet structure	3 days	Thu 23/10/14	Mon 27/10/14	7	0 days
14		Forebay/wetland weir	4 days	Tue 28/10/14	Fri 31/10/14	13	0 days
15		Wetland/outlet micro-pool weir	4 days	Mon 03/11/14	Thu 06/11/14	14	0 days
16		Outlet structure	3 days	Fri 07/11/14	Tue 11/11/14	15	1 day
17		Landscaping/Botany					37 days?
18		Planting wetland species	5 days	Tue 18/11/14	Mon 24/11/14	11	0 days
19		Landscaping and reseeding	5 days	Tue 25/11/14	Mon 01/12/14	18	0 days
20		Clean-up and commisioning	2 days	Tue 02/12/14	Wed 03/12/14	19	0 days



Project: General Schedule
Date: Wed 26/03/14

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

Figure 4: General schedule Gantt chart

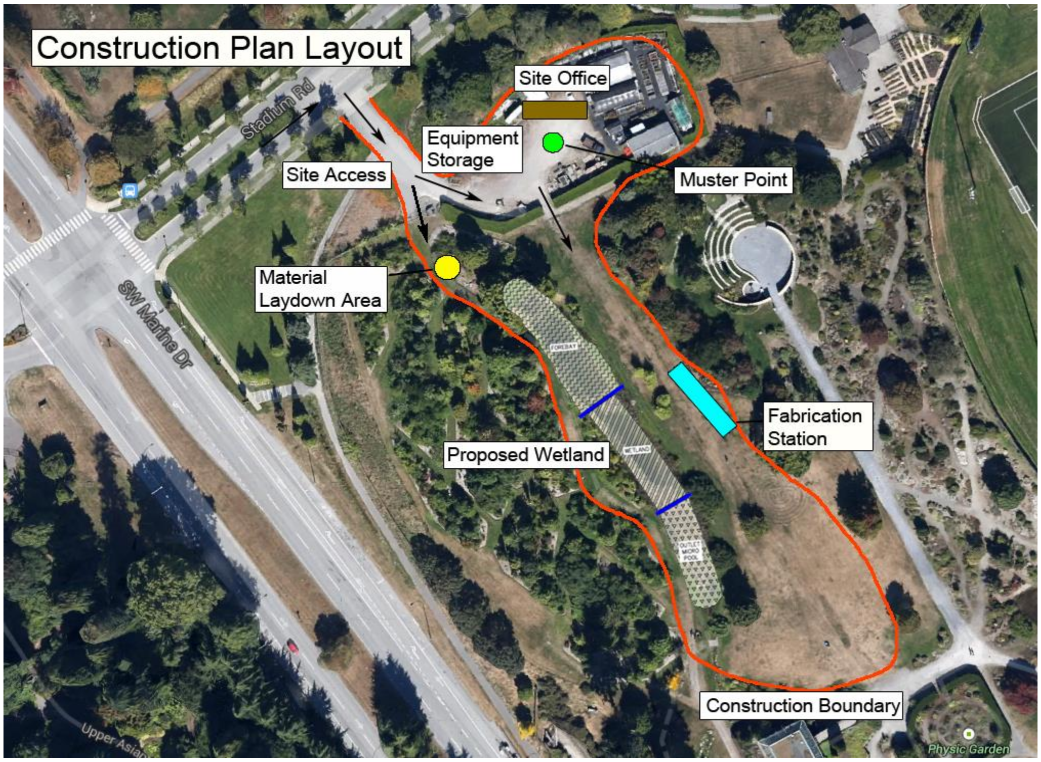


Figure 5: Construction plan layout

Construction Monitoring (QA/QC) will be provided through site inspections scheduled periodically throughout construction by a project manager. Additionally a site superintendent will be present for constant monitoring. **Workplace Safety** is critical and will be carefully adhered to in accordance to BMPs and WCB regulations. This will include a site specific hazard assessment and provision of appropriate orientation and PPE for all workers. Additionally, a safety officer will be appointed to the site. **Efficiency Management** will be facilitated through optimization of operational methods and processes. This will be done via resource allocation and crew organization. **Information management and communication** will be maintained through BMPs for optimal site efficiency regular site meetings will be held with issuing of daily progress reports and issuing updated schedules. **Financial management** will regulate cash flow between project elements and ensure no improper designation of funds. This will also involve an element of documenting and monitoring any alterations to any project element.

4.2 Detailed Forebay Design

Tasks necessary for forebay construction are outlined in Table 20: Forebay List of Tasks. Elements of subgrade construction will be conducted sequentially beginning at the inlet. Subgrade construction will be completed prior to installation of structural elements in the forebay. Final landscaping will be conducted following completion of construction to prevent damage inherent to construction activities.

4.2.1 Work Plan

Table 20: Forebay List of Tasks

Task Group	Task	Details
Site Prep	Construction survey boundaries	Survey layout
	Garden collection relocation	Relocate plants from wetland to safe area
	Dewatering	Pump out forebay and groundwater for construction
Earthworks	Excavation/stripping	Excavate to grade, stockpile forebay growth media
	Importing/haul away material	Import gravel, clay, and topsoil; haul away unwanted
	DP1 material placement	Clay liner and growth media placement
	DP2 material placement	Clay liner and growth media placement
	DP3 material placement	Clay liner and growth media placement
	DP4 material placement	Clay liner and growth media placement
	Compaction and grading	Compact and grade to appropriate elevations
Utilities/ Structures	Inlet structure	Excavate to grade
		Tie-in and install PVC pipe
		Install headwall
		Backfill and drain rock
	Forebay/wetland weir	Structural base aggregate
		Assemble rebar and handrails
		Assemble formwork
		Pour concrete and set
		Strip formwork
Landscaping and Botany	Planting wetland species	Various submerged and floating plants
	Aesthetic and Landscaping	Planting in banks and garden area

