UBC Botanical Garden Traffic System Re-Design

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CIVL 446 Engineering Design and Analysis II

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EXECUTIVE SUMMARY

The following report is a proposal for the redesign of the traffic systems in the vicinity of the UBC Botanical Garden. It addresses issues of safety, accessibility, and sustainability within close proximity to the Garden by proposing a roundabout at the intersection of SW Marine Drive and 16th Avenue, a pedestrian overpass crossing SW Marine at Stadium Road, and a renovated parking system.

The primary sub-disciplines involved in the design include traffic engineering, construction management, and hydrotechnical engineering. Development of an overall traffic concept for flow of pedestrians, bicycles, and vehicles has been conducted for the existing traffic condition. A detailed design of the roundabout and analysis by way of traffic flow theory have been performed so as to optimize the traffic system. The corresponding drainage system has been designed to accommodate peak flows from the 200-year event. A traffic management plan with six phases has been devised to minimize traffic disturbances during roundabout construction. Excess capacity along SW Marine has been reduced to meet the lower existing demand while increasing parking capacity for the Botanical Garden. Unused lanes have been developed into roadside parking in conjunction with the redesign of the existing parking lot to increase parking capacity for the Garden during large events. In addition, a conceptual design has been proposed for the pedestrian overpass that compliments the Botanical Garden and functions to bridge both sides while serving as an advertisement for the Garden to traffic along SW Marine.

The purpose of this project as a whole is to facilitate improved traffic flow around the UBC Botanical Garden. Construction schedules, cost estimates, and work plans have also been included in the report.

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1.0 INTRODUCTION

The traffic system in the vicinity of the UBC Botanical Garden serves students traveling to the main UBC campus grounds, residents of the Southern campus neighbourhood, and patrons of the Botanical Garden. In its current state, SW Marine, the southernmost arterial road leading to UBC, enables vehicles to travel at dangerously high speeds through this region, which is frequented by pedestrians and cyclists. The corridor of Marine Drive between 16th Avenue and Stadium Road is part of an arterial road with a capacity that greatly exceeds demand, even during peak volume periods. This in conjunction with a lack of traffic control devices (i.e. traffic lights, stop signs, or roundabouts) allows vehicles to greatly exceed posted traffic speeds, posing a threat to pedestrians and cyclists crossing the road. This report addresses these issues, explores potential solutions, and presents a re-designed traffic system that meets the needs of all users in a safer, more sustainable fashion.

In addition to traffic speed and safety, other traffic-related issues have beleaguered the UBC Botanical Garden including limited parking and inter-garden accessibility. During events such as weddings or Apple Festival that draw high patronage volumes to the Garden, parking becomes a significant issue. In this report, West Coast Consulting (henceforth WCC) presents a strategy to increased parking capacity by over 200%. To address accessibility to the Northern side of the Garden from the Southern, WCC proposes building a pedestrian overpass across SW Marine Drive at Stadium Road.

West Coast Consulting has created a three-phase development plan to facilitate final design and implementation of the project components. This is a long-term strategy created with the purpose of addressing the abovementioned issues of safety and accessibility. The goal of the project is to create safe, seamless traffic flow for all users within the vicinity of the UBC Botanical Garden. Cost estimates, construction plans, and schedules are also provided in the report.

2.0 ROUNDABOUT

The conversion of signalized intersections to roundabouts generally results in safety and operations improvement, reduced environmental impacts from vehicular traffic, and reduced maintenance costs. Recently, the signalized intersections along 16th Avenue at Wesbrook Mall, and East Mall were replaced by new roundabouts, leaving the intersection on W 16th Ave & SW Marine Drive as the only intersection along the 16th Ave UBC corridor that is operated with traffic signals. The following section of the report provides an overview of West Coast Consulting's traffic flow analysis, conceptual designs, hydrotechnical analysis, construction schedule, traffic management plans, and cost estimate for the proposed roundabout that would replace the existing signalized intersection on SW Marine Drive and W 16th Avenue.

2.1 Traffic Flow Analysis

Traffic flow analysis has been performed in order to assess the feasibility of various options that aim to optimize on-street parking capacity and traffic flow at the road segment of Marine Drive between 16th Avenue and Stadium Road. Furthermore, the advantages associated with the proposed roundabout installation at 16th Avenue have also been investigated. A comparison of the different options considered as potential solutions can be found in Table 1.

Option Number	Total Number of Lanes	Posted Speed Limit
Option #1	5	60 km/h
Option #2	4	50 km/h
Option #3	3	50 km/h
Option #4	2	30 km/h

Table 1: Comparison of Traffic Flow Input Parameters for Potential Solutions

These options were compared with respect to the level of service (LOS), safety implications, environmental impacts, and the potential for on-street parking implementation. The subsequent sections of this report provide a brief overview of West Coast Consulting's findings.

2.1.1 Level of Service (LOS)

The LOS was the main indicator used for analysis of operating conditions for each modeled option. Greenshield's Model of Traffic Flow Theory was used to derive the Flow VS. Density and velocity functions that correspond to the various options considered. The traffic volume data provided by UBC Transportation Planning was used for calculating the LOS for each option based on the volume/capacity ratio (V/C). The LOS was found to be "A" for all of the four options. This result indicates that both the road capacity and the demand are not the governing criteria in this project. More importantly, this also implies that implementing on street parking along the outer lanes of Marine Drive between 16th Ave and Stadium Road, as per option #3, would not reduce the existing LOS. Appendix A provides more details about the derived traffic flow functions, sample calculations, and a summary table of the V/C and LOS for each option.

2.1.2 Annual Operating Cost and Crash Costs

The cost projections highlighted in the UBC 16th Ave Consultation Report (2006) were used as a basis to compare the annual operating and crash costs for the proposed roundabout and for the existing signalized intersection at SW Marine Dr. and W 16thAve. As illustrated by the results shown in Table 2, the total annual operating and crash costs for the proposed roundabout are lower than that of the existing signalized intersection.

Marine Drive at 16th Ave		Roundabout	Signal
Operating Costs	**Signals**	0	$8,333/year
	Landscaping	$7,666/year	0
Crash Costs		$4,000/year	$13,333/year
Total Costs		$11,666/year	$21,666/year

Table 2: Marine Drive at 16th Ave – Projected Operating and Crash Costs/Year

2.1.3 Safety

The replacement of the existing signalized intersection at Marine Drive & 16th Ave with a new roundabout and the proposed reduction in the posted speed limit from 60 to 50 kph are expected to result in significant safety improvements. Most severe accidents at intersections occur due to the various types of crossing conflict points shown in Figure 1. With this in mind, roundabouts are considered to be relatively safer than signalized intersections primarily due to the lower number of vehicle conflict points and the reduced probability of severe accidents (see Figure 1).

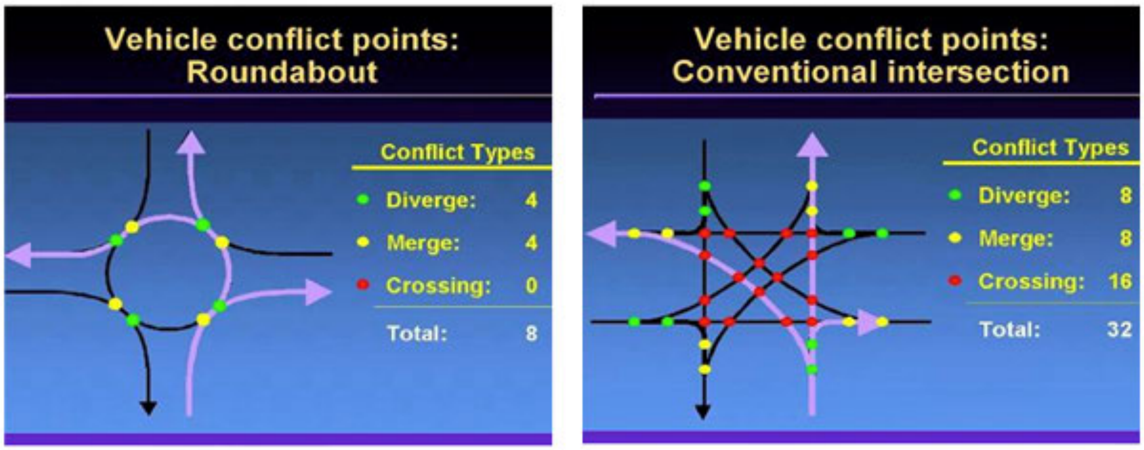

Figure 1: Comparison of Vehicle Conflict Points for Roundabouts and Signalized Intersections

In addition, the reduction in the posted speed limit will directly reduce both the frequency and severity of collisions. As per the Vision Zero Initiative, a traffic safety strategy implemented by the Swedish Government since 1994, reducing the posted speed limit is one of the key concepts for successfully minimizing the number of fatal collisions (see Figure 2).

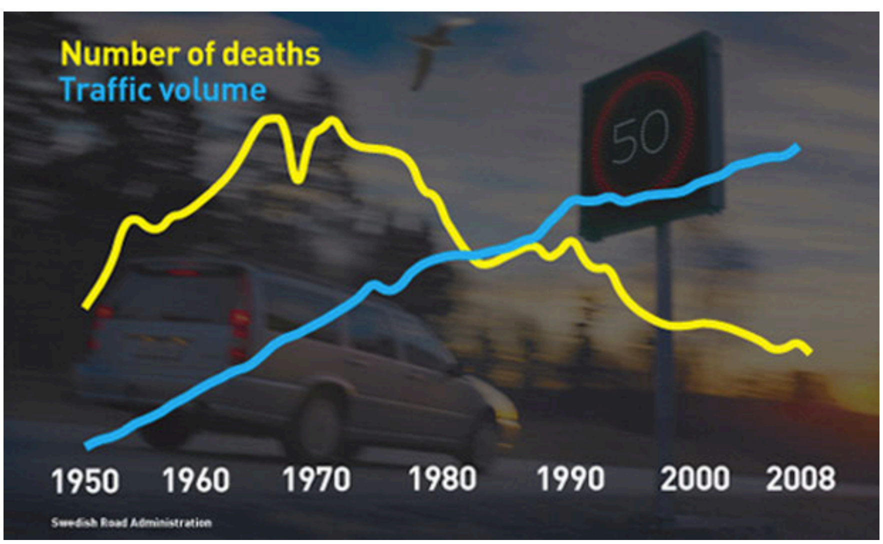

Figure 2: Number of Deaths and Traffic Volume VS. Time (Vision Zero Initiative, 2014)

2.1.4 Environmental Impacts

As illustrated in Figure 3, transportation is widely considered as the most significant source of CO_2 emission in British Columbia in 2011.

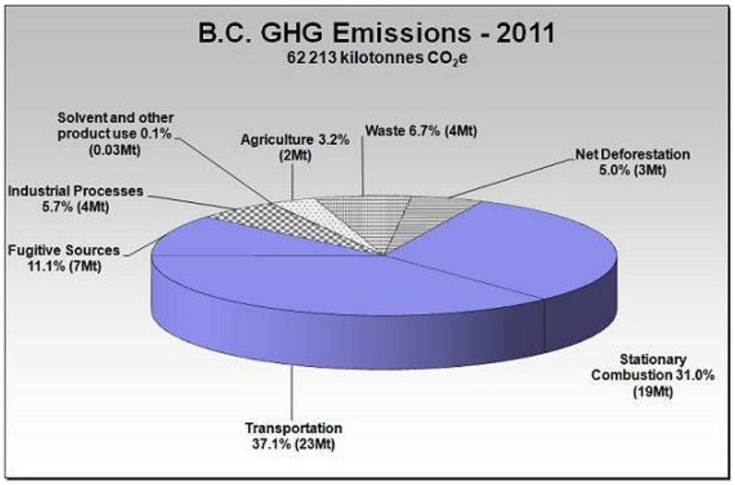

Figure 3: 2011 British Columbia GHG Emissions (Lim, 2014)

During vehicle operation, GHG emissions increase as the engine's number of revolution per minute increases. As shown in Figure 4, the maximum is reached during the idling process.

