Richmond

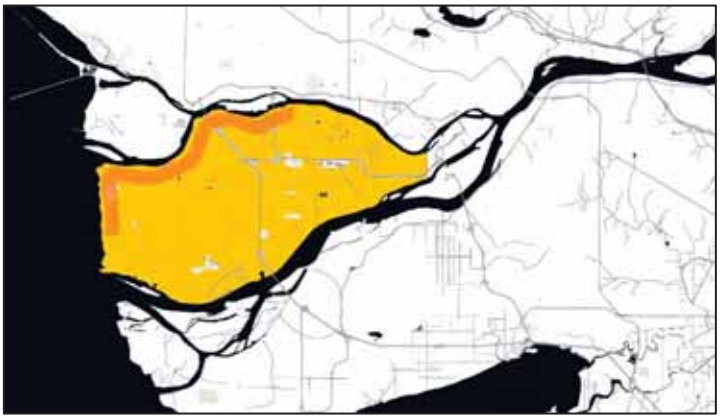
LULU ISLAND DIKE MASTER PLAN
PHASE 2
FINAL REPORT

Parsons

475287 - FEBRUARY 2018

Executive Summary

The purpose of the Lulu Island Dike Master Plan (LIDMP) is to identify preferred methods for implementing the objectives of the City of Richmond's 2008 – 2031 Flood Protection Strategy. The Lulu Island Dike Master Plan is being prepared in phases. Parsons (as Delcan) prepared Phase 1 of the plan for the Steveston and southern West Dike areas[1] (Phase 1 LIDMP). The Study Area for Phase 2 has been defined from Williams Road on the West Dike to No. 6 Road on the North Dike. The Study Area is highlighted orange within Lulu Island in the figure below. Lulu Island lies in the Fraser River Delta, and is surrounded by the Fraser River Estuary. The estuary provides critical habitat for many species of fish and wildlife, and important ecosystems services such as erosion control, shoreline stabilization and storm surge protection.



Phase 2 LIDMP Study Area on the West Dike and North Dike within Lulu Island

The Phase 1 LIDMP focused largely on technical issues of assessing significant changes in dike alignment. Instead of adapting upgrades to the existing shoreline alignment which may have impacted heritage structures in Steveston, the engineering feasibility of a future dike and flood-gate along Steveston Island was presented.

In the Phase 2 Study Area, the existing dike alignment along the waterfront is established and well defined. There is limited basis to support any major changes to the alignment of the existing dike, thus the recommendations are generally in keeping with traditional dike crest increases, with consideration for localized constraints and opportunities. The Study Area has been segmented into thirteen design areas to make these recommendations on an area specific basis. There are also opportunities to consider flood protection strategies that are applicable throughout the entire Study Area. These area wide strategies may be implemented to fortify the area specific adaptations.

The City has identified a target dike crest elevation of 4.7 m, with consideration for raising the dike to 5.5 m in the long term future. Dike adaptations that achieve the target crest elevation are considered by area, forming the area specific adaptations. These include dikes and floodwalls in any conformation. Area wide adaptations are those which may not achieve the target dike crest elevation on their own, but contribute to overall flood protection. For example, barrier islands that reduce wave run-up to eliminate the need for additional target crest increases, or policy changes that facilitate the implementation of dike adaptations are both categorized as area wide adaptations. Both area wide and area specific strategies will be presented in the LIDMP, forming a comprehensive plan to achieve the objectives of the Flood Protection Strategy. Area wide and area specific strategies will be considered within the context of the City's Ecological Network Management Strategy (ENMS) such that the recommendations presented in the LIDMP are consistent with strengthening the City's green infrastructure, while managing and enhancing ecological assets.

Area Wide Protection Strategies

A number of area wide approaches can be considered to enhance long term flood protection in the City and create resiliency in addressing climate change and sea level rise. Preferred strategies are summarized below.

Plan for the long-term raising of lands adjacent to and inland of the existing dikes: Long term raising of land levels has previously been recommended (2008-2031 Flood Protection Strategy). Maximizing the width of raised land adjacent to the river decreases flood and seismic risks by increasing the integrity of the dike. Plan to raise the ground elevation of waterfront development sites to the prescribed dike crest elevation.

[1] Lulu Island Dike Master Plan Phase 1, Delcan, March 2013

Enhance floodproofing through amendments to the FCL By-law: The City's Flood Construction Level (FCL) Bylaw establishes minimum levels to which land needs to be raised. Amending the FCL bylaw is the recommended area wide strategy to regulate raising ground elevations with redevelopment to improve flood protection throughout the Study Area.

Support site assemblies along the waterfront that promote cohesive adaptations for flood protection: Large developments along the waterfront allow for major improvements to flood protection infrastructure and often result in robust superdike conditions.

Plan for implementation of offshore protection on Sturgeon Banks: If climate change and sea level rise predictions materialize, increased depths offshore could simultaneously increase wave heights, particularly in the Georgia Strait. Upland limitations to natural accretion within the Sturgeon Bank Wildlife Management Area may also contribute to increased offshore depths beyond the West Dike. Offshore barrier islands are one option to consider to dissipate wave energy prior to waves reaching the West Dike and stabilize shorelines, thereby minimizing future dike crest increases. Enhancement of intertidal habitat alongside the creation of offshore barrier islands may provide natural ecosystem mechanisms to further dissipate wave energy. The City may consider offshore protection in its long-term plans for flood protection along the West Dike.

Area Specific Flood Protection Strategies

In practice, when dike upgrades have been made, they have been made along the existing alignment. Apart from select site specific constraints and opportunities, the recommended future dike alignment for the Phase 2 Study Area matches the existing dike alignment. Area specific strategies were selected with consideration for: flood protection, environmental, geotechnical, infrastructure, site-specific constraints, social, property, economic, operational and cost considerations. The City is committed to avoid, mitigate or compensate for any environmental impacts that may result from dike adaptation projects. Completely avoiding any impact on an environmental area may not be feasible in some cases, for example where dikes are highly constrained. In these instances, mitigation or compensation that follows a net gain approach may be pursued.

Area specific strategies for the Phase 2 study are summarized below:

West Dike: Raise the dike on the existing alignment. Additional studies required to quantify drainage impacts of land side expansion, habitat impacts and costs associated with water side or land side expansion, and long term resiliency of a constrained dike solution. Consider routing the dike inland through Terra Nova Rural Park.

North Dike: Terra Nova to No. 2 Road Bridge: Raise the dike on the existing alignment with land side expansion. Plan for the raising of River Road.

North Dike: No. 2 Road Bridge to Dinsmore Bridge: Existing and proposed developments are raising elevations to 4.0 m to 4.7 m. Future raisings to 5.5 m can take place on the existing alignments and integrate into the adjacent landscaping.

North Dike: Dinsmore Bridge to Moray Bridge: Raise the dike with land side expansion. Consider creation of a set-back dike and inland raising (superdike) in conjunction with the future Middle Arm Waterfront Park construction. Ensure any interim dike upgrades are compatible with the long term strategy of constructing superdikes.

North Dike: Moray Bridge to Oak Street Bridge: Implement flood protection with approved development plans for Duck Island and the River Rock Casino when available. If required to address sea level rise and climate change prior to implementation of the approved strategy at the Duck Island or River Rock Casino sites, plan for a temporary adaptation, such as a demountable floodwall, to protect City assets

North Dike: Oak Street Bridge to No. 4 Road: Raise the dike on the existing alignment. Site specific solutions may be required at the Fraser River Terminal site. Plan for temporary dike along the alternate alignment if required to address sea level rise and climate change prior to implementation of a strategy at the Fraser River Terminal site.

North Dike: No. 4 Road to Shell Road: Existing and proposed developments will raise the area generally to an elevation of 4.7 m. Future raisings to 5.5 m can take place on the existing alignments and integrate into the adjacent landscaping.

North Dike: Shell Road to No. 6 Road: Raise the dike on the existing alignment. Land acquisition may be required to facilitate construction of a trapezoidal dike (through redevelopment or otherwise). Implementation of a temporary floodwall

adjacent to the waterfront lots may be required in advance of a permanent adaptation to address sea level rise and climate change. Consider Bath Slough Revitalization Initiative for future designs. Additional studies are required to quantify drainage, habitat impacts, and costs associated with land side expansion of a trapezoidal dike. A constrained land side slope may be required to integrate with the existing drainage infrastructure.

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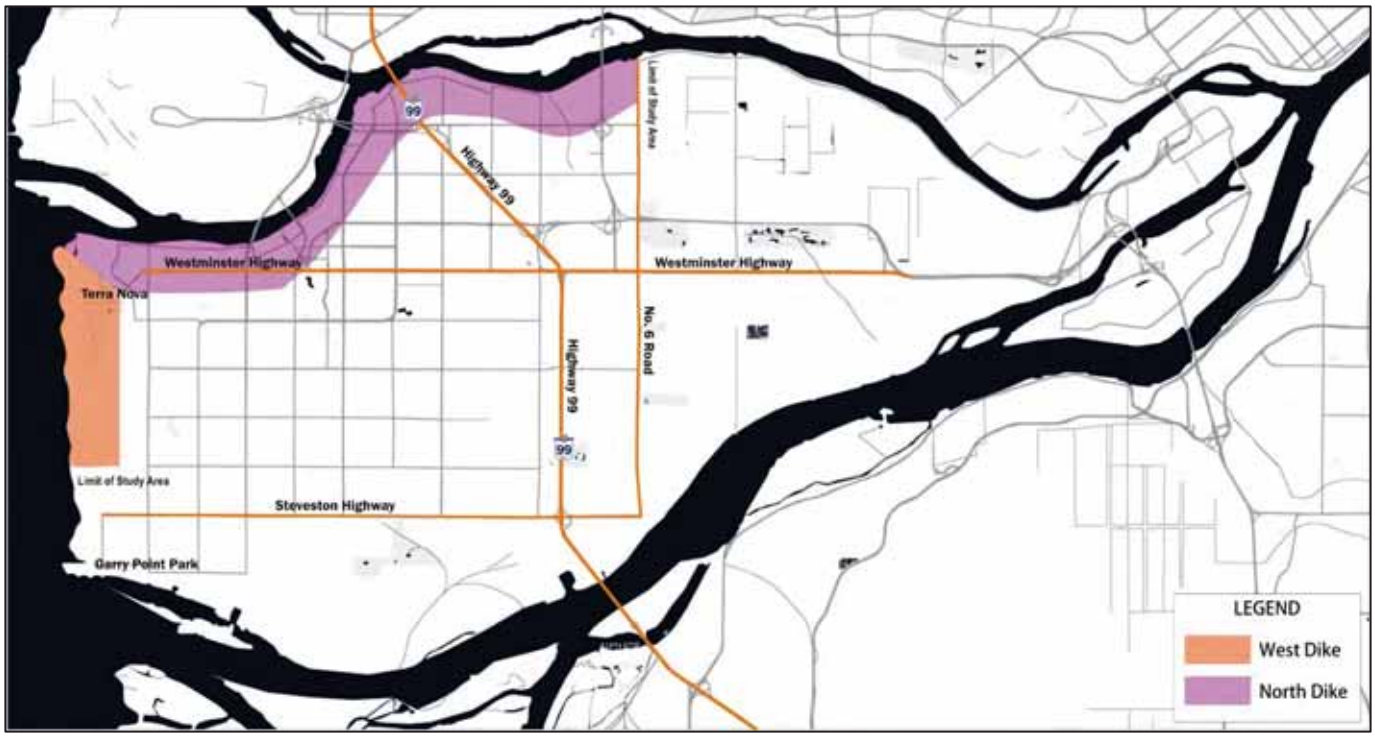
1 Introduction

Richmond is a city of over 200,000 people in 130 square kilometres with considerable assets to be protected from flood damage. The City has endeavoured to adapt its flood protection systems to changing flood risks, including anticipated increases to flood levels resulting from climate change and sea level rise. With the establishment of the 2008 – 2031 Flood Protection Strategy, the City committed to prepare and implement a perimeter dike improvement program. The purpose of the Lulu Island Dike Master Plan (LIDMP) is to identify preferred methods for implementing the objectives of the City of Richmond's 2008 – 2031 Flood Protection Strategy.

With Richmond located at the mouth of the Fraser River, and the flood protection infrastructure interfacing with the high ecological value of the Fraser River Estuary, the LIDMP also works to integrate the objectives of key City documents such as the City's Ecological Network Management Strategy (ENMS), and put forward recommendations that will strengthen the City's green infrastructure network.

The LIDMP is being prepared in phases. Parsons (as Delcan) prepared Phase 1 of the LIDMP for the Steveston and southern West Dike areas[2] (Phase 1 LIDMP). The Study Area for the second phase of the LIDMP (Phase 2 LIDMP) includes the West Dike from Willams Road to Terra Nova Rural Park, and the North Dike from Terra Nova Rural Park to No. 6 Road as shown in ***Figure 1***.

Figure 1: Study Area



The Phase 2 LIDMP provides the framework to direct future dike improvement projects and ensure that diking requirements are considered as waterfront lands are redeveloped. It establishes a well-planned strategy to identify future flood protection infrastructure requirements along the waterfront. The Phase 2 LIDMP presents recommended adaptations for flood protection, including guidelines for incorporating flood protection into future waterfront developments. It also presents considerations for any dike adaptation project in the Study Area to minimize impacts and to integrate adaptations within the public and natural realms.

[2] Lulu Island Dike Master Plan Phase 1, Delcan, March 2013

1.1 SCOPE

The recommended flood protection adaptations forming the Phase 2 LIDMP are assessed for their ability to achieve a minimum crest elevation of 4.7 m, and accommodate a future increase to 5.5 m as prescribed by the City. No independent evaluation of these crest elevations has been conducted by Parsons. These target elevations have been accepted as the basis for the Phase 2 LIDMP.

Recommendations have been categorized as either area wide or area specific adaptations. Area wide strategies encompass adaptations that are applicable for the entire Study Area, or a substantial part of it. These include policy adaptations, as well as structural adaptations that would fortify the primary dike, but would not achieve the City's target crest elevation on its own. The Phase 2 LIDMP recommends adaptations in both categories to produce a comprehensive strategy for improving flood protection in the Study Area.

Area specific strategies are structural adaptations that modify the existing dike or replace it to achieve the City's target dike crest elevation of 4.7 m. The Study Area has been broken into thirteen design areas to recommend area specific adaptations. The design areas have been delineated according to the boundaries for planning areas in the City's Official Community Plan (OCP). The design areas are described further in ***Section 2*** and ***Section 4.2***.

The Phase 2 LIDMP is a guidance document for future dike adaptation design and construction projects. No detailed design, nor any construction will be undertaken as part of the Phase 2 LIDMP. Design and construction projects are beyond the scope of the current planning exercise. Proponents of diking design and construction projects will need to confirm their projects are in compliance with all regulatory requirements, in addition to adhering to the Master Plan, when projects move forward.

1.2 APPROACH

In preparation of the Phase 2 LIDMP, Parsons previously prepared and submitted two technical memos to the City. Technical Memo #1[3] (TM #1) presented potential flood protection options that may be appropriate for implementation in the Study Area, based on a detailed review of current and future land uses, environmental and geotechnical conditions, and other City guidance documents. Technical Memo #2[4] (TM #2) outlined the evaluation of potential flood protection adaptations within the Phase 2 Study Area, and presented the preliminary concept for the Phase 2 LIDMP. Both technical memos have been attached to the Phase 2 LIDMP as ***Attachment 1*** and ***Attachment 2*** for reference.

Both technical memos were circulated internally to relevant City departments for review. The feedback received from these stakeholders was integrated into the technical memos before each was finalized. The final Phase 2 LIDMP is derived from these previous studies and as such, City feedback has been incorporated into the Phase 2 LIDMP.

1.3 ADDITIONAL GUIDANCE DOCUMENTS

The recommendations in the Phase 2 LIDMP have been prepared in keeping with other City strategies and plans. Any proposed diking projects should be designed and constructed with consideration for the Phase 2 LIDMP, as well as any other City guidance documents in effect at the time an adaptation project proceeds to design and construction. Policy adaptations should also be implemented with consideration for compatibility with other City strategies and guidelines. City guidance documents considered in the development of the Phase 2 LIDMP included:

2009 Waterfront Strategy: The five Strategic Directions of the 2009 Waterfront Strategy were considered in the development of the Phase 2 LIDMP. The Strategic Directions include: 1) Working Together; 2) Amenities and Legacy; 3) Thriving Ecosystems; 4) Economic Vitality; and 5) Responding to Climate Change and Natural Hazards.

[3] Lulu Island Dike Master Plan Phase 2 – Technical Memo No. 1: Review of Existing Conditions, Parsons, Oct 5, 2016
[4] Lulu Island Dike Master Plan Phase 2 – Technical Memo No. 2: Analysis of Flood Protection Alternatives, Parsons, Oct 5, 2016

Flood Plain Designation and Protection By-Law 8204:	The Phase 2 LIDMP considers the existing Flood Plain Designation and Protection By-Law, and will consider outlines potential options to amend or accelerate increasing flood construction levels adjacent to the foreshore.
2008 – 2031 Richmond Flood Protection Strategy:	The Phase 2 LIDMP has been developed to address the goals of the Flood Protection Strategy.
2015 Ecological Network Management Strategy:	The Phase 2 LIDMP is informed by the strategic goals outlined in the 2015 Ecological Network Management Strategy (ENMS) to promote the Ecological Network. The City's ENMS is an ecological blueprint for the preservation of natural land City-wide. Through the ENMS the City will protect, restore and connect natural lands to avoid habitat fragmentation. The strategic goals outlined in the ENMS are: 1) Manage and Enhance Ecological Assets; 2) Strengthen City Green Infrastructure; 3) Create, Connect, and Protect Diverse and Healthy Spaces; 4) Engage through Stewardship and Collaboration. The objective of developing an Ecological Network was initially outlined in the OCP under Chapter 9: Island Natural Environment (and Ecological Network Approach).
2006 Riparian Response Strategy:	The Phase 2 LIDMP is consistent with the Riparian Response Strategy (RRS), which protects Riparian Management Areas that form part of the City's Ecological Network. The RRS identifies 5 m and 15 m Riparian Management Area (RMA) setbacks on minor and major watercourses that flow into and support fish life in the Fraser River, and are to remain free from development in accordance with requirements under the provincial Riparian Area Regulation. The RRS applies to riparian habitat on the City's inland watercourses but does not apply to the Fraser River, which is protected through designation as Environmentally Sensitive Area (ESA) in the OCP.
2008 Climate Change Response Agenda:	The recommendations from the Phase 2 LIDMP are made with consideration of the 3rd pillar of the City's Climate Change Response Agenda – implement strategies for adapting to unavoidable changes. Strategies have been considered that can meet the short and long term goals with respect to crest elevations; however, they must also be adaptable to change.
2010 Richmond Trail Strategy:	The Phase 2 LIDMP is developed with regard for the goal of maximizing access to the waterfront, as identified in the Richmond Trail Strategy.

2 Study Area

The Phase 2 Study Area includes parts of the West Dike and the North Dike. The West Dike section of the Study Area spans from Williams Road to Terra Nova Rural Park at the Middle Arm of the Fraser River. The North Dike section of the Study Area spans from Terra Nova Rural Park to No. 6 Road.

On the water side of the West Dike is Sturgeon Bank, a provincially designated Wildlife Management Area (WMA) within the Fraser River Estuary. It is comprised primarily of near shore and intertidal brackish marsh, sandflats, mudflats, and open water. It is a protected area for the conservation of critical, internationally significant habitat for year-round migration and wintering waterfowl populations and important fish habitat. The water side of the North Dike includes pockets of mud flat, salt marsh, and eelgrass habitat.

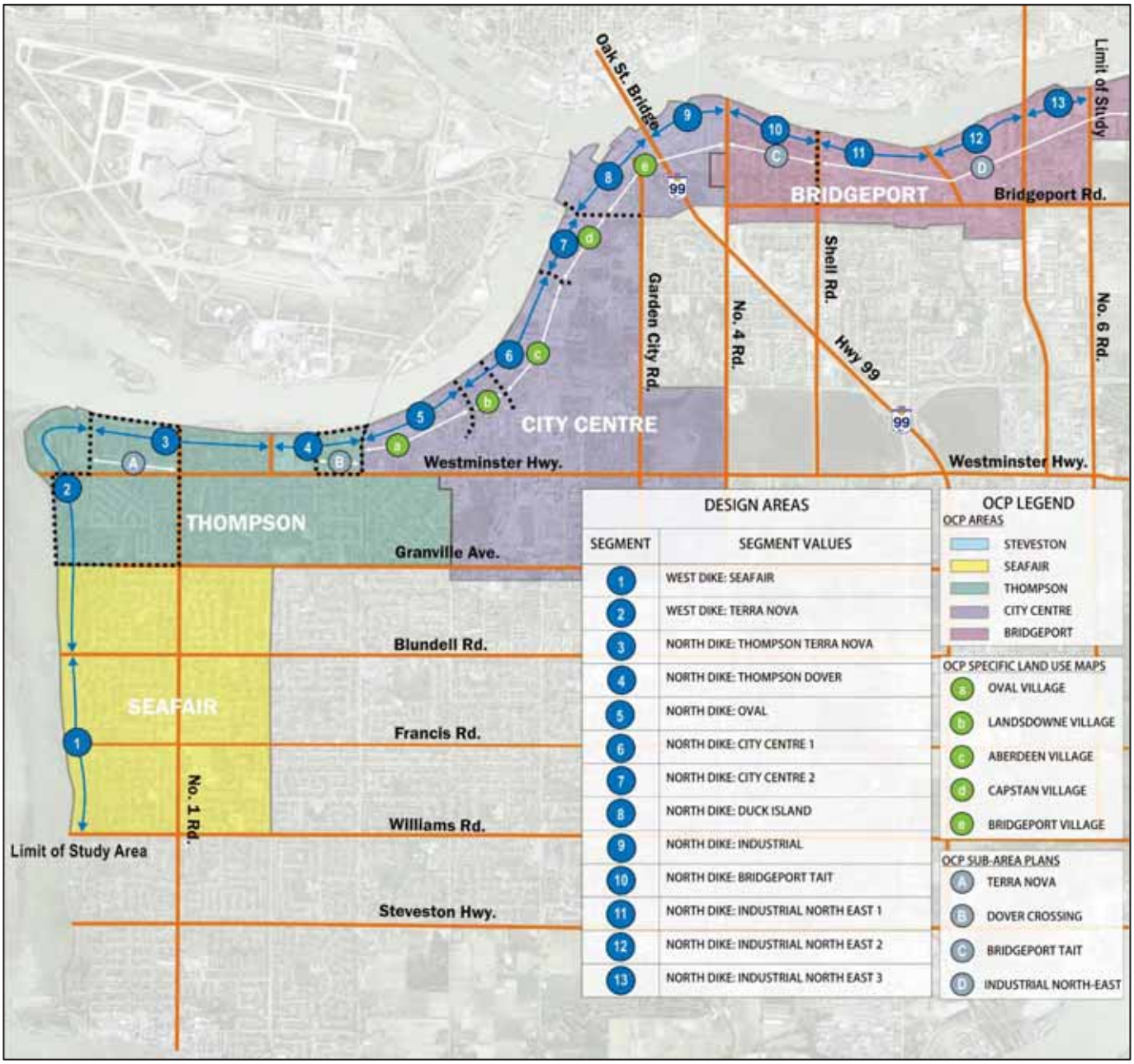
On the land side of the West and North Dikes, Riparian Management Areas (RMA's) are interspersed throughout the Study Area. RMA designated watercourses are wetted the majority of the year and flow into and support fish life in the Fraser River. The City's RMA's have predetermined setbacks of 5 m or 15 m from top of bank to delineate areas that support the form and function of the watercourses. These areas are protected under the provincial Riparian Area Regulation and form

a key component of the City's ENMS. The entire Study Area is also designated Environmentally Sensitive Area (ESA) within the OCP.

For the purposes of evaluating current and future land conditions and recommending appropriate structural adaptations, the Study Area has been broken into thirteen design areas. These areas are based on the planning boundaries established in the OCP for OCP Areas, OCP Sub-Area Plans, and OCP Specific Land Use Maps. The relevant OCP figures showing these areas are provided for reference in ***Appendix A***.

The design areas have been delineated using the OCP boundaries to ensure that the recommendations in this Master Plan can be readily integrated with other City guidelines and City planning initiatives. Area specific adaptations are recommended by area, with consideration for special sites within the thirteen design areas. Existing conditions for each design area, as well as future conditions as provided for in the OCP, are described in ***Section 2.1***. The design areas within the Study Area are illustrated in ***Figure 2***.

Figure 2: Design Areas and OCP Boundaries



2.1 PRESENT AND FUTURE LAND USE

A brief summary of existing conditions and planned future uses (as outlined in the OCP) for each of the thirteen design areas is provided in ***Table 1***. Site conditions or future uses having an anticipated impact on dike planning are discussed in more detail in the discussion of each design area in ***Section 4.2***, where the recommended adaptation is presented for each design area.

Table 1: Summary of Existing and Future Conditions

DESIGN AREA	BOUNDARIES		DESCRIPTION OF EXISTING AND FUTURE CONDITIONS PER OCP
SEAFAIR	Williams Rd to Granville Ave	Existing	Primarily established single family and low-rise residential. Sturgeon Bank is west of the dike. The West Dike Trail is over the dike, with natural areas on either side. The northern third of the plan is the Quilchena Golf & Country Club, situated on Agricultural Land Reserve (ALR) lands. ESA type is Shoreline on the land side and Intertidal on the water side.
		Future	No major changes anticipated.
TERRA NOVA	Granville Ave to Terra Nova Rural Park	Existing	Situated entirely on ALR lands. Primarily open space, with few buildings. Includes Quilchena Golf & Country Club, Terra Nova Rural Park, and agricultural areas. Sturgeon Bank is west of the dike; includes the Grauer Lands, an enhanced habitat site. West Dike Trail continues north. ESA type is Shoreline on the land side and Intertidal on the water side.
		Future	No major changes anticipated.
THOMPSON TERRA NOVA	Terra Nova Rural Park to McCallan Road	Existing	Established residential neighbourhood of single family homes. River Road is substantially offset from the waterfront, with a wide open space from the road to the dike, which includes a trail. Typical park amenities are in the open space, including benches, sign posts and washroom facilities. ESA type is Shoreline on the land side and Intertidal on the water side.
		Future	No major changes anticipated.
THOMPSON DOVER	McCallan Road to No. 2 Rd Bridge	Existing	Half industrial, a City works yard and recycling depot. Half residential neighbourhood of townhouses and medium-density apartment complexes. Buildings are set back from River Road, and built on higher land than the road elevation. No driveway access from River Road to the condo complexes. ESA type is Shoreline on the land side and Intertidal on the water side.
		Future	No major changes anticipated.
OVAL	No. 2 Rd Bridge to Dinsmore Bridge	Existing	Mostly redeveloped in the past fifteen years, with the Olympic Oval, high-rise condos and offices. River Road is realigned behind waterfront development. A waterfront trail and recreational areas are along the waterfront, including intertidal zones and park amenities, such as benches. ESA type is Shoreline on the land side and Intertidal on the water side.
		Future	Development is currently underway for the remaining sites, and nearly complete. These areas are designated for mixed use in the OCP. Retail and other commercial uses will be at the main levels of new developments.
CITY CENTRE 1	Dinsmore Bridge to Cambie Rd	Existing	Low-rise office industrial lands and parking lots. Office sites have substantial footprints. River Road is adjacent to the waterfront. The UBC Boathouse and other marinas are on the water. Along the waterfront there is a thin linear park including a dike trail with park amenities and public art. ESA type is Shoreline on the land side and Intertidal on the water side.
		Future	The area from the waterfront to the former rail corridor is planned to be the proposed Middle Arm Park, a large park surrounded by high density mixed use and commercial uses of the planned Pedestrian-Oriented Retail Precincts. A museum and arts centre are proposed for this area.
CITY CENTRE 2	Cambie Rd to Moray Bridge	Existing	Low-rise office industrial lands and parking lots. Office sites have smaller footprints with narrow frontages on the water. River Road is adjacent to the waterfront, with parking lots along the dike. Marinas are present along this entire area. ESA type is Shoreline on the land side and Intertidal on the water side.
		Future	Intensification of the urban area with high density mixed use and commercial zones in planned Pedestrian-Oriented Retail Precincts. Expansion of marinas for residential and non-residential boats. The proposed Capstan Canada Line Station .

DESIGN AREA	BOUNDARIES		DESCRIPTION OF EXISTING AND FUTURE CONDITIONS PER OCP
DUCK ISLAND	Moray Bridge to Oak St Bridge	Existing	Former industrial lands, currently vacant lots that host the Richmond Night Market during the summer. River Rock Casino & Marina, and large parking lots. A constructed wetland between the parking lot and the marina. Smaller industrial sites west of the Oak Street Bridge. Disused CP Rail bridge. ESA type is Shoreline on the land side and Intertidal on the water side.
		Future	Parklands and marinas along the waterfront. Development of urban commercial and residential uses. A bridge for the Canada Line and a new Skytrain station. NOTE: Private developers are currently submitting development plans to the City for approval.
INDUSTRIAL	Oak St Bridge to No. 4 Rd	Existing	Industrial facilities and parking lots. Fraser River Terminal, BC Hydro power station. Canada Line and Bikeway bridge. River Drive in aligned inland. ESA type is Shoreline on the land side and Intertidal on the water side.
		Future	No major changes anticipated. Industrial lands for the foreseeable future. Residential uses are prohibited.
BRIDGEPORT TAIT	No. 4 Rd to Shell Rd	Existing	Formerly industrial, presently existing high-rise condos; approved condo and townhouses currently under development. River Road at the waterfront was decommissioned on this section. Small light industrial site remains. Single family residential south of the waterfront area. Log booms on the water. ESA type is Shoreline on the land side and Intertidal on the water side.
		Future	Ongoing redevelopment to be completed in the near future. No major changes anticipated once redevelopment is complete.
INDUSTRIAL NORTH EAST 1	Shell Rd to Bath Slough	Existing	Industrial area. Businesses and associated parking lots on the narrow strip of land between River Road and the waterfront. Log booms on the water. ESA type is Shoreline, Intertidal or Freshwater Wetland.
		Future	No major changes anticipated.
INDUSTRIAL NORTH EAST 2	Bath Slough to Knight St Bridge	Existing	Industrial area. Offices and parking lots. River Road is against the waterfront. Large trees and established vegetation on the waterfront area north of River Road. A small vacant lot under Port Metro Vancouver ownership is west of the Knight Street Bridge. Drainage ditches south of River Road. ESA type is Shoreline, Intertidal or Freshwater Wetland.
		Future	No major changes anticipated.
INDUSTRIAL NORTH EAST 3	Knight St Bridge to No. 6 Rd	Existing	Industrial area. Large lumber processing yard and waterfront log transport facilities. Large trees and established vegetation on the waterfront. Public access to River Road is blocked by gates however the City has a ROW. ESA type is Shoreline on the land side and Intertidal on the water side.
		Future	No major changes anticipated.

2.2 GEOTECHNICAL CONDITIONS

Thurber Engineering Ltd (Thurber) conducted a review of the Study Area to assess the anticipated geotechnical conditions. Based on their review, the anticipated subsurface conditions within the Study Area are primarily fill and silt overlying alluvial Fraser River deposits. The silt is clayey near the surface and becomes sandier with depth. This layer is generally about 2 to 4 m thick, although it ranges from about 1 m to 6 m thick. Below the silt, there is a zone that transitions from silt to sand at about 7 m depth. The sand layer below about 7 m depth becomes cleaner and coarser with depth and is typically 8 to 25 m thick. This sand layer is susceptible to seismically induced liquefaction. Below the sand there is a sequence of silt and sand layers. Underlying the silt and sand sequence, there is a thick deposit of silt, which is underlain by dense till-like soil at depths of 50 m or more. Geotechnical investigations and modelling may be required at the design stage of a dike adaptation project to establish site-specific subsurface conditions, and any associated geotechnical requirements.

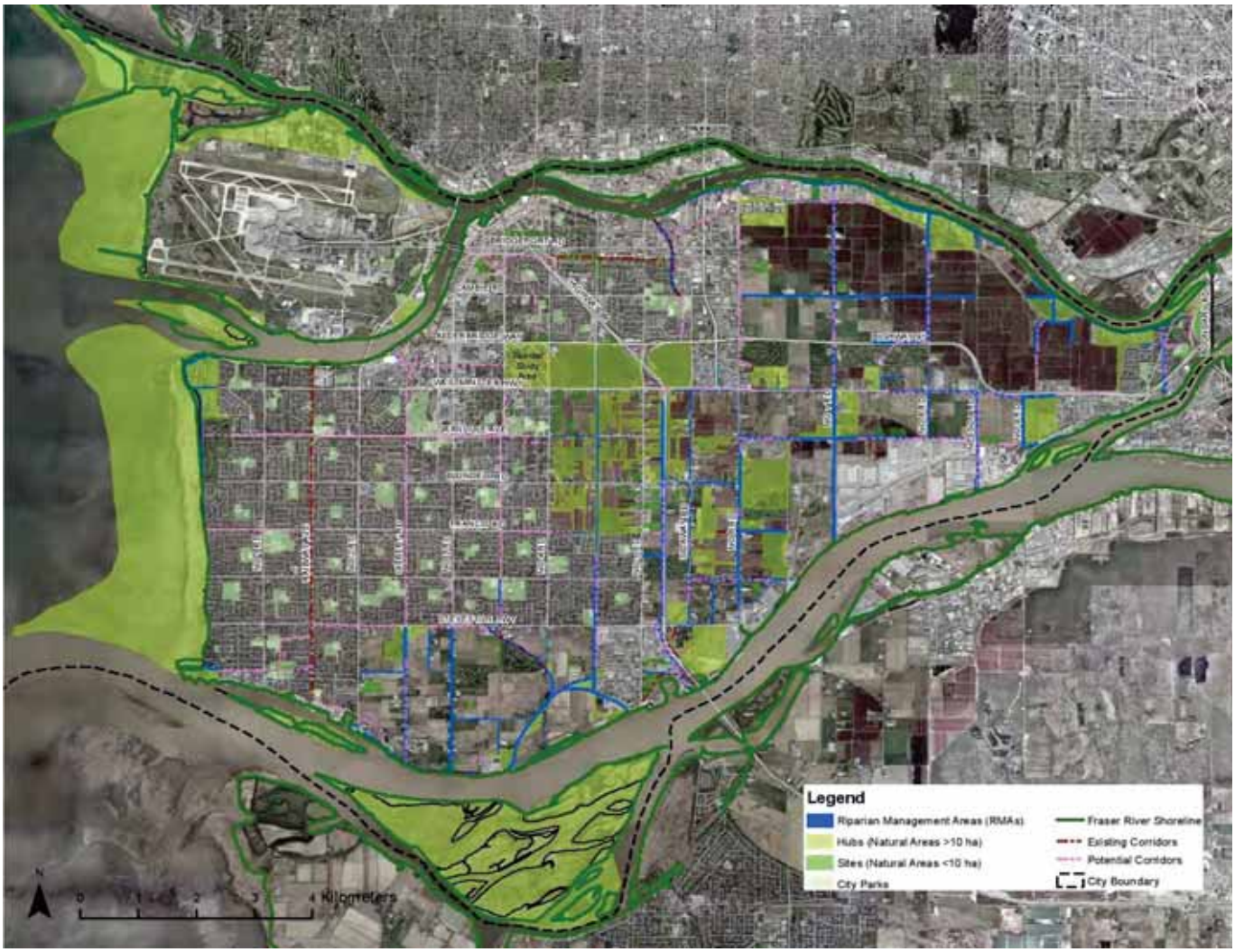
The report[5] prepared by Thurber in support of the Phase 2 LIDMP is included as ***Attachment 3*** for reference.

[5] Lulu Island Dike Master Plan - Phase 2: Geotechnical Input, Thurber Engineering Ltd., October 6, 2016

2.3 ENVIRONMENTAL CONDITIONS

Richmond is located at the mouth of the Fraser River, an urban and agricultural City juxtaposed within the high ecological values of the Fraser River Estuary. The City's Ecological Network Management Strategy (ENMS) provides context for the protection, enhancement and connectivity of an interconnected system of natural areas that make up Richmond's distinctive landscape. The ENMS recognizes the essential ecosystem services integral to the subtidal, intertidal and upland riparian areas within the Study Area, such as water storage and filtration, wave energy attenuation, temperature mitigation and prevention of soil erosion. Green infrastructure, which refers to components of the natural and built environment that provide ecosystem services, are also promoted within the ENMS. A map of Riparian Management Areas (RMA's) of Lulu Island is shown below in ***Figure 3*** and provided in full size in ***Appendix B***.

Figure 3: Riparian Management Areas (RMA's)



Ecological lands within the LIDMP Study Area include City parks, RMA's and ESA's designated in the OCP, as well as other ecologically valuable lands such as the provincially designated Sturgeon Bank WMA. The LIDMP Study Area includes six of the ten geographic strategy areas identified within the ENMS: Traditional Neighbourhoods, City Centre, West Dike, WMA's, Industrial Area and the Fraser River. The ENMS and associated Strategy Areas inform the LIDMP.

The ENMS encompasses all ecological lands in the City, regardless of tenure. Priorities to reduce the fragmentation of natural habitats is central to the ENMS principles. The LIDMP Study Area includes some of the City's highest ecological values within the Fraser River delta. An overview of the City and non-City designated ecological attributes within the Study

Area is provided below. Further detail is provided in the Envirowest Technical Brief[6] included as ***Attachment 4*** for reference. The following discussion presents environmental factors, regulations and guidance documents in place at the time of this writing. Any additional regulations that may be in place in future at the time that any diking project moves forward should also be reviewed and considered in the preparation of dike design and construction plans.

Riparian Management Areas (RMA's) and Channelized Watercourses

Richmond has interconnected drainage catchments that are delineated by the operation of pump stations that discharge into the Fraser River. The inland watercourses are slow moving and wetted the majority of the time. The high groundwater table that feeds local watercourses and sloughs contains naturally-occurring dissolved iron and other metals, and low levels of dissolved oxygen. These water quality conditions are generally inhospitable to salmon and trout; however, other species of fish, reptiles and amphibians may utilize the inland aquatic areas.

The City's watercourses flow into and contribute to fish and wildlife resources sustained by the Fraser River. As such the watercourses are designated fish habitat under the federal Fisheries Act, the provincial Water Sustainability Act, and the provincial Riparian Areas Protection Act. While the majority of these watercourses have been historically realigned into road grid to support agricultural development, they are identified by the City as channelized watercourses and not stormwater ditches. To support the form and function of these channelized watercourses, pre-designated riparian setbacks of 5 m and 15 m are designated by the City on minor and major watercourses, respectively. These setbacks, developed in consultation with the Department of Fisheries and Oceans (DFO), are identified by the City as Riparian Management Areas (RMA's) and protected from development. Channelized watercourses, and their associated RMA's, are interspersed on the landside of the West and North dikes within the LIDMP Study Area. Locations of RMA's are shown on the map included in ***Appendix B***.

Environmentally Sensitive Areas

The City has designated Environmentally Sensitive Areas (ESA's) throughout the City. As identified in Chapter 9 of the OCP, intertidal and shoreline ESA Development Permit (DP) areas are in place around the Lulu Island perimeter. The intertidal DP area is defined as 30 m out into the intertidal or subtidal area measured from the High Water Mark as defined in the Riparian Area Regulations. The shoreline DP area is defined as 30 m inland of the shoreline into upland riparian habitat. This ESA recognizes the estuarine values surrounding Lulu Island and provide direction for application of the DP through DP permit guidelines. Along the West Dike section of the Study Area, ESA DP areas contain upland riparian, brackish marsh, sandflats, mudflats, and open water habitat. Along the North Dike section of the Study Area, ESA DP areas contain pockets of mud flat, salt marsh, eelgrass and upland riparian habitat. This ESA recognizes the estuarine values surrounding Richmond and provides direction for application of the DP through DP permit guidelines. Along the West Dike section of the LIDMP Study Area, the ESA Development Permit Area contains upland riparian, brackish marsh, sandflats, mudflats, and open water habitat. Along the North Dike section of the LIDMP Study Area, the ESA Development Permit Area contains pockets of mud flats, salt marsh, eelgrass and upland riparian habitat. Locations of ESA's are shown on the map included in ***Appendix C***.

City Parks

The West Dyke Trail and Terra Nova Rural Park are both City park attributes contained within the Study Area. There is habitat functionality and ecological value comprised within these lands.

Bath Slough

The Study Area includes Bath Slough at the boundary between the Industrial North East 1 and Industrial North East 2 design areas. Bath Slough forms part of the historical watercourse complex that stretched across Lulu Island, and receives run-off from industrial and residential lands in the Bridgeport area. Through the 2014 Bath Slough Revitalization Initiative, the City has conducted a number of innovative ecological initiatives along Bath Slough including water quality improvements, riparian enhancements and native pollinator pasture initiatives. The Bath Slough Revitalization Initiative should be considered in the design and construction phase of proposed dike upgrade projects in this area.

[6] Lulu Island Dike Master Plan Phase 2: Technical Brief, Envirowest Consultants, November 2, 2016.

Ecological Network Management Strategy (ENMS) Strategy Areas

Both inland and foreshore ecological values are embedded within the six ENMS Strategy Areas. The ENMS and associated Strategy Areas provide key ecological context within the Study Area. ENMS Strategy Areas as shown on the map included in ***Appendix D***.

Wildlife Management Area (WMA) – Sturgeon Bank

Sturgeon Bank is a provincially designated Wildlife Management Area (WMA) established in 1998 and is located on the water side of the West Dike. It is protected for the conservation of critical, internationally-significant habitat for year-round bird migration and wintering waterfowl populations. It is also important fish habitat. It is comprised primarily of near shore and intertidal brackish marsh, sandflats, mudflats, and open water. The WMA foreshore marsh and mudflat habitats provide critical ecological values as well as ecosystem services for wave energy attenuation and shoreline erosion and stabilization. Consideration for these key climate change adaptation and resiliency attributes along Sturgeon Bank should be considered in the design and construction phase of proposed dike upgrade projects in this area.

Fraser River Estuary Management Program (FREMP) Mapping

Since the mid-1980's habitat productivity mapping has been undertaken along the Fraser River shoreline from the mouth of the Fraser River Delta upstream to the Pitt River/Maple Ridge area. This mapping was undertaken by the former Fraser River Estuary Management Program (FREMP). FREMP was a cooperative agreement amongst member agencies, including Environment Canada, Fisheries and Oceans Canada, Transport Canada, Fraser River Port Authority, North Fraser Port Authority, BC Ministry of Environment, and the Greater Vancouver Regional District. Though FREMP ceased to exist in 2013, the City continues to utilize this data resource to inform activities in and along the City's Fraser River foreshore. The FREMP classification system comprises a three tiered colour-coded system: habitats are colour-coded red, yellow or green. Red-coded shorelines sustain highly productive fish and wildlife habitats. Yellow-coded shorelines sustained moderately productive habitats, while green-coded shorelines were characterized by habitats of low productivity. Generally development constraints are greatest within red-coded habitats, while development within green-coded habitats are constrained the least. Habitat productivity within the LIDMP Study Area includes a majority of red-coded reaches along the West Dike and North Arm.

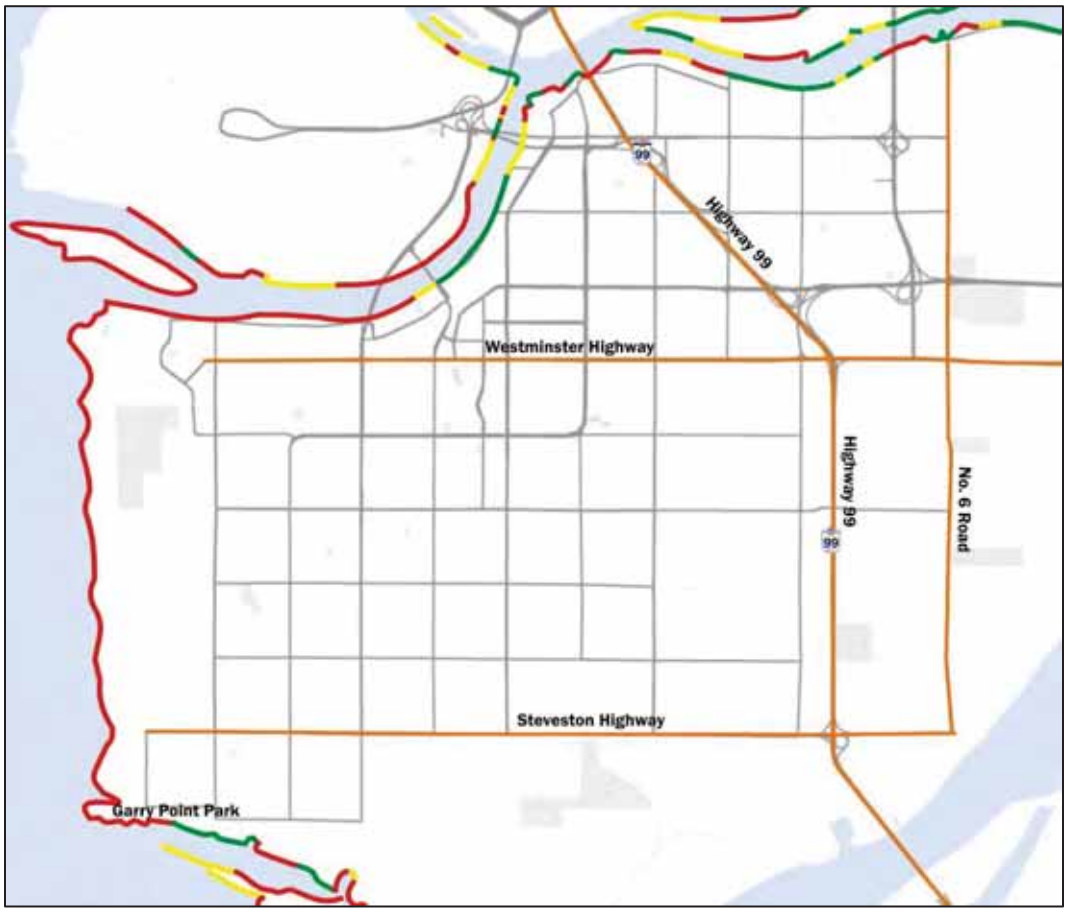
Detailed maps showing habitat coding throughout the Study Area are presented in ***Appendix E***. An overview of the foreshore habitat coding in the Study Area is shown in ***Figure 4***. High productivity habitat is depicted to extend along the north dike generally from No. 6 Road to the Knight Street bridge, along the Tait Waterfront Park, from No.4 Road to the Canada Line bridge, under the Oak Street Bridge, immediately west of the River Rock casino, south of the Canada Line YVR line, and west of Hollybridge Way to the Terra Nova Rural Park. Moderate and low productive habitat are interspersed along this shoreline between Hollybridge Way and Knight Street bridge. High productivity habitat is depicted to extend along the entire seaward edge of the west dike fronting Sturgeon Bank and Terra Nova Rural Park.

Fraser River Fish and Species at Risk Values

The Fraser River Estuary contains rich habitat for many species of fish and wildlife. Estuary marshes support a significant portion of the regions migrating salmon. While the inland watercourses are generally considered to not be hospitable to salmon and trout species, they do flow into and support fish life in the Fraser River and are therefore considered to be nutrient providing fish habitat.

A desktop review for species of management concern (i.e. included in Schedule 1 of the Federal Species at Risk Act, and Provincial Conservation Data Centre red- and blue-listed species) was undertaken on the Provincial Conservation Data Centre web map. The search provided a single result, specifically utilization of the Fraser River by white sturgeon. The search did not provide any results along the seaward extent of the west dike, or along inland channelized watercourses . The absence of search results does not indicate that species at risk or of management concern are absent, but that they have either not been observed and /or recorded within these areas. A detailed species at risk assessment will need to be undertaken at the time of design construction as the potential for listed species such as white sturgeon, Vancouver Island beggertick, streambank lupin etc. within the Study Area is high.

Figure 4: Foreshore Habitat Coding in the Study Area



2.4 EXISTING FLOOD PROTECTION INFRASTRUCTURE

At present, Lulu Island is protected from flood hazards by a perimenter ring dike consisting of the West Dike, the North Dike, and the South Dike. The Study Area comprises the waterfront and lands protected by the West Dike, and part of the North Dike from Terra Nova Rural Park to No. 6 Road. These dikes provide flood protection from storm surges and Fraser River freshet events. Generally the dike is a standard trapezoidal earth dike in most locations, with a trail or a road over the dike crest.

The existing dike crest elevations in the Study Area vary from 3.0 m to 4.7 m depending on when the dike was last upgraded, or when surrounding lands were last redeveloped. Drainage ditches and storm sewers behind the dikes convey storm flows and flood waters to pump stations discharging to the Fraser River and the Georgia Strait. Public dikes and all drainage infrastructure are now owned solely by the City of Richmond.

The West Dike protects the City from high tides and storm surges originating in the Strait of Georgia. Sturgeon Bank, a mudflat and marshland, extends up to 6 km into the Strait of Georgia from the toe of the dike. These lands consist of a relatively flat face with grass cover next to the dike, then marsh and mudflats further out towards the sea. Sturgeon Bank currently provides some protection from wave run-up to the West Dike.

The North Dike protects the City from high tides and storm surge impacts originating in the Strait of Georgia and migrating up the North and Middle Arms of the Fraser River. To a lesser extent, these dikes protect from high Fraser River freshet events. Generally the North Dike is bounded by the Fraser River foreshore and River Road. Through the City Center OCP Area, the dike is primarily a linear park on the waterfront bounded on the land side by River Road or development. Waterfront developments that have been constructed in the past ten years have often elected to raise their lands to the

dike crest elevation, forming a superdike. A superdike is formed whenever the lands behind the dike are filled to the same elevation as the dike crest, and development is built on a ground elevation equal to the dike crest. Superdikes are discussed in greater detail in ***Section 4.1.2***. Through the industrial areas north of the City Center, the dike remains generally earthfill with sections of sheet pile and floodwalls associated with specific sites.

2.5 EXISTING FLOOD PROTECTION POLICY

The City of Richmond has two primary policies in place that guide flood protection initiatives. The OCP establishes flood protection as a priority in the context of land use planning. Flood proofing objectives are enforced through Bylaw No. 8204.

At present, the OCP states that ESA's serve the dual purpose of planning for environmental and flood protection needs. Flood protection has been established as a priority alongside environmental priorities within the OCP, especially in areas that are designated ESA's. This includes the entire waterfront of the Study Area. The OCP also establishes a priority for a green infrastructure network throughout the City's ecological network, including the intertidal, shoreline and upland riparian areas. A green infrastructure network integrates the built and natural environment to realize associated ecosystem services such as flood mitigation, and stormwater management.

The City currently enforces flood proofing through the Flood Plain Designation and Protection Bylaw No. 8204, established in 2008 to set minimum Flood Construction Levels (FCL's) throughout the City. The FCL prescribes the minimum elevation where the underside of a floor system can be constructed. The By-law also provides for diking needs such as ROWs by specifying that lands at a certain distance from the dike or waterfront must be dedicated to dike works.

Proposed developments at the waterfront must commit to implementing flood protection measures in order to secure approval for development plans. These are typically negotiated with the City on a site-by-site basis. In recent years, residential developers have voluntarily raised the elevation of development lands to the same elevation as the dike crest (creating a superdike) to ensure that the units on the ground floor will have a view of the water.

3 Considerations

The considerations in this section were used to evaluate potential flood protection adaptations to make the recommendations that comprise the Phase 2 LIDMP. Any flood protection adaptation, whether in compliance with or deviating from the Phase 2 LIDMP, should use the following considerations in evaluating the suitability of a proposed flood protection project for implementation. It is important that any proposed project avoid or mitigate negative impacts, while maximizing the benefits, as a balance of the following considerations. In the event that a dike adaptation project differs from the recommended adaptation for that design area, the project should still take these considerations into account. These considerations outline important factors that should be incorporated into the implementation plans for both structural adaptations that will alter the existing landscape, or policy adaptations that have indirect impacts on the landscape.

3.1 FLOOD PROTECTION CONSIDERATIONS

The City has established a design crest elevation of 4.7 m with consideration to be further raised to 5.5 m in response to climate change and sea level rise predictions. These design crest elevations have been adopted by the City in response to a combination of sea level rise predictions (1.0 m) and land subsidence (0.2 m)[7], anticipated to materialize by the year 2100.

Increases in dike crest levels (up to 4.7 or future 5.5 m) to address sea level rise and climate change are anticipated to be staged and implemented over the next few decades to respond to rising sea levels. The City will continue to monitor sea level rise and adjust the target dike crest elevations as required. Any flood protection project in the Study Area should, at

[7] Sea Level Rise Adaptation Primer, Arlington Group et. al, January 2013

a minimum, adhere to these elevations. Additional regional guidelines should also be considered at the design stage of dike improvements.

Adaptations should be compatible with existing dikes and other flood protection measures adjoining the site of proposed works. Connections to existing flood protection works should be designed to ensure there will not be inconsistencies or weak points where an adaptation meets a pre-existing dike.

3.2 ENVIRONMENTAL CONSIDERATIONS

The Study Area is situation along the Georgia Strait and the Fraser River, two important fish and wildlife habitats. There are also riparian areas and intertidal zones that have ecological value. Any diking projects should be well-integrated with the surrounding natural realm, and should be designed to mitigate alterations that compromise the local environment, either aesthetically or ecologically. The Study Area includes substantial open space and parklands, including wetlands and natural areas on the waterfront. The City has an interest in preserving the environment at the waterfront for public uses, in particular the dike trail for cyclists and pedestrians. The aesthetic value of the natural environment along the trails should be considered as well as ecological significance.

The breadth of ecological values comprised within the study area is reflective of estuary habitats as described in ***Section 2.3***. The perimeter ring dike in the Study Area is flanked by either ripariam or upland ESA habitat to the landside, and high value shoreline & intertidal ESA or WMA habitats on the foreshore. Any proposed dike design and construction projects should undertake an assessment of the adjacent ecological values to determine the most appropriate dike design and footprint using an approach to avoid alterations in high value habitats, and if that is not feasible, then mitigate or compensate with a net gain approach. The Study Area is comprised of large tracts of open space and park lands that contribute significant aesthetic values within the estuary which must be considered in concert with the ecological values.

An overview of the federal and provincial regulatory context is provided above in ***Section 2.3***. Detrimental impacts to the environment are to be avoided wherever possible, in accordance with the City's environmental regulations. In addition, sea level rise should be monitored and reviewed in order to determine the impact on existing foreshore wetlands within the Study Area. Additional guidance documents outlining the City's environmental protection and enhancement strategies are listed in ***Section 1.3***. Any flood protection project should be prepared by qualified persons having reviewed and understood these documents, as well as any environmental guidance documents or regulations in effect at the time a project is proposed. The design of proposed diking projects should follow the City's approach regarding the priority to avoid habitat impact first. Where that is not feasible, enhancement and mitigation may be pursued with a net gain approach.

3.3 GEOTECHNICAL CONSIDERATIONS

Geotechnical design considerations for dike adaptations include seepage control both under and through the dike, dike slope stability, dike crest settlement, and seismic performance. Furthermore, additional loading from increased dike size over any existing structures, such as building footings or bridge abutments, will need to be verified for confirmation that existing infrastructure will not be negatively impacted. Other types of structural flood protection measures will also need to be verified for impacts to existing infrastructure.

Thurber has reviewed the existing geotechnical conditions in the Study Area. Their comments on the key design considerations are outlined on the following pages.