4.2.2 Forebay Construction Schedule

The schedule of the forebay will occur over 2.5 weeks, beginning on October 16 and ending on October 31. A Gantt chart is provided in Figure 6. Major tasks are as follows:

1. Dewatering for the entire period - 2 weeks
2. Excavation - 2 days
3. Inlet structure - 2 days
4. Material placement starting form inlet and working downstream - 2 days
5. Weir construction at the same time as material placement – 3.5 days
6. Compaction and final grading – 1 day
7. Planting and landscaping – 4 days

4.2.3 Cost Estimate

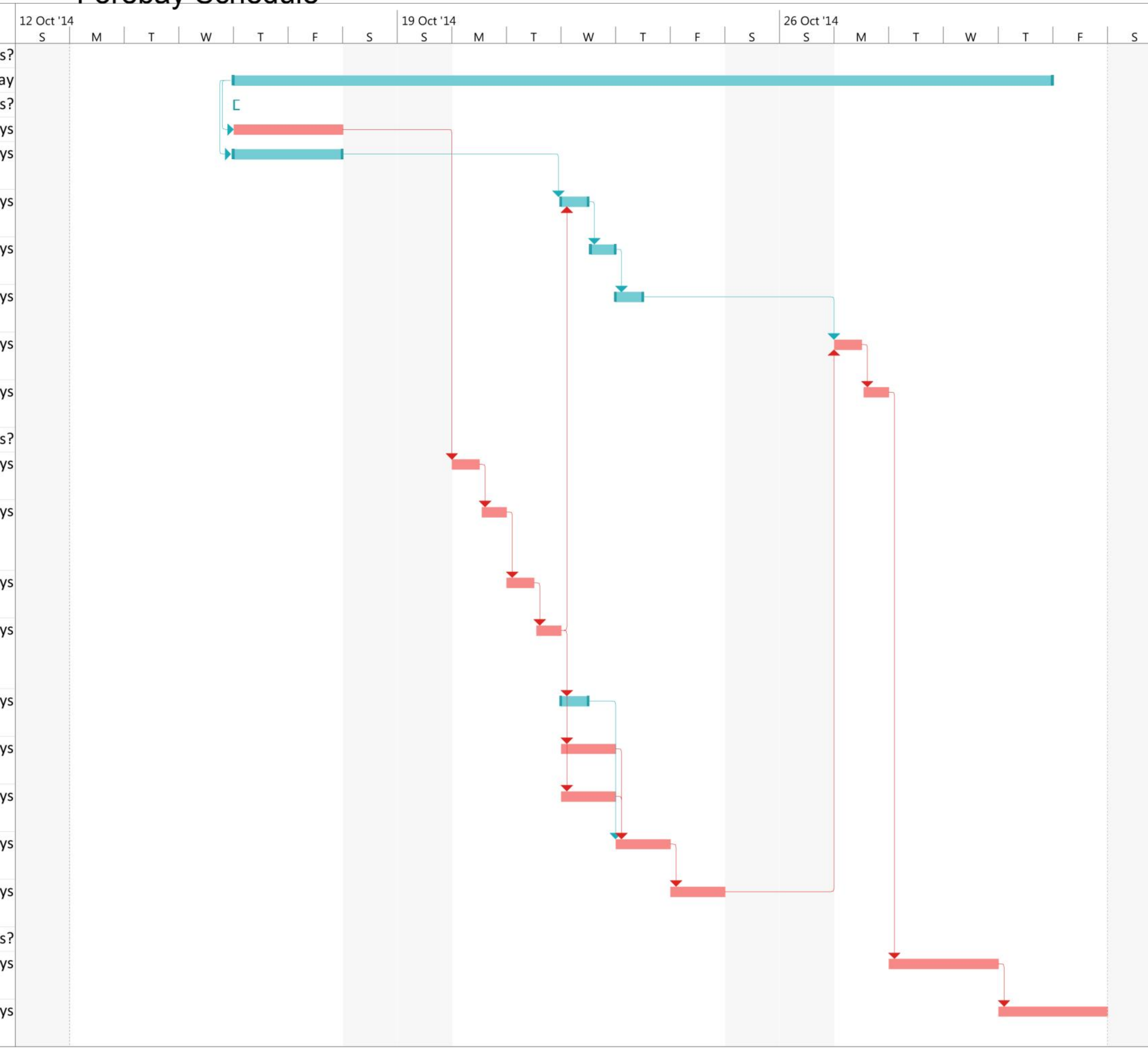
RSMeans data is used for the following cost analysis (similar to the general estimate) with time, location, and applicable tax factors applied. Estimated as 25% of total project cost, the forebay constitutes a lower proportion of cost due to minimal mechanical requirements. Detailed cost breakdown is provided in Appendix B.

Table 21: Forebay cost estimate

Materials	$25,132.98
Labour/Equipment/Maintenance	$34,594.16
Engineering/Design	$8,700
Taxes (materials sales and unemployment tax)	$3,970.07
Time adjustment	$8,586.64
Location adjustment	$7,184.85
Final	~ **$90,000**