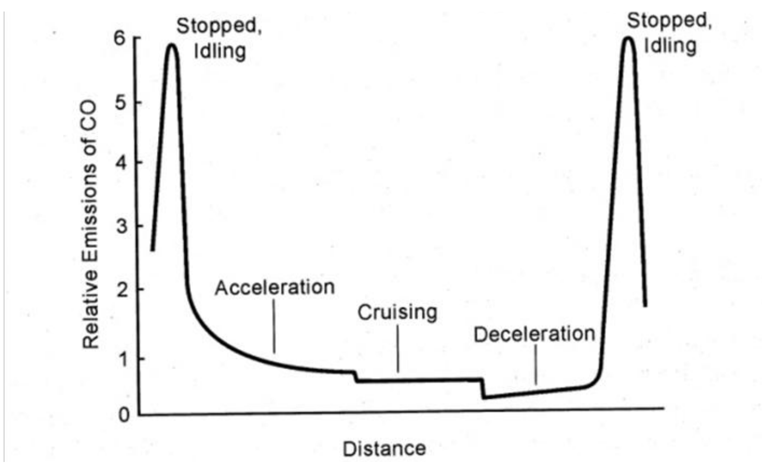

Figure 4: Relative Emissions of CO during Vehicle Operation (Lim, 2014)

For roads with relatively low traffic flow demand, such as SW Marine Drive between W 16th Ave and Stadium Rd., idling is only necessary at the signalized intersections. Replacing the existing signal from 16th Ave with a roundabout will minimize the vehicle idling, and will consequently reduce GHG emissions.

2.1.5 Traffic Flow Analysis Summary

The findings from the traffic flow analysis performed for the road segment of Marine Drive between 16th Ave and Stadium Road are summarized in Table 3. After comparing the options with respect to the investigated parameters, each option was evaluated with a certain number of points on a scale from 1 to 3 (i.e. 3 being the highest, 1 being the lowest score). Based on this method of comparison, it was determined that option #3 is the most desirable alternative.

Option #	No. of Lanes	Speed Limit (km/h)	LOS	Safety	GHG	Side Parking Possibility	Total No. of Points
1	5	60	A (3)	Min (1)	Max (1)	Not Possible (1)	(6)
2	4	50	A (3)	Med (2)	Min (3)	One Lane Possible (2)	(10)
3	3	50	A (3)	Med (2)	Min (3)	Two Lane Possible (3)	(11)
4	2	30	A (3)	Max (3)	Max (1)	Two Lane Possible (3)	(10)

Table 3: Summary of Results obtained for All Road Segment Options

Table 4 summarizes the various criteria used to identify the advantages of a roundabout relative to the existing signalized intersection at Marine Drive & 16th Avenue.

Criteria	Measure	Roundabout	Signal
LOS	Delay, v/c	✓	✕
Safety	Statistics	✓	✕
GHG	CO_2 Emission	✓	✕
Operating and Crash Cost	Canadian Dollars	✓	✕
Overall	N/A	✓	✕

Table 4: Comparison between Roundabouts and Signalized Intersections based on Various Criteria

Overall, based on the traffic flow analysis and careful consideration of each of the abovementioned criteria, it was determined that the existing signalized intersection at Marine Drive & 16th Ave should be replaced with a roundabout. West Coast Consulting also determined that two outer travel lanes (one in each direction) within the road segment of Marine Drive between 16th Ave and Stadium Road could be decommissioned and used as roadside parking without affecting the road's existing level of service. More importantly, the posted speed limit along this segment should be reduced from 60 km/h to 50 km/h in order to improve pedestrian, cyclist, and vehicle safety.

2.2 Roundabout Design

A roundabout in the intersection of SW Marine Drive and 16th Avenue is proposed to replace the current signalized intersection. The new design will feature a roundabout with two travel lanes and three approach legs for traffic coming from SW Marine Drive and 16th Avenue. The current four-lane configuration on 16th Avenue and the four-lane configuration on SW Marine Drive are retained to minimize changes in the traffic pattern. As shown in Figure 5, cyclists entering the intersection will use the designated bike lanes paved on the outside edge of the roundabout and the crosswalks for road crossing within the intersection.

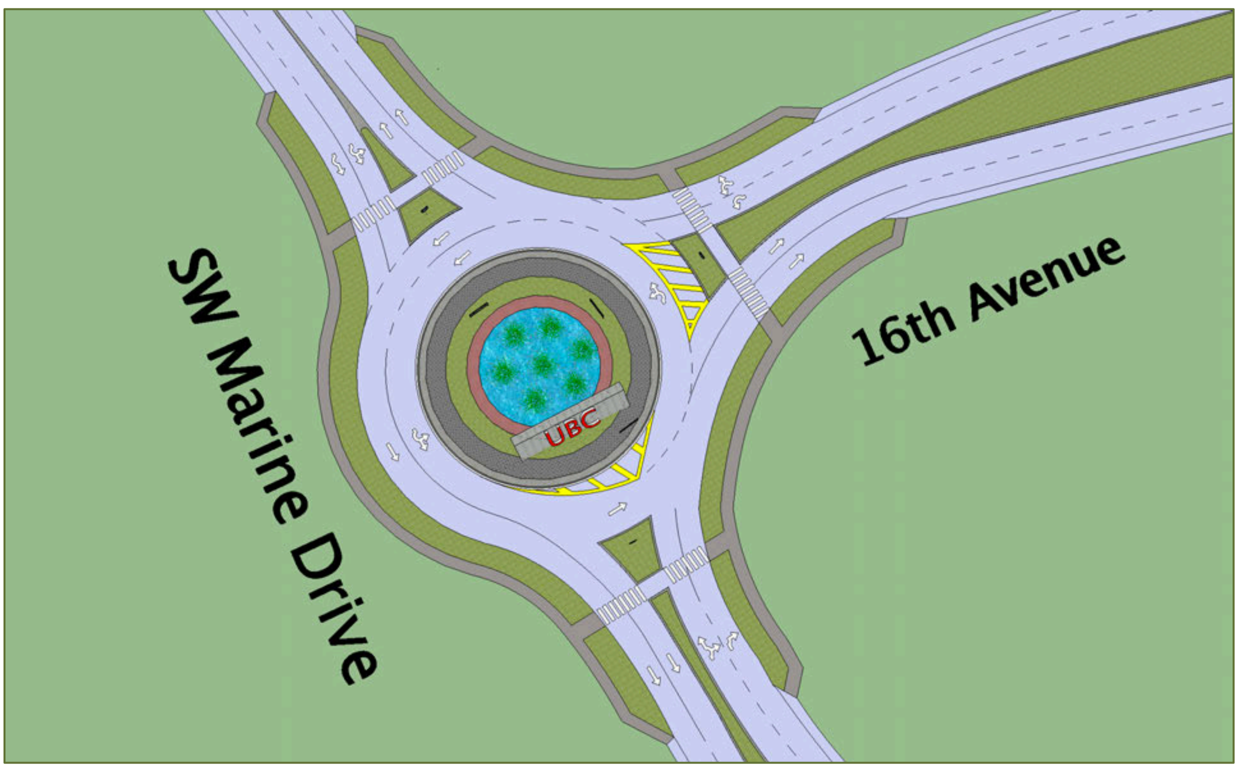

Figure 5: Proposed Roundabout Design

2.2.1 Design Features

The new design promotes sustainability by reusing the current road structures as much as possible to reduce demolition, using recycled concrete as a construction material, and minimizing the overall construction period and cost. Aligning the new pavements and medians to the existing ones along SW Marine Drive and 16th Avenue can reduce the construction time and cost significantly by limiting the required amount of excavation and pavement installation. Additional space that will be unoccupied after roundabout construction are proposed to be reclaimed as green space to further promote sustainability. This can also serve as a riparian barrier to filter and detain stormwater runoff. As shown in Figure 7, the inner roundabout circle can also be used by the Botanical Garden or UBC for advertisement purposes.

Along SW Marine Drive between 16th Avenue and Stadium Road, the two lanes will merge into a single lane for both directions. As a result, the outside lane (in each direction) can serve as roadside parking for Botanical Garden visitors. This will create an additional 30 parking spaces for the garden visitors and help cease the shortage of parking space during UBC BG events.

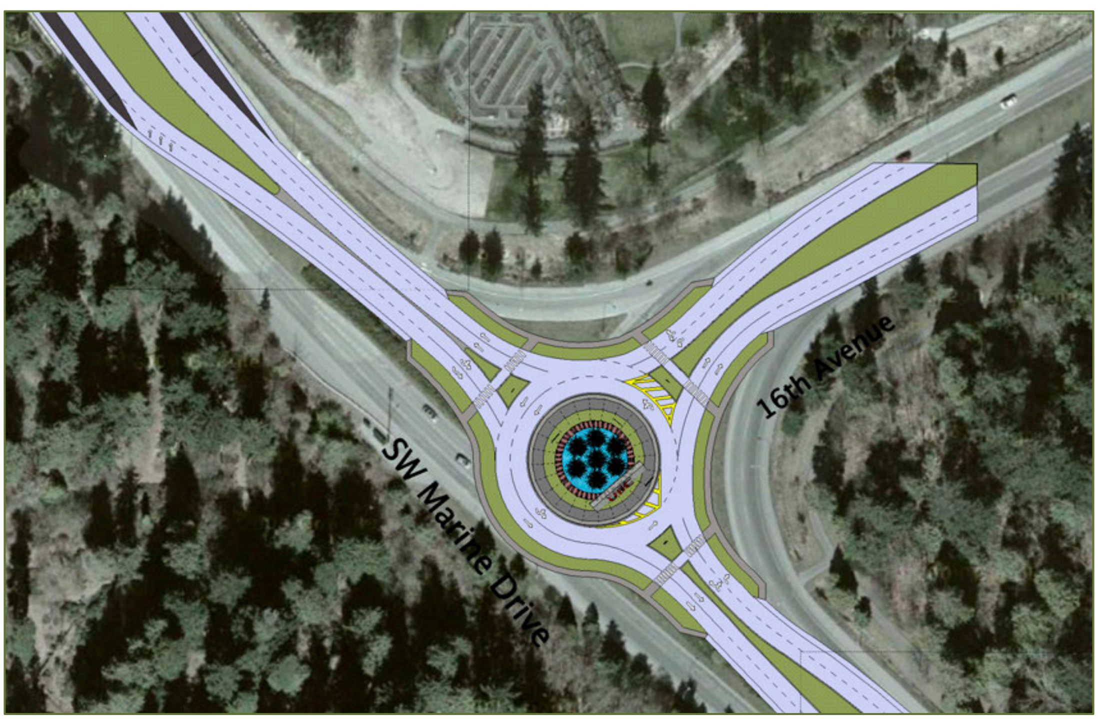

Figure 6: Proposed Roundabout Layout at 16th Avenue & SW Marine Drive

2.2.2 Design Specifications

The design specifications for the proposed roundabout have been determined in accordance with the codes outlined in the MUTCD 2009, NCHRP Report 672, and ITE Traffic Engineering Handbook. The outside diameter of the roundabout is 55 metres, while the diameter of the inner circle is 37 metres. Travel lanes within the roundabout are 4.5 metres wide, and the entry lanes in the approach legs are 3.7 metres wide. Signs and pavement markings in compliance with the above codes are included in the roundabout to guide vehicles, balance the traffic volumes between the entry lanes, and minimize the number of potential conflict points. Signs are placed in advance of the roundabout for lane assignments. Lane markings are added within the roundabout and entry lanes.