Seepage

Seepage risk should be assessed and mitigated for any dike adaptation project, whether for dikes or floodwall systems. Seepage becomes problematic where water flow through or under the dike dislocate the fill materials forming the dike, which may weaken the integrity of the dike and increase the risk of failure during high water events. Adaptations should be designed with proper drainage to mitigate seepage risks.

Increasing the height of an existing dike to 4.7 m or 5.5 m may increase the design flood height, defined as the height from the ground at the land side toe of the dike to the height of water against the dike during a high water event. Existing dikes

are between 3.0 m and 4.7 m, and the ground elevation on the landside of the dikes is generally at about 2.0 m. Raising an existing dike may also increase the flood height, unless the lands adjacent to the dike are also raised in conjunction with crest height increases, forming a superdike. Increasing the flood height may increase risks of landside heave of the less permeable surficial silt layer, and piping through the dike or its foundation.

Piping occurs when excessive seepage forces cause the migration of soil particles through the soil matrix resulting in internal erosion and eventually retrogressive failure. Heave can occur when there are excessive hydraulic pressures on the landside of the dike caused by a lower permeability soil layer forming a cap over a more permeable layer near the ground surface. Heave can lift and fracture the cap, causing large localised seepage volumes and internal erosion, which could cause a dike breach.

To provide reliable protection from higher design flood heights, a system of seepage control measures will likely be required for any dike adaptation project. The potential for heave and piping may be mitigated using relief wells, drainage blankets or trenches to drain water from behind the dike face to an outlet such as a sewer or ditch. The receiving system's capacity should be verified to ensure drainage can be accommodated in the system. Relief wells and trenches should be designed with filters, such as a geotextile, to prevent piping and internal erosion. Seepage exits should be similarly protected with filters to minimize risk of fill materials migrating out of the dike.

Where there are ditches at the toe of an existing dike, filling the ditches may be considered within the scope of a proposed dike adaptation project. Ditches at the toe of a dike increase the risk of piping, since these ditches shorten the seepage path length and increase the hydraulic gradient. Filling the ditches may contribute to a comprehensive plan to reduce the risk of seepage.

Seepage potential should be evaluated and mitigated for any structural adaptation, as seepage may cause build-up of pressures behind the structure that may increases risks of failure. Constrained dikes, designed with a retaining wall on one or both sides, may be less susceptible to seepage risk if the dike face is a uniform material, such as a concrete cut-off wall or a floodwall. A dike face constructed with a segmental wall system, such as lock blocks or armour stone, may need to have the joints between segments grouted to prevent seepage at the joints.

Stability

Any dike adaptation project should be designed and constructed to withstand pressures and forces it may be subjected to during a high water event. For dike adaptations, high quality dike fill materials should be used and placed in accordance with accepted engineering practice to maximize stability. The standard dike section is anticipated to be generally stable with increased flood heights, although it will be less stable than the lower height configuration. In areas where stability is a concern, minor modifications to the standard dike section may be required, such as flattening the landside slope, constructing a toe berm or providing a seepage cut-off and filter within the dike. The stability of dikes may be further improved where ditches at the landside toe are infilled.

Settlement

Any dike adaptation project should be designed and constructed with consideration for settlement. Designs that minimize settlement are preferred, though some measure of settlement is anticipated in the long-term in all cases.

Raising existing dikes may induce consolidation settlement of the surficial silt layers. This settlement could be up to about 5% of the increase of the thickness of new dike fill placed. Dikes and surrounding areas may also experience compression settlement due to on-going long-term compression of deeper silt layers. This ongoing settlement is typically in the range of 1 to 2 mm per year for dikes built on soil conditions in Richmond. Settlement could potentially be compensated for by overbuilding the dike to a higher initial crest elevation, anticipating that it will settle to the target dike crest.

Local soil properties should be investigated prior to finalizing the design of any adaptations. Where construction is over peat or highly organic soils, settlement may be higher.

Seismic Performance

The Provincial Seismic Design Guidelines for Dikes[8] (Seismic Guidelines) published in June 2014 recommends designing high consequence dikes to control seismic deformations within prescribed limits. For a trapezoidal dike to achieve the objectives of the Seismic Guidelines, ground improvement may be required. Ground improvement reduces seismic vulnerability by densifying the foundation of the dike. Compaction of the ground underlying the dike may achieve the targets in the Seismic Guidelines. However, more intensive methods such as deep soil mixing or vibro-replacement to a specified depth may be pursued if compaction alone is found to be insufficient. These ground improvements may be very costly. Dikes that are set back from the waterfront are more resistant to seismic events due to being restrained by earth at both dike toes, as compared to a waterfront dike where the waterside toe is much deeper and may provide less force anchoring the dike in place. Therefore, setback dikes require less intensive methods to meet the Seismic Guidelines. Likewise, widening the dike crest to create a superdike increases resilience to seismic events without typically requiring ground improvements. Superdikes are discussed in greater detail in ***Section 4.1.2***.

To further understand the potential seismic risks to dikes within the Study Area, Thurber conducted seismic deformation analyses at three select locations (No. 1 Road Pump Station, No. 4 Road Pump Station, and Bath Slough Pump Station). Results are included in their Seismic Deformation Analysis report[9] included in ***Attachment 5***. Results from the assessment identified that at the three sites selected, horizontal deformations were within the allowances prescribed for the 1:2,475 year event by the Seismic Guidelines. Vertical deformations exceeded the tolerances; however, overbuilding the dike to provide post-earthquakle freeboard may be an acceptable alternate to meet the Seismic Guidelines instead of costly ground improvements. The results are largely depended on the underlying soil conditions, slope of the riverbank, and depth of the river bottom. Larger deformations could be expected where the river channel is deeper and steeper. The results discussed in the Seismic Deformation Analysis pertain only to the three sections analyzed; these are generally representative of Lulu Island however the results cannot be assumed to be consistent for any other locations. At the design stage of a proposed dike adaptation project, a site-specific seismic deformation analysis should be conducted to confirm seismic risks, and possible mitigation requirements. A seismic deformation analysis, for example a Plaxis model, may inform whether ground improvements may be required, and what level of ground improvements may be required to meet the Seismic Guidelines.

3.4 INFRASTRUCTURE CONSIDERATIONS

It is advantageous to pursue dike works alongside other infrastructure upgrades in the vicinity of the dike. Where infrastructure works are proposed on the waterfront, local diking needs should be evaluated and included in the scope of proposed work wherever possible. For example, when a road is being raised or resurfaced, the adjacent dike could be upgraded concurrently. Including dike adaptations within the scope of other municipal works may also present a cost savings as compared to pursuing projects independently. The resulting dikes may also be better integrated with the local landscape if they proceed concurrently with neighbouring infrastructure upgrades.

Any impacts to local stormwater drainage patterns should be evaluated to ensure compatibility with the local infrastructure, such as pump stations or roads. Where adaptations will interfere with existing drainage patterns, the capacity of the receiving pump station must be confirmed. If ditches at the toe of the dike are to be filled, the associated loss of stormwater storage and conveyance functions may need to be compensated with underground pipes or alternative systems.

Above ground utilities may be impacted by diking projects. Utility poles may need to be temporarily relocated while dike works are underway, and relocated to a permanent position when works are complete. There may be an opportunity to relocate cables underground when dike works proceed, particularly if roadworks are included. The dike trail and associate park infrastructure, such as park benches and lookouts, may need to be relocated to accommodate dike adaptations.

[8] Seismic Design Guidelines for Dikes, 2nd ed., Golder, Ministry of Forests Lands and Natural Resources (MFLNRO) Flood Safety Section, Jun 2014
[9] Lulu Island Dike Master Plan - Phase 2: Seismic Deformation Analysis, Thurber Engineering Ltd., Sep 12, 2016

3.5 SITES WITH UNIQUE CONSTRAINTS

There may be sites with unique features that must be accommodated when adaptations proceed. Dike adaptations may be realigned to avoid special sites, however this may not always be feasible. Where development and infrastructure exists along the waterfront where a dike adaptation project would ideally proceed, a custom design to accommodate that site may be required. Examples include pump stations, bridges, or industrial sites located immediately on the water. There are a number of bridges in the Study Area. Adaptations at bridge sites are discussed further under ***Section 4.3***.

The adjoining adaptations on either side of the special site should be well-integrated with that site's custom adaptation design, to ensure there are no vulnerabilities in the flood protection strategy at the boundaries between adaptation types. For example, a section of floodwall within a dike should be protected at the joints to ensure the joints are as robust as both the dike and floodwall. The joints should be as capable of withstandard high water levels as the adaptations on either side.

3.6 SOCIAL CONSIDERATIONS

Dike adaptations should be designed with consideration of the public realm. The City's 2009 Waterfront Strategy presents a vision that promotes community wellness, economic vitality and a healthy environment through initiatives that integrate the waterfront with the urban landscape. The Study Area contains recreation, culture and heritage resources to be preserved wherever feasible, according to the regulatory protections in place for heritage resources. Recreational uses may include walking and cycling on the trail, as well as offshore activities such as sport fishing and boating.

Heritage sites may be treated as sites with unique constraints, as described in ***Section 3.5***, that require special accommodations within a diking project. Heritage sites that have been identified as culturally significant should be preserved per the Heritage Procedures Bylaw 8400 as applicable.

Any impacts that restrict use and enjoyment of the waterfront, as well as views of the waterfront, should be mitigated. Impacts on cultural and heritage resources limiting the accessibility of these sites should be mitigated. Sites should remain accessible to all people including those using mobility aids, such as wheelchairs or crutches.

Public access to the waterfront is provided by the perimeter dike trail system. Where waterfront access is constrained, the City's Parks Planning and Design (Parks) department has identified connectivity at the waterfront as preferable to inland trail detours. For example, where the existing dike trail alignment crosses under low bridges, raising the dike may not provide adequate clearance to maintain the trail over the dike. The preference is to keep the trail at the waterfront. A boardwalk at the waterside toe of the dike would be a preferred approach as opposed to directing pedestrians up to the road to circumvent a barrier.

Adaptations should be aesthetically integrated with the surrounding area. For example, in recreational areas or ecological landscapes, adaptations that do not detract from the natural beauty of the local environment are preferable to those adaptations requiring severe hardscaping, such as concrete or retaining walls. The local character of industrial areas is amenable to man-made structures thus floodwalls may be in keeping with the landscape themes in industrial areas.

Adaptations should support, and be integrated with, the habitat functionality and aesthetics of the surrounding environment.

3.7 PROPERTY CONSIDERATIONS

The City must have permanent access to the dike adaptations in the long-term, for both construction and ongoing maintenance operations. Acquiring property may add considerable costs to a diking project. Wherever feasible, adaptations should proceed within the lands that are already under City ownership, or that the City may access through easements or right-of-ways (ROW's).

Much of the City's waterfront was developed prior to the establishment of robust policies for dedicating lands to diking. As a result, older buildings remain directly on the waterfront, or within 30 m from the natural boundary. In cases where no alternative alignment can be implemented, it may be necessary for the City to acquire waterfront lands or obtain easements or ROWs to construct or maintain adaptations.

3.8 ECONOMIC CONSIDERATIONS

For the purposes of the Phase 2 LIDMP, economic considerations encompass impacts to local businesses operating in the vicinity of existing or proposed dikes. The cost of adaptation projects is also an economic consideration, however for the purposes of the Phase 2 LIDMP these will be referred to as "cost considerations," discussed further under ***Section 3.10***.

Flood protection projects provide an overall economic good by preventing damage to assets. However, any changes to existing conditions may trigger negative impacts to the local economy. For example, diking may damage views to the waterfront, or challenge industrial activities by limiting water access.

Where economic impacts cannot be completely avoided, they should be mitigated to the extent feasible. Dike adaptations should consider local economic factors in the overall decision making context.

Lands that were formerly used for economic purposes, such as waterfront shipping facilities, but are no longer being used for economic activities may be suitable lands for dike adaptations. If alternative lands are available that do not have any associated economic uses, those lands should be used rather than compromising lands of economic interest.

3.9 OPERATIONAL CONSIDERATIONS

Dikes in the Study Area provide access to City assets that must be maintained, such as drainage ditches and trails. Adequate clearance must be retained for maintenance vehicles to navigate the dikes where required, and carry out maintenance activities. For example, if a dike is raised in an area where there are drainage ditches at the dike toe, the boom of an excavator on the dike must be able to reach the ditches for cleaning and maintenance.

Raising a dike may complicate access as the slopes must remain suitable for maintenance and emergency access. Additional lands may be required to improve access to the dike.

3.10 COST CONSIDERATIONS

The overall cost of implementing adaptations is driven by a number of factors that include habitat consideration, land acquisition and ground improvements. When evaluating the cost of an adaptation, the costs of all associated works and mitigation plans should be included. A project with relatively higher construction costs may still be the least expensive option if it does not require any habitat compensation, for example.

3.11 STAKEHOLDER FEEDBACK

The diking solutions were presented to key stakholders and the general public. The public and key stakeholder groups were pleased with the City's proactive approach to addressing climate change and sea level rise in the community. Comments with the West Dike and North Dike (from Terra Nova to No. 6 Road) related to the height in which the dikes would be raised, possible increased dredging needs, and the disruption it may cause to the environment, wildlife and their habitats were raised.

Two public open houses were held to present the flood protection concepts for the Phase 2 area. The first session was held at City Hall on April 20th, 2017 and the second session was held at the City Centre Community Centre on June 21st, 2017. All materials provided at the Open Houses were made available on the City's community engagement website address, Letstalkrichmond.ca. There were 532 individuals that viewed the project on this website, 68 of which provided feedback.

A summary of the open house and website feedback is presented in ***Table 2***.

Table 2 – Public Consultation Feedback

TOPIC	SUMMARY OF COMMENTS
Dike Raising / Construction Time	Most of the comments expressed that the dikes are not being raised high enough. Some additional comments noted that the timeline for raising the dikes may also be too slow. The majority of the commentary referenced media and scientific reports that suggest the rate and amount of sea level rise could be more accelerated and higher than previously estimated.
Dike Esthetics / Recreational use	There was a strong desire to maintain walkways and recreational access on and along the dikes, with some individuals preferring not to have a paved path to maintain a more natural aesthetic in and around key wildlife areas and others preferring a paved path to increase convenient access for pedestrians and cyclists.
Seismic	Some individuals raised the issue of seismic stability and the desire to have an increased level of safety in the event of an earthquake or tsunami.
Superdikes	Individuals who commented on superdikes were generally in support of this option.
Development	Comments were received from several residents that the flood control level for new developments should be raised for further protection. One resident expressed concern about the raising the flood control levels for new developments could also be detrimental to the character of the neighbourhoods.
Flood Protection	Concerns were raised about what additional flood protection measures are in place in the event of the dike breach, such as increased pump station capacity to reduce flooding. One resident also suggested installing new data recording instruments to monitor flood levels and settlement of the dikes more regularly.
The Environment	Two residents commented that the City should consider all of the environmental impacts of the dike and flood protection upgrades, emphasizing that preservation of the natural environment be considered during all phases of the dike master planning and upgrades.
Barrier Island	Several residents commented on their interest in a barrier island, but wanted more information on the cost of these features and if they might impact the water quality or natural ocean processes.
Property Value	One resident expressed that the dike upgrades would help keep property values high.
Funding	Several residents questioned what the cost of the dike upgrades would be for taxpayers and where there were opportunities for residential developers to pay for upgrades.
General	Several comments were received that indicated a desire for more information on the key solutions being considered as well as access to the consultation and feedback from environmental agencies.

In addition to the two public open houses, all materials were provided to key stakeholders. The City also hosted a number of individual key stakeholder meetings to solicit feedback. Comments received in the meetings and through email correspondence are summarized in Table 3.

Table 3 – Other Key Stakeholder Feedback

STAKEHOLDER	SUMMARY OF COMMENTS
Provincial Inspector of Dikes	The Deputy Inspector of Dikes did not foresee any major issues in moving forward with the master plan, but noted that additional discussion and correspondence would be required where alternative strategies that deviate from the existing flood protection (e.g. superdikes) are proposed.
City of Richmond Advisory Committee for the Environment	The Advisory Committee for the Environment (ACE) did not have any comments after the City presented the Phase 2 LIDMP to them in April 2017.
Urban Development Institute	The Urban Development Institute (UDI) noted that the Phase 2 LIDMP will mutually benefit the City of Richmond and UDI as the flood protection solutions will increase the livability and value of development within the City. UDI has acknowledged support of the presented flood protection strategies with the awareness that there could be increased costs incurred by the development industry.
Port of Metro Vancouver	Port Metro Vancouver (PMV) had the following comments: • The Vancouver Fraser Port Authority (VFPA) does not have any infrastructure in the area and the report recommendations do not affect the two Port Sites within the study areas. • The report refers to secondary dikes that work in conjuction with primary dikes. Has consideration been given to extending the secondary sike concept to inlands (perhaps through improving performance/raising elevations of existing roads) to provide redundancy and limit extent of area being flooded in the event a section of dyke is breached?
City of Richmond Heritage Commission	The Heritage Commission supports the “Dike Master Plan – Phase 2” initiative and recommends that staff/Council take into account the cultural and historical aspect of the diking system as imporvements are designed and implemented.
Department of Fisheries and Oceans – Small Craft Harbours Branch (SCH)	The Small Craft Harbours (SCH) Branch of the Department of Fisheries and Oceans provided the following comments: • The longer the distance incoming storm waves travel over shallow tidal flats the less vulnerability and the need for dike wave run-up freeboard and armouring. The concept is to provide replacement for lost sediment nourishment to and allow natural wave action to distribute the sediment pile gradually over the flats over time (as used to be the case prior to manmade deflection and interception of river supplied Sturgeon Bank sediment accretion). This would go hand in hand with investigating the details of the more intrusive and expensive approach of constructing offshore barrier islands as mentioned in the report. • The offshore berms could be a challenging geotechnical and coastal design with considerable expense and risk. • A side observation is the likely contributing effects of dredging of the legacy Fisherman' slough harbour cut into the southern area of the flats. This probably confounds the above situation in that it provides a sediment "sink" for any mobile sediments that fined their way into the harbour "hole" which is then removed from time to time by dredging and removed from the system by disposal at sea. Either the slough harbour should be isolated in such a way so as not to be a sediment sink or it should be eliminated. In any situation, material removed from the slough belongs on the tidal flats and not removed and dumped in deep water. • Considering the above, there are a couple of primary observations that map directly to the Phase 2 report. Firstly, making it clear that the erosional loss of elevation and width of the tidal flats of Sturgeon Bank due to a century of indiscriminate messing about with the natural sediment regimes needs to be highlighted. It is inferred in the report but does not stand out. This is the core of the seaward vulnerabilities both present and future with SLR. I am aware for instance that Golder has produced a DRAFT (2015) report on the erosion of Point Grey which has similar issues regarding loss of sediment supply and erosion of tidal flats and perhaps should be appended to the Sturgeon Bank Report. • The proposals for the barrier islands are a conceptual means to address the problems of protecting the dikes from increased wave attack and a "squeeze" on the upper shore, including wave run up on dikes. This squeeze will be aggravated by SLR as the deeper water allows for both larger storm waves penetrating to the dike as well as increased erosion of the highly mobile tidal flat due to both the intensity of wave induced particle movements, increased transport by tide induced flows and the net amount of time of these conditions occurs. To aggravate the situation, storm waves will be partially reflecting from a rock armoured dike. Tidal flood and ebb and storm setup currents behind and around the barrier islands would be likely to cause gullying of the fine tidal flat sediments. Anything that puts sediment back to accrete and be wave sorted naturally and gently on the tidal flats and upper marsh zones, whether deflected from the river freshens or enhanced artificially with placement (i.e. dredgeate) should have net positive outcomes provided the material is "clean" biologically speaking, and is representative in the mix of sand and silt particle sizes of what had been deposited naturally in the past. • We would have reservations about the more intrusive barrier island concept. It is complicated and it would lead to significant wave concentration at the hardened boundaries of the armoured islands. They would also create concentrated tidal flow and wave induced currents. The fine particle size silty sands of the outer flats would be extremely sensitive to those flows and also to compression and settlement under the weight and cyclical tidal buoyancy fluxes of

STAKEHOLDER	SUMMARY OF COMMENTS
	the placed islands. Being well out into the deep water, exposed to higher wave regimes, the islands would need to be Rock armoured and constructed to very rigorous standards to stay put. Indeed they would have to be constructed very expensively as rock breakwaters. As such, they would also load the delta slopes and under earthquake shakes would likely increased the risk of major deltaic slumps or slides into deep water. The SCH Branch provided the following conculsions: • A serious study of the history, evolution and current status of the flats including updated data on the hydrographic changes, the sediment size characteristics today and yesterday, the baseline sediment chemical conditions (I.e. Pah's) and of course the biological values both current and historic with the trends indicated. • A serious pilot program to place clean Fraser River silty sands into the tidal flats regime, probably as before, placed in one corner and allowed to spread by wave action over time. This would be monitored for effects and quality, and then linked to the potential for being part of a larger long term sediment management plan, encompassing Sturgeon Bank flats, and both Cannery Channel and the Ports shipping channel. The SCH Branch provided the following additional comments on the report document: *Executive Summary* • "For example, barrier islands that reduce wave run-up to eliminate the need for additional target crest increases,"... SCH Comment: And/or barrier islands in concert with restoring intertidal sediment supply and elevations as part of overall sediment management plan including redirection of dredgeate and in river sediment bypassing. • FCL should be incorporated in planning for small craft harbours harbour buildings and infrastructure as well as potential increased use of floating structures for enhanced adaptation long term. • SCH Comment: Restoring sediment input to intertidal areas may be an environmental net gain if done in an integrated manner. *Additional Guidance Documents* • With respect to the Phase 2 LIDMP reference to the existing Floodplain Designation and Protection By-Law 8204, it should be linked with overall Fraser River sediment management plan. Past practices and jurisdictional stovepipes have increased flood risk to West Dike area due to reductions of previous natural rates of sediment accretion and intertidal elevation. • The 2015 Ecological Network Management Strategy items are a potential fit with in river sediment bypass as well as sediment nourishment to sturgeon bank tidal flats. *Environmental Conditions* • What has been and will be the impacts to the environmental sensitive areas due to the combination of lowered intertidal elevations combined with SLR and what might be done to reverse impacts over time? • High productivity habitat is depicted to extend along the entire sea-ward edge of the west dike fronting Sturgeon Bank and Terra Nova Rural Park, but could be negatively impacted if tidal flat elevations do not keep pace with SLR armouring of west dikes would aggravate erosion of tidal flats. • There is an overall lack of comprehensive data on the species risk within the study area. This should be a top priority. *Flood Risk Management Adaptations* • Small craft harbours could continue science examination of nourishment to intertidal areas as part of overall sediment management plan. • With respect to breakwaters and barrier islands, there is an opportunity for SCH to provide resources and guidance in the planning process. • With respect to enhancement of intertidal habitat, the City could restore wide flat and elevated tidal flats uniformly with or without barrier islands. • With respect to barrier islands, raised islands may be more problematic than simply restoring sediment nourishment to raise overall tidal flats. • There is an overall lack of comprehensive data on the species risk within the study area. This should be a top priority. • With respect to slough dredging, any repeated dredging of the slough may be contributing to impacts on tidal flats especially if mandated to be disposed out of the sturgeon bank sediment regime by ocean disposal regulations. • With respect to discussion of breakwaters, expand to encompass raising of tidal flats with restored sediment supply.

4 Flood Risk Management Adaptations

Flood Risk Management adaptations have been categorized as either area wide or area specific.

Ultimately the City's goal is to fortify the perimeter ring dike to a design crest elevation of 4.7 m, with consideration to be further raised to 5.5 m in response to climate change and sea level rise predictions. Area wide adaptations are those that facilitate the City's flood protection objectives in tandem with the dikes or alternative protection measures in place at the waterfront. These could be policy adaptations, structural measures, or enhancement of green infrastructure to secure additional benefits to an adaptation that will achieve the 4.7 m crest elevation. Area wide adaptations may not be sufficient to meet the City's target dike crest elevation if implemented in isolation, however they may facilitate achieving the City's flood protection goals. For example, revising City policies to include specific diking requirements would be an area wide adaptation, as this is applicable across the entire Study Area, however, on its own, a revision to City policy would not achieve the target dike crest elevation. Area wide adaptations encompass strategies to facilitate implementing flood protection projects, and seizing opportunities presented by waterfront development to implement flood protection works concurrently. Area wide adaptations are defined and described in further detail in ***Section 4.1***.

Area specific adaptations are recommended for each of the thirteen specified design areas. These include all dike and floodwall adaptations that may achieve the 4.7 m design crest, and may be further raised to 5.5 m in future when required. As noted in ***Section 2***, the design areas have been delineated using the City's Official Community Plan (OCP) boundaries as identified in the OCP Areas, OCP Land Use Maps and OCP Sub-Area Plans. OCP Areas have been subdivided where similar waterfront conditions exist for a clearly defined part of an area. Area specific adaptations are defined and described in further detail in ***Section 4.2***.

Recommendations from both area wide and area specific categories have been made to create a comprehensive flood protection strategy for the Study Area. A summary of the recommended Flood Risk Management Stragies that apply to either specific design areas, or all of the Study Area is provided in ***Table 4***. The contexts for the recommended application of each adaptation are detailed in ***Section 4.1*** and ***Section 4.2***.

Table 4: Recommended Flood Risk Management Strategies

AREA SPECIFIC				AREA WIDE				
DIKES		FLOODWALLS						
Widen Footprint to Land or Water Side	Raise in Place / Constrained Dike	Permanent	Demountable	Superdikes	Flood Proofing	Planning and Development Controls	Breakwaters and Barrier Islands	Secondary Dikes

Note that other adaptations were reviewed and evaluated for implementation in the Study Area, though only the recommended adaptations are presented in the Phase 2 LIDMP. Adaptations that were eliminated at the evaluation phase include coastal wetlands, emergency preparedness and response, and managed retreated.

Coastal Wetlands: Coastal wetlands, including intertidal habitat such as brackish wetlands, eelgrass beds, mud flats, and sandflats, temper the extremity of storm impacts by attenuating wave energy, similar to breakwaters. There are no candidate sites within the Study Area to create new coastal wetlands for the purposes of flood protection; however, existing coastal wetlands can be maintained and enhanced to improve their flood protection characteristics.

The West Dike runs adjacent to the Sturgeon Bank WMA which is comprised of intertidal brackish marsh, sandflats, mudflats, and open water. The North Dike runs adjacent to pockets of mud flat, salt marsh, and eelgrass habitat. This intertidal habitat currently provides ecosystem services such as erosion and wave attenuation. Where feasible through dike upgrades this intertidal habitat could be enhanced. As part of the LIDMP the City will need to continue to work with inter-jurisdictional partners to monitor the complexity of the surrounding intertidal habitat, evaluate the existing ecosystems services that this habitat provides, and based on monitoring collaborate of efforts and initiatives to maintain and enhance this area.

Emergency Preparedness and Response: This strategy accommodates flood risks by preparing robust mitigation plans, to be carried out in the event of flood emergencies. The City has an existing emergency response plan: the Emergency Operations Centre coordinates with various departments to execute the Emergency Preparedness Flood Management Plan. The plans in place have not been reviewed as part of the Phase 2 LIDMP as this is beyond the scope of this study.

Managed Retreat: Managed retreat involves decommissioning or demolishing existing assets within a specified hazard zone, thereby eliminating flood risk by removing any development where flooding may occur. This strategy is not appropriate for the Study Area. The economic value of retaining existing assets exceeds the cost of reducing the risk of flood damage by relocating assets. The existence of development on Lulu Island that must be protected from flooding is considered a permanent condition for the purposes of the LIDMP.

4.1 AREA WIDE ADAPTATIONS

In the context of the Phase 2 LIDMP, area wide adaptations are those that facilitate the City's flood protection objectives in tandem with the dikes or alternative protection measures in place at the waterfront, but may not be sufficient to meet the City's target dike crest elevation in isolation. The target dike crest elevation is addressed through the area specific adaptations described in ***Section 4.2***.

The recommended area wide adaptations are: superdikes; floodproofing; planning and development controls; breakwaters and barrier islands; and, secondary dikes,. Each recommended adaptation is discussed in the following sections.

4.1.1 SUPERDIKES

As noted in ***Section 2.4***, a superdike is formed where the lands behind the dike are filled to the same elevation as the dike crest. Development is then built on a ground elevation equal to the dike crest.

Maximizing the width of raised land adjacent to the river decreases flood and seismic risks by increasing the integrity of the dike. The existing dikes of Lulu Island are built on soft soils that are subject to liquefaction during seismic events. These dikes may require ground improvements to meet the 2014 Seismic Design Guidelines (Seismic Guidelines). Superdikes are an approach to achieve the dual objectives of reducing vulnerability to both high water levels and seismic events. A superdike is more likely to withstand lateral movement and sloughing of the dike face without resulting in a dike breach, as compared to a standard trapezoidal dike alone. By raising lands to a superdike condition, costly ground improvements may not be required, even if they may have been required for a standard trapezoidal dike in the same area.

Any proposed dike adaptation project should comply with the Seismic Guidelines. If a proposed dike adaptation project will not meet the requirements in the Seismic Guidelines, superdikes may be considered as an alternative to ground improvements. At the design stage, a number of strategies should be investigated to determine which will meet the Seismic Guidelines at the lowest cost, on the overall balance of the considerations listed in ***Section 3***.

Any redevelopment of waterfront sites presents an opportunity to fortify existing flood protection measures. Although the Study Area is already fully built out, lands will continue to be redeveloped over the long-term future. Opportunities for implementing superdikes are most attainable where existing commercial and industrial sites are leveled in support of

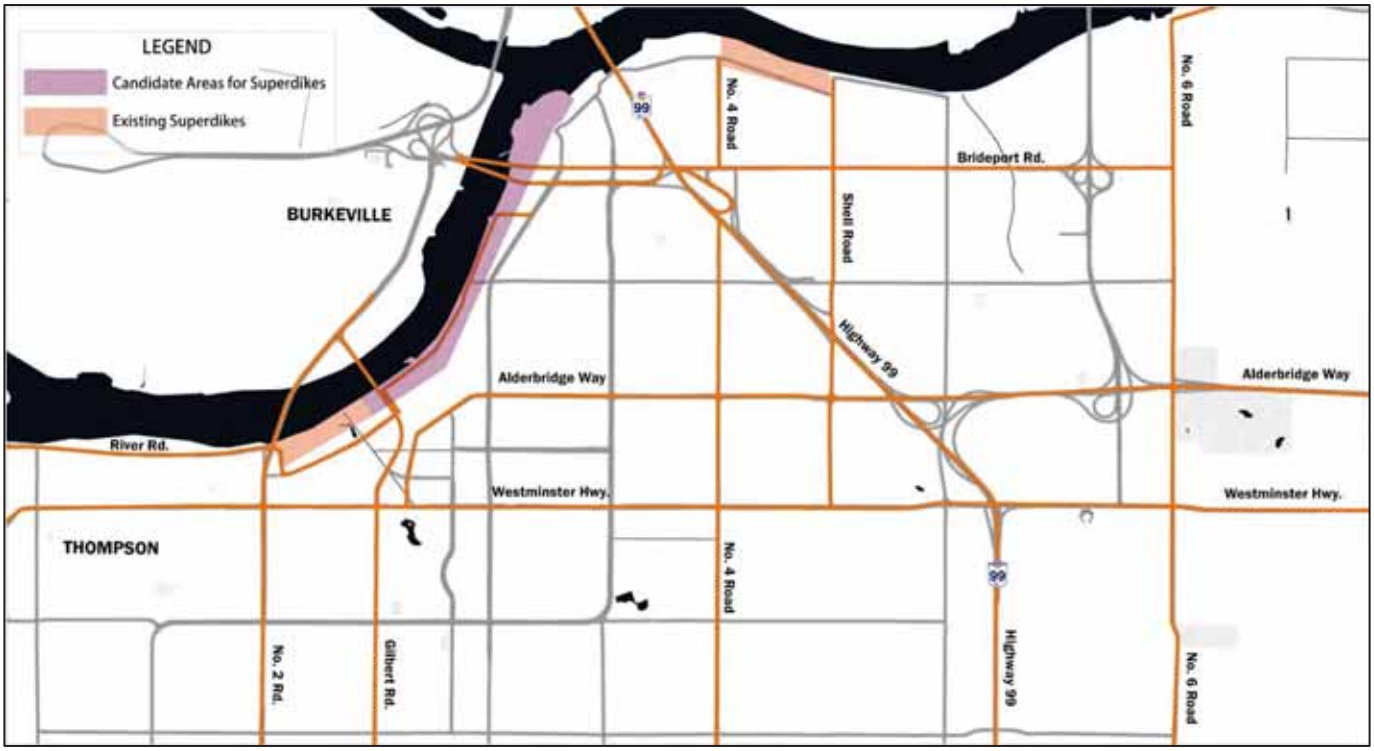
developing residential uses. Generally, industrial sites have different waterfront access and aesthetic needs than residential sites, which benefit most from a superdike condition. In recent years, residential developers have voluntarily raised the ground elevation of development sites to the same elevation as the dike crest to ensure that the units on the ground floor will have a view of the water. Within the Study Area, this has been the case at the multi-family residential developments next to the Olympic Oval, and the multi-family residential development under construction on the formerly industrial waterfront sites between No. 4 Road and Shell Road.

Application: Commercial & Residential Lands on the North Dike

The lands of the City Centre area are anticipated to experience extensive intensification and redevelopment in the coming years, further detailed in ***Section 4.2.7*** and ***Section 4.2.8***. This area has been identified as a candidate for superdikes, as shown in ***Figure 5***.

Redevelopment of waterfront sites presents opportunities to implement flood protection works concurrently with development. The optimal time for implementing superdikes is when existing assets are demolished and the site is leveled to accommodate new development.

Figure 5: Superdikes in the Study Area



4.1.2 FLOOD PROOFING

Flood proofing is a strategy to minimizing the damage to critical infrastructure in the event of a dike breach. Buildings can be constructed as flood proofed by ensuring habitable space is set at an elevation above the flood risk zone. Damage and losses incurred during flooding are minimal as any valuable or vulnerable assets are located above the possible flood elevation. In these buildings, habitable space and sensitive assets are located above a prescribed ground floor elevation, and lower floors are used only for storage of flood-resistant or low value assets. Another flood proofing strategy is using only impermeable building materials and watertight building equipment below the prescribed flood risk elevation.

The City's influence on where private building operators locate their assets within their buildings is limited, however construction of buildings with habitable space or vital assets below a specified elevation may be prohibited through legislation. By flood proofing buildings located in a specified waterfront or low elevation area, vital assets are prohibited from being located in high risk zones so that flooding will only affect non-vital infrastructure. Generally, flood proofing

legislation impacts only the construction of new buildings; existing buildings constructed prior to the legislation's implementation are typically not impacted except through building permit applications for renovations or additions.

As noted in ***Section 2.5***, the City currently enforces flood proofing through the Flood Plain Designation and Protection Bylaw No. 8204. The Bylaw sets minimum Flood Construction Levels (FCL's) throughout the City. The FCL prescribes the minimum elevation where the underside of a floor system can be constructed. Long term raising of land levels has previously been recommended (2008-2031 Flood Protection Strategy); however, is challenging to implement in already built up areas. The bylaw also specifies setbacks from a dike ROW to make land available for diking.

Application: Flood Construction By-law Amendments

Every part of Lulu Island has a designated FCL, not only the waterfront area. The bylaw organizes FCL's by area, as shown in ***Figure 6***. Presently, the majority of the Study Area fronting the existing dikes is within 'Area A' of the bylaw. The requirements for 'Area A' are to construct to 2.9 m or at least 0.3 m above the highest elevation of the crown of any road that is adjacent to the parcel. Commercial and industrial buildings are fully exempt if the main entrance is within 3 m of a road. Developments within the Terra Nova Area are further exempt only requiring the underside of the floor slab to be greater than 2.6 m. There are no exemptions in the north-east portion of the Study Area, where a 2.9 m FCL is required.

Figure 6: Flood Construction Levels (FCL's)

Amendments to Bylaw No. 8204 may be appropriate given the current predictions for sea-level rise. These amendments could include creation of an additional FCL Area adjacent to or within a stipulated distance from the existing dike or waterfront. The area could require an FCL of 4.7 m with exemptions based development size or parcel size. The FCL's would also have to consider overall lot raising and not just habitable space.

Examples of alternate concepts for consideration are provided below:

> ***Single Family Dwellings and Small Lots***: The bylaw could be amended to increase the rate at which land is raised concurrently with redevelopment. Presently, this rate is 0.3 m above the road centreline. For smaller lots, this strategy may then present challenges to local grading, producing inconsistent grades across lots and possibly introducing complex drainage patterns. Smaller lots are more likely to be highly constrained by existing grades on neighbouring lots and the road. Where grading is highly constrained, retaining walls may be required to accommodate substantial changes in elevation. Aesthetically, abrupt grade changes are undesirable, especially in neighbourhoods of single family homes. Varied grading between lots can also create issues with differential settlement. Grading designs that are consistent with the surrounding lot fabric and do not use retaining walls are

preferred. The sidewalks and road network must also be carefully graded to maintain minimal slopes and safe connections at intersections. Any FCL increase must be implemented strategically to mitigate the potential grading challenges it may introduce.

Zoning bylaws could potentially be modified to provide additional guidance and requirements for lot coverage, setback, building heights, and others to help plan how the greater staggered lot elevations may integrate with each other. This will be challenging to implement but would increase the rate of increasing the land height in residential areas.

Mid-Size Development Lots or Building Permit Value Criteria: The bylaw could be amended to require raising to 4.7 m or 1 m (or alternate) above the road. Challenges may still exist with incorporating grading to adjacent parcels and roads.

Large Development Lots or Building Permit Value Criteria: The bylaw could be amended to require raising to 4.7 m and upgrading the local road network to accommodate access. This is currently done in practice, however, it is not specifically required under the current bylaw.

Additional studies on implementation of modified FCL bylaws should be conducted prior to proceeding with any changes. Input should be provided from architects, planners, engineers, environmental consultants and key stakeholders to obtain a comprehensive understanding of opportunities and factors to be mitigated while achieving flood protection goals.

Flood risk should be evaluated by the City periodically to determine whether increased risk warrants raising the target dike crest elevation. The bylaw can be amended as required to meet evolving City guidelines as they are adjusted per changes to flood risk conditions. For example, if the design crest elevation is raised from 4.7 m to 5.5 m, the FCL bylaw can be amended to reflect the new minimum elevation. In this way, flood proofing can progress over time as required.

4.1.3 PLANNING AND DEVELOPMENT CONTROLS

Planning and development controls may be implemented by enacting legislation to prohibit or restrict development in a defined hazard zone, such as a floodplain. More flexible policies can also be enacted to include conditional development approvals, where projects may be approved on condition that developers commit to implementing flood protection measures such as raising the abutting dike or raising the land elevation to a superdike.

Application: Site Assembly Size in the City Centre

In the Study Area, there are opportunities to pursue flood protection improvements in conjunction with new development, especially in areas expected to be intensified in the coming years. In Richmond, planning and development controls can be implemented through bylaws or amendments to the OCP.

Increasing the ground elevation of a single waterfront site is restricted by the existing elevations of adjacent lands. Where adjacent sites remain low, a redevelopment site can only be minimally raised without introducing challenges to the local road network and drainage patterns. To avoid complications arising from steep grades or retaining walls, the City can encourage developers to assemble multiple adjacent sites until a specified minimum waterfront frontage can be developed concurrently. This strategy permits increasing the dike crest level fully to the current standard elevation, and eases the transition of the waterfront to a superdike.

4.1.4 BREAKWATERS AND BARRIER ISLANDS

Breakwaters may be constructed to dissipate wave energy before waves reach the shore. This reduces the burden on the flood control structures at the waterfront. In combination with a foreshore structure, flood control structures with lower crest elevations may remain adequate to withstand increased wave run-up associated with increased water depths due to climate change and sea level rise.

With appropriate environmental consideration during design and construction, breakwaters and barrier islands can create intertidal habitat, such as sand flats, mud flats, salt marsh and eelgrass beds. These features can assist with erosion and

wave attenuation. The intertidal habitat can work in combination with a constructed flood control structures like dikes and floodwalls, to mitigate flood risk.

Sea level rise and upland limitations to natural accretion within the Sturgeon Bank WMA could result in increased offshore depths beyond the West Dike, which could simultaneously increase wave heights reaching the West Dike.

Increased water depths off-shore reduce the wave attenuating properties of Sturgeon Bank. The current predictions and assumptions used in the BC Sea Dike Guidelines[10] for the year 2100 suggest wave run-up may account for up to 2.7 m of the future dike crest elevation. The full extent of future crest height increases will require detailed observation and study of observed sea level rise.

Application: The West Dike Foreshore - Sturgeon Bank

The West Dike runs adjacent to Sturgeon Bank WMA comprised of intertidal brackish marsh, sandflats, mudflats, and open water. Maintenance and enhancement of these areas could provide wave dissipation and erosion protection.

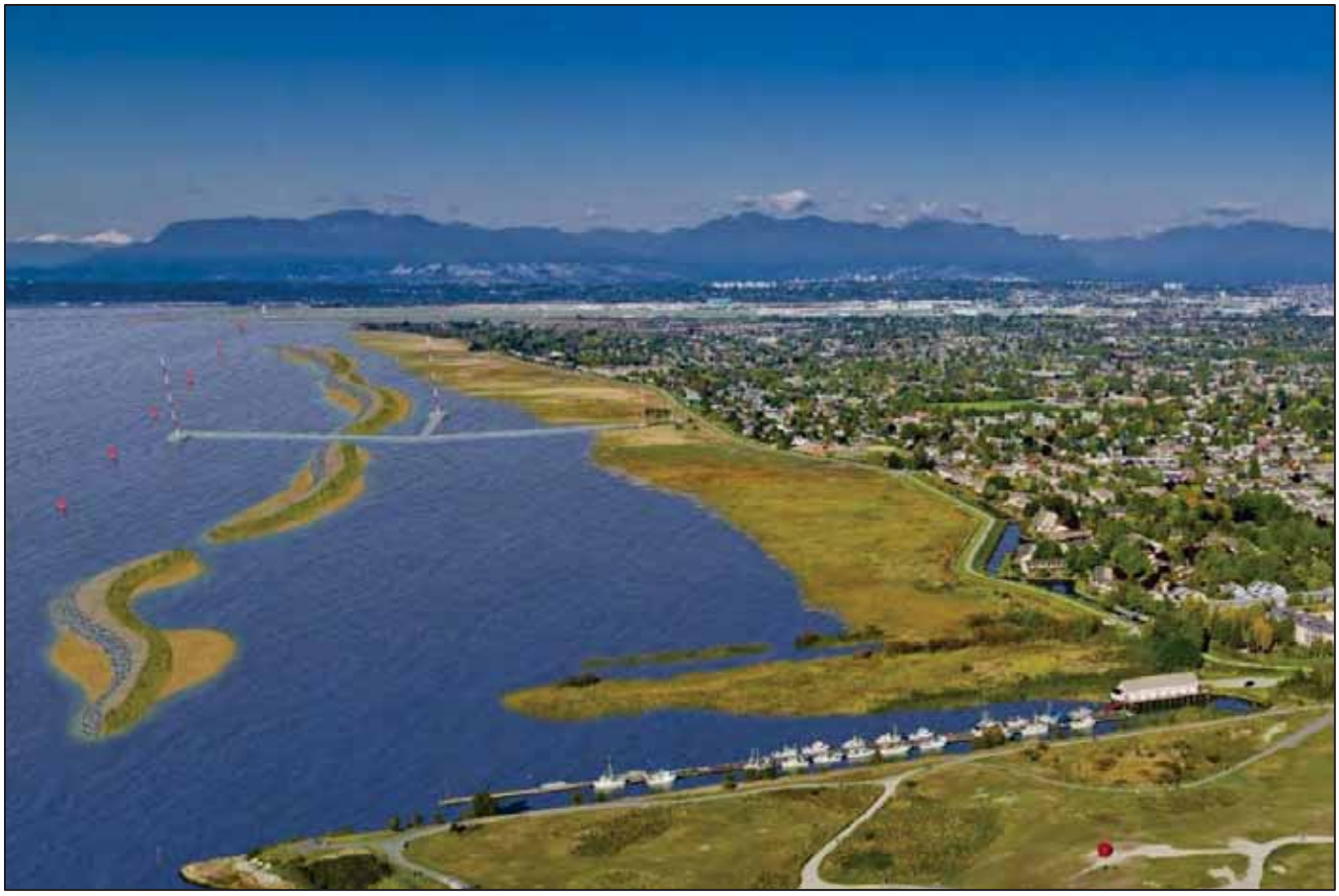
Photograph: Sturgeon Bank Management Area

The West Dike is a candidate for barrier islands, as presented in the Phase 1 LIDMP. Presently, the features of Sturgeon Bank dissipate wave energy. With future increased water depths on the Sturgeon Bank, wave heights are expected to increase, reducing the wave dissipate benefits of Sturgeon Bank, putting the West Dike at higher future risk of overtopping. Construction of breakwaters or barrier islands, including the maintenance and enhancement of intertidal habitat, is one approach to offset the potential future loss the existing wave dissipation benefits of Sturgeon Banks.

While breakwaters and barrier islands will not address the immediate crest elevation requirements of 4.7 m, construction of barrier islands may allow for future deferrals of crest height increases. A general concept plan showing possible locations for barrier islands is presented in ***Figure 7***.

[10] Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use Draft Policy Discussion Paper, Ausenco Sandwell, Jan 27 2011

Figure 7: Artistic Rendering of Barrier Island Concept for Sturgeon Bank



Breakwaters are most effective when constructed close to the shore, as broken waves grow again behind the breakwater under the influence of wind. The effectiveness depends also on the crest height of the breakwater, with a higher breakwater giving more wave reduction. Preliminary calculations from the Phase 1 LIDMP indicated that wave reduction with a breakwater or barrier islands constructed to +3.0 m geodetic would reduce wave height by 70% if constructed 200 m offshore, 60% at 500 m offshore, and 45% at 2000 m offshore.

Intertidal ecosystems are driven by interdependent components including rates of accretion, stream velocity, salinity, water quality, sea level, temperature, vegetation productivity, adjacent land use etc. that are complex to measure and model. Understanding the complexity of current conditions to better prepare for predictable increases in sea level rise will help direct strategies to maintain and enhance intertidal ecosystems. To this end, the City continues to work on inter-jurisdictional efforts to better understand the influencing factors that affect the Sturgeon Bank WMA, and intertidal habitat throughout the Fraser River Estuary.

4.1.5 SECONDARY DIKES

Secondary dikes work in conjunction with primary dikes to reduce the impact of a flood in the event that a primary dike is breached or overtopped. A secondary dike protects assets behind the secondary dike alignment while the lands between the primary and secondary dikes may flood intermittently. Secondary dikes are appropriate for implementation where the lands between the primary and secondary dike require a different measure of protection than lands behind the secondary dike. Eligible areas may include parking lots, parks or natural areas that can withstand intermittent flooding with minimal damage or losses incurred.

As secondary dikes are built inland, they can be less costly to build and less susceptible to damage during seismic events as compared to adaptations directly on the waterfront. The advantage is that an equivalent measure of protection can be

extended to important inland assets, at a lower cost and lower seismic risk, than raising the primary dike at the waterfront. In the Study Area, secondary dikes are recommended for consideration where no critical assets are located on waterfront lands and there are assets further inland that require protection.

Application: Terra Nova

In future, the City may consider exploring establishing an alternative dike alignment for a part of the Terra Nova area through the park lands, as shown in ***Figure 8***.

By setting the alignment inland, the City may avoid costly ground improvement measures that may be required for upgrading the existing alignment on the waterfront. Assets sensitive to flooding, such as private homes and heritage sites, would be protected by the secondary dike. Less sensitive assets, such as the park, trails and open space lands, can withstand occasional flooding with minimal losses incurred and therefore may be adequately protected by a dike with a relatively lower crest elevation.

A proposed breach in the primary dike to connect the Terra Nova Slough to the Fraser River for the purpose of creating a Chum Salmon spawning slough will increase flood risk to the City. A secondary dike will mitigate the risk.

Figure 8: Secondary Dike Alignment through Terra Nova

4.2 AREA SPECIFIC ADAPTATIONS

For the purposes of the master plan, an area specific adaptation is a structural adaptation that can achieve the target 4.7 m crest height, with consideration for a future increase to 5.5 m. This section outlines the preferred area specific adaptation measures for each of the thirteen design areas.

The recommended approaches to area specific adaptations includes: widen footprint to land or water side; raise in place / constrained dike; permanent floodwall; demountable floodwall.

Widen Footprint to Land or Water Side

Dikes are the most common form of structural flood protection. Lulu Island is currently protected by a perimeter ring dike, with floodwalls or alternative protections at some sites. In the Study Area, improvements to the existing dike should be pursued wherever possible.

As per the typical dike sections presented in ***Appendix F***, the typical City dike upgrade cross-section consists of a 2:1 slope on the water side, and a 3:1 slope on the land side[11]. Raising a dike by 1 m then triggers a 5 m horizontal space requirement (assuming the standard slopes are applied). Land side dike expansions can be challenging where the footprint is constrained by existing buildings, infrastructure, drainage ditches, or RMA's at the toe. Where a dike's land side toe is heavily constrained, a standard dike can be raised by widening its footprint onto the water side.

While shoreline habitat within the Fraser River Estuary will generally have a higher habitat value, and expansion into this area should be avoided, this may not always be the case. Implementation of area specific flood protection strategies will have an environmental impact regardless of the strategy put forth for a given area. Environmental assessments and valuation will be undertaken in the design construction phase, where possible habitat impact will be avoided. Where impact cannot be avoided, efforts will be made to mitigate, and if necessary compensate for impact following a net gain approach.

Raise in Place / Constrained Dike

Where dike expansion is constrained on both the land and water sides, it may be possible to raise a dike within its existing footprint, creating a constrained dike. This may be achieved by introducing a retaining wall on one or both sides. In Richmond, RMA's, development and infrastructure may abrupt to the landside of the dike, and intertidal habitat or marine infrastructure may be on the water side of the dike, meaning the dike may have constraints on both sides. In the Study Area, raising the dike in place can be pursued to minimize impacts on adjacent lands.

Permanent Floodwall

A floodwall is a constructed barrier designed to hold back flood waters. In the Study Area, floodwalls can be implemented where space is limited and a dike would interfere with other land uses or infrastructure, such as existing buildings. Floodwalls may also be preferable to a dike where access to the water is required for economic activity, such as fishing or shipping. Generally, where feasible, earth fill trapezoidal dikes are preferable as they generally have lower costs, they are easier to maintenance, they are more reliable and easier to repair in emergency situations.

Demountable Floodwall

In areas where waterfront access is desired, demountable flood barriers can be constructed so that the barrier is erected only when required, during storm events. Regular access to the waterfront is maintained otherwise. This adaptation may be applied in the Study Area at industrial sites or marinas, where activities require amenities directly on the waterfront that cannot be set back behind a floodwall or dike. Where possible, this form of dike is avoided due to their higher costs, mobilization requirements, and reliability concerns.

Parsons assessed each potential dike adaptation strategy based on the considerations outlined in ***Section 3***. A summary of the recommendations for each design area is provided in ***Table 5***. Key issues and opportunities to be considered when implementing the recommended adaptations are presented for each design area in ***Section 4.2.1*** through ***Section 4.2.13***.

[11] Typical Cross Section River Dike Upgrade, City Drawing Mb-98, Golder Associates, 2008

Table 5: Recommended Area Specific Adaptations

FLOOD PROTECTION SEGMENT	RECOMMENDATION
WEST DIKE	
Seafair	Raise the dike on the existing alignment. Additional studies required to quantify drainage impacts of land side expansion, habitat impacts and costs associated with water side or land side expansion, and long term resiliency of a constrained dike solution.
Terra Nova	Raise the dike on the existing alignment. Additional studies required to quantify drainage impacts of land side expansion, habitat impacts and costs associated with water side or land side expansion, and long term resiliency of a constrained dike solution. Alternatively, consider routing a secondary dike inland through Terra Nova Rural Park, in lieu of raising the primary dike at the waterfront.
NORTH DIKE	
Thompson Terra Nova	Raise the dike on the existing alignment with land side expansion. Plan for the long-term raising of River Road.
Thompson Dover	Raise the dike on the existing alignment with land side expansion. Plan to raise River Road.
Oval	Existing area generally redeveloped as a superdike scenario (elevations from 4.0 to 4.5m). Future raisings to 5.5 m can take place on the existing alignments and integrate into the adjacent landscaping.
City Centre 1	Raise a dike with land side expansion. Consider creation of a set-back dike and inland raising (superdike) in conjunction with the future Middle Arm Waterfront Park construction.
City Centre 2	Raise the dike on the existing alignment with land side expansion in conjunction with redevelopment. Ensure any interim dike upgrades are compatible with the long term strategy of constructing superdikes.
Duck Island River Rock	Implement approved development plans. Plan for temporary dike to protect City assets if required to address sea level rise and climate change prior to implementation of the approved strategy at the Duck Island or River Rock Casino sites.
Industrial	Raise the dike on the existing alignment. Site specific solutions may be required at the Fraser River Terminal site. Plan for temporary dike along the alternate alignment if required to address sea level rise and climate change prior to implementation of a strategy at the Fraser River Terminal site.
Bridgeport Tait	Existing area generally redeveloped as a superdike scenario (elevation 4.7m). Future raisings to 5.5 m can take place on the existing alignments and integrate into the adjacent landscaping.
Industrial North East 1	Raise the dike on the existing alignment. Land acquisition may be required to facilitate construction of a trapezoidal dike (through redevelopment or otherwise). Implementation of a temporary floodwall adjacent to the waterfront lots may be required in advance of a permanent adaptation to address sea level rise and climate change. Consider Bath Slough Revitalization Initiative for future designs.
Industrial North East 2	Raise the dike on the existing alignment. Additional studies required to quantify drainage, habitat impacts, and costs associated with land side expansion of a trapezoidal dike. A constrained land side slope may be required to integrate with the existing drainage infrastructure. Consider Bath Slough Revitalization Initiative for future designs.
Industrial North East 3	Raise the dike on the existing alignment. Additional studies required to quantify drainage, habitat impacts, and costs associated with land side expansion of a trapezoidal dike. A constrained land side slope may be required to integrate with the existing drainage infrastructure.

4.2.1 SEAFAIR

The Seafair design area consists of established residential neighbourhoods of single family homes and townhouse complexes. On the foreshore, lands are undeveloped as is the case for the entirety of Sturgeon Bank. The Quilchena Golf & Country Club makes up the northern third of the plan; it sits entirely on Agricultural Land Reserve (ALR) lands. No major changes to the Seafair waterfront are identified in the OCP.

The preferred adaptation is to raise the dike on its existing alignment. Expansions to either side are constrained by environmental and infrastructure factors. These should be evaluated at the time an adaptation project is proposed to inform a detailed design that will best balance the considerations outlined in *Section 3*.

Barrier islands may be considered to reduce wave run-up and mitigate the need for future dike crest increases, as discussed in *Section 4.1.4*.

If ditches at the toe of the dike are to be filled, the associated loss of stormwater storage and conveyance may need to be compensated with underground pipes or alternative systems. Ditches may be designated as RMA's. Associated restrictions to alterantions should be investigated when dike adaptations proceed to design and construction. Revised drainage plans must be compatible with local pump stations.

The Williams Road pump station was upgraded in 2013. The dike crest in the vicinity of the pump station is higher than adjacent lands. The pump station is not anticipated to pose special requirements for raising the dike on adjacent lands, however raising the dike crest over the pump station may increase the loading on this infrastructure. Dike adaptation projects that include raising the dike crest over the pump station should consider the pump station's structural and operational needs, including access.