Forebay Schedule

ID	Task Name	Duration	Start	Finish	Predecess	Total Slack
1	Site Preparation					14 days?
2	Dewatering	11 days	Thu 16/10/14	Thu 30/10/14		1 day
3	Earthworks		Thu 16/10/14			11 days?
4	Excavation/stripping	2 days	Thu 16/10/14	Fri 17/10/14	2SS	0 days
5	Importing/hauling away material	2 days	Thu 16/10/14	Fri 17/10/14	2SS	3.5 days
6	DP1 Material placement	0.5 days	Wed 22/10/14	Wed 22/10/14	15,5	1.5 days
7	DP2 Material Placement	0.5 days	Wed 22/10/14	Wed 22/10/14	6	1.5 days
8	DP3 Material Placement	0.5 days	Thu 23/10/14	Thu 23/10/14	7	1.5 days
9	DP4 Material Placement	0.5 days	Mon 27/10/14	Mon 27/10/14	8,20	0 days
10	Compaction and Grading	0.5 days	Mon 27/10/14	Mon 27/10/14	9	0 days
11	Utilities/Structures					14 days?
12	Inlet structure -Excavate to grade	0.5 days	Mon 20/10/14	Mon 20/10/14	4	0 days
13	Inlet Structure - Tie-in and install pipe	0.5 days	Mon 20/10/14	Mon 20/10/14	12	0 days
14	Inlet Structure - Install headwall	0.5 days	Tue 21/10/14	Tue 21/10/14	13	0 days
15	Inlet Structure - Backfill and drain rock	0.5 days	Tue 21/10/14	Tue 21/10/14	14	0 days
16	Weir - Structural base aggregate	0.5 days	Wed 22/10/14	Wed 22/10/14	15	0.5 days
17	Weir - Assemble rebar & handrails	1 day	Wed 22/10/14	Wed 22/10/14	15	0 days
18	Weir - Assemble formwork	1 day	Wed 22/10/14	Wed 22/10/14	15	0 days
19	Weir - pour concrete and set	1 day	Thu 23/10/14	Thu 23/10/14	16,17,18	0 days
20	Weir - Strip formwork	1 day	Fri 24/10/14	Fri 24/10/14	19	0 days
21	Landscaping/Botany					14 days?
22	Planting forebay species	2 days	Tue 28/10/14	Wed 29/10/14	10	0 days
23	Aesthetic and landscaping	2 days	Thu 30/10/14	Fri 31/10/14	22	0 days



Project: Forebay Schedule
Date: Wed 26/03/14

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

Page 1

Figure 6: Forebay schedule Gantt chart

5.0 Conclusion and Recommendations

Design detail presented of hydrotechnical, structural, and project management elements of the forebay is indicative of future works of the rest of the CW that will be required prior to construction. Typical cross sections are specified as they facilitate constructability and lead to economy in design. With aims to meet UBC sustainability goals, the CW will be constructed to optimize implementation of natural systems.

Site specific studies are recommended prior to full operation. Existing studies are limited in applicability due to scope and location. Recommended preliminary studies include a geotechnical investigation and a base-flow study for contaminants in the system. Current water quality estimates from the Rock Creek study may be used for preliminary design in conjunction with an as-built survey. Information on actual background levels at CW intake, contaminant removal capacity, operational HRT, and flow conditions will be provided by the advised as-built tracer study. Basic site-specific geotechnical investigations such as test pits and boreholes would decrease uncertainty in soil parameters used in design. This is highly recommended for enhanced geotechnical design, as current studies are not site-specific and soil parameters are highly variable.

CW design encompasses the ability to increase capacity and effluent quality with minor upgrades which may be considered for future expansion. For example simple addition of a return flow would drastically impact the solids retention and therefore removal capacity of the system. This would be done at a higher operational cost due to mechanical requirements, but limited additional manual maintenance would be necessary.

Liner material is recommended as a clay liner for its natural appeal as well as ease of maintenance and upkeep; however, this may be modified to meet stakeholder priorities.

The CW will meet the UBC water management sustainability goals while adhering to the botanical garden's reputation as a premier research facility. By meeting water self-sustainability goals of the campus this project has potential to become an anchor to the garden, drawing in academic and community visitors alike.

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Appendix A: Design Drawings

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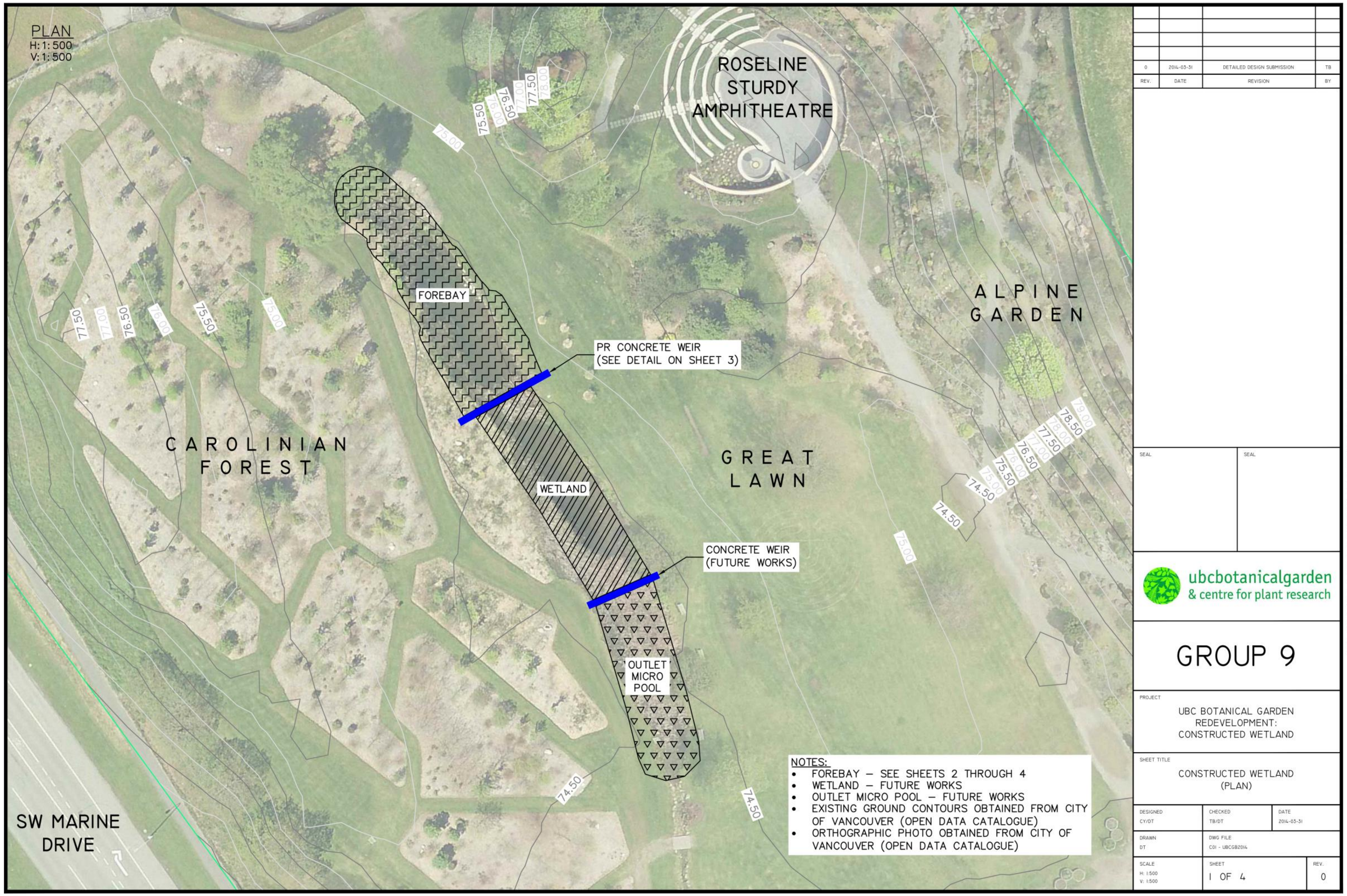

