



Burrard Inlet Rapid Transit Study

Stage 2 Engineering Review

September 9, 2020

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Executive Summary

Introduction

The Burrard Inlet Rapid Transit (BIRT) Feasibility Study was conceived to evaluate “the conditions for rapid transit between the North Shore and Burrard Peninsula” as recommended by the [‘Integrated North Shore Transportation Planning Project’, INSTPP, in 2018](#).

Following the INSTPP recommendation, a Partner Working Group (PWG) was established, representing the Province, TransLink, and municipal partners to develop the scope of the BIRT Study and to work closely with the project team to provide ongoing feedback and support during the study. The scope of the study is a unique technical analysis, focused primarily on the feasibility of a new transit system crossing the Burrard Inlet, and its work is intended to initiate and support further analysis of a rapid transit system connecting the North Shore with the wider transit network in the Lower Mainland.

Stage 1 of the BIRT Study included the development of a variety of plausible crossing options. Through an iterative process of high-level conceptual engineering and travel demand modelling assessments, PWG feedback, and Level 1 Multiple Account Evaluation, these options were screened to a short list of six crossing options to carry forward to Stage 2 for further review. The six crossing options, shown below in Figure 1, for Stage 2 review include:

Blue Zone:

- Option 2A – Burrard Station via First Narrows/Park Royal to Central Lonsdale (Tunnel)
- Option 3A – Burrard Station via Brockton to Central Lonsdale (Tunnel)

Green Zone:

- Option 1A – Waterfront Station via Lonsdale to Park Royal (Tunnel)

Purple/Yellow Zone:

- Option 5B2 – Waterfront Station via Second Narrows to Lower Lonsdale (New Bridge)
- Option 5B – Brentwood via Second Narrows to Lower Lonsdale (New Bridge)
- Option 5C – Brentwood via Second Narrows to Lower Lonsdale (Existing Bridge)



Figure 1: Six Crossing Options Advanced to Stage 2

Stage 2 Engineering Scope

The work completed in Stage 2 focused on high-level engineering assessments, building upon the work completed in Stage 1, within the vicinity of the six shortlisted Burrard Inlet crossings and their potential high-level connections to existing transit infrastructure. The engineering activities in Stage 2 will support potential future study work, such as further transit network integration and optimization, and potential inclusion in TransLink's Transport 2050 and/or as part of the Mayors' Council Investment Plan and provide additional technical information to inform potential future stages of the BIRT Study.

Stage 2 did not expand upon the multiple account evaluation (MAE) framework developed in Stage 1 or review further optimization of transportation network performance, such as extensions of routing connections to existing or planned transit systems. The work completed to-date has primarily focussed on the feasibility of the water/inlet crossing options and the development of conceptual tunnel and bridge geometry.

Stage 2 Options Review

Each of the options carried forward from Stage 1 were reviewed and assessed in further detail during Stage 2. The options were categorized into the same zoning areas defined in Stage 1.

Blue Zone (First Narrows Crossing)

In the blue zone, tunnel alignment options 2A and 3A were refined, and the conceptual design work further explored the feasibility of tunnelling under the inlet in the First Narrows area, including development of plausible alignment locations to surface the tunnel alignment on the North Shore. Two plan-profile concepts were advanced, showing possible alignment locations and rights-of-way. The engineering work completed in 2A and 3A demonstrated various feasible options, given the information available to-date, and will therefore advance to future stages of the study. As more engineering work and data is gathered, such as geology and existing infrastructure (i.e. utilities and underground structures), the technical feasibility of the crossing options in the blue zone will continually gain clarity and definition.

Green Zone

In the green zone, two sub options for option 1A in downtown Vancouver were explored to see if an alternate to the deep transfer station required at Waterfront station was feasible. This included a potential spur alignment off the Canada Line located somewhere in downtown Vancouver. After review of the Canada Line as-built drawings, it was determined that there are no vertical grades, of track and tunnel, within the downtown area of sufficient length and suitable grade for switches to enable a spur line. Thus, the spur sub-option of Option 1A was deemed infeasible and removed from further study.

The second sub-option examined the feasibility of rebuilding a portion of the Canada line from Yaletown-Roundhouse Station to Waterfront Station to lower the existing track's profile to enable a continuous extension of the Canada Line under Burrard Inlet to the North Shore. In order for the tunnel profile to be low enough to facilitate removing a transfer station at Waterfront Station for the 1A alignment option, the profile would need to be lowered approximately 20-35m below the current track elevation through the existing Canada Line City Centre and Waterfront Stations. This would require a re-construction of Canada Line of approximately 1,100m. The challenges and cost premiums associated with this sub-option are anticipated to be high; however, because this sub-option has not undergone modelling ridership analysis or costing (compared to the Waterfront to Lonsdale option explored in Stage 1), it will be advanced to future

stages of the study to undergo the same due-diligence as other options underwent in Stage 1. Alternative options such as an independent line from Waterfront to future transit systems (i.e. Broadway Subway Project) may also be explored.

Yellow and Purple Zone (Second Narrows Crossing)

In the yellow and purple zone, two bridge options were reviewed: a new bridge (Option 5B and 5B2) and the potential retrofit of the existing Iron Worker's Memorial Bridge (IWMB) (Option 5C) to allow for the addition of rapid transit underneath the existing bridge deck. For the new bridge options, several potential crossing alignments were developed. These alignment locations were selected based on existing terrain and land use constraints in the area as well as potential pier placement and navigational requirements. Several alternative new bridge alignments were developed, and all shown to be feasible, based on the information available to-date. In future stages, the new bridge alignment and pier placement will need to be discussed further with key stakeholders, such as Vancouver Fraser Port Authority (VFPA), Transport Canada and the MoTI technical team responsible for the existing IWMB.

Option 5C (Use of existing bridge) was further examined and additional data on the existing structure from MoTI was provided. The existing IWMB has both seismic and ship impact deficiencies that do not meet current design standards for a major structure. Additionally, retrofitting IWMB could not achieve the same resiliency of a new bridge. It was also noted that the potential savings on permitting time and environmental impact were unlikely to be realized based upon the typical project lifecycle of a transit project. Thus, Option 5C was screened out from further investigation in future phases.

Stage 2 Options for Advancement

Following completion of the Stage 2 engineering activities, the PWG decided to remove Option 5C (Use of existing bridge) from further analysis at this time because of the structural challenges associated with retrofitting the Iron Workers Memorial Bridge (IWMB), including seismic, ship collision, wind, and fatigue vulnerabilities. In addition, the potential savings on cost and permitting timelines associated with this option are unlikely to be realized, given the current climate on funding approval processes in the Lower Mainland.

The five remaining options to carry forward for further analysis are:

- Option 1A (Canada Line Extension (or another potential alternate) to Lower Lonsdale) - Tunnel
- Option 2A (Burrard via First Narrows to Central Lonsdale) – Tunnel
- Option 3A (Burrard via Brockton Point to Central Lonsdale) – Tunnel
- Option 5B (Brentwood via Second Narrows to Lower Lonsdale) – New Bridge
- Option 5B2 (Waterfront via Second Narrows to Lower Lonsdale) – New Bridge

Recommendations for Next Steps

Following the work completed to-date in both Stage 1 and Stage 2, a number of work activities which will provide more information to help facilitate comparisons between the different options and decisions to be made are recommended to be completed as part of future stages. This recommended work includes, but is not limited to:

- Refinement of option routing beyond the inlet crossings to optimize system integration and maximize ridership potential.
- Further transportation modelling;

- Further engineering work to support a more comprehensive routing concept, costing, MAE work, and achieve housing and land development objectives.
- Preparation of high-level capital costing estimates.
- Update Level 1 MAE transportation accounts as well as development and implementation of Level 2 MAE with consideration to align the MAE with evaluation criteria developed for ongoing regional long-term strategic planning (e.g. Transport 2050); and
- Evaluate opportunities for staged expansion.

In addition, activities in potential future stages should coordinate with the multi-agency North Shore economic impact assessment, to ensure alignment of complementary tasks between the studies. It is expected that the Economic Study will advance some early findings on wider economic benefits such as community infrastructure and affordable housing opportunities.

As future work on the BIRT study is considered, ongoing collaboration with the PWG and engagement with the various relevant governments, including First Nations, municipalities, regional and local agencies, and provincial agencies should be continued. Active participation of all parties in future stages will help to identify important project considerations and enable effective decision making.

1 Introduction

1.1 Project Background

The Burrard Inlet Rapid Transit Feasibility (BIRT) Study is the first stage in the exploratory planning process for identifying a potential fixed link rapid transit corridor between the North Shore and the Burrard Peninsula. It was initiated as a direct outcome of the Integrated North Shore Transportation Planning Project (INSTPP) process in 2018. INSTPP recommended further work to “evaluate the conditions for rapid transit between the North Shore and Burrard Peninsula, connecting Lonsdale City Centre with Vancouver’s metropolitan core and the regional rapid transit network.”

Following this recommendation, a Partner Working Group (PWG) was established to develop a scope of work for the BIRT Study and work closely with the consulting team in a collaborative environment to facilitate effective partnerships and ongoing feedback during the study process. The PWG includes the following partners:

- Ministry of Transportation and Infrastructure
- Ministry of Municipal Affairs and Housing
- TransLink
- District of West Vancouver
- City of North Vancouver
- District of North Vancouver
- City of Vancouver

In Stage 2, the project welcomed new PWG representation from Squamish First Nation, and outreach to other First Nations, such as Musqueam and Tsleil-Waututh, is currently underway to include more Indigenous community representation in the next stages of the Study.

Stage 1 of the BIRT Study included the development of a variety of plausible crossing options. Through an iterative process of high-level conceptual engineering and travel demand modelling assessments, PWG feedback, and Level 1 Multiple Account Evaluation, these options were screened to a short list to carry forward to Stage 2 for further analysis. For a detailed account of the work completed in Stage 1, refer to *514100116-MMD-00-P0-RP-PM-0001 – Stage 1 Feasibility Screening Report*, dated March 31, 2020.

To organize the variety of alignment options explored, four distinct Burrard Inlet crossing zones were identified to better categorize options. These groupings are based on different segments of the overall travel market that are being served and were developed to align with key activity nodes maximizing ridership potential and are as follows:

- Blue Zone – Western connection via First Narrows
- Green Zone – Direct connection between Waterfront and Lonsdale
- Yellow Zone – Hastings Sunrise to Lonsdale connection
- Purple Zone – Eastern connection via Second Narrows

Upon completion of Stage 1, six crossing options, shown below in Figure 1-1 were advanced to Stage 2 and include:

Blue Zone:

- Option 2A – Burrard Station via First Narrows/Park Royal to Central Lonsdale (Tunnel)
- Option 3A – Burrard Station via Brockton to Central Lonsdale (Tunnel)

Green Zone:

- Option 1A – Waterfront Station via Lonsdale to Park Royal (Tunnel)

Purple/Yellow Zone:

- Option 5B2 – Waterfront Station via Second Narrows to Lower Lonsdale (New Bridge)
- Option 5B – Brentwood via Second Narrows to Lower Lonsdale (New Bridge)
- Option 5C – Brentwood via Second Narrows to Lower Lonsdale (Existing Bridge)

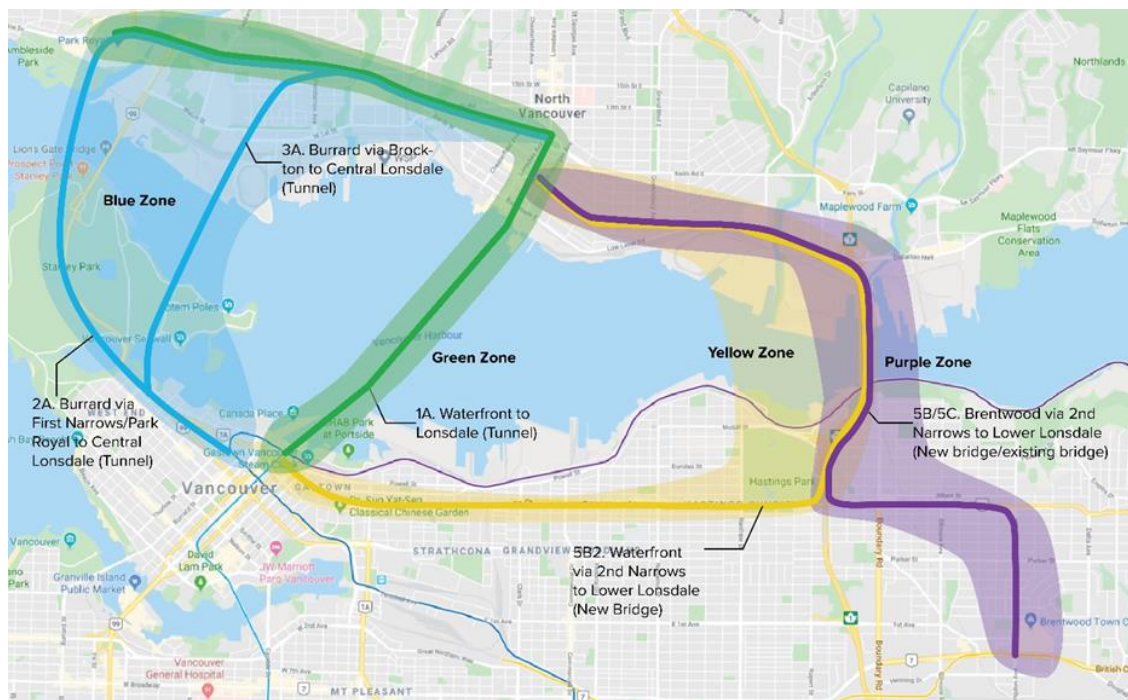


Figure 1-1: Options to carry forward to Stage 2

1.2 Stage 2 Scope

Following completion of Stage 1 work, the consulting team in collaboration with the PWG reviewed various scope activities identified as next steps in Stage 1. Following a fulsome discussion, it was agreed that the focus of the Stage 2 study would be to advance specific engineering activities that may further identify key differentiators between options. These activities included further geometric reviews of alignment options at crossings and discussions with various stakeholders including TransLink and MoTI to gather additional data and identify potential opportunities and technical constraints associated with crossing options. It will also support future study work such as potential inclusion in TransLink's Transport 2050 and/or as part of the next Mayors' Council Investment Plan.