LOCATION:

Williams Road to Granville Avenue

RECOMMENDATION:

Raise the dike on the existing alignment. Additional studies required to quantify drainage impacts of land side expansion, habitat impacts and costs associated with water side or land side expansion, and long term resiliency of a constrained dike solution.

ENVIRONMENTAL CONSIDERATIONS:

ENMS Strategy Area

- West Dike
- Traditional Neighbourhood

ESA Habitat Type

- Intertidal
- Shoreline

FREMP Data

- Red-coded

RMA Presence

- 5m RMA Presence

PHOTOGRAPH:

West Dike, facing north at Williams Road Pump Station

4.2.2 TERRA NOVA

The Terra Nova area is primarily recreational and agricultural including small, low density areas of single family homes. Recreational and natural areas include the Quilchena Golf & Country Club and Terra Nova Rural Park. The park has extensive natural areas with trails and observation decks at the slough and wetland areas. A large children's play structure, the Adventure Play Environment, opened in 2014 at the northwest corner of the park. No major changes to the waterfront or parklands are identified in the OCP for this design area. The entire park is identified as conservation lands within the OCP.

The open space provides a unique setting within the Study Area to consider both waterfront adaptations at the existing primary dike, or a secondary dike alignment through the park. For more information on the secondary dike option, refer to ***Section 4.1.5***. Barrier islands may be considered for implementation on Sturgeon Bank to reduce wave run-up and avoid the need for future dike crest increases, as discussed in ***Section 4.1.4***. Opportunities to create intertidal habitat areas in the park may be pursued when dike adaptations proceed.

The historic Terra Nova Cannery site is present on the north side of the park, in front of the private homes on River Road within the park. There are no visible remains of the cannery, except the shoreline recedes inwards around the former cannery's boundaries. Heritage status and associated restrictions to local alterations should be investigated when dike upgrades at the waterfront are proposed. Sheet pile may need to be considered for the segment adjacent to the Cannery site to minimize impacts.

LOCATION:

Granville Avenue to Terra Nova Rural Park

RECOMMENDATION:

Raise the dike on the existing alignment. Additional studies required to quantify drainage impacts of land side expansion, habitat impacts and costs associated with water side or land side expansion, and long term resiliency of a constrained dike solution.

Alternatively, consider routing a secondary dike inland through Terra Nova Rural Park, in lieu of raising the primary dike at the waterfront.

ENVIRONMENTAL CONSIDERATIONS:

ENMS Strategy Area

- West Dike

ESA Habitat Type

- Intertidal
- Shoreline

FREMP Data

- Red-coded

RMA Presence

- 5 m & 15m RMA Presence

PHOTOGRAPH:

West Dike, facing north at Terra Nova Rural Park

4.2.3 THOMPSON TERRA NOVA

The Thompson Terra Nova design area is residential, with recreational uses between River Road and the waterfront in the form of the dike trail and surrounding open space. The residential areas consist primarily of single family homes. No major changes to the Thompson Terra Nova design area are identified in the OCP.

The existing dike is situated between the Middle Arm of the Fraser River and River Road. Future expansions in some areas will be challenging due to the lack of space. Raising River Road will help with future dike crest elevation increases; however, will be challenging to implement.

Single family homes have driveway access from River Road throughout the design area. Individual lots are anticipated to be incrementally raised as they are redeveloped, however, this will take numerous decades to occur.

LOCATION:

Terra Nova Rural Park to McCallan Road

RECOMMENDATION:

Raise the dike on the existing alignment with land side expansion. Plan for the long-term raising of River Road.

ENVIRONMENTAL CONSIDERATIONS:

ENMS Strategy Area

- Fraser River
- Traditional Neighbourhood

ESA Habitat Type

- Intertidal
- Shoreline

FREMP Data

- Red-coded

RMA Presence

- None

PHOTOGRAPH:

North Dike, facing east near Terra Nova Rural Park entrance

4.2.4 THOMPSON DOVER

The Thompson Dover design area includes a City works yard and recycling facility, as well as mid-rise multi-family residential complexes. Recreational uses exist between River Road and the waterfront in the form of the dike trail and surrounding open space. Within the Thompson Dover design area, only the City works yard has driveway access to River Road. No major changes to the Thompson Dover design area are identified in the OCP. It is anticipated that the City works yard will be redeveloped to residential uses consistent with the surrounding neighbourhood at some point in the future.

It would be advantageous to raise River Road and assist in future land and dike crest increases in the long term. The multi-family residential lands were raised much higher than River Road when these sites were developed. Raising River Road at this location would not have the same access challenges as the Thompson Terra Nova area as there is no driveway access and the buildings are already on high land. River Road may be raised to the dike crest elevation on this section at any time. It would be advantageous to do a longer segment of River Road together, thus raising the road here should proceed concurrently with raising River Road in the Thompson Terra Nova design area to the west. Raising River Road along the City works yard may be considered concurrently with redevelopment of the site in the event that this site is redeveloped.

Issues and opportunities with raising River Road are further discussed in *Section 4.3.2*.

LOCATION:

McCallan Road to No. 2 Road Bridge

RECOMMENDATION:

Raise the dike on the existing alignment with land side expansion. Plan for the long-term raising of River Road.

ENVIRONMENTAL CONSIDERATIONS:

ENMS Strategy Area

- Fraser River
- City Centre

ESA Habitat Type

- Intertidal
- Shoreline

FREMP Data

- Red-coded

RMA Presence

- None

PHOTOGRAPH:

North Dike, facing east at Lynas Lane

4.2.5 OVAL

Within the Oval design area, the River Road alignment has been relocated south of development to the former rail corridor. The dike trail is part of a wide landscaped area abutting high rise condos. Redevelopment of the Oval design area began in advance of the 2010 Vancouver Winter Olympics, for which the Richmond Olympic Oval skating and fitness centre was built. The adjacent sites have since been redeveloped as well. The majority of these lands were filled to the dike crest elevation when the dike was raised in conjunction with site redevelopment. This design area is considered complete for the time being as the dike crest elevations vary from 4.0 m to 4.5 m, which is within range of the current 4.7 m target dike crest elevation.

There is one existing building directly west of the Dinsmore Bridge, forming the one remaining section of this design area to be raised. As this building has been set back from the waterfront, there is land available to raise the dike by widening the footprint to the land side at this site. This option may be pursued when this segment of River Road is decommissioned and relocated to the former rail corridor inland.

LOCATION:

No. 2 Road Bridge to Dinsmore Bridge

RECOMMENDATION:

Existing area generally redeveloped as a superdike scenario (elevations from 4.0 to 4.5m). Future raisings to 5.5m can take place on the existing alignments and integrate into the adjacent landscaping.

ENVIRONMENTAL CONSIDERATIONS:

ENMS Strategy Area

- Fraser River
- City Centre

ESA Habitat Type

- Intertidal
- Shoreline

FREMP Data

- Red-coded

RMA Presence

- 5 m & 15 m RMA Presence

PHOTOGRAPH:

North Dike, facing east at the Richmond Oval

4.2.6 CITY CENTRE 1

The City Centre 1 design area is is presently long-established office industrial sites with sizeable parking lots. All sites have access from River Road, which runs along the waterfront in this design area. Marinas exist along the waterfront. The existing Middle Arm Waterfront Park is a linear park along the waterfront constructed concurrently with the Olympic Oval in 2009. The park's amenities include the dike trail, playgrounds, and piers. Outdoor seating and stages for public events have been inset on the water side dike face. The OCP identifies major changes, including commercial intensification and creation of a large park.

A new park, Middle Arm Park, is proposed in the OCP adjacent to the existing Middle Arm Waterfront Park, as shown on the City Centre Area Plan presented in ***Appendix A***. The existing River Road is planned to be realigned to the former rail corridor, and all lands between the rail corridor (the future River Road) and the waterfront are proposed to become the parklands forming Middle Arm Park. A concept sketch[12] is presented in ***Figure 9***.

LOCATION:

Dinsmore Bridge to Cambie Road

RECOMMENDATION:

Raise dike with land side expansion. Consider creation of a set-back dike and inland raising (superdike) in conjunction with the future Middle Arm Waterfront Park construction.

Plans for the new park have not yet been formalized; however, based on consultation with City staff, there is support for establishing the future dike alignment inland to improve public connectivity with the waterfront, and facilitate creation of intertidal habitat within the park. A set-back dike combined with inland raising to create a superdike would provide the most resilient solution for this area. Dike plans should be prepared concurrently with plans for the proposed park.

In the event that the City wishes to fortify the existing dike in advance of the development of Middle Arm Park, the City may consider raising a temporary flood protection adaptation in the interim until the proposed park's plans are finalized and implemented.

Figure 9: 2006 Concept Plan for the Proposed Middle Arm Park

ENVIRONMENTAL CONSIDERATIONS:

ENMS Strategy Area
- Fraser River
- City Centre

ESA Habitat Type
- Intertidal
- Shoreline

FREMP Data
- Yellow-coded
- Green-coded

RMA Presence
- None

PHOTOGRAPH:

North Dike at Gilbert Road, facing east

[12] Middle Arm Open Space Master Plan Concept, PFS Studio, December 2006

4.2.7 CITY CENTRE 2

Marinas are present throughout the City Centre 2 design area. The dike trail ends approximately 200 m north of Cambie Road, where the dike becomes marina parking lots. The proposed Middle Arm Park ends where the dike trail becomes parking lots. These parking lots are directly adjacent to the trafficable road; there is no shoulder between the road and the parking lots. Parking lots are raised from River Road with either steep slopes or retaining walls. This section of River Road will ultimately be realigned to the former rail corridor. Lands are planned to be redeveloped into high density commercial and mixed use buildings. Redevelopment of this area has begun.

While the optimal time to implement flood protection adaptations is concurrently with redevelopment of adjacent sites, the parcels of land in this area have narrow frontages, and smaller lot depths. This lot geometry can create challenges in implementing flood protection upgrades alongside redevelopment. These issues can be addressed through site assemblies, as detailed above in ***Section 4.1.3***. The approach to flood protection in this area should generally mimic the recent improvements in the Oval area, with redevelopment raising the waterfront and the development site to establish a superdike.

The adaptations along this design area may include sites with floodwalls in order to maintain access and usage of the existing marinas. Any interim dike upgrades planned in this area should be designed with consideration for future adaptations to establish a superdike, the long-term goal in this area.

LOCATION:

Cambie Road to Moray Bridge

RECOMMENDATION:

Raise the dike on the existing alignment with land side expansion in conjunction with redevelopment. Ensure any interim dike upgrades are compatible with the long term strategy of constructing superdikes.

ENVIRONMENTAL CONSIDERATIONS:

ENMS Strategy Area

- Fraser River
- City Centre

ESA Habitat Type

- Intertidal
- Shoreline

FREMP Data

- Yellow-coded
- Green-coded

RMA Presence

- None

PHOTOGRAPH

Float homes off North Dike at Capstan Way

4.2.8 DUCK ISLAND

The Duck Island design area consists of former industrial lands, substantial parking lots and the River Rock Casino, which includes a marina and a wetland. The River Road alignment is inland from Duck Island. The former industrial area, now vacant, hosts the Richmond Night Market in the summer. The landowners of this area are currently seeking development approval to develop the site for commercial uses, consistent with the land uses identified in the OCP.

The existing waterfront lands in the Duck Island design area are entirely privately-owned. The landowners are currently developing private flood protection plans, to be reviewed and approved by the City. The plans are expected to be implemented in the near future, upon approval by the City.

In the event that a suitable strategy is not developed for the private waterfront lands in this area, or if an interim adaptation measure is required, there are inland alternative alignments available to the City to maintain protection for Lulu Island. The alternate alignment would follow River Road or the CN Rail Corridor through this design area. This approach is not preferred; however, details on the alignment and approach are outlined in TM#2 (*Attachment 2*).

LOCATION:

Moray Bridge to Oak Street

RECOMMENDATION:

As per approved development plans. Plan for temporary dike to protect City assets if required to address sea level rise and climate change prior to implementation of the approved strategy at the Duck Island or River Rock Casino sites.

ENVIRONMENTAL CONSIDERATIONS:

ENMS Strategy Area

- Fraser River
- City Centre

ESA Habitat Type

- Intertidal
- Shoreline

FREMP Data

- Red-coded
- Yellow-coded
- Green-coded

RMA Presence

- None

PHOTOGRAPH:

Marina at River Rock Casino

4.2.9 INDUSTRIAL

The Industrial design area includes industrial areas and parking lots. The Fraser River Terminal and a BC Hydro power station are located here. River Drive is aligned south of these sites, set back from the waterfront. These lands are anticipated to be industrial uses for the foreseeable future, as noted in the OCP.

The North Arm Bridge carrying the Canada Line and a bikeway was constructed in this design area in 2009 with ample clearance for dike works beneath the bridge deck. At the detailed design stage, dike works would need to be verified for confirmation that the footings can withstand additional loading without risk of settling, or any other risks that may compromise the bridge structure.

Adaptations in this area are constrained by existing waterfront development and uses. This industrial area includes the Fraser River Terminal - a shipping port and ship repair centre – as well as the BC Hydro Kidd #2 Substation. This area is anticipated to be industrial for the foreseeable future. Because waterfront lands are constrained by private industrial uses, the City may consider pursuing a temporary adaptation in the interim until the industrial sites are redeveloped. A temporary structure along the River Drive alignment may be considered. This approach is not preferred; however, details on the alignment and approach are outlined in TM#2 (***Attachment 2***).

LOCATION:

Oak Street Bridge to No. 4 Road

RECOMMENDATION:

Raise the dike on the existing alignment. Site specific solutions may be required at the Fraser River Terminal site. Plan for temporary dike along the alternate alignment if required to address sea level rise and climate change prior to implementation of a strategy at the Fraser River Terminal site.

ENVIRONMENTAL CONSIDERATIONS:

ENMS Strategy Area

- Fraser River
- City Centre

ESA Habitat Type

- Intertidal
- Shoreline

FREMP Data

- Red-coded
- Green-coded

RMA Presence

- None

PHOTOGRAPH:

North Dike, west of Fraser River Terminal

4.2.10 BRIDGEPORT TAIT

The Bridgeport Tait design area was formerly entirely industrial. An auto repair facility remains at its eastern edge. The remainder of these lands were recently developed to high-rise multi-family residential, with ongoing development of associated residential and commercial uses.

During site devepment, the dike crest elevation was raised to 4.7 m and the development lands were filled to a superdike condition. This area is considered complete for the time being. A wide landscaped area exists between the waterfront and the buildings, providing a trail through the neighbourhood at the waterfront. Future dike crest height increases can be accommodated in this area, and integrated with the local landscaping and waterfront trail.

LOCATION:

No. 4 Road to Shell Road

RECOMMENDATION:

Existing area generally redeveloped as a superdike scenario (elevation 4.7m). Future raisings to 5.5 m can take place on the existing alignments and integrate into the adjacent landscaping.

ENVIRONMENTAL CONSIDERATIONS:

ENMS Strategy Area

- Fraser River
- City Centre

ESA Habitat Type

- Intertidal
- Shoreline

FREMP Data

- Red-coded
- Yellow-coded

RMA Presence

- None

PHOTOGRAPH:

North Dike, facing west at the Park Riviera Development

4.2.11 INDUSTRIAL NORTH EAST 1

The Industrial NE 1 design area is entirely industrial, and no major changes are outlined in the OCP. Limited space is available in this design area as River Road is either directly on the waterfront or confined by developed lots. Where River Road is adjacent to the waterfront, it will need to be raised concurrently with dike works to meet the target dike crest elevation with a standard trapezoidal cross-section. This may impact driveway access to the lots south of River Road. An interim constrained land side dike toe may be required to mitigate impacts to adjacent lots in the interim until redevelopement and land raising occurs.

A number of small businesses operate on a narrow strip of land between River Road and the waterfront. These lands, approximately 2 ha, are privately owned. The City may consider acquiring these lands to implement diking in this area. The acquisition of approximately 2 ha of private lands north of Simpson Road may add significant costs to diking in this area.

A floodwall may be considered for this section of the design area as an interim solution in advance of the City implementing a permanent trapezoidal dike adaptation. Any interim solutions will require cooperation with the existing landowners. Outside this section, there are lands available from the River Road ROW to the shore to raise the existing dike. At the detailed design stage, if lands are too highly constrained to expand the dike footprint, the City may also consider acquiring additional lands from the parking lots on the south side of River Road.

The Industrial North East 1 LIDMP Study Area is bounded by Bath Slough. Through the Bath Slough Revitalization Initiative, adopted in 2014, the City has conducted a number of innovative ecological initiatives along Bath Slough including water quality improvements, riparian enhancement and native pollinator pasture initiatives. The Bath Slough Revitalization Initiative should be considered in the design and construction phase of diking in this area.

LOCATION:

Shell Road to Bath Slough

RECOMMENDATION:

Raise the dike on the existing alignment. Land acquisition may be required to facilitate construction of a trapezoidal dike (through redevelopment or otherwise). Implementation of a temporary floodwall adjacent to the waterfront lots may be required in advance of a permanent adaptation to address sea level rise and climate change. Consider Bath Slough Revitalization Initiative for future designs.

ENVIRONMENTAL CONSIDERATIONS:

ENMS Strategy Area

- Fraser River
- Industrial

ESA Habitat Type

- Intertidal
- Shoreline
- Freshwater Wetland

FREMP Data

- Yellow-coded
- Green-coded

RMA Presence

- 15m RMA Presence

PHOTOGRAPH:

North Dike, facing west at No. 5 Road

4.2.12 INDUSTRIAL NORTH EAST 2

The Industrial NE 2 design area is entirely industrial. River Road abuts the waterfront. Port Metro Vancouver owns a vacant lot west of the Knight Street Bridge. There are large ditches along the south side of River Road. No major changes to this area are presented in the OCP.

River Road is currently the dike in this design area. There are insufficient lands available north of the road to raise the dike, although the elevation of the entire River Road may be raised. No businesses within this area access the waterfront directly from their lots, therefore maintaining waterfront access for these businesses is not required. Existing drainage on the land side may need to be modified as large ditches are present along River Road.

Public access to the waterfront may be improved by the addition of a trail adjacent to the raised River Road, in compliance with the City's long term vision of a connected trail system at the waterfront of the entire island.

The Industrial North East 2 LIDMP Study Area is bounded by the Bath Slough. Through the Bath Slough Revitalization Initiative, adopted in 2014 the City has conducted a number of innovative ecological initiatives along Bath Slough including water quality improvements; riparian enhancement and native pollinator pasture initiatives. The Bath Slough Revitalization Initiative should be considered in the design construction phase of dike upgrades in this area.

LOCATION:

Bath Slough to Knight Street Bridge

RECOMMENDATION:

Raise the dike on the existing alignment. Additional studies required to quantify drainage, habitat impacts, and costs associated with land side expansion of a trapezoidal dike. A constrained land side slope may be required to integrate with the existing drainage infrastructure. Consider Bath Slough Revitalization Initiative for future designs.

ENVIRONMENTAL CONSIDERATIONS:

ENMS Strategy Area

- Fraser River
- Industrial

ESA Habitat Type

- Intertidal
- Shoreline
- Freshwater Wetland

FREMP Data

- Red-coded
- Yellow-coded
- Green-coded

RMA Presence

- 15m RMA Presence

PHOTOGRAPH:

North Dike, facing east at Bath Slough Pump Station

4.2.13 INDUSTRIAL NORTH EAST 3

The Industrial NE 3 design area is entirely industrial. River Road abuts the waterfront and provides access to substantial parking lots for associated industrial sites and businesses. There are large ditches along the south side of River Road. No major changes to this area are presented in the OCP.

River Road is currently the dike in this design area. Large natural areas along the waterfront host mature trees, primarily on the north side of the dike. There is also smaller, less established vegetation along the south side of River Road. It is anticipated that the entire road must be raised to implement dike crest increases.

A lumber yard occupies a substantial part of this design area. The City has a ROW through the site over the River Road alignment, however access is blocked off with gates at either end of the lumber yard site. The waterfront trail is also currently blocked off through this area. If ever this site is redeveloped, dike adaptations may be pursued concurrently. However, no major changes to this industrial area are anticipated in the near future.

LOCATION:

Knight Street Bridge to No. 6 Road

RECOMMENDATION:

Raise the dike on the existing alignment. Additional studies required to quantify drainage, habitat impacts, and costs associated with land side expansion of a trapezoidal dike. A constrained land side slope may be required to integrate with the existing drainage infrastructure.

ENVIRONMENTAL CONSIDERATIONS:

ENMS Strategy Area

- Fraser River
- Industrial

ESA Habitat Type

- Intertidal
- Shoreline

FREMP Data

- Red-coded
- Green-coded

RMA Presence

- 15m RMA Presence

PHOTOGRAPH:

Conveyor belt over North Dike at No. 6 Road.

4.3 SITE SPECIFIC ADAPTATIONS

Where existing infrastructure conflicts with the recommended flood protection adaptation, a custom design for that site may be required, or the existing infrastructure may be retrofitted to accommodate diking. Infrastructure including but not limited to pump stations, road or railways, bridges or industrial infrastructure may present site-specific constraints that preclude the implementation of the recommended adaptation for the rest of that design area.

Ideally, dike adaptations are pursued when the adjacent lands are redeveloped. Flood protection measures can then be included in the scope of the proposed works. However, existing infrastructure may be suitable for a design life extending far into the future, farther than the City wishes to defer dike adaptations. In these cases, interim adaptations may be pursued.

Site-specific adaptation designs, whether permanent or temporary, should take into account all the considerations listed in *Section 3*.

4.3.1 BRIDGES

Bridges have unique constraints within a design area. The recommended adaptation for a design area may not be feasible at a bridge site, in which case a site-specific adaptation may be designed to be integrated with the standard adaptation on either side of the bridge.

A list of bridges and the particular constraints that may guide a site-specific adaptation is presented in *Table 6* below. Note that the recommended adaptation strategies in the table are recommended based on adaptations proceeding in advance of any bridge upgrades or replacement. If any bridges are to be upgraded or replaced, flood protection measures at the bridge site should be included within the scope of work.

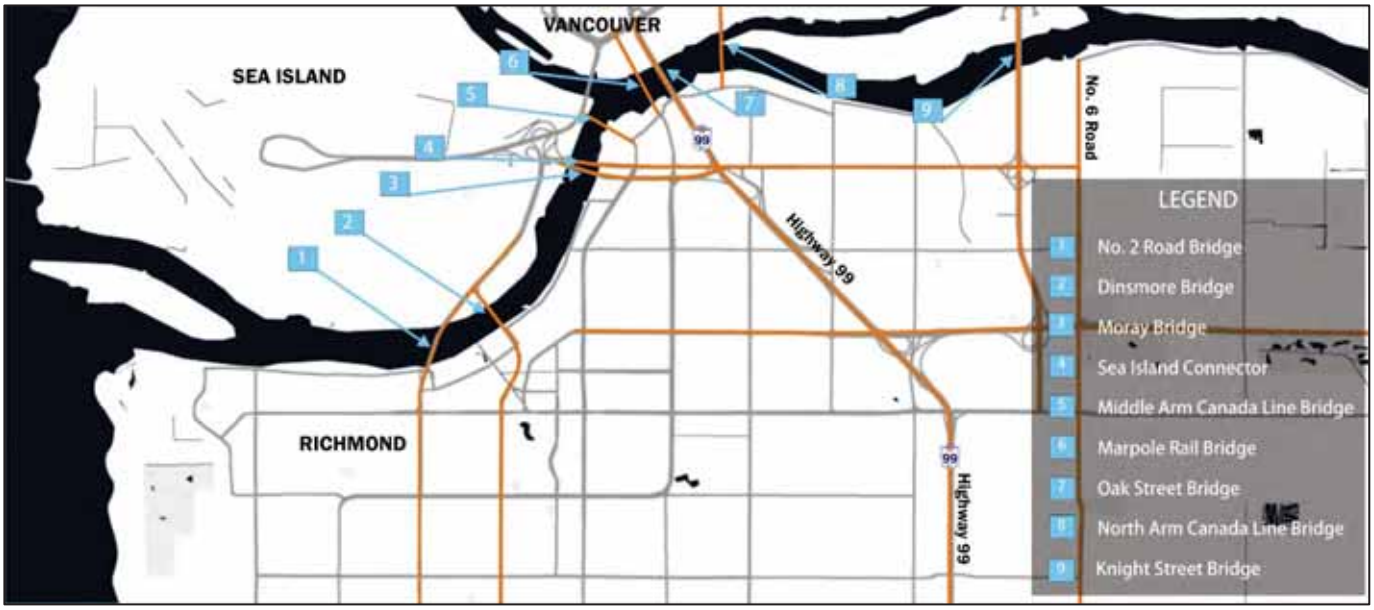
Table 6: Bridge Constraints and Recommended Adaptations

BRIDGE NAME (OWNERSHIP, BRIDGE TYPE)		
AREA	**CONSTRAINTS AND CONDITIONS**	**RECOMMENDED ADAPTATION STRATEGY**
1) NO. 2 ROAD BRIDGE (CITY OF RICHMOND, ROAD)		
Oval	• Bridge deck is low. • Footings are under the existing dike. • Bridge crosses over River Road. • Bridge crosses over dike trail. • Bike ramp to bridge from dike trail sensitive to grade changes.	Tied to abutments
2) DINSMORE BRIDGE (CITY OF RICHMOND, ROAD)		
Oval	• Bridge deck is low. • Footings are under the existing dike. • Bridge crosses over River Road with 4.3m clearance. • Bridge crosses over dike trail.	Tied to abutments
3) MORAY BRIDGE (CITY OF RICHMOND, ROAD)		
City Centre 1	• Bridge deck is very low. • Existing dike is inland, not under the bridge. • Bridge does not cross any road or trail. • No waterfront trail currently exists under the bridge. • Existing dike is aligned over the bridge.	Tied to abutments
4) SEA ISLAND CONNECTOR (CITY OF RICHMOND, ROAD)		
City Centre 1	• Bridge deck is very low. • Existing dike is inland, not under a bridge. • Bridge does not cross any road or trail. • No waterfront trail currently exists under the bridge. • Existing dike is aligned over the bridge.	Tied to abutments

BRIDGE NAME (OWNERSHIP, BRIDGE TYPE)		
AREA	**CONSTRAINTS AND CONDITIONS**	**RECOMMENDED ADAPTATION STRATEGY**
5) MIDDLE ARM CANADA LINE BRIDGE (TRANSLINK, RAIL)		
Duck Island	• None	Under span
6) MARPOLE RAIL BRIDGE (CP RAIL, RAIL)		
Duck Island	• Bridge deck is low. • Timber trestle bridge; minimal space between footings. • Not currently operational. • Repairs required to return bridge to operational conditions. • CP Rail's intentions for future use are unknown.	Tied to abutments
7) OAK STREET BRIDGE (BC MINISTRY OF TRANSPORTATION, ROAD)		
Duck Island	• None	Under span
8) NORTH ARM CANADA LINE BRIDGE (TRANSLINK, RAIL)		
Industrial	• None	Under span
9) KNIGHT STREET BRIDGE (TRANSLINK, ROAD)		
Industrial NE2	• None	Under span
10) PROPOSED BURKEVILLE PEDESTRIAN BRIDGE (CITY OF RICHMOND, PEDESTRIAN)		
City Centre 1	• Proposed bridge design has not yet been prepared. • Diking to be incorporated when design proceeds.	N/A

The locations of all bridges listed in *Table 6* are shown in *Figure 10.*

Figure 10: Bridges in the Study Area



4.3.2 RAISE RIVER ROAD

In the Thompson Terra Nova and Thompson Dover areas, River Road is immediately adjacent to the existing dyke; however, is constructed at a lower elevation to match the existing developed area. It is anticipated that land-side expansion of the existing dike will encroach on River Road. As such, the City should consider raising the grade of River Road from Cornwall Drive to No. 2 Road. The area identified for this strategy is show in *Figure 11*.

Figure 11: Raising River Road in the Thompson Neighbourhood

The benefits to long-term flood protection assocated with raising River Road include:

- Improves dike stability and seepage performance;
- Reduce requirement for water-side expansion and impacts to environmental habitat;
- Promotes the long-term increase in site grades for redevelopment of the Thompson Residential Area; and,
- Facilitates future dike crest increases or overbuilding of the existing dike height to accommodate settlement during a seismic event.

Challenges to raising River Road will include:

- Maintaining driveway access and for the single family residential developments;
- Tieing the raised River Road into adjacent streets;
- Addressing settlement concerns with underground utilities;
- Planning to cost-effectively stage incrementally raising of River Road; and,
- Addressing potential impacts to RMA's and ESA's.

Raising River Road is then a very long-term strategy to assist with achieving higher waterfront land elevations, and minimize future waterside works to achieve higher crest elevations.

5 Timing of Adaptation Projects

Implementation of adaptations is best pursued alongside adjacent works. For example, when adjacent lands are being developed, dike adaptations can be included in the scope of site redevelopment. If there are substantial works to an area that are upcoming, the City may choose to implement an interim adaptation until those adjoining works proceed.

5.1 REDEVELOPMENT OF SMALL LOTS

Small lots with narrow frontages are highly constrained by grading. There must be adequate lands available to raise a dike immediately to the target crest elevation. In areas where lot sizes are too small to implement adaptations that may immediately achieve the dike crest elevation, lands can be incrementally raised by raising the lots in small intervals each time it is redeveloped. Similarly, the frontage road can be raised by a practical interval whenever substantial road rehabilitation works proceed. This is a very long-term strategy.

The ground elevation of individual lots may be raised as they are redeveloped, however the grading will be constrained by matching neighbouring ground elevations, as well maintaining driveway access to the road. If the road is also raised, then individual lots can be raised higher, however existing lots at relatively low elevations must still have driveway access to the road. This limits the overall height that the frontage road can be raised. Over time, the frontage road and adjoining lots are raised at different times. In this way, the road and surrounding lots are raised in steps. In the very long term, the overall land elevation can be raised to the target dike crest elevation using this strategy. The City may pursue interim adaptations if a greater level of flood protection is deemed to be required before the lands can be raised to the specified elevation.

Where flood protection will be integrated with redevelopment, lot consolidation is preferred to minimize impacts associated with tying in to neighbuoring properties.

5.2 LAND ACQUISITIONS & LEGAL ACCESS

The City may need to acquire property where development is immediately adjacent to the waterfront, and bound on the land side by roads, buildings or other assets. Obtaining a sufficient ROW from some properties for diking may effectively sterilize the lot, leaving insufficient space available for development. In those instances, the City may need to acquire the entire property in order to implement dike adaptations. The riverfront lots between Shell Road and No. 5 Road may be candidates for acquisition when dike upgrades proceed in that area, depending on land requirements to implement dike upgrades.

The City should acquire easements where dikes are being constructed on private property. All adaptations on private lands depend on the City being able to secure legal access to the property in order to maintain them.

5.3 RAISING THE TARGET DIKE CREST ELEVATION

The City should monitor sea level rise to pursue flood protection adaptations when higher dike crest elevations become necessary. Presently, all adaptations will be designed to meet the 4.7 m target crest elevation, with consideration for an increase to 5.5 m. Depending on whether sea level rise predictions materialize, the City may wish to raise the target dike crest elevation.

5.4 INTERIM ADAPTATIONS

Temporary adaptations, such as a demountable floodwall, may be necessary where existing conditions are constrained by existing infrastructure (such as bridges, roads, ditches, or buildings) that cannot be impacted or modified to make way for diking. Temporary adaptations may also be pursued in instances where the City cannot yet secure adequate lands or capital to implement the ultimate adaptation.

The timeline until the ultimate adaptation can be implemented should be considered when allocating resources to temporary works. For example, if the interim adaptation will only be in place for a period of a few months, it it likely not worth investing substantial resources into it. Interim adaptations may be considered if necessitated by sea level rise or any other increase in flood risk.

Compatibility with the ultimate adaptation should be considered in the design of any interim adaptation. An interim adaptation should be easily decommissioned, or able to remain in place indefinitely without interfering with the ultimate

adaptation or any other land use. The ultimate adaptations are anticipated to be implemented alongside concurrent waterfront works, as noted in *Table 7*.

Table 7: Triggers to Implementation of Adaptations

AREA	EXISTING	SUMMARY OF RECOMMENDED ADAPTATION	TRIGGER TO IMPLEMENTATION OF RECOMMENDED ADAPTATION
Steveston	Earthfill Dike	Raise Dike on Existing Alignment & Consider Construction of Barrier Islands	City Initiative
Seafair	Earthfill Dike	Raise Dike on Existing Alignment & Consider Construction of Barrier Islands	City Initiative
Terra Nova	Earthfill Dike	Raise Dike on Existing Alignment & Consider Construction of Barrier Islands	City Initiative
Thompson Terra Nova	Earthfill Dike	Raise Dike on Existing Alignment & Plan for Long-term Raising of River Road	River Road is Reconstructed
Thompson Dover	Earthfill Dike	Raise Dike on Existing Alignment & Plan for Long-term Raising of River Road	River Road is Reconstructed
Oval	Superdike	Complete	N/A
City Centre 1	Earthfill Dike	Raise Dike at Waterfront or Set Back & Fill Adjoining Lots to Superdikes	Development of Middle Arm Park
City Centre 2	Earthfill Dike	Raise Dike on Existing Alignment & Fill Adjoining Lots to Superdikes	Redevelopment
Duck Island	Varies	Implement Recommendations of Approved Developer's Plan	Approval of Developer's Plan
Industrial	Varies	Raise Dike on Existing Alignment	Redevelopment of Fraser River Terminal
Bridgeport Tait	Superdike	Complete	N/A
Industrial North East 1	Earthfill Dike	Raise Dike on Existing Alignment	Assembly of Sufficient Lands to Implement Dike Upgrades
Industrial North East 2	Earthfill Dike	Raise Dike on Existing Alignment	Rehabilitation of River Road or Redevelopment of Industrial Sites
Industrial North East 3	Earthfill Dike	Raise Dike on Existing Alignment	Rehabilitation of River Road or Redevelopment of Industrial Sites

6 Implementation Opportunities

Dike upgrades are best undertaken alongside alterations to adjacent lands and infrastructure. In addition to the examples of concurrent infrastructure development noted in the sections above, dike adaptations may present opportunities to implement projects strategically to accomplish other City goals.

6.1 WATERFRONT TRAIL SYSTEM

The City's Parks Planning and Design (Parks) department has identified a goal to improve public access to the waterfront. Recreational trails and linear parks should be considered wherever dikes are modified. Even where waterfront trails are

already present, there may be an opportunity to increase waterfront access by improving trails with ramps or paved surfaces. Dike trails should remain accessible to people using mobility aids, such as wheelchairs or strollers.

The Parks department's preference is to have a trail directly adjacent to the water, without any rerouting inland, even if this means trails are sometimes flooded.

6.2 INTERTIDAL ZONES

Dike adaptations that proceed alongside the development of waterfront parks may be suited to the concurrent development of intertidal zones, to create additional habitat. The local ecosystem's productivity may be increased by providing a rich riparian environment. These intertidal zones may be integrated with the typical foreshore rip rap or other erosion protection by insetting habitat at lower elevations to be closer to the daily water level, and flooded during high water events. Projects incorporating the development of intertidal habitat may be designated as compensation sites for alterations required in environmentally sensitive areas.

6.3 HABITAT BANKING

As the Study Area lies within intertidal, shoreline and upland riparian habitat, environmental impact may be unavoidable. Environmental assessments and valuation will be undertaken in the design construction phase, where possible habitat impact will be avoided. Where impact cannot be avoided, efforts will be made to mitigate, and if necessary compensate for impact following a net gain approach. To achieve a net gain approach to compensation the City may consider establishing a formal habitat banking program. Habitat banking guidelines should articulate appropriate compensation ratios by habitat type, monitoring periods and success measures for created or enhanced habitat. Additionally a hierarchy of compensation options may be considered that replaces habitat types in order of priority as follows:

- Create or increase productive capacity of like for like habitat within the same ecological unit;
- Create or increase the productive capacity of unlike habitat in the same ecological unit; and
- Create or increase the projective capacity of habitat in a different ecological unit.

Habitat credits could be applied to multiple projects, or stored for future dike works. A formal habitat banking program may assist with the implementation of long term flood protection infrastructure upgrade programs.

7 Recommendations

Key recommendations for the Phase 2 LIDMP Study Area are outlined as follows:

1. Plan to raise the existing dike on its existing alignment.

   The existing dike alignment along the waterfront is established and well defined. There is limited basis to support any major changes to the alignment of the existing dike, thus the recommendations are generally in keeping with traditional dike crest increases, with consideration for area specific constraints and opportunities.

2. Prepare conceptual level designs for the West Dike upgrades and conduct drainage and environmental studies on the alternatives.

   Future crest height increases to the West Dike will required landside or waterside expansion. Both will have impacts to either intertidal, or upland riparian habitat. Environmental impacts should be quantified, and an approach of avoid, mitigate, and compensate following a net gain approach should be used to in evaluating the preferred strategy.

   Landside expansion will impact drainage infrastructure. Impacts should be quantified to identify potential internal drainage network upgrades required if landside expansion is the preferred alignment.

3. Continue to monitor sea level rise.

   Design crest height elevations are selected with consideration for climate change and sea level rise predictions. The City should continue to monitor sea level rise and adjust crest height targets and City flood protection police as required to address any changes in predicitons.

4. Plan to establish a habitat banking program for dike improvement projects.

   Where impact to habitat cannot be avoided, efforts will be made to mitigate, and if necessary compensate for impacts following a net gain approach. To achieve a net gain approact to compensation, the City may consider establishing a formal habitat banking program. Habitat banking guidelines should outline appropriate compensation ratios by habitat type, monitoring periods, and success measures.

5. Plan for implementation of offshore protection along the West Dike as a response to climate change and sea level rise.

   Sea level rise and upland limitations to natural accretion within the Sturgeon Bank WMA could result in increased offshore depths beyond the West Dike, which could simultaneously increase wave heights reaching the West Dike. Offshore barrier islands are one option to consider to dissipate wave energy prior to reaching the west dike, thereby minimizing future dike crest increases.

   With appropriate environmental consideration during design and construction, breakwaters and barrier islands can create intertidal habitat, such as sand flats, mud flats, salt marsh and eelgrass beds. These features can assist with erosion and wave attenuation. The intertidal habitat can work in combination with a constructed flood control structures like dikes and floodwalls, to mitigate flood risk.

   The City should continue to coordinate with relevant agencies including (Port of Vancouver, Fisheries and Oceans Canada, and others) to research and identify opportunities to improve flood protection and enhance interdital habitats in the Sturgeon Bank WMA and throughout the Fraser River Estuary.

6. Plan to raise River Road in the Thompson neighborhood.

   The existing dike in the Thompson Neighborhood is confined by the Fraser River and River Road. Increasing the grade of River Road will improve dike stability and resilence; and minimize requirement to expand the dike into the Fraser River. The City should plan to incrementally raise River Road.

7. Consider aquiring land to accommodate future dike construction between Shell Road and No. 5 Road.

   Land acquisition may be required to accommodate construction of a future trapezoidal dike between Shell Road and No. 5 Road. It is anticipated that acquisition will primarily be achieved through redevelopment, however, where redevelopment does not occur; the City may consider opportunistic land purchase to accommodate future dike crest height increases in the area. Plan to complete a conceptual design of the future dike through the constrained area to verify the future dike footprint.

8. Plan for the long-term raising of lands adjacent to and inland of the existing dikes.

   Long term raising of land levels has previously been recommended (2008-2031 Flood Protection Strategy). Maximizing the width of raised land adjacent to the river decreases flood and seismic risks by increasing the integrity of the dike. Plan to raise the ground elevation of waterfront development sites to the prescribed dike crest elevation.

9. Support site assemblies along the waterfront that promote cohesive adaptations for flood protection.

   Large developments along the waterfront allow for major improvements to flood protection infrastructure and often result in robust superdike conditions.

10. Consider enhanced floodproofing through amendments to the FCL Bylaw

The City's Flood Construction Level (FCL) Bylaw establishes minimum levels to which land needs to be raised. Amending the FCL bylaw is the recommended area wide strategy to regulate raising ground elevations with redevelopment to improve flood protection throughout the Study Area. Plan to conduct an assessment on the implementation of a modified FCL bylaw.

11. Facilitate public access to the waterfront.

Integrate new trails and trail improvements with diking projects; provide trails and waterfront recreation areas that are accessible to persons using mobility aids; and, route any new trails along the waterfront instead of rerouting the trail inland.

Regards,

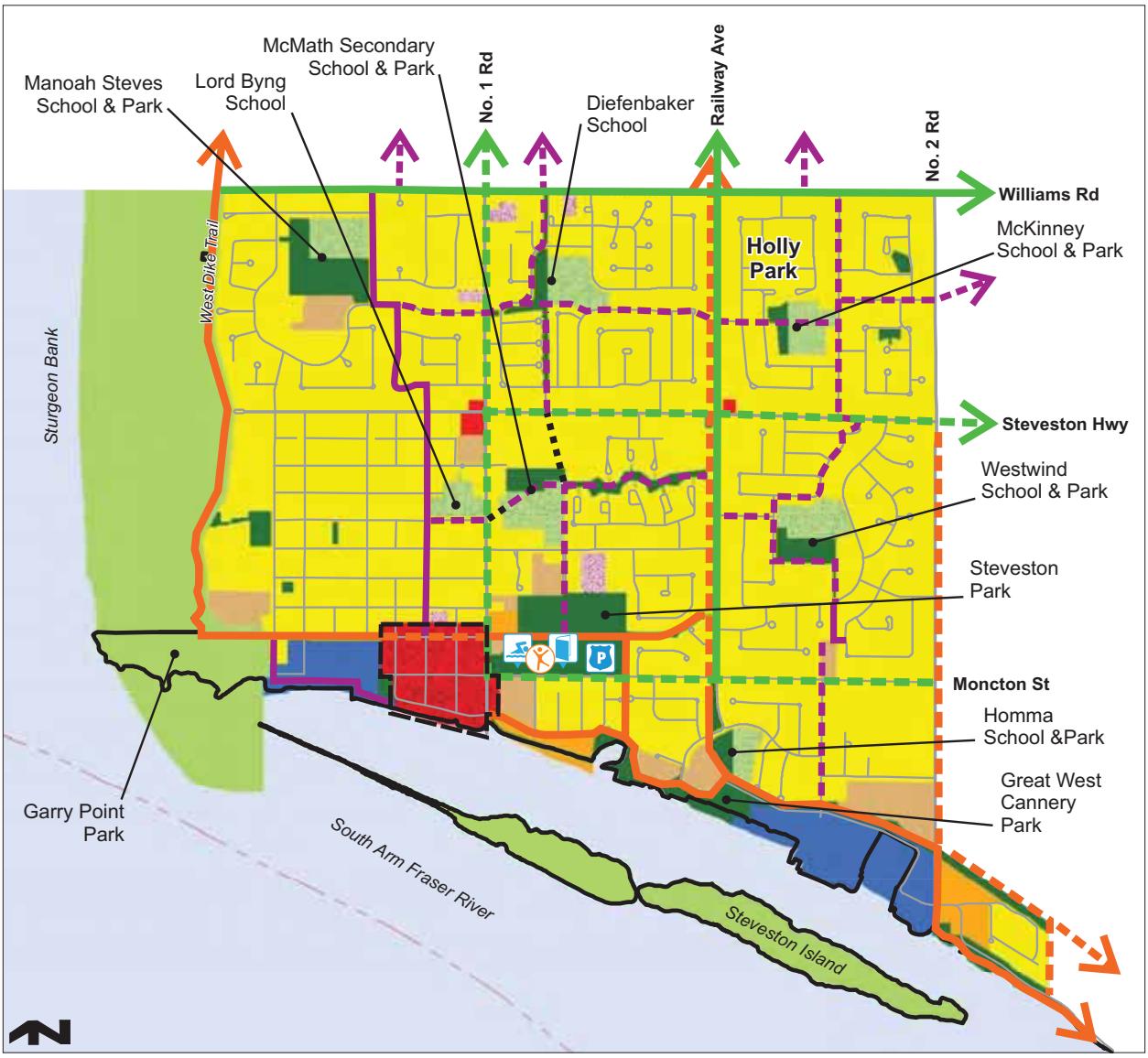
Alex McBride, P.E.
Project Manager

Phil Lobo, P.Eng.
Project Reviewer

Appendix A

Official Community Plan Maps

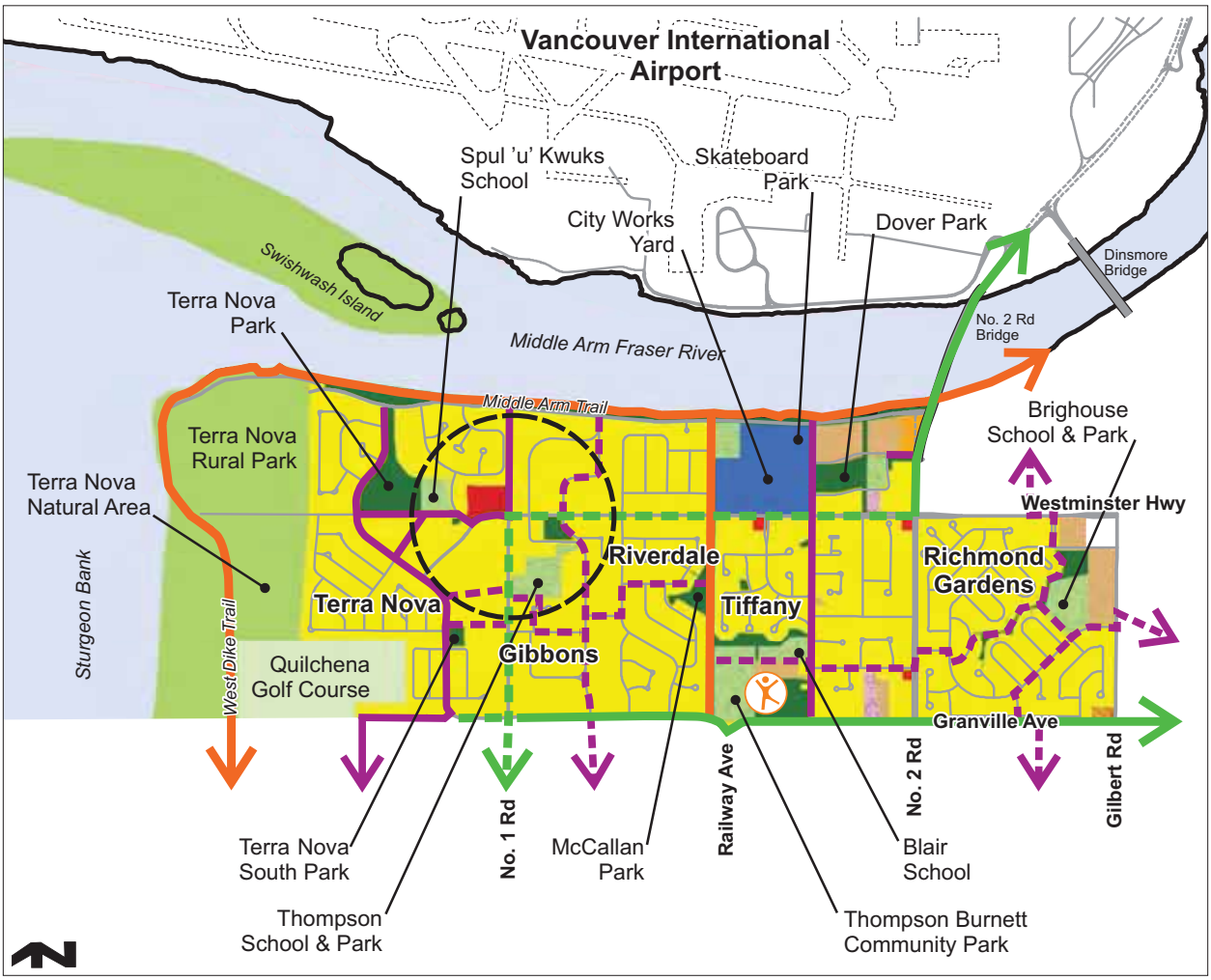
4. Steveston


Manoah Steves School & Park
Lord Byng School
McMath Secondary School & Park
No. 1 Rd
Diefenbaker School
Railway Ave
No. 2 Rd
Williams Rd
McKinney School & Park
Holly Park
West Dike Trail
Sturgeon Bank
Steveston Hwy
Westwind School & Park
Steveston Park
Moncton St
Homma School &Park
Great West Cannery Park
Garry Point Park
South Arm Fraser River
Steveston Island
Apartment Residential
Commercial
Community Institutional
Conservation
Industrial
Mixed Use
Neighbourhood Residential
Neighbourhood Service Centre
Park
School
Steveton Community Centre
Police Steveston Community Station
Steveston Libary
Steveston Pool
Steveston Neighbourhood Centre (future)
Existing Major Street Bike Route
Future Major Street Bike Route
Existing Greenway/Trail
Future Greenway/Trail
Existing Neighbourhood Link - enhanced
Future Neighbourhood Link - unenhanced
Future Neighbourhood Link

3. Seafair

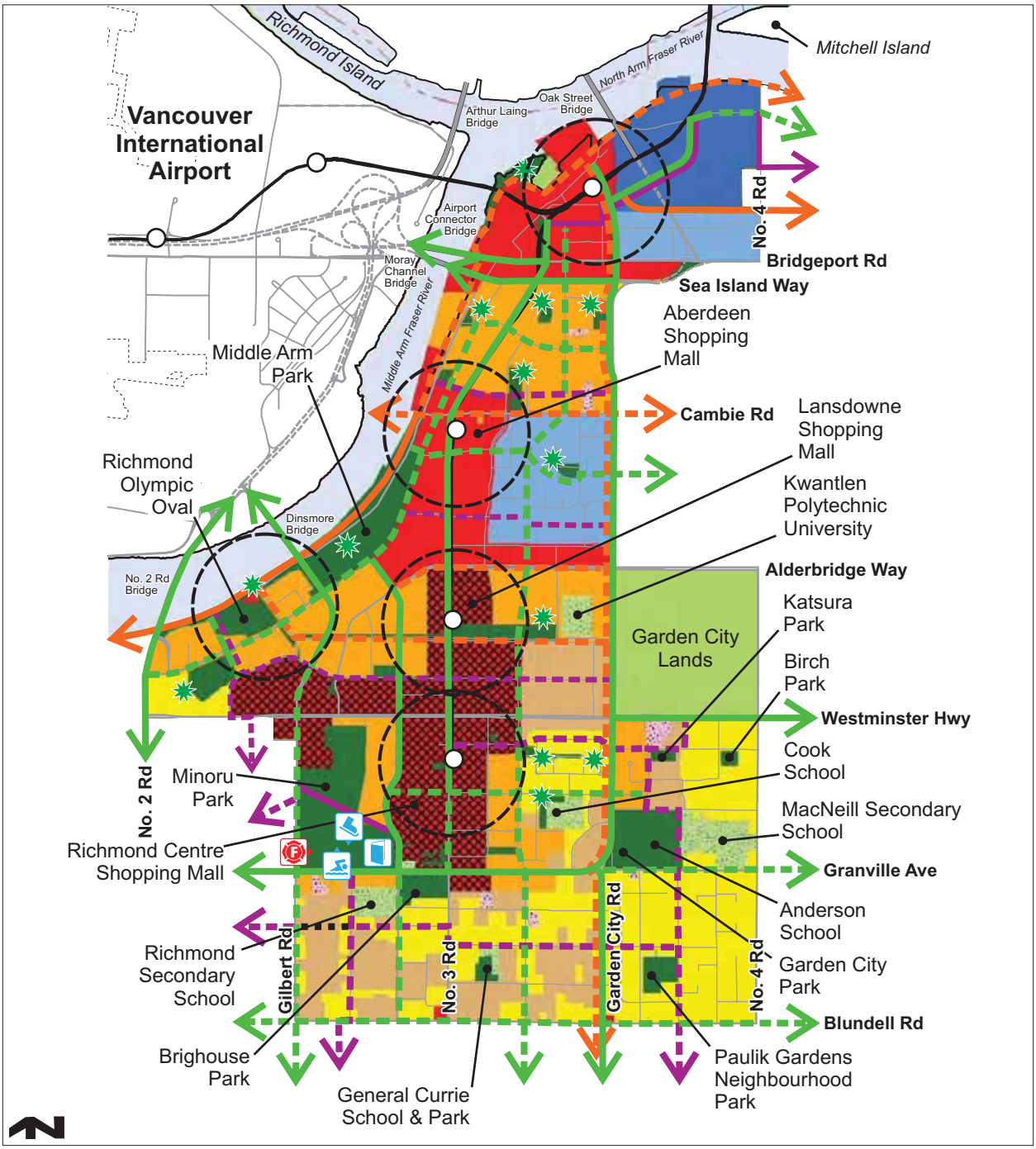

Quilchena School & Park
Morris Park
Granville Ave
Quilchena Golf Course
Quilchena
Blundell Rd
Grauer School & Park
Seafair
Mores
Sturgeon Bank
West Dike Trail
Gilmore School & Park
Francis Rd
Monds
Hugh Boyd Secondary School & Park
Boyd
Williams Rd
Dixon School & Park
No. 1 Rd
Railway Ave
Agricultural
Apartment Residential
Commercial
Community Institutional
Conservation
Neighbourhood Residential
Neighbourhood Service Centre
Park
School
Seafair Neighbourhood Centre (future)
West Richmond Community Centre and Pitch & Putt
Existing Major Street Bike Route
Future Major Street Bike Route
Existing Greenway/Trail
Future Greenway/Trail
Existing Neighbourhood Link - enhanced
Future Neighbourhood Link - unenhanced
Future Neighbourhood Link