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Figure 7: Constructed Wetland (Plan) (Design Drawing)

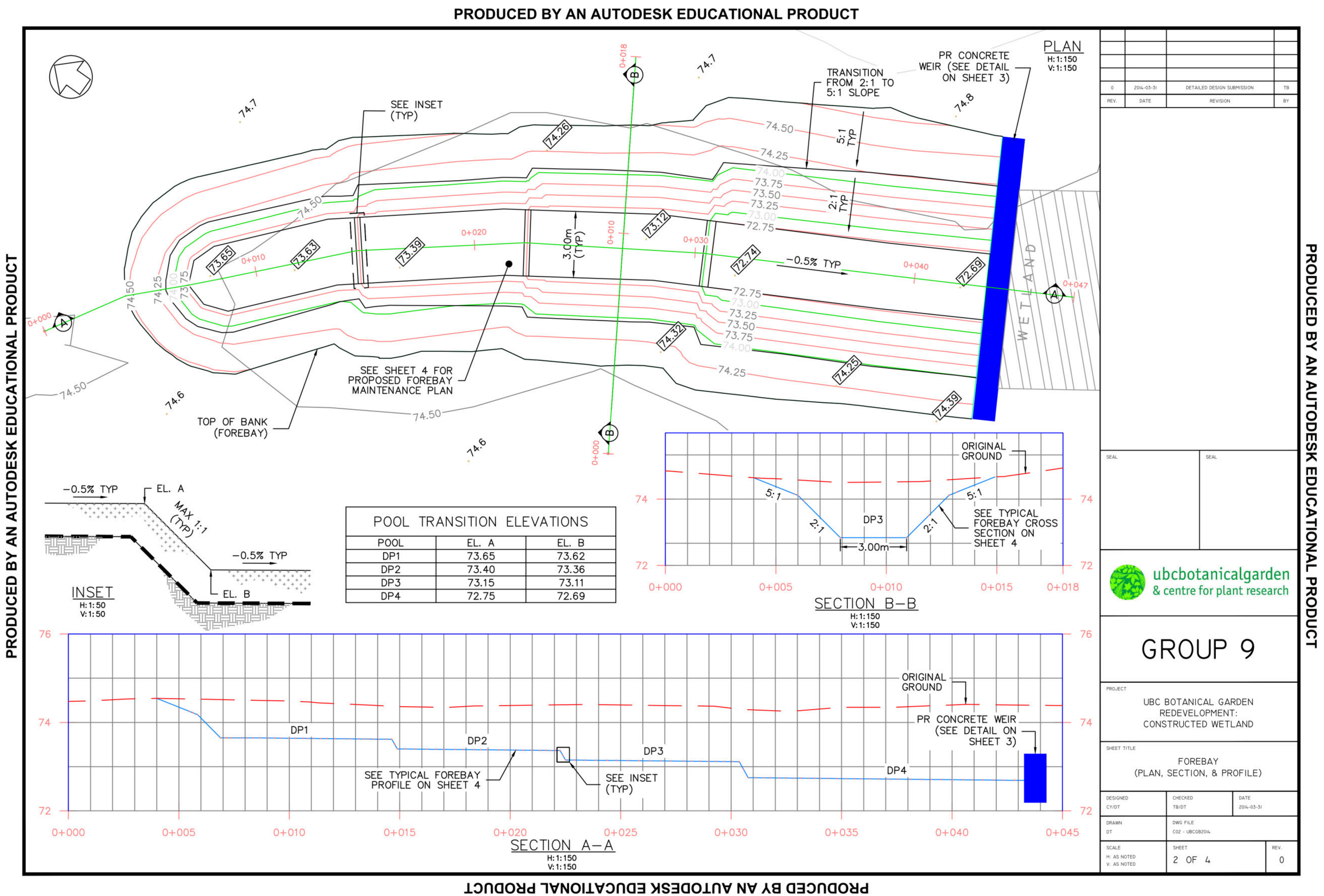

Figure 8: Forebay (Plan, Section, & Profile) (Design Drawing)