The engineering work in Stage 2 includes the following activities:

- Meeting with TransLink (BCRTC) to confirm SkyTrain extension operational assumptions assumed in the transportation modelling work completed in Stage 1
- Meeting with MoTI technical staff to discuss bridge structural issues for Option 5C (use of existing Ironworkers Memorial Bridge (IWMB))
- Further engineering review of Option 5C crossing (use of IWMB)
- Further engineering review of Option 5B (new second narrows transit bridge crossing)
- Further engineering review of geological and tunnelling considerations for blue zone crossings (2A/3A)
- Meeting with Vancouver Fraser Port Authority (VFPA) to review options and collect additional data/feedback
- Further engineering assessment of Option 1A to determine if this crossing could become an extension or spur of the existing Canada Line in Vancouver's downtown core

Exclusions in Stage 2 scope include transportation modelling activities, environmental activities, cost estimation, further multiple account evaluation, structural analysis and geotechnical analysis.

1.3 Limitations of Study and Future Work Required

Stages 1 and 2 of the BIRT Study are not an exhaustive study of how the Burrard Inlet rapid transit crossing would fit into the regional transportation network. The work completed to-date has primarily focussed on the technical feasibility of the water/inlet crossing options. The alignment options proposed are for comparative purposes only and refinement of them further could affect their performance in the transportation accounts of the MAE. There will be significantly more engineering work required, as more information is gathered during future stages of the study, such as geotechnical investigations and review of existing infrastructure conflicts such as utilities and building foundations. In addition, more analysis is required with respect to system integration, land development and housing opportunities, phased expansion, costing, and economic development opportunities. As engineering work progresses, it may be determined that a specific alignment option, alternative or sub-option is no longer deemed feasible.

The work completed in Stage 2 focused on high-level engineering assessments within the vicinity of the six shortlisted crossings, and their potential connections to existing transit. It did not expand upon the multiple account evaluation framework developed in Stage 1 or review further optimization of transportation performance, such as extensions of routing connections to existing or planned transit systems. These activities will be critical in further assessment and refinement of evaluating crossing options and should continue into future stages of the study. Section 6 of this report includes recommendation for next steps including but not limited to the work activities described above.

Moving beyond Stage 2 of the BIRT Study to future phases, the technical complexity and deliverability of infrastructure crossing options will continually gain clarity and definition. Stage 1 included high-level engineering desktop assessments based on the available terrain, bathymetry and geology data and known previous studies available in the study area. Stage 2 engineering work is an expansion of the work completed in Stage 1 with engineering primarily focused on progression of the potential geometric alignments and profiles within the crossing areas, with consideration of available information collected to-date and in consultation with some key stakeholders such as VFPA, MoTI, and TransLink.

In later potential stages of the study and beyond, the objective will be to ultimately identify a single preferred option with connections to the wider rapid transit network through iterative evaluation, technical analysis, and partner, stakeholder, and public engagement.

2 Engineering Considerations

The following sections summarize the BIRT Study's key engineering considerations that informed Stage 2 work.

2.1 Alignment and Profile Assumptions

As a part of Stage 1, high-level route alignments for each of the options were developed to identify key issues to help inform the Stage 1 Multiple Account Evaluation (MAE) work. The intent of developing these alignments was not to identify each and every potential issue or concern with an alignment but to allow the identification of fundamental aspects which could influence the MAE results, such as extensions of existing SkyTrain lines and ridership patterns.

During Stage 2, the six alignment options were advanced to an early engineering conceptual design level and included plausible horizontal and vertical alignment sub options within each zone. It was assumed that alignments would utilize existing SkyTrain technology design parameters. As the limiting parameters for SkyTrain are more restrictive than they would be for bus or light rail, doing so means that a broad range of technologies can be accommodated as the options evolve (i.e. SkyTrain, CanadaLine, light rail, etc.).

The SkyTrain geometry constraints were considered in conjunction with current shipping clearances, known infrastructure (such as the Canadian Pacific (CP) tunnel to the Second Narrows), bathymetry, and geotechnical information from previous studies.

Key geometric assumptions when developing alignment and profiles included:

- Maximum track gradient of 6% and minimum horizontal curve radius of 80m, with a preferred minimum horizontal curve radius of greater than 130m, which is typical for SkyTrain standards.
 - The minimum horizontal curve radius is for the track and is achievable for both at-grade and elevated track.
 - The limiting geometry constraints for a bored tunnel will be dependent on the diameter of the tunnel (see Section 2.4.3).
- Minimum vertical clearances over roadways and Highway 1 is 5.5m.
- Minimum vertical clearance over CN/CP rail tracks is 7.163m (23.5ft)
- Minimum navigation clearances for channel width and maximum air draft at higher high-water large tide (HHWLT) is dependent on vessel beam. For Second Narrows, the full matrix of values is provided in VFPA's Port Information Guide (May 2018), Appendix B.
 - For designing a new bridge at Second Narrows, a maximum vessel air draft of 42.7m HHWLT requires a channel width of 66.4-77m
- A conservative minimum vertical clearance between an existing tunnel or underground structure to a new tunnel is 10m, which is approximately one tunnel diameter of a single bored tunnel

2.2 Operational Assumptions

In Stage 1, various operational assumptions were made for demand modelling with regards to the feasibility of extending the Expo Line from Waterfront Station or implementing a spur line from the Expo Line at Burrard Station for the various options undergoing Stage 1 multiple account evaluation. As part of Stage 2, the Stage 1 operational assumptions were discussed

with TransLink to confirm operational feasibility and validate the performance outputs from the transportation accounts in the Level 1 MAE.

The key assumptions which were discussed with TransLink and confirmed to be reasonable are:

- A spur connecting to the Expo Line at Burrard Station (Options 2A and 3A) could see 1 in 3 trains continue to the North Shore with the other 2 continuing to Waterfront where they would terminate. This would be similar to the current eastern extent of the Expo Line where 1 train travels to Production Way, to provide connections to the Millennium Line, while the other 2 continue to King George Station in Surrey. Trains would operate at approximately 4 min 30s intervals during peaks.
- Option 1A, as an extension of the Canada Line, could operate all services to the North Shore. With the Stage 2 engineering analysis considering the potential to create a spur, a different service pattern could be required, and ridership modelling would need to be reassessed.
- Any option continuing from the Expo Line terminus at Waterfront Station (Option 5B2) could theoretically operate at the full Expo Line frequency. However, ridership demand is unlikely to require such a high frequency (at least initially) and operating a similar 1 in 3 patterns of trains as a spur is a suitable assumption.
- All other options which do not extend existing SkyTrain Lines, thus requiring a transfer, were assumed to operate at 3-minute headways.

It should be noted that these operational assumptions have not considered the potential impacts associated with adding ridership onto a system that is already overcrowded in places. This should be addressed in later stages of the project.

2.3 Geological Considerations

The topography and nature of the soil units located within the study area have been greatly influenced by repeated glacial and interglacial periods and accompanying sea level changes over the last 10,000 to 2 million years. The resulting erosional and depositional processes have left in place complex deposits of highly variable soil units that range in thicknesses from thin veneers to greater than 100m thick and have variable engineering behavior and properties.

For the purpose of the BIRT Study, surficial geology in the study area can be generally broken down into units classified by the Geological Survey of Canada (GSC) Surficial Geology Map 1486A (Armstrong & Hicock, 1976) shown on Figure 2-1 below. Additional information can be drawn from records included within historical projects, observation from current construction, and/or from ground investigations as part of ongoing design processes.

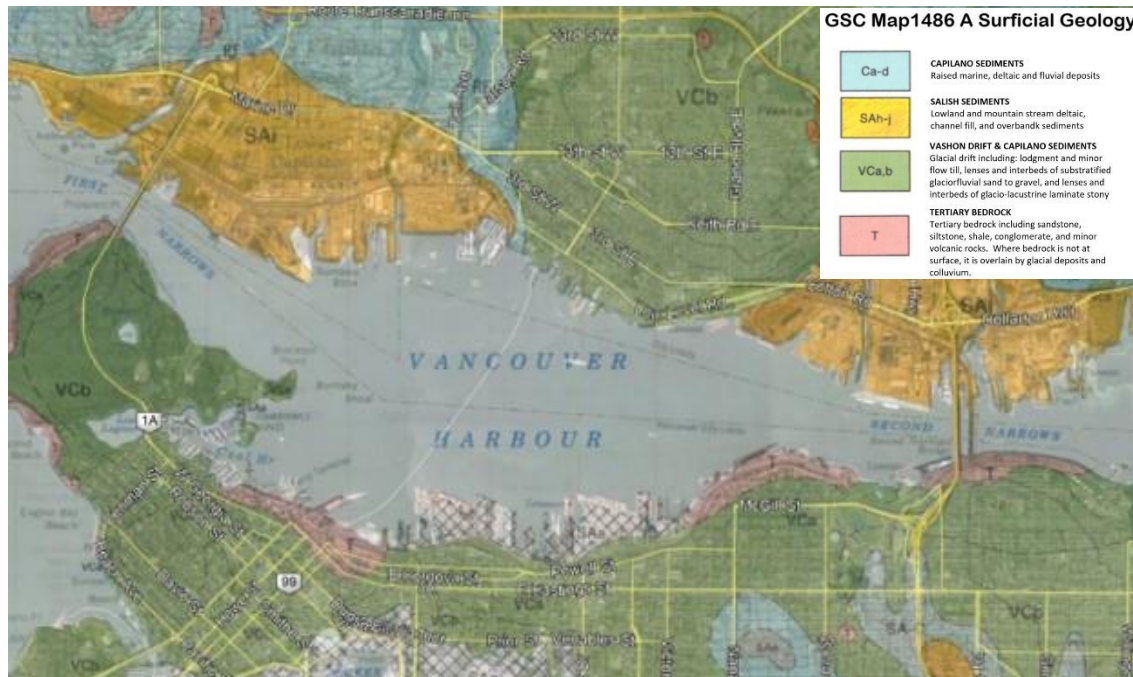


Figure 2-1: Burrard Inlet Study Area - Surficial Geology (adapted from GSC Surficial Geology Map 1486A (Armstrong & Hicock, 1976))

A sampling of the main soil units prevalent within the study area and proposed infrastructure are listed below:

Salish Sediments - (orange shaded areas on Figure 2-1)

Complex post glacial sequences of sediments that are deposited in low-lying areas above the Capilano Sediments. Within the area of interest, these units are found at surfaces at the mouth of the Lynn Creek, Seymour and Capilano River confluences with Burrard Inlet. These units extend further south into Burrard Inlet and are found to be 15m to 50m thick and consist of medium to coarse sands, gravels, cobbles and boulders. This unit ranges from loose to compact with layers subject to liquefaction.

Tunnelling through this unit presents challenges related to its coarseness, abrasivity of large boulders, hydraulic conductivity, potential for the presence of contamination and saline groundwater, settlement and uncertain seismic performance.

Capilano Sediments - (light blue shaded areas on Figure 2-1)

This unit typically overlies Vashon Drift and are described as marine and glaciomarine stony (including till-like deposits) to stoneless silt loam to clay loam with minor sand and silt. At the Second Narrows area of Burrard Inlet, this glaciomarine sequence directly underlies the Salish Sediments and consist of relatively flat lying silt and clay units that are over 30m thick. Within Stanley Park, this unit is normally less than 3m thick but can be up to 10m thick in upland areas and directly overlies Vachon Drift. The liquefaction potential under earthquake loading is highly variable and is directly associated to soil type and depth of burial.

Tunnelling through these materials can present challenges with potentially unstable and flowing ground, particularly where high groundwater pressures are encountered, sticky clay soils and risks of encountering abrasive cobbles and boulders.

Vachon Glacial Drift – (green shaded areas on Figure 2-1)

While there are several formation processes, typically this glacial drift unit consists of unsorted material deposited directly by and/or over-ridden by glacial ice and possesses very little stratification. Glacial till units range from less than 5m to 25m thick and are dense to very dense, moderately well graded sands and silt mixtures with variable gravel to boulder and clay content. The unit is typically lower permeability, but they can include interbeds/layers of higher permeability glaciofluvial sands and gravels. As can be seen from Figure 6-3, Vachon Drift is found to underlie much of downtown Vancouver on the south side of Burrard Inlet as well as between the Capilano and Seymour delta areas of North Vancouver and West Vancouver. In these same areas, this unit is most often found directly over bedrock and includes an overlying thin veneer (<5m) of Capilano Sediments. From an engineering foundation and seismic resiliency standpoint, Vachon Drift is generally considered a competent geological unit to excavate or locate structures on.

Tunnelling challenges through Vachon till primarily revolve around encountering boulders, as these are often high strength and can be quite large or found in concentrations. The Canada Line successfully tunnelled through this unit below False Creek as the tunnel boring machine (TBM) advanced toward downtown Vancouver.

Tertiary Bedrock

The surficial soil deposits overlie sedimentary bedrock units including relatively young Tertiary sandstone, siltstone, shale, conglomerate. Infrequent, thin coal seams and associated claystone layers are also known to be present at periodic locations within the sedimentary sequence. These formations have been raised and tilted to the south due to the uplift of the Coast Mountains over the past 10 million years. Bedding dip angles of 8° to 15° to the south can be observed at outcrops on the north and west side of Stanley Park sea wall and include local intrusions of volcanic (basalt) bedrock, such as Siwash Rock and Prospect Point.

While variable, this unit has been successfully tunnelled through for several tunnels using various tunnelling methods including Canada Line, First Narrows, Dunsmuir, and Eight Avenue (TBM)

Earthquakes & Faulting

The Lower Mainland is located within a seismically active area of southwest British Columbia. The area is susceptible to seismic hazards from various deep and shallow sources requiring proposed structures to meet the appropriate seismic design standards for public transport projects. Seismically induced lateral spreading along the shoreline will need to be assessed, and if present, investigations and analysis will be required to determine the magnitude and depth of ground movements to be designed for or eliminated by relocation or increasing the depth of cover below these movements.

Tunnels located within geological units such as the Salish sediments that are susceptible to liquefaction or other forms of ground deformation will represent a challenge that may require considerable ground improvement to mitigate or relocation to avoid.