2. Thompson



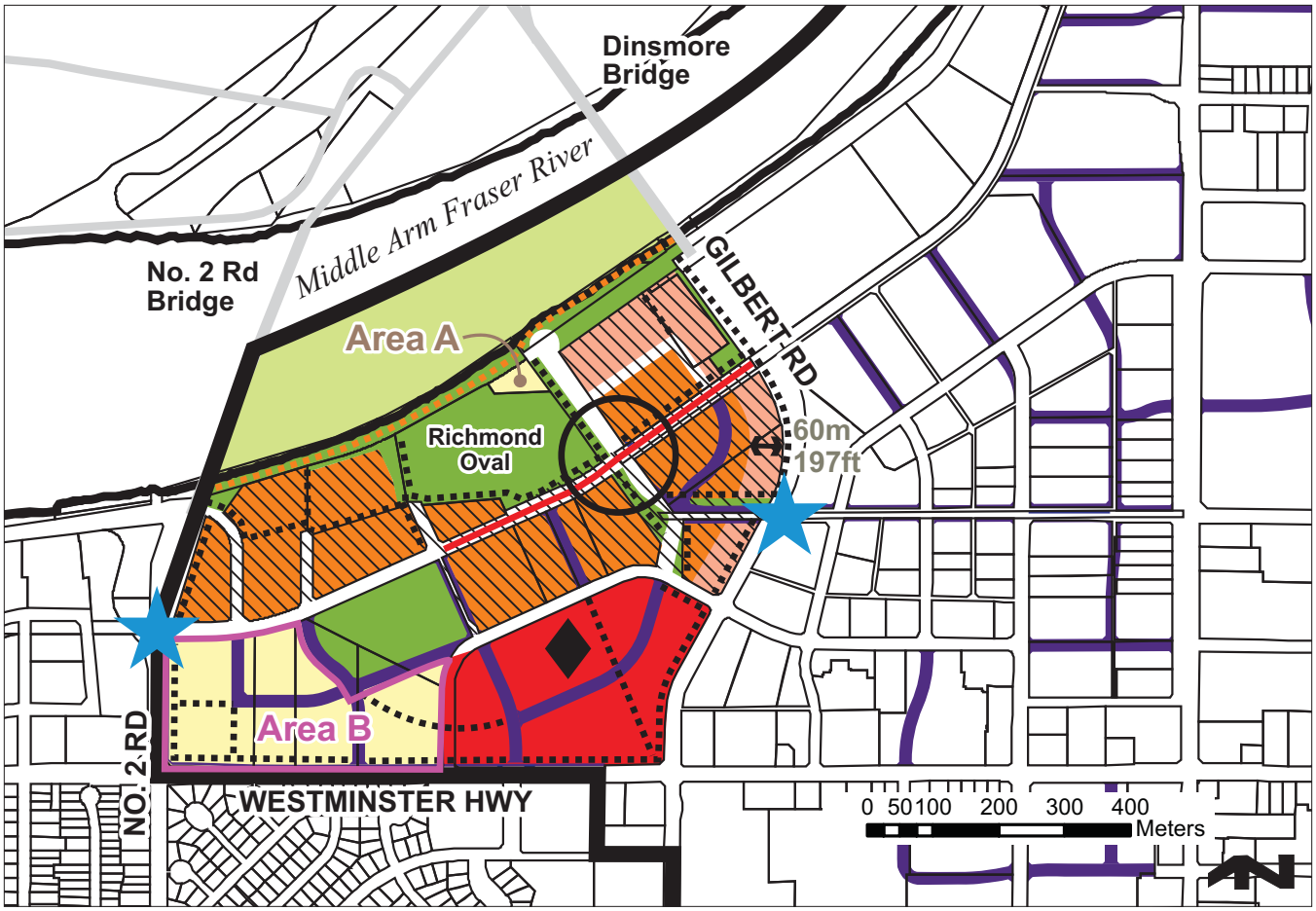
- Agricultural
- Apartment Residential
- Commercial
- Community Institutional
- Conservation
- Industrial
- Limited Mixed Use
- Mixed Use
- Neighbourhood Residential
- Neighbourhood Service Centre
- Park
- School
- Terra Nova Neighbourhood Centre (future)
- Thompson Community Centre
- Existing Major Street Bike Route
- Future Major Street Bike Route
- Existing Greenway/Trail
- Future Greenway/Trail
- Existing Neighbourhood Link - enhanced
- Future Neighbourhood Link - unenhanced

10. City Centre



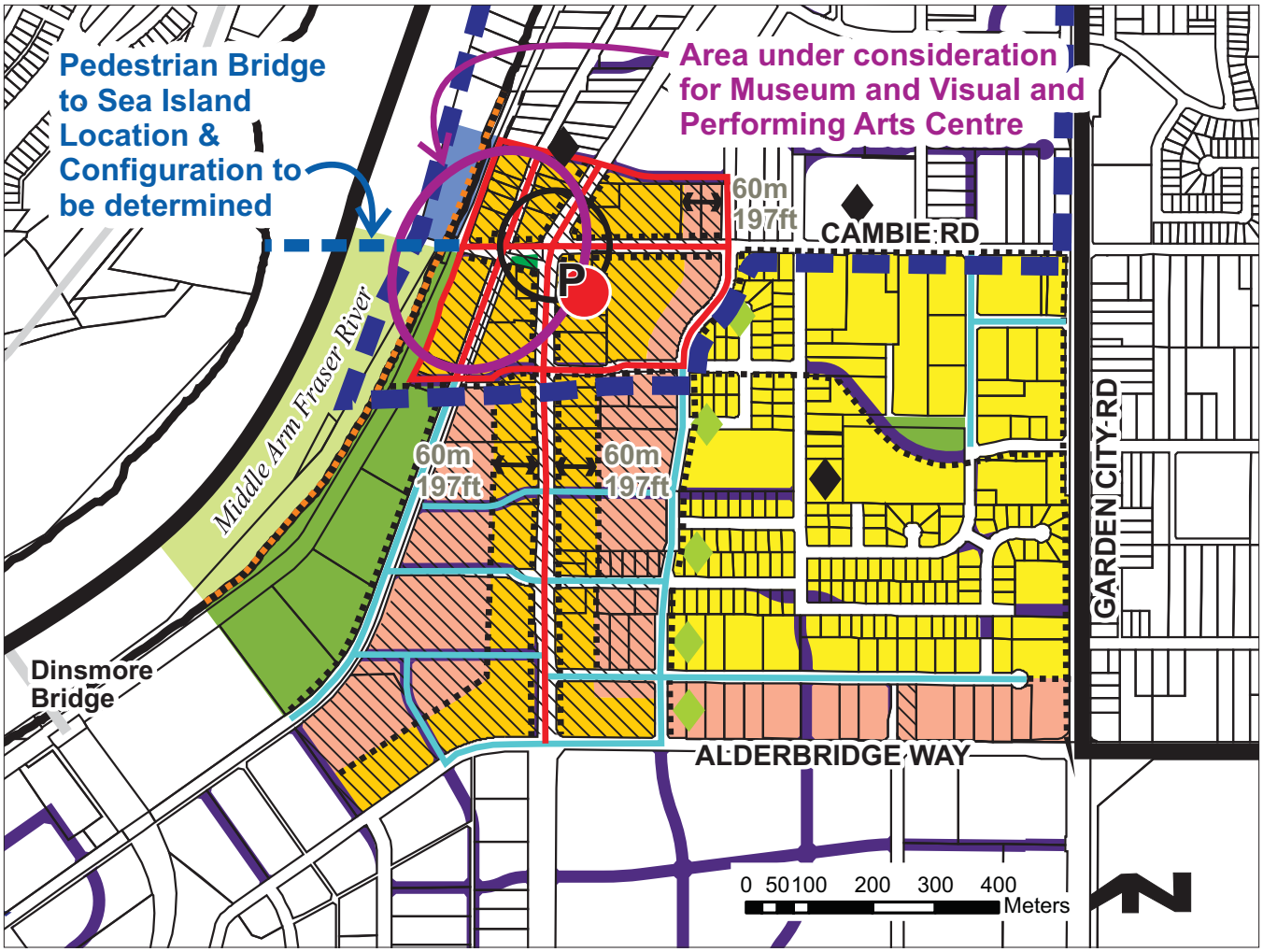
Specific Land Use Map: Oval Village (2031)

Bylaws 8685, 8701 2011/10/24



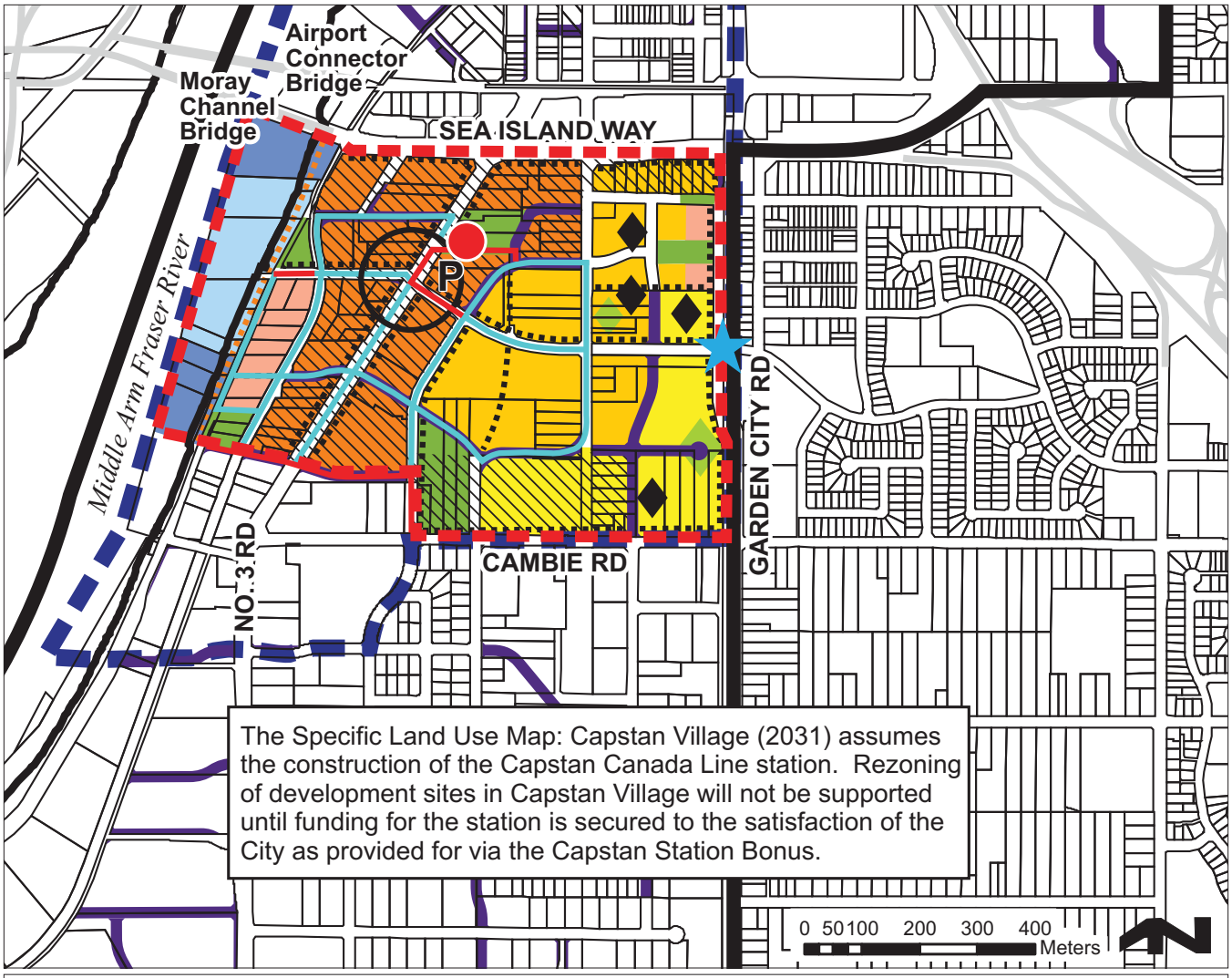
Specific Land Use Map: Aberdeen Village (2031)

Bylaw 8728
2011/07/26



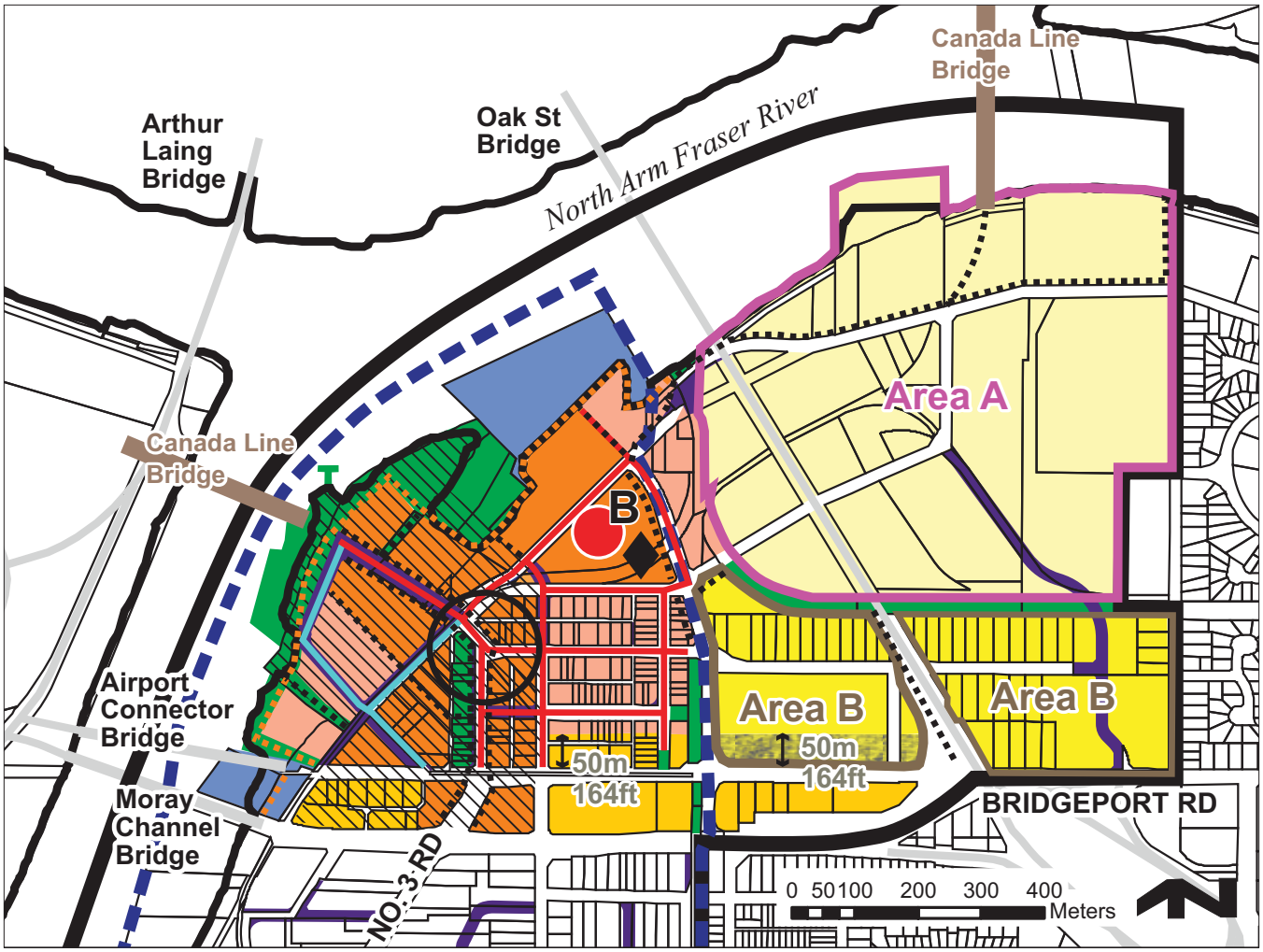
Specific Land Use Map: Capstan Village (2031)

Bylaw 8841
2013/02/12

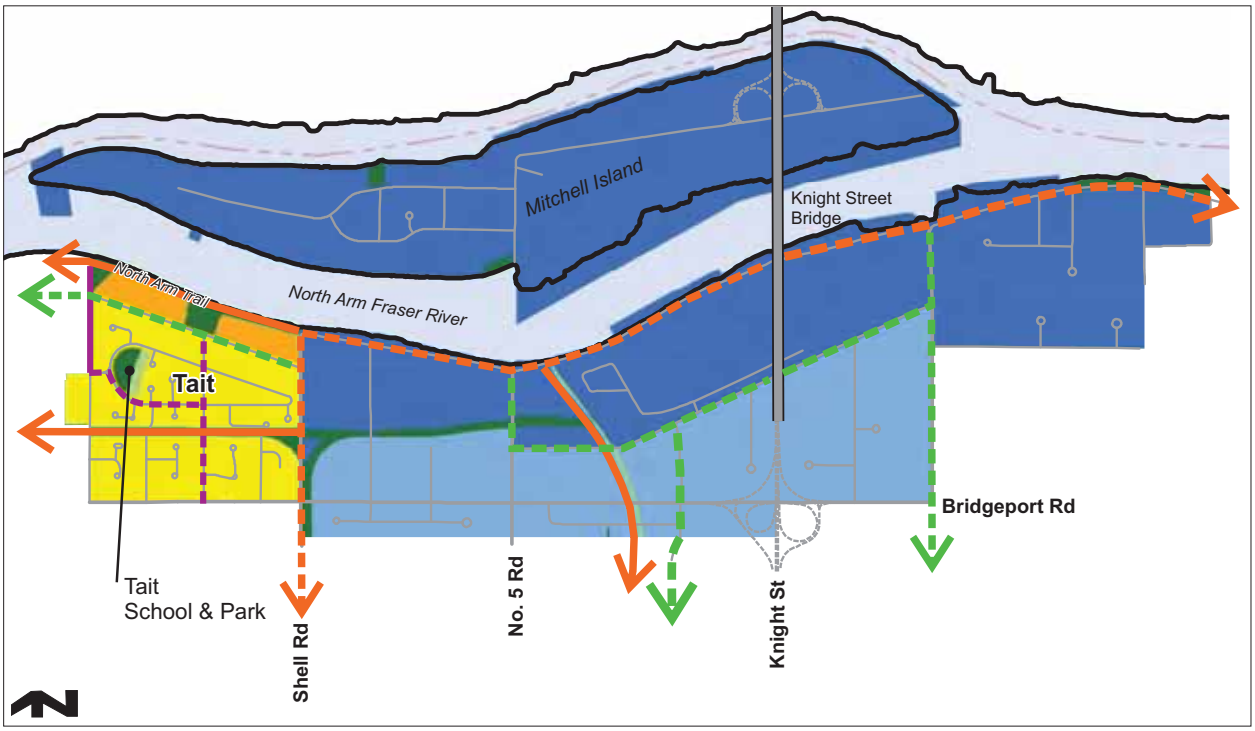


Specific Land Use Map: Bridgeport Village (2031)

Bylaw 9065 2015/07/27

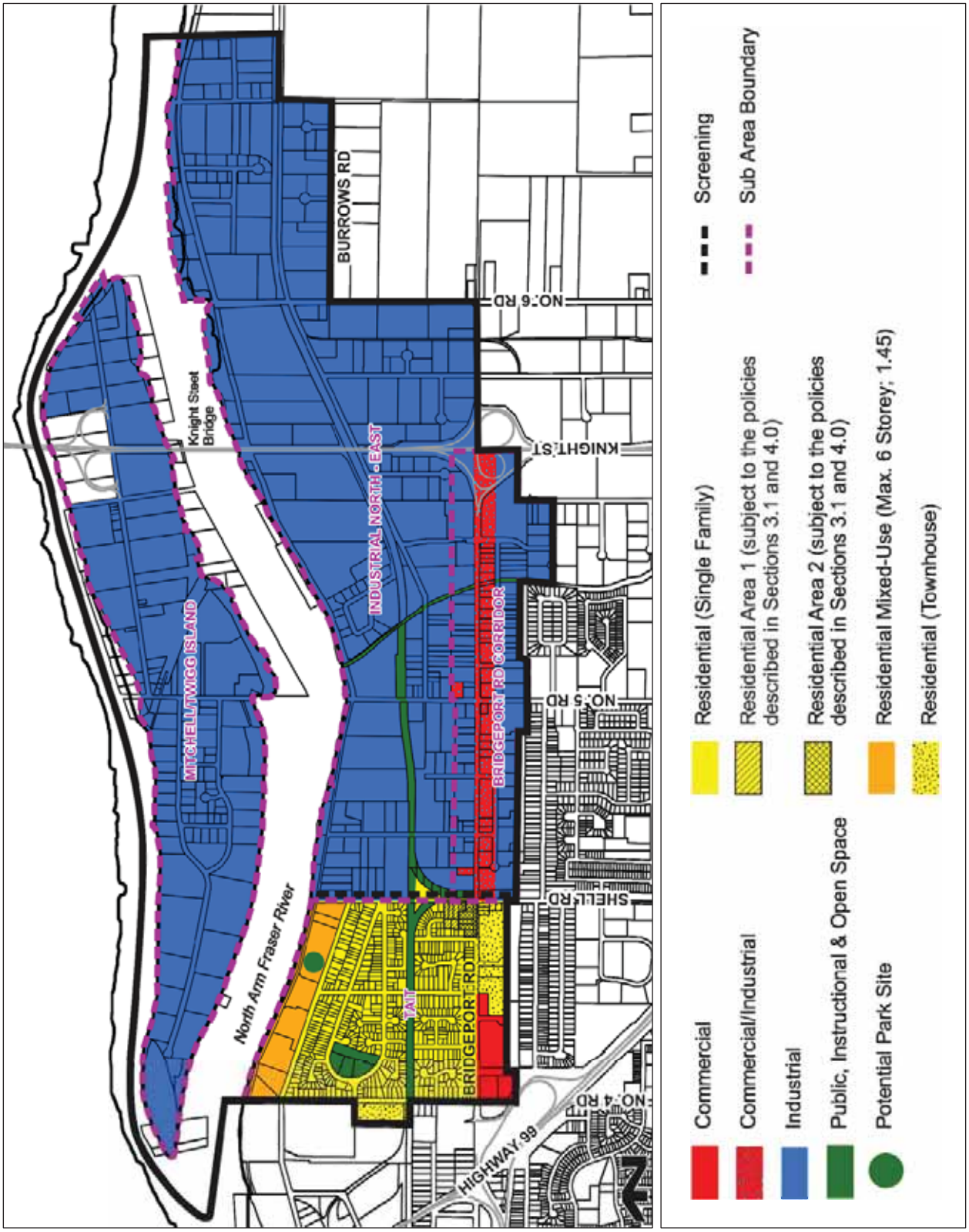


12. Bridgeport (Tait)



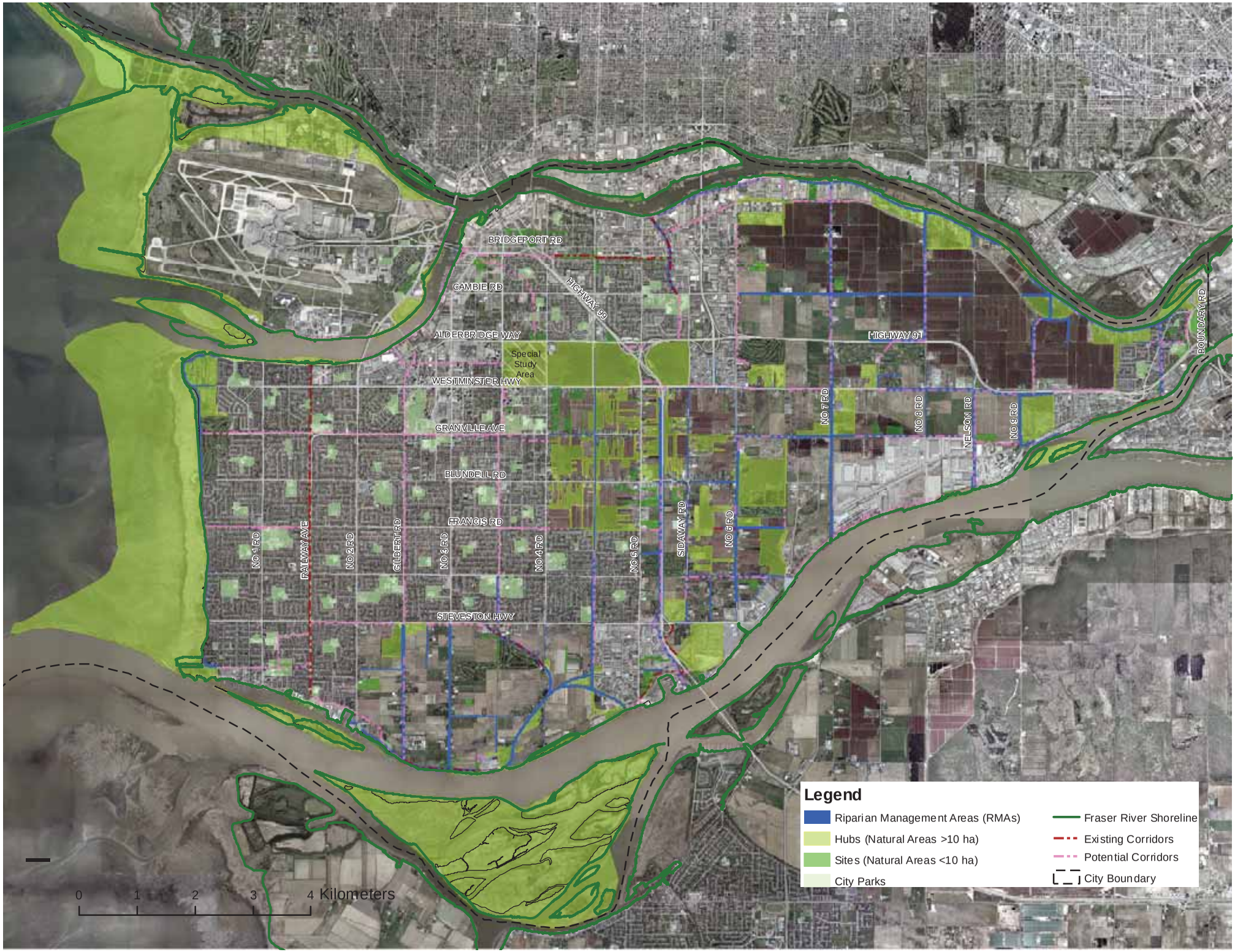
Land Use Map – Bridgeport

Bylaw 9024
2013/11/18



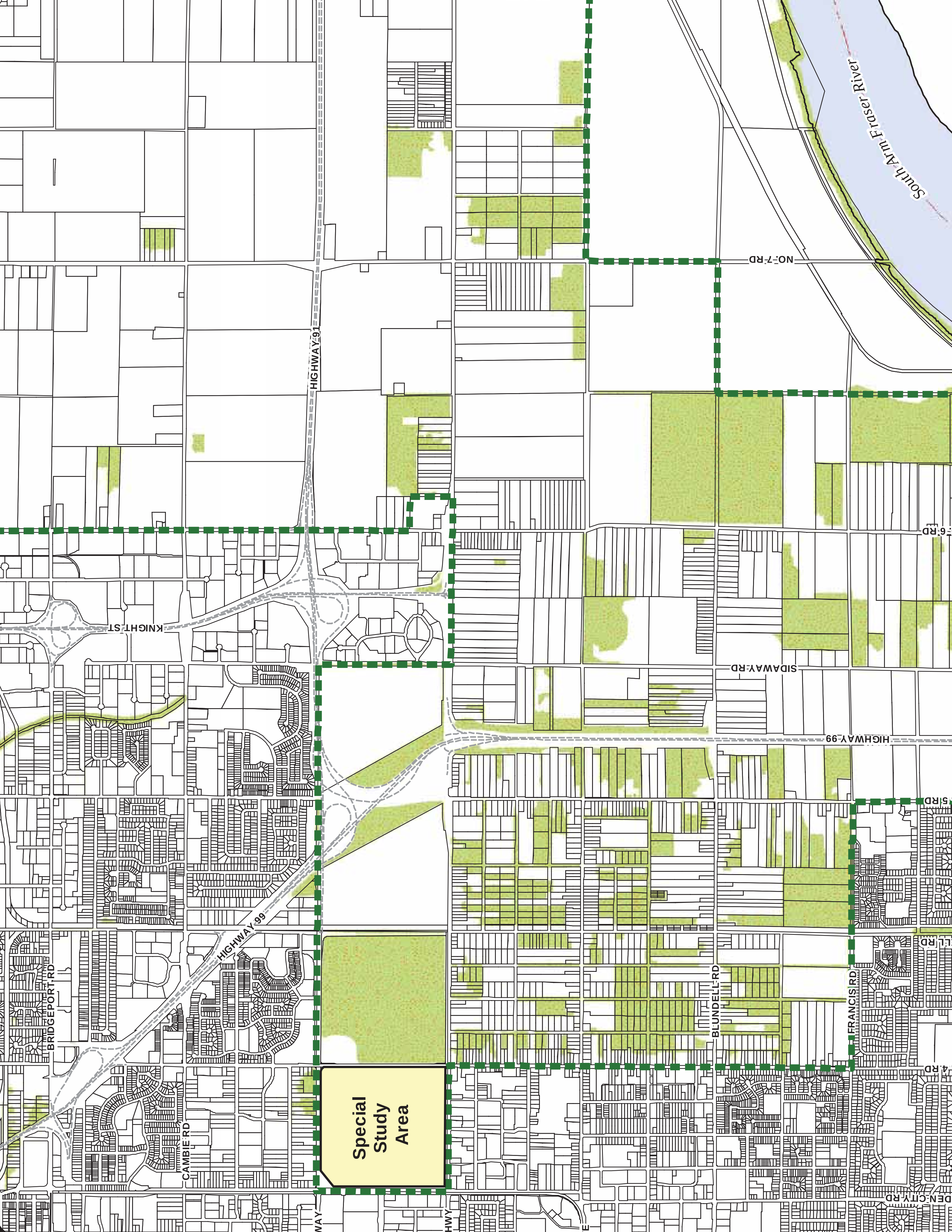
Appendix B

Riparian Management Areas


BRIDGEPORT RD
CAMBIE RD
HIGHWAY 99
ALDERBRIDGE WAY
Special Study Area
HIGHWAY 91
BOUNDARY RD
WESTMINSTER HWY
NO 7 RD
NO 8 RD
NELSON RD
NO 9 RD
GRANVILLE AVE
BLUNDELL RD
FRANCIS RD
NO 1 RD
RAILWAY AVE
NO 2 RD
GILBERT RD
NO 3 RD
NO 4 RD
NO 5 RD
SIDAWAY RD
NO 6 RD
STEVESTON HWY
0 1 2 3 4 Kilometers
Legend
Riparian Management Areas (RMAs)
Hubs (Natural Areas >10 ha)
Sites (Natural Areas <10 ha)
City Parks
Fraser River Shoreline
Existing Corridors
Potential Corridors
City Boundary

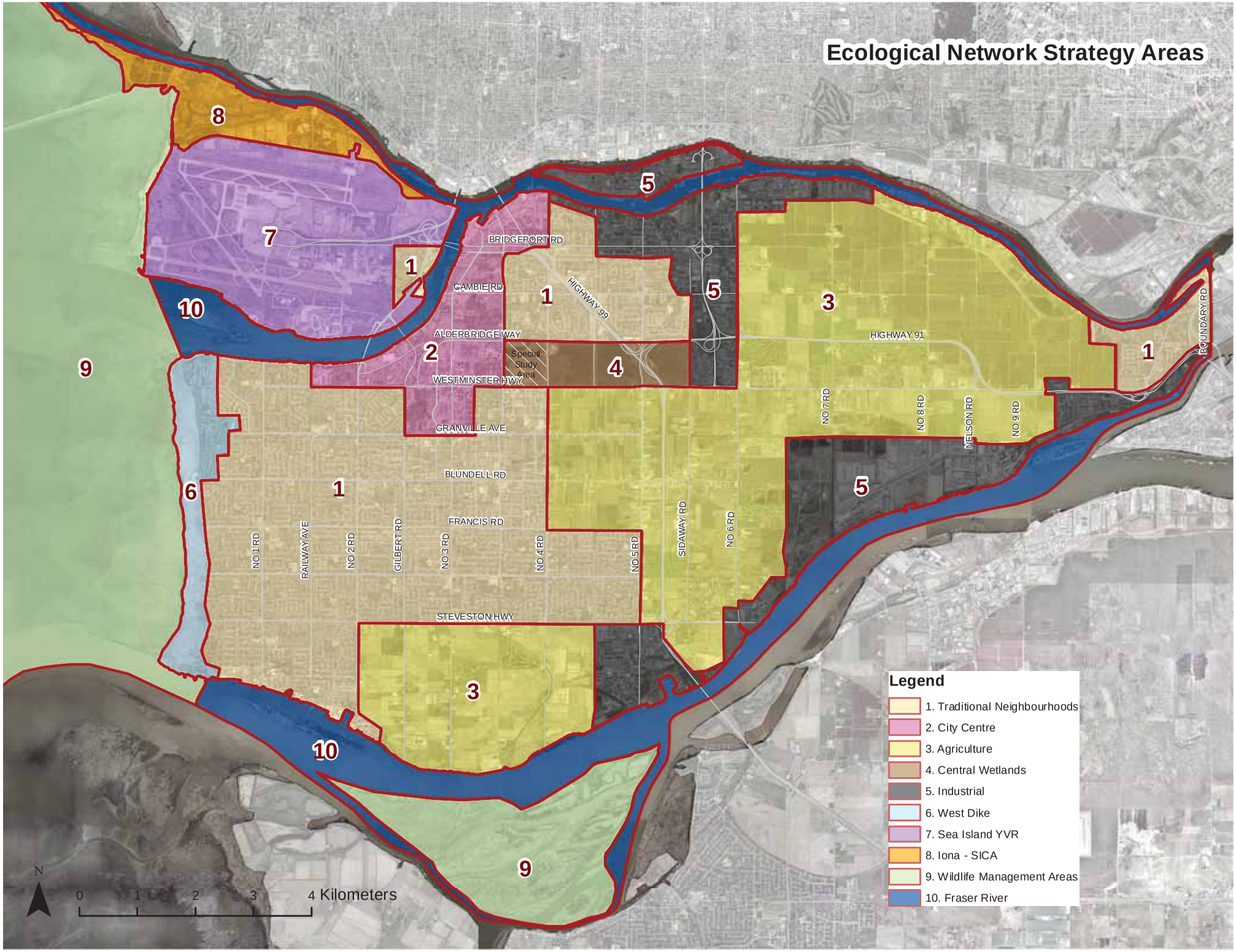
Appendix C

Environmentally Sensitive Areas


South Arm Fraser River
NO 7 RD
HIGHWAY 91
KNIGHT ST
SIDAWAY RD
HIGHWAY 99
HIGHWAY 99
BRIDGEPORT RD
CAMBIE RD
BLUNDELL RD
FRANCIS RD
Special Study Area

Appendix D

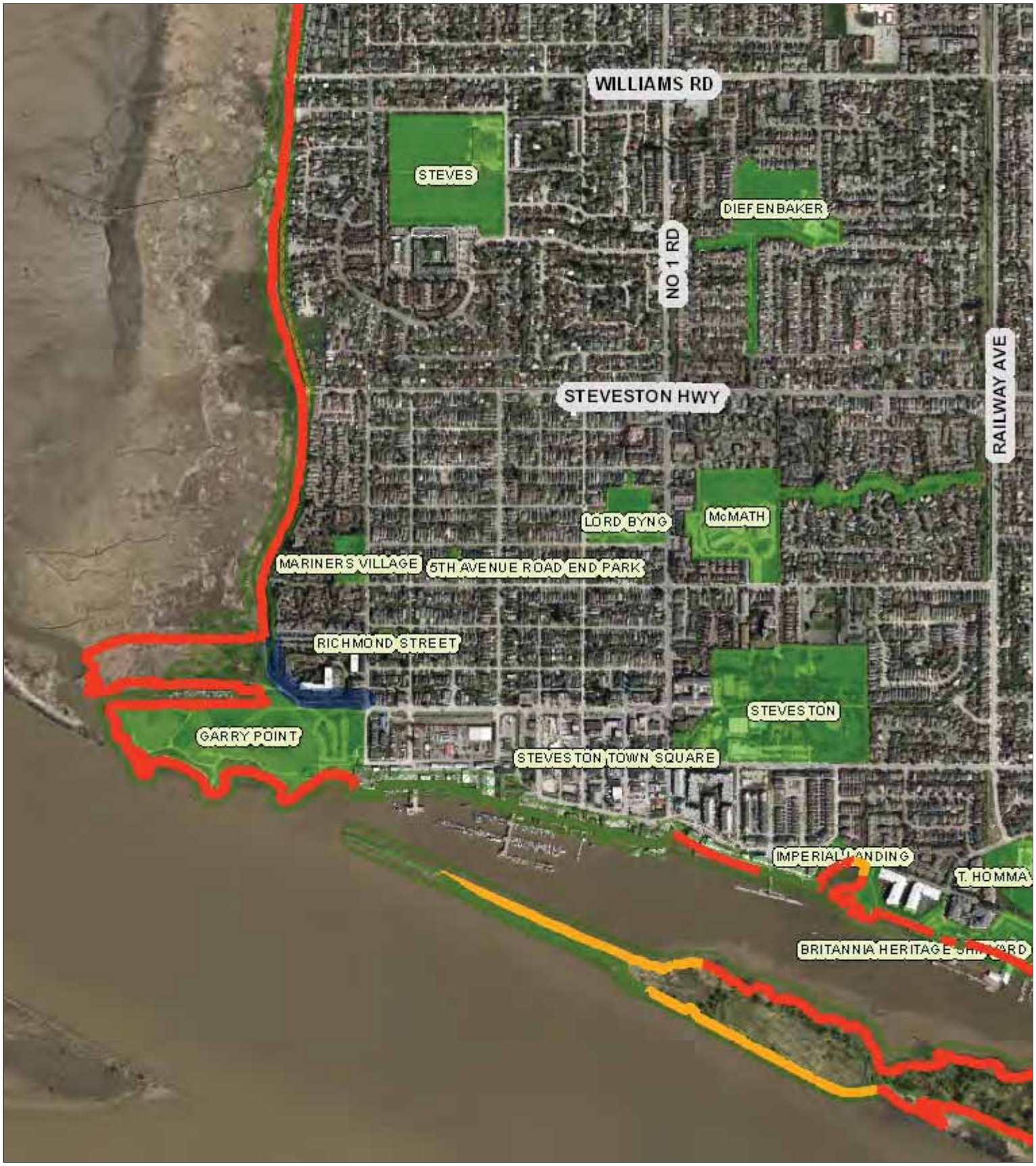
Ecological Network Strategy Areas


Ecological Network Strategy Areas
BRIDGEPORT RD
CAMBIE RD
ALDERBRIDGE WAY
WESTMINSTER HWY
GRANVILLE AVE
BLUNDELL RD
FRANCIS RD
STEVESTON HWY
HIGHWAY 99
HIGHWAY 91
NO 1 RD
RAILWAY AVE
NO 2 RD
GILBERT RD
NO 3 RD
NO 4 RD
NO 5 RD
SIDAWAY RD
NO 6 RD
NO 7 RD
NO 8 RD
NELSON RD
NO 9 RD
BOUNDARY RD
Special Study Area
Legend
1. Traditional Neighbourhoods
2. City Centre
3. Agriculture
4. Central Wetlands
5. Industrial
6. West Dike
7. Sea Island YVR
8. Iona - SICA
9. Wildlife Management Areas
10. Fraser River
N
0 1 2 3 4 Kilometers

Appendix E

Habitat Coding Maps

West Dike Steveston

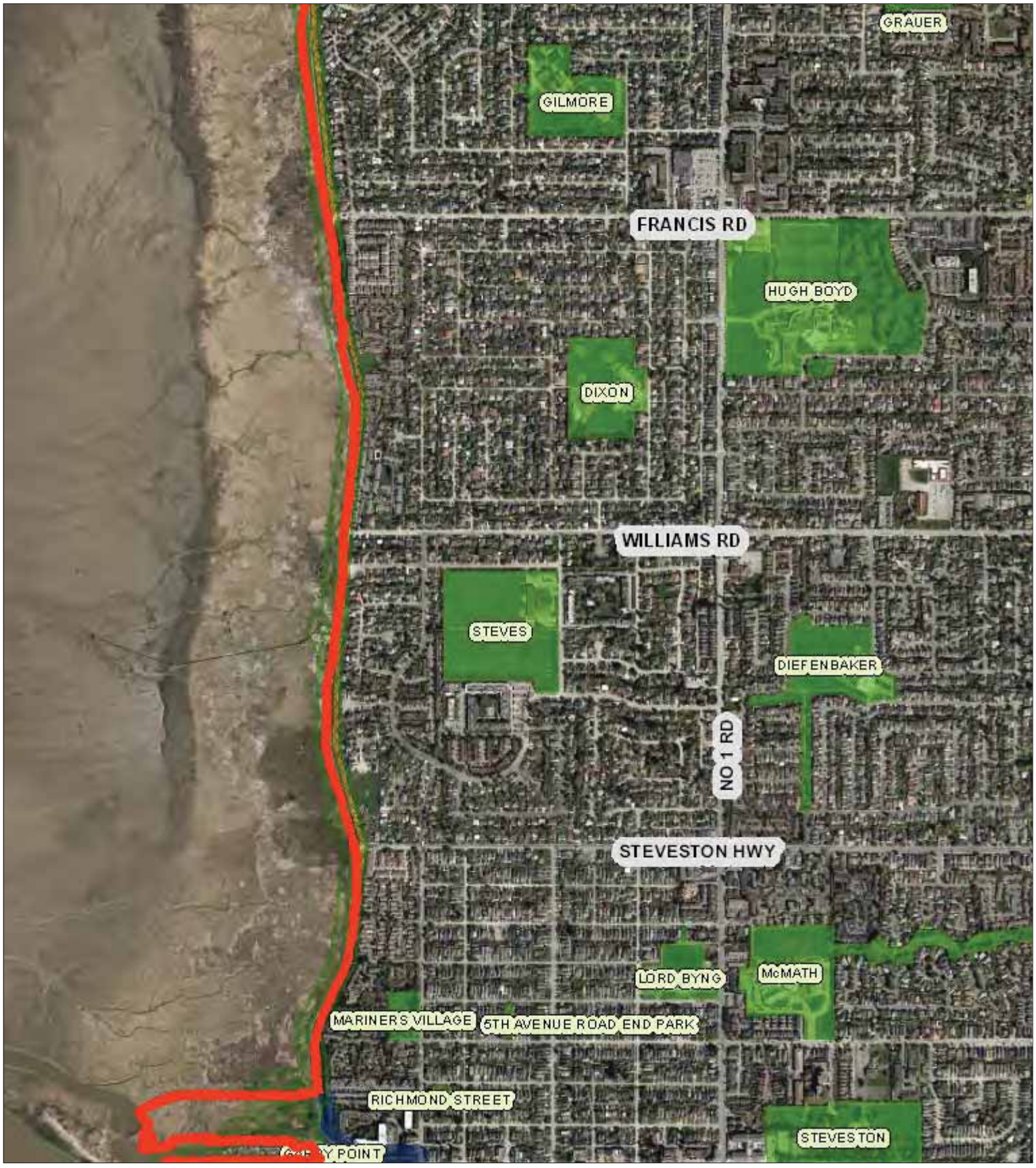


664.0 0 332.00 664.0 Meters

This map is a user generated static output from an Internet mapping site and is for reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable.

THIS MAP IS NOT TO BE USED FOR NAVIGATION

West Dike Williams Road



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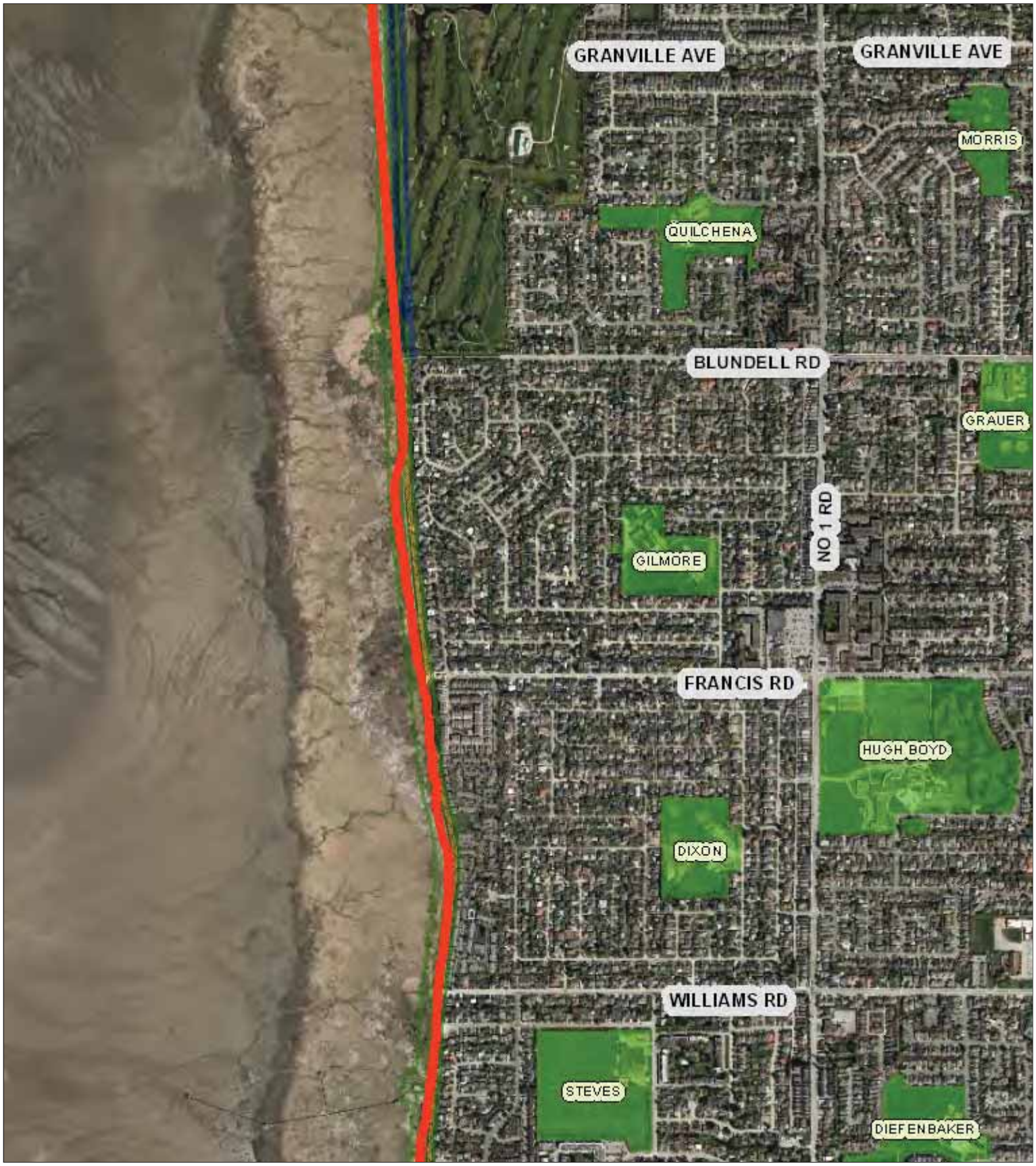
THIS MAP IS NOT TO BE USED FOR NAVIGATION

West Dike Francis Road



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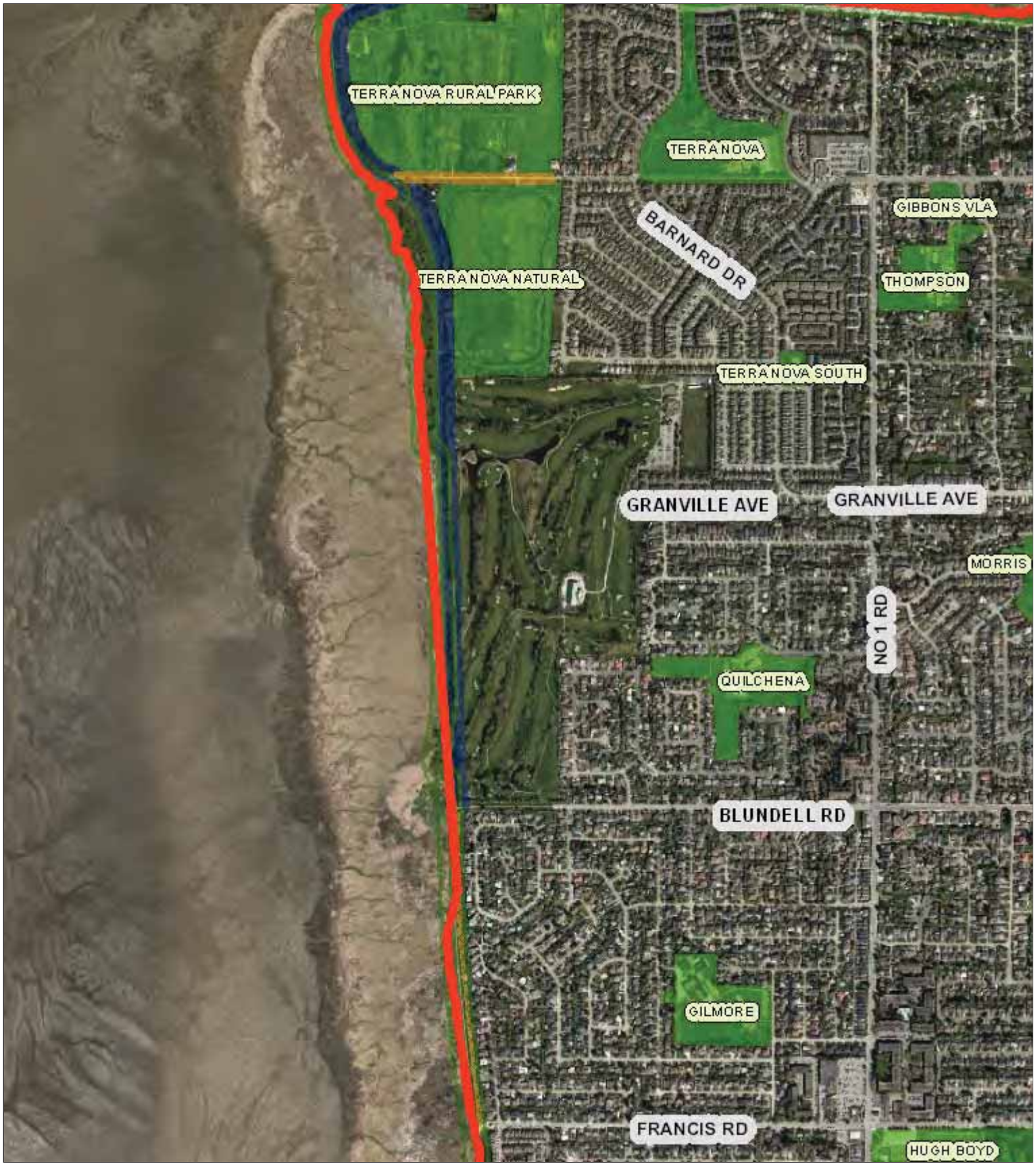
West Dike Granville Avenue



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This map is a user generated static output from an Internet mapping site and is for reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable.

THIS MAP IS NOT TO BE USED FOR NAVIGATION

West Dike Terra Nova

664.0 0 332.00 664.0 Meters

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THIS MAP IS NOT TO BE USED FOR NAVIGATION

North Dike Terra Nova

508.0 0 254.00 508.0 Meters

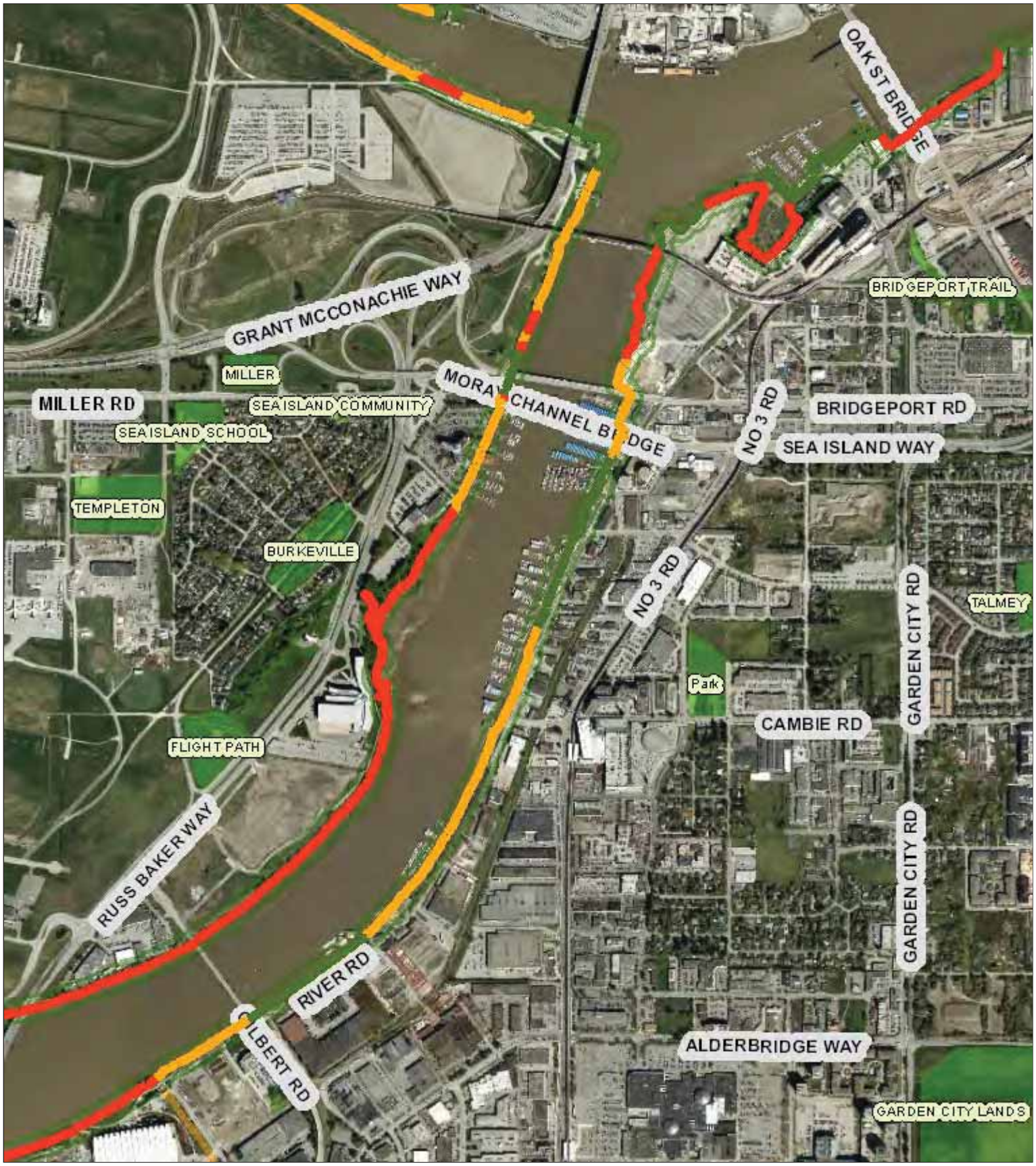
This map is a user generated static output from an Internet mapping site and is for reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable.

THIS MAP IS NOT TO BE USED FOR NAVIGATION

North Dike No 2 Road

508.0 0 254.00 508.0 Meters

North Dike Cambie road



664.0 0 332.00 664.0 Meters

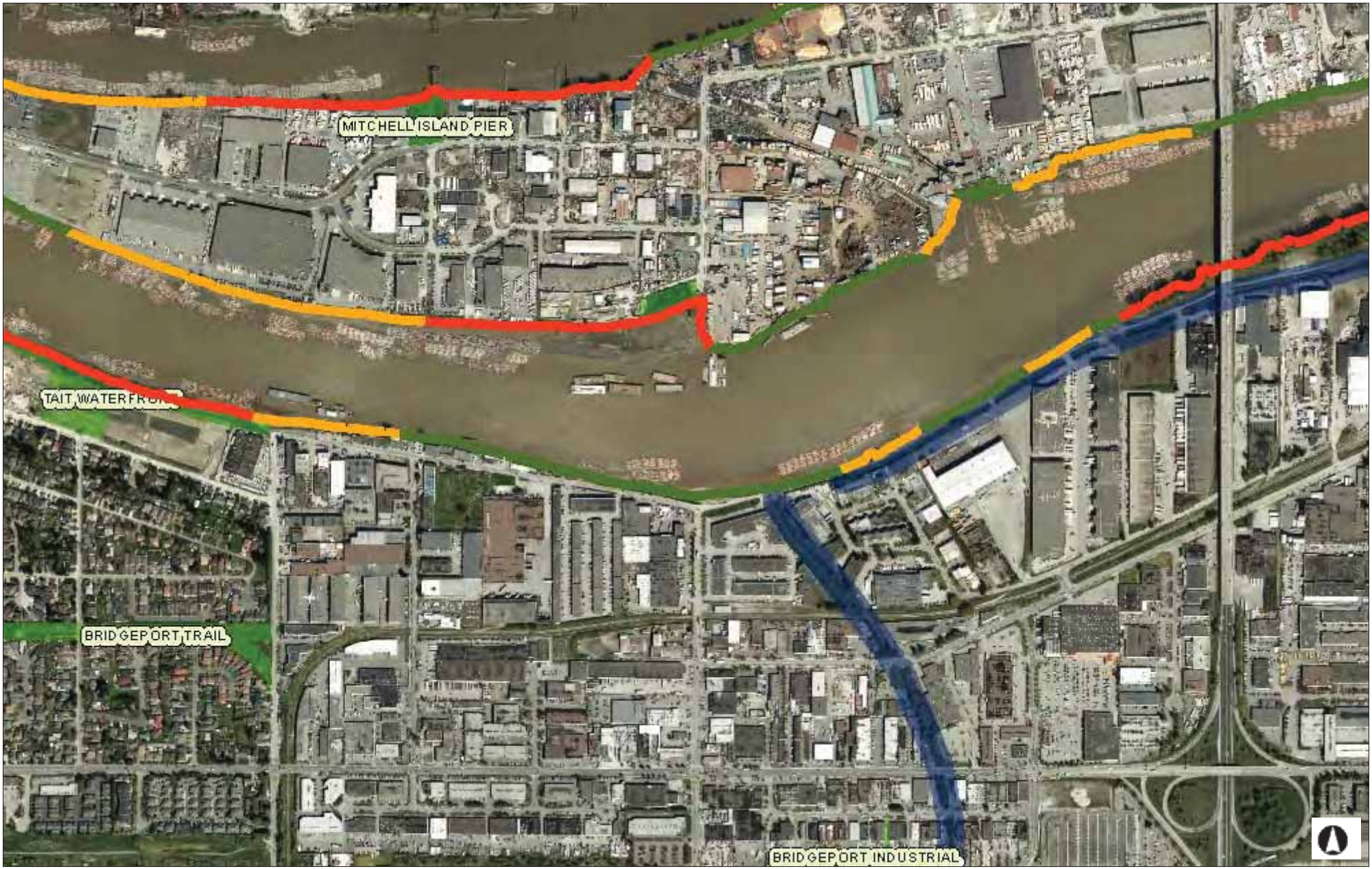
This map is a user generated static output from an Internet mapping site and is for reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable.