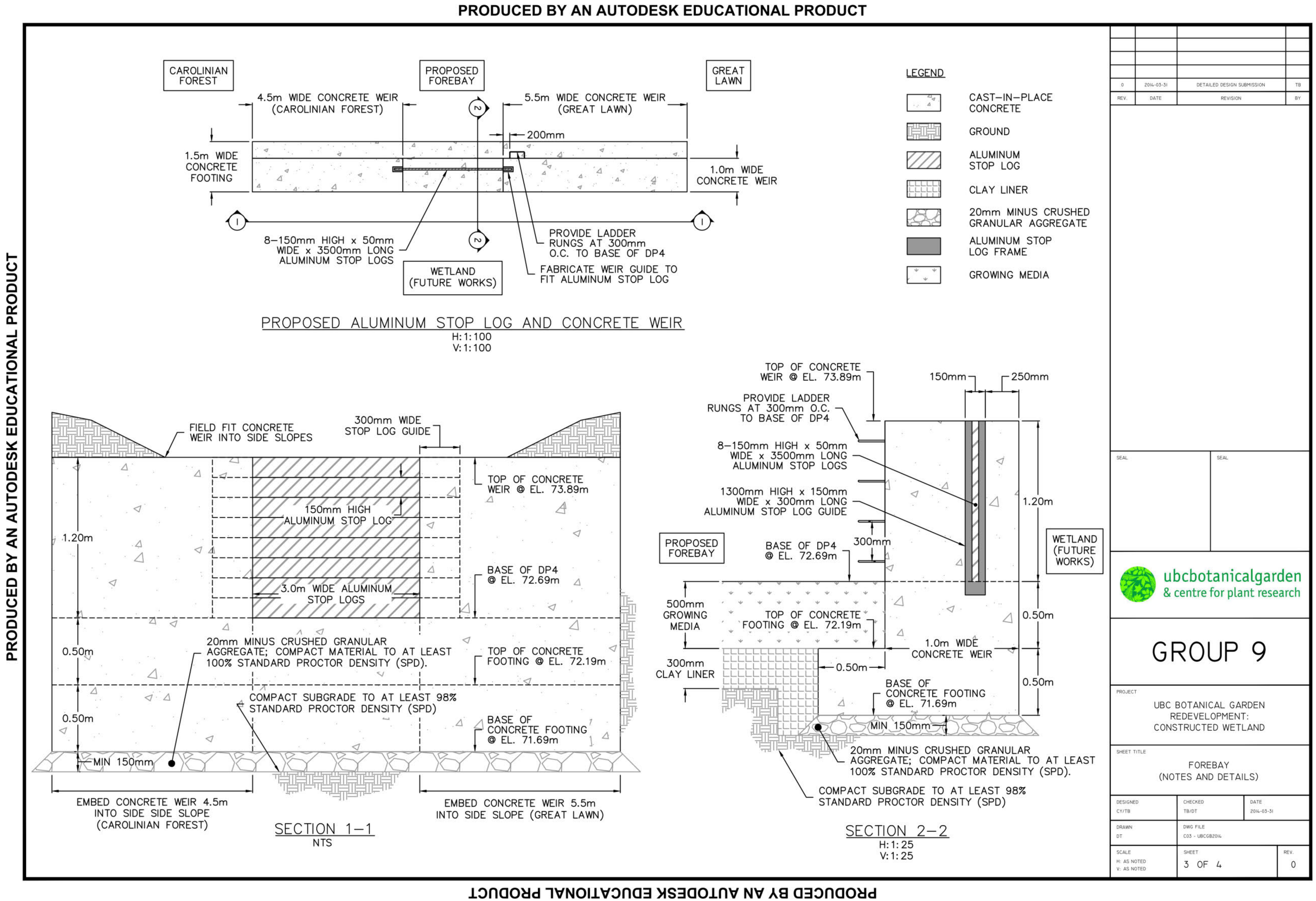

Figure 9: Forebay (Notes and Details) (Design Drawing)