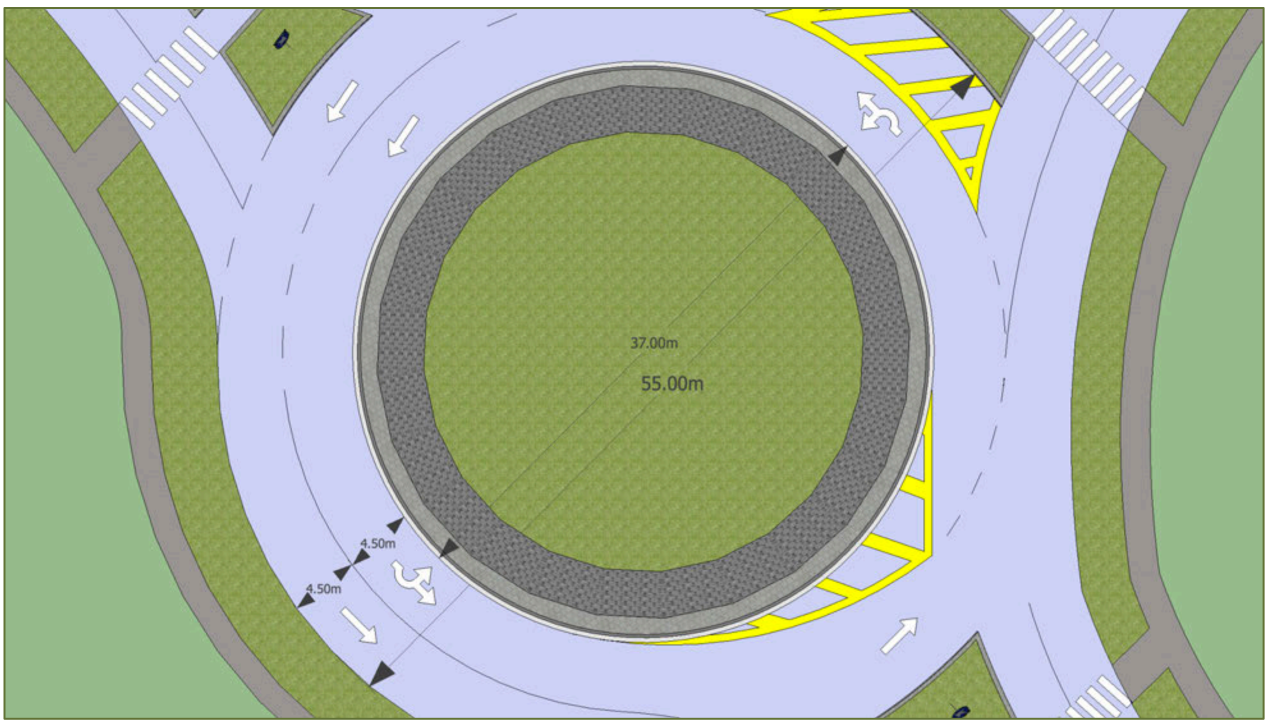

Figure 7: Roundabout Dimensions

2.3 Stormwater Management Strategy

The redevelopment of the intersection at 16th Avenue and SW Marine Drive will require a new drainage system. The traditional approach to urban stormwater management involves drainage and removal via piping or through channelized flow in protective structures. The following sustainable approach will be taken to manage the stormwater runoff and peak flows:

- Minimize the road size (percentage of impervious surfaces) to facilitate infiltration
- Avoid use of curbs and gutters
- Design swales and riparian barriers
- Promote ground water recharge
- Facilitate filtration, retention, and detention
- Provide an aesthetically pleasing environment near the UBC Botanical Garden
- Prevent erosion to land between SW Marine and the coastline
- Design for the 200-yr storm
- Meet the requirements of the MoT and align the design with UBC's South Campus Sustainable Drainage Strategy

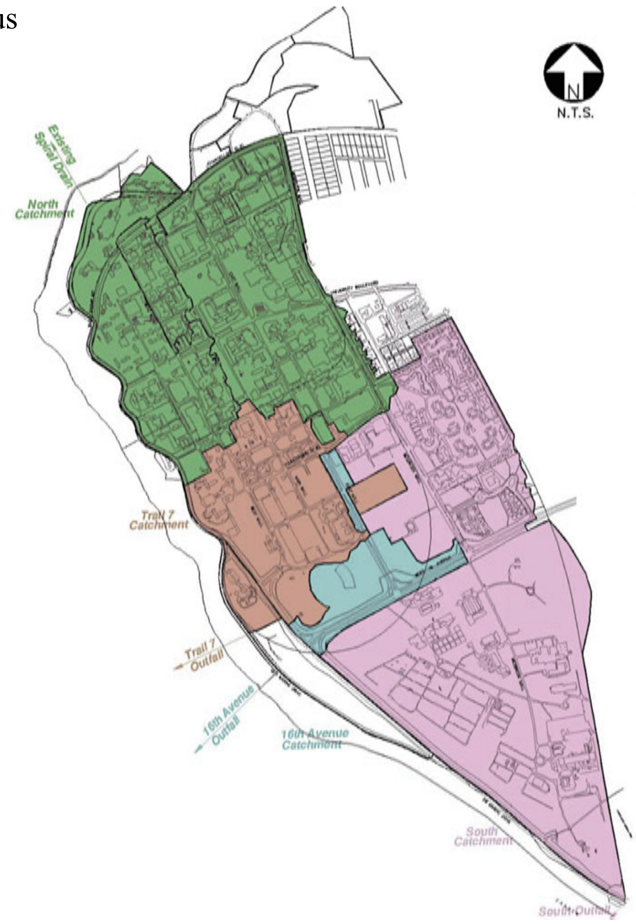

Figure 8: The UBC Watershed

The design service level for the 200-year storm is a requirement of the Ministry of Transportation, and is also in alignment with UBC's South Campus stormwater management strategy. Such a design life is justified due to the significant soil erosion that could result from uncontrolled flows between Marine Drive and the ocean. Peak flows for a 200-year event were determined by applying the Rational Method for the two sub-watersheds that meet at the intersection—the 16th Avenue and Trail 7 catchments.

Peak flows were determined for each of the two catchment areas by applying the Rational Method. Table 5 provides a summary of the data and results from the stormwater analysis. Detailed design calculations are provided in Appendix A.

Catchment	**16th Ave**	**Trail 7**
Average grade of drainage area	2.40%	2.40%
Approximate catchment area (ha)	20	45
Storm Duration = T_c (min)	18.4	25.1
Rainfall Intensity (mm/hr)	48	42
Runoff Coefficient (weighted average)	0.4875	0.575
Peak Runoff (m^3/s)	**1.31**	**3.04**

Table 5: Peak Runoff at SW Marine Drive

Since all outflows and catch basins will divert runoff through the arterial road to the Trail 7 outfall and 16th Avenue outfall along the coastline, the drainage system at SW Marine Drive must be designed to accommodate peak flows of approximately 4.35 m^3/s. Manning's equation and the principle of continuity were applied to design a trapezoidal swale.

Figure 9: 16th Ave Drainage

A cross section of the 6.0m wide swale modeled after the drainage further up the road at 16th Avenue is shown in Figure 10. Design calculations for the swale and culverts can be found in Appendix A.

Although hydrophilic vegetation is not shown in Figure 10, it would be included as shown in Figure 9 to help detain runoff, prevent soil erosion, and reduce the flow velocity. A permeable, geotextile fabric and a sand layer are placed below 30cm of topsoil to prevent erosion by increasing shear resistance of the soil to stresses imposed by peak flows. As shown in Figure 10, 0.3m diameter corrugated steel culverts run perpendicular to SW Marine spaced at 25 meters, carrying flows across the road to connect to the main storm sewer line that runs beneath and parallel with 16th Avenue.

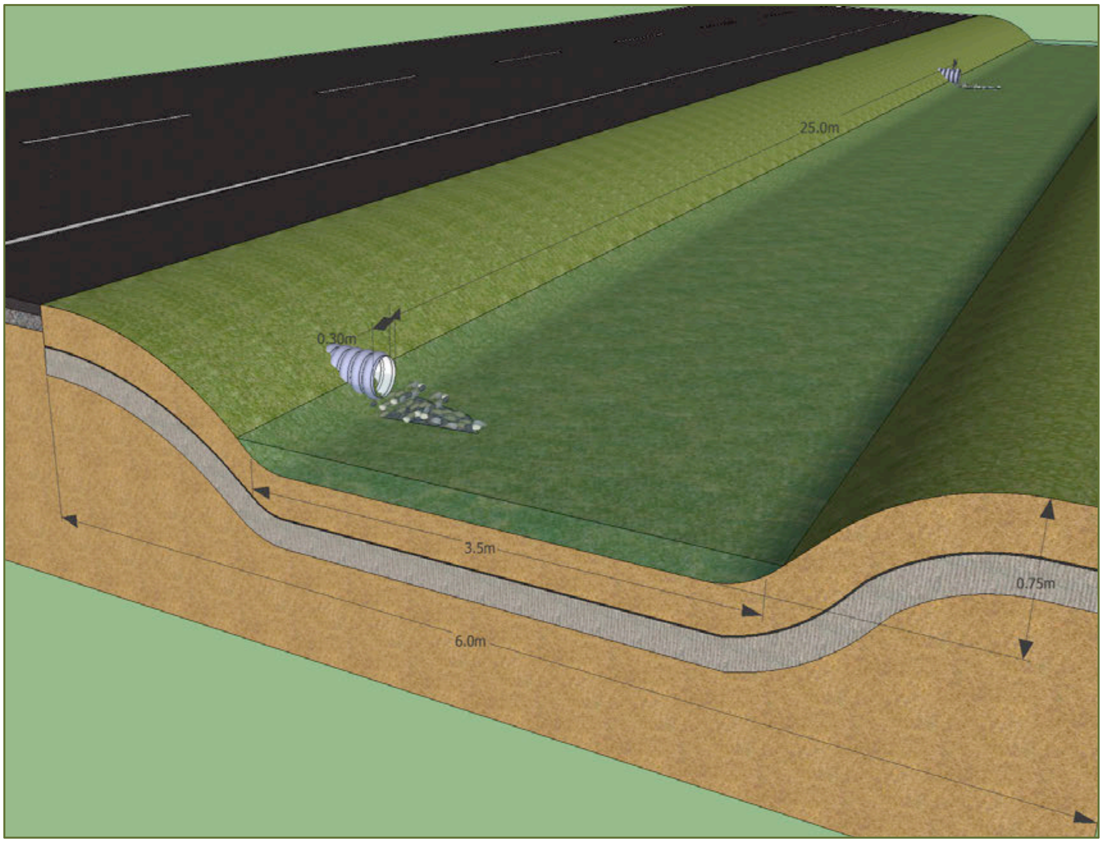

Figure 10: Proposed Swale Design

2.4 Utilities

Existing utilities beneath the new roundabout such as stormwater, electrical and tele-communications must be taken into account. In addition to obtaining necessary permits and approvals, roundabout construction will be carefully coordinated with UBC Utilities staff in order to ensure that all requirements are being met. Utilities that may be affected by roundabout construction will be discussed in this section of the report.

2.4.1 Tele-Communications Infrastructure

The Roger's Telecommunication tower and service box do not conflict with the proposed location of the roundabout; however, a temporary barricade would need to be built to protect this infrastructure from heavy machinery during construction.

2.4.2 Stormwater Drainage

The existing stormwater drainage utilities at this intersection include six stormwater drains and one manhole. These would be removed while tearing up the old pavement at different phases of the roundabout construction; however, the entire system would need to be capped outside on the construction site and an alternate pathway created (UBC Technical Guidelines).

2.4.3 Electrical, Lighting and Signals

There are many streetlights and signals above this intersection that will be relocated or removed to enable the construction of the new roundabout. As per UBC standards, the existing electrical utilities that support this infrastructure will need to be disconnected prior to commencement of construction activities (UBC Technical Guidelines).

2.4.4 Pre-Construction Schedule

Pre-construction activities would start with the permitting and approval process in mid-February with the aim of having proper shut downs of existing utilities completed in early to mid-April. This will be done so that phase 1 of the roundabout construction can begin May 1st—as soon as UBC's Winter Academic session is complete. The Gantt chart shown in Figure 11 illustrates the proposed pre-construction schedule.