It is understood that a Metro Vancouver 2018 seismic resiliency study for the nearby Cleveland Dam indicates that there are no active faults near the dam or records of significant earthquakes that might indicate active fault rupture within 10km of the dam. However, if further design is to be undertaken, an additional document data review and study should be undertaken to confirm.

2.4 Tunnel Considerations

2.4.1 Relevant Historical / Planned Tunnelled Crossings

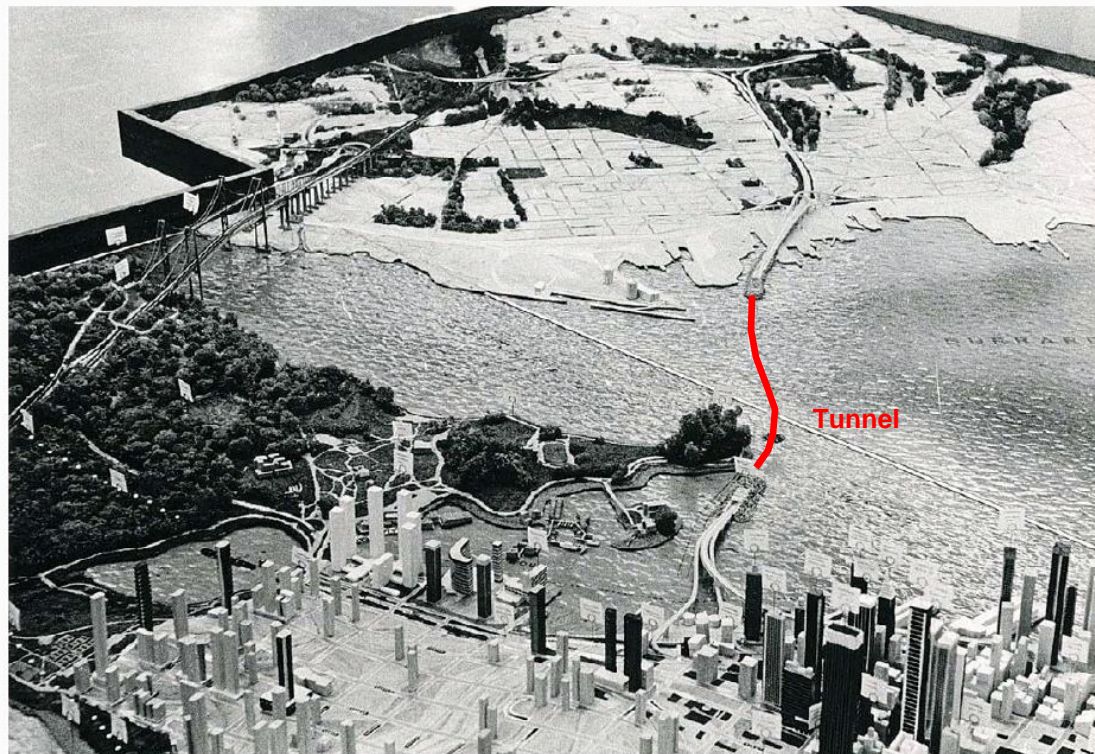
Table 2-1 provides a compilation of completed and planned tunnels in the vicinity of Burrard Inlet and Vancouver. There is precedence for tunnel crossings at First Narrows, downtown Vancouver, below False Creek and one currently under construction at Second Narrows. Based on construction records and site investigations for these tunnels, information for top of bedrock depths, bedrock type and quality, soil stratigraphy and seismic demands is available to inform geological conditions for potential tunnel alignments explored as part of this study.

A sample list of completed, studied and future tunnels is also shown in Table 2-1. The table includes information on tunnel methodology, length of water crossing and purpose for multiple projects in the Lower Mainland. The table provides supporting information and summarizes the considerable experience with designed and planned land and water tunnel crossings within both bedrock and overburden in the Lower Mainland.

Table 2-1: Sample of Existing & Proposed Tunnels in Lower Mainland / Water Crossings

Tunnel	Purpose - Owner	Construction Method (Ground Conditions)	Status	Tunnel Dimensions, (Water Crossing)
First Narrows	Water Supply – Metro Vancouver	Drill & Blast (Bedrock)	Constructed 1930	3m dia, (900m length crossing of Burrard Inlet)
Dunsmuir Street	Rail – Freight (Now Metro) CP (Now TransLink)	Drill & Blast (Bedrock)	Constructed 1930s	9m high x 7m wide, 2km long, (no water crossing)
George Massey	4 lane Highway Tunnel	Immersed Tube (Soil Backfilled Trench)	Constructed 1959	24m wide x 7m high 630m long, (600m of length underlies Fraser River)
Thornton	Freight Rail - CN Rail	Drill & Blast (Bedrock)	Constructed late 1960s	10m high x 7m wide, 3.4km long, (no water crossing)
Burrard Inlet Crossing (Harbour Crossing)	7 lane Highway Tunnel - Vancouver Harbour Board	Immersed Tube (Soil Backfilled Trench)	Not Constructed - Studied in late 1960s	10m high x 38m wide, (1.4km long tunnel below Burrard Inlet), includes 750m and 1.1km long approach structures into Burrard Inlet,
8th Avenue	Sewer Tunnel – Metro Vancouver	Open TBM, minor D&B (Bedrock)	1960s	4m dia, 8km, (no water crossing)
Canada Line	Metro Tunnel TransLink, Twin Bore	Pressurized Face TBM Segmental Lined and Cut & Cover (Soil & Bedrock)	Constructed 2009	2x 6m dia, 2.4km long, (350m length underlies False Creek), plus 6km Cut & Cover
Evergreen Line	Metro Tunnel TransLink, Single Bore (Twin Lanes)	Pressurized Face TBM Segmental Lined (Soil)	Constructed 2016	10m dia, 2km long, (no water crossing)
Port Mann Water Supply	Water Supply – Metro Vancouver	Pressurized Face TBM Segmental Lined (Soil)	Constructed 2016	4m dia, 1km long, (600m length underlies Fraser River)
Second Narrows Water Supply	Water Supply – Metro Vancouver	Mined (Roadheader)	Under Design, Construction Start Est. 2022	6m dia, 1.1 km long, (400m length underlies Burrard Inlet)

Tunnel	Purpose - Owner	Construction Method (Ground Conditions)	Status	Tunnel Dimensions, (Water Crossing)
Broadway Subway Project to Arbutus	Metro Tunnel – TransLink	Pressurized Face TBM Segmental Lined (Bedrock & Soil)	Bid Phase, Construction Start Est 2022	6m dia, 4.5km long, (no water crossing)
Burnaby Mountain	Energy Pipeline - TransMountain	Pressurized Face TBM Segmental Lined (Bedrock & Soil)	Construction Start Est. 2021	4m dia, 2.6km long, (no water crossing)
Stanley Park Water Supply	Water Supply – Metro Vancouver	Pressurized Face TBM Segmental Lined (Bedrock)	Under Design, Construction Start Est. 2022	4m dia, 1.4km long, (350m length underlies Lost Lagoon)
Annacis Water Supply	Water Supply – Metro Vancouver	Pressurized Face TBM Segmental Lined (Soil)	Under Design, Construction Start Est 2022	4m dia, 2.3km long, (900m length underlies Fraser River)
George Massey Tunnel Replacement	8 lane Highway Tunnel	Immersed Tube Studied (Backfilled Trench)	Not Known	2km long, (600m length underlies Fraser River)



A 1967 model depicts a proposed causeway, tunnel and twin bridge from downtown to the North Shore.

Figure 2-2: Burrard Inlet Highway Crossing Study in 1960s using approach structures with Immersed Tube Tunnel (The Burrard Inlet crossing: a report to the National Harbours Board. Swan & Wooster, 1967)

2.4.2 Tunnelling Methods

Of the multiple methods of tunnelling, the most appropriate method depends on the type of soil/bedrock, tunnel characteristics (length, grade, size, depth) and groundwater pressures. The types of local tunnels listed in Table 2-1 are representative of a typical range of tunnelling methods appropriate for water tunnel crossings. A brief summary of these is provided below:

- **Conventional Drill and Blast (D&B)** – This method has been used locally to excavate the CN freight rail bedrock tunnels as well as First Narrows water supply tunnel. Conventional D&B tunnel excavation is highly adaptable to tunnel size, grade and length and is commonly used today. Noise and vibration from the explosive charges can restrict the viability of this method in an urban/sensitive environment. This methodology is typically not suitable for very weak rocks or unconsolidated sedimentary deposits.
- **Roadheader** – This is a mechanized tunnelling method typically used for softer bedrock units that utilizes a boom-mounted rotating cutterhead, which can be used for a wide variety of sizes and shapes of bedrock tunnels. It is not suitable for mixed ground tunnelling but because no blasting is required, it can be employed in urban environments.
- **Tunnel Boring Machines – (TBM)** – This is a mechanized bored tunnelling method that uses thrust (pushing off rock or segments) and rotation (with cutters/scrapers) against bedrock or soil to progressively remove material and support the excavated ground as the TBM advances. There are numerous types/variations of TBMs but for the purpose of this study, the focus is limited to Pressurized Face TBM due to the anticipated mixed ground conditions for the tunnel options considered. This class of tunnel boring machines can successfully be used to tunnel through a wide range of both soil and bedrock units and is adaptable to different lining methods and groundwater pressures. This kind of TBM can also easily accommodate ranges of diameter required for metro tunnels:
 - 6m diameter - single track (i.e. Canada Line), requires cross passages for egress
 - 10m diameter (Evergreen Line) for twin track and internal egress
 - 15m diameter for twin track (stacked configuration), internal egress and stacked boarding platforms.

There are two main types of Pressurized Face TBMs - Slurry Shield and Earth Pressure Balance (EPB) that are selected based on factors such as soil gradation, presence of boulders, and groundwater pressures. These types of TBMs have been used for several water crossing tunnel projects in the Lower Mainland as listed in Table 2-1.

- **Immersed Tube Tunnel (ITT)** – These tunnels are comprised of fabricated rectangular sections of reinforced concrete segments that are floated from their fabrication location (i.e. typically a dry dock) and lowered into place onto a prepared trench in the base of a water body. The sections of concrete have watertight connections to allow them to be pulled together and permanently sealed. Once attached, the trench and concrete element are backfilled. ITT's can be a preferred solution over a bored tunnel approach for a particular crossing depending on the specific project conditions and constraints. ITT's are shorter than a corresponding bored tunnel option. A bored tunnel is normally deeper than an ITT to satisfy minimum cover or depths such that the tunnel is excavated within soil or bedrock units with beneficial performance under the design seismic event such that ground improvement measures are not required or are reduced considerably. As the bored tunnel is now deeper, it also requires longer approach structures at each end to access these depths using maximum allowable grades. Shorter and shallower tunnels may have easier connection to existing infrastructure and typically have lower overall capital costs, construction schedules and operational and maintenance costs than a longer tunnel.

Preparation of the trench for the ITT foundation can typically range from:

- Simple removal of a shallow layer of loose material(s) to suit grade requirements
- Deeper excavation to remove additional materials to expose more competent unit(s) prior to backfilling back up to desired grade
- Use of piled foundations
- Completing ground improvement of the ITT foundation soils that can include drainage columns to increase its resiliency under the design seismic event. Depending on the degree of ground improvement required, this can be quite costly and result in more disturbance to the environment.

The George Massey Tunnel is a local example of a ITT project successfully completed in the late 1950s. Studies are underway for a replacement crossing to confirm that ITT remains the preferred replacement crossing method. For Burrard Inlet, ITT can be a viable alternative to bored tunnelling depending on issues such as:

- Soil conditions below the inlet and their sensitivity to seismic deformation and resulting ground improvement costs
- Environmental restrictions: shoreline construction and dredging across the inlet
- Water depths: the deeper the water, the more costly an ITT is and typical maximum depths of 50m has been completed to date.

- **Submerged Floating Tunnel (SFT)** – Compared to the other types of tunnels listed above, SFT tunnels are a new technology. While none have been constructed, detailed design options are under consideration in China and Norway. SFT tunnels are reinforced concrete elements connected together within the water body. SFT's have various configurations related to their type of buoyancy and restraint including:

- Buoyant and restrained by tethers – uses offshore tension leg platform technology
- Negatively/neutrally buoyant – suspended from floating pontoons
- Neutrally buoyant – fixed end short crossing (underwater bridge), no intermediate supports
- Negatively buoyant – supported on underwater piers/trestles

The closest to construction are in Norway, where recent extensive detailed studies have been made for the E39 Highway for a number of fjord crossings as alternatives to suspension bridges. SFT designers have taken some aspects to detailed design level; however, none have been constructed. At the time of this report, it is understood that a prototype has been designed in China for pedestrian/tourist use and is planned to be built across Qingdao Lake, but it has not yet received development funding.

This tunneling method would need to overcome design challenges at Burrard Inlet that include: associated tidal currents, minimum depths below an active shipping channel, design loading from future sunken ships and any anchor damage, seismic demands, aesthetic (if floating pontoons used), anchoring restraints as well as requirements to construct portal approaches to access deep enough water or dredge soils to increase the water depth to the approach structure. Subject to satisfying the above design constraints, one of the other remaining challenges would be public perception and client willingness to risk being the first to construct a SFT.

2.4.3 Tunnel Design Considerations

This section summarizes the main considerations of tunnel design: alignment, geological units, TBM repair, tunnelling induced settlement, tunnel depth and seismic induced constraints.