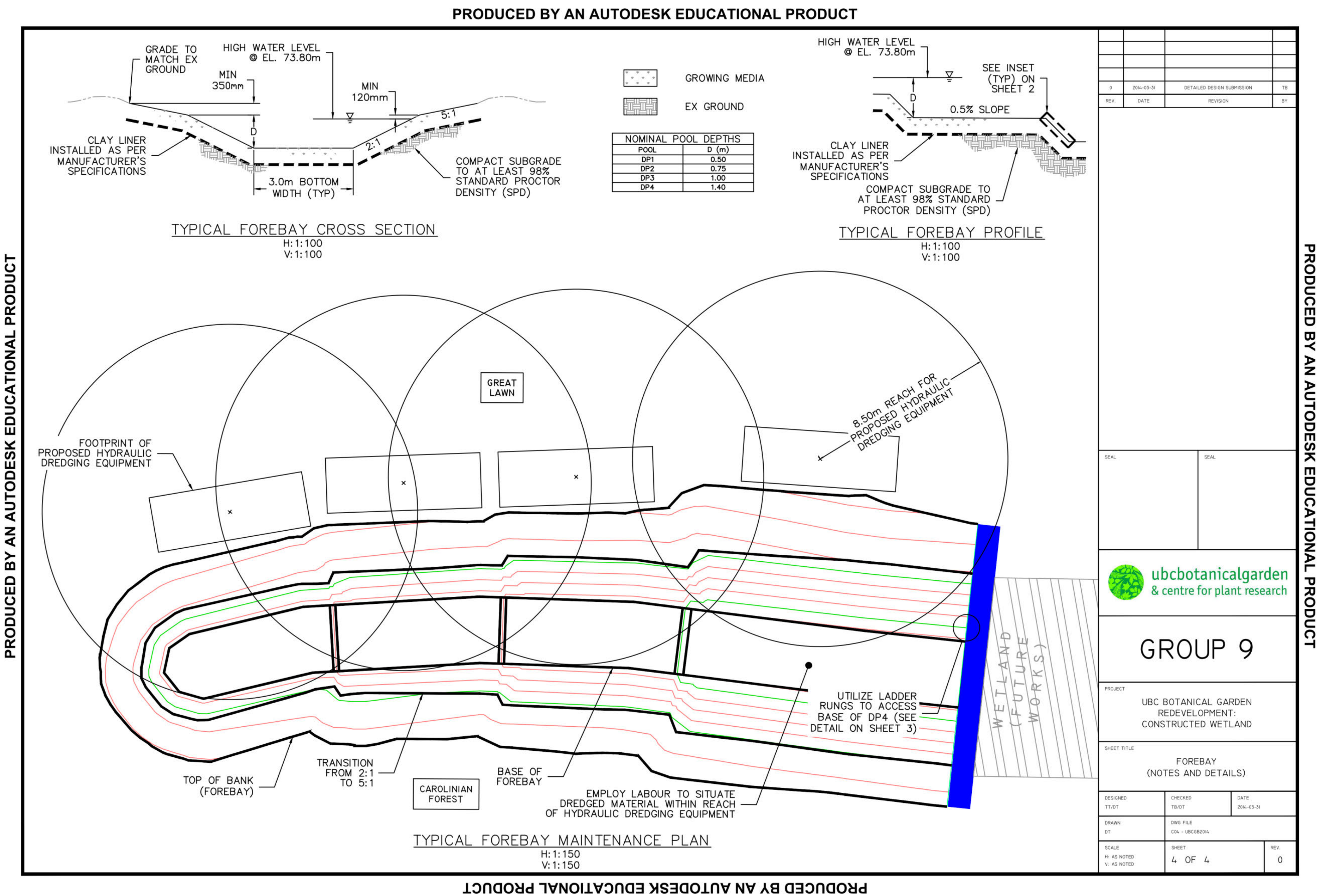

Figure 10: Forebay (Notes and Details) (Design Drawing)

Appendix B: Cost Estimate

General Cost Estimate

Table 22: General cost estimate

Summary

	Materials		$ 106,241.95	
	Labour/Equipment		$ 118,849.70	
	Engineering/Design		$ 45,528.67	
Taxes	Material Sales Tax (avg)	5.06%	$ 5,375.84	
	Unemployment (avg)	7.80%	$ 9,270.28	
Time cost index	2009	180.1		RSMeans
	2014	202.7	$ 33,959.02	
City cost index	Avg	100		
	Vancouver	110.5	$ 28,415.13	MF2004
		Final Total	**$ 347,640.58**	

Materials

Category	Item	Crew	Units	Quantity	Daily Output	Duration	Unit Cost	Total Cost	Sources
Site prep	Site Trailers	B-14	Each	1	1	1.00	$ 700.00	$ 700.00	http://www.360mobileoffice.com/mobile-c
	Temporary fencing (Modu-loc rented)	B-14	m	410			$ 16.14	$ 6,618.11	01 56 26.50 0200 + (modu-loc website)
	Dewatering (3 x 4" diaphram pump)	B-14	Per pump	3	8 hour days	49.00	$ 386.00	$ 18,914.00	31 23 19.20 0650 (+2 additional pumps)
Earthworks	Excavating/Stockpile stripped material/Haul away unwanted	B-34A	m3	307.2	159	1.93	$ 21.98	$ 6,752.76	31 23 23.20 0036 (20 MPh, cycle 8 miles)
	Gravel and coarse aggregate (25mm)	B-14	m3	10	459	0.02	$ 74.07	$ 740.69	31 05 16.10 0300 (+compaction)
	Impermeable clay/till (bentonite)	B-14	m3	292.8	547	0.54	$ 17.54	$ 5,135.60	31 23 23.15 6000 (+compaction)
	Growth media (spreading reused existing wetland soil, include gr	B-14	m3	179.5	459	0.39	$ 4.19	$ 751.29	31 23 23.17 0170 (+spreading)
	Nutrient rich topsoil	B-14	m3	113.3	459	0.25	$ 47.61	$ 5,394.15	31 05 13.10 0800 (+ Hauling)
Concrete	Concrete (30 MPa) (+ waterproofing)	C-15	m3	30	69	0.44	$ 168.86	$ 5,065.69	03 31 05.35 0350 + 03 05 13.80 00500
Metal	Aluminum hand rails	C-15	m	31.2	42	0.75	$ 254.27	$ 7,933.07	05 52 13.50 0140
	Use 20M bar size (+ galvanize)	C-15	Ton	0.3561	0.9	0.40	$ 3,425.00	$ 1,219.64	03 21 10.60 0550 + 03 21 13.10 0150
Formwork	Concrete forming	C-15	m2	64.6	34.47	1.87	$ 68.35	$ 4,415.47	03 11 13.45 5050
Utilities	PVC Pipe (SDR35 sanitary) 200mm	B-14	m	10	102.11	0.10	$ 38.22	$ 382.22	33 31 13.25 2080
	Culvert/headwall (pre cast)	B-14	Each	2			$ 3,600.00	$ 7,200.00	G3030 310 4500
	Trash Guard (grating)	B-14	m2	10	48.31	0.21	$ 387.50	$ 3,875.01	05 53 19.50 0212
	Weir Boards (aluminum plates - pre fabricated)	B-14	m2	7.2			$ 726.56	$ 5,231.26	05 12 23.65 0500
Mechanical	4" MS Stainless Steel Series Submersible Pump (2HP) Pump End		Each	1			$ 1,171.00	$ 1,171.00	
	4" MS+ Stainless Steel Series Submersible Pump (3/4HP) Pump End, PENTEK Motor, CSCR Control Box		Each	1			$ 1,203.00	$ 1,203.00	
	Pentek XE Series Motor		Each	1			$ 782.00	$ 782.00	
	Motor Control Box		Each	1			$ 213.00	$ 213.00	
	Pentek Intellidrive Constant Pressure Controller		Each	1			$ 1,721.00	$ 1,721.00	
	LAKOS PC Screen		Each	2			$ 2,270.00	$ 4,540.00	
	LAKOS ILB-ILS Separator		Each	2			$ 1,151.50	$ 2,303.00	
Botany	Rushes *(Juncus)*	Land	Each	600	900	0.67	$ 4.66	$ 2,796.00	32 93 13.4
	Reeds (*Poaceae spp.*)	Land	Each	600	900	0.67	$ 4.66	$ 2,796.00	
	Duckweed (*Lemnaeceae*)	Land	Each	600	900	0.67	$ 4.66	$ 2,796.00	
	Pennywort (*Centella asiatica*)	Land	Each	600	900	0.67	$ 4.66	$ 2,796.00	
	Spike Rush (*Eleocharis palustri*)	Land	Each	300	900	0.33	$ 4.66	$ 1,398.00	
	Hyacynth (*Hyacythus*)	Land	Each	300	900	0.33	$ 4.66	$ 1,398.00	