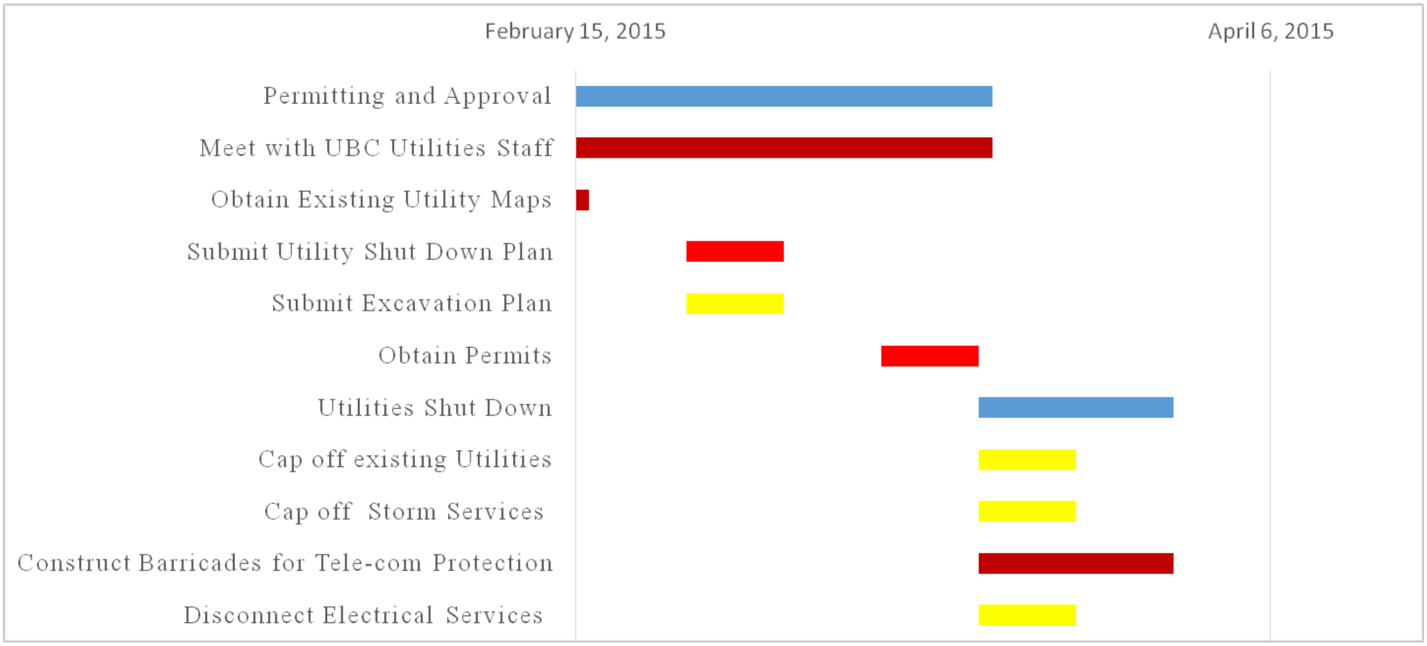

Figure 11: Pre-Construction Schedule

2.5 Roundabout Construction Schedule

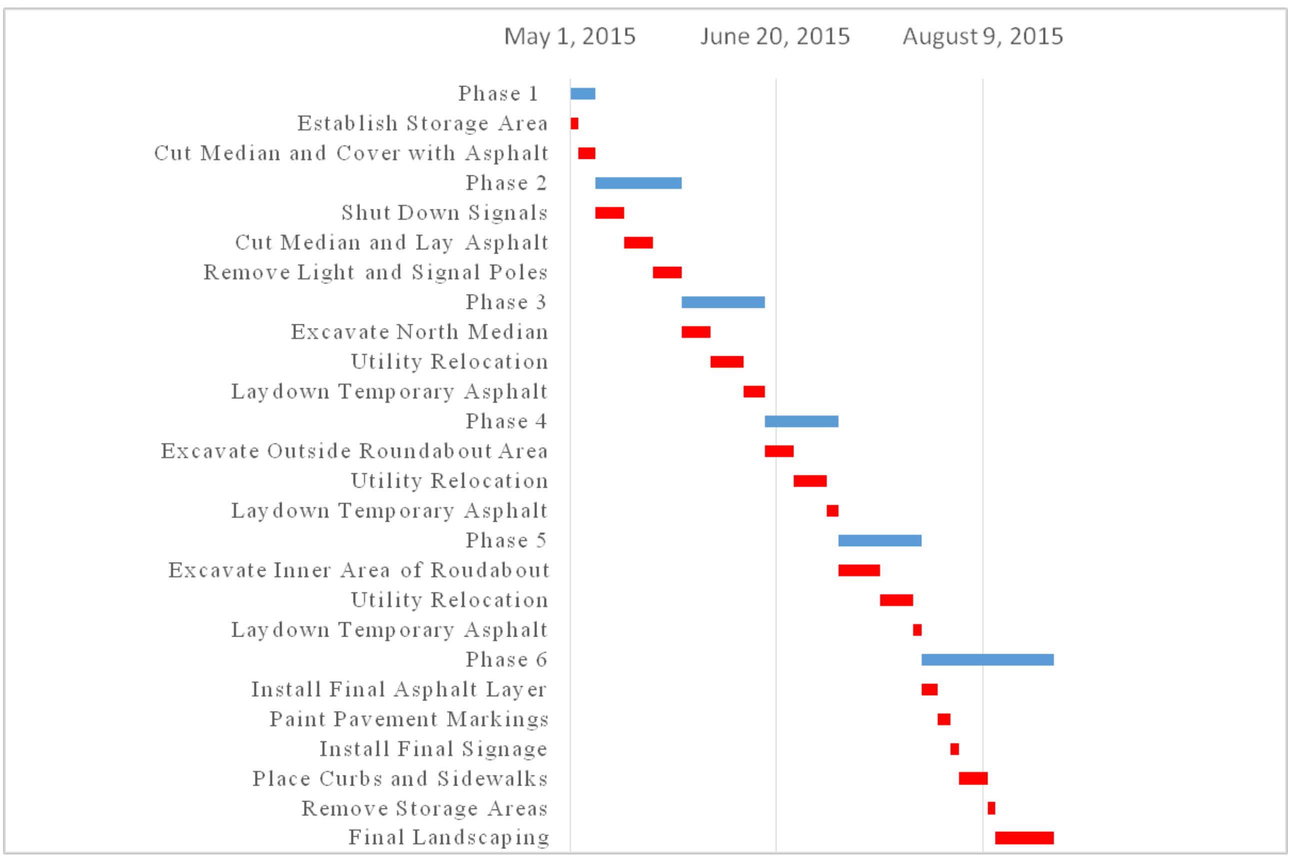

Figure 12: Roundabout Construction Schedule

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The Gantt chart shown in Figure 12 presents a four-month construction schedule as well as the tasks required to complete the roundabout construction. The blue bars represent the overall phases, while the red bars represent critical tasks. The various phases involved in the roundabout construction are discussed in Section 2.6.

2.5.1 Utility Relocation

New utilities will be installed section by section during phases 3, 4, and 5 of the roundabout construction. As the old road is torn up, existing utilities are likewise to be dug up and replaced in their relocated position. The Gantt chart shown in Figure 13 illustrates the processes involved in the utility relocation that will take place in various phases of the project.

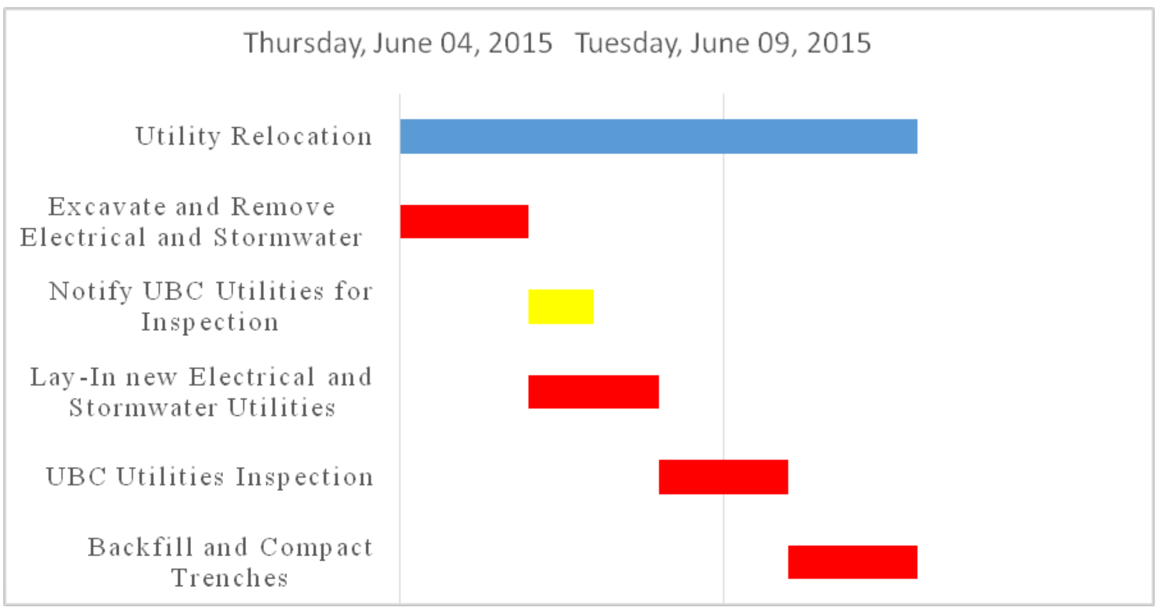


Figure 13: Proposed Schedule for Utility Relocation

2.6 Traffic Management Plans

As highlighted within the 2010 British Columbia Traffic Control Manual (BCTCM), a traffic control management plan (TMP) is required when the traffic must be moved through or around highway or street during construction (TCM, 2012). As outlined within the construction schedule, there will be a total of six different phases. Consequently, an appropriate TMP has been developed for each phase. A summary of the expected duration, crews required, and heavy machinery required for each phase can be found in Table 6.

Phase #	**Expected Duration**	**Crews Required**	**Heavy Machinery Required**
Phase 1	1 week	• 1 excavator operator • 3 truck drivers • 2 flag persons • 5 labour workers	• 1 excavator • 3 dump trucks
Phase 2	3 weeks	• 1 site supervisor • 1 excavator operator • 1 truck driver • 2 flag persons • 1 paver operator • 10 labour workers	• 1 excavator • 1 dump truck • 1 paver machine
Phase 3	3 weeks	• 1 site supervisor • 1 excavator operator • 3 truck drivers • 3 flag persons • 1 paver operator • 10 labour workers	• 1 excavator • 3 dump trucks • 1 paver machine
Phase 4	3 weeks	• 1 site supervisor • 1 excavator operator • 3 truck drivers • 3 flag persons • 1 paver operator • 10 labour workers	• 1 excavator • 3 dump trucks • 1 paver machine
Phase 5	3 weeks	• 1 site supervisor • 1 excavator operator • 3 truck drivers • 3 flag persons • 1 paver operator • 10 labour workers	• 1 excavator • 3 dump trucks • 1 paver machine

Phase 6	3 weeks	• 1 site supervisor • 1 excavator operator • 3 truck drivers • 2 flag persons • 1 paver operator • 10 labour workers	• 1 excavator • 3 dump trucks • 1 paver machine

Table 6: Expected Duration, Crews Required, and Heavy Machinery Required for Phase 1 to 6

2.6.1 Phase 1

The TMP for phase 1 is illustrated in Figure 14. The location of each traffic control device is determined in compliance with the Canadian Manual of Uniform Traffic Control Devices (MUTCD) and the 2010 BCTCM. During this phase, the outer southbound (SB) lane along Marine Drive will designated as work area. As shown in Figure 14, this lane is separated from the inner SB lane by using traffic delineators that are positioned at 15 metre intervals. The two main storage areas and the existing designated bike-lane will be located at portions of the outer SB lane along Marine Drive. The northern storage area will be mostly used for equipment, while the southern storage area will be the designated lay-down area for gravel, debris, and any other material requiring temporary storage on-site. In addition to the major lane closure of the SB lane along Marine Drive, a portion of the inner northbound (NB) lane along Marine Drive will be closed in order to remove a portion of the existing median located south of the intersection (see work area #2 on Figure 14). The removal of this part of the median is necessary for maintaining sufficient traffic flow conditions in the following two phases.