- **Tunnel Alignment and Profile** – Geometry is typically constrained within a certain range for most tunnel projects. In some cases, maximum practical grades are determined by operation requirements versus construction constraints. In general, flatter grades and straighter tunnels are desired for both. For a metro/light rail tunnel, typical maximum grades of 5.5% to 6% are common locally (Canada Line, Evergreen & proposed Broadway Subway Project to Arbutus) for bored tunnel. Preferred turning radius would be in the range of 160m for a 6m diameter tunnel and typically twice that for larger diameter tunnels. While low points in the tunnel result in drainage water pumping requirements during operation, they are common in most water crossing tunnels.
- **Geological Units** – Tunnel alignment are normally designed to minimize intersection and length of potentially problematic soil or bedrock units and to minimize the types of potentially unfavourable ground that the tunnelling method needs to overcome. Technology has significantly advanced over the years to enable TBMs to successfully advance through a wide range of soil and bedrock units within a single tunnel drive. For example, soil units containing concentrations of high strength large cobbles and boulders will cause delays to remove them or repair damage to the TBM and therefore these soil units are typically avoided if possible. Higher abrasivity soil or bedrock units can be tunnelled through, but will require increased design/fabrication costs, as well as demand higher maintenance/repairs to replace/refurbish worn out parts.
- **TBM Repairs** – As discussed above, TBMs will require repairs to replace worn and damaged components as they advance. Repairs to the cutter head at the front of the TBM are particularly challenging as high groundwater pressures present issues due to potential instability of the ground and having to work under the high atmospheric pressure required to prevent uncontrolled water ingress. For pressurized face TBM tunnels operating within soil or rock under higher groundwater pressures, the following options are available to undertake repairs:
 - Construct “safe havens” or blocks of competent, self-supporting in situ material ahead of the TBM such that crews can undertake repairs in atmospheric pressures. This typically requires access by drilling from above the tunnel alignment and therefore long, deep water, or environmental sensitive, shipping channel crossings may present considerable access challenges. Often safe havens are located at a point along the tunnel alignment prior to the tunnel entering below a water crossing such that machine repairs are completed before access to the tunnel becomes more problematic. Other safe havens are selected to be within soil or bedrock units that are competent, and self supporting under soil / groundwater pressures and require lower or no air pressure.
 - Complete repairs using hyperbaric interventions that involves designing the TBM with airlocks such that compressed air can be extended to other areas of the TBM chamber to continue to balance the soil/groundwater pressures acting on the tunnel face, but also allow access by specialized crews to undertake repairs. Similar to working underwater, the greater the pressure, the lower the duration that crews can be work at those pressures at one time such that the repairs become more time consuming and costly.
 - Water Lengths / Groundwater Pressures – Tunnel alignments are normally optimized to minimize the length of the section of tunnel below large lengths of bodies of water, especially where access is restricted on the water and/or water depths are high. This is less true for portions of tunnels excavated within stronger, more competent bedrock due

to the ability to better reduce risks associated with unstable ground or high inflows. Greater water pressures also require thicker and more costly concrete segmental lining.

- **Tunnelling Induced Settlement** – It has been demonstrated that settlement caused by TBM tunnel excavation can be controlled to acceptable levels in many urban tunnels. In general, the larger and shallower the tunnel, the greater the potential for higher levels of settlement and wider zone of influence. Settlement in soft ground bored tunnels is primarily caused by ground loss (difference between what was excavated by the TBM prior to installing the permanent lining) as well as impacts from allowing the groundwater table to change as tunnelling progresses. Tunnel alignments are typically designed to avoid locations immediately below or adjacent to sensitive structures to minimize the degree of differential settlement on the structure. If close proximity of the tunnel and structure cannot be avoided, careful consideration is given to the susceptibility of ground loss to a particular geological unit, vertical separation between the tunnel and the structure, mitigation measures to control face pressures and ground loss to appropriate levels, and increased monitoring of the ground and structure during tunnel excavation. Failure to match face pressures can result in excessive soil displacement that can cause sinkholes, blow-outs or excessive settlement.
- **Tunnel Depth** - As the tunnel depth increases, pressure demand increase, such that there becomes less choice in the type of pressurized face TBM that can be used, and costs increase accordingly. Tunnelling at depths of 60m below water levels are becoming more common with face maximum achievable face pressures of 12 bar observed on projects within North America and the world.
- **Seismic Induced Constraints** - As stated earlier, the study area for Burrard Inlet is susceptible to seismically induced ground movements. In common with other recent critical infrastructure projects, considerable effort will be required to identify potentially vulnerable sedimentary horizons and a tunnel alignment selected to avoid or minimize the hazards. This often results in longer deeper tunnels and with steeper gradients leading from/to the portals. Unfortunately, it is highly likely that sections of a tunnel crossing will be located within potentially vulnerable soil units that will require implementation of ground improvement strategies, required to mitigate the risks of liquefaction and other deformation. A further consideration for tunneling would be the presence of active faulting along the tunnel alignment that may result in ground displacement as the fault moves during an earthquake. It is understood that the Metro Vancouver 2018 Cleveland Dam seismic resiliency study did not identify evidence for active faults rupture within 10km of the dam.

2.4.4 Tunnel Constructability Considerations

There are several constructability factors that can impact the viability of proposed tunnel alignments and each tunnelling method will have slightly different requirements. Some of the key considerations are briefly summarized below:

- **Portal / Laydown Area** – Providing sufficient construction work area at least at one of the tunnel portals to launch and construct the tunnel from is extremely important. Additional room for storage of segmental lining segments, muck disposal, power generation, offices, storage can be quite large. For ITT, dry dock fabrication facilities for the individual components of the structure tend to be very large.
- **Construction Impacts** – Heavy civil tunnel projects require construction 24 hours a day, seven days a week, during which time generate noise, dust and truck traffic. Locating portal construction within areas that can accommodate these impacts is essential. Excavated material from the tunnels and portals may require special consideration for disposal requiring transportation by truck or barge to approved receiving facilities.

- **Avoidance of Existing Structures** – Much of the shoreline on both sides of the inlet is occupied by commercial or industrial structures. Initial tunnel alignments, following more detailed engineering, may have difficulty threading their way through or far enough away from surface or underground structures to reduce settlement to acceptable levels; which could nullify the viability of any particular alignment option. More assessment in this area would be required to confirm a specific alignment's acceptance
- **Permitting / Regulatory** – Harbour water crossings will involve multiple levels of regulatory bodies, which will present challenges to tunneling methods or areas of construction. For example, obtaining regulatory permission to undertake dredging, approach structures that encroach on the inlet, or ground improvement within inlet may prove problematic.

2.5 Bridge Considerations

New transit bridge locations in Stage 2 are limited to the vicinity of Second Narrows crossing. As evident by existing Lions Gate and Second Narrows, and many other long span bridge crossings in the region, a transit bridge at this crossing is technically feasible. Key engineering considerations for any new future bridge crossing at Second Narrows include:

- Preferred location of the bridge is at areas with the shortest water crossing
- Keeping marine piers out of the navigation channels
- Keeping the superstructure above the ship clearance envelope when over the navigation channel (which will need to at least match existing bridges and may need to exceed existing clearances)
- Location of the north and south ends of the bridge where the onshore alignment best fits the surrounding constraints and connections
- Seismic performance design requirements to match or exceed the rest of the rapid transit system, to provide consistent resilient infrastructure
- Land use and transportation system integration

3 Stage 2 Engineering Options Review

This section describes the work completed for the six shortlisted options during the Stage 2 Engineering Review, as captured in Figure 3-1 below. It outlines technical engineering work completed in Stage 2 for each option, and the key opportunities and constraints associated with options in each zone.



Figure 3-1: Alignment Options reviewed in Stage 2

3.1 Blue Zone – First Narrows Crossing

Within the Blue Zone, two tunnel crossing options were explored further as part of Stage 2 (see Figure 3-2)

- Option 2A – Burrard Station via First Narrows/Park Royal to Central Lonsdale (5.9km Tunnel)
- Option 3A – Burrard Station via Brockton to Central Lonsdale (4.6km Tunnel)

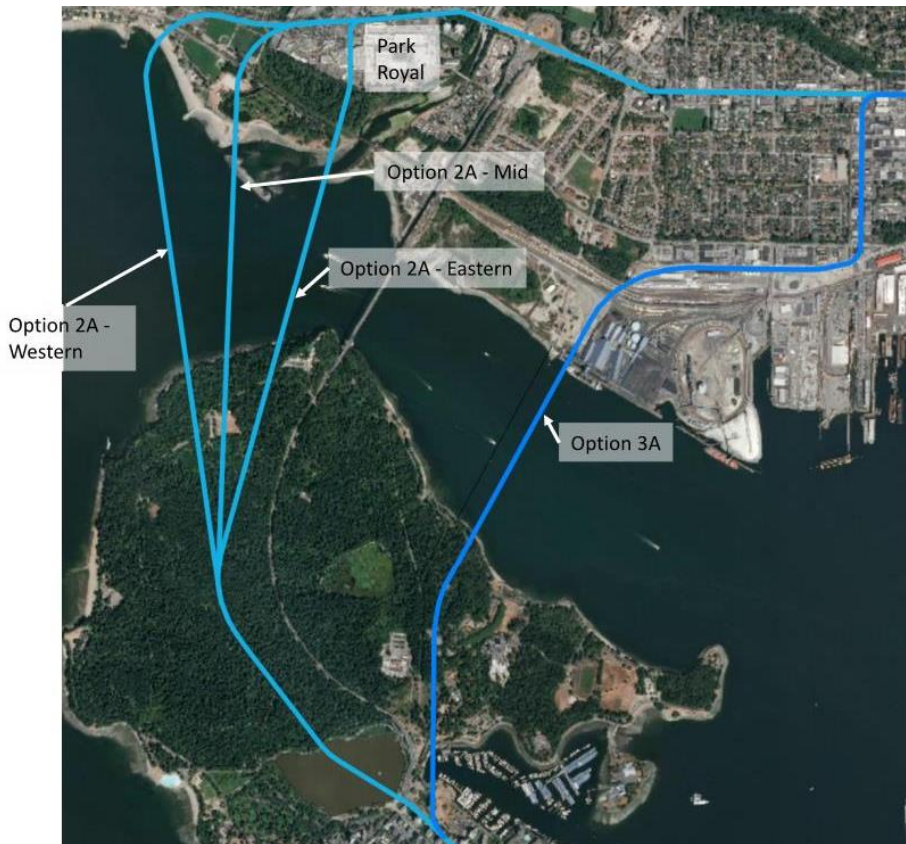


Figure 3-2: Blue Zone Alignment options

3.1.1 Option 2A – Burrard via First Narrows/Park Royal to Central Lonsdale (Tunnel)

Option 2A crossing assumes a proposed tunnel connecting to the Expo Line at Burrard Station via a spur through the west of downtown Vancouver and across Burrard Inlet west of Lions Gate Bridge. On the North Shore, for the purpose of this study, due to known challenging geological conditions, it was assumed that the tunnel would transition to an elevated guideway as soon as the grades allowed, following road right-of-way (ROW) to connect Park Royal and Lions Gate Village to Capilano Mall and Central Lonsdale. The portal, where the tunnel surfaces, would be located near Park Royal to allow sufficient distance for the tunnel to surface from Burrard Inlet and existing railway corridors. In future phases of work, a balance of functional requirements for rapid transit technology and urban design / commercial / retail viability would need to be considered to confirm or revise these assumptions.

During Stage 1, an alignment was developed for the purposes of the Level 1 MAE modelling and comparative analysis. As part of Stage 2, this alignment was further refined, and several potential alternative alignments variations were explored. The alternative alignments looked at three potential Burrard Inlet crossing skews affecting the location where the tunnel would come to surface in West Vancouver. The three alignment variations included:

- *Option 2A – Western:* The longest alignment crossing, surfacing at Park Royal near Ambleside Park and Rutledge Sports fields. This alignment provides a longer length of alignment on the north side of the inlet to provide more distance for the tunnel to come to surface. This alignment was not explored further because:

- It has a longer water crossing as compared to Option 2A – Mid
- It provides no significant additional ridership catchment area, being only slightly west of Park Royal; and
- The bathymetry is deeper at this location therefore a deeper tunnel is anticipated than option further east.
- *Option 2A – Mid:* This alignment was developed in order to minimize impacts on Park Royal South and the Village at Park Royal while providing sufficient horizontal length for the tunnel to come to surface along Marine Drive, in close proximity to Park Royal.
- *Option 2A – Eastern:* An alignment that followed the Stage 1 proposed route and aimed to have the alignment follow a north-south road ROW within Park Royal. This alignment was not explored further because:
 - Of its close proximity to Capilano River rail bridge abutment, which raises settlement concerns due to the poor soil conditions;
 - Of close proximity to Park Royal buildings, which raises settlement concerns due to the poor soil conditions; and
 - The alignment has similar length water crossing to Option 2A – Mid.

Based on the above alignment variations that were reviewed, *Option 2A – Mid* was reviewed further to assess alignment geometry and tunnel feasibility, particularly under Stanley Park and the Burrard Inlet.

Alignment

A conceptual alignment plan-profile was developed for Option 2A – Mid and has been included in Appendix A. This drawing captures the alignment and profile from the western edge of downtown Vancouver to Marine Drive at Taylor Way in West Vancouver.

Option 2A – Mid has an approximate tunnel length of 5.9km from Burrard Station on the Expo Line to the portal (transition to surface) located along Marine Drive near Park Royal. It crosses under Lost Lagoon and the Capilano Main No. 5 water main that is currently being constructed through Stanley Park and under Lost Lagoon. Option 2A – Mid has a water crossing, under Burrard Inlet, of approximately 900m. This alignment option should be developed further following additional investigation into existing utilities, easements, building foundations depths, and geological information.

Tunnelling and Geological

From a geological perspective, the southern section of the alignment through downtown Vancouver represents a lower risk compared to the northern section due to precedence tunneling through these bedrock units in other projects. However, the alignment through downtown is highly conceptual and utilizes road ROW as an assumption to minimize easements under properties. The depth of building foundations and utility information has not been confirmed. This information is necessary to confirm the feasibility of tunnelling through downtown and ensure that the tunnel does not impact any existing buildings and existing infrastructure.

It should be noted that the tunneling risks have higher uncertainty for Option 2A compared to Option 3A due to lack of geotechnical information in area. From the mid-way point, under the water crossing at Burrard Inlet, the tunnel is assumed to transition from bedrock to glacial drift, towards the North Shore. While these transition areas can be problematic, there is precedence for dealing with issues which can occur such as nested boulders and poorer bedrock. However, if the portal is to be located within the

Capilano River delta, it will require the tunnel to be excavated through the Salish coarse sand, gravel and boulder deposits. As discussed in Section 2.4, this represents considerable abrasion and wear on the TBM to advance through. In addition, moving north, as the tunnel elevation becomes shallower relative to ground surface, the potential impact of the tunnel to existing structures (i.e. inducing settlement), as well as ground improvement to prevent movement will need to be assessed. To minimize risk in this challenging ground, the tunnel would be declined as steeply as possible to reduce the length of excavation (and potential ground improvement) within this Salish unit. It should be noted that the tunneling risks have higher uncertainty for Option 2A compared to Option 3A due to lack of geotechnical information in area.