Labour & Equipment

Category	Crew no.	Description	Quantity	Unit Cost	Unit	Daily Unit Cost	No. Days	Total Cost
Surveying	A-6	Instrument man	1	$60.00	per hour	$475.00	2	$ 950.00
		Rodman	1	$55.00	per hour	$440.00	2	$ 880.00
		Laser, transit and level	1		daily	$65.00	2	$ 130.00
Construction	B-14	Labor foreman	1	$50.00	per hour	$385.00	24	$ 9,240.00
		Laborers	4	$45.00	per hour	$1,430.00	24	$ 34,320.00
		Equipment operator (light)	1	$55.00	per hour	$445.00	24	$ 10,680.00
		Backhoe Loader (36kW)	1		daily	$270.00	24	$ 6,480.00
Material transport	B-34A	Truck driver heavy	1	$45.00	per hour	$365.00	5	$ 1,825.00
		Dump truck	1		daily	$585.00	5	$ 2,925.00
Weir and Structures (Formwork, rebar, and concrete)	C-15	Carpenter Foreman	1	$65.00	per hour	$520.00	8	$ 4,160.00
		Carpenters	2	$60.00	per hour	$990.00	8	$ 7,920.00
		Laborers	3	$50.00	per hour	$1,175.00	8	$ 9,400.00
		Cement finishers	2	$55.00	per hour	$895.00	4	$ 3,580.00
		Rodman (rein)	1	$70.00	per hour	$585.00	8	$ 4,680.00
Landscaping	Self Assigned	Landscape Designer/Supervisor	1	$80.00	per hour	$640.00	13	$ 8,320.00
		Labourer	2	$50.00	per hour	$400.00	13	$ 5,200.00

Maintenance

Category	Crew no.	Description	Units	Quantity	Daily Output	Duration	Unit Cost	Total Cost	
Dredging	Contractor	Dredging (once a year)	m3	93.92	300	0.313	$ 12.00	$ 1,127.04	3
	Contractor	Disposal	m3	93.92			$25.00	$ 2,348.00	
		Dredging Permit		1				$ 2,500.00	
Re-seeding	Landscaping	Athletic field seeding (1 acre)	m2	4045		2		$ 1,100.00	3

Clean-up

Category	Crew no.	Description	Units	Quantity	Daily Output	Duration	Unit Cost	Total Cost
Clean-up	B-14	Site clean-up and take down	entire project			2	0.5%	1084.655
							Prelim. Tot:	**$ 118,849.70**

Engineering/Design

Item	Quantity	Unit Cost	Unit	No. of item	Total Cost	Sources
Design & Procurement						3 month time frame
Engineering fees	%	2.5%	Entire project	$ 225,091.65	$5,627.29	01 11 31.30 0800 (minimum)
Site plan layout model	1	$1,350.00	per model	1	$1,350.00	01 11 31.50 0300 (minimum)
Renderings (color matted 20"x30")	1	$1,950.00	per render	1	$1,950.00	01 11 31.75 0200 (minimum)
Renderings (Aerial perspective, color)	1	$2,775.00	per render	1	$2,775.00	01 11 31.75 2000 (minimum)
Construction						
Project manager	1	$2,550.00	Per week	7	$17,850.00	01 31 13.20 0180 (minimum)
Project coordinator/inspector (Junior Engineer)	1	$1,800.00	per week	7	$12,600.00	01 31 13.20 0120 (average)
Permits						
Section 404 clean water act; general work		1.25%	Entire Project	$ 225,091.65	$2,813.65	01 41 26.50 0100
Insurance						
All-risk Type Insurance (R013113-60)		0.25%	Entire Project	$ 225,091.65	$562.73	01 31 13.30 0200
				Prelim. Total	**$45,528.67**	

Forebay Cost Estimate

Table 23: Forebay cost estimate

Summary				
	Materials		$ 26,248.40	
	Labour/Equipment		$ 34,594.16	
	Engineering/Design		$ 8,700.00	
Taxes	Material Sales Tax (avg)	5.06%	$ 1,328.17	
	Unemployment (avg)	7.80%	$ 2,698.34	
Time cost index	2009	180.1		RSMeans
	2014	202.7	$ 8,726.61	
City cost index	Avg	100		
	Vancouver	110.5	$ 7,301.97	MF2004
	Final Total		$ 89,597.64	

Labour & Equipment

Category	Crew no.	Description	Quantity	Unit Cost	Unit	Daily Unit Cost	No. Days	Total Cost	Sources
Construction	B-14	Labor foreman	1	$50.00	per hour	$385.00	8	$ 3,080.00	
		Laborers	4	$45.00	per hour	$1,430.00	8	$ 11,440.00	
		Equipment operator (light)	1	$55.00	per hour	$445.00	8	$ 3,560.00	
		Backhoe Loader (36kW)	1		daily	$270.00	8	$ 2,160.00	
Material transport	B-34A	Truck driver heavy	1	$45.00	per hour	$365.00	2	$ 730.00	
		Dump truck	1		daily	$585.00	2	$ 1,170.00	
Weir and Structures (Formwork, rebar, and concrete)	C-15	Carpenter Foreman	1	$65.00	per hour	$520.00	2	$ 1,040.00	
		Carpenters	2	$60.00	per hour	$990.00	2	$ 1,980.00	
		Laborers	3	$50.00	per hour	$1,175.00	2	$ 2,350.00	
		Cement finishers	2	$55.00	per hour	$895.00	1	$ 895.00	
		Rodman (rein)	1	$70.00	per hour	$585.00	1	$ 585.00	
Landscaping	Self Assigned	Landscape Designer/Supervisor	1	$80.00	per hour	$640.00	2	$ 1,280.00	
		Labourer	2	$50.00	per hour	$400.00	2	$ 800.00	