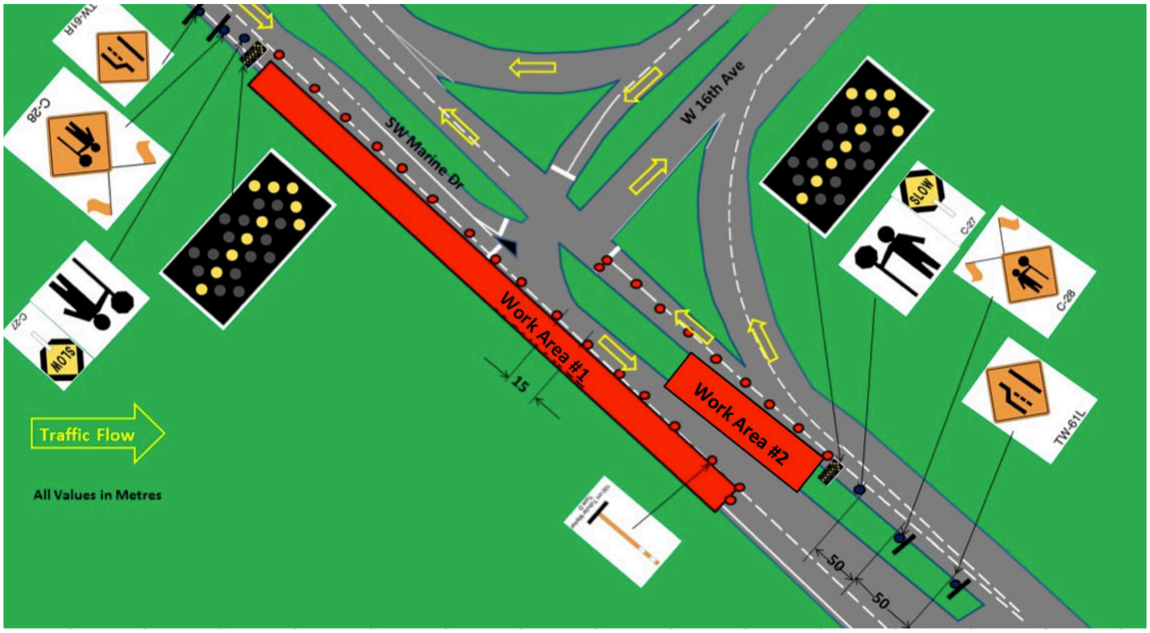


Figure 14: TMP for Phase 1

2.6.2 Phase 2

The TMP for phase 2 is illustrated in Figure 15. In this phase, both SB lanes along Marine Drive will be closed between Stadium Road and 16th Avenue (see work area #1 on Figure 15). The majority of construction activities within the west half of Marine Drive (including the adjacent median) will be performed in this phase. The existing NB lanes along Marine Drive between Stadium Road and 20 metres south of the intersection will be designated for traffic in both SB and NB directions – the existing NB outer lane will serve the NB traffic flow only, while the existing NB inner lane will serve the SB traffic only. These lanes will be separated by traffic delineators that are positioned at 15 metre intervals. Two flag persons and proper traffic control devices will assist the traffic operations, as shown in the figure below. The small portion of the median that was removed in phase 1 will enable SB traffic to merge onto Marine Drive, transitioning from one to two travel lanes. Finally, a small portion of the existing median along 16th Avenue as well as along Marine Drive will be removed in order to maintain sufficient traffic flow during phase 3 (see work areas #2 and #3 in Figure 15).

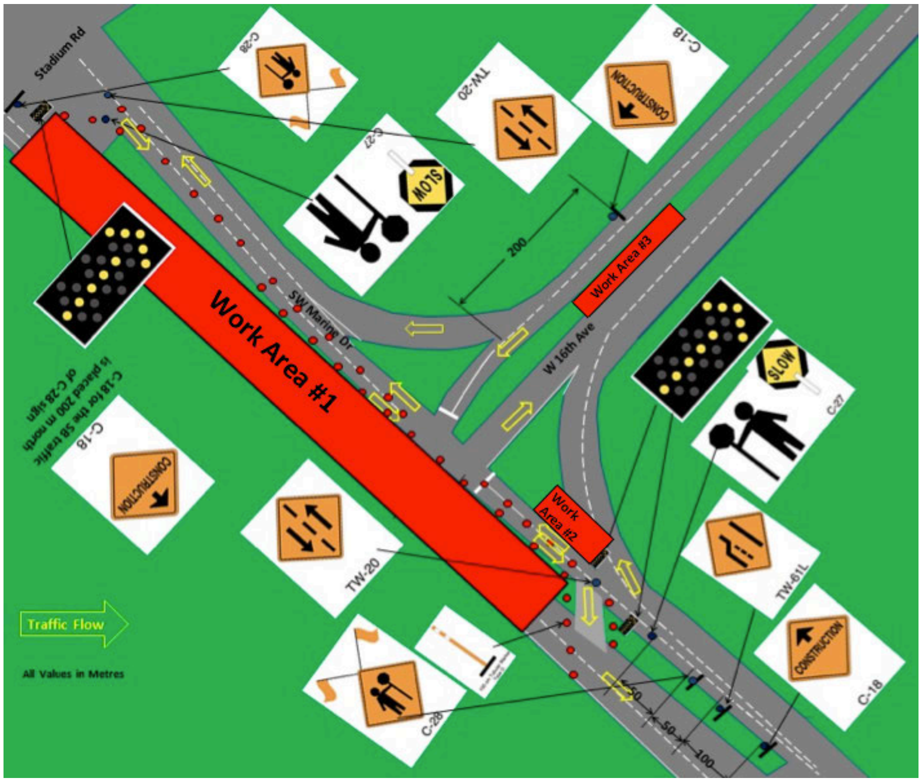


Figure 15: TMP for Phase 2

2.6.3 Phase 3

The TMP for phase 3 is illustrated in Figure 16. The west half of the roundabout has been established in phase 2.With this in mind, the majority of the construction required for the east half of the roundabout will be performed in phase 3 (see work area #1 on Figure 16). Only one lane is used for traffic in any direction. The replaced portions of the medians within the previous phases enable traffic flow conditions that are typically observed for T-intersections. The traffic in opposite directions is separated by using traffic delineators. Three flag persons assist the traffic operations. One temporary stop sign is used for the westbound (WB) traffic entering from West 16 Avenue into Marine Drive, and all required signage as per MUTCD requirements.

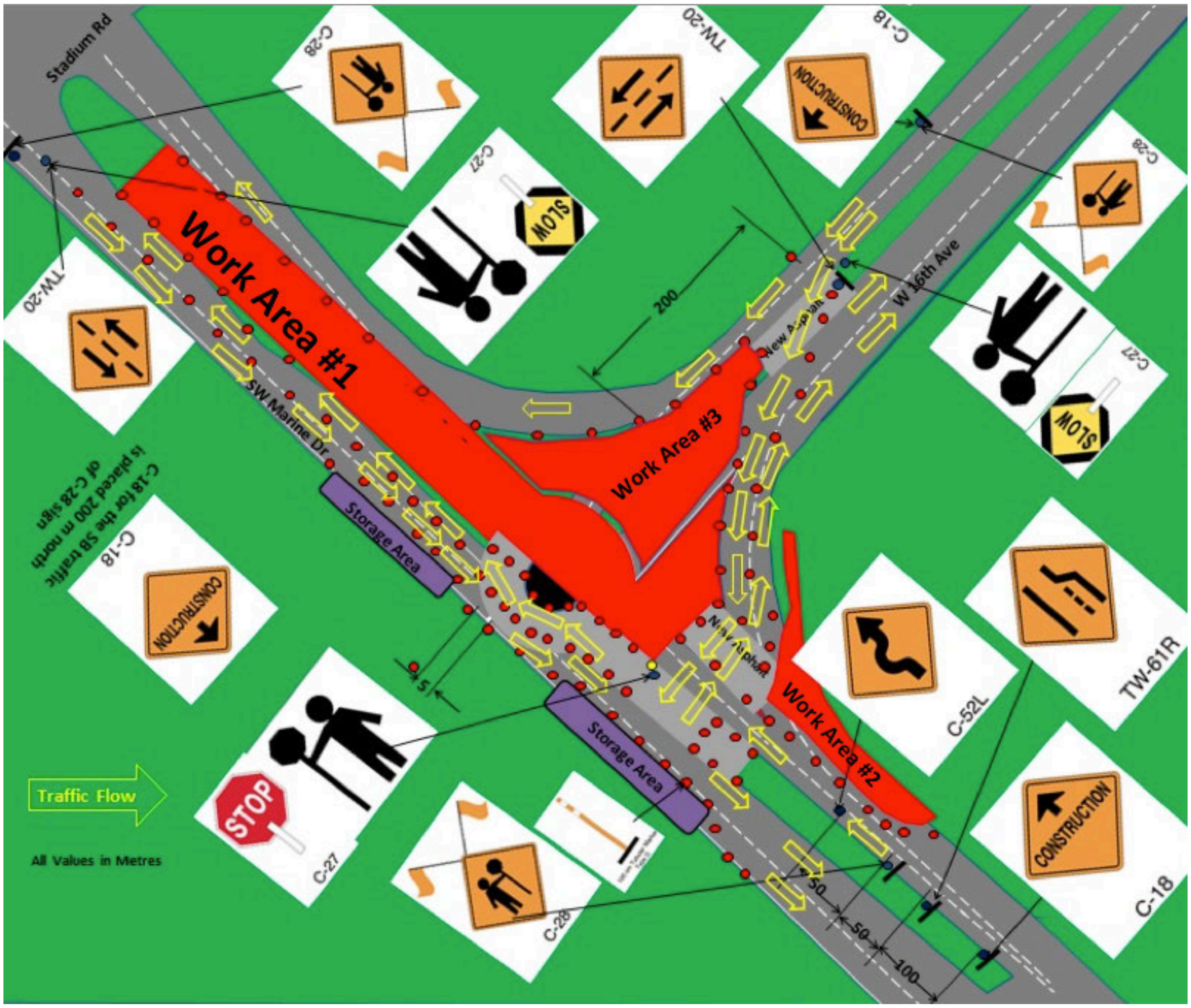


Figure 16: TMP for Phase 3

2.6.4 Phase 4

The TMP for phase 4 is illustrated in Figure 17. Starting from this phase, the traffic operations at the intersection will follow the roundabout pattern. The first layer of temporary asphalt will be installed; however, pavement markings will not be added prior to phase 6. As shown in Figure 17, the inner lanes will be used for vehicular traffic, while the outer lanes will be closed and under construction. Three traffic persons along with proper traffic control devices will assist the traffic operations.

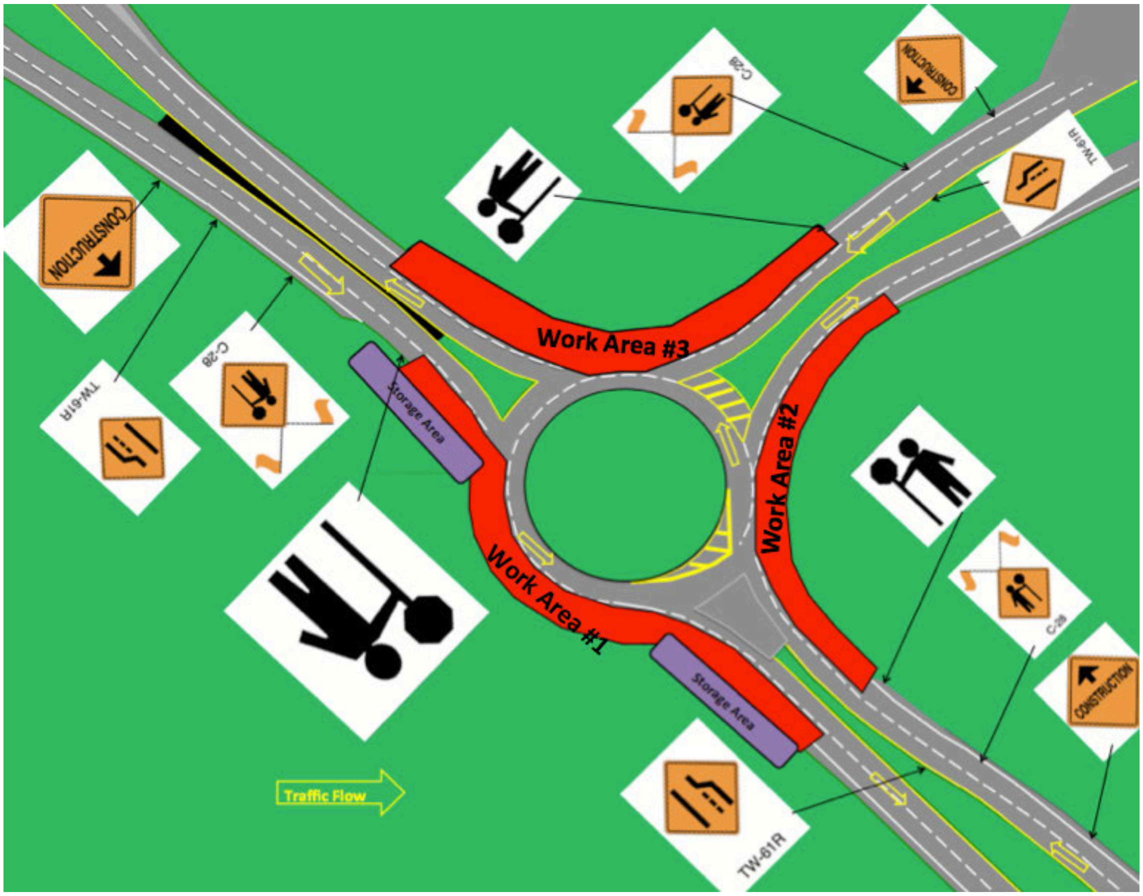


Figure 17: TMP for Phase 4

2.6.5 Phase 5

The TMP for phase 5 is illustrated in Figure 18. As shown in Figure 18, the traffic flow is enabled through the outer lanes, while most of the inner lanes and the medians are under construction during phase 5. Moreover, the inner circle of the roundabout will also be under construction during this phase. Traffic operation is assisted by three flag persons and through the use of proper traffic control devices.