THIS MAP IS NOT TO BE USED FOR NAVIGATION

North Dike Oak Street

508.3 0 254.15 508.3 Meters

North Dike (Knight Sreet)

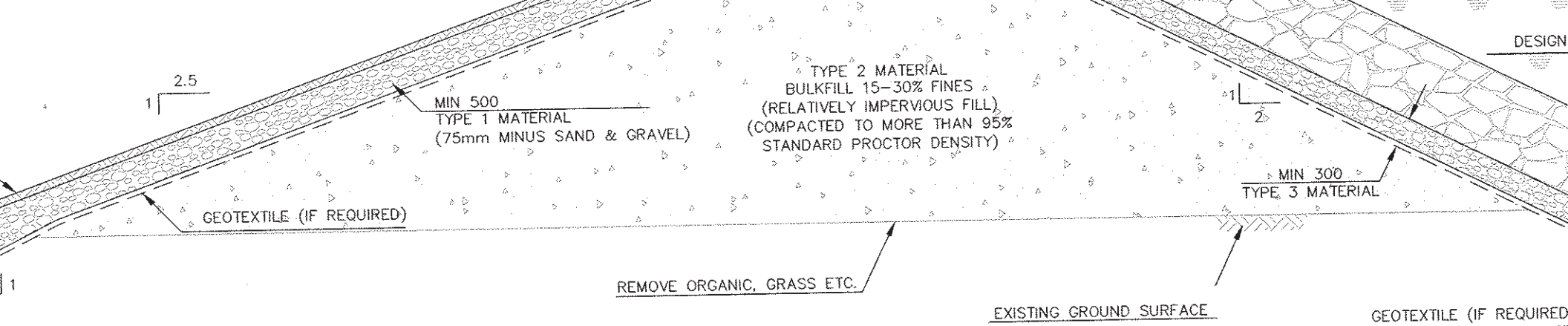


508.0 0 254.00 508.0 Meters

169.4 0 84.72 169.4 Meters

Appendix F

Typical Dike Cross Sections



E 2 MATERIAL (BULK FILL)

E 2 material shall consist of well-graded sand with 15 percent fines passing the U.S. Standard No. 200 meeting the following gradation limits:

S STANDARD SIEVE SIZE	PERCENTAGE BY WEIGHT PASSING
3/4"	100
#4	80 to 100
#40	25 to 90
#100	18 to 50
#200	15 to 30

TYPE 3 MATERIAL (RIPRAP FILTER)

Type 3 material shall consist of well-graded pit-run or processed sand, gravel and cobbles, or quarried stone meeting the following gradation limits:

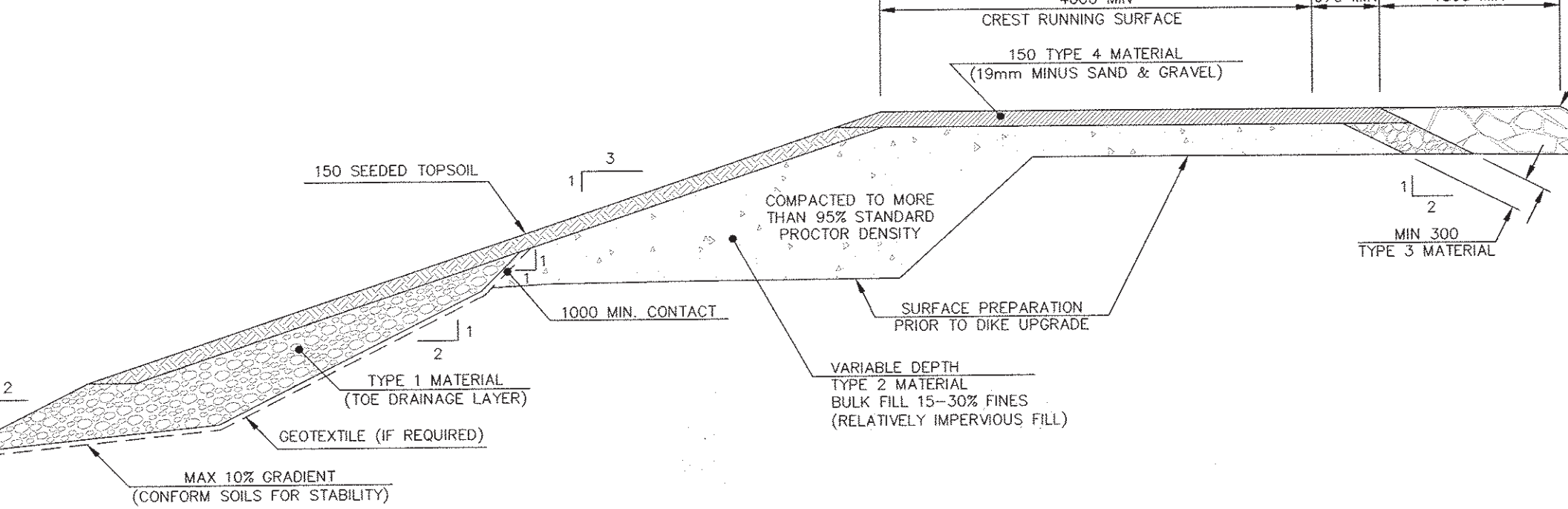
US STANDARD SIEVE SIZE	PERCENTAGE BY WEIGHT PASSING
8"	100
3"	60 to 90
3/8"	30 to 65
# 20	5 to 30
# 100	0 to 5

THE CITY OF RICHMOND
IS NOT RESPONSIBLE
FOR ERRORS NOR OMISSIONS

TYPE 4 MATERIAL (RUNNING SURFACE)

Type 4 material shall consist of a clean, well- 19mm minus sand and gravel or road mulch following gradation limits:

US STANDARD SIEVE SIZE	PERCENTAGE WEIGHT PASS
3/4"	100
1/2"	75 to 100
3/8"	60 to 90
#4	40 to 70
#8	27 to 55
#16	16 to 42
#30	8 to 30
#50	5 to 20
#200	2 to 8



2 MATERIAL (BULK FILL)

2 material shall consist of well-graded sand with 15 percent fines passing the U.S. Standard No. 200 meeting the following gradation limits:

STANDARD IEVE SIZE	PERCENTAGE BY WEIGHT PASSING
3/4"	100
#4	80 to 100
#40	25 to 90
#100	18 to 50
#200	15 to 30

TYPE 3 MATERIAL (RIPRAP FILTER)

Type 3 material shall consist of well-graded pit-run or processed sand, gravel and cobbles, or quarried stone meeting the following gradation limits:

US STANDARD SIEVE SIZE	PERCENTAGE BY WEIGHT PASSING
8"	100
3"	60 to 90
3/8"	30 to 65
# 20	5 to 30
# 100	0 to 5

THE CITY OF RICHMOND
IS NOT RESPONSIBLE
FOR ERRORS NOR OMISSIONS

TYPE 4 MATERIAL (RUNNING SURFACE)

Type 4 material shall consist of a clean, well-g 19mm minus sand and gravel or road mulch n following gradation limits:

US STANDARD SIEVE SIZE	PERCENTAGE E WEIGHT PASSI
3/4"	100
1/2"	75 to 100
3/8"	60 to 90
#4	40 to 70
#8	27 to 55
#16	16 to 42
#30	8 to 30
#50	5 to 20
#200	2 to 8

Attachment 1

Technical Memo #1 - Parsons

PARSONS

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August 18, 2016

Engineering Planning Department
City of Richmond
4th Floor, 6911 No. 3 Road
Richmond, BC V6Y 2C1

Subject: **Lulu Island Dike Master Plan Phase 2**
Technical Memo No. 1: Review of Existing Conditions – Final Letter Report

Dear Lloyd Bie, P.Eng:

1 Introduction

Parsons was retained by the City of Richmond (City) to establish Phase 2 of the Lulu Island Dike Master Plan (LIDMP). The purpose of the overall LIDMP is to establish a well-planned strategy to identify future flood protection infrastructure requirements along the waterfront. The plan will present feasible alternatives for flood protection, and establish guidelines for incorporating flood protection into future waterfront developments.

The purpose of this technical memo is to outline the existing conditions and constraints within the Phase 2 study area. This memo also presents potential flood protection options that may be appropriate for implementation within the study area. This information will establish the basis for identifying, assessing, and selecting a preferred strategy for the area.

The Phase 2 study area spans approximately 16 kilometers of the waterfront from Garry Point Park in Steveston, north to Terra Nova Rural Park, then east to No. 6 Road. This area can be broadly conceptualized as two sections: the West Dike and the North Dike.

1.1 BACKGROUND

Richmond is a city of over 207,000 people with considerable assets to be protected from flood damage. The City covers a land area of approximately 130 square kilometers that is protected from flood hazards by a perimeter ring dike, and a drainage system of ditches and sewers conveying storm flows and flood waters to pump stations discharging to the Fraser River and the Georgia Strait.

As Richmond is located on a low lying, coastal island, dikes have been present on Lulu Island since settlement. The existing dikes provide flood protection from winter storm surge and Fraser River freshet events. Federal and Provincial Agencies conducted dike improvements and new constructions under the Fraser River Flood Control program beginning in 1968. At that time, dike crest elevations were set at the highest water level on record plus 2 ft (60 cm) of freeboard. In 2006, the Provincial Government increased the standard sea dike crest elevation from 3.35 m to 3.5 m.

Public dikes and all drainage infrastructure are now owned solely by the City of Richmond. The City has endeavoured to adapt its flood protection systems to changing flood risks, including anticipated increases to flood levels resulting from climate change and sea level rise. With the establishment of the 2008 – 2031 Flood Protection Strategy, the City committed to prepare and implement a perimeter dike improvement program. The complete LIDMP will provide the framework to direct future perimeter dike improvement projects and ensure that diking requirements are considered with future re-development.

In 2013, Parsons[1] established the Phase 1 LIDMP for the City. Phase 1 primarily focussed on the Steveston neighbourhood; however, it included the southern portion of the West Dike. Phase 2 of the study includes the entire West Dike to establish a cohesive strategy for the full alignment.

2 Local Context

Prior to identifying alternatives for flood protection, an understanding of the existing and future conditions within the study area is required. The following section outlines the present and future land use, geotechnical conditions, environmental conditions, and the existing local flood protection infrastructure. This information will serve as the baseline conditions for the master plan.

2.1 PRESENT AND FUTURE LAND USE

The study area has been reviewed with consideration of the planning areas delineated in the City of Richmond's Official Community Plan (OCP). The OCP identifies future uses for all lands in the City boundary. The OCP identifies planning guidelines on a neighbourhood basis by delineating smaller Area Plans within City limits. The Area Plans identified in the OCP have been adopted in this study for ease of reference, and consistency with other City documents. However, while each Area Plan includes considerable inland area, only the lands in the vicinity of the waterfront will be considered for the purposes of this study.

Given the high value of the land that is being protected, it is assumed that flood protection and defenses will generally remain near the existing waterfront; as such, conditions of inland areas become less relevant to determining appropriate flood protection adaptations once far enough removed from the waterfront. Only areas impacting flood protection options are considered. Key plans showing the extent of all Area Plans are presented in ***Attachment 1***. Area Plans have also been broken down into sub-area plans depending on local constraints as they relate to flood protection improvements.

Generally, land uses along the West Dike are consistent, and will not change substantially through the 2041 planning horizon. Existing and future conditions along the North Dike will vary. Considerable development and intensification is anticipated in this area, primarily in the City Centre. A summary of the existing and future land uses based on site reviews conducted in August 2015 and a review of the OCP is presented below.

2.1.1 WEST DIKE

The West Dike spans the entire western waterfront of Lulu Island. The existing dike alignment is a multi-use trail adjacent to Sturgeon Banks, a designated Environmentally Sensitive Area (ESA) per the OCP as well as a provincially-designated Wildlife Management Area (WMA). The OCP identifies three area plans with frontage on the West Dike: Steveston, Seafair and Thompson. These areas consist primarily of residential and recreational uses, described in further detail below.

Steveston

The Steveston Area Plan mainly consists of the south waterfront area along the South Arm of the Fraser River, beyond the limits of the study area. The Steveston Harbour and the southern portion of the West Dike were extensively discussed in the Phase 1 LIDMP. Only the western waterfront portion of the Steveston Area Plan is within the study area. It extends from Garry Point to Williams Road.

This area is primarily established residential neighbourhoods of single family homes and low-rise townhouse complexes. The area also includes parklands, notably Garry Point Park, and some agricultural lands for the Steveston Stock and Seed Farm. This heritage farm was established in the 1880's and is currently operational. The farm's cattle graze on both the land side and water side of

[1] Formerly Delcan

the dike. The OCP does not identify any substantial land use changes in the Steveston Area Plan within the study area.

Seafair The Seafair Area Plan extends from Williams Road to Granville Avenue. This area is primarily established residential neighbourhoods of single family homes and low-rise townhouse complexes. The Quilchena Golf & Country Club makes up the northern third of the plan. It is situated entirely on Agricultural Land Reserve (ALR) lands. No major changes to the waterfront are identified in the OCP for this area.

Thompson The Thompson neighbourhood includes portions of both the West Dike and the North Dike. The Thompson portion of the West Dike is from Granville Avenue to Terra Nova Rural Park, the northern limit of the West Dike. This area is entirely agricultural and recreational, from the Quilchena Golf & Country Club to Terra Nova Rural Park. The park includes extensive children's play areas (notably the Adventure Play Environment opened in 2014), a demonstration farm and naturalized areas. The entire park is identified as conservation lands within the OCP. No major changes to the waterfront are identified in the OCP for this area.

2.1.2 NORTH DIKE

The North Dike portion of the study area is the south waterfront of the Middle and North Arms of the Fraser River from Terra Nova Rural Park to No. 6 Road, the eastern limit of the study area. The North Dike area is currently fully developed with residential, recreational, commercial, and industrial uses. The OCP has identified substantial intensification of these lands, primarily in the City Centre area. Existing and future conditions are discussed in further detail below.

Thompson The North Dike portion of the Thompson area extends from Terra Nova Rural Park at the northern limit of the West Dike to the No. 2 Road Bridge. It is primarily residential and recreational, with a small industrial area between McCallan Road and Lynas Lane hosting a City Works Yard, the Richmond Recycling Depot and a skate park. The River Road frontage of the industrial area has a wide shoulder for nose-in parking.

Throughout the Thompson Area Plan, all development is south of River Road with the dike on the north side, directly adjacent to the waterfront. The dike supports a multi-use trail throughout the Thompson area. The OCP identifies two sub-areas within the Thompson Area Plan: Terra Nova and Dover Crossing.

Thompson
Terra Nova The Terra Nova sub-area is an established residential neighbourhood of single family homes extending from the boundary of Terra Nova Rural Park to No. 1 Road. Throughout the sub-area, River Road is substantially offset from the waterfront, creating a wide open space between the road and the dike trail. This open space area contains typical park amenities such as benches, sign posts and a washroom facility. The No. 1 Road Drainage Pump Station on the north side of River Road receives piped drainage only; there are no conveyance ditches in its vicinity. The OCP does not identify any substantial changes to the plan in this area.

Thompson
Dover Crossing The Dover Crossing sub-area from Lynas Lane to the No. 2 Road Bridge is a residential neighbourhood of townhouses and medium-density apartment complexes with sizeable courtyards. Buildings are set back from River Road by several meters, leaving a wide landscaped area south of the roadway. This landscaped area has been graded up away from the road with slopes and retaining walls such that the buildings are substantially higher than the roadway. River Road is at a minimum setback from the dike trail in this sub-area.

Per the OCP, the easternmost section of this sub-area at Dover Crescent and the No. 2 Road Bridge has been identified for mixed-use development. It is currently an empty lot. The remainder of the sub-area plan will remain as existing for the foreseeable future.

City Centre

The City Centre Area Plan extends from the No. 2 Road Bridge to No. 4 Road. Residential, recreational, commercial and industrial uses are established in this area, which encompasses eight crossings of the Fraser River. This area has marked cultural and economic significance: the central business district and the arts district are both located within this Area Plan.

Future land uses are similar to existing conditions, with substantial intensification planned for the existing commercial and residential areas. The OCP identifies new waterfront parks, mixed-use developments, and pedestrian-oriented retail precincts. Several development projects are currently planned or under construction along the waterfront. City Centre contains four sub-areas: Oval Village, Aberdeen Village, Capstan Village and Bridgeport Village.

City Centre
Oval Village

The Oval Village sub-area is between the No. 2 Road Bridge and the Dinsmore Bridge. West of the Oval Village Area Plan, River Road is adjacent to the waterfront but within this area plan the road alignment has been relocated south to the former rail corridor. The dike trail is part of a wide landscaped area abutting high rise condos constructed since the 2010 Winter Olympics. Multiple sites are now being redeveloped into high-density mixed-use spaces, both east and west of the Olympic Oval. In general, these sites have been filled to the flood construction levels requested by the City at the time of redevelopment (4.0 m to 4.7 m).

City Centre
Aberdeen Village

The Aberdeen Village Area Plan spans from the Dinsmore Bridge to the marinas north of Cambie Road. Per the OCP, there is a small section of the Lansdowne Village Area Plan extending to the waterfront directly east of the Dinsmore Bridge but this will be considered a part of Aberdeen Village for the purposes of this study.

The waterfront area from the Dinsmore Bridge to Cambie Road is presently long-established office industrial. The OCP has designated this entire area as future park lands, a substantial expansion of the existing Middle Arm Waterfront Park. The Gilmore sanitary trunk sewer has been relocated from the waterfront to the proposed realignment of River Road over the former rail corridor. At present, the sewer has been built but the road has not yet been constructed over it. The current River Road alignment will be decommissioned and replaced with parklands.

City Centre
Capstan Village

The entire waterfront of the Capstan Village sub-area will be marinas, both residential and non-residential. The proposed realignment of River Road will join the existing River Road alignment north of Capstan Way. All lands between the proposed alignment and the waterfront will be redeveloped from light industrial to dense commercial uses, forming pedestrian-oriented retail precincts.

City Centre
Bridgeport Village

The Bridgeport Village sub-area extends from the Moray Channel Bridge to No. 4 Road. Redevelopment is planned in this area, most significantly on Duck Island. A local flood protection plan is currently being developed independently by stakeholders. Any development in this area should defer to those guidelines, being prepared independently of the Phase 2 LIDMP. Similarly, the River Rock Casino is developing a long-term strategy for flood protection at that site.

Bridgeport

The Bridgeport Area Plan extends from No. 4 Road to No. 6 Road. The area is primarily industrial, with a residential area from No. 4 Road to Shell Road. The remainder of the waterfront lands are currently industrial, and will remain industrial up to the 2041 planning horizon. Two sub-areas exist within the Bridgeport Area Plan: Tait and Industrial North-East.

Bridgeport *Tait*

The Tait sub-area extends from No. 4 Road to Shell Road. There is an established residential neighbourhood of single family homes south of River Drive. North of River Drive, there is an automotive service yard on Shell Road frontage, with the remainder of these lands currently being redeveloped into high-rise apartments and townhouses.

The OCP identifies this area as mixed-use and parkland. Development in this area is currently underway. There is no road adjacent to the waterfront; the new developments are directly on waterfront frontage. A pedestrian trail is currently under construction over the new dike in this area, which was raised on the existing dike alignment during construction.

The No. 4 Road Drainage Pump Station is located at the waterfront. This pump station receives piped drainage only; there are no conveyance ditches in its vicinity.

Bridgeport *Industrial North-East*

The Industrial North-East sub-area extends from Shell Road to No. 6 Road, the eastern limit of the study area. The current and future land uses are all industrial.

East of Shell Road, there is existing industrial development directly on the waterfront north of River Road. This area is protected by a floodwall on private property; there is no dike, nor is there any land available to construct a dike in future. A dike resumes east of this industrial waterfront, and continues until the Bath Slough Drainage Pump Station east of No. 5 Road at which point River Road becomes the dike. There is a large ditch on the south side of River Road conveying drainage from lands as far as No. 6 Road to the Bath Slough Drainage Pump Station. River Road is publicly accessible until the Knight Street Bridge, beyond which a barrier restricts eastward access. This section of River Road, from the barrier until No. 6 Road, is owned by the City of Richmond; however, the mill operations cross the land and it appears to be closed to public access for safety and security reasons.

2.2 GEOTECHNICAL CONDITIONS

Thurber Engineering Ltd (Thurber) conducted a review of the existing data to assess the anticipated geotechnical conditions within the study area. Based on their review, the anticipated subsurface conditions within the study area are primarily fill and silt overlying alluvial Fraser River deposits. The silt is clayey near the surface and becomes sandier with depth. This layer is generally about 2 to 4 m thick, although it ranges from about 1 m to 6 m thick. Below the silt, there is a zone that transitions from silt to sand at about 7 m depth. The sand layer below about 7 m depth becomes cleaner and coarser with depth and is typically 8 to 25 m thick. This sand layer is susceptible to seismically induced liquefaction.

Below the sand there is a sequence of silt and sand layers. Underlying the silt and sand sequence, there is a thick deposit of silt, which is underlain by dense till-like soil at depths of 50 m or more.

Thurber will prepare an assessment with respect to geotechnical considerations for use in the development of the Phase 2 LIDMP. They will advise on areas of particular geotechnical concern, and strategies for mitigation.

2.3 ENVIRONMENTAL CONDITIONS

The study area includes substantial open space and parklands including wetlands and natural areas on the waterfront. The dike trail's natural setting attracts cyclists and pedestrians to the waterfront. The City has an interest in preserving the environment at the waterfront for public uses. The aesthetic value of the natural environment along the trails will be considered as well as ecological significance. Detrimental impacts to the environment are to be avoided wherever possible, in accordance with the City's environmental regulations.

The City has outlined environmentally sensitive areas (ESA's) in the OCP. Within the study area, the entire waterfront area is designated ESA. Marine and freshwater habitats have also been categorized as red, yellow or green according to habitat

value. Red coding indicates high productivity habitat, yellow coding indicates moderate productivity habitat, and green coded areas are low productivity habitat. An area's habitat coding provides an overall measure of its habitat value, indicating the likelihood and extent of restrictions if alterations are required within that area. Habitat coding was initially developed in collaboration between all member agencies of the Fraser River Estuary Management Program (FREMP) and updated every five years. The member agencies were Environment Canada, Fisheries and Oceans Canada (DFO), BC Ministry of Environment, Metro Vancouver (formerly Greater Vancouver Regional District), and Port Metro Vancouver. In 2013 when FREMP was dissolved, the City received the latest habitat coding data available.

The existing foreshore is predominantly red-coded habitat along the 16 km alignment. The entire West Dike is red-coded, and the North Dike is red-coded east to the Hollybridge Pump Station. From Hollybridge Pump Station through to No.6 Road, the foreshore alternates with sections of red, yellow, and green-coded foreshore depending on the existing land use and waterfront conditions. The status of the existing condition and habitat value of the foreshore will direct whether raising dikes by filling to the water side is feasible from a costs and regulatory perspective.

Envirowest Consultants Ltd (Envirowest) are preparing an overall existing conditions assessment with respect to environmental considerations for use in the development of the Phase 2 LIDMP. They will advise on areas of ecological significance and any resulting restrictions on alterations.

2.4 ADDITIONAL GUIDANCE DOCUMENTS

In addition to the OCP, the City has developed a number of additional guidance documents that will be considered in development of the Phase 2 LIDMP.

2009 Waterfront Strategy:	The Phase 2 LIDMP will be developed with consideration of the five Strategic Directions of the 2009 Waterfront Strategy: 1) Working Together; 2) Amenities and Legacy; 3) Thriving Ecosystems; 4) Economic Vitality; and 5) Responding to Climate Change and Natural Hazards.
Flood Plain Designation and Protection By-Law 8204:	The Phase 2 LIDMP will consider the existing Flood Plain Designation and Protection By-Law, and will consider options to amend or accelerate increasing flood construction levels adjacent to the foreshore.
2008 – 2031 Richmond Flood Protection Strategy:	The Phase 2 LIDMP will be established to meet the goals of the Flood Protection Strategy.
2015 Ecological Network Management Strategy:	The Phase 2 LIDMP will be informed by the strategic goals outlined in the 2015 Ecological Network Management Strategy to promote the Ecological Network: 1) Manage and Enhance Ecological Assets; 2) Strengthen City Green Infrastructure; 3) Create, Connect, and Protect Diverse and Healthy Spaces; 4) Engage through Stewardship and Collaboration. The objective of developing an Ecological Network was initially outlined in the OCP under Chapter 9: Island Natural Environment (and Ecological Network Approach).
2008 Climate Change Response Agenda:	The Phase 2 LIDMP will be established with consideration of the 3rd pillar of the City's Climate Change Response Agenda – implement strategies for adapting to unavoidable changes. Strategies will be considered that can meet the short and long term goals with respect to crest elevations; however, they must also be adaptable to change.
2010 Richmond Trail Strategy:	The Phase 2 LIDMP will be developed with regard for the goal of maximizing access to the waterfront, as identified in the Richmond Trail Strategy.

2.5 EXISTING FLOOD PROTECTION INFRASTRUCTURE

The study area is currently protected by the perimeter ring dike around the entire Richmond portion of Lulu Island. Details on the existing flood protection infrastructure are summarized below.

2.5.1 WEST DIKE

The West Dike protects the City from high tides and storm surges originating in the Strait of Georgia. Sturgeon Bank, a mudflat and marshland, extends up to 6 km into the Strait of Georgia from the toe of the dike. The dike forms part of the trail network along Sturgeon Bank, connecting Terra Nova Rural Park to Garry Point Park. The dike's water side has a relatively flat face with grass cover, followed by the marsh and mudflats of the Sturgeon Bank. The crest is a gravel path, and the inland slope is typically a grass revetment with a ditch or swale separating it from residential uses.

Sturgeon Bank currently provides some protection from wave run-up to the West Dike. Sea level rise will reduce this level of protection unless Sturgeon Bank is raised in conjunction with the sea level. Recent studies have shown that the leading edge of Sturgeon Bank has been receding.

There are a number of pump stations along the West Dike. Most have been upgraded, and the immediately adjacent sections of dike have been raised to 4.0 m. The upgraded pump stations have been design to be functional with dike crests increased to 4.7 m.

2.5.2 NORTH DIKE

The North Dike protects the City from high tides and storm surge impacts originating in the Strait of Georgia and migrating up the North and Middle Arms of the Fraser River. To a lesser extent, these dikes protect from high Fraser River freshet events.

For most of the study area, the existing dike is earth fill and located within open space or linear water front trail. Generally it is bounded by the foreshore and River Road. Through the City Center Area it continues to be linear park; however, is often bounded on the landside by development. Numerous sections of the City Center portion of the dike have been raised over the past several years in conjunction with redevelopment of waterfront properties. In many of these cases, the land side of the dike has been raised so that the development is situated at, or above, the crest level.

Through the industrial areas north of the City Center, the dike remains generally earthfill; however, there are portions of sheet pile and flood walls associated with specific sites. Dike access can be restricted by private waterfront industrial uses. East of No. 5 Road, the dike is the River Road alignment that is publicly accessible except at the mill and adjacent industrial complex between the Knight Street Bridge and No. 6 Road.

Current dike crest elevations vary from 3.0 m to 4.7 m depending on when the surrounding lands were last redeveloped. A 2015 survey of the dike crest elevations and LIDAR collected in 2005 were provided by the City. Subsequent to these field investigations, the dikes have been raised at new developments and pump stations upgraded in the past five years.

3 Technical Considerations

There are a number of technical considerations that need to be accounted for to establish the preferred dike master plan for the area. These technical considerations include: crest elevation requirements; geotechnical issues; environmental issues; regulatory requirements; and adaptation options. These considerations, as they relate to the study area are outlined as follows.

3.1 CREST ELEVATION REQUIREMENTS

The City has established a design crest elevation of 4.7 m with consideration to be further raised to 5.5 m in response to climate change and sea level rise predictions. These elevations are used as the basis for this study.

3.2 GEOTECHNICAL CONSIDERATIONS

Geotechnical design considerations for dike adaptations include seepage control both under and through the dike, dike slope stability, dike crest settlement, and seismic performance. Furthermore, additional loading from increased dike size over any existing structures, such as building footings or bridge abutments, will need to be verified for confirmation that existing infrastructure will not be negatively impacted. Any other flood protection measures having a structural component will also need to be verified accordingly.

Thurber has reviewed the existing geotechnical conditions in the study area. Their comments on the key design considerations are outlined below.

3.2.1 SEEPAGE

The existing dike crest elevation varies from 3.3 m to 4.7 m and the ground elevation on the landside of the dike is generally at about 2.0 m. Increasing dike heights to 4.7 m (or ultimately 5.5 m) will increase the design flood height[2] of the dike unless the land side is raised accordingly. The potential increases in flood height (if the land side of the dike is not raised with crest increases) are significant and will increase the risk of 1) landside heave of the less permeable surficial silt layer above the sand and 2) increase the risk of piping through the dike, the dike foundation, and the surficial silt layer. These increased seepage demands are likely one of the most significant design considerations for future upgrades.

Piping occurs when excessive seepage forces cause the migration of soil particles through the soil matrix resulting in internal erosion and eventually retrogressive failure. Heave can occur when there are excessive hydraulic pressures on the landside of the dike caused by a lower permeability soil layer forming a cap over a more permeable layer near the ground surface. Heave can lift and fracture the cap resulting large localised seepage volumes and internal erosion, which could cause a dike breach if it occurs near the dike.

Evaluating the potential for piping in unfiltered dikes is difficult to analyse and predict. Accordingly, piping is one of the leading causes of failure of earth dams and dikes that have unfiltered seepage exits.

To provide reliable protection from higher design flood heights, a system of seepage control measures will probably be required for almost all of the dike. The potential for heave and piping could be mitigated using relief wells, drainage blankets or trenches. Relief wells and trenches should have filters designed to prevent piping and internal erosion and have filtered seepage exits.

Retaining the existing landside ditches increases the risk of piping as they shorten the seepage path length and increase the hydraulic gradient. Accordingly, these ditches may need to be filled in order to provide the required level of flood protection.

[2] the height of water above the land side ground surface

3.2.2 STABILITY

No significant stability issues are anticipated in association with construction of a standard dike section to a crest elevation of 4.7 m or 5.5 m provided high quality dike fill materials are used and placed in accordance with accepted engineering practice. The standard dike section is also anticipated to be generally stable under these higher floods (although it will be less stable than the lower height configuration). In areas where stability is a concern, minor modifications to the standard dike section may be required, such as flattening the landside slope, constructing a toe berm or providing a seepage cut-off and filter within the dike. The stability of dikes will be improved where ditches at the landside toe are infilled.

3.2.3 SETTLEMENT

Raising the dikes will induce primary consolidation settlement of the surficial silt layers. This settlement could be up to about 5% of the increase of the thickness of new dike fill placed and could potentially be compensated for by nominally overbuilding the dike. Also settlement where construction is over peat or highly organic soils will be higher. The dike and surrounding area are experiencing secondary compression settlement due to on-going long-term compression of deeper silt layers. This on-going settlement is in the range of a 1 to 2 mm per year and is not anticipated to be significantly affected by raising the dike by the amounts considered.

Infilling ditches is not anticipated to significantly affect settlement.

3.2.4 SEISMIC PERFORMANCE

The Ministry of Forests Lands and Natural Resources (MFLNRO) June 2014 “Seismic Design Guidelines for Dikes” (2014 seismic guidelines) recommend designing high consequence dikes to control seismic deformations within prescribed limits.

The dikes in the scope of this study are anticipated to be underlain by sand with a high susceptibility to liquefaction. Based on Thurber’s experience with dike projects in the Lower Mainland, it is their opinion that some of the dike (and raised dike) could possibly meet the displacement criteria in 2014 seismic guidelines for the 1 in 100 year return period earthquake without ground improvement. However, extensive ground improvement is almost certainly required in order to conform to the displacement criteria for the 1 in 2475 year return period earthquake.

Along the west side of Lulu Island, the mud bank is relatively flat and extends out a significant distance. This mud bank will mitigate seismic deformations. However, it is anticipated that the dike will still experience lateral spreading and liquefaction reconsolidation settlements that could potentially exceed the 2014 seismic guidelines displacement limits for the 1 in 2475 year return period earthquake.

Along the North Arm of the Fraser River, where the dike comprises a “waterside” dike (i.e. on the riverbank), flow slides caused by liquefaction during the 1 in 2475 year return period earthquake are almost certain. A flow slide is a slide with large, uncontrolled deformations (i.e. greater than a meter) caused by the sand loosing strength in its liquefied state. Accordingly, extensive ground improvement may be required to meet the displacement criteria in the 2014 seismic guidelines.

Where dikes comprise “setback” dikes, they might be far enough away from the riverbank to be outside of the flow slide zone. For conceptual planning purposes, dikes with 50 to 100 m setback should be considered to be far enough away from most of the influence of riverbank flow slides. Setback dikes will still experience lateral spreading and liquefaction reconsolidation settlements that could potentially exceed the displacement limit in the 2014 seismic guidelines. Waterside dikes will almost certainly require extensive seismic remediation measure, such as reinforcement or densification of the foundation soils to meet the deformation limits of the 2014 Seismic Guidelines. For conceptual purposes, a 15 m high by

15 m wide zone of ground improvement below the waterside toe of the dike could be required. A Plaxis analysis will be carried out by Thurber at characteristic sections within the study area to illustrate the behaviour of dikes during seismic events. This analysis will inform the seismic component of the master plan.

3.3 ENVIRONMENTAL CONSIDERATIONS

Envirowest is preparing an overall existing conditions assessment with respect to environmental considerations for use in the development of the Phase 2 LIDMP. This assessment will identify potential environmental and habitat conflicts that may result in restrictions on alterations for flood protection purposes. As part of this assessment, key environmental considerations will be identified for use in assessing alternative strategies to flood protections.

Within the study area, particularly in the industrial and formerly-industrial areas, sites may be contaminated. Identification of contaminated sites is beyond the scope of the master plan. At the detailed design stage, remediation plans may be required prior to the construction of any flood protection adaptations in the event that a site is found to be contaminated.

3.3.1 STURGEON BANK

In Phase 1 of the LIDMP, the design team conducted a cursory review of the morphology of Sturgeon Bank. Based on this review it is considered that the mudflats are slowly eroding.

Key reasons are identified as follows:

- The existing Lulu Island dikes and Fraser River jetties block sediment transport onto the Sturgeon Bank. As a result, sand transport from the Fraser River goes to deep water zones and Sturgeon Bank is not nourished.
- Large portions of river sediment is dredged and used for construction (taken out of the system).

Reversing the erosion of Sturgeon Bank is challenging. Removing the Lulu Island dike is not on option. Removing the jetty to allow nourishment of the mudflats would cause slumping of the mudflat into the navigation channel, uncontrolled migration of the river requiring intensive dredging to sustain required depth, and possibly undesired formation of dendritic channels on the mudflat. High level numerical modeling of sediment transport patterns for several options would provide greater insight into feasibility.

It may be feasible to slow down or reverse this process by strategically placing dredged material and allowing the banks to nourish themselves overtime, thereby maintaining their effective wave attenuation properties as sea-levels rise.

3.4 REGULATORY CONSIDERATIONS

Regulatory approvals may be required for flood protection projects implementing the recommendations of the master plan. Agencies from which approvals may be required include, but are not limited to: Fisheries and Oceans Canada (DFO), MFLNRO, BC Ministry of Environment, Transport Canada, Port Metro Vancouver and First Nations. Where appropriate, key stakeholders and agencies will be contacted for input in the final LIDMP. At the time that a project proceeds, the proponent will be responsible for verifying that their project is in compliance with all regulatory requirements, and that all required approvals have been obtained.

3.5 ADAPTATION OPTIONS

The provincial Climate Change Adaptation for Sea Dikes and Coastal Flood Hazard Land Use Draft Policy Discussion Paper (2011) categorizes options for managing flood risk into structural options and non-structural options, listed in ***Table 1*** and summarized further in the following sections.

Table 1: Flood Risk Management Strategies

STRUCTURAL						NON-STRUCTURAL				
PROTECT						ACCOMMODATE			RETREAT	AVOID
DIKES		FLOODWALLS		FORESHORE						
Widen footprint to land side	Widen footprint to water side	Permanent	Demountable	Breakwater / Barrier Islands	Coastal wetlands	Flood proofing	Secondary Dikes	Emergency preparedness and response	Managed Retreat	Planning and Development Controls

3.5.1 PROTECT

To protect against flooding is to construct protective works that form a barrier between the flood hazard and the at risk property behind the hazard. Flood protection works can be 'hard', such as dikes and floodwalls, or 'soft', such as dunes or tidal marshes. Lulu Island, including the study area, is currently primarily protected by a perimeter ring dike, with floodwalls and foreshore structures in some areas.

Dikes

A dike is an embankment constructed on dry ground along a riverbank or shoreline to prevent overflow of water into the lowlands behind. Dikes have a long history of use within Richmond and are the most common form of structural flood protection. Many dikes in Richmond were constructed or upgraded during the Fraser River Flood Control Program of the 1960's and 1970's. At that time, the dikes were generally upgraded with expansions to the land side and increases to crest height and width.

Options to fortify dikes are dictated by local conditions. Typically dike crest elevation increases are obtained by expanding to the land side to minimize environmental concerns and construction costs associated with works on the water side. However, water side dike expansion can be considered if there is development constraining expansion on the land side. Dikes can also be raised in place by steepening side slopes to construct higher dikes within the same footprint.

Potential Use in Phase 2 LIDMP:

It is anticipated that the majority of the flood protection measures recommended in the Phase 2 LIDMP will consist of earth fill dikes. Existing geometry, development plans, and environmental considerations will dictate whether landside or water side is preferred. Where feasible, earth fill would be expanded to the land side or set back from the waterfront.

Floodwalls

A floodwall is a constructed barrier designed to hold back flood waters. Floodwalls are typically used at locations where space is limited and a dike would interfere with other land uses or structures, such as existing buildings. Floodwalls are also required where access to the water is required for economic activity such as fishing or shipping. A floodwall can be constructed from a number of different materials including concrete, steel or plastic. Some floodwalls can be designed to be demountable and are only erected prior to a flood.

Potential Use in Phase 2 LIDMP:

Flood walls are generally more costly and not as reliable as earth fill dikes. Use of flood walls in the LIDMP is expected to be restricted to areas where constraints preclude use of earth fill (i.e. under bridges, tying into existing structures, corridor width constraints)

Foreshore Structures

In areas where raising shoreline dikes to full heights to withstand wave run-up is impractical, foreshore structures can be constructed. These structures dissipate wave energy and reduce the burden on the dike allowing for lower crest levels.

Potential Use in Phase 2 LIDMP:

Foreshore structures have been previously considered for the West Dike. Though they will not address the immediate crest elevation requirements of 4.7 m (future 5.5 m), with further study, they could be shown to be a cost effective approach to reducing increased wave run-up associated with increased water depths on the Sturgeon Bank due to climate change and sea level rise. This may allow for future deferrals of crest height increases.

3.5.2 ACCOMMODATE

The accommodation approach to flood risk management involves planning for development with the expectation that the area may occasionally be flooded. This includes flood proofing individual buildings, constructing secondary dikes, or developing emergency preparedness and response programs. The accommodation approach allows for meeting the varied flood protection needs of diverse assets located in the same area. Robust flood protection measures can be applied to vital infrastructure such as hospitals and power plants, while nearby parks or athletic fields can be left unprotected.

Flood Proofing

Flood proofing can be achieved, fully or in part, by enacting bylaws that regulate the use of building space below a set flood construction level (FCL). This strategy prohibits vital assets from being located in high risk zones, such that any flooding will only impact non-critical infrastructure. In 2008, the City established the Flood Plain Designation and Protection Bylaw No. 8204 that set minimum FCL's throughout the City. Bylaws can be revised to raise FCL's as necessary in response to evolving design flood conditions.

Potential Use in Phase 2 LIDMP:

It is anticipated that one option for consideration in the Phase 2 LIDMP will be modifications to the City's current FCL by-law. To address long term dike seepage and seismic stability concerns, it is advisable to a have a wide area raised land adjacent to the water front, or a "superdike". Creating a new FCL zone adjacent to the waterfront that requires immediate raising to 4.7 m with redevelopment, or an accelerated version of the current 300 mm above road centreline, could help achieve this.

Secondary Dikes

Secondary dikes work in conjunction with primary dikes to reduce the impact of a flood in the event that a primary dike is breached. This option is suited for areas with sufficient land available for a set-back dike at some distance inland from the primary dike, and the assets located between the primary and secondary dikes would not suffer substantial damage in the event of a flood.

Potential Use in Phase 2 LIDMP:

Temporary secondary dikes may need to be considered outside of specific isolated areas (ie. Duck Island) dependant on future plans for the site.

Emergency Preparedness and Response

An essential strategy for reducing flood risk is to prepare for emergencies with robust mitigation plans. The City has established an Emergency Operations Centre that coordinates with various departments to establish and implement the City's Emergency Preparedness Flood Management Plan.

Potential Use in Phase 2 LIDMP:

Emergency preparedness and responses is not within scope of the dike master plan; however, is an overall necessity for the City.

3.5.3 RETREAT

In some cases an approach for flood protection is to move back from the flood hazard over time such that development would no longer be located in flood prone areas.

Managed Retreat

In this approach, existing development within a specified hazard zone is decommissioned and demolished in advance of the end of its typical service life. The land is returned to a coastal land form that would periodically be flooded without consequence, as no damageable assets would remain in the hazard zone.

Potential Use in Phase 2 LIDMP:

Not applicable for this study area. The economic value of retaining existing assets in their current locations exceeds the benefit of lowering flood damage risk by relocating assets. The existence of waterfront assets is considered a permanent condition for this study.

Development Restrictions

This approach is similar to a managed retreat except existing non-critical infrastructure can remain within the hazard zone until the end of its service life, at which point it would be decommissioned and demolished. Any new development within the area is meanwhile prohibited. Ultimately this approach also returns the hazard area to a coastal land form, subject to inconsequential flooding.

Potential Use in Phase 2 LIDMP:

Not applicable for this study area. The economic value of maintaining assets in these locations exceeds the benefit of lowering flood damage risk by relocating assets. The existence of substantial assets along the waterfront is considered a permanent condition for this study.

3.5.4 *Avoid*

The general principle of this approach is to provide space for the river by keeping development out of the floodplain. The avoid approach is most suitable for new development. This approach is currently being applied to the lands that lie on Sturgeon Bank beyond the West Dike, where no development is permitted.

Planning and Development Controls

The City may prevent flood damage by restricting the types of assets permitted in the floodplain by enacting by-laws restricting development in proscribed areas.

Potential Use in Phase 2 LIDMP:

Not applicable for this study area as it is already fully developed.

4 Flood Protection Approach Alternatives

As part of the review of existing conditions, Parsons has identified preliminary adaptation alternatives for flood protection along the entire study are alignment. At this stage, these adaptation alternatives are limited to those flood risk management strategies identified and described in **Section 3.5 – Adaptation Options**. These adaptation alternatives will be further refined during the next stage of the study to identify technically feasible strategies for flood protection.

Details on the delineation of the study area and the preliminary adaptation alternatives are outlined in the following sections.

4.1 FLOOD PROTECTION SEGMENTS

Adapting to evolving design flood conditions involves understanding the constraints of specific areas, and the flood risk management strategies that could be effectively implemented within those constraints. Based on the review of the study area and site reviews conducted in August 2015, flood protection segments have been defined to represent areas subject to uniform constraints where a single strategy could be adopted.

4.1.1 WEST DIKE

For the purposes of this study, the West Dike will be considered one segment. Conditions are generally consistent along the alignment. Specific site conditions may vary slightly (ie. presence of a landside ditch, landscaping, and setbacks); however, segmenting the alignment is not required to establish the preferred strategy.

4.1.2 NORTH DIKE

The North Dike has been divided into numerous segments based on a review of the existing conditions. Each segment represents an area subject to relatively uniform constraints that can be assessed to identify a preferred approach to flood protection. Constraints typically include abutting land uses, ease of access to the dike alignment and existing infrastructure that may interfere with dike adaptations.

Twenty-one segments have been delineated, with special consideration for waterfront infrastructure such as pump stations and bridges. A table establishing the boundaries and applicable constraints of each segment are included in ***Attachment 2***. Figures depicting a key plan of the segment boundaries and cross sections at selected segments have been included in ***Attachment 3***.

These twenty-one segments will be used for local analysis and interpretation of potential flood protection adaptations. For the final master plan, applicable flood protection strategies will be presented per the OCP areas described above, for ease of reference and consistency with other City development guidelines.

4.2 PRELIMINARY ADAPTATION ALTERNATIVES

Based on the above review of existing and future conditions, adaptation options that may be appropriate for a specified segment have been identified for further consideration. Generally, the preferred option is to raise the dike on the existing alignment wherever feasible in the study area. In isolation, foreshore structures and all the non-structural adaptations are inadequate to fulfill the target 4.7 m perimeter crest elevation. Adaptations in these categories have been identified for

further study where they may provide a significant added benefit in combination with a waterfront adaptation. Both flood proofing and emergency preparedness would provide general benefits across the entire study area.

Demountable floodwalls must be raised to prevent flooding each time high water levels are anticipated. As they are labour intensive and less reliable than permanent structures, they have been eliminated except where there is a benefit to maintaining open access to the waterfront area, for example driveways to marinas.

Foreshore structures are only feasible on the West Dike. There is limited space on the North Dike for foreshore structures, and also less of a requirement for wave attenuation. Moreover, foreshore structures may conflict with ship traffic and dredging operations on the Fraser River.

A managed retreat is only potentially feasible along the existing natural and recreational areas of the West Dike as the remainder of the study area is developed with considerable assets at the waterfront. Planning and development controls to prevent development along the waterfront is also only feasible along the foreshore and adjacent recreational trail of the West Dike, where lands remain undeveloped. The City's planning guidelines for the remainder of the study area indicate intensification of development, thus development controls to prevent development on the waterfront have been eliminated as this would be inconsistent with the City's vision.

Potential adaptation measures identified for further study for each flood protection segment are summarized in ***Table 2.*** Flood protection adaptation measures that may be feasible within the specified segment are identified in the table with an "x". If the adaptation option is not considered feasible, the box is left blank.

Table 2: Potential Adaptation Measures at Each Dike Segment

ADAPTATION MEASURE	STRUCTURAL						NON-STRUCTURAL				
CATEGORY	PROTECT						ACCOMMODATE			RET-REAT	AVO-ID
	DIKES		FLOOD-WALLS		FORE-SHORE						
Flood Protection Segment – OCP Area *Description of Segment Boundaries*	Widen footprint to land side	Widen footprint to water side	Permanent	Demountable	Breakwater / Barrier Islands	Coastal wetlands	Flood proofing	Secondary Dikes	Emergency preparedness and response	Managed Retreat	Planning and Development Controls
Segment W – West Dike	X	X	X		X	X	X		X	X	X
Segment 1 – Thompson Terra Nova *Terra Nova Park parking lot*	X	X	X				X	X	X		
Segment 2 – Thompson Terra Nova *Terra Nova Park wetland and parking*	X	X	X				X	X	X		
Segment 2a – Thompson Terra Nova *Driveway to Terra Nova Park*	X	X	X				X		X		
Segment 3 – Thompson Terra Nova *Low-Rise Residential*	X	X	X				X		X		
Segment 3a – Thompson Terra Nova *No. 1 Road Pump Station*	X	X	X				X		X		
Segment 4 – Thompson *Low-Rise Residential*	X	X	X				X		X		
Segment 4a - Thompson *McCallan Road Pump Station*	X	X	X				X		X		
Segment 5 – Thompson *Recycling Depot*	X	X	X				X		X		
Segment 6 – Thompson Dover Crossing *Mid-Rise Residential Blocks*	X	X	X				X		X		

ADAPTATION MEASURE	STRUCTURAL						NON-STRUCTURAL				
CATEGORY	PROTECT						ACCOMMODATE			RET-REAT	AVO-ID
	DIKES		FLOOD-WALLS		FORE-SHORE						
Flood Protection Segment – OCP Area *Description of Segment Boundaries*	Widen footprint to land side	Widen footprint to water side	Permanent	Demountable	Breakwater / Barrier Islands	Coastal wetlands	Flood proofing	Secondary Dikes	Emergency preparedness and response	Managed Retreat	Planning and Development Controls
Segment 7 – Thompson Dover Crossing *New Mid-Rise Mixed Use Block*	X	X	X				X		X		
Segment 7a – Thompson Dover Crossing *No. 2 Road Bridge*		X	X				X		X		
Segment 8 - City Centre Oval Village *Olympic Oval*	X	X	X				X		X		
Segment 8a - City Centre Oval Village *New High-Rise Development*	X	X	X				X		X		
Segment 9 - City Centre *Dinsmore Bridge*		X	X	X			X		X		
Segment 10 - City Centre Aberdeen Village *Industrial, Future Parklands*	X	X	X				X	X	X		
Segment 11 - City Centre Capstan Village *Industrial, Future Parklands & Mixed Use*	X	X	X				X	X	X		
Segment 11a - City Centre Capstan Village *West Cambie Road Pump Station*		X	X	X			X		X		
Segment 12a - City Centre Bridgeport Village *Moray Bridge*		X	X	X			X		X		
Segment 12b - City Centre Bridgeport Village *Sea Island Connector Bridge*	X	X	X	X			X		X		
Segment 13 - City Centre Bridgeport Village *Richmond Night Market*	X	X	X	X			X	X	X		

ADAPTATION MEASURE	STRUCTURAL						NON-STRUCTURAL				
CATEGORY	PROTECT						ACCOMMODATE			RET-REAT	AVO-ID
	DIKES		FLOOD-WALLS		FORE-SHORE						
Flood Protection Segment – OCP Area *Description of Segment Boundaries*	Widen footprint to land side	Widen footprint to water side	Permanent	Demountable	Breakwater / Barrier Islands	Coastal wetlands	Flood proofing	Secondary Dikes	Emergency preparedness and response	Managed Retreat	Planning and Development Controls
Segment 13a - City Centre Bridgeport Village *Middle Arm Bridge, Canada Line*	X	X	X	X			X	X	X		
Segment 14 - City Centre Bridgeport Village *River Rock Casino*	X	X	X	X			X		X		
Segment 14a - City Centre Bridgeport Village *Marpole Rail Bridge*		X	X	X			X		X		
Segment 14b - City Centre Bridgeport Village *Oak Street Bridge, Hwy 99*	X	X	X	X			X		X		
Segment 15 - City Centre Bridgeport Village *Industrial, Fraser River Terminal*	X	X	X	X			X		X		
Segment 16 - City Centre Bridgeport Village *BC Hydro Kidd 2 Substation*	X	X	X	X			X	X	X		
Segment 16a - City Centre Bridgeport Village *North Arm Bridge, Canada Line*	X	X	X	X			X		X		
Segment 17 – Bridgeport Tait *Park Riviera New High-Rise Development*	X	X	X				X		X		
Segment 17a – Bridgeport Tait *No. 4 Road North Pump Station*		X	X	X			X		X		
Segment 18 – Bridgeport Industrial North-East *Industrial*	X	X	X				X		X		
Segment 18a – Bridgeport Industrial North-East *Bath Slough Pump Station*	X	X	X				X		X		

ADAPTATION MEASURE	STRUCTURAL						NON-STRUCTURAL				
CATEGORY	PROTECT						ACCOMMODATE			RET-REAT	AVO-ID
	DIKES		FLOOD-WALLS		FORE-SHORE						
Flood Protection Segment – OCP Area *Description of Segment Boundaries*	Widen footprint to land side	Widen footprint to water side	Permanent	Demountable	Breakwater / Barrier Islands	Coastal wetlands	Flood proofing	Secondary Dikes	Emergency preparedness and response	Managed Retreat	Planning and Development Controls
Segment 19 – Bridgeport Industrial North-East *Industrial*	X	X	X				X		X		
Segment 20 – Bridgeport Industrial North-East *Industrial*	X	X	X				X		X		
Segment 20a – Bridgeport Industrial North-East *Knight Street Bridge*	X	X	X				X		X		
Segment 21 – Bridgeport Industrial North-East *Lumber Yard*	X	X	X	X			X		X		
Segment 21a – Bridgeport Industrial North-East *Lumber Yard Overhead Conveyor*	X	X	X	X			X		X		

5 Process for Selection of Recommended Adaptations

Both area specific and regional adaptations will be further analyzed in Technical Memo #2 (TM #2) to refine the list of options under consideration, and select the recommended adaptations for the master plan. TM #1 focuses on existing conditions within the study area, and the categories of adaptations which may be feasible for implementation. TM #2 will evaluate which adaptations are practicable and best suited to achieve the City's flood protection objectives.

Regional adaptations comprise City policies that may be implemented for the entire study area. In TM #2, existing policies will be reviewed to identify opportunities to achieve flood protection objectives through amendments or new policies.

Area specific adaptations are structural measures that must be evaluated based on the constraints and opportunities present in a specified area. In TM #2, these will be further refined using more detailed selection criteria, such as social or economic considerations, as well as any additional considerations discussed during the upcoming stakeholder meetings.

In TM #2, analysis of area specific adaptations will proceed with areas delineated within the OCP Area Plans and Land Use Maps, with some variation as required to capture areas with similar waterfront conditions. The intent of fitting the analysis areas within boundaries specified in the OCP is to form recommendations that can be easily integrated with other City

planning guidelines. For this reason, the twenty-one segments identified in TM #1 will no longer be used as they will be replaced by analysis areas more consistent with the OCP.

The recommended area specific and regional adaptations will be presented in the final master plan.

6 Next Steps

Parsons has characterized the existing conditions and constraints of the study area, and has established preliminary adaptation measures. These adaptation measures will be further refined to ultimately select preferred alternatives for flood protection along the alignment.