Overall, the additional engineering work in Stage 2 did not rule out Option 2A from future phases of study. In future stages, as more information about the geology, existing infrastructure (i.e. utilities and underground structures) is gathered the technical feasibility of the crossing option will continually gain clarity and definition.

3.1.2 Option 3A – Burrard via Brockton Point to Central Lonsdale (Tunnel)

Option 3A crossing assumes a proposed tunnel connecting to the Expo Line at Burrard Station via a spur connection through the west of downtown Vancouver and across Burrard Inlet west of the Brockton Point area in Stanley Park and provides a more direct connection to central Lonsdale than Option 2A. However, it does bypass Park Royal and Lions Gate Village.

During Stage 1, an alignment was developed for the purposes of the Level 1 MAE modelling and comparative analysis. The alignment through the Norgate neighbourhood on the North Shore, between Marine Drive and Welch Street on the north and south and Lower Capilano Road and Pemberton Street on the east and west, in North Vancouver was approximately drawn on a diagonal through the neighbourhood with a high-level approximation of length of tunnel versus surface running lengths. For Stage 2, the alignment was re-examined, and an alignment was developed that follows road ROWs in order to minimize risks, potential property impacts and required easements for both the tunnel and elevated guideway.

On the North Shore, for the purpose of this study, due to known challenging geological conditions, it was assumed that the tunnel would transition to an elevated guideway as soon as possible along West 1st Street near Phillip Avenue after crossing under the CN rail yard tracks. The elevated guideway would follow Pemberton Avenue and then turn onto Marine Drive before then following Keith Road to connect to Lonsdale Avenue. The alignment of the elevated guideway utilizes the absolute minimum allowable horizontal curve radius for SkyTrain technology of 80m needed to turn 90° following the road ROWs. More information is needed about the buildings along Pemberton Avenue. In particular, building height and building envelopes are required to confirm the feasibility of constructing the guideway while minimizing property impacts. In future phases of work, a balance of functional requirements for rapid transit technology and urban design/commercial /retail viability would need to be considered to confirm or revise these assumptions.

Alignment

A plan-profile conceptual alignment was developed for Option 3A and is included in Appendix A. This drawing captures the alignment and profile from the western edge of downtown Vancouver to West 1st Street in North Vancouver.

Option 3A has an approximate tunnel length of 4.6km from the Burrard Station on the Expo Line to the portal (transition to surface) located along West 1st Avenue. It has a water crossing under Burrard Inlet of approximately 900m. The tunnel is assumed to

come to surface along West 1st Avenue after crossing under the CN rail yard tracks. This alignment option needs to be developed further following additional investigation into existing utilities, easements, building foundations depths, and geological information. This further development will need to consider the location and depth of the conveyance pipeline that connects the Lions Gate Wastewater Treatment Plant to the new North Shore Wastewater Treatment Plant.

As an alternative to the alignment following West 1st Avenue, the feasibility of the tunnel coming to surface on the north side of Welch Street within the existing greenway and Spirit Trail area is an option that could be explored further. The impacts on the Norgate neighbourhood and greenspace as well as the feasibility of tunnelling under the Norgate Substation need to be considered.

Tunnelling

From a geological perspective, the southern section of the alignment through downtown represents a lower risk than the northern section due to precedence tunneling through these bedrock units in other projects. However, the alignment through downtown is highly conceptual and utilizes road ROW as an assumption to minimize easements under properties. However, the depth of building foundations and utility information has not been confirmed. This information is necessary to confirm the feasibility of tunnelling through downtown and ensure that the tunnel does not impact any existing buildings and existing infrastructure.

From the approximate mid-way point under the water crossing at Burrard Inlet, the tunnel is assumed to transition from bedrock to glacial drift. This is similar to the concerns raised for Option 2A in Section 3.1.1. As the tunnel becomes shallower relative to ground surface, the potential impact of the tunnel to existing structures and the CN rail yard tracks (i.e. inducing settlement), as well as ground improvement to prevent movement will need to be assessed. To minimize risk in this challenging ground, the tunnel would be declined as steeply as possible to reduce the length of excavation (and potential ground improvement) within this Salish unit. Generally, there is more existing geological information available for Option 3A due to close proximity to other infrastructure.

Overall, the additional engineering work in Stage 2 did not screen out Option 3A from future phases of study. In future stages, as more information about the geology, existing infrastructure (i.e. utilities and underground structures) is gathered the technical feasibility of the crossing option will continually gain clarity and definition.

3.2 Green Zone – Option 1A – Downtown to Lonsdale

Option 1A crossing connects Waterfront to Park Royal via Lonsdale Quay and provides the most direct connection from downtown Vancouver to Central Lonsdale. The proposed tunnel location (Downtown Waterfront to Lonsdale Quay) to Park Royal travels directly across the deepest portion of Burrard Inlet Where water depths are in excess of 50m. Less is known about the underlying ground conditions here compared to the western and eastern alignment options, but the shorelines at both sides are underlain by more competent Vashon Drift, avoiding the challenges with Salish deltaic deposits. However, the combination of the bathymetric low elevations, coupled with the steepness of the North Vancouver Lonsdale Avenue slope results in the highest water pressures, as well as long, steep (6%) tunnel alignments on the 6km long tunnel. Also, this tunnel alignment has a 3.4km long water crossing which is almost four times longer than the other two Burrard Inlet tunnel water crossing options in the Blue Zone. It should

also be noted that this tunnel length is also four times longer than what has been planned or completed for bored tunnels, water and transit, in the Lower Mainland.

The deep depths of the inlet along the Option 1A alignment between Waterfront and Lonsdale dictate that any tunnel crossing this area will require a deep underground station at Waterfront of approximately 50-60m below grade. The current track elevation through the Canada Line's Waterfront Station at an approximate depth of 12.5m below grade. In Stage 1, a deep transfer station was assumed and through ridership modelling it showed that this would lead to significant transfer penalties to ridership. Also, any continuation of a route travelling north to upper Lonsdale from the Lower Lonsdale area would be challenging against the topography of the North Shore, which is often in excess of 10%. This steep mountainous terrain combined with the track gradient limitations of 6% would result in required tunneling to upper Lonsdale and potentially further north.

The MAE evaluation results from Stage 1 showed that the Option 1A transportation accounts performed the lowest, compared to the other five crossing options in the Blue, Yellow, and Purple zones. It has been speculated, that transportation performance could improve with the elimination of the deep transfer requirement associated with the 1A alignment at Waterfront Station Stage 2 engineering work, therefore focussed on exploring alternative sub-options within downtown Vancouver of Option 1A that would remove the requirement for a transfer at Waterfront Station.

The following sections outline the sub-options of Option 1A that were investigated as part of Stage 2 and that are captured in Figure 3-3.

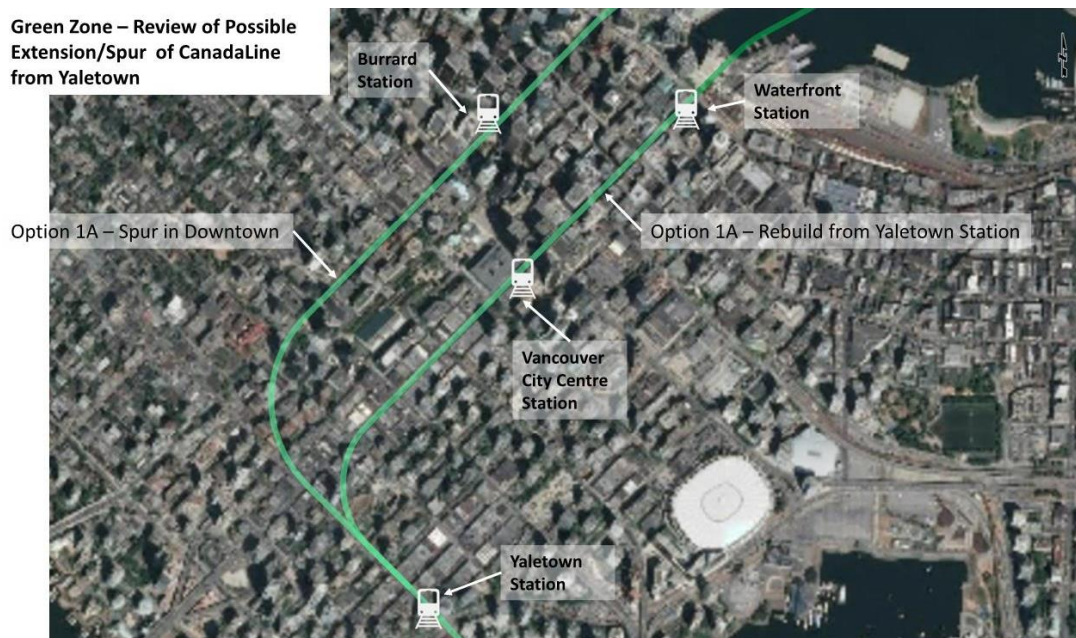


Figure 3-3: Green Zone – Feasibility Review of Extension and Spur sub-options of Canada Line

3.2.1 Option 1A - Possible Spur of Canada Line

A spur off the Canada Line in downtown Vancouver was explored. In order for this to be feasible, there needs to be enough space to accommodate another tunnel structure as well as enough horizontal and vertical tangent sections along the existing Canada Line track to accommodate connections.

The Canada Line tunnel alignment, located within the road ROWs of Davie Street and Granville Street, was reviewed to determine how the twin bored tunnels were situated in the road ROWs and if there was any remaining space available for a spur track. Both road ROWs are approximately equal width thus have similar constraints when considering if they can accommodate another tunnel. Thus, an alignment for the spur was suggested based upon its potential to follow Burrard Street and potentially provide a connection to the Expo Line at Burrard Station.

In reviewing this proposed spur alignment, which would follow Davie Street to Burrard Street, it was noted that the Canada Line twin bored tunnels utilize the entire road ROW. Thus, a tunnel for a spur line would require an easement under existing buildings and properties. This would also require the tunnel to be deep enough below any existing and potential building foundations.

The existing alignment and profile between Yaletown-Roundhouse Station and Waterfront Station were examined to determine if there is sufficient coincidental vertical and horizontal tangent to accommodate the required special trackwork (switches) for the spur. The special trackwork requirements for a spur are:

- Max grade through switch = 0.5%
- Min. length of tangent for switch = approx. 25-30m
- Min. length of tangent prior to switch = 5m
- Total length required = 30-35m minimum

Through reviewing the Canada Line as-built drawings, it was determined that there are no vertical grades within downtown, between Yaletown-Roundhouse Station and Waterfront Station, of sufficient length and suitable grade for switches to enable a spur line.

Therefore, the spur sub-option of Option 1A was deemed infeasible and removed from further study.

3.2.2 Option 1A - Rebuilding Canada Line from Yaletown-Roundhouse Station

The potential to rebuild the Canada Line from Yaletown-Roundhouse Station was considered. The Canada Line as-built drawings were reviewed, particularly the track's vertical constraints within downtown Vancouver. In considering the rebuild of the Canada Line, the proposed tunnel would need to be vertically clear of building foundations and future development, as well as have sufficient vertical clearance to cross the Expo Line Dunsmuir Tunnel. In development of the profile it was conservatively assumed that one tunnel diameter shall be maintained as clearance between the top of a new tunnel and bottom of the existing infrastructure. This would mean vertical separation of approximately 10-11m. This produced critical constraint locations along the profile.

A conceptual alignment plan-profile was developed for Option 1A - Rebuild in Appendix A. This drawing captures the alignment and profile within downtown Vancouver along Granville Street. It shows that the minimum extent of rebuild is approximately 1,100m and includes lowering both the City Centre and Waterfront Station of the Canada Line by approximately 20-35m. The lowering of the profile is to allow for the Canada Line to traverse under the Expo Line Dunsmuir Tunnel as well as the Expo Line Waterfront Station. This will also allow for the tunnel profile that is required to go under the Burrard Inlet at this crossing location.

Rebuilding the Canada Line for this length including rebuilding the two underground stations is expected to have a significant cost (subject to confirmation via costing estimate exercise in the next phase of the study). It would also have a substantial impact to the existing system during

construction because at a minimum the Canada Line operations would need to terminate at Yaletown-Roundhouse Station.

Overall, the additional engineering work in Stage 2 did not screen out this option from future phases of study. Noting that the modelling for a Canada Line extension has not been completed. The cost and full extent of the impacts to the existing system, during construction and operation, will also need to be assessed. Alternative options, such as a new transit line extending south towards Broadway Subway or other future planned transit networks could also be explored in future phases of the Study.

3.3 Yellow and Purple Zone – Options 5B, 5B2 and 5C

Within the yellow and purple zone, two main options were investigated: a new bridge (Options 5B and 5B2) and the potential retrofit of the existing IWMB (Option 5C) to allow for the addition of rapid transit underneath the existing bridge deck. Accounting for the various alignment connections on the south shore, the yellow and purple zone crossing options are:

- Option 5B – New Bridge with connection to Brentwood
- Option 5B2 – New Bridge with connection to Downtown
- Option 5C – Existing Bridge with connection to Brentwood

The additional engineering work in Stage 2 focused solely on the water crossing at Second Narrows and the feasibility of the two bridge options. Discussions were held with MoTI technical staff regarding the existing IWMB bridge structure, and meeting with VFPA informed the location of potential new bridge alignments and initial layouts of pier locations.

3.3.1 Option 5B and 5B2 – New Bridge

The new bridge option at Second Narrows is applicable to both Option 5B, with a connection to Brentwood and the Millennium Line, as well as Option 5B2 which would connect to the Expo Line downtown. On the North Shore, for the purpose of this study, it was assumed that the bridge would transition to an elevated guideway as soon as possible and follow existing road ROWs where feasible to connect to central Lonsdale.