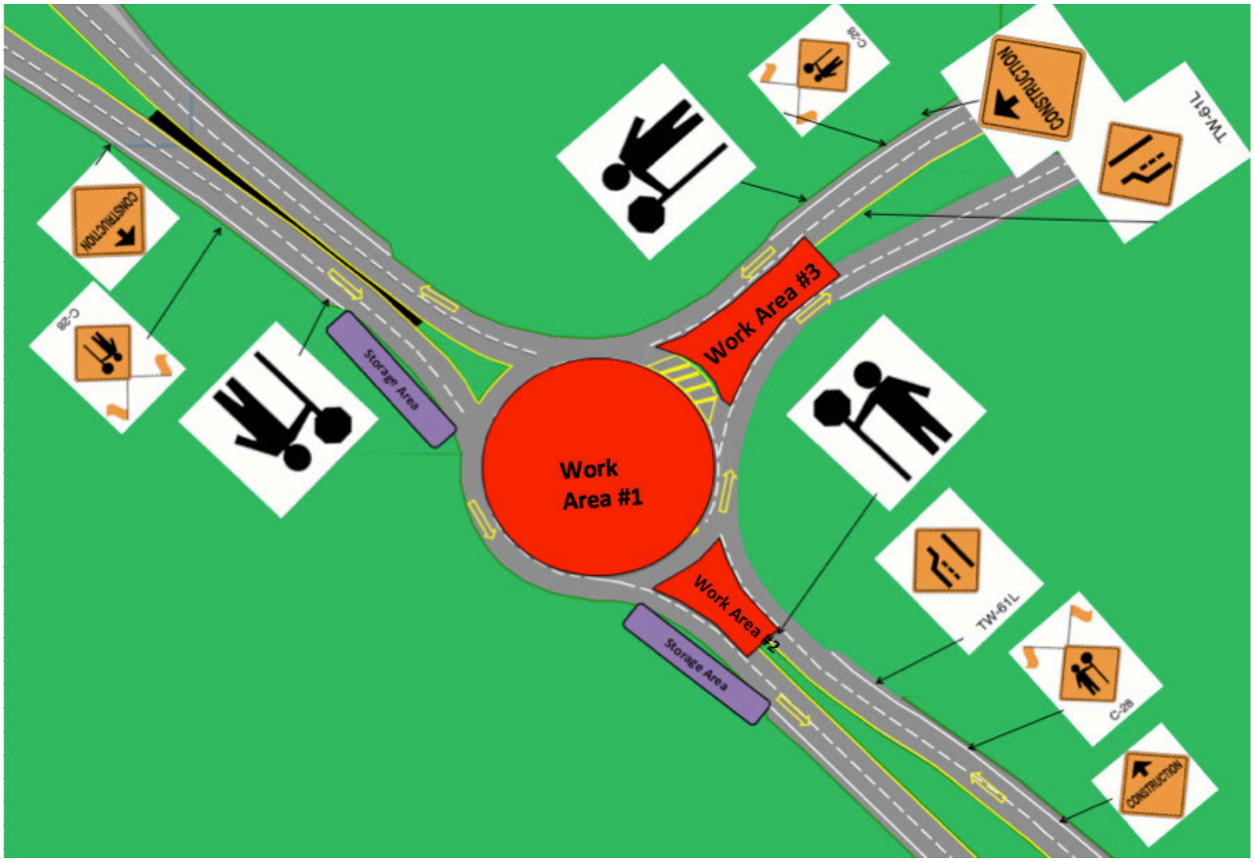


Figure 18: TMP for Phase 5

2.6.6 Phase 6

The TMP for phase 6 is illustrated in Figure 19. During this final phase, the installation of the final layer of asphalt will be completed. Subsequently, proper pavement markings and signage will be installed in compliance with the MUTCD. Once the final asphalt is installed and the curbs and sidewalks are finished, the final landscaping work will be performed. At the end of this phase, both storage areas will be removed. Proper signage and 2 flag persons will be required to assist the traffic operations during this phase.

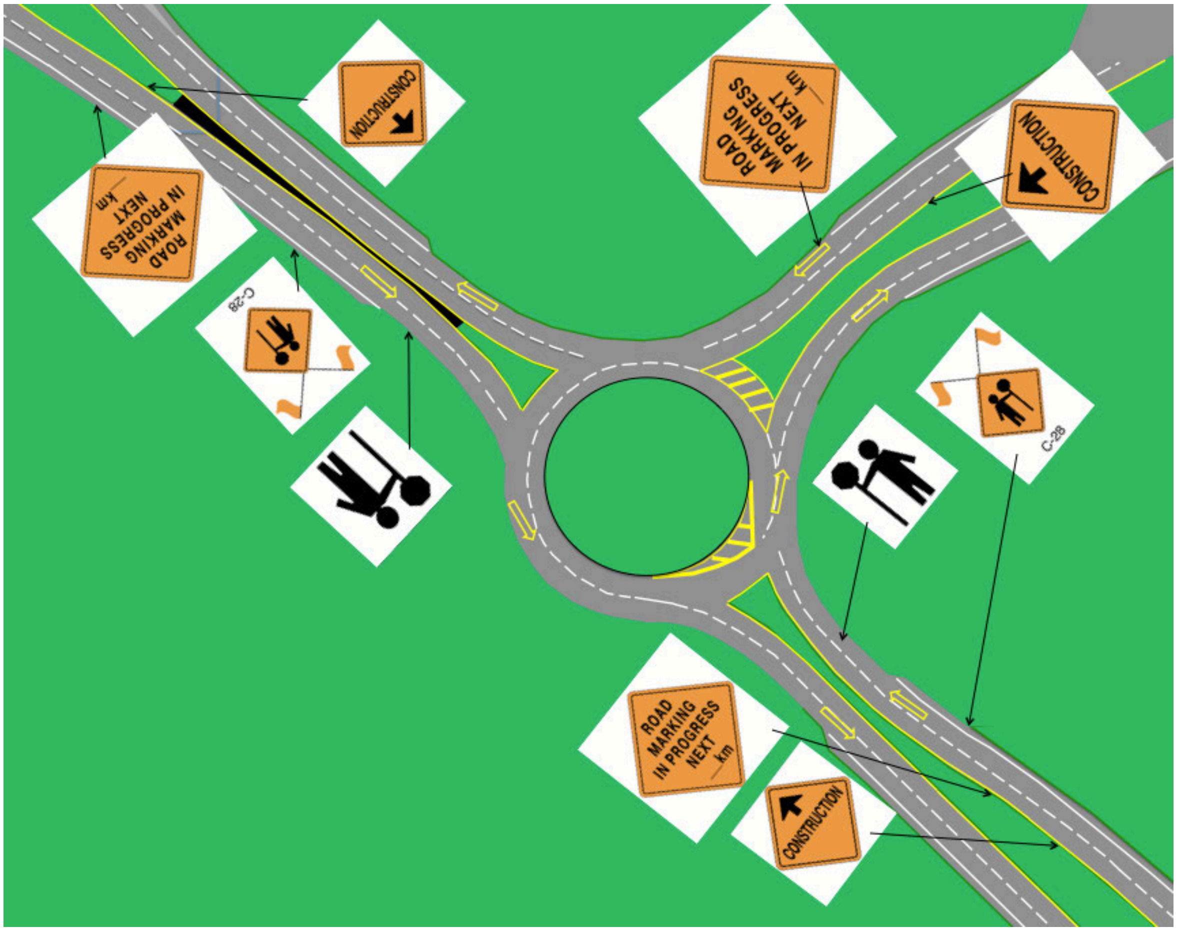


Figure 19: TMP for Phase 6

2.7 Cost Estimate

A conceptual cost estimate for the construction of a roundabout at 16th Avenue and SW Marine Drive was provided in the 16th Avenue consultation report submitted to UBC in February 2006. According to this report, roundabout construction at this intersection is expected to cost \$2,200,000. Since construction costs increase over time, a time factor has been calculated in order to adjust for inflation.

The Georgia Department of Transportation (GDOT) has established a Construction Estimation System Tool by compiling and analyzing construction cost data for various transportation-related projects (including roundabout construction) in the United States. As shown in Table 7, the GDOT's Construction Estimation System Tool suggests the percentage of total project costs associated with various components of roundabout projects. These components include earthwork, landscaping, drainage, erosion control, signs, pavement markings, traffic control, utilities, engineering, and inspection.

Mark-up Items	Default Percentages	
	Turning Lanes	Roundabout
Earthwork	75%	65%
Drainage	18%	18%
Erosion Control	12%	12%
Signs	1%	4%
Pavement Marking	4%	8%
Traffic Control	15%	15%
Utility	3%	3%

Table 7: Percentage Breakdown of Total Project Costs for Construction of Turning Lanes and Roundabouts

In addition to developing a cost estimate for the proposed roundabout construction based on the percentage breakdown shown in Table 7, West Coast Consulting has also looked into bid proposals for similar roundabout projects (both in Canada and the United States) in order to obtain a more accurate cost estimate. With these accounted for, WCC's overall cost estimate can be found in Table 8.

Items/Activities Required	% of Conceptual Cost Estimate (based on GDOT's Construction Estimation System Tool)	Total Cost
Earthwork	65%	$1,865,965
Landscaping and Drainage	18%	$516,729
Erosion Control	-	$120,000
Signs	-	$15,000
Pavement Markings	-	$30,000
Traffic Control	15%	$430,607
Utilities (i.e. Lighting)	3%	$86,121
Construction Cost Estimate:		$3,064,423
Engineering (Contractor Fee)	5%	$153,221
Inspection (Contractor Fee)	5%	$153,221
Contingencies	10%	$306,442
Overall Cost Estimate:		$3,677,307

Table 8: Cost Estimate for Proposed Roundabout at W16th Avenue and SW Marine Drive

3.0 PEDESTRIAN OVERPASS

In order to improve circulation throughout the UBC Botanical Garden, West Coast Consulting proposes to construct a pedestrian overpass that will connect the east and west ends of the garden and span over NW Marine Drive. Along with the existing tunnel underneath NW Marine Drive, the pedestrian overpass will complete the pedestrian loop throughout the gardens. This will greatly improve the circulation for pedestrians. The pedestrian overpass will also attract vehicles passing underneath the overpass to the gardens by using the span as a source for advertising.

3.1 Design

The conceptual design of the UBC Botanical Garden Pedestrian Overpass proposed by West Coast Consulting can be seen below.