The recommended next steps in this study are:

1. Meet with the City project team, review existing conditions, verify current assumptions, and review Parsons' initial technical thoughts for adaptation along the study area.
2. Hold an internal stakeholder meeting with City staff (planning, parks, and development) to review each dike segment and discuss strategies.
3. Further refine preferred alternatives.
4. Draft Technical Memo #2 outlining preferred flood protection strategies.
5. Internal City Review
6. Agency Stakeholder Review
7. Update Strategies
8. Public Information Session / Consultation
9. Final Report

7 Closure

We trust the information provided above provides sufficient details of the design team's understanding of the existing conditions and constraints within the study area for Phase 2 of the LIDMP and establishes the framework for developing the strategy for flood protection along the West and North Dikes.

Regards,

Evelyne Russell, EIT
Project Engineer

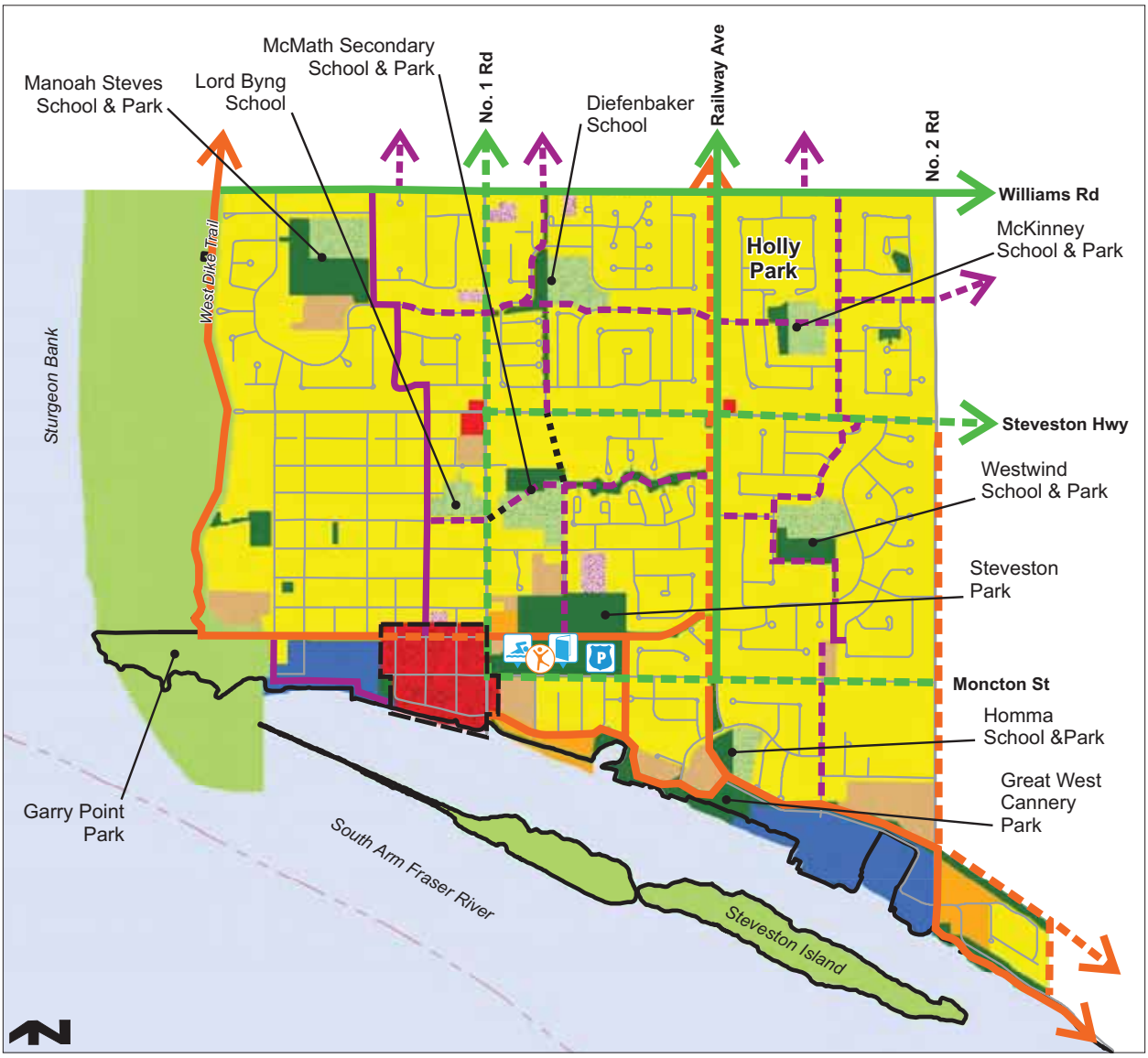
Reviewed By:

PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
T. D. BOWIE
34409
AUG 18 2016

Todd Bowie, P.Eng
Project Manager

ATTACHMENT 1 – OCP PLANS

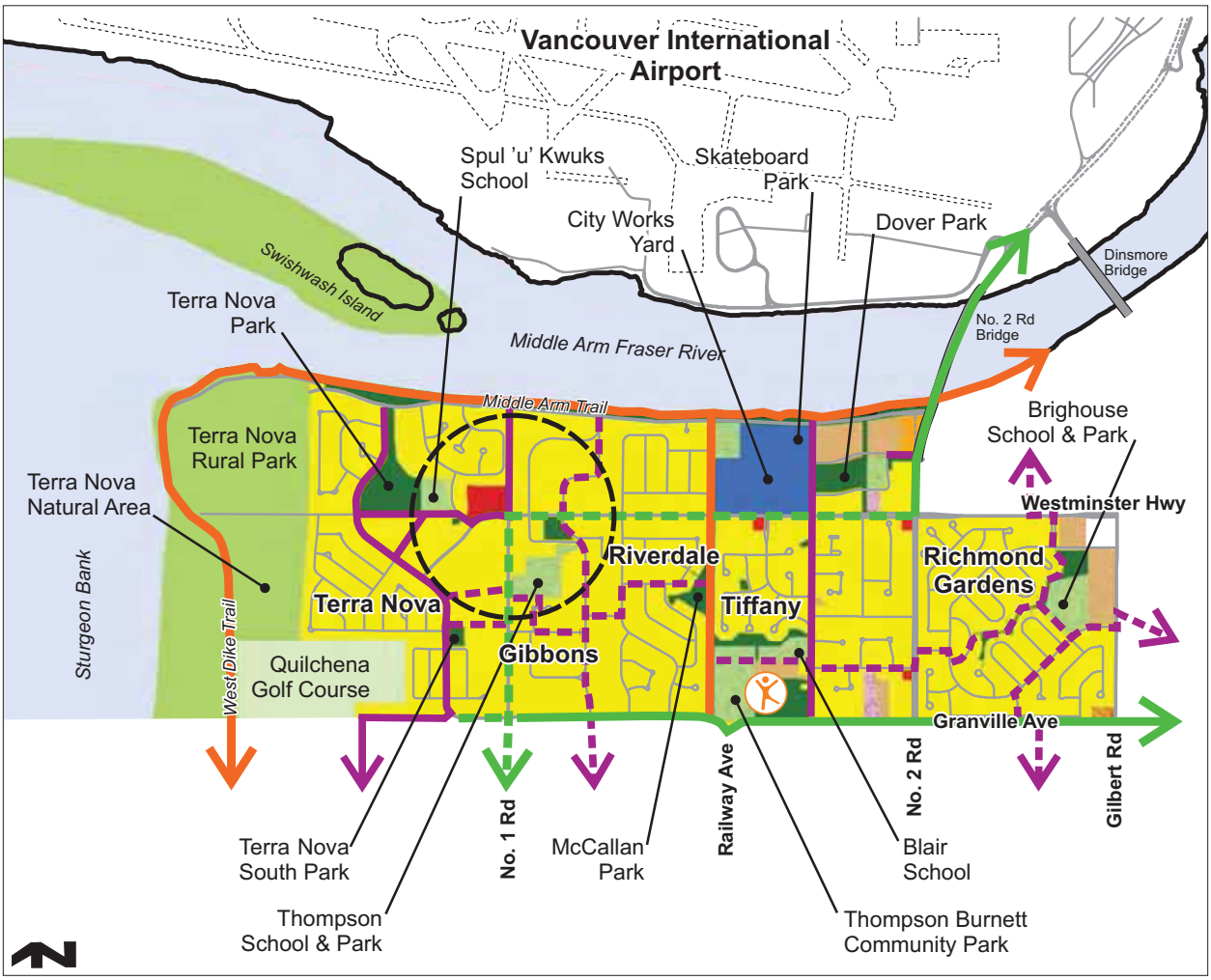
4. Steveston


Manoah Steves School & Park
Lord Byng School
McMath Secondary School & Park
No. 1 Rd
Diefenbaker School
Railway Ave
No. 2 Rd
Williams Rd
McKinney School & Park
Holly Park
West Dike Trail
Sturgeon Bank
Steveston Hwy
Westwind School & Park
Steveston Park
Moncton St
Homma School &Park
Great West Cannery Park
Garry Point Park
South Arm Fraser River
Steveston Island
Apartment Residential
Commercial
Community Institutional
Conservation
Industrial
Mixed Use
Neighbourhood Residential
Neighbourhood Service Centre
Park
School
Steveton Community Centre
Police Steveston Community Station
Steveston Libary
Steveston Pool
Steveston Neighbourhood Centre (future)
Existing Major Street Bike Route
Future Major Street Bike Route
Existing Greenway/Trail
Future Greenway/Trail
Existing Neighbourhood Link - enhanced
Future Neighbourhood Link - unenhanced
Future Neighbourhood Link

3. Seafair

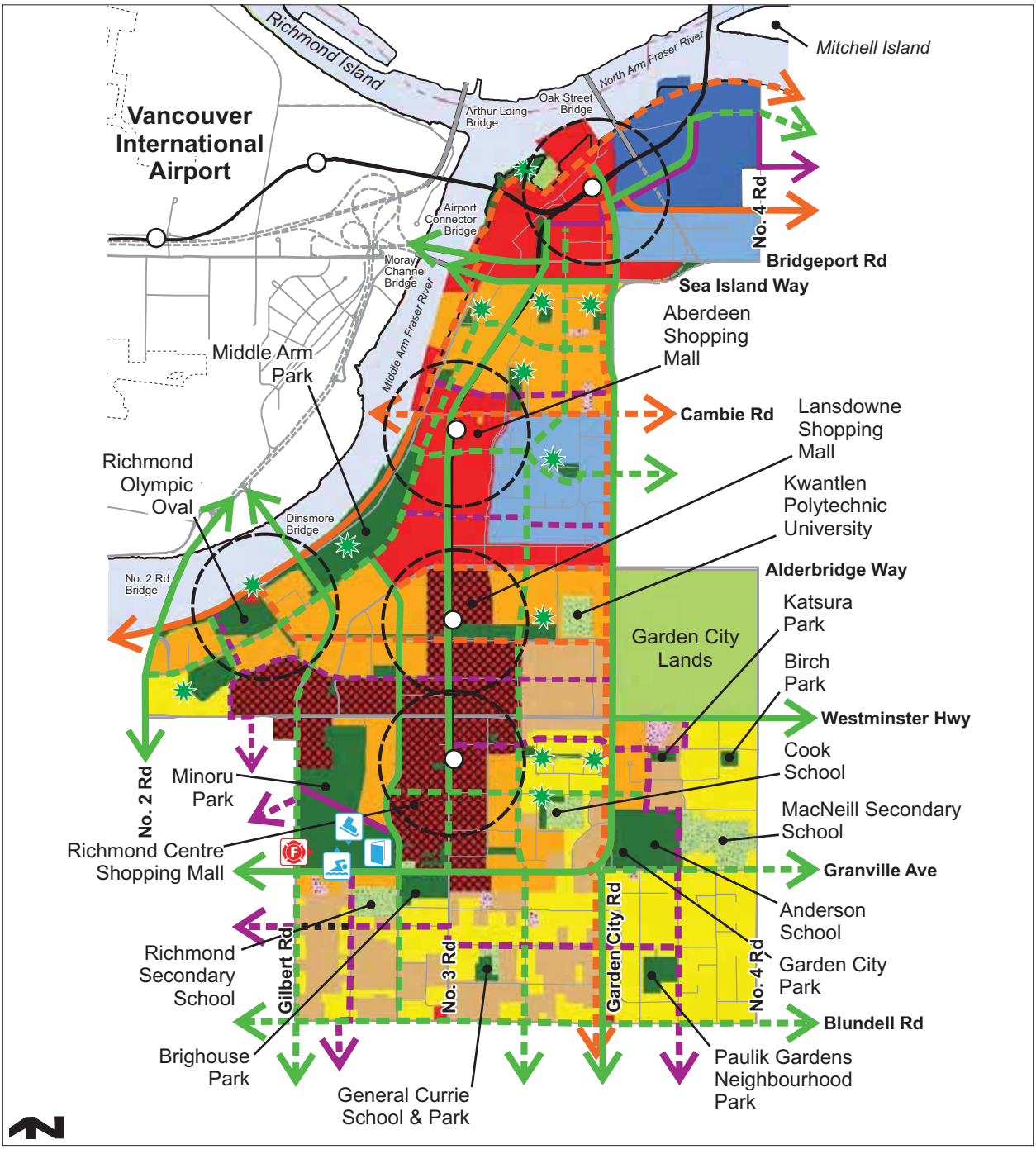

Quilchena School & Park
Morris Park
Granville Ave
Quilchena Golf Course
Quilchena
Blundell Rd
Grauer School & Park
Seafair
Mores
Sturgeon Bank
West Dike Trail
Gilmore School & Park
Francis Rd
Monds
Hugh Boyd Secondary School & Park
Boyd
Williams Rd
Dixon School & Park
No. 1 Rd
Railway Ave
Agricultural
Apartment Residential
Commercial
Community Institutional
Conservation
Neighbourhood Residential
Neighbourhood Service Centre
Park
School
Seafair Neighbourhood Centre (future)
West Richmond Community Centre and Pitch & Putt
Existing Major Street Bike Route
Future Major Street Bike Route
Existing Greenway/Trail
Future Greenway/Trail
Existing Neighbourhood Link - enhanced
Future Neighbourhood Link - unenhanced
Future Neighbourhood Link

2. Thompson



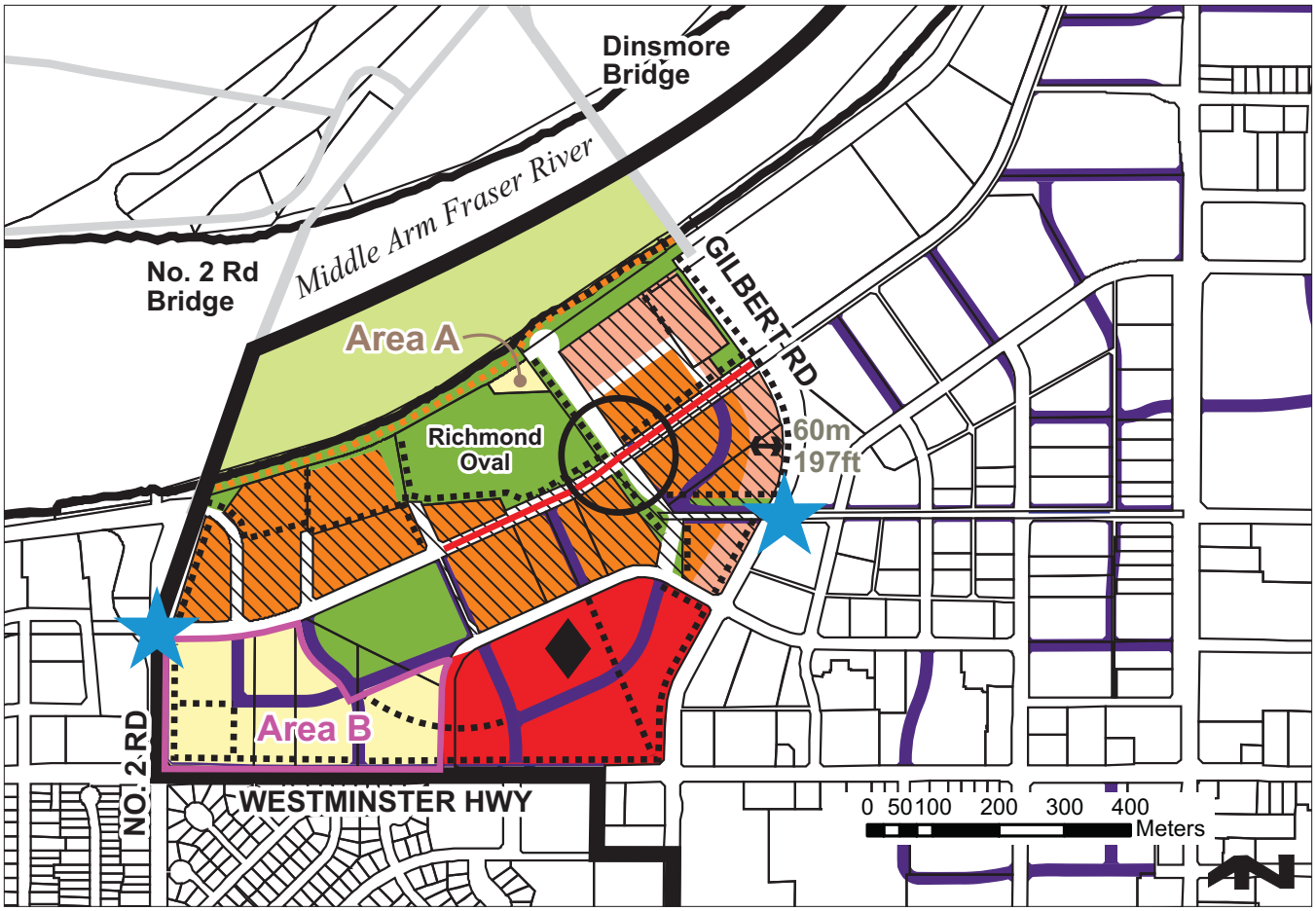
- Agricultural
- Apartment Residential
- Commercial
- Community Institutional
- Conservation
- Industrial
- Limited Mixed Use
- Mixed Use
- Neighbourhood Residential
- Neighbourhood Service Centre
- Park
- School
- Terra Nova Neighbourhood Centre (future)
- Thompson Community Centre
- Existing Major Street Bike Route
- Future Major Street Bike Route
- Existing Greenway/Trail
- Future Greenway/Trail
- Existing Neighbourhood Link - enhanced
- Future Neighbourhood Link - unenhanced

10. City Centre



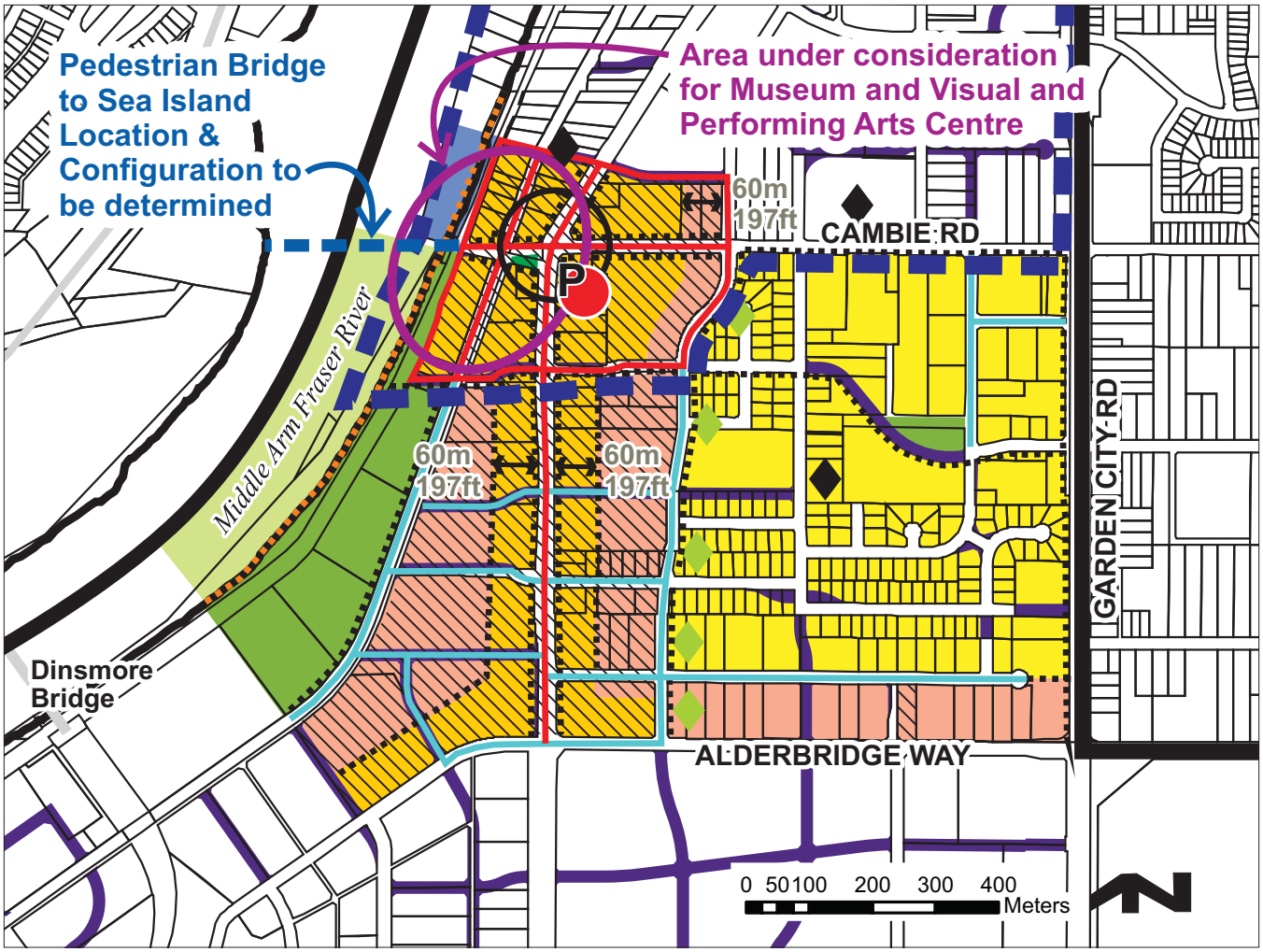
Specific Land Use Map: Oval Village (2031)

Bylaws 8685, 8701 2011/10/24



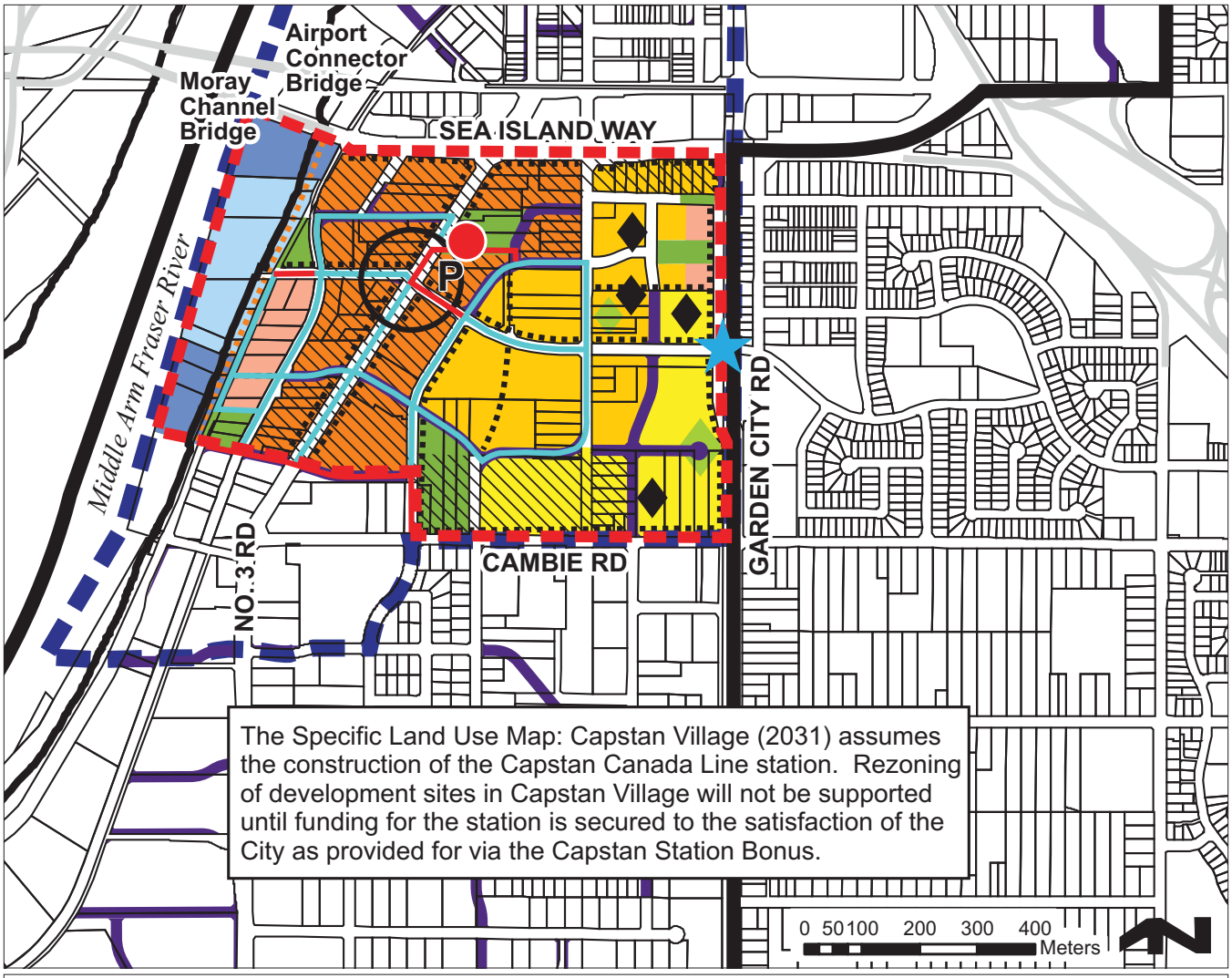
Specific Land Use Map: Aberdeen Village (2031)

Bylaw 8728
2011/07/26



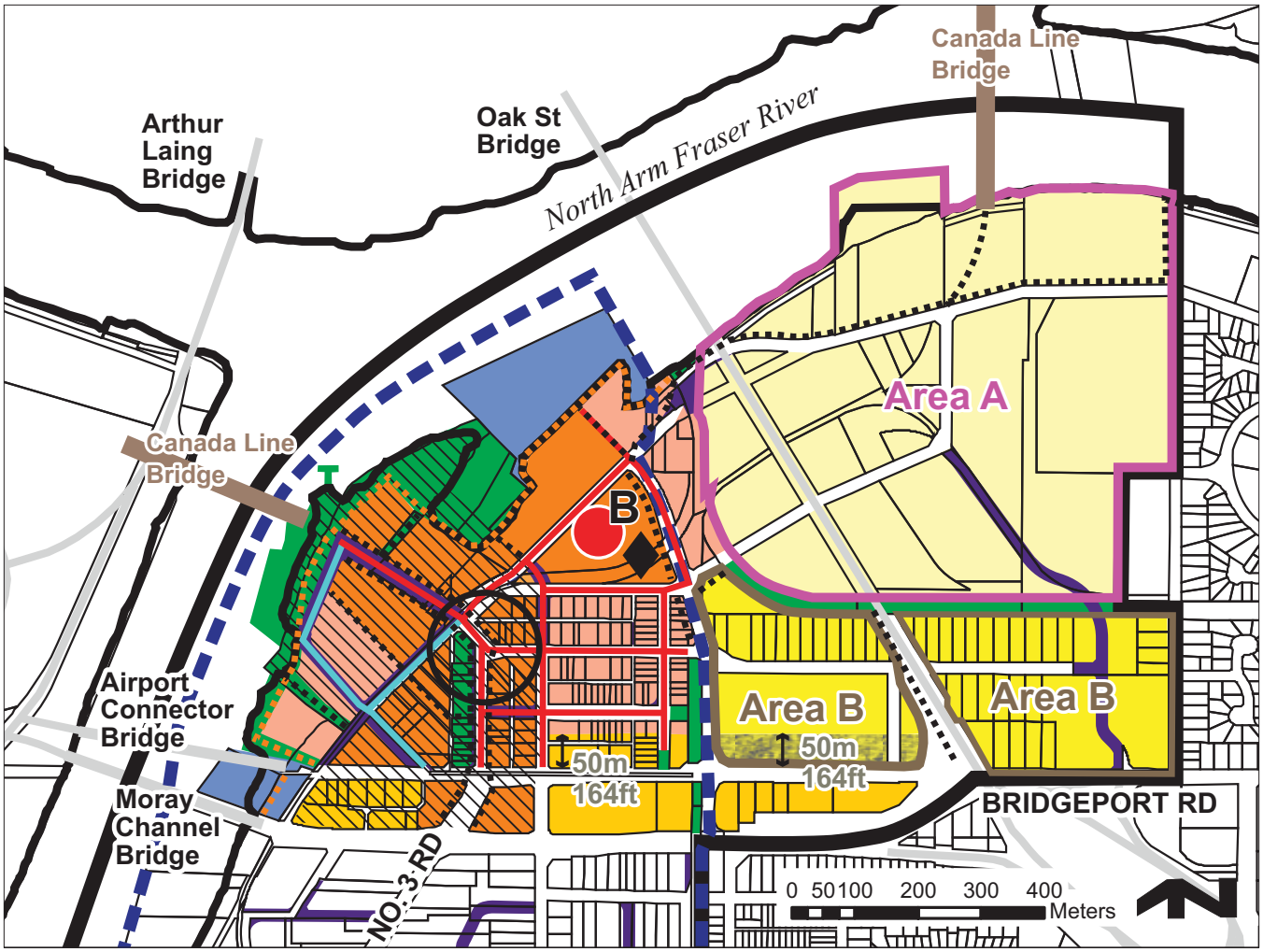
Specific Land Use Map: Capstan Village (2031)

Bylaw 8841
2013/02/12

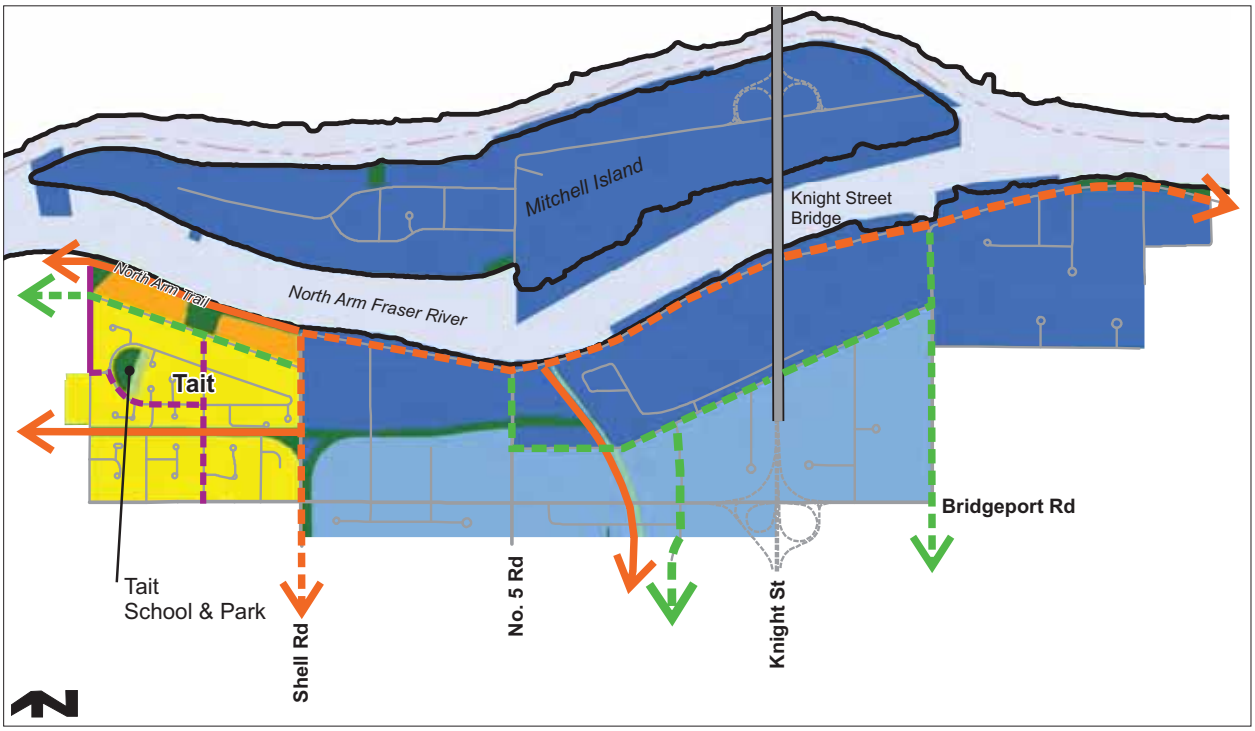


Specific Land Use Map: Bridgeport Village (2031)

Bylaw 9065 2015/07/27

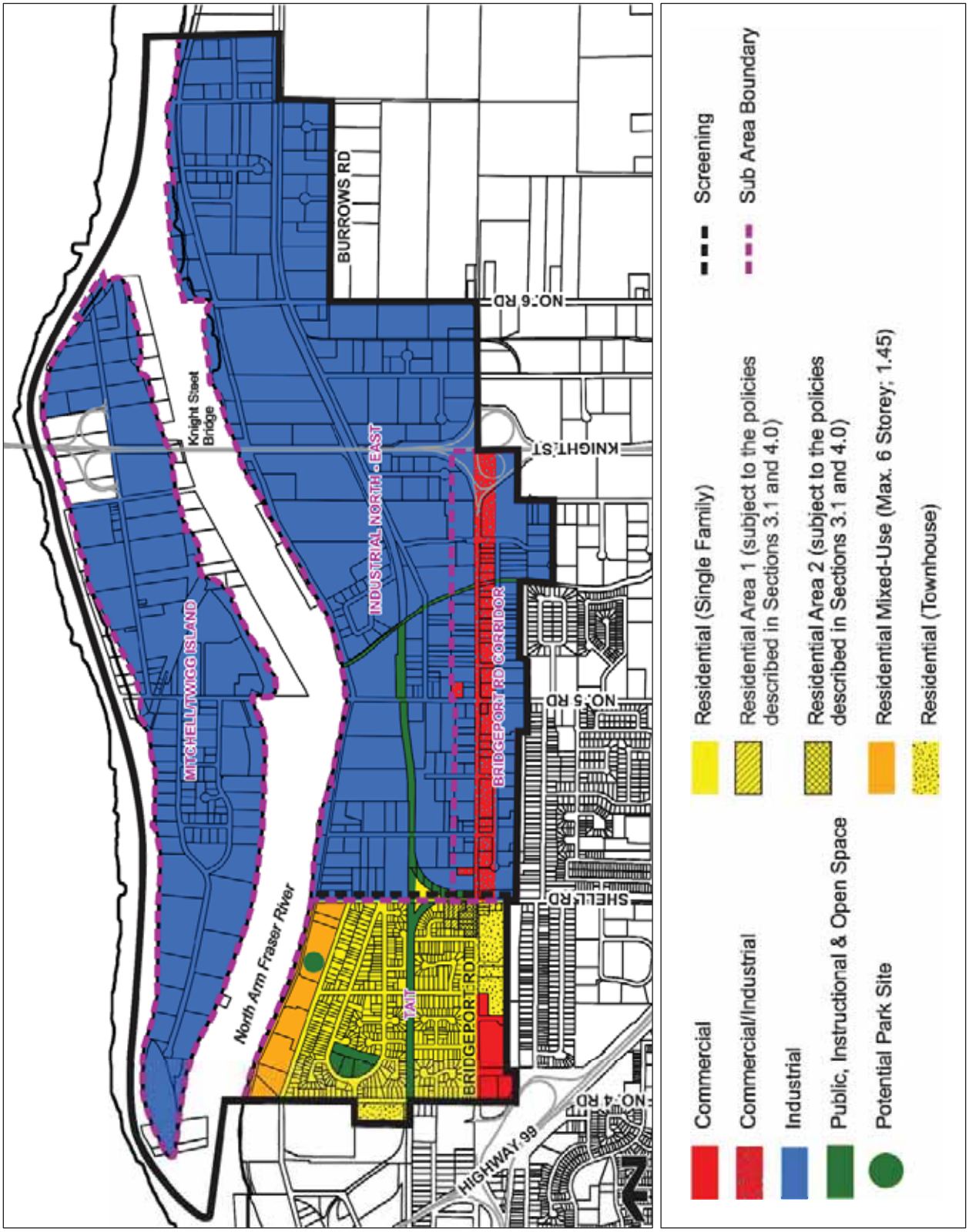


12. Bridgeport (Tait)



Land Use Map – Bridgeport

Bylaw 9024
2013/11/18



ATTACHMENT 2 – FLOOD PROTECTION SEGMENTS TABLE

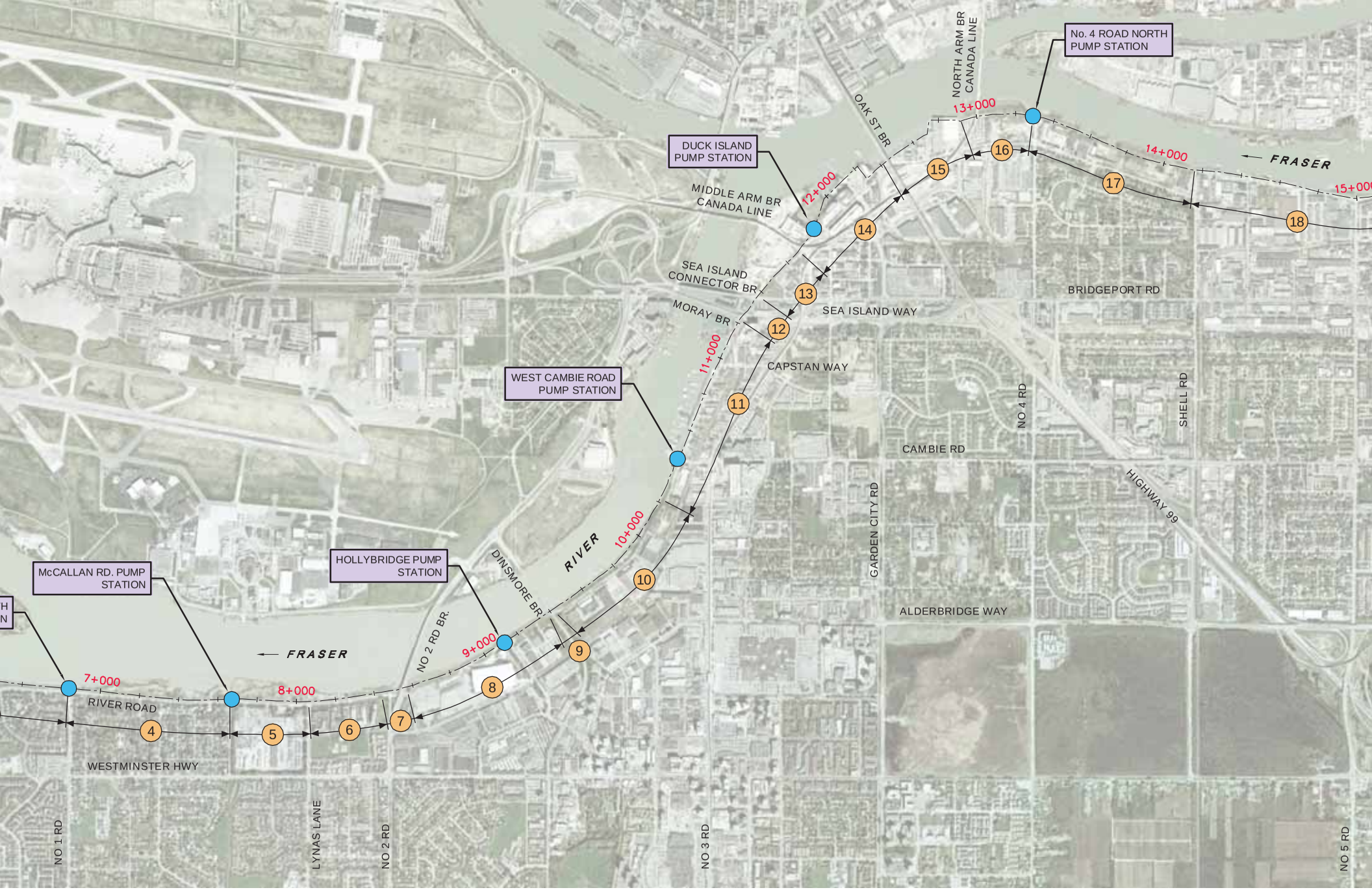
	Gary Point	Terra Nova Park	- Entire West Dike - Sturgeon Bank on water side of dike - Trail spans entire dike alignment - Natural areas and wide open space throughout - Large drainage ditch and landscaping on inland side	- No major changes	3.0 - 3.5 m per 2005 LIDAR, 4.0 m at recent pump station upgrades	- Environmental considerations for wate - Drainage swales on land side constrai
ark	End of River Road, trailhead of the West Dike Trail	2820 River Road, where the Dike Trail briefly joins River Road	- Wide area between River Road and the Dike Trail - Two parking areas for 10 - 15 cars each - Park infrastructure: benches, picnic tables, washroom building - No substantial vegetation in open space - Swales on either side of River Road	- No major changes	3.5 m per 2005 LIDAR	- No impediments to land side dike expa - Parking areas can be reconfigured as - Potential for a secondary dike to be m Park at a lower level of protection in the
ark	2820 River Road	2860 River Road, east of small parking lot at lookout	- River Road is the dike for this segment - Private homes on south side of River Road - Dike Trail is north shoulder of River Road - Wetland abutting dike for 80m - Lookout and small parking lot (10 - 15 cars) east of wetland	- No major changes	3.2 m per 2005 LIDAR	- Highly constrained area for 80m at we expansion - Water side wetland may be a protecte - Land available to expand dike at looko
erra	Terra Nova Park, east of small parking lot at lookout	River Road	- River Road is the dike for the west part of this segment, sloping down off the dike to the residential road	- No major changes	3.2 m per 2005 LIDAR	- Lands available to relocate driveway s - Large trees in relocation area south of - Regraded driveway to the park must m toe of the dike
	Terra Nova Park	No. 1 Road	- River Road is substantially offset from the Dike Trail, leaving a wide open space area - Single Family Homes	- No major changes	3.2 m per 2005 LIDAR	- Space available for land side expansio - Incremental grade increases to River R
ump			- Dike was raised locally raised to 4.0 m as part of the No. 1 Road pump station upgrade	- No major changes	4.0 m per pump station plans by Opus DaytonKnight, 2012	- Space available for land side dike expa grade increases to River Road - Outlet to Fraser River must remain un
	No. 1 Road	McCallan Road	- Single Family Homes - Heavy vegetation and large trees north of the dike - Substantial land on water side, though it may be protected habitat - Dike Trail is north of River Road - Single family homes on south side of River Road - McCallan Road Pump Station has not been upgraded recently	- No major changes	3.3 m per 2005 LIDAR	- Space available for water side dike exp - Potential environmental concerns - Limited driveway accesses to River Ro - Some land side expansion could occu Road
ad			- Older pump station, small footprint - Outlet channel from pump station to Fraser River through wetland - Water side is heavily vegetated	- No major changes	4.0 m per 2005 LIDAR	- Potential environmental concerns - Outlet to Fraser River must remain un - Some land side expansion could occu Road - Raising River Road would trigger upgr
oot	McCallan Road	Lynas Lane	- Substantial land on water side - Heavy vegetation north of the dike - Dike Trail is north of River Road - City Works Yard	- No major changes	3.3 m per 2005 LIDAR	- Space available for land side dike expa increases and realignment of River Roa - Time works with improvements to the elevation
ocks	Lynas Lane	5860 Dover Crescent	- Existing mid-rise residential complexes - Wide landscaped area on south side of River Road includes trees and pedestrian trail - Slopes and retaining walls in landscaped area; buildings are high relative to River Road elevation	- No major changes	3.4 m per 2005 LIDAR	- Land is available on south side of Rive - Opportunity to raise River Road in con dike footprint
ock	5860 Dover Crescent	No. 2 Road Bridge	- Empty lot east of existing mid-rise residential - Trees along River Road and on the lot - No. 2 Road North Discharge Structure at the foot of the cycling ramp - The existing land side developments are built higher than River Road	- Mixed-use development in empty lot between condos and bridge	3.2 m per 2005 LIDAR	- Space available for land side dike expa grade increases to River Road - River Road would need to transition d
ridge			- Clearance from River Road to the bridge is minimal, enough for trucks to	- Mixed-use developments on either	3.2 m	- River Road could not be raised here a

	No. 2 Road Bridge	Dinsmore Bridge	- Olympic Oval and waterfront park constructed before 2010 - River Green development with recent dike upgrades	- No major changes	4.0 m to 4.45 m with recent dike improvements	- Space within the waterfront park is ava however this area is heavily landscaped - The existing dike is at or near the targe - The land side has been filled. - Incremental increases should be achie
e	Hollybridge Pump Station	Dinsmore Bridge	- River Green Village new development east of Olympic Oval - Established office complex west of the Dinsmore Bridge	- River Green Village development by ASPAC is underway - Abutting established office complex is zoned for mixed use; may be redeveloped	4.7m per River Green development plans prepared by GeoPacific Consultants, 2014	- New development has achieved the pr - Dike at the established office complex - Dike increases would need to be caref where the dike trail will remain low to ma - Space for land side dike expansion wil decommissioned here
dge			- 4.3 m clearance from River Road to the bridge - Dike trail crosses under the bridge with low clearance	- River Road will be decommissioned from the Dinsmore Bridge east, and relocated to the former CN rail corridor	3.4 m per 2005 LIDAR	- Raising the dike would restrict clearan - No space for land side expansion in th dike - River Road cannot be raised without ir - Space for land side expansion may be realigned - Flood walls may need to be considere
ure	Dinsmore Bridge	Browngate Road	- Middle Arm Waterfront Park constructed along waterfront at UBC John Lecky Boathouse in 2009 before the 2010 Olympics - Area is heavily landscaped - Marinas present on the waterfront	- Industrial lands to be decommissioned and replaced with a large park from waterfront to new River Road alignment on former CN Rail corridor	3.5 - 5.0 m per Middle Arm Waterfront Park plans prepared by AECOM, 2009	- Dike has been raised to the target elev Park - With realignment of River Road, and d to create a wide swath of filled land ('sup
ure Mixed	Browngate Road	Moray Channel Bridge	- Industrial and redevelopment sites on the waterfront south of River Road - Marinas present on the waterfront	- River Road to be decommissioned south of Cambie - Richmond Arts District to be developed here, incl. museum - Pedestrian-oriented retail precinct along waterfront park - Proposed pedestrian bridge to Sea Island at Cambie Road	3.3 m per 2005 LIDAR	- Lands will undergo substantial redevel - Land side dike expansion can be incor - With redevelopment there is the poten ("superdike")
Road			- Pump station was upgraded in 2008	- No change	4.0 m per pump station drawings prepared by Aplin Martin, 2008	- Outlet to Fraser River must remain un - Pump station plans must be reviewed expansion
			- Marinas present north and south of the bridge - Boat launch from marina parking lot to south side of bridge - The Boathouse restaurant parking lot on north side of bridge	- Lands south of bridge to be redeveloped into mixed use sites	3.0 m per 2005 LIDAR	- Bridge deck is very low - Marina dock is directly adjacent to brid - No space available for land side dike e - Strategy applied should be consistent - Structural measures may be required (
dge			- Marinas present south of the bridge - The Boathouse restaurant parking lot south of bridge - Richmond Night Market north of bridge	- No major changes	3.0 m per 2005 LIDAR	- Space restrictions south of the bridge - No space restrictions north of the bridg - Strategy applied should be consistent - Structural measures may be required (
ght	Sea Island Connector	Middle Arm Bridge	- Former industrial site - Large concrete surface and parking area - Existing floodwall at waterfront	- Mixed use development	3.0 m per 2005 LIDAR	- Duck Island area is under review by lo Casino; final master plan will be consist
ridge,			- Constructed in 2009	- No major changes	3.4 m per 2005 LIDAR	- Bridge is high; no clearance issues an - Duck Island area is under review by lo Casino; final LIDMP report will be consi

asino	Middle Arm Bridge	Oak Street Bridge	- River Rock Casino and marina - Constructed wetland on waterfront	- Mixed use development	4.2 m per concept design report for River Road prepared by Golder, 2007	- Duck Island area is under review by lo Casino; final LIDMP report will be consis
Bridge			- Constructed in 1967, damaged by fire in 2014 - Bridge is currently not operational however it connects to the Arbutus Corridor which is currently being upgraded for use - CP may resume use of the bridge shortly - Bridge is approx. 50 m west of the Oak Street Bridge	- No major changes	4.0 m per 2005 LIDAR	- Bridge is very low, restricting land side - Structural measures may be required - Integrity of bridge must be maintained
idge			- Established industrial uses on either side of the bridge - Dike is north of River Road but not easily accessible; it is not a public trail here - River Road crosses under the bridge at the waterfront	- No major changes	4.0 m per 2005 LIDAR	- Bridge is very high, clearance is not a - Log storage on waterfront east of the b - Duck Island area review includes lands protection should connect with Duck Isla
ser al	Oak Street Bridge	North Arm Bridge	- River Road is not at the waterfront here - Dike is a trail a - High clearance to the bridge - Log storage along the waterfront	- No major changes	4.0 m per 2005 LIDAR	- Private industrial site with marina and - Buildings directly on the waterfront - Existing flood wall could be incorporate
tion	North Arm Bridge	No. 4 Road	- Upgraded in 2014 - Three large hydro towers for lines crossing the Fraser River - Log storage along the waterfront	- No major changes	4.3 m per 2005 LIDAR	- Hydro towers can be accessed from th would not limit maintenance access - Land is available for land side expansi - Industrial uses along waterfront limit st
dge, to ation			- River Road is not at the waterfront here; the dike is a trail - High clearance to the bridge - Log storage along the waterfront	- No major changes	4.3 m per 2005 LIDAR	- Industrial uses along waterfront limit st - High clearance from the trail to the bri - Integrity of bridge footings must be co
	No. 4 Road	Shell Road	- Former industrial lands currently under construction - Dike is a waterfront trail being landscaped alongside new development - High Rise developments underway, next phase is townhouses - Observations on site show the dike elevation at the new development matches the elevation at the pump station - North of established neighbourhood of single family homes	- Currently being redeveloped to residential and commercial uses	4.7 m per pump station plans prepared by Aplin Martin, June 2010	- Industrial uses along waterfront limit st - Dike has been raised and abutting lan development, essentially a "superdike" i - No further adaptions are anticipated in
ump			- New pump station integrated into trail system - Pedestrian access to roof serves as a lookout - Constructed alongside Park Rivera new development - Landscape is consistent with Park Riviera new development	- Recently constructed in conjunction with abutting new residential development; no major changes upcoming	4.7 m per pump station plans prepared by Aplin Martin, June 2010	- Industrial uses along waterfront limit st - Outlet to Fraser River must remain un - Dike has been raised and abutting lan development, essentially a "superdike" i - No further adaptions are anticipated in
	Shell Road	Bath Slough Pump Station	- Dike is a trail north of River Road - Public access is limited where established industrial uses are directly on the waterfront north of River Road - Log storage at No. 5 Road	- No major changes	3.25 m per 2005 LIDAR	- Industrial uses along waterfront limit st - Space available for land side expansio River Road
Pump			- Trailhead of the Bath Slough Trail - Receives drainage from a large inland channel and River Road swale east of the pump station	- Pump station is currently being upgraded	3.25 m per 2005 LIDAR	- Industrial uses along waterfront limit st - Outlet to Fraser River must remain un
	Bath Slough Pump Station	West of Knight Street Bridge	- Existing industrial to remain - River Road is the dike - Large swales on south side of River Road draining west	- No major changes	3.25 m per 2005 LIDAR	- Industrial uses along waterfront limit st - Swales may need to be filled to accom
	West of Knight Street Bridge	Barricade east of Knight Street Bridge	- Existing industrial to remain - River Road is the dike; it is publicly accessible here - Heavy vegetation north of River Road including large trees - Log storage along waterfront	- No major changes	3.2 m per 2005 LIDAR	- Industrial uses along waterfront limit st - Swales may need to be filled to accom - City has unencumbered access for ma

			- Very high clearance to road below - River Road is the dike; it is a private road here - No public access - Heavy vegetation north of River Road including large trees - Log storage along waterfront	No major changes	3.25 m per 2005 LIDAR	- No clearance issues anticipated - Impact on bridge footings to be consid '- Industrial uses along waterfront limit s - City's access is limited, restricting mai
	Barricade east of Knight Street Bridge	Barricade west of No. 6 Road	- Lumber yard and associated industrial complex - River Road is the dike; it is a private road here - No public access - Heavy vegetation north of River Road including large trees - Log storage along waterfront	- No major changes	3.25 m per 2005 LIDAR	- Industrial uses along waterfront limit st - City's access is limited, restricting mai
nveyor	Barricade west of No. 6 Road	No. 6 Road	- River Road is the dike; it is a private road here - Overhead conveyor belt and associated infrastructure for wood products - Large overhead infrastructure hanging over the waterfront - Overhead hydro feeding the site - No public access - Heavy vegetation north of River Road including large trees - Log storage along waterfront	- No major changes	3.3 m per 2005 LIDAR	- Industrial uses along waterfront limit st - City's access is limited, restricting mai

ATTACHMENT 3 – FLOOD PROTECTION PLAN & SECTIONS



KEY PLAN
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Lulu Island Dike M
North Dike Floo

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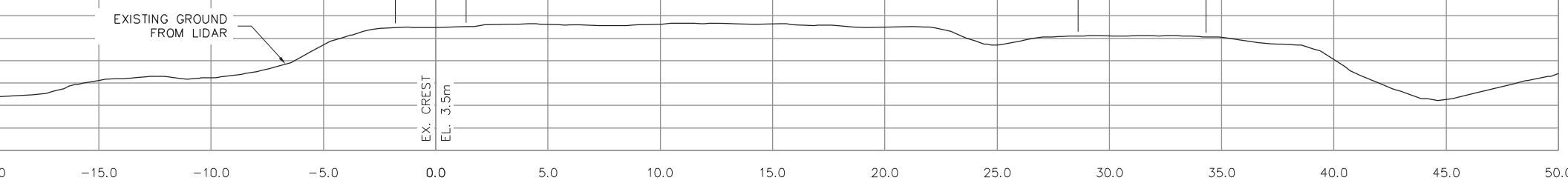

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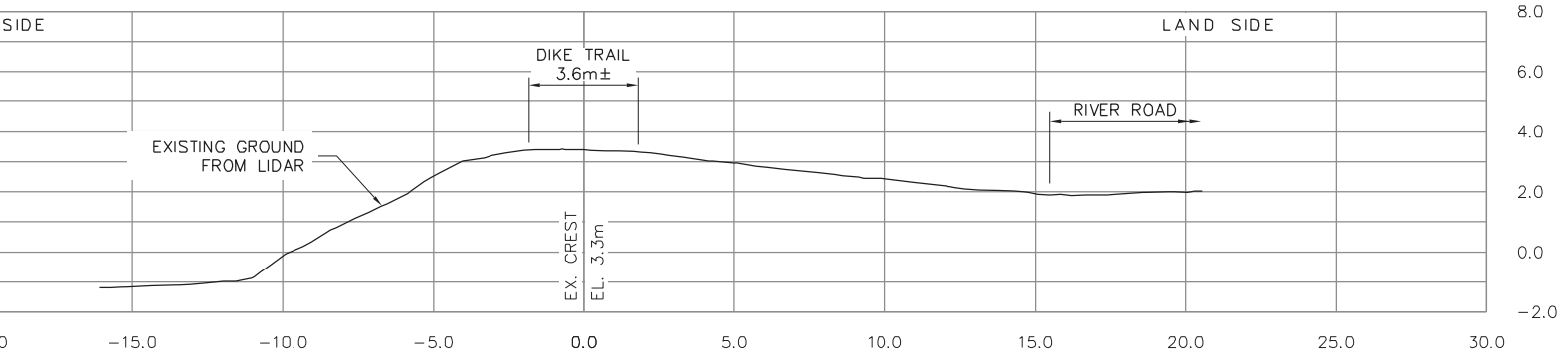