Maintenance

Category	Crew no.	Description	Units	Quantity	aily Outpu	Duration	Unit Cost	Total Cost	Sources
Dredging	Contractor	Dredging (once a year)	m3	27.68	300	0.6	$ 12.00	$ 332.16	35 20 23.23 1000
	Contractor	Disposal	m3	27.68			$ 25.00	$ 692.00	(EPA, 2014)
		Dredging Permit		1				$ 2,500.00	(PortMetroVan, 2014)
							Prelim. Total	$ 34,594.16	

Materials

			Metric						
Category	Item	Crew	Units	Quantity	Daily Output	Duration	Unit Cost	Total Cost	Sources
Site prep	Dewatering (3 x 4" diaphram pump)	B-14	Per pump	1	8 hour days	11.00	$ 199.00	$ 2,189.00	31 23 19.20 0650
Earthworks	Excavating/Stockpile stripped material/Haul away unwanted	B-34A	m3	127.33	159	0.80	$ 8.76	$ 1,115.41	31 23 23.20 0036 (20 MPh, cycle 8 miles)
	Gravel and coarse aggregate (25mm)	B-14	m3	4	459	0.01	$ 74.07	$ 296.28	31 05 16.10 0300 (+compaction)
	Impermeable clay/till (bentonite)	B-14	m3	74.75	547	0.14	$ 17.54	$ 1,311.09	31 23 23.15 6000 (+compaction)
	Growth media (spreading reused existing wetland soil, include gr	B-14	m3	74.75	459	0.16	$ 4.19	$ 312.86	31 23 23.17 0170 (+spreading)
	Nutrient rich topsoil	B-14	m3	52.6	459	0.11	$ 47.61	$ 2,504.25	31 05 13.10 0800 (+ Hauling)
Concrete	Concrete (30 MPa) (+ waterproofing)	C-15	m3	15	69	0.22	$ 168.86	$ 2,532.85	03 31 05.35 0350 + 03 05 13.80 00500
Metal	Aluminum hand rails	C-15	m	15.6	42	0.37	$ 254.27	$ 3,966.54	05 52 13.50 0140
	Use 20M bar size (+ galvanize)	C-15	Ton	0.178	0.9	0.20	$ 3,425.00	$ 609.65	03 21 10.60 0550 + 03 21 13.10 0150
Formwork	Concrete forming	C-15	m2	32.3	34.47	0.94	$ 68.35	$ 2,207.73	03 11 13.45 5050
Utilities	PVC Pipe (SDR35 sanitary) 200mm	B-14	m	5	102.11	0.05	$ 38.22	$ 191.11	33 31 13.25 2080
	Culvert/headwall (pre cast)	B-14	Each	1			$ 3,600.00	$ 3,600.00	G3030 310 4500
	Weir Boards (aluminum plates - pre fabricated)	B-14	m2	3.6			$ 726.56	$ 2,615.63	05 12 23.65 0500
Botany	Rushes *(Juncus)*	Land	Each	200	900	0.22	$ 4.66	$ 932.00	32 93 13.4
	Reeds (*Poaceae spp.*)	Land	Each	200	900	0.22	$ 4.66	$ 932.00	
	Spike Rush (*Eleocharis palustri*)	Land	Each	100	900	0.11	$ 4.66	$ 466.00	
	Hyacynth (*Hyacythus*)	Land	Each	100	900	0.11	$ 4.66	$ 466.00	
							Prelim Total	$ 26,248.40	

Engineering/Design

Item	Quantity	Unit Cost	Unit	No. of item	Total Cost	Sources
Construction						
Project manager	1	$2,550.00	Per week	2	$5,100.00	01 31 13.20 0180 (minimum)
Project coordinator/inspector (Junior Engineer)	1	$1,800.00	per week	2	$3,600.00	01 31 13.20 0120 (average)
				Prelim. Total	$8,700.00	

Appendix C: Design Calculations

Hydrological

(i) Irrigation

Irrigation Demand for Native Garden in the months of May and November:
The demand for the Native Garden was assumed proportional to monthly vs peak monthly demand.
Example: May, the demand would be equal to: {(24.1 m^3/day)x(450/3340) = 3 m^3/day}.

(ii) Evapotranspiration

Adjust potential ET_o values for "evaporating surface condition" using a "crop coefficient", K_c value of 0.9 (S. Chieng, personal communication, March 7, 2014).

The ET_o values from the Vancouver International Airport were averaged over 2012 and 2013, multiplied by a factor of 0.9 and by the surface area of the forebay (203.228 m^2) to provide the information in

	J	F	M	A	M	J	J	A	S	O	N	D
Mean Daily ET (mm/day) [1]	0.41	0.63	1.17	1.89	2.75	3.15	3.42	3.15	2.03	1.04	0.50	0.32
Mean Daily Outflow (m^3/day)	0.08	0.13	0.24	0.38	0.56	0.64	0.70	0.64	0.41	0.21	0.10	0.06

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Example:
January: ET_o = 0.45 mm/day (average ET_o from 2012 and 2013)
ET = (0.45 mm/day)*0.9 = 0.41 mm/day
ET = (0.41 mm/day)/(1000 mm/m)*203.228 m^2 = **0.08 m^3/day**

Project Management

Scheduling:
Total Slack time (amount of time task can be delayed before delaying the whole project)

$$Total\ Slack = Late\ start - Early\ start = Late\ Finish - Early\ finish$$

Cost:

$$Total\ Cost = Unit\ Cost * Quantity$$

$$Duration = \frac{Quantity}{Daily\ Output}$$

Conversions:

$$1\ m^3 = 1.3\ Cubic\ Yard$$
$$1\ m^3 = 35.3\ ft^3$$
$$1\ m^2 = 10.8\ ft^2$$
$$1\ m^3 = 3.3\ ft^3$$