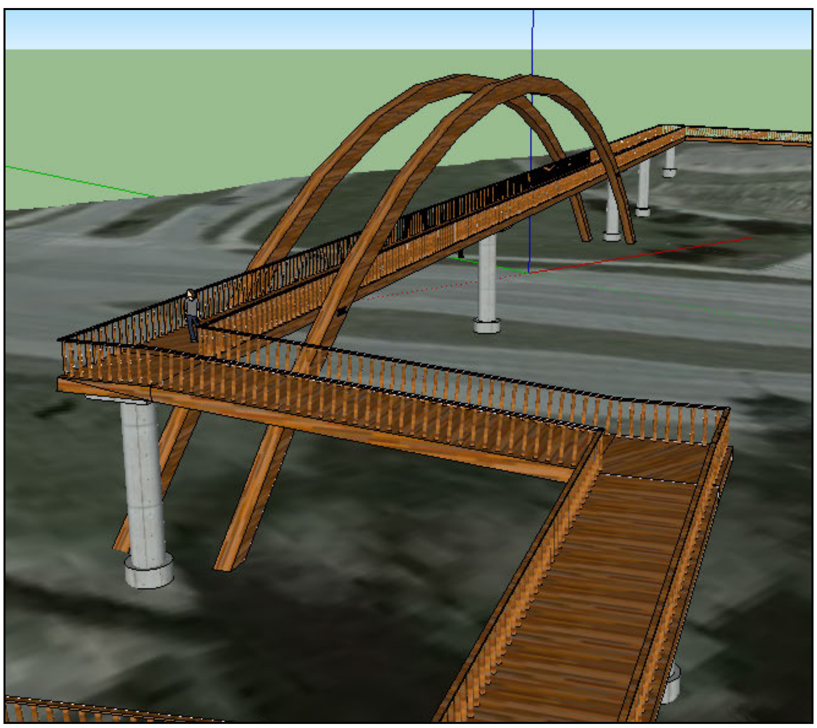


Figure 20: UBC Botanical Garden Pedestrian Overpass Design

The majority of the pedestrian overpass will be constructed of glulam timber in accordance with the Canadian Wood Design Manual. This includes the large arches and the deck that spans across NW Marine Drive. The connection from the timber arches to the deck will consist of self-tapping screws oriented in a moment design connection. The timber design was chosen to match the organic spirit of the garden. The span of the pedestrian overpass is roughly 95 meters in length and is supported by concrete columns with drop panels to assist with the vertical loading on the structure. In order to reduce construction time, most of the overpass' components will be prefabricated offsite (the deck and arches).

As described by the Ministry of Transportation in the Bridge Standards and Procedures Manual (2007), the pedestrian overpass will have a minimum clearance of 5.5 meters over the paved surface of NW Marine Drive. The ramps leading up the pedestrian overpass will adhere to a 1:12 slope to ensure that it is wheelchair accessible (Bridge Standards and Procedures Manual, 2007).

3.2 Cost Estimate

The overall cost of the UBC Botanical Garden Pedestrian Overpass was estimated to be $9.0 million. To achieve this estimate, we analyzed and adjusted the final project cost of Tynehead Pedestrian Overpass (a similar project) that was constructed in Surrey in 2011. The breakdown of our estimate can be found in Table 9.

	Factor	Description
Tynehead P.O. Cost (million)	$6.78	Final project Cost
Location Factor	1	From Surrey to UBC
Year Factor	1.12	From 2011 to 2015 (including inflation)
UBC Factor	1.2	UBC construction factor
Material Factor	0.9	From steel to timber
Construction Factor (material)	1.1	Complications in timber construction
UBC Botanical Garden P.O.	**$9.00**	**million**

Table 9: Cost Estimate for Pedestrian Overpass

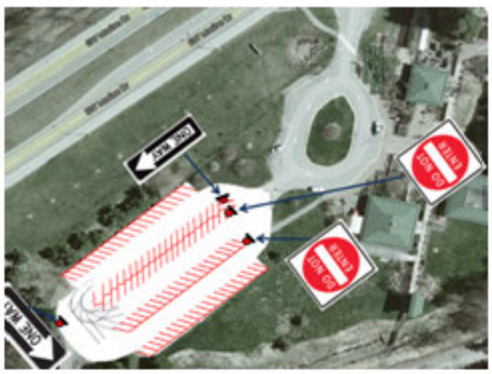
The time factor in the above table was calculated using cost indexes between 2011 and 2014 and by calculating a projected cost index from 2014 to 2015. The UBC Factor, Material Factor, and Construction Factor were estimated based on the complications that arise when constructing on the UBC campus and when using timber as a construction material.

3.3 Construction Schedule

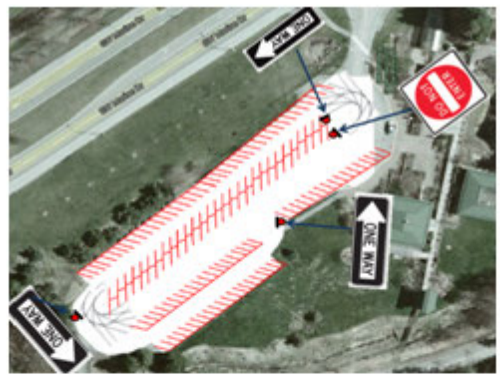
The construction period for the pedestrian overpass will last six months. This is the same construction period that took place for the construction of the Tynehead Pedestrian Overpass. The majority of the UBC Botanical Garden Pedestrian Overpass will be prefabricated offsite to reduce the time spent constructing onsite. The overpass deck and arches will be prefabricated offsite in segments. The deck and arches will be hauled onsite and erected using a crane. The concrete columns with drop panels will be constructed onsite.

4.0 PARKING LOT IMPROVEMENTS

Increasing parking capacity at the UBC Botanical Gardens will allow more people to visit the garden with greater ease. The current capacity can be significantly increased by optimizing the existing parking lot layout. The entire cost is evaluated at approximately $300,000. As mentioned previously, the decommissioning of two lanes along SW Marine Drive (one on each direction) will create additional street-side parking for UBC BG visitors. The design, cost estimate, and construction schedule for parking lot improvements are explained in the following sections.



Parking Lot Improvements - Stage 1



Parking Lot Improvements - Stage 2

Figure 21: Stage 1 and 2 of Parking Lot Improvements

4.1 Parking Lot Design

The parking lot serves multiple functions. For instance, it is the location where the popular event, Apple Fest, is hosted. With this in mind, conventional pavement has been selected as opposed to alternative pavement types such as permeable pavers because it is a neat and clean solution. In addition to suiting the needs of the user, conventional pavement is also the most cost effective solution because its design life of 20 years is greater than those among other pavement options. As a result, the selection of conventional pavement will also reduce the maintenance and replacement costs.

4.2 Cost Estimate for Parking Lot Improvements

Cost estimate data for typical parking lot construction is used to develop a cost estimate for the proposed parking lot improvements. In addition to removing the existing median, the proposed parking lot improvements will require the excavation of the existing pavement, installation of required signage, and addition of new pavement markings. A breakdown of the cost estimate for the parking lot improvements can be found in Table 10.

Cost Estimate for Parking Lot Improvements				
Item/Activities Required	**Quantity**	**Unit**	**Unit Cost**	**Cost**
Concrete Pavement Installation (includes excavation)	56000	S.F.	$4.00	$224,000.00
Signage	1	L.S.	$500.00	$500.00
Pavement Marking	1	L.S.	$2,000.00	$2,000.00
Subtotal				$226,500.00
Contingency (10%)				$22,650.00
Total Cost (unadjusted)				$249,150.00
Location Factor				1.066
Total Cost (adjusted with Location Factor)				**$265,593.90**

Table 10: Cost Estimate for Parking Lot Improvements

4.3 Construction Schedule

The construction of the parking lot would be scheduled to take place during the period with the lowest visitor volumes (i.e. sometime in the winter season). The expected duration for parking lot improvements is approximately 1 month. The Gantt chart shown in Figure 22 illustrates the proposed construction schedule. Blue bars highlight the main construction phases, while red bars show the critical path of the project.

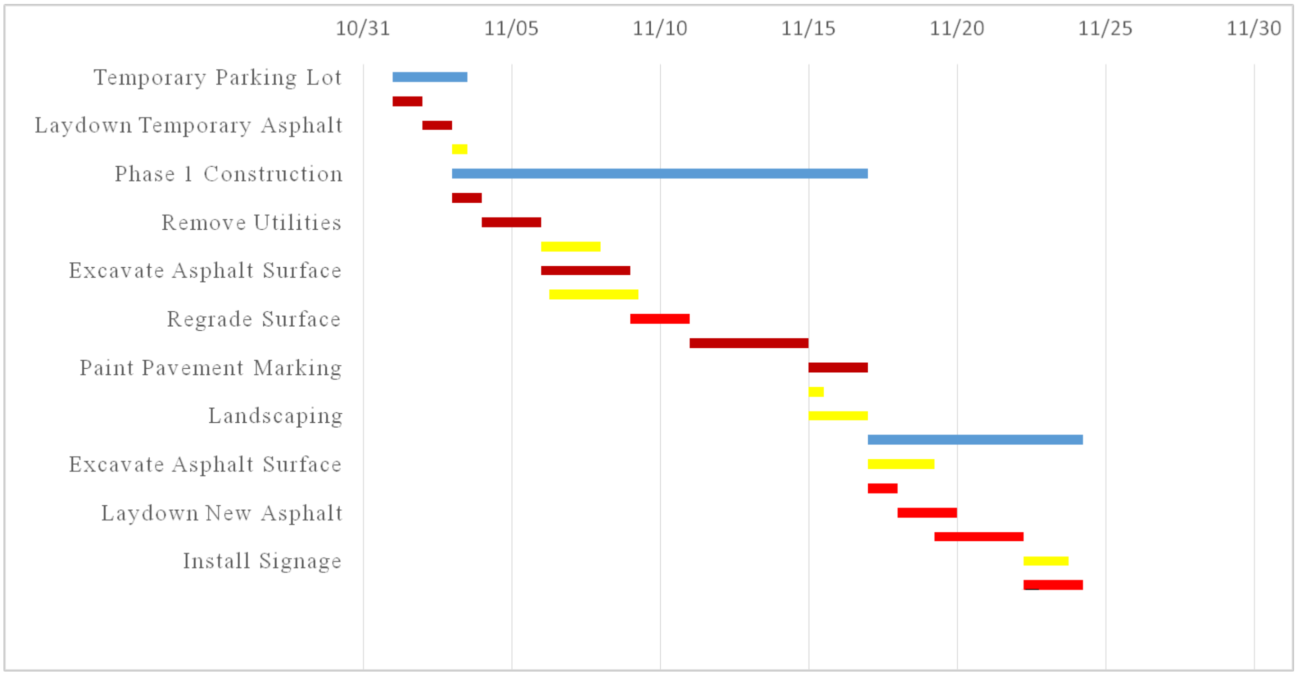


Figure 22: Construction Schedule for Parking Lot Improvements

5.0 IMPLEMENTATION PLAN

The implementation of this design plan will take place over an extended period of time. We propose to implement this plan over the next three years.

5.1 Sequence

We propose that the three phases of this project will be constructed sequentially in the order outlined in this development plan (starting with the roundabout and ending with the parking lot expansion). The projects involved in this development plan are not constricted to any specific order. Since each individual project is designed as a stand-alone structure that does not depend on the other projects, the client may choose to construct these projects in a different sequence.

5.2 Cost Overview

The following table summarizes the cost estimates of each component of the proposed design plan.

Project	Total Project Cost ($)
Roundabout	$3,677,307
Pedestrian Overpass	$9,000,000
Parking Lot	$265,593.90
TOTAL COST	$12,942,901

Table 11: Final Budget Summary

As shown above, the total cost estimates for the roundabout, pedestrian overpass, and parking lot expansion are roughly 3.7, 9.0, and 0.27 million dollars respectively. The total cost of our design plan is roughly 13.0 million dollars. We believe that these estimates lie within realistic cost parameters. Each phase can be implemented as financing for the development of the UBC Botanical Garden becomes available.

6.0 CONCLUSION

The three-phase development plan proposed by West Coast Consulting within this report is a long-term traffic system improvement strategy. Implementation of the plan increases the safety of all road users in the vicinity of the UBC Botanical Garden, facilitates improved traffic flow, minimizes the environmental impacts from the motor vehicles, encourages the use of sustainable modes of transportation, and promotes new structures that assist to attract more visitors to the UBC Botanical Garden.