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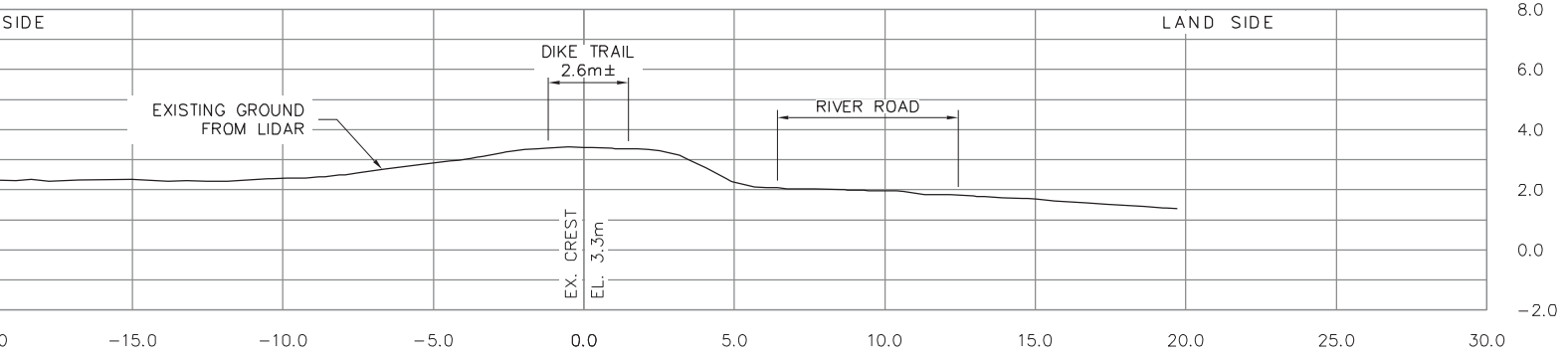

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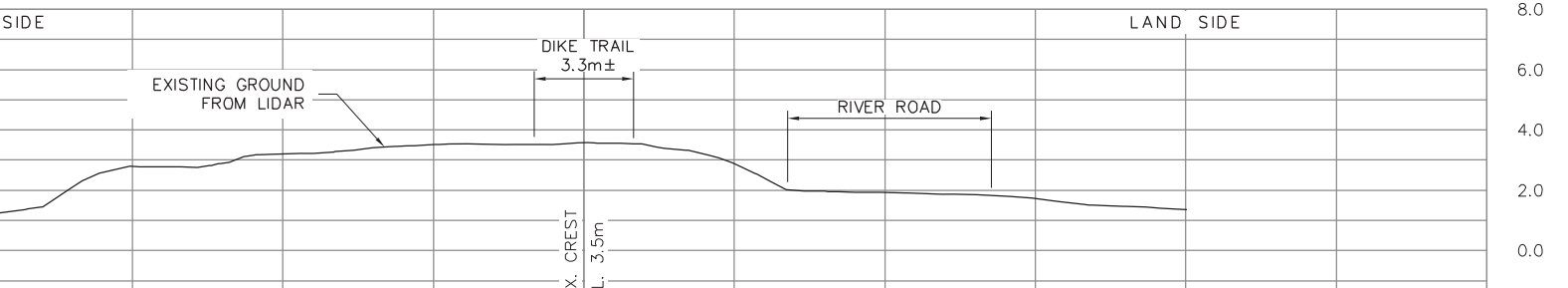

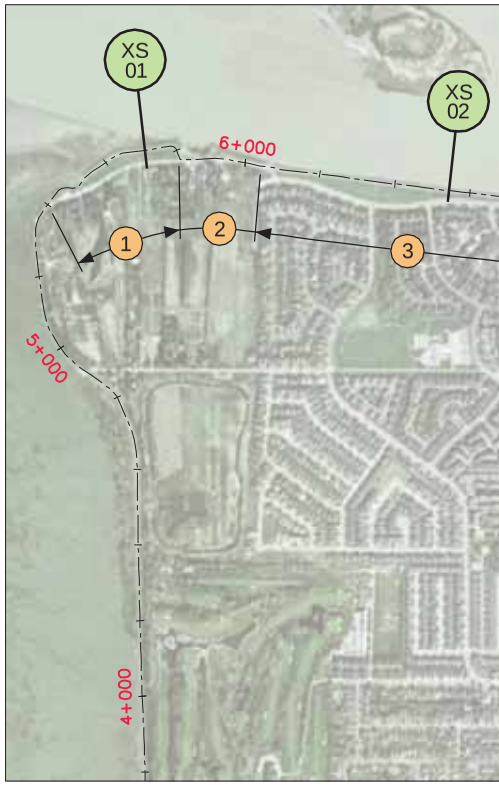

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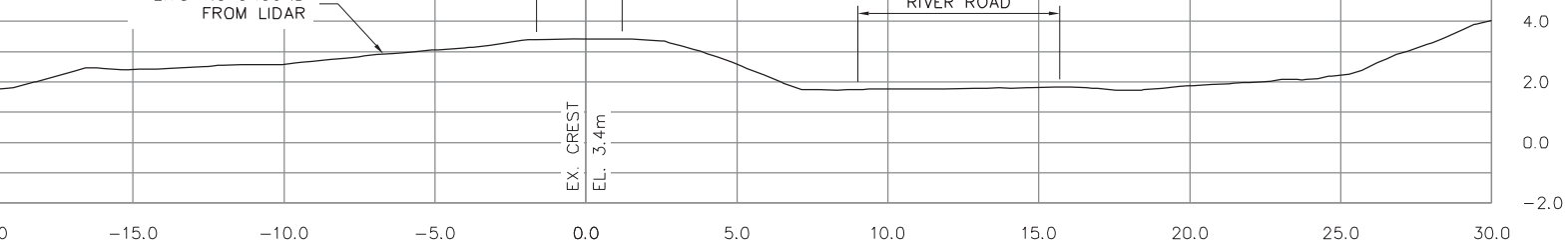
EXISTING PUMP STATION

5 DIKE SEGMENT NUMBER

Lulu Island Dike M
North Dike Floo



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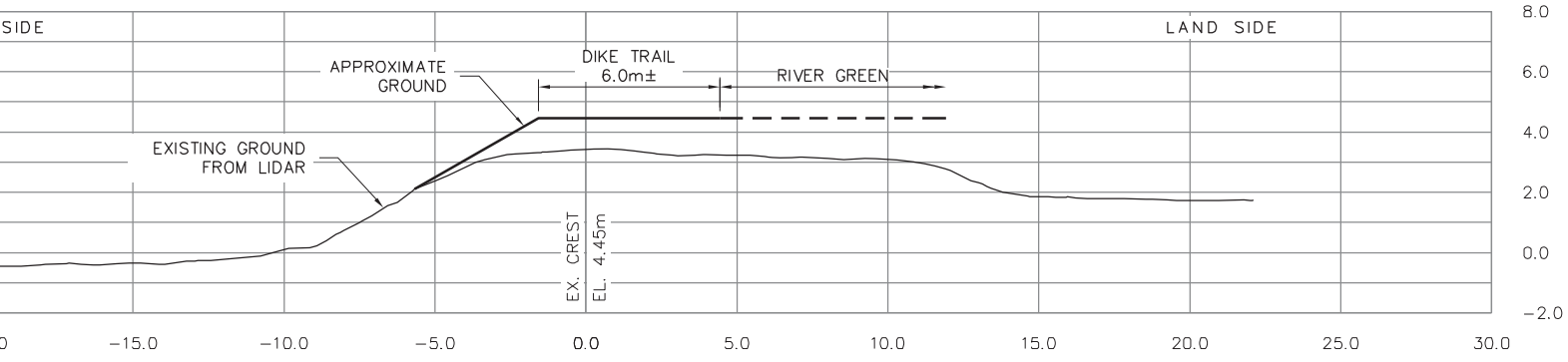

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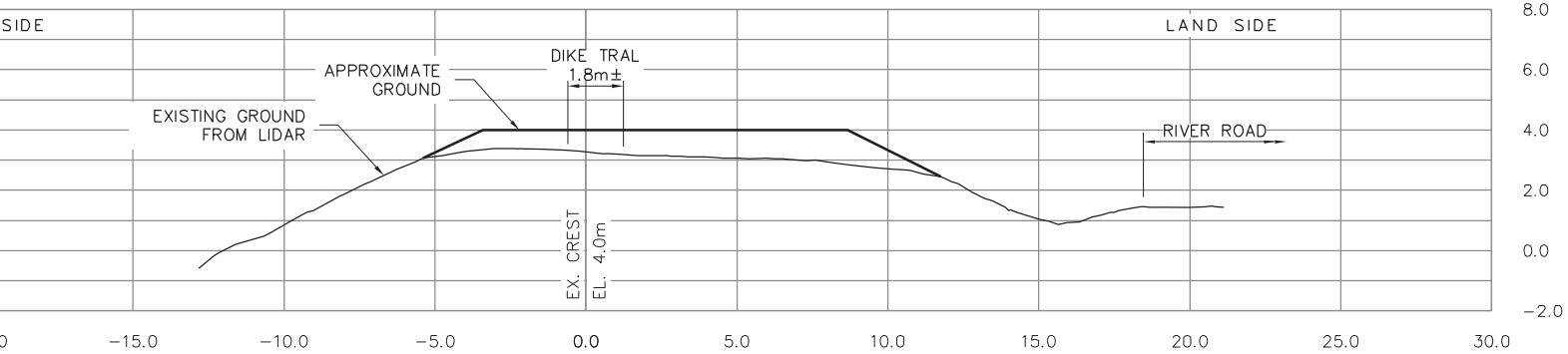

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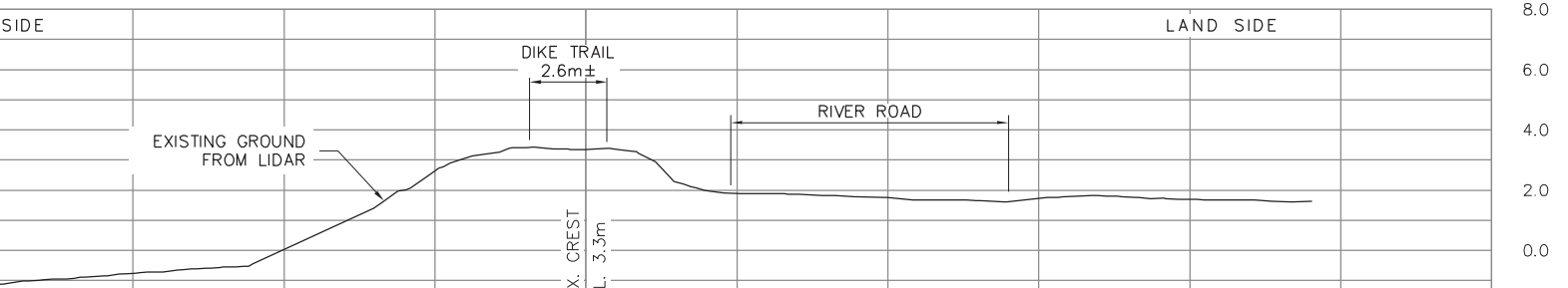

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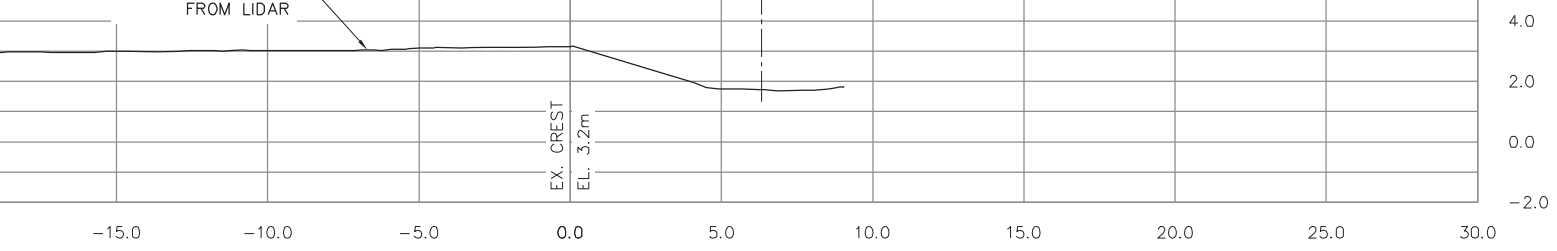
EXISTING PUMP STATION

5 DIKE SEGMENT NUMBER

Lulu Island Dike M
North Dike Floo



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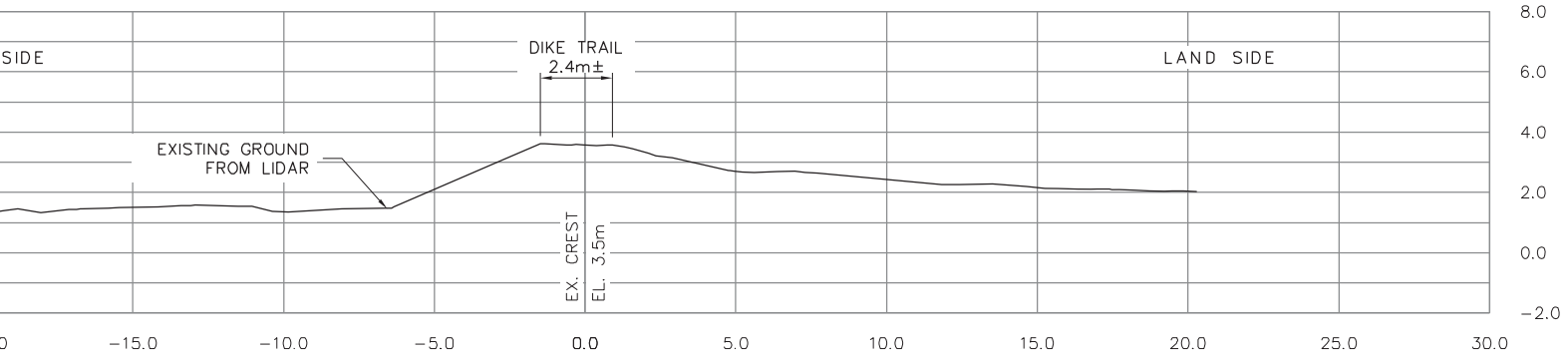

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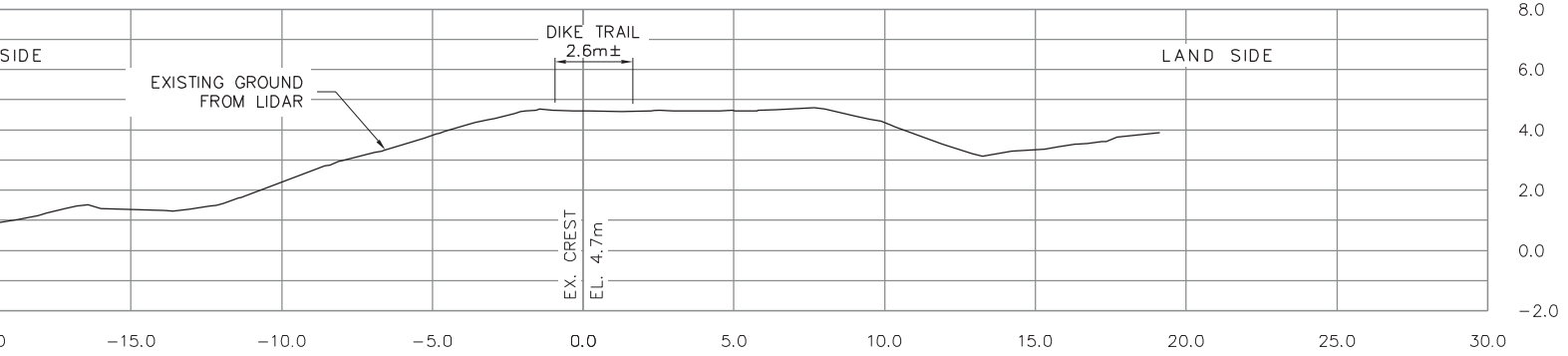

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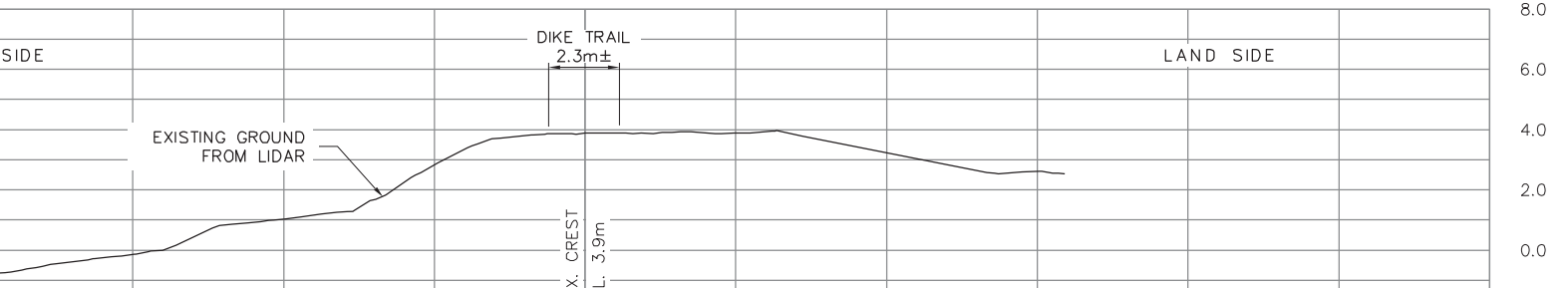

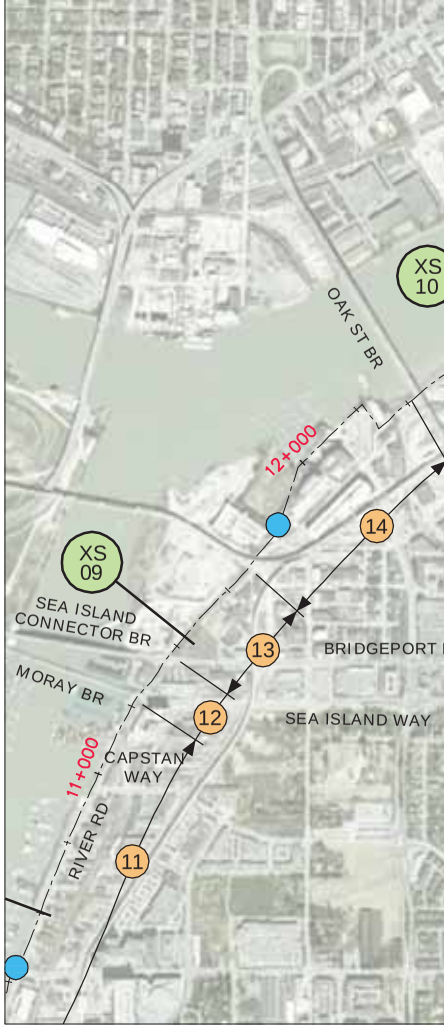

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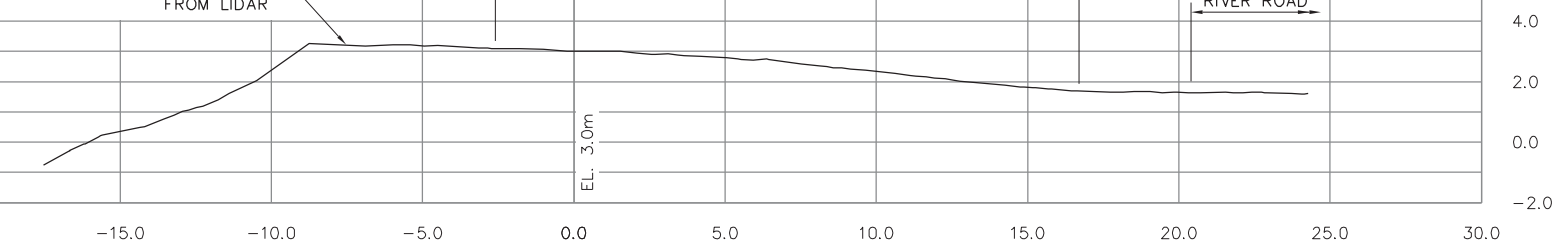
- EXISTING PUMP STATION
- 5 — DIKE SEGMENT NUMBER

Lulu Island Dike M
North Dike Floo



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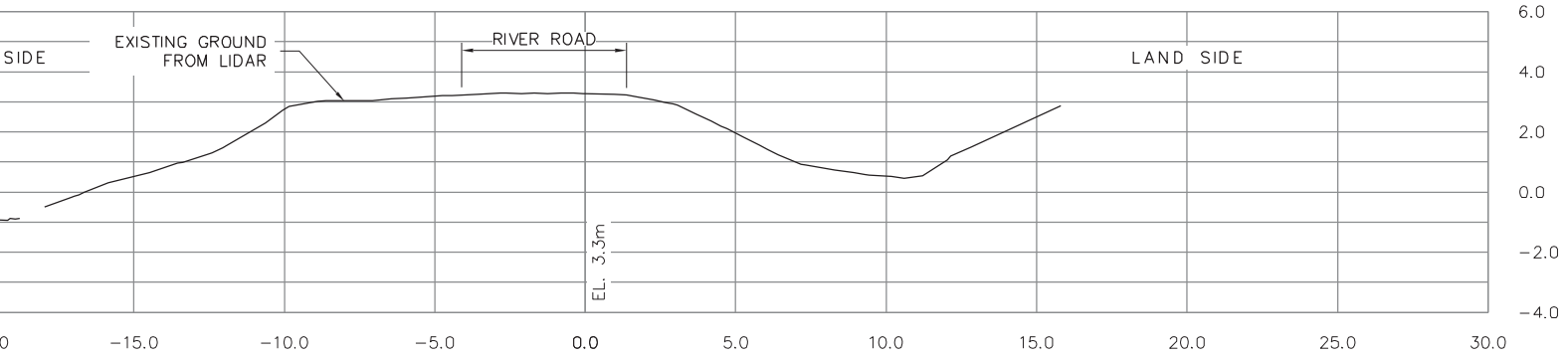

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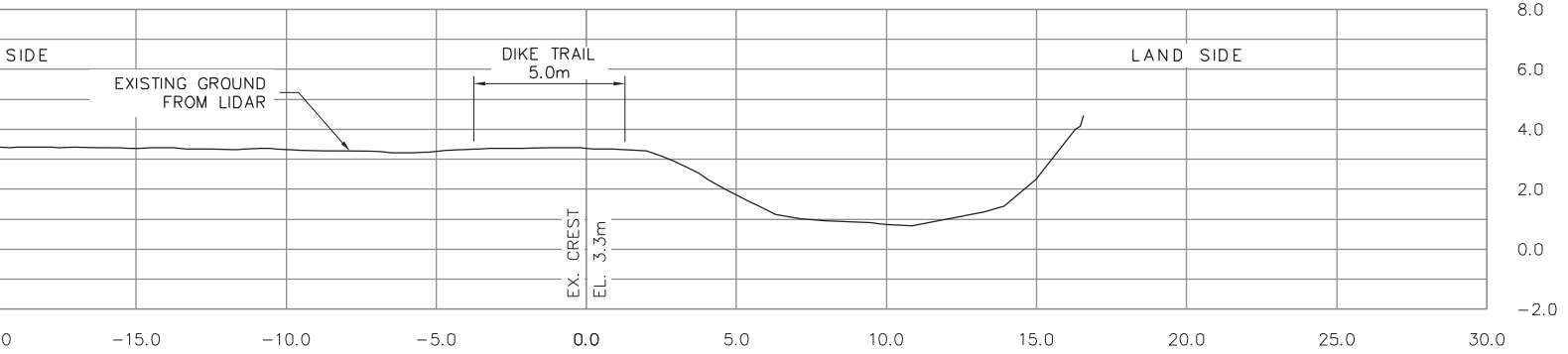

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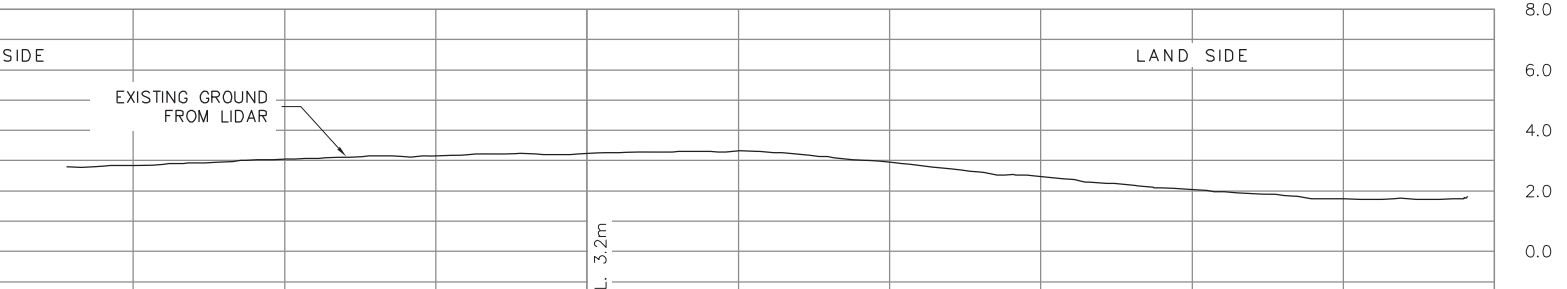

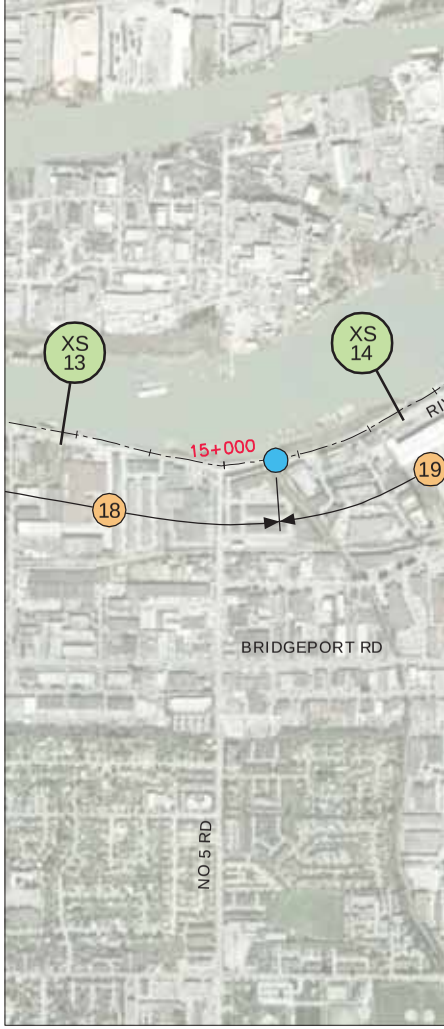

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EXISTING PUMP STATION

5 DIKE SEGMENT NUMBER

Lulu Island Dike M
North Dike Floo

Attachment 2

Technical Memo #2 - Parsons

PARSONS

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August 28, 2016

Engineering Planning Department
City of Richmond
4th Floor, 6911 No. 3 Road
Richmond, BC V6Y 2C1

Subject: **Lulu Island Dike Master Plan Phase 2**
Technical Memo No. 2: Analysis of Flood Protection Alternatives

Dear Lloyd Bie, P.Eng:

Executive Summary

The purpose of the Lulu Island Dike Master Plan (LIDMP) is to identify preferred methods for implementing the objectives of the City of Richmond's 2008 – 2031 Flood Protection Strategy.

The Lulu Island Dike Master Plan is being prepared in phases. Parsons (as Delcan) prepared Phase 1 of the plan for the Steveston and southern West Dike areas[1] (Phase 1 LIDMP). Phase 2, this study, focuses on the entire West Dike, and the North Dike from Terra Nova Park east to No. 6 Road as shown in the ***Key Plan*** attached at the end of this summary.

The Phase 1 LIDMP focused largely on technical issues of assessing significant changes in dike alignment: namely the engineering feasibility of a future dike and flood-gate along Steveston Island to protect both Steveston and Steveston Harbour, as opposed to adapting upgrades to the existing shoreline alignment, in order to maintain the heritage structures in Steveston.

The nature of the assignment is different for the Phase 2 alignment. The existing dike alignment along the waterfront is well defined and established. There is limited basis to support any major changes to the alignment of existing dike on an area specific basis. However, there are opportunities within the Phase 2 study area to consider alternate regional approaches to flood protection to implement the objectives of the Flood Protection Strategy. Accordingly, the Phase 2 LIDMP has been considered on two levels: Regional Approaches; and, Area Specific Approaches.

Regional Flood Protection Strategies

A number of regional approaches can be considered to enhance long term flood protection in the City and create resiliency in addressing climate change and sea level rise. Preferred strategies are summarized below.

Adopting policies to promote the long-term raising of lands adjacent to and inland of the existing dikes into superdikes: Superdikes are created by infilling lands behind the dike to raise the ground elevation of development. Long term raising of land levels has previously been recommended (2008-2031 Flood Protection Strategy). Maximizing the width of raised land adjacent to the river decreases flood and seismic risks by increasing the integrity of the dike.

The City's Flood Construction Level (FCL) Bylaw establishes minimum levels to which land needs to be raised. Amending the FCL bylaw is the preferred regional strategy to achieve this goal and improve flood protection throughout the study area.

[1] Lulu Island Dike Master Plan Phase 1, Delcan, March 2013

These amendments could include creation of an additional FCL area adjacent to or within a stipulated distance from the existing dike or waterfront. The area could require an FCL of 4.7 m with exemptions based development size or parcel size. The FCLs would also have to consider overall lot raising and not just habitable space.

Additional studies on implementation of modified FCL bylaws should be conducted prior to proceeding with any changes. Input should be provided from architects, planners, environmental consultants, engineers, and key stakeholders to obtain a comprehensive understanding of factors to be mitigated while achieving flood protection goals.

Planning for implementation of offshore protection on Sturgeon Banks: If climate change and sea level rise predictions materialize, increased depths offshore could simultaneously increase wave heights, particularly in the Georgia Strait. Offshore barrier islands are one option to consider to dissipate wave energy prior to reaching the west dike, thereby minimizing future dike crest increases.

Breakwaters are most effective when constructed close to the shore, as broken waves grow again behind the breakwater under the influence of wind. The effectiveness depends also on the crest height of the breakwater, with a higher breakwater giving more wave reduction.

The City should consider offshore protection in its long-term plans for flood protection along the West Dike.

Consider establishing a habitat banking program: It is anticipated that for diking projects both within the study area and City-wide, alterations to environmentally sensitive areas may be unavoidable and habitat compensation may be required. The City may consider establishing a formal habitat banking program to allow for flexibility to create habitat. Habitat credits can be applied to multiple projects, or stored for future dike works. A formal habitat banking program may assist with the implementation of long term flood protection infrastructure upgrade programs.

Area Specific Flood Protection Strategies

In practice, when dike upgrades have been made, they have been made along the existing alignment. Apart from select site specific constraints and opportunities, the recommended future dike alignment for the Phase 2 study area matches the existing dike alignment. Consideration has been given to potential measures to achieve the future dike upgrades. However, future studies tied to specific design exercises will confirm the preferred dike cross-section.

Area specific strategies for the Phase 2 study are summarized below:

West Dike: Raise the dike on the existing alignment. Additional studies required to quantify drainage impacts of land side expansion, habitat impacts and costs associated with water side or land side expansion, and long term resiliency of a constrained dike solution. Consider routing the dike inland through Terra Nova Park.

North Dike: Terra Nova to No. 2 Road Bridge: Raise the dike on the existing alignment with land side expansion. Plan for the raising of River Road.

North Dike: No. 2 Road Bridge to Dinsmore Bridge: Existing and proposed developments will bring grades up to 4.0 to 4.7 m. Future raisings to 5.5 m can take place on the existing alignments and integrate into the adjacent landscaping.

North Dike: Dinsmore Bridge to Moray Bridge: Raise the dike with land side expansion. Consider creation of a set-back dike and inland raising (superdike) in conjunction with the future Middle Arm Waterfront Park construction. Ensure any interim dike upgrades are compatible with the long term strategy of constructing superdikes.

North Dike: Moray Bridge to Oak Street Bridge: Implement flood protection with approved development plans for Duck Island and the River Rock Casino when available. If required to address sea level rise and climate change prior to implementation of the approved strategy at the Duck Island or River Rock Casino sites, plan for a temporary adaptation, such as a demountable floodwall, to protect City assets

North Dike: Oak Street Bridge to No. 4 Road: Raise the dike on the existing alignment. Site specific solutions may be required at the Fraser River Terminal site. Plan for temporary dike along the alternate alignment if required to address sea level rise and climate change prior to implementation of a strategy at the Fraser River Terminal site.

North Dike: No. 4 Road to Shell Road: Existing and proposed developments will raise the area generally to elevation 4.7m. Future raisings to 5.5 m can take place on the existing alignments and integrate into the adjacent landscaping.

North Dike: Shell Road to No. 6 Road: Raise the dike on the existing alignment. Acquiring some existing lots north of River Road may be required to facilitate construction of a trapezoidal dike. A plan for temporary dike or flood wall adjacent to the waterfront lots may be required to address sea level rise and climate change prior to acquiring all required property. Additional studies required to quantify drainage, habitat impacts, and costs associated with land side expansion of a trapezoidal dike. A constrained land side slope may be required to integrate with the existing drainage infrastructure.

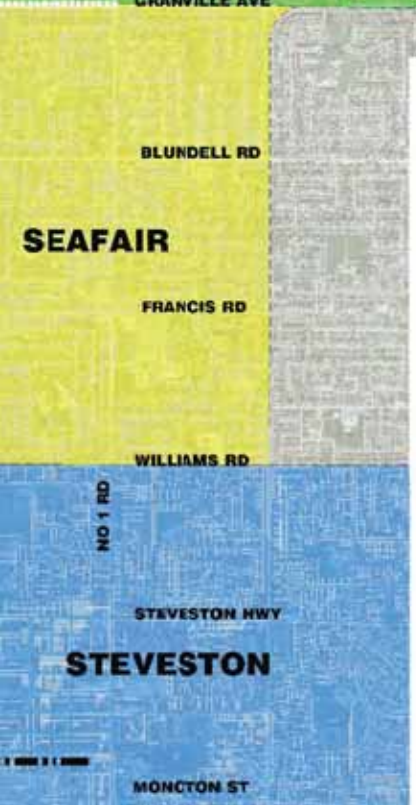
Next Steps

Parsons has characterized the existing conditions and constraints of the study area, and has established and recommended preferred regional and area specific adaptation measures for the City's consideration. Following receipt of additional City feedback, these adaptation measures and implementation strategies will be further refined to establish the Draft Lulu Island Dike Master Plan Phase 2 Document.

The recommended next steps in this study are:

1. Internal City Review;
2. Update Strategies per Stakeholder Feedback;
3. Council Review;
4. Agency Stakeholder Review;
5. Public Information Session and Consultation;
6. Final Master Plan Report; and
7. Council adoption of Final Master Plan Report.

KEY PLAN
N.T.S.



DESIGN AREAS	
SEGMENT	SEGMENT NAME
1A	WEST DIKE: STEVESTON
1B	WEST DIKE: SEAFAIR
2	WEST DIKE: TERRA NOVA
3	NORTH DIKE: THOMPSON TERRA NOVA
4	NORTH DIKE: THOMPSON DOVER
5	NORTH DIKE: OVAL
6	NORTH DIKE: CITY CENTRE 1
7	NORTH DIKE: CITY CENTRE 2
8	NORTH DIKE: DUCK ISLAND
9	NORTH DIKE: INDUSTRIAL
10	NORTH DIKE: BRIDGEPORT TAIT
11	NORTH DIKE: INDUSTRIAL NORTH EAST 1

Lulu Island Dike M
Flood P

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1. Introduction

Parsons was retained by the City of Richmond (City) to establish Phase 2 of the Lulu Island Dike Master Plan (LIDMP). The purpose of the overall LIDMP is to establish a well-planned strategy to identify future flood protection infrastructure requirements along the waterfront. The plan will present feasible adaptations for flood protection, and establish guidelines for incorporating flood protection into future waterfront developments.

The purpose of this technical memo is to evaluate potential flood protection adaptations within the Phase 2 study area and present the preliminary concept for the Phase 2 LIDMP. The concepts identified in this memo will be carried forward for City staff review and approval.

Parsons previously submitted Technical Memo #1[2] (TM #1), which presented potential flood protection options that may be appropriate for implementation in the study area based on a detailed review of current and future land uses, environmental and geotechnical conditions, and other City guidance documents. The information in TM #1 is used as the basis for further study in TM #2, to identify, assess, and select the preferred concepts for the Phase 2 LIDMP.

1.1 SCOPE

The master plan will adhere to the scope defined by the City in the initial request for proposal. Flood protection alternatives presented in this memo are assessed for their ability to achieve the minimum crest elevation of 4.7m, and accommodate a future increase to 5.5 m as prescribed by the City.

In this memo, key considerations for selecting preferred adaptations to meet the flood protection objectives will be identified. A comparison of feasible adaptations will be conducted to recommend the preferred regional and area-specific strategies. Detailed design of structural adaptations is beyond the scope of this report. Likewise, regional adaptations may require further study prior to implementation. The scope of the master plan is to identify adaptations that may be successfully implemented in the study area in future based on a high level analysis of options per the relevant design considerations.

Geotechnical considerations have been identified by Thurber Engineering Ltd., the geotechnical consultant. The geotechnical scope has been defined to include input on dike upgrade options to contribute to selection of the preferred adaptations. Both seismic and flood protection objectives are considered from a geotechnical perspective in selecting preferred adaptations. The geotechnical scope does not include detailed site-specific analysis of design elements, for example calculations of ground improvement depths or required grades for slope stability. Geotechnical input is limited to the general benefits and concerns impacting the applicability of a given adaptation in the study area. The master plan will include an overview of geotechnical factors impacting selection of the preferred alignment and adaptations.

Environmental considerations have been identified by Envirowest Consultants Inc., the environmental consultant. The environmental scope includes identifying which areas are anticipated to be habitat, as well as the legislative classifications and associated constraints that may limit the feasibility of adaptations. Envirowest has advised on the potential risks and consequences of encroaching in habitat; however, detailed review of habitat boundaries within the study area and exact compensation requirements for alterations are site-specific in nature, and beyond the scope of the master plan. The preferred alignment and adaptations will be recommended as a result of an analysis that includes a high level review of environmental factors impacting the feasibility of proposed adaptations.

In preparation of this technical memorandum, City staff were consulted to provide input into development of the master plan. Three meetings were held. Stakeholders and general discussion topics are summarized in ***Table 1***.

[2] Lulu Island Dike Master Plan Phase 2 – Technical Memo NO. 1: Review of Existing Conditions, Parsons, Aug 18, 2016

Table 1: Internal Stakeholder Consultation Meetings

ATTENDEE	DEPARTMENT
FEBRUARY 22ND, 2016 – 1:30PM OPERATIONS & MAINTENANCE & ENVIRONMENTAL INPUT	
Carli Edwards	Engineering Planning
Corrine Haer	Engineering Planning
Lloyd Bie	Engineering Planning
Ben Dias	Roads & Operations
Brad Gushel	Roads & Operations
Dave Richards	Roads & Operations
Kimberly Armour	Sustainability
FEBRUARY 29ND, 2016 – 10:00AM INTEGRATION WITH PARKS PLANS & VISIONS	
Jamie Esko	Parks Planning & Design
Kevin Connery	Parks Planning & Design
FEBRUARY 29ND, 2016 – 3:00PM IMPLICATIONS ON DEVELOPMENT CONTROL BYLAWS	
Carli Edwards	Engineering Planning
Corrine Haer	Engineering Planning
Barry Konkin	Planning & Development
Tina Atva	Planning & Development
John Hopkins	Planning & Development
Wayne Craig	Planning & Development

The feedback received in these meetings has been incorporated into this memo. Additional stakeholder consultation is anticipated as the Master Plan is finalized.

1.2 STUDY AREA

The Phase 2 study area spans approximately 16 kilometers of the waterfront from Garry Point Park in Steveston, north to Terra Nova Rural Park, then east to No. 6 Road, as shown on ***Figure 1***. The study area can be broadly conceptualized as two sections: the West Dike and the North Dike.

The West Dike spans the entire western waterfront of Lulu Island. The existing dike alignment is a multi-use trail adjacent to Sturgeon Banks, a designated Environmentally Sensitive Area (ESA) per the Official Community Plan (OCP) as well as a provincially-designated Wildlife Management Area (WMA). The OCP identifies three area plans with frontage on the West Dike: Steveston, Seafair and Thompson. These areas are primarily residential and recreational.

The North Dike is the southern waterfront of the Middle and North Arms of the Fraser River. The study area portion of the North Dike includes Terra Nova Rural Park to No. 6 Road, the eastern limit of the study area. This area is currently fully developed with residential, recreational, commercial, and industrial uses. The OCP identifies three area plans on the North Dike: Thompson (primarily residential), City Centre (primarily commercial) and Bridgeport (primarily industrial). The OCP presents Specific Land Use Maps for subareas within these broader areas. Substantial intensification of these lands is expected in the near future, primarily in the City Centre area.

Figure 1: Study Area

The area-specific analysis presented in ***Section 4*** focuses on structural, waterfront adaptations applicable to each of the specified design areas. The design areas have been delineated using the OCP boundaries identified in the OCP Areas, OCP Land Use Maps and OCP Sub-Area Plans. OCP Areas have been subdivided where similar waterfront conditions exist for a clearly defined part of an area. A total of fourteen design areas have been identified in the study area. The Key Plan in ***Appendix D*** shows the design areas as well as all relevant OCP boundaries.

Further details on both the existing and anticipated future conditions in the study area are provided in TM #1.

1.3 ADDITIONAL GUIDANCE DOCUMENTS

In addition to the OCP, the City has developed a number of additional guidance documents that will be considered in development of the Phase 2 LIDMP.

2009 Waterfront Strategy: The Phase 2 LIDMP will be developed with consideration of the five Strategic Directions of the 2009 Waterfront Strategy: 1) Working Together; 2) Amenities and Legacy; 3) Thriving Ecosystems; 4) Economic Vitality; and 5) Responding to Climate Change and Natural Hazards.

Flood Plain Designation and Protection By-Law 8204:	The Phase 2 LIDMP will consider the existing Flood Plain Designation and Protection By-Law, and will consider options to amend or accelerate increasing flood construction levels adjacent to the foreshore.
2008 – 2031 Richmond Flood Protection Strategy:	The Phase 2 LIDMP will be established to meet the goals of the Flood Protection Strategy.
2015 Ecological Network Management Strategy:	The Phase 2 LIDMP will be informed by the strategic goals outlined in the 2015 Ecological Network Management Strategy to promote the Ecological Network: 1) Manage and Enhance Ecological Assets; 2) Strengthen City Green Infrastructure; 3) Create, Connect, and Protect Diverse and Healthy Spaces; 4) Engage through Stewardship and Collaboration. The objective of developing an Ecological Network was initially outlined in the OCP under Chapter 9: Island Natural Environment (and Ecological Network Approach).
2008 Climate Change Response Agenda:	The Phase 2 LIDMP will be established with consideration of the 3rd pillar of the City's Climate Change Response Agenda – implement strategies for adapting to unavoidable changes. Strategies will be considered that can meet the short and long term goals with respect to crest elevations; however, they must also be adaptable to change.
2010 Richmond Trail Strategy:	The Phase 2 LIDMP will be developed with regard for the goal of maximizing access to the waterfront, as identified in the Richmond Trail Strategy.

2. Flood Risk Management Adaptation Measures

The provincial Climate Change Adaptation for Sea Dikes and Coastal Flood Hazard Land Use Draft Policy Discussion Paper (2011) categorizes options for managing flood risk into structural options and non-structural options. TM #1 provides a summary of the various options within the two categories, listed in ***Table 2***.

Table 2: Flood Risk Management Strategies

STRUCTURAL						NON-STRUCTURAL				
PROTECT						ACCOMMODATE			RETREAT	AVOID
DIKES		FLOODWALLS		FORESHORE						
Widen footprint to land side	Widen footprint to water side	Permanent	Demountable	Breakwaters / Barrier Islands	Coastal wetlands	Flood proofing	Secondary Dikes	Emergency preparedness and response	Managed Retreat	Planning and Development Controls

For the analysis in TM #2, the categories of adaptation options explored in TM #1 have been refined to more specific adaptations, as appropriate for application within the specific context of the study area. Adaptations have been categorized as regional or area-specific adaptations for the purposes of the analysis in TM #2. Ultimately the City's goal is to fortify the perimeter ring dike to a design crest elevation of 4.7 m with consideration to be further raised to 5.5 m in response to climate change and sea level rise predictions. These target elevations are used as the basis for this study.

In the context of the Phase 2 LIDMP, regional adaptations are those that facilitate the City's flood protection objectives in tandem with the dikes or alternative protection measures in place at the waterfront, but may not be sufficient to meet the

City's target dike crest elevation in isolation. Area specific adaptations have been evaluated for implementation at each of the fourteen specified design areas. These include all dike and floodwall adaptations that would be implemented to achieve the 4.7 m design crest.

Constrained dikes have been introduced in TM #2 as an additional diking strategy under the broader category of structural protections. Constrained dikes are a variation on a standard trapezoidal dike where the dike slope is replace with a retaining wall on one or both sides. This minimizes the land required to raise the dike by eliminating one or both slopes in favour of a vertical barrier, reducing the horizontal space requirements. This adaptation may be appropriate where land uses are restricted and widening the footprint may be impractical.

Superdikes were briefly introduced in TM #1 and will be further analyzed in TM #2 as a regional adaptation option. Superdikes are an addition to a standard trapezoidal dike where the land behind the dike is filled to the same elevation as the dike crest, and becomes the ground elevation for waterfront development.

A summary of the regional and area-specific adaptations is provided in ***Table 3***. A discussion of each adaptation, including the rationale for either retaining or eliminating it for further study, is provided in ***Sections 2.1*** and ***2.2***. The master plan will consider adaptations in both categories to produce a comprehensive strategy for improving flood protection in the study area.

Table 3: Regional and Area-Specific Categorization of Flood Risk Management Strategies

AREA-SPECIFIC				REGIONAL							
IDENTIFIED FOR FURTHER STUDY									NO FURTHER CONSIDERATION		
DIKES		FLOODWALLS									
Widen Footprint to Land or Water Side	Raise in Place / Constrained Dike	Permanent	Demountable	Secondary Dikes	Superdikes	Breakwaters / Barrier Islands	Flood Proofing	Planning and Development Controls	Coastal Wetlands	Emergency preparedness and response	Managed Retreat

2.1 REGIONAL ADAPTATIONS

The regional adaptations are defined below with consideration for their applicability within the study area, and within the scope of the master plan. Regional adaptations are either eliminated, or carried forward to ***Section 3*** for further discussion if assessed to be feasible for applications in the study area.

2.1.1 SECONDARY DIKES

Secondary dikes work in conjunction with primary dikes to reduce the impact of a flood in the event that a primary dike is breached or overtopped. A secondary dike protects assets behind the secondary dike alignment while the lands between

the primary and secondary dike are allowed to flood intermittently. Dikes built inland can be less costly to build and less susceptible to damage during seismic events.

Secondary dikes may be applied in the study area where no critical assets are located on waterfront lands. Eligible areas may include parking lots, parks or natural areas that can withstand intermittent flooding. In those areas, a secondary dike can be constructed to protect infrastructure set inland. This may be applicable in the Terra Nova Park area.

2.1.2 SUPERDIKES

A superdike is an addition to a standard trapezoidal dike where the land behind the dike is filled to the same elevation as the dike crest, and becomes the ground elevation for waterfront development. Trapezoidal dikes adjacent to the waterfront in the study area can be vulnerable to failure during a seismic event. They are underlain by soft soils, as discussed in ***Section 4.1.2***. As discussed in more detail in ***Section 2.2.1*** below, ground improvements for a trapezoidal dike to meet the Seismic Guidelines can be very costly. These costs may be avoided by creating superdikes, as superdikes are less likely to require ground improvements.

Maximizing the width of the dike crest can reduce the risk of breach or failure by ensuring that if the dike face experiences sloughing or it moves laterally towards the river, there remains high ground behind it. Raising a wider area of land along the waterfront is desirable for this reason, as well as to address long term dike seepage concerns, further detailed in ***Section 4.1.2***.

Creating a superdike can be incorporated into redevelopment, as discussed in ***Section 3.2.1***. For the purposes of the analysis presented in this memo, a superdike is considered an additional protection measure above and beyond the standard trapezoidal dike, to be implemented wherever feasible where a trapezoidal dike adjacent to development is the preferred adaptation. Adaptations that contribute to the long-term goal of a superdike at the entire developed waterfront of the North Dike are preferred as compared to interim adaptations that will ultimately be decommissioned or abandoned in favour of a superdike.

The West Dike would not substantially benefit from superdike elevations as it is adjacent to the tidal flats of Sturgeon Banks and is restrained by earth on either side. This provides more stability during seismic events as compared to dikes adjacent to deep waters, such as the Fraser River. Superdikes will not be considered further for the West Dike.

2.1.3 FLOOD PROOFING

Flood proofing is a strategy for accommodating flood events by minimizing the damage to critical infrastructure. Buildings can be constructed as flood proofed by ensuring habitable space is set at an elevation above the flood risk zone. Damage and losses incurred during flooding are minimal as any valuable or vulnerable assets are located above the possible flood elevation. In these buildings, habitable space and sensitive assets are located above a prescribed ground floor elevation, and lower floors are used only for storage of flood-resistant or low value assets. Another flood proofing strategy is using only impermeable building materials and watertight building equipment below the prescribed flood risk elevation.

The City's influence on where private building operators locate their assets within their buildings is limited, however construction of buildings with habitable space or vital assets below a specified elevation may be prohibited through legislation. By flood proofing buildings located in a specified waterfront or low elevation area, vital assets are prohibited from being located in high risk zones so that flooding will only affect non-vital infrastructure. Generally, flood proofing legislation impacts only the construction of new buildings; existing buildings constructed prior to the legislation's implementation are typically not impacted except through building permit applications for renovations or additions.

The City currently enforces flood proofing through the Flood Plain Designation and Protection Bylaw No. 8204, established in 2008 to set minimum Flood Construction Levels (FCL's) throughout the City. The FCL prescribes the minimum elevation

where the underside of a floor system can be constructed. Long term raising of land levels has previously been recommended (2008-2031 Flood Protection Strategy); however, is challenging to implement in already built up areas.

Strategies to amend the FCL bylaw to improve flood protection on Lulu Island are discussed in ***Section 3***.

2.1.4 PLANNING & DEVELOPMENT CONTROLS

Planning and development controls may be implemented by enacting legislation to prohibit or restrict development in a defined hazard zone, such as a floodplain. More flexible policies can also be enacted to include conditional development approvals, where projects may be approved on condition that developers commit to implementing flood protection measures such as raising the abutting dike or raising the land elevation to a superdike.

In the study area, there are opportunities to pursue flood protection improvements in conjunction with new development, especially in areas expected to be intensified in the coming years. In Richmond, planning and development controls can be implemented through bylaws or amendments to the Official Community Plan (OCP). These strategies are discussed further in ***Section 3***.

2.1.5 BREAKWATERS & BARRIER ISLANDS

Breakwaters may be constructed to dissipate wave energy before waves reach the shore. This reduces the burden on the flood control structures at the waterfront. In combination with a foreshore structure, flood control structures with lower crest elevations may remain adequate to withstand increased wave run-up associated with increased water depths due to climate change and sea level rise.

The West Dike is a candidate for barrier islands, as presented in the Phase 1 LIDMP[3]. Construction of barrier islands may present an opportunity to create habitat, and retain sediment on the tidal flats, which are currently eroding. While barrier islands will not address the immediate crest elevation requirements of 4.7 m, construction of barrier islands may allow for future deferrals of crest height increases.

2.1.6 COASTAL WETLANDS

Similar to breakwaters, coastal wetlands temper the extremity of storm impacts by attenuating wave energy. The study area does not include any sites where coastal wetlands may be applied at this time. The shore of the West Dike, Sturgeon Bank, is already a tidal flat. Coastal wetlands could not be constructed on the North Dike as they are incompatible with the current uses of the Fraser River, a heavily trafficked navigation channel. No further discussion of coastal wetlands is required.

2.1.7 EMERGENCY PREPAREDNESS AND RESPONSE

The City has an existing emergency response plan: the Emergency Operations Centre coordinates with various departments to execute the Emergency Preparedness Flood Management Plan. Emergency preparedness and responses is not within scope of the dike master plan and will not be discussed further in this memo.

2.1.8 MANAGED RETREAT

Managed retreat involves decommissioning or demolishing existing assets within a specified hazard zone. This strategy is not appropriate for the study area. The economic value of retaining existing assets exceeds the cost of reducing the risk of

[3] Lulu Island Dike Master Plan Phase 1, Delcan, March 2013

flood damage by relocating assets. The existence of development on Lulu Island that must be protected from flooding is considered a permanent condition for this study. This option will not be explored further.

2.2 AREA SPECIFIC ADAPTATIONS

The area specific adaptations can all be classified as variations of dikes or floodwalls. Options are summarized below, with comments on their general applicability to the Phase 2 study area.

2.2.1 RAISE EXISTING DIKE BY WIDENING FOOTPRINT

Dikes are the most common form of structural flood protection. At present, Lulu Island is protected by a perimeter ring dike. In the study area, improvements to the existing dike should be pursued wherever possible.

As per the typical dike sections presented in ***Appendix A***, the typical City dike upgrade cross-section consists of a 2:1 slope on the water side, and a 3:1 slope on the land side[4]. The existing dike elevation varies throughout the study area though it is approximately 3.5 m on average. Raising the dike by 1.2 m to the target 4.7m elevation requires a horizontal space of 4.2 m, assuming the standard slopes are applied. The additional dike height increase to an elevation of 5.5 m in future would require 6.6 m of additional toe width. Land side dike expansions can be challenging where the footprint is constrained by existing buildings or other infrastructure, such as drainage ditches at the toe. Where a dike's land side toe is heavily constrained by existing infrastructure, a standard dike can be raised by widening its footprint onto the water side. Generally the preferred option in raising existing dikes is to widen the footprint inland to avoid alterations to the foreshore, which may impact habitat. Alterations to existing habitat may trigger compensation requirements. Land side expansions may also impact habitat where the land side toe is constrained by habitat. The implications of habitat compensation are discussed further in ***Section 3.2.4*** and ***Section 4.1.1***.

The Ministry of Forests Lands and Natural Resources' (MFLNRO) "Seismic Design Guidelines for Dikes" (Seismic Guidelines) published in June 2014 recommend designing high consequence dikes to control seismic deformations within prescribed limits. For a trapezoidal dike to achieve the objectives of the Seismic Guidelines, ground improvement may be required. Ground improvement reduces seismic vulnerability by densifying the foundation of the dike. Compaction alone is unlikely to achieve the targets in the Seismic Guidelines, hence more intensive methods such as deep soil mixing or vibro-replacement to a specified depth may be required. These methods are described further in ***Section 4.1.2***. Ground improvements for a trapezoidal dike to meet the Seismic Guidelines may be very costly. Dikes that are set back from the waterfront are more resistant to seismic events due to being restrained by earth on either side. Therefore, they require less intensive methods to meet the Seismic Guidelines. Likewise, widening the dike crest to create a superdike increases resilience to seismic events without typically requiring ground improvements. Superdikes are discussed in greater detail below.