During Stage 1, a nominal alignment was developed for the purposes of the Level 1 MAE and comparative analysis. As part of Stage 2, this alignment was further refined, and several potential alternative crossing alignments were developed. These alternative alignments focussed on potential Second Narrows crossing options being mindful of the constraints on the north and south shores as well as potential pier placement. The three alignment options, as shown in Figure 3-4, included:

- Option 5B/5B2 – West Skew: An alignment to the west of the existing IWMB and is on a slight angle from the existing bridge as to be clear of the Viterro Cascadia Terminal on the south shore and to provide more space between the existing IWMB and new bridge.
 - The pier placement needs to consider the main navigation channel as well as how vessels navigate into the Lynnterm Eastgate facility, and how other boats access the adjacent marina. The main span length was assumed to be approximately 400m which allowed for the northern pier to be placed in line with the line of dolphins of the Lynnterm Eastgate berth.
- Option 5B/5B2 – West Parallel: An alignment to the west of the existing IWMB that remains parallel to the existing structure for its entire length.
 - The pier placement needs to consider the main navigation channel, proposed dolphins and ground improvements that are a part of the vessel collision risk mitigation. The main

span length is approximately 400m. The north approach follows the shoreline and aims to place piers with minimal impact to Columbia Street and the vehicle access to the marina.

- Option 5B – East: An alignment to the east of the existing IWMB and CN Second Narrows Rail Bridge that connects to Maplewood Town Centre in North Vancouver and to Brentwood in Burnaby. Due to the existing high-voltage transmission lines within the centre boulevard of Boundary Road, Gilmore Street was proposed as a potentially suitable corridor as the road ROW is of sufficient width and the existing vertical grades are within the acceptable limits for SkyTrain. The alignment was also selected to avoid conflict with the CN Thornton Tunnel and the Second Narrows water tunnel, including the south shaft, which is under construction.

An option to place a new bridge close to the eastern side of the IWMB was also reviewed but was ruled out without significant engineering being undertaken for the following reasons:

- Constructing a new structure between the IWMB and the rail bridge could be challenging as there is only 100m between the two structures;
- The high voltage powerlines which cross the inlet just east of the rail bridge follow Railway Street to a tower placed less than 15m from the edge of the IWMB structure where it crosses the rail tracks. Navigating a transit route past this point would prove complex.
- The Seymour River and its delta pose significant geological challenges for the bridge foundations and construction.

Yellow/Purple Zone Engineering Review

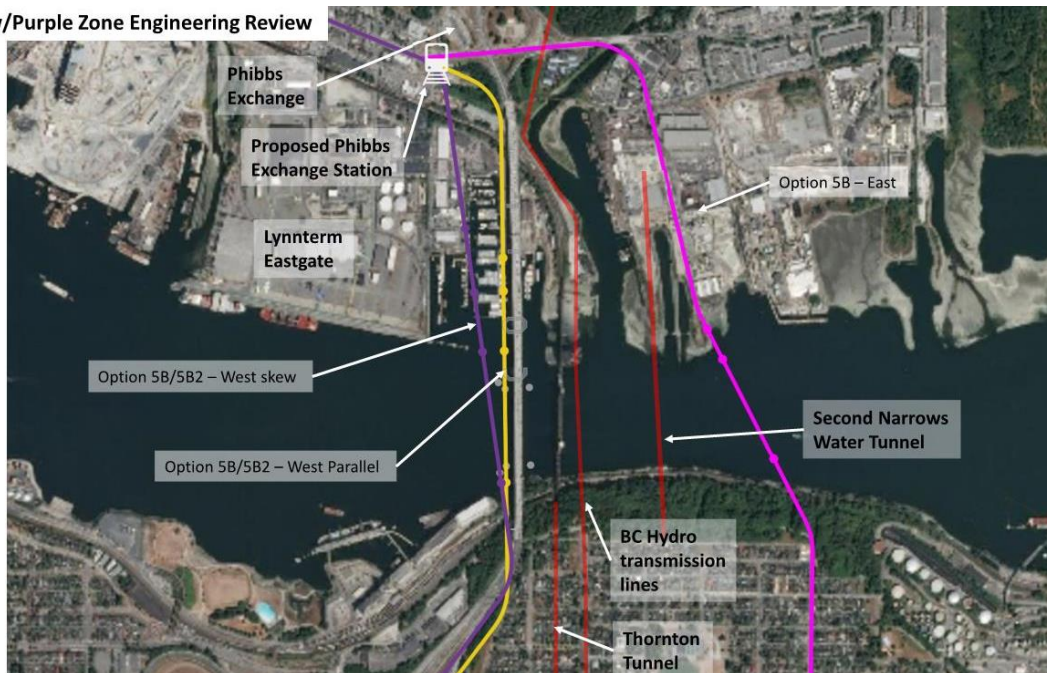


Figure 3-4: New bridge alignment options in Yellow/Purple Zone

This high-level examination of these three variations of crossings at Second Narrows demonstrate that there are likely a number of plausible crossing locations and demonstrates that there is some flexibility in the new bridge crossing alignment. Based on this high-level assessment, the west parallel option was developed further to a conceptual alignment plan-profile drawing and is included in Appendix A. This drawing captures the alignment and profile for the western parallel alignment from the south shore to Phibbs Exchange.

In future stages, the new bridge alignment and pier placement will need to be discussed further with key stakeholders, such as VFPA and the MoTI technical team responsible for the existing IWMB.

3.3.2 Option 5C – Use of Ironworkers Memorial Bridge

The use of IWMB for rapid transit was identified by bridge engineer Peter Taylor, separate from the BIRT Study consultant team, in an initial preliminary feasibility study he conducted independently in July 2019. The option proposed is a self-supporting structure within the existing IWMB as depicted in the sketches provided and shown in Figure 3-5, Figure 3-6 and Figure 3-7. It would use the existing foundations of the IWMB and require some modification of existing lateral bracing.

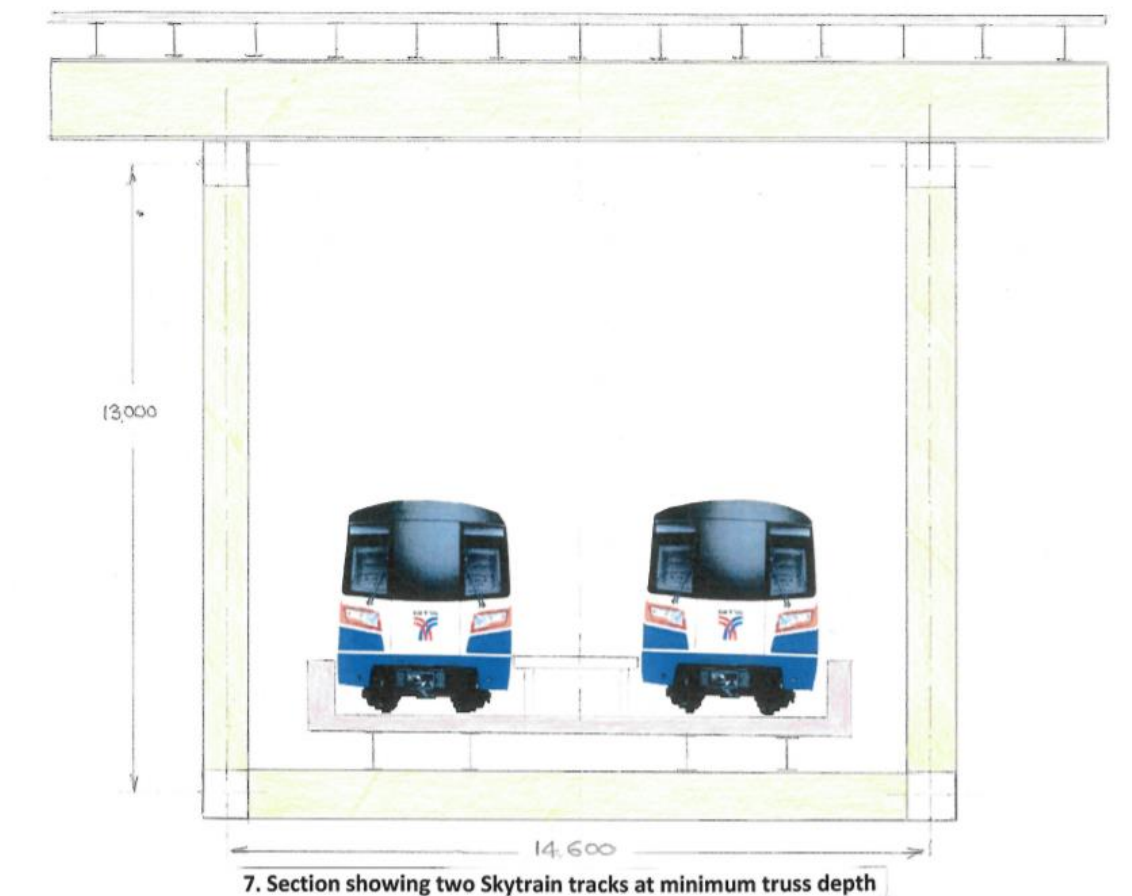


Figure 3-5: Image from Peter Taylor's conceptual schematic of two SkyTrain tracks within the existing truss of IWMB.

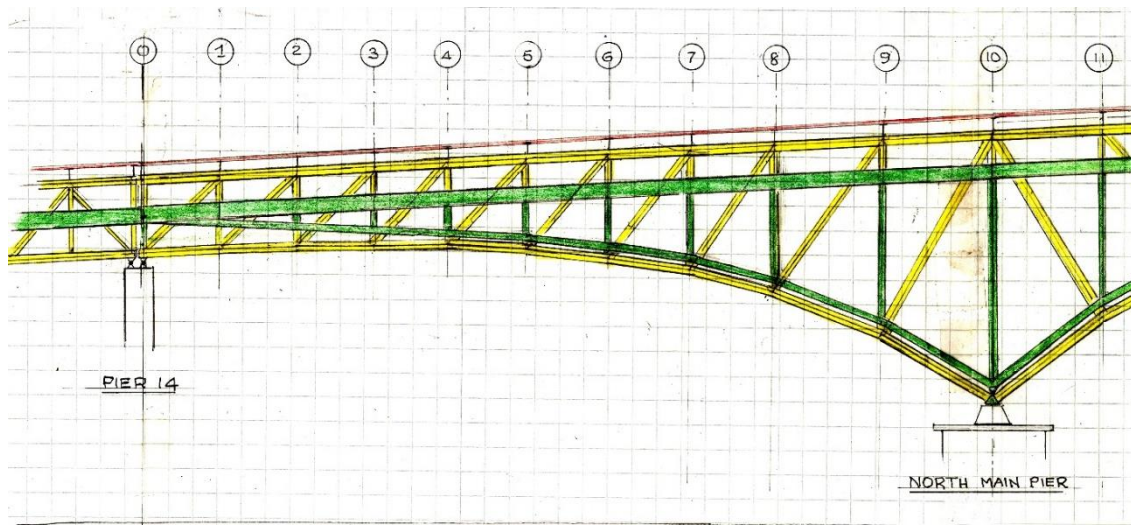


Figure 3-6: Image from Peter Taylor's conceptual schematic showing a long section of the new truss within the existing truss of IWMB.

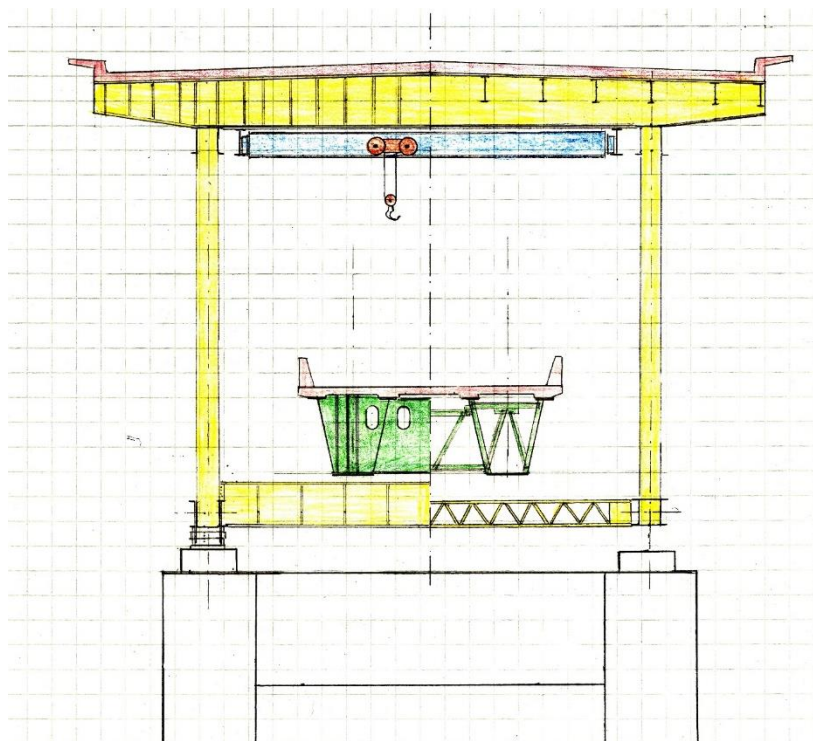


Figure 3-7: Image from Peter Taylor's conceptual schematic showing a cross-section of the new truss within the existing truss of IWMB.

Option 5C utilizes the existing internal space of the main steel truss underneath the bridge deck to accommodate rapid transit, either as bus rapid transit or rail rapid transit. This concept is anticipated to extend over approximately 950 meters of the bridge main span and allow the rapid transit system to pass over the Burrard Inlet. The concept uses the existing superstructure only to assist in the erection of the second internal superstructure that fully supports the rapid transit system. However, the concept does rely on using the concrete substructure and

foundations to fully support the additional loads, of the rapid transit system and the second internal substructure.

The concept's potential advantages over a new bridge would be:

- Savings on permitting schedule.
- No foundation work for the 950 m span of the inlet.
- Early start to construction work.

However, the IWMB is not a new structure and has undergone several rehabilitations and retrofits to keep it functioning for its current use. The bridge deck has seen one overlay and will most likely need another within 20 years. The IWMB has had a seismic retrofit to a life safety level for a 1 in 475yr return period but is unlikely to reach the reliability of a Major Route Bridge using the current design seismic event of 1 in 2475 year return. During the recent Second Narrows Water Tunnel project of the GVRD, the larger design seismic event was found to cause significant liquefaction and lateral spread of the west shoreline next to the bridge. Significant ground improvement would be required around all the main truss piers if the desired reliability of the combined transit system is to match that of the rest of the system's infrastructure.