The recommendations outlined in this report include replacing the existing signalized intersection on Marine Drive at 16th Avenue with a 37-meter diameter roundabout, implementation of several changes to the existing traffic operations along Marine Drive between 16th Avenue and Stadium Road, construction of a new pedestrian overpass, and re-design of the existing Garden's parking lot. Each recommendation has been determined after conducting a comprehensive traffic flow, hydrotechnical, and structural analysis, by our team of experienced civil engineering professionals, and supported by our construction management associates. The report is only a brief summary of our findings and recommendations, and our engineering team is looking forward to discuss each of the outlined recommendations in more details.

In conclusion, although the total costs of the entire development plan are quite high, the road users' safety is priceless. Also, the nature of the phasing, and the ability to separate components within a phase allow for a much more affordable approach to development, one which will allow the UBC Botanical Gardens to move towards improved fiscal sustainability.

REFERENCES

Aplin& Martin Consultants Ltd. (2006) *A Sustainable Drainage Strategy for the South Campus Neightbourhood*. Rep. UBC Properties Trust, Jan. 2005. Retrieved from planning.ubc.ca/sites/planning.../SC_StormwaterMgmtStrategy.pdf

Bedient, Philip B., and Wayne Charles. Huber. (1998) *Hydrology and Floodplain Analysis*. Reading, MA: Addison-Wesley

British Columbia Ministry of Transportation and Infrastructure. (2010). *Traffic Control Manual*. Retrieved from http://www.th.gov.bc.ca/publications/eng_publications/TCM/Traffic_Control_Manual.ht

British Columbia Ministry of Transportation and Infrastructure.(2007). *Bridge Standards and Procedures Manual*. Retrieved from http://www.th.gov.bc.ca/publications/eng_publications/bridge/standards/BSM-Volume-1_2007/BSM_Vol-1_All_Sections_Aug_2007.pdf

HNTB. (n.d.). Planning Level Cost Estimation Tool User's Manual. Retrieved from http://www.atlantaregional.com/File%20Library/Transportation/Financing_Transportation/tp_costingtool_usermanual_032410.pdf

Lim, Clark. (2014). *UBC CIVL 441 – Transportation Planning, Lecture 11*. Retrieved from http://elearning.ubc.ca/connect/

Roess, Roger. (1990). *Traffic Engineering*. New Jersey: Prentice Hall

Tech. Forestry Department, Food and Agriculture Organization of the United Nations (FAO), (2011). *Watershed Management Field Manual, Chapter 4: Drainage Design*. Retrieved from http://www.fao.org/docrep/006/t0099e/t0099e04.htm

UBC Campus and Community Planning. (2006). 16th Avenue Consultation Report. Retrieved from http://planning.ubc.ca/sites/planning.ubc.ca/files/documents/transportation/reports/Roundabout-consultation-report-6-Feb-06.pdf

UBC Technical Guidelines. (2014). UBC Utilities Design Review Information Package. Retrieved from http://www.technicalguidelines.ubc.ca/div_02_files/Division_2/UBC%20%20DesignReviewInfoPkg.pdf

Vision Zero Initiative. (2014). *Traffic Safety by Sweden*. Retrieved from http://www.visionzeroinitiative.com/

APPENDIX A: SAMPLE CALCULATIONS

Traffic Flow Analysis – LOS for Marine Dr. from 16 Ave to Stadium Rd

The flow vs. density curves for each option were created by using the general equations from the Greenshield's Model - Traffic Flow Theory:

$$V = V_f - \frac{V_f}{K_j} * K \qquad q = V_f * K - \frac{V_f}{K_j} * K^2 \text{ derived from } q = k * V$$

Below is provided a brief explanation with a sample calculation for option #3: assumed three lanes to be used for vehicular traffic flow, and two (i.e. the outer NB and SB lanes) to be designated for on street parking. For the free flow speed (V_f) is assumed 55 km/h, based on the suggested 50 km/h speed limit. Total road capacity is 5400 pcph, in passenger cars per hour, found from the product of 1800 x N, where 1800 is the suggested design freeway capacity per lane from the Highway Capacity Manual, while N is the total number of lanes. Jam density (K_j) is 393 pc/km:

$$K_j = \frac{4 * q_{max}}{V_f} = \frac{4 * 5400}{55} = 393 \text{ pc/km}$$

The Greenshield's Model for option #3 is defined by the equations:

$$V = 55 - \frac{55}{393} * K$$

$$q = 55 * K - \frac{55}{393} * K^2$$

Similarly, the traffic flow representative equations for each option were derived, and the plot of the flow vs. density was created (Figure A1)

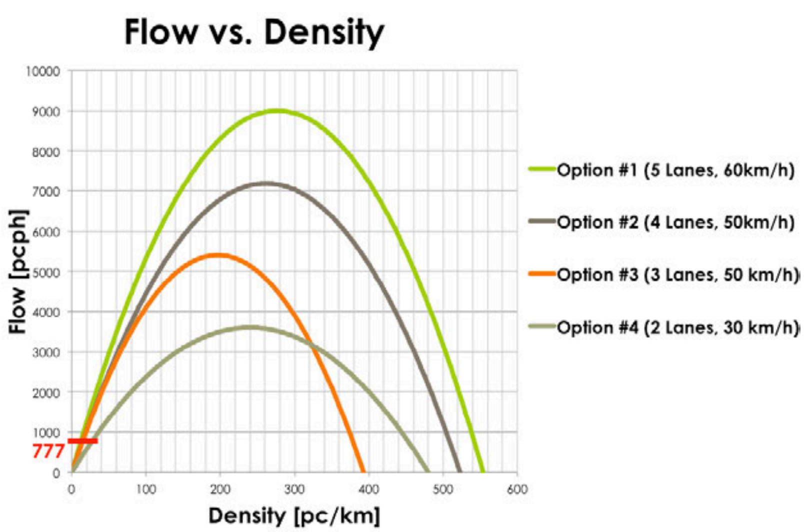


Figure A.1: Flow vs. Density for Each Option

The Highway Capacity Manual suggests that the LOS equals A when the volume over capacity ratio is less than 0.35. Based on the peak hour volume provided by UBC Transportation Planning (777 pcph), the LOS for each of the four considered options was stable A, with existing v/c values significantly lower than 0.35:

Option	Capacity, c	Volume, v	Existing v/c	Existing LOS
#1	9000pcph	777 pcph	0.086	A
#2	7200pcph	777 pcph	0.108	A
#3	5400pcph	777 pcph	0.144	A
#4	3600 pcph	777 pcph	0.216	A

Hydrologic Analysis - Peak Runoff

Introduction

Our project cross the boundary between two catchment areas - the Trail 7 Catchment and the 16th Avenue Catchment

Peak Runoff will be determined for each of the catchment areas using the ***Rational Method***

Inherent assumptions of the Rational Method:

1) the rainfall is uniformly distributed over the entire drainage area and is constant over time
2) the predicted peak discharge has the same probability of occurrence (Return Period) as the used rainfall intensity
3) the peak runoff rate can be represented by rainfall intensity averaged over the same time period as the drainage area's time of concentration
4) the runoff coefficient is constant during the storm event

Calculations

Q = 0.0028 CiA

Q = peak runoff
C = runoff coefficient
i = rainfall intensity
A = drainage area

Rainfall Intensity

Time of Concentration - based on Empirical Equation below

Tc = 0.0195*L^0.77*S^-0.385

Elevations and Distances were determined using **Google Earth**

	16th Ave Catchment	Trail 7 Catchment
Elevation at NE Boundary (m)	90	96
Elevation at SW Boundary (m)	69	79
Distance between boundaries (m)	872	700
Average grade of drainage area	2.4%	2.4%
Approximate catchment area (ha)	20	45
Longest catchment diagonal (m)	870	1000
Diversion factor	1.3	1.7
Flow Length (m)	1131	1700
Time of Concentration (min)	**18.4**	**25.1**

Design Frequency:

According to the Sustainable Drainage Strategy for the South Campus Neighbourhood:
"Because of the potential damage that could result from uncontrolled flows between Marine Drive and the ocean, sewers, channels, and outfalls west of Marine Drive should be designed to accommodate the 200-year storm. Also, since Marine Dr. is under the jurisdiction of the Ministry of Transportation and Highways, the design service level for infrastructure must be for the 200-year storm"

Extrapolating from Figure C.2 Rainfall Intensity Curves for the Lower Fraser Valley (from Atmospheric Environment Service)

Storm Duration = Tc (min)	18.4	25.1
Return Period (years)	200	200
Rainfall Intensity (mm/hr)	**48**	**42**

Runoff Coefficient

"South Campus soils consist typically of about 0.5m of organic topsoil, underlain by up to 30m of relatively impermeable glacial till"

16th Ave Catchment			
Subcatchment	A	B	C
Area (ha)	10	5	5
Description	Cultivated, Loam, Flat	Woodland, Flat	Urban, 70% Impervious, Flat
Runoff Coefficient	0.5	0.3	0.65

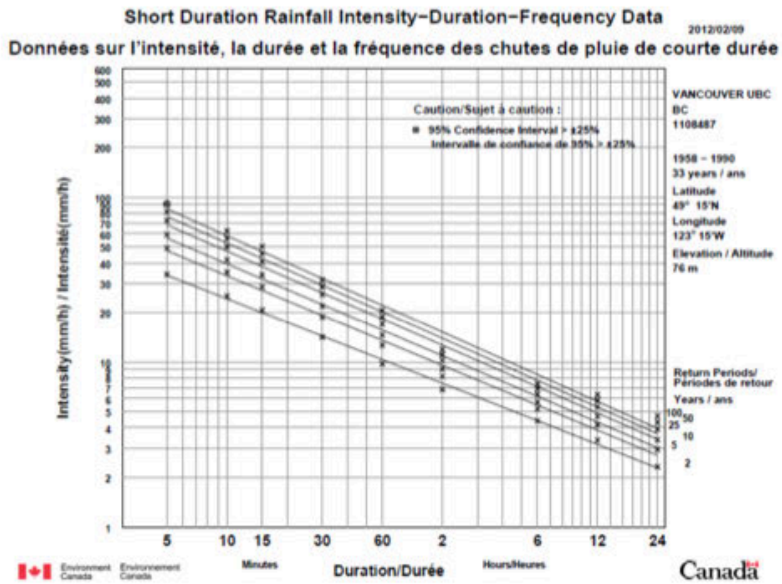
C = sum(CiAi)/sum(Ai) **0.4875**

Trail 7 Catchment		
Subcatchment	C	D
Area (ha)	22.5	22.5
Description	Urban, 70% Impervious, Flat	Cultivated, Flat
Runoff Coefficient	0.65	0.5

C = sum(CiAi)/sum(Ai) **0.575**

Peak Runoff

	16th Ave Catchment	Trail 7 Catchment
Runoff Coefficient	0.4875	0.575
Rainfall Intensity (mm/hr)	48	42
Catchment Area (ha)	20	45
Peak Runoff (m^3/s)	**1.31**	**3.04**



Trapezoidal Swale Design

Peak Design Flow, Q_{max} **4.35 m^3/s**

Manning's Equation $Q = (1/n)\, A\, R_h^{2/3} So^{1/2}$
$Q = (1/n) * A^{5/3}/P^{2/3} * So^{1/2}$

Swale height and side wall slope were iterated through to achieve required capacity

y =	0.75 m	
αmax =	30 degrees	*(FAO, 2014)*
αmax =	0.52 rad	
Bmax =	3.40 m	
Wmax =	6 m	

For a channel with significant vegetation and erosion resistant soil,

n =	0.06	*(FAO, 2014)*
Vmax =	2 m/s	*(FAO, 2014)*

The slope along SW Marine Drive is

So =	0.025	*(Google Earth)*

A = y(y/tanα) + yB

P = B + 2(y/sinsα)

Q = So^(1/2) * (y^2/tanα + yB)^(5/3)/(B + 2y/sinα)^(2/3)

Maximum width of the swale:

Wmax = 6 m
Bmax = Wmax - 2y/tanα

Iterate through y and α to obtain solution

Flow Capacity = **6.24** cms

Checks:		
	Q =	6.24 **OK**
	A =	3.53
	V =	1.77 **OK**

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