In addition, in 2018, MoTI commissioned a study on the IWMB Vessel Collision Risk Assessment and Mitigation. The key finding was that the IWMB does not meet the criteria for a Class I (Critical Important) highway bridge. The estimated cost for a phased approach to install a truss fendering system and 6 in-water dolphins to protect the main bridge pier was 58 million dollars.

As a part of the "Safety Fence and Sidewalk Widening" project of IWMB, some truss members were identified to be over-stressed for the wind loading according to S6-06. The wind loadings provided by RWDI, based on a desktop study of previous wind testing, resulted in some lateral bracing members having to be strengthened.

Various fatigue cracks were detected in the stringers and floor beams at various locations along the bridge circa 2005. The cracking was not considered to be impacting the safety, structural integrity, or operational integrity of the bridge. Several cracks were repaired to retard the crack growth. Annual inspections of all susceptible fatigue details have been established to monitor the status of crack. In addition, local recoating work in areas of the steel deck system close to deck joints and other areas of the structural steel components where the existing coating has reached its service life. Other miscellaneous repair works, such as joint repairs, drainage water catchment/shedding, bird droppings removal and mitigation work will also be done during the recoating project.

Given that the IWMB has both seismic and ship impact deficiencies that do not meet current design standards for a major structure, it may not seem prudent to connect a new rapid transit to it for the relatively short 950 meters of the system.

Overall, the following vulnerabilities and issues were identified during discussions with MoTI in Stage 2:

- Seismic upgrades are to 1/475yr event, with a lower performance level than a Major Route structure. (*)
- Possible ship collision of the superstructure has been identified (MOTI has started some work on mitigation)
- Some truss members have been identified as overloaded during maximum wind loading. Strengthening of some lateral bracing is required

- Load capacity of steel superstructure is fully utilized after recent Safety Fence and Sidewalk Retrofit
- Various fatigue cracks in the stringers and floor beams have been detected and are being monitored.
- Ongoing Maintenance
 - Original lead-based paint is being recoated in selected areas
 - Joint replacement
- Potentially limited additional value from investment compared to a new bridge which would achieve higher design standards (i.e. Option 5B)
- Potential savings on permitting and environmental impacts (but unlikely to be realized with typical length of time for transit projects to go through various engineering development and funding approvals)

could not achieve the same resiliency/ductility/load path of a new bridge

In addition to structural feasibility of Option 5C, the approach alignments and profiles were also examined further. For the north approach, it was determined that the rail transit structure could not be accommodated underneath the IWMB north of pier bent 6 due to the limited vertical space available over the existing CN railway tracks. Thus, the track alignment would need to transition away from the IWMB structure before pier bent 6 (see Figure 3-8 below). Based upon the track alignment requirements, it is not feasible to keep the tracks adjacent and navigate around the existing pier bents. Following the track alignment requirements this means that northbound track could transition using 160m radius curve to become parallel to the railway while the southbound track would need to use a 80m radius curve navigate between pier bent 7 and 8. For the southbound track structure, including an allowance for an emergency walkway to navigate between bent 7 and 8 there would be minimal clearance (less than 200mm) between the edge of the guideway structure and the bent. This is very constrained and typically at this stage in an engineering study a larger clearance should be allowed.

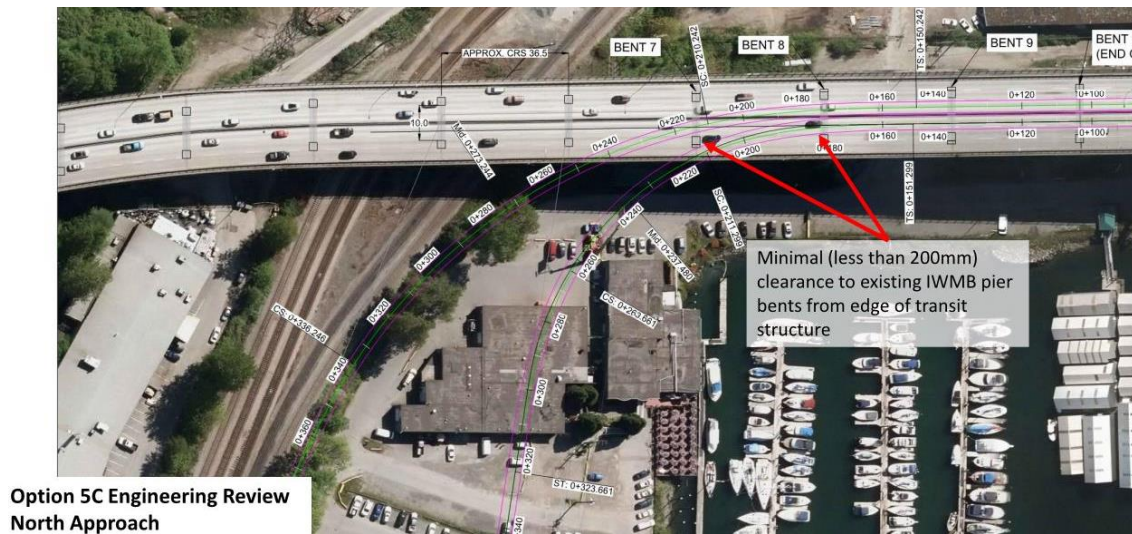


Figure 3-8: North approach for Option 5C

For the south approach, this study reviewed two alignments to explore how the transit system could exit the existing bridge structure (shown in Figure 3-9). One option would pass through the side of the existing truss structure to allow the transit alignment to remain elevated over top

of Highway 1. The other alignment option would go through the south abutment and into a tunnel to navigate under Highway 1 and the McGill Street interchange.

Both of these alignment options have significant impacts on the structural integrity of the existing structure. For an option that deflects the transit structure west through the side of the existing IWMB truss, approximately 65m of truss would be impacted, using minimum alignment curvature to deflect. Similarly challenging, would be the option to pass the alignment through the south abutment, resulting in significant impacts to the abutment. This area is also highly constrained with terrain, residential, port, and Highway infrastructure thus construction laydown area may be limited.

Option 5C Engineering Review South Approach

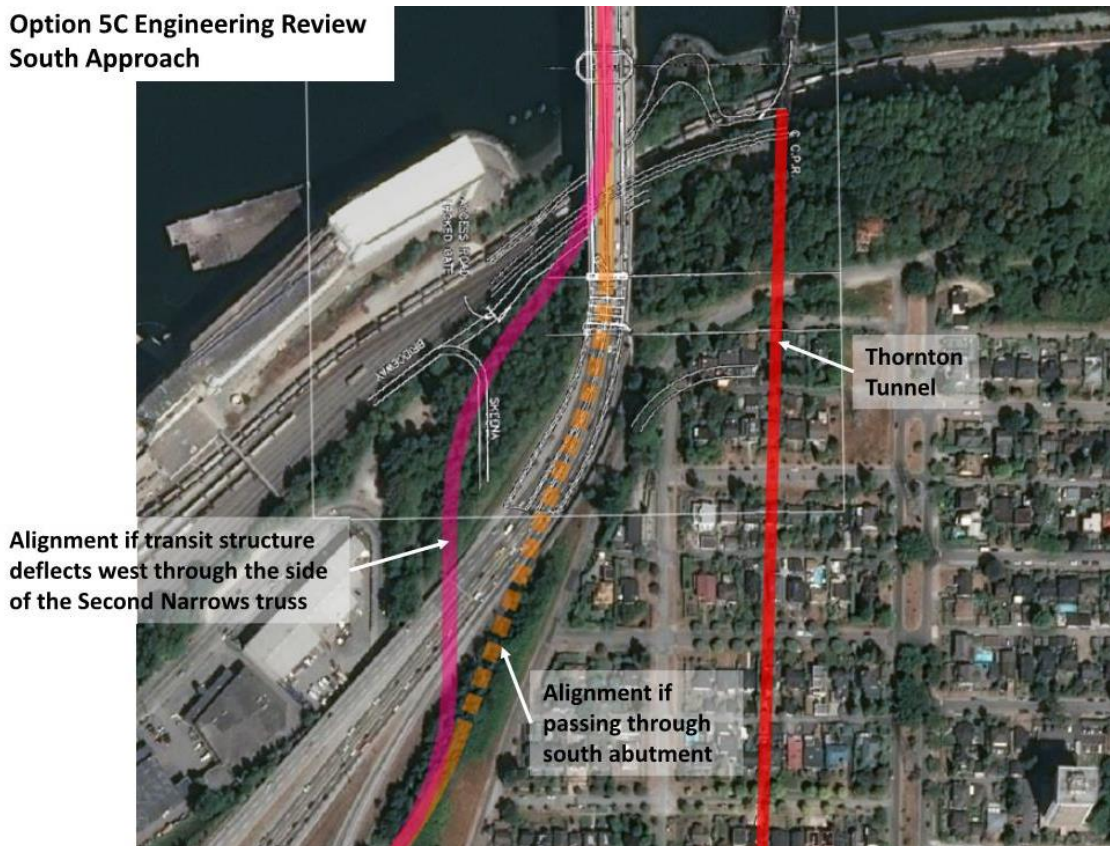


Figure 3-9: Option 5C south approach alignment options

In general, significant structural challenges for Option 5C include the existing IWMB seismic vulnerabilities, ship collision, wind and fatigue. Retrofitting IWMB could not achieve the same resiliency of a new bridge, and any potential savings on permitting time and environmental impacts are unlikely to be realized with the typical length of time required for transit projects funding approvals within the Lower Mainland.

4 Summary of Stage 1 and Stage 2

The following tables provide a summary of some key metrics and findings of the BIRT Study to-date. Table 4-1 sets out the operational assumptions, opportunities, challenges, risks, and key differentiators between options:

Table 4-1: Summary of Stage 1 and 2 Operational Assumptions, Opportunities, Challenges and Risks

	Blue Zone		Green Zone	Yellow Zone	Purple Zone	
	2A	3A	1A	5B2	5B	5C
Operational Assumptions	<ul style="list-style-type: none"> Assume a seamless connection with Expo Line via a spur at Burrard Station SeaBus remains in operation Headways limited by connection to Expo Line (1 in 3 trains continue to the North Shore with the other 2 continuing to Waterfront) 		<ul style="list-style-type: none"> SeaBus removed and replaced by fixed link transit Transfer was assumed at Waterfront Station (rebuild option/extension has not gone through ridership modelling) 	<ul style="list-style-type: none"> Assume a seamless connection with Expo Line via an extension SeaBus remains in operation Headways may be limited by operational restrictions on Expo Line (1 in 3 trains) 	<ul style="list-style-type: none"> Transfer at Brentwood Station to the Millennium Line SeaBus remains in operation 	
	<ul style="list-style-type: none"> Stations at Burrard, West End, Park Royal, Lions Gate Village, Capilano Mall and Lonsdale 	<ul style="list-style-type: none"> Stations at Burrard, West End, Capilano Mall and Lonsdale 	<ul style="list-style-type: none"> Stations at Waterfront, Lonsdale Quay, Central Lonsdale, Capilano Mall, Lions Gate Village and Park Royal 	<ul style="list-style-type: none"> Stations at Waterfront, Main St, Commercial, Nanaimo, Renfrew, Phibbs Exchange, Moodyville and Lonsdale 	<ul style="list-style-type: none"> Stations at Brentwood, Boundary, Phibbs Exchange, Moodyville and Lonsdale 	
Opportunities	<ul style="list-style-type: none"> Options in the Blue Zone have shown high potential to generate new ridership, connect key activity nodes in the region, and provide an efficient and seamless connection between downtown Vancouver and the North Shore without the need for transfers 		<ul style="list-style-type: none"> Direct route with shortest crossing time between Waterfront and Lonsdale For the extension of Canada Line sub-option, there would be a seamless integration with the Canada Line and the destinations along it. 	<ul style="list-style-type: none"> Provides access to the well developed residential and commercial corridor through East Vancouver Connects directly to Phibbs Exchange providing better access to the Marine Drive RapidBus and buses serving Capilano University and Maplewood Town Centre New bridge provides opportunity for high quality active transportation infrastructure 	<ul style="list-style-type: none"> Connects directly to Phibbs Exchange providing better access to the Marine Drive RapidBus and buses serving Capilano University and Maplewood Town Centre Very large reduction in travel time to and from Brentwood which is slated for significant development in the near- and longer-term future. Extension to Metrotown provides opportunity to connect both the Expo and Millennium Line to the North Shore. * Note: this scenario was not considered in Stage 1. Extension to Metrotown should be modelled for ridership potential Opportunity to stimulate mode shift and reduce congestion on IWMB. 	

	Blue Zone		Green Zone	Yellow Zone	Purple Zone	
	2A	3A	1A	5B2	5B	5C
	<ul style="list-style-type: none"> A station at Park Royal means a connection to a significant activity node in West Vancouver 	<ul style="list-style-type: none"> Likely lower cost relative to Option 2A due to shorter overall tunnel length, however, misses key activity nodes (Park Royal and Lions Gate Village) 		<ul style="list-style-type: none"> Generates high ridership, some of it within Vancouver/Burnaby long Hastings corridor Provides a secondary 'relief valve' to downtown that better utilizes the traditional 'off-peak' direction within existing rapid transit network Opportunity for spur to Brentwood/Metrotown 	<ul style="list-style-type: none"> New bridge provides opportunity for high quality active transportation infrastructure New bridge can be designed to higher resilience level as well as latest seismic, durability and ship impact requirements 	<ul style="list-style-type: none"> Potential savings on permitting time and environmental impacts <ul style="list-style-type: none"> These are unlikely to be realized with the typical length of time for transit projects to go through various engineering development and funding approvals
Challenges and risks	<ul style="list-style-type: none"> Tunneled options which connect to the Expo Line near Burrard Station will require careful assessment of routing through the western end of downtown Vancouver in order to navigate a route through the urban environment which includes many underground structures and utilities Tunnel construction downtown may be difficult given multiple tall buildings with significant basement levels – route will need to be identified to navigate a section which is not simple grid Tie into existing Expo Line tunnel west of Burrard Station could be complex and disruptive Long tunnel through differing ground conditions including challenging soils, sensitive to seismic events Routing will need to avoid sensitive structures on the north shore, including buildings and the railway There are potential impacts to First Nations land which need to be further understood through consultation 		<ul style="list-style-type: none"> Crosses the Burrard Inlet at its deepest location For sub-option explored in Stage 1, requires a transfer with significant delay penalty for Waterfront transfer scenario For sub-option explored in Stage 1, independent line with a traditional tunnel, the depth of the stations presumed for 1A at both Waterfront and Lonsdale would be in the order of 50m to 60m deep below ground-level. This results in long station access/egress walk time due to station depths. Rebuild Canada Line sub-option in Stage 2 has significant length of rebuilt and lowering 2 underground station by 25 – 27.5m This is anticipated to have significant costs as well as significant impact on the existing system during construction. 	<ul style="list-style-type: none"> Circuitous route does not provide the fastest travel times between key OD pairs <ul style="list-style-type: none"> Substantial trips via SeaBus were still shown in the ridership modelling Tunnel construction along the foreshore would avoid construction in downtown but introduce interfaces with railways Tunnel alignments on south shore would need to be developed to minimize passage under property, particularly in the Gastown area where heritage buildings could be sensitive to disturbance New bridge will require in water works 	<ul style="list-style-type: none"> New bridge will require in water works and land in areas of poor ground conditions on the North Shore Constrained placement of piers Requires a transfer 	<ul style="list-style-type: none"> The existing IWMB vulnerabilities of seismic, ship collision, wind and fatigue. Retrofitting IWMB could not achieve the same resiliency, ductility and load path of a new bridge. Requires a transfer
	<ul style="list-style-type: none"> Likely higher cost option due to total length and long tunnels section Mix of elevated and underground stations Higher uncertainty for Option 2A tunnel compared to Option 3A due to lack of geotechnical information in area 	<ul style="list-style-type: none"> Several constraints along First Street including the conveyance pipeline alignment that connects the Lions Gate Wastewater Treatment Plant to the new North Shore Wastewater Treatment Plant 				

	Blue Zone		Green Zone	Yellow Zone	Purple Zone	
	2A	3A	1A	5B2	5B	5C
Differentiators	<ul style="list-style-type: none"> Connects the Expo Line with the following activity nodes <ul style="list-style-type: none"> West End and Stanley Park, Park Royal, Lions Gate Village Capilano Mall, Lower or Central Lonsdale Large coverage of downtown and reasonable coverage on the North Shore including parts of Park Royal, and does serve all three North Shore municipalities. Largest reduction in auto demand across Burrard Inlet compared to other options 	<ul style="list-style-type: none"> Connects the Expo Line with the following activity nodes <ul style="list-style-type: none"> West End and Stanley Park, Capilano Mall, Lower or Central Lonsdale Large increase in ridership but does not include Park Royal or Lions Gate Village stations but provides faster connection between downtown and Lonsdale Noticeable reduction in auto demand across the Burrard Inlet 	<ul style="list-style-type: none"> In Stage 1, Option 1A did not perform well comparatively largely due to the deep station requirements and therefore transfer penalties at Lonsdale Quay and Waterfront Station. The alternate/sub-option of Option1A examined in Stage 2, that looked to extend the Canada Line through rebuilding a significant portion of the downtown, has not been retested to see if this would improve its performance comparatively. Provides the most direct connection between downtown Vancouver and Lonsdale 	<ul style="list-style-type: none"> A bridge crossing provides improved opportunities for active transportation modes Connects key activity nodes including Waterfront, Granville, Stadium, Chinatown, PNE, Lonsdale Quay, Phibbs Exchange 	<ul style="list-style-type: none"> Provides improved opportunities for active transportation modes Connects key nodes including Brentwood, Kootenay Loop, Phibbs Exchange, Lonsdale Quay <ul style="list-style-type: none"> Potential to extend to Metrotown High capacity with potential expandability to connect Millennium Line, Expo Line and potential Hastings Line Independent line that is not limited by operational constraints of the Expo Line 	<ul style="list-style-type: none"> High capacity with potential expandability to connect Millennium Line, Expo Line and potential Hastings Line User experience less optimal due to operating under car deck Less potential for multimodal integration by using existing bridge the existing IWMB vulnerabilities of seismic, ship collision, wind and fatigue. Retrofitting IWMB could not achieve the same resiliency, ductility and load path of a new bridge. Independent line that is not limited by operational constraints of the Expo Line

5 Options for Advancement

Following the Stage 2 engineering activities and discussion with PWG, the following decisions were made for each of the six options evaluated in Stage 2:

- Remove Option 5C (Existing Bridge) from further analysis at this time because of:
 - Significant structural challenges including the existing IWM Bridge vulnerabilities related to seismic, ship collision, wind and fatigue
 - Retrofits solutions could not achieve the same resiliency/ductility/load path of a new bridge and would therefore not provide the same resiliency of infrastructure compared to the rest of the new proposed transit system.
 - Potential savings on permitting time and cost savings are unlikely to be realized, given the typical length of time for transit funding approval processes in the Lower Mainland and also the significant structural complexity associated with retrofits for this option.
- Continue to carry Option 1A forward for further analysis to future stages of the study so that ridership modelling of the Canada Line extension and associated costing can be completed.

There are several challenges with Option 1A and its variants, specifically:

 - Option 1A (Waterfront transfer assumption in Stage 1) yielded relatively low ridership performance compared to other alignment crossings
 - Option 1A (Canada Line re-build option developed in Stage 2) is anticipated to have significant cost and challenges associated with the deep re-construction required of the Canada Line.

Irrespective of the above challenges, it is recognized that Option 1A is a logical 'direct link' between Vancouver and the North Shore, and thus, scrutiny around screening this option is anticipated. It was therefore decided that a similar ridership modelling assessment and high-level costing exercise of the Canada Line re-build options should be completed for due diligence before any consideration of screening can occur. Alternative options, such as a new transit line extending south towards Broadway Subway or other future planned transit networks could also be explored in future phases of the Study for the Green crossing zone.
- Continue to carry forward for further analysis:
 - Option 2A (Burrard via First Narrows to Central Lonsdale) – Tunnel
 - Option 3A (Burrard via Brockton Point to Central Lonsdale) – Tunnel
 - Option 5B (Brentwood via Second Narrows to Lower Lonsdale) – New Bridge
 - Option 5B2 (Waterfront via Second Narrows to Lower Lonsdale) – New Bridge

6 Recommendations for Next Steps

The objective of any future work will be to continue an iterative process through a variety of technical assessments and evaluations to ultimately select a preferred option which will meet the objectives of the region and be supported by the majority of stakeholders. To get to this stage, significant work is still required, including:

- further refinement of the overall routing of each option, expanding the focus of effort beyond the crossing locations; and
- additional planning-level assessments to understand the opportunities, risks and trade-offs between each option more clearly.

Following the work completed to-date in both Stage 1 and Stage 2, a number of work activities which will provide more information to help facilitate comparisons between the different options and decisions to be made are recommended to be completed as part of future stages. The tasks listed below have been identified as high priority because the outcomes are anticipated to provide additional differentiators, such as relative cost and network performance, providing the necessary supporting information for further screening and refinement of options.

This recommended work includes but is not limited to:

- Refinement of routing beyond the inlet crossings to further define the extent of options and interfaces with other parts of the transit network and station locations. Areas of further study would include:
 - the routing and extent of options across the North Shore;
 - refinement of alignment options through east Vancouver to the Second Narrows crossings;
 - further consideration of the routing and extent of options from the Second Narrows crossings to Burnaby; and
 - exploration of alternate network concepts including an orbital route.
 - exploration of alternative green zone routes through Vancouver
- Further transportation modelling:
 - for a new scenario where the purple zone alignment Option 5B extends south to Metrotown station.
 - of an alternative Option 1A, where the crossing to the North Shore is an extension of the CanadaLine (i.e. re-construction of Canada Line from Yaletown-Roundhouse to Waterfront Station), or other potential routing of a new line extending south from Waterfront to future transit connections (i.e. Broadway Subway project).
 - to support assessments and refinements to the routing overall routing of options and proposed station locations
 - to understand ridership effects with alternative network integration strategies and extensions and a relatively equivalent service hour baseline
- Further engineering work to advance the level of detail beyond crossing location to support a more comprehensive routing concept, costing, and MAE work (as well as identifying additional feasibility issues), including investigation of existing utility easements, building foundation depths and geological information. Specific areas of focus include but are not limited to:

- Tie-in detail requirements at Burrard Station for Option 2A/3A tunnels
- Tie-in detail or terminus requirements at Waterfront Station for Option 5B2
- Alignment review from Waterfront to Hastings through Gastown for Option 5B2
- Downtown tunnel routing for Option 2A/3A west of Burrard Station to Stanley Park
- Pier Placement of Option 5B2/5B and additional engagement with VFPA and other stakeholders in the vicinity of the Second Narrows crossing
- More detailed consideration of tunnel portal and station interfaces with Park Royal for Option 3A
- Refinement of the routing and requirements for a new bridge adjacent to IWMB, including further consultation with stakeholders regarding onshore and in water constraints and requirements.
- Corridor selection across the North Shore in consideration of available right-of-way, and economic, land development and housing impact to existing neighbourhoods.
- Preparation of high-level capital cost estimates for the options, reflecting possible network routing alterations and further engineering, to a level suitable for initial discussions around funding.
- Update of Level 1 MAE transportation accounts based on the updated modelling scenarios for Option 1A and 5B using municipal OCPs and First Nation land development objectives.
- Development and implementation of Level 2 MAE, including development and expansion of criteria and accounts, building upon the foundational framework for project evaluation from Stage 1.
- More detailed assessment and optimization of the underlying bus feeder network and revision of outcomes of the long-range transportation strategy, Transport 2050.

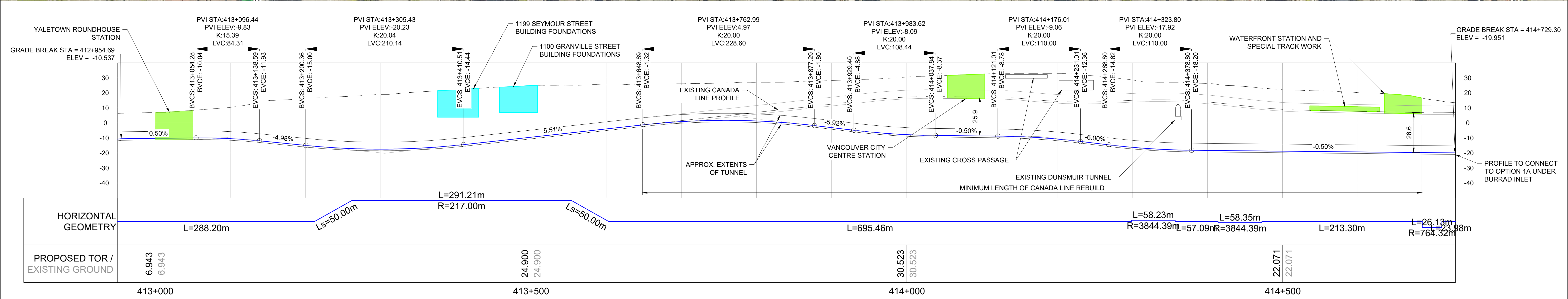
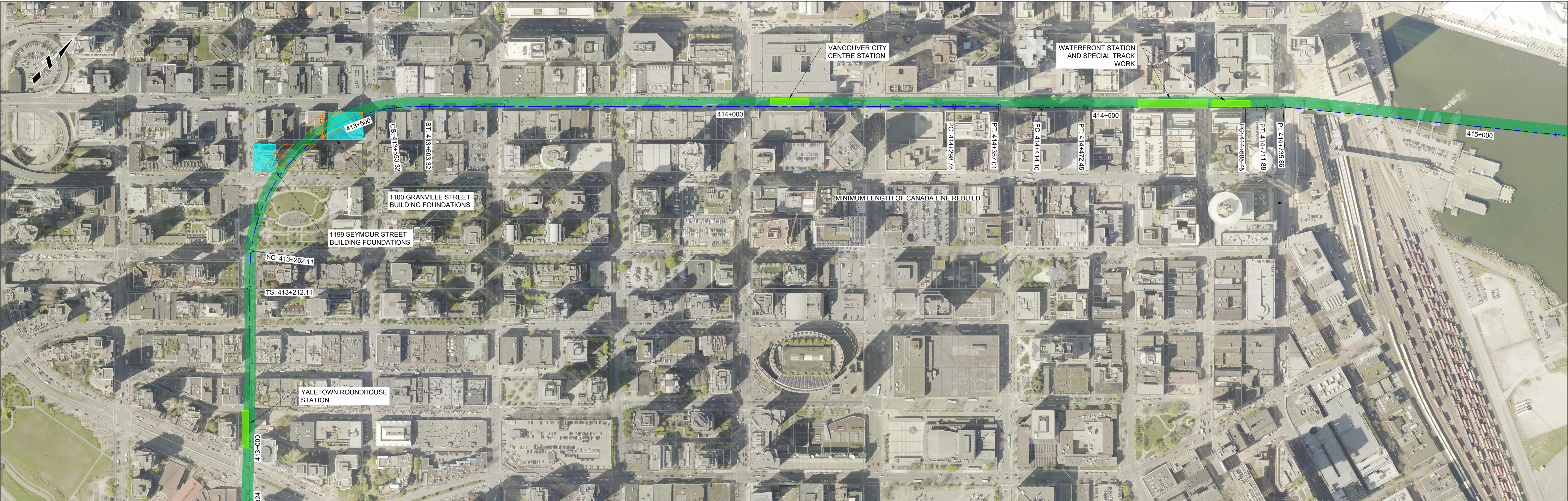
Throughout this work it will be important to continue to engage with the various relevant governments, including First Nations, municipalities, and regional and local agencies. Continued, active participation of all parties in future stages will help to identify important project considerations and enable effective decision making.

Increased participation from other key stakeholders and communities is recommended as the study progresses. This should include but not be limited to:

- Vancouver Fraser Port Authority
- The City of Burnaby
- Metro Vancouver
- BC Hydro
- CN Rail
- Transport Canada

The outcomes from the City of North Vancouver's current economic study should be considered complementary to the work undertaken in this study and should be factored into the planning of any future advancement of this project.

A. Alignment Options Plan-Profile Drawings



<div>Legend:</div> <div><div></div>STATIONS & SPECIAL TRACK WORK</div> <div><div></div>BUILDING FOUNDATIONS</div> <div><div></div>CANADA LINE EASEMENT REQUIRED FOR BUILDING CROSSINGS</div>
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