2.2.2 RAISE EXISTING DIKE BY RAISING IN PLACE

Where dike expansion is constrained on both the land and water sides, it may be possible to raise a dike within its existing footprint by means of a constrained dike. This may be achieved by introducing a retaining wall on one or both sides. In Richmond, drainage ditches may be designated sensitive ecosystems, meaning the dike may have environmental constraints on both sides and alterations in either direction may impact habitat and trigger compensation requirements. In the study area, raising the dike in place can be pursued to minimize impacts on adjacent lands.

[4] Typical Cross Section River Dike Upgrade, City Drawing Mb-98, Golder Associates, 2008

2.2.3 PERMANENT FLOODWALL

A floodwall is a constructed barrier designed to hold back flood waters. In the study area, floodwalls can be implemented where space is limited and a dike would interfere with other land uses or infrastructure, such as existing buildings. Floodwalls may also be preferable to a dike where access to the water is required for economic activity, such as fishing or shipping. Generally, where feasible, earth fill trapezoidal dikes are preferable due to their lower costs, ease of maintenance, increased reliability, and easier emergency repairs.

2.2.4 DEMOUNTABLE FLOODWALL

In areas where waterfront access is desired, demountable flood barriers can be constructed so that the barrier is erected only when required, during storm events. Regular access to the waterfront is maintained otherwise. This adaptation may be applied in the study area at industrial sites or marinas, where activities require amenities directly on the waterfront that cannot be set back behind a floodwall or dike. Where possible, this form of dike is avoided due to their higher costs, mobilization requirements, and reliability concerns.

3. Evaluation of Regional Flood Protection Strategies

The City manages flood risk through a combination of structural protections and policy. Structural adaptations must be evaluated on an area basis, as the feasibility of a given adaptation depends on the existing landscape. Analysis of structural alternatives is presented in ***Section 4***. Policy adaptations are applicable on a regional basis. They can be implemented to ensure that when structural adaptations are constructed, the City's flood protection objectives will be met.

3.1 EXISTING APPROACH TO REGIONAL FLOOD PROTECTION

City policy on flood protection is established as a priority in the Official Community Plan, under Floodproofing and Dike Setbacks (Section 14.2.9), which stipulates:

> "No landfill or structural support required to support a floor system or pad shall be constructed, reconstructed, moved, extended or located:
>
> - where a standard dike exists, within 7.5 m (24.6 ft.) of a dike right-of-way;
> - where a standard dike does not exist and land is situated within the dike alignment, within 30 m (98.4 ft.) of the natural boundary."

This policy strives to ensure that adequate lands are available for diking. Existing and future dike right-of-ways (ROW's) are protected by prohibiting construction as noted above. A dike ROW is a legal land parcel dedicated to a public interest, similar to municipal ROW's used for roads or trails. A ROW is generally under City ownership, though easements over lands held by private companies or other governments can be granted to accomplish the same purpose. An easement is a defined land area where the City has a legal right to access for a specific purpose, typically maintenance of infrastructure owned by the City. In this context, the City may be granted an easement to maintain dikes located on private or provincial/federal property.

In 2008 the City established minimum Flood Construction Levels (FCL's) through the Flood Plain Designation and Protection Bylaw No. 8204. The bylaw restricts the use of building space beneath a set elevation by requiring that new buildings, or alterations to existing buildings, meet the FCL as a condition of approval. FCL requirements are triggered only by changes to site use. There is no requirement that existing buildings be retrofit to meet the FCL. An existing building with a floor system lower than the FCL may remain at that elevation until an owner undertakes site alterations requiring a permit, such as renovations. The City may require plans be amended to meet the FCL prior to issuing a permit. The FCL only indicates

the minimum elevation of habitable floor space, not necessarily the overall ground level of the lot although these elevations are intrinsically linked.

Waterfront development sites with substantial footprints typically negotiate flood control measures with the City in the development approval process. Prior to issuing a development approval, the City may request specific flood control measures in keeping with the neighbourhood strategy, or require developers to prepare a flood protection plan. In recent years, waterfront developers with substantial riverside frontage have raised the bulk of the lot's waterfront frontage in order to preserve sightlines and access to the water from ground floor units. This establishes a wide buffer of land at the water's edge (superdike) that provides additional resilience to flood protection as compared to a typical trapezoidal dike. Establishment of superdikes on smaller lot assemblies can be challenging due to issues associated with tying grades to adjacent lots.

3.2 FUTURE CONSIDERATIONS FOR REGIONAL FLOOD PROTECTION

A number of alternatives have been identified for consideration to improve the current approach to regional flood protection in the City and create resiliency in addressing climate change and sea level rise. Opportunities include: creating policy changes to facilitate the long-term development of a superdike along the City waterfront; adapting long-term strategies to implement off-shore flood protection measures; and, consideration of secondary dikes to enhance flood protection. Regional based approaches would take place in parallel to area specific approaches. Details on the regional strategies identified are discussed in the following sections.

3.2.1 SUPERDIKES

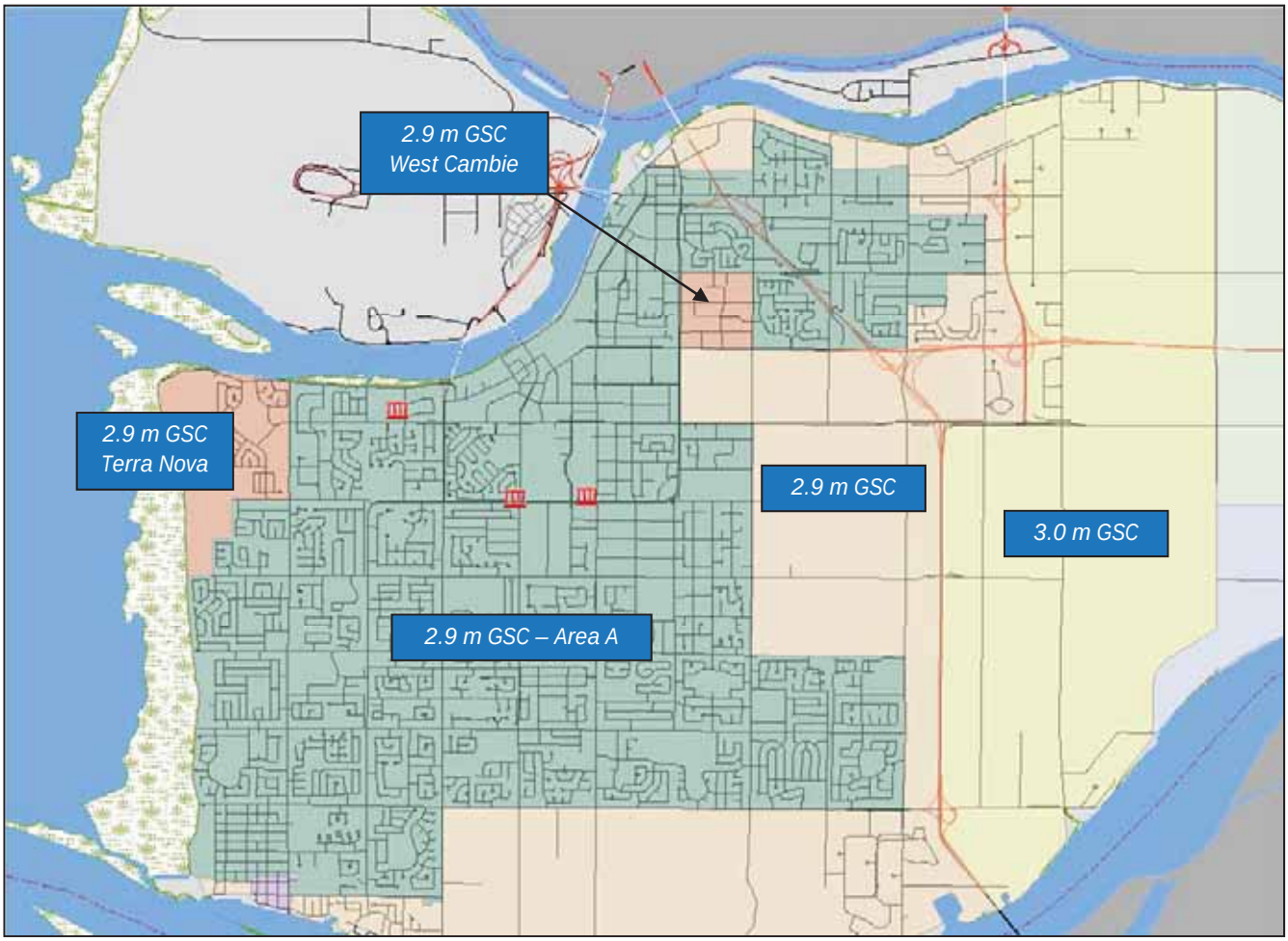
The existing dikes of Lulu Island are built on soft soils and subject to liquefaction during seismic events and may require ground improvements to meet the 2014 Seismic Design Guidelines. An alternative approach to achieve the dual objectives of reducing vulnerability to both high water levels and seismic events, all waterfront lots could be raised to the design crest elevation as a superdike. Maximizing the width of raised land adjacent to the river decreases flood and seismic risks by increasing the integrity of the dike. A superdike is more likely to withstand sloughing of the dike face without resulting in a dike breach, as compared to a standard trapezoidal dike. The master plan will present adaptations maximizing the width of raised land adjacent to the river. This strategy is compatible with a long-term future where the perimeter ring dike is fortified to a superdike across the study area. With this approach, costly ground improvements may not be required.

Any redevelopment of waterfront sites presents an opportunity to fortify existing flood protection measures. Although the study area is already fully built out, lands will continue to be intensified, particularly in the City Centre area. The City has an opportunity to revise existing development policies address evolving flood protection needs. Possible policy adaptations are discussed on the following pages.

3.2.1.1 FCL By-Law Amendments

As noted previously, the City establishes minimum FCL's through Bylaw No. 8204. The bylaw also specifies setbacks from a dike ROW to make land available for diking. Every part of Lulu Island has a designated FCL, not only the waterfront area. The bylaw organizes FCL's by area, as shown in ***Figure 2***. Presently, the majority of the study area fronting the existing dikes are within 'Area A' of the bylaw. The requirements for 'Area A' are to construct to 2.9 m or at least 0.3 m above the highest elevation of the crown of any road that is adjacent to the parcel. Commercial and industrial buildings are fully exempt if the main entrance is within 3 m of a road. Developments within the Terra Nova Area are further exempt only requiring the underside of the floor slab to be greater than 2.6 m. There are no exemptions in the north-east portion of the study area, where a 2.9 m FCL is required.

Figure 2: Flood Construction Levels



Amendments to Bylaw No. 8204 may be appropriate given the current predictions for sea-level rise. These amendments could include creation of an additional FCL Area adjacent to or within a stipulated distance from the existing dike or waterfront. The area could require an FCL of 4.7 m with exemptions based development size or parcel size. The FCLs would also have to consider overall lot raising and not just habitable space.

Examples of alternate concepts are provided below; however, details and feasibility would need to be confirmed:

Single Family Dwellings and Small Lots: The bylaw could be amended to increase the rate at which land raises with redevelopment. Presently, this rate is 0.3 m above the road centreline. For smaller lots, this strategy may then present challenges to local grading, producing inconsistent grades across lots and possibly introducing complex drainage patterns. Smaller lots are more likely to be highly constrained by existing grades on neighbouring lots and the road. Where grading is highly constrained, retaining walls may be required to accommodate substantial changes in elevation. Aesthetically, abrupt grade changes are undesirable, especially in neighbourhoods of single family homes. Varied grading between lots can also create issues with differential settlement. Grading designs that are consistent with the surrounding lot fabric and do not use retaining walls are preferred. The sidewalks and road network must also be carefully graded to maintain minimal slopes and safe connections at intersections. Any FCL increase must be implemented strategically to mitigate the potential grading challenges it may introduce.

Zoning bylaws could potentially be modified to provide additional guidance and requirements for lot coverage, setback, building heights, and others to help plan how the greater staggered lot elevations may integrate with each

other. This will be challenging to implement but would increase the rate of increasing the land height in residential areas.

Mid-Size Development Lots or Building Permit Value Criteria: The bylaw could be amended to require raising to 4.7 m or 1 m (or alternate) above the road. Challenges may still exist with incorporating grading to adjacent parcels and roads.

Large Development Lots or Building Permit Value Criteria: The bylaw could be amended to require raising to 4.7 m and upgrading the local road network to accommodate access. This is currently done in practice, however, it is not specifically required under the current bylaw.

Additional studies on implementation of modified FCL bylaws should be conducted prior to proceeding with any changes. Input should be provided from architects, planners, engineers, environmental consultants and key stakeholders to obtain a comprehensive understanding of opportunities and factors to be mitigated while achieving flood protection goals.

Flood risk should be evaluated by the City periodically to determine whether increased risk warrants raising the target dike crest elevation. The bylaw can be amended as required to meet evolving City guidelines as they are adjusted per changes to flood risk conditions. For example, if the design crest elevation is raised from 4.7 m to 5.5 m, the FCL bylaw can be amended to reflect the new minimum elevation. In this way, flood proofing can progress over time as required.

3.2.1.2 Development Permit Area

An additional potential option to expedite implementation of flood protection adaptations concurrently with development is to establish a Development Permit (DP) area requiring these works. The OCP defines the purpose and function of DP Area policies as follows:

> "The DP Areas and Guidelines support the goals, objectives and policies of the OCP. They outline the City's expectations for future growth and change by redevelopment and development, and provide guidance regarding form and character of development or other objectives (i.e., promotion of energy conservation) for the community."

In practice, a DP Area ensures that any redevelopment plans must be in compliance with the goals stated in the OCP for that DP Area in order to be approved by the City. An application to redevelop a site in a DP Area will trigger additional City reviews per the specific guidelines of that DP Area. Guidelines can include anything from preservation of farmland to adequate sunlight penetration.

The OCP provides for the creation of a flood protection DP Area by stipulating that the ESA (Environmentally Sensitive Area) DP Area doubles as a flood protection DP Area. Section 14.1.3 of the OCP states: "The foreshore areas are designated as an ESA DP Area and the DP Guidelines serve the dual purpose of flood and environmental protection." The entire study area's waterfront is designated ESA DP Area per the OCP ESA Plan. A new DP Area could be established to include a given distance inland from the established waterfront ESA DP Area, for example the first 100 m. Any redevelopment sited in whole or in part within that boundary would then trigger an additional flood protection review and approval.

As required by the Local Government Act, the OCP must be reviewed at minimum once every five years. In Richmond, these reviews are conducted by Policy Planning. Typically the City publishes multiple amendments per year to keep the OCP up to date. The OCP can be amended at any time, as deemed necessary by Council.

In consultation with City staff, it was confirmed that FCL bylaw amendments would provide the City greater enforcement power with a relatively less intensive process to implementation, as compared to implementing a new DP zone. Amending the OCP is considered more challenging, and results in less flexibility for City discretion as compared to amending the FCL bylaw. For these reasons, amendments to the FCL bylaw are the preferred regional adaptation to accomplish flood protection objectives. As such, establishment of a flood protection DP Area will not be considered for the Phase 2 LIDMP.

3.2.1.3 Site Assembly Size Requirements

Increasing the ground elevation of a single waterfront site is restricted by the existing elevations of adjacent lands. Where adjacent sites remain low, a redevelopment site can only be minimally raised without introducing challenges to the local road network and drainage patterns. To avoid complications arising from steep grades or retaining walls, the City can encourage developers to assemble multiple adjacent sites until a specified minimum waterfront frontage can be developed concurrently. This strategy permits increasing the dike crest level fully to the current standard elevation, and eases the transition of the waterfront to a superdike.

3.2.2 WEST DIKE – OFFSHORE PROTECTION

If climate change and sea level rise predictions materialize, increased depths offshore could simultaneously increase wave heights, particularly in the Georgia Strait. Presently, the Sturgeon Banks provide wave dissipation. With future increased water depths on the Sturgeon Banks, wave heights may increase putting the West Dike at higher risk of overtopping. Increased water depths off-shore reduce the wave attenuating properties of the Sturgeon Banks. The current predictions and assumptions used in the BC Sea Dike Guidelines for the year 2100 suggest wave run-up may account for up to 2.7 m of the future dike crest elevation. The full extent of future crest height increases will require detailed observation and study of observed sea level rise.

Additional protection for wave run-up, when required, could be provided in the form of wave attenuation structures, or by providing additional crest height. Wave energy can be reduced before reaching the dike by establishing a breakwater on the foreshore. This reduces the burden on the dike, allowing for lower future crest elevations. One form of breakwater for the West Dike would be barrier islands constructed on Sturgeon Banks. This concept was introduced in the Phase 1 LIDMP. In the future, barrier islands may serve the dual purpose of flood protection and habitat creation.

Breakwaters are most effective when constructed close to the shore, as broken waves grow again behind the breakwater under the influence of wind. The effectiveness depends also on the crest height of the breakwater, with a higher breakwater giving more wave reduction. Preliminary calculations from the Phase 1 LIDMP indicated that wave reduction with a breakwater or barrier islands constructed to +3.0 m geodetic would reduce wave height by 70% if constructed 200 m offshore, 60% at 500 m offshore, and 45% at 2000 m offshore.

Construction of breakwaters or barrier islands at this time could result in adverse impacts on fish habitats. Habitat compensation would be necessary, and given the potentially large footprint of the barrier islands or breakwaters, this could be prohibitive. However, in the long term if sea level rise is observed and future tidal conditions reduce or eliminate the existing intertidal marsh, then future barrier islands have the potential to create habitat. This future habitat could potentially be a compensation site.

Barrier islands may be an option at present day if the barrier islands or breakwaters could be constructed in waters of lesser habitat (deeper and further offshore) provided that the wave reductions are achieved.

3.2.3 SECONDARY DIKES

3.2.3.1 Terra Nova Park

There are limited opportunities for secondary dikes in the study area. In general, all of the lands protected by the study area high asset value and has justification for a high standard of protection; however, one area was identified that may benefit from being protected to a lower level than the remainder of the study area.

In future, the City may explore establishing an alternative dike alignment for a part of this area through the park lands, as shown in ***Figure 3***. By setting the alignment inland, the City may avoid costly ground improvement measures that may be

required for upgrading the existing alignment. Assets sensitive to flooding, such as private homes and heritage sites, would be protected by the secondary dike. Less sensitive assets, such as the park, trails and open space lands, can withstand occasional flooding with minimal losses incurred and therefore may be adequately protected by a dike with a relatively lower crest elevation. This may also facilitate the planned future improvements to connectivity of the inland drainage features in the area to the Fraser River.

Figure 3: Secondary Dike Alignment though Terra Nova Park

3.2.4 HABITAT BANKING

It is anticipated that within the study area, alterations to environmentally sensitive areas may be unavoidable and habitat compensation may be required. The City may consider establishing a formal habitat banking program to allow for flexibility to create habitat. Habitat credits can be applied to multiple projects, or stored for future dike works. A formal habitat banking program may assist with the implementation of long term flood protection infrastructure upgrade programs.

4. Evaluation of Area Specific Flood Protection Strategies

The area specific analysis presented below focuses on structural strategies applicable to each area. As noted in ***Section 1.2***, the areas have been delineated following the OCP area boundaries. Areas have been subdivided where similar conditions exist for a clearly defined portion of an area.

This organization of analysis facilitates integration of the adaptations presented in this report with the City's other planning documents. The OCP identifies three area plans with frontage on the West Dike: Steveston, Seafair and Thompson. Steveston and Seafair are considered together as these areas are subject to similar constraints. On the North Dike, OCP areas have been subdivided per the Specific Land Use Maps, or further subdivided to group together areas with similar conditions. Fourteen areas have been identified for the analysis in TM #2, to be carried forward to the final Master Plan. A detailed description of current and future land uses for both the West Dike and the North Dike are presented in TM #1.

At present, the study area is protected by a perimeter ring dike at elevations varying from 3.2 m – 4.7 m, as well as flood walls in industrial areas. The existing dike alignment is presented in ***Appendix B***. Existing flood protection measures, as well as possible adaptations, are presented in detail in TM #1.

4.1 EVALUATION CRITERIA

The evaluation criteria listed below has been applied to feasible adaptation options for each of the fourteen areas within the study area to compare options and select the preferred adaptation.

4.1.1 ENVIRONMENTAL CONSIDERATIONS

A review of environmental factors and associated regulatory frameworks is provided by Envirowest, the environmental consultant. The feasibility of a given adaptation depends on the extent that its implementation may impact habitat, both to conserve habitat and avoid incurring costs for compensation. Adaptations are compared on environmental factors by evaluating which option can completely avoid alterations in habitat. Where both options require alterations in habitat, the extent that alterations can be minimized is compared.

The local ecosystem is bounded by the Fraser River and the Georgia Strait. These areas are generally important habitat for fish and wildlife. For this reason, alterations impacting habitat may require environmental approvals at the federal, provincial or municipal level, depending on the nature of the alteration. Federally, the Department of Fisheries and Oceans (DFO) approves alterations in or near aquatic habitat, and Environment Canada may also be involved where an environmental assessment is required. At the provincial level, the Ministry of Forests, Lands and Natural Resources (MFLNRO) administers environmental approvals through the Water Sustainability Act.

The City of Richmond has outlined environmentally sensitive areas (ESA's) in the OCP. The waterfront of the entire study area is designated ESA. The City uses the classification system developed by the now defunct Fraser River Estuary Management Program (FREMP) for marine and freshwater habitats. Aquatic habitat is coded red, yellow or green according to its value. Red coding indicates high value habitat, while green coded areas have less habitat value and therefore have fewer restrictions when alterations are required. Sturgeon Bank is entirely red coded. Sections of the Fraser River are coded according to the local habitat value, thus the full spectrum of coding is represented on the river. Watercourses on Lulu Island, including drainage ditches, are generally classified as Riparian Management Areas (RMA's). City key plans showing habitat coding and other environmental designations within the study area are presented in ***Appendix C***. Conservation of natural areas is preferred in all cases; however, where alterations within environmentally sensitive areas cannot be avoided, habitat impact mitigation or compensation plans can be pursued.

Ideally, mitigation and compensation plans are provided at or near the site of the alteration. These can be integrated directly into the alteration, for example constructing marsh benches on the water side of a dike, or spits that extend seaward from the dike. These habitat features can be designed to provide an additional flood protection function, for example by creating a breakwater from a spit. Habitat can be constructed on the land side and connected to the water, for example a slough connected to a pump station on the West Dike. Where it is not feasible to provide mitigation and compensation near the alteration, compensation can be pursued off-site. Habitat compensation requirements are site specific and should be investigated prior to construction.

Any flood protection adaptations should be compatible with the City's ecological network approach as outlined in the four strategic goals of the 2015 Ecological Network Management Strategy:

1) Manage and Enhance Ecological Assets
2) Strengthen City Green Infrastructure
3) Create, Connect, and Protect Diverse and Healthy Spaces
4) Engage through Stewardship and Collaboration

All City guidance documents in effect at the time a project moves forward to the design and construction phase should be reviewed at that time to ensure compatibility with all City objectives. Environmental requirements should be investigated prior to construction.

4.1.2 GEOTECHNICAL CONSIDERATIONS

As detailed in TM #1, geotechnical design considerations of adaptations include seepage control both under and through the dike, dike slope stability, dike crest settlement, and seismic performance. These considerations are especially critical for riverside dikes, although they apply for any kind of structural adaptation.

Seepage is a concern where the land side of the dike is not raised concurrently with crest increases. Leaving the land side dike toe elevation low increases the risk of land side heave of the less permeable surficial silt later above the sand. Piping through the dike, its foundation, or the surficial silt layer is also a concern where the land side has been left relatively lower. Seepage and piping risks can be decreased by maximizing the width of the dike crest, or building a superdike. The potential for heave and piping could be mitigated using relief wells, drainage blankets or trenches. Relief wells and trenches should have filters designed to prevent piping and internal erosion and have filtered seepage exits.

Ditches at the toe of the dike slightly reduce stability, and consequently filling existing ditches will provide a minor increase in stability. Provided the dikes are raised using high quality fill material and constructed in accordance with accepted engineering practise, stability (non-seismic related) is not anticipated to be a concern in the study area.

As noted in ***Section 2.2.1***, ground improvement prior to constructing adaptations may be required to achieve the objectives of the Seismic Guidelines. Deep soil mixing or Vibro replacement methods may be used to densify the foundation of the dike. Deep soil mixing involves injecting a binder to a specified depth to effectively create soil cement piles. Vibro replacement is similar: a vibrating probe removes a column of material and replaces it with stone. In either case the depth of ground improvement methods must be specified by a qualified geotechnical engineer at the detailed design stage.

Dikes that are set back from the waterfront are more resistant to seismic events due to being restrained by earth on either site. Therefore, they may require less intensive methods to meet the Seismic Guidelines. Geotechnical modeling must be completed on a site-specific basis to determine how far from the waterfront a dike or secondary dike must be located to render ground improvements unnecessary.

Adaptations will be evaluated on geotechnical factors by comparing the relative resistance to seismic deformation, risk of critical geotechnical failure and the resources required to provide the same level of protection. For example, a riverside dike may be anticipated to require ground improvements to meet the seismic guidelines, whereas a secondary dike built inland is not. Generally, the adaptation that best satisfies the geotechnical aspects is the superdike. Where superdikes cannot be implemented in the short term future, interim adaptations that can be best adapted in future to a superdike are preferred.

4.1.3 INFRASTRUCTURE CONSIDERATIONS

Interference with existing or future infrastructure should be avoided wherever possible. Generally where linear infrastructure has been constructed under a road, it is on the far side of the dike, though conflicts may still exist. Where a

road is to be raised in conjunction with raising the dike, linear infrastructure must be reviewed to determine whether increased loads will cause settlement or pipe failure. Risk of failure should be investigated and mitigated by replacement, reinforcement or relocation at the time that detailed design plans are prepared.

At the waterfront, a drainage system of ditches and underground pipes conveys stormwater to pump stations, where runoff is discharged out to the sea or the Fraser River. Drainage ditches are present at the toe of the dike along the West Dike, and in the industrial section of the north dike east of the Bath Slough. Where ditches must be filled to accommodate dike alterations, the loss of storage and conveyance will need to be compensated. Pump station capacity must also be reviewed to ensure that any changes to drainage patterns can be accommodated.

The West Dike is used for City maintenance vehicle access but it is not a public road; hence, this area is not subject to road network constraints. The road network on the north dike constrains potential dike expansions where River Road is adjacent to the dike, as intersections must be properly graded to make safe connections to local roads. Connections to existing roads restrict the extent that River Road can be raised. Sidewalk connections are also a consideration in producing an effective grading design. In commercial areas it is advantageous to have building entrances meet the sidewalk at a gentle slope rather than with risers, in order to accommodate pedestrians with strollers or those using mobility aids, such as wheelchairs and walkers. Sidewalk grading adjustments triggered by flood protection alterations should uphold principles of accessibility, and reduce barriers to entry wherever possible.

Adaptations will be compared based on the noted infrastructure factors. Adaptations that do not negatively impact existing infrastructure, or restrict future infrastructure development, are preferred. Where impacts on local infrastructure cannot be avoided, the adaptation with the least impact is preferred. For example, from an infrastructure perspective, an adaptation that triggers relocation of a single utility pole is preferable to an adaptation that requires extensive road, sewer and watermain replacements.

Adaptations are also compared by determining which option presents the least costly and resource-intensive resolution to conflicts. For example, if raising a dike by widening its footprint to the land side requires filling drainage ditches and replacing their functions with box culvert, then this adaptation would comparatively be a costlier, higher impact strategy than widening the dike footprint to the water side where no existing infrastructure is located. On an infrastructure basis alone, a dike expansion to the water side would have fewer impacts and would better satisfy the criteria of minimizing infrastructure conflicts. Ultimately the preferred adaptation is selected based on a combination of all considerations. Infrastructure considerations are generally not the governing criteria for adaptation selection, however they are an essential component of a comprehensive analysis.

Dike improvements may also present opportunities for the City to undertake associated infrastructure upgrades, such as raising River Road or replacing linear infrastructure at the end of its service life. The City may benefit from an overall cost savings by bundling necessary infrastructure projects together. The comparison of adaptations will also consider whether additional infrastructure benefits can be provided through conducting simultaneous local infrastructure improvements.

4.1.4 LOCATIONS FOR SPECIAL CONSIDERATIONS

Unique site features requiring accommodation may limit the applicability of standard adaptations. Special structures may be investigated where complex constraints limit the options available. Standard methods can be combined, for example a dike with a demountable floodwall only at a driveway entrance. In areas where redevelopment is anticipated in the near future, there may be a desire to improve the interim conditions with a temporary adaptation, such as lock blocks that can be easily removed and reused elsewhere. Existing bridges may also require unique design solutions to provide increased flood protection.

Locations for special consideration within each area have been identified. Relative impacts of one alternative over the other are considered when selecting the preferred approach. Sites in the study area with unique constraints are also discussed in *Section 4.3*.

4.1.5 SOCIAL CONSIDERATIONS

Social considerations arise from those elements impacting cultural significance, use and enjoyment of the waterfront. The City's 2009 Waterfront Strategy presents a vision that promotes community wellness, economic vitality and a healthy environment through initiatives that integrate the waterfront with the urban landscape. The study area contains recreation, culture and heritage resources to be preserved wherever feasible. Recreational uses may include walking and cycling on the trail, as well as offshore activities such as sport fishing and boating. Heritage sites that have been identified as culturally significant should be preserved per the Heritage Procedures Bylaw 8400.

Public access to the waterfront is provided by the perimeter dike trail system. Where waterfront access is constrained, the City has identified connectivity at the waterfront as preferable to inland trail detours. For example, where the existing dike trail alignment crosses under low bridges, raising the dike may not provide adequate clearance to maintain the trail over the dike. The preference is to keep the trail at the waterfront by creative means, for example a boardwalk at the water side toe of the dike, rather than direct pedestrians up to the road to circumvent a barrier.

Adaptations are compared on how well they can be aesthetically integrated with the surrounding area. For example, in recreational areas or ecological landscapes, adaptations that do not detract from the natural beauty of the local environment are preferable to those adaptations requiring severe hardscaping, such as concrete or retaining walls. The local character of industrial areas is amenable to man-made structures thus floodwalls may be in keeping with the landscape themes in industrial areas.

Social considerations include the impacts to both public and private views with respect to dike improvement alternatives.

4.1.6 PROPERTY CONSIDERATIONS

Much of the City's waterfront was developed prior to the establishment of robust policies for dedicating lands to diking. As a result, older buildings remain directly on the waterfront, or within 30 m from the natural boundary. In cases where no alternative alignment can be implemented, it may be necessary for the City to acquire waterfront lands or obtain easements to construct adaptations.

Adaptations will be compared on their respective property needs, in addition to what property is presently under City ownership or otherwise available for diking. Adaptations that do not require any additional property are preferred.

4.1.7 ECONOMIC CONSIDERATIONS

While flood protection provides an overall economic good by preventing damage to assets, there may be negative impacts to the local economy. For example, diking may damage views to the waterfront, or challenge industrial activities by limiting water access. Where economic costs cannot be completely avoided, they should be mitigated to the extent feasible. The preferred strategy should accommodate factors producing local economic benefits, or remain economically neutral. Adaptations will be compared on whether the local economy is anticipated to be adversely impacted, and to what extent these impacts can be easily mitigated.

4.1.8 OPERATIONS & MAINTENANCE CONSIDERATIONS

Dikes in the study area provide access to City assets that must be maintained, such as drainage ditches and trails. Adequate clearance must be retained for maintenance vehicles to navigate the dikes where required, and carry out maintenance activities. For example, if a water side dike expansion is implemented where there are drainage ditches on the land side, the boom of an excavator on the dike must be able to reach the ditches for cleaning and maintenance.

Adaptations will be compared on whether any operations and maintenance activities are anticipated to be interrupted or complicated by their implementation.

4.1.9 FLOOD RISK MANAGEMENT CONSIDERATIONS

Considerations have been made with respect to the reliability and effectiveness of structural alternatives. In general, a standard trapezoidal dike is more reliable, easier to maintain, and easier to repair than a rigid wall structure.

4.1.10 COST CONSIDERATIONS

Costs of implementing alternate strategies are a consideration in selection of the preferred approach. Costs have been reviewed on an area specific basis. Based on this review, the driving factors for costs are not the actual dike infrastructure costs, rather the associated environmental, seismic, and associated infrastructure upgrades costs. Given that additional studies and analyses are generally required to fully confirm the requirements for these items, a value for capital cost is not used in the comparison of alternatives. The comparison relies on the qualitative factors of environmental, seismic, and infrastructure improvement requirements as a placeholder for cost.

4.2 EVALUATION OF AREA SPECIFIC FLOOD PROTECTION STRATEGIES

The evaluation and selection of the preferred adaptation for flood protection on each design area are presented in the following sections. As noted in ***Table 2***, the area specific adaptations under consideration are dikes and floodwalls. Dike adaptations include raising the dike by widening the footprint to either the land side or the water side, as well as a constrained dike adaptation where the dike is raised in place with a retaining wall to avoid widening the footprint. Floodwall adaptations include permanent and demountable installations.

Raising the existing dike on its existing alignment is the preferred option by default as it is the most effective flood protection strategy satisfying the considerations outlined in ***Section 4.1***. Barring site-specific conditions that complicate or prevent raising an existing dike on its existing alignment, this is generally the preferred option. Other adaptation options are considered where raising the dike on its existing alignment may be impractical, or where an alternative would provide a substantial benefit.

Raising a dike by widening its footprint is preferred as compared to a constrained dike. Constrained dikes require retaining walls, which are to be avoided in favour of an earth slope wherever possible. Retaining walls require more frequent inspections and maintenance, and are therefore more costly to operate than earth slopes. Retaining walls are also more difficult to repair during a flood in the event of a breach. Constrained dikes will only be considered for design areas where the drawbacks of widening the footprint are substantial, and a constrained dike would relieve these issues.

Permanent floodwalls are generally preferred over demountable floodwalls as they do not require any labour to operate. Demountable floodwalls require monitoring of flood event triggers such as tides and freshet, and the availability of staff for operations. Permanent floodwalls are preferred unless a demountable floodwall provides a substantial benefit.

All adaptation options are capable of achieving the flood protection goals. The purpose of the following evaluation is to select the optimal adaptation for the specified design area, given the considerations outlined in ***Section 4.1***. For design areas where two options are subject to comparable benefits and drawbacks, a comparison table is provided to show details of the evaluation. The purpose of the comparison tables is not to provide a fulsome evaluation of each option's standalone merits, but to provide a comparison of the two options relative to each other in order to select the preferred adaptation.

4.2.1 WEST DIKE: STEVESTON & SEAFAIR

The Steveston area spans from Garry Point Park at the southern limit of the Study Area north to Williams Road. Seafair begins at the Williams Road Pump Station, continuing north to the Quilchena Golf Course. These areas have similar constraints and will be considered together.

Land uses inland are primarily residential, consisting of single family homes and townhouse complexes. Outside the dike, lands are mostly undeveloped. A section of Sturgeon Banks is used for cattle grazing. Within Sturgeon Banks, a federally-owned 18 ha parcel of land has hosted CBC Radio towers since 1968. Four 61m-high AM transmission towers are located within Sturgeon Banks, connected to the main building directly off the dike, accessed from the dike trail. The CBC last conducted major rehabilitation works on these structures in 2011. These towers are anticipated to be operating on-site for the foreseeable future.

The dike was raised to 4.0 m in the vicinity of the Williams Road pump station when it was upgraded in 2013. Likewise, the dike crest elevation surrounding the Francis Road pump station (upgraded in 2007) is higher than the rest of this dike segment. The majority of the existing dike in this area is approximately 3.30 m high.

Given there is an existing dike footprint and land is available, the simplest, least expensive and most effective flood protection strategy is to raise the dike on its existing alignment. For this reason, floodwalls will not be considered for this design area. The dike can either be raised by widening the footprint (landside or waterside), or raising it in place with a constrained dike. A comparison of these two options is provided in ***Table 4***.

Table 4: Comparison of Adaptations in Steveston & Seafair – West Dike

	OPTION 1: RAISE DIKE BY WIDENING FOOTPRINT	OPTION 2: RAISE DIKE IN PLACE (CONSTRAINED)
Environmental Considerations	• Red coded habitat on Sturgeon Banks at the water side. • Ditch on land side is designated RMA. • Compensation may be required if expanding the footprint to either side.	• Alterations in habitat can be avoided.
Geotechnical	• Ground improvements may be required to meet seismic guidelines. • Dike face slope is less vulnerable to wave energy than a vertical wall.	• Ground improvements may be required to meet seismic guidelines. • Wall on water side more vulnerable to wave energy without a slope acting as an energy dissipater.
Infrastructure	• Ditches and landscaping at the land side toe of the dike may require relocation or infilling to accommodate a wider land side footprint. • Loss of stormwater storage and conveyance functions may need to be compensated with a landside expansion. • Revised drainage plans must be compatible with local pump stations.	• No conflicts anticipated.
Locations for Special Considerations	• Existing drainage pump stations. • Maintenance vehicle access locations.	• Existing drainage pump stations. • Maintenance vehicle access locations.
Social	• Earth fill dike consistent with this area's natural realm. • Similar reduction in views for both options. • Heavy landscaping of private developments, including ponds and fountains connected to the drainage ditches.	• Floodwalls or sheet piling detract from the natural realm. • Similar reduction in views for both options.
Property	• Easements may be required from federal, provincial and private landowners to widen the footprint to the water side. • City owns lands on the land side of the dike up to the private residential boundary.	• Dike can be raised on its existing footprint, no additional property or easements required.

	OPTION 1: RAISE DIKE BY WIDENING FOOTPRINT	OPTION 2: RAISE DIKE IN PLACE (CONSTRAINED)
Economic	• Cattle grazing lands may be reduced if the dike expands to the water side.	• Cattle may no longer be able to reach Sturgeon Banks from the farm.
Operations & Maintenance	• Boom on City trucks may be unable to reach the bottom of the ditches for dredging if dike crest is raised higher and farther from the ditches (water side expansion).	• Retaining walls are more costly to maintain than earth slopes.
Flood Risk Management	• Inherent reliability with traditional trapezoidal dike cross sections.	• A constrained dike would consist of a vertical wall at the water side and potentially an additional wall on the land side. • Vertical walls would be susceptible to damage from heavy wave action off of the Georgia Strait.

Both alternatives present issues and opportunities; and the selection of the preferred approach in this area is governed by the following key factors that will ultimately dictate the final project costs and impacts:

1) Impacts to drainage infrastructure with land side expansion: Widening the dike to the land side will require infilling of drainage ditches. Potential storage and conveyance impacts on the regional drainage system should be assessed to confirm feasibility and costs of offsetting the impacts.
2) Habitat impacts and compensation costs: The impacts and compensation costs associated with either a land side or water side expansion would need to be confirmed. It is anticipated that water side expansion would require the most compensation.
3) Resiliency of a constrained dike solution: The costs and long term resiliency of a constrained dike solution fronting the Georgia Strait would need to be confirmed. Impacts of wave action and overtopping on a retained water side wall would need to be studied.

Recommendation: Raise the dike on the existing alignment. Additional studies required to quantify drainage impacts of land side expansion, habitat impacts and costs associated with water side or land side expansion, and long term resiliency of a constrained dike solution.

4.2.2 WEST DIKE: TERRA NOVA

The Terra Nova area spans from Williams Road north to the end of the West Dike, at the Fraser River. The area includes some residential, though land uses are primarily recreational. The area includes the Quilchena Golf Course and Terra Nova Rural Park, 25 ha of public parkland. River Road begins at the western limit of the park.

The existing dike crest elevation is approximately 3.5 m. To achieve the required 4.7 m design crest elevation, the existing dike will be raised. This may be accomplished by raising the dike in place or widening the footprint, with similar constraints as presented in ***Section 4.2.1*** for Steveston and Seafair. As raising the existing dike is feasible in this area, floodwalls will not be considered further.

A comparison of these two options is provided in ***Table 5***.

Table 5: Comparison of Adaptations in Terra Nova – West Dike

	OPTION 1: RAISE DIKE BY WIDENING FOOTPRINT	OPTION 2: RAISE DIKE IN PLACE (CONSTRAINED)
Environmental Considerations	• Red coded habitat on Sturgeon Banks at the water side. • Ditch on land side is designated RMA. • Compensation may be required if expanding the footprint to either side.	• Alterations in habitat can be avoided.
Geotechnical	• Ground improvements may be required to meet seismic guidelines. • Dike face slope is less vulnerable to wave energy than a vertical wall.	• Ground improvements may be required to meet seismic guidelines. • Wall on water side more vulnerable to wave energy without a slope acting as an energy dissipater.
Infrastructure	• Ditches and landscaping at the land side toe of the dike may require relocation or infilling to accommodate a wider land side footprint. • Loss of stormwater storage and conveyance functions may need to be compensated with a landside expansion. • Revised drainage plans must be compatible with local pump stations. • Parking stalls for the park at the edge of River Road may need to be relocated.	• Connections from the dike trail to the park may be disrupted, such as the bridge from the trail to the Adventure Playground.
Locations for Special Considerations	• Historic Cannery site. • Existing drainage pump stations. • Maintenance vehicle access locations.	• Historic Cannery site. • Existing drainage pump stations. • Maintenance vehicle access locations.
Social	• Earth fill dike consistent with this area's natural realm. • Similar reduction in views for both options. • The heritage cannery may require special accommodations to be preserved. • Heavy landscaping of private developments, including ponds and fountains connected to the drainage ditches.	• Floodwalls or sheet piling detract from the natural realm. • Similar reduction in views for both options. • The heritage cannery may require special accommodations to be preserved.
Property	• Acquisition of property is not anticipated; area is primarily City-owned.	• Acquisition of property is not anticipated.
Economic	• None anticipated.	• None anticipated.
Operations & Maintenance	• Boom on City trucks may be unable to reach the bottom of the ditches for dredging if dike crest is raised higher and farther from the ditches (water side expansion).	• Retaining walls are more costly to maintain than earth slopes.
Flood Risk Management	• Inherent reliability with traditional trapezoidal dike cross sections.	• A constrained dike would consist of a vertical wall at the water side and potentially an additional wall on the land side. • Vertical walls would be susceptible to damage from heavy wave action off of the Georgia Strait.

Similar to the previous area, both alternatives present issues and opportunities; and the selection of the preferred approach in this area is governed by impacts to drainage infrastructure with land side expansion; habitat impacts and compensation costs; and the long term resiliency of a potential constrained dike solution. Site specific solutions may be required at the heritage cannery site.

Recommendation: Raise the dike on the existing alignment. Additional studies required to quantify drainage impacts of land side expansion, habitat impacts and costs associated with water side or land side expansion, and long term resiliency of a constrained dike solution.

4.2.3 NORTH DIKE: THOMPSON TERRA NOVA

The Thompson Terra Nova area spans from Terra Nova Park to McCallan Road. City lands are available to raise the dike by expanding the footprint therefore this strategy should be pursued as a standard earth fill dike is the preferred strategy wherever feasible. Floodwalls will not be considered further. ***Table 6*** evaluates considerations for widening the footprint to either the land side or water side. A constrained dike will not be considered as lands are available to widen the footprint.

Table 6: Comparison of Adaptations in Thompson Terra Nova – North Dike

	OPTION 1: RAISE DIKE BY WIDENING FOOTPRINT (LAND SIDE)	OPTION 2: RAISE DIKE BY WIDENING FOOTPRINT (WATER SIDE)
Environmental Considerations	• No ditches or other environmental constraints restricting alterations or triggering compensation.	• Red coded habitat on Fraser River at the water side. • Compensation may be required.
Geotechnical	• Similar seismic issues with both options.	• Similar seismic issues with both options.
Infrastructure	• River Road may be raised in conjunction with expanding the dike. • Driveway access from River Road may be complicated by raising the dike and road. • Positive drainage from homes on River Road may be compromised if the road is raised. • Six intersections in this area may be complicated by raising the dike and River Road. • Linear infrastructure on River Road may be replaced concurrently with dike improvements.	• No impact on River Road.
Locations for Special Considerations	• Drainage pump stations.	• Drainage pump stations.
Social	• Similar reduction in views for both options.	• Similar reductions in views for both options.
Property	• Municipal ROW and City-owned park lands are available adjacent to the shore; no easements or acquisitions required.	• No easements or acquisitions required.
Economic	• None anticipated.	• None anticipated.
Operations & Maintenance	• Similar maintenance needs for both options.	• Similar maintenance needs for both options.
Flood Risk Management	• Same for both options.	• Same for both options.

Water side expansion into red-coded Fraser River habitat is anticipated to be costly; and, with a viable land side expansion alternative it is anticipated to not be supported or approved from a regulator standpoint. As such, land side expansion is the preferred approach.

Raising River Road can be considered to align with a long-term strategy of maximizing the raised crest width of lands on the waterfront. With incremental increases over time, River Road may form part of a superdike in the long-term future.

A land side constrained solution (i.e. land side toe retaining wall) may need to be considered in the interim if raising River Road is not possible at the time of proceeding with dike improvements.

Recommendation: Raise the dike on the existing alignment with land side expansion. Plan for the long-term raising of River Road.

4.2.4 NORTH DIKE: THOMPSON DOVER

Thompson Dover spans from McCallan Road to the No. 2 Road Bridge. The area includes the City works yard and recycling depot, a skate park, and mid-rise multi-family dwellings. In the event that the City works yard is sold to private ownership, any development permits may be issued on the condition that a flood protection plan is implemented, as per the planning and policy options discussed in Section 3.2.

The multi-family lands have been set back from the road and raised at the time of development. Minimal disturbance to the existing lot is anticipated if River Road is raised. Views from the existing development are not anticipated to be impacted significantly with an increase in dike height. There is no road access to the multi-family units from River Road. The only road grading constraints are the intersections with Lynas Lane and No. 2 Road at either end of the area.

A constrained dike will not be considered further as lands are available to raise the dike by widening the footprint, either towards the land side or the water side. A comparison of these options is presented in ***Table 7***

Table 7: Comparison of Adaptations in Thompson Dover – North Dike

	OPTION 1: RAISE DIKE BY WIDENING FOOTPRINT (LAND SIDE)	OPTION 2: RAISE DIKE BY WIDENING FOOTPRINT (WATER SIDE)
Environmental Considerations	• No ditches or other environmental constraints restricting alterations or triggering compensation.	• Red coded habitat on Fraser River at the water side. • Compensation may be required.
Geotechnical	• Similar seismic issues with both options.	• Similar seismic issues with both options.
Infrastructure	• No driveway access to multi-family units from River Road setting grading constraints. • City works yard can be accessed from Lynas Lane; accesses from River Road may be closed or regraded to accommodate River Road elevation increases.	• No impact on River Road.
Locations for Special Considerations	• Drainage pump stations. • No. 2 Road Bridge.	• Drainage pump stations. • No. 2 Road Bridge.
Social	• Similar reduction in views for both options.	• Similar reductions in views for both options.
Property	• City works yard may be sold and redeveloped, at which time City can negotiate flood protection adaptations.	• No easements or acquisitions required.
Economic	• None anticipated.	• None anticipated.
Operations & Maintenance	• Similar maintenance needs for both options.	• Similar maintenance needs for both options.
Flood Risk Management	• Same for both options.	• Same for both options.

Water side expansion into red-coded Fraser River habitat is anticipated to be costly; and, with a viable land side expansion alternative it is anticipated to not be supported or approved from a regulator standpoint. As such, land side expansion is the preferred approach.

The land side expansion adaptation presents an opportunity to raise River Road where there are relatively few constraints, as compared with other areas. Raising River Road serves the long-term strategy of maximizing the raised crest width of lands on the waterfront. In Thompson Dover, River Road can be raised to meet the ground elevation of the multi-family residential development in a single event, rather than raising River Road incrementally over time as required in more constrained areas. The entire River Road alignment west of the No. 2 Road Bridge may form a superdike in the long-term future. This area can be raised first to set the precedent for future upgrades in more constrained areas nearby.

Recommendation: Raise the dike on the existing alignment with land side expansion. Plan to raise River Road.

4.2.5 NORTH DIKE: OVAL

The Oval area is between the No. 2 Road Bridge and the Dinsmore Bridge. The majority of these lands were developed for the Vancouver Olympics in 2010, at which time the dike was raised to elevations from 4.0 to 4.5 m. Lands between the buildings and the dike were filled at the Olympic Oval, creating a superdike in this area. This strategy has been replicated in the adjacent multi-family developments, where construction is either complete or currently underway. The Syscon Justice Systems building directly west of the Dinsmore Bridge is the one remaining section to be raised. As this building has been set back from the waterfront, there is land available to raise the dike by widening the footprint to the land side at this site. This option may be pursued when this segment of River Road is decommissioned and relocated to the former rail corridor inland.

Recommendation: Existing area generally redeveloped as a superdike scenario (elevations from 4.0 to 4.5m). Future raisings to 5.5 m can take place on the existing alignments and integrate into the adjacent landscaping.

4.2.6 NORTH DIKE: CITY CENTRE 1

The City Centre 1 area spans from the Dinsmore Bridge to Cambie Road. All lands in the City Centre OCP area have been identified for intensification up to the planning horizon of 2041. Substantial redevelopment of these lands is anticipated in the near and long-term future.

For this study, the City Centre OCP area has been divided at Cambie Road. West of Cambie Road, all lands between the waterfront and the future River Road alignment over CP Rail's former Van Horne Spur line, will be park lands of the proposed Middle Arm Park. The timeline for this redevelopment is unknown; however, ultimately it is anticipated that the preferred flood protection strategy will be integrated with this park development.

The existing Middle Arm Waterfront Park (MAWP) is a linear park along the waterfront constructed concurrently with the Olympic Oval in 2009. The park's amenities include the dike trail, playgrounds, and piers. Outdoor seating and stages for public events have been inset on the water side dike face. The dike was raised to approximately 4.0 m at the time of construction.

Plans for the new park have not yet been formalized; however, based on consultation with City staff, it appears there is support to establish the future dike alignment set back from the waterfront to improve public connectivity with the waterfront, and facilitate creation of intertidal habitat within the park. A set-back dike, combined with inland raising to create a superdike would provide the most resilient solution for this area.

An analysis of options is presented in ***Table 8*** for near-future adaptation scenarios, with the understanding that diking will proceed in the proposed Middle Arm Park at the time of park development. For this scenario, lands are available for widening the dike footprint, thus a constrained dike will not be considered further.

Table 8: Comparison of Adaptations in City Centre 1 – North Dike

	OPTION 1: RAISE DIKE BY WIDENING FOOTPRINT (LAND SIDE)	OPTION 2: RAISE DIKE BY WIDENING FOOTPRINT (WATER SIDE)
Environmental Considerations	• No ditches or other environmental constraints restricting alterations or triggering compensation. • Mature trees are present at the land side toe of the existing dike. • Future dike alignment could be inland of the trees in coordination with the park redevelopment. • Opportunities to create intertidal habits by moving the dike inland.	• Green and yellow coded habitat on Fraser River at the water side. • Compensation may be required. • Mature trees are not impacted.

	OPTION 1: RAISE DIKE BY WIDENING FOOTPRINT (LAND SIDE)	OPTION 2: RAISE DIKE BY WIDENING FOOTPRINT (WATER SIDE)
Geotechnical	• Seismic conditions improve as dike is moved inland.	• Similar but slightly worse than a land side expansion.
Infrastructure	• Dike improvements made prior to the park redevelopment could impact River Road.	• Access to UBC boathouse and marinas may be impacted, or require accommodation with a demountable floodwall.
Locations for Special Considerations	• UBC boathouse and marina. • Drainage pump stations. • Gilbert Road Bridge.	• UBC boathouse and marina. • Drainage pump stations. • Gilbert Road Bridge.
Social	• Dike can be planned to integrate with the future park. • MAWP amenities may be impacted or removed by diking, though will be replaced at the time of future park development.	• MAWP amenities on the dike crest, such as playgrounds and the trail, may be similarly impacted for both options. • Water side MAWP amenities considered to have greater tourism and recreation appeal.
Property	• Future park lands to be acquired.	• None anticipated, existing MAWP parks lands are City-owned.
Economic	• Dike improvements made prior to the park redevelopment could impact River Road.	
Operations & Maintenance	• Inland or set-back dike would require less maintenance.	
Flood Risk Management	• Same for both options.	• Same for both options.

Water side expansion into the Fraser River is anticipated to be costly; and, with a viable land side expansion alternative coordinated with the park development, it is anticipated to not be supported or approved from a regulatory standpoint. As such, land side expansion is the preferred approach. As park planning efforts move ahead, consideration of integration of alternate dike upgrades can be made. Preference should be given to concepts that either: allow for the dike to be set-back from the waterfront; or, allow for creation of a superdike.

Recommendation: Raise a dike with land side expansion. Consider creation of a set-back dike and inland raising (superdike) in conjunction with construction of the proposed Middle Arm Park in future.

4.2.7 NORTH DIKE: CITY CENTRE 2

City Centre 2 spans from Cambie Road to the Moray Bridge. The waterfront in this area is entirely dedicated to marinas. The dike trail ends approximately 200 m north of Cambie Road, where the dike becomes marina parking lots. These parking lots are directly adjacent to the trafficable road; there is no shoulder between the road and the parking lots. Parking lots are raised from River Road with either steep slopes or retaining walls.

This section of River Road will ultimately be realigned to the former rail corridor. Lands are planned to be redeveloped into high density commercial and mixed use buildings. The proposed waterfront park ends where the dike trail becomes parking lots.

Redevelopment is occurring in this area. Smaller lot depths and lot assemblies for redevelopment create challenges with implementation of flood protection upgrades with redevelopment. These issues should be addressed on policy basis to require larger lot assemblies such that the required waterfront dike improvements can be made with redevelopment.

In general, the approach to flood protection in this area should mimic the recent improvements in the Oval area, with redevelopment raising the waterfront and the development site to establish a superdike. The form of dike along this area may include components of flood walls (concrete or sheetpile) in order to maintain access and usage of the existing

waterlots (marinas); however, landside expansion should be considered the preferred approach. Any interim dike upgrades planned in this area should be designed to adapt to the long term goals of establishing a superdike.

Recommendation: Raise the dike on the existing alignment with land side expansion in conjunction with redevelopment. Ensure any interim dike upgrades are compatible with the long term strategy of constructing superdikes.

4.2.8 NORTH DIKE: DUCK ISLAND & RIVER ROCK CASINO

There are presently plans to redevelop Duck Island. The development team is responsible for establishing a flood protection strategy that ties into the City-wide dike master plan, and dedicate ROWs to the City. The River Rock Casino is preparing a strategy to improve flood protection around their property for the City. The approved strategy will be implemented following a trigger prescribed by the City.

For the area between the Sea Island Connector Bridge and the Oak Street Bridge, the master plan will defer to the approved plans resulting from these independent studies. Depending on development timeframes, the City may wish to consider implementation of alternate adaptation measures. These could consist of temporary, permanent, or a combination of both forms of flood protection. Alternatives alignments are shown in **Figure 4**.

Figure 4: Alternate Dike Alignments for Duck Island & River Rock Casino

The existing waterfront lands in this area are entirely private (Duck Island / River Rock). It is assumed that the City would not secure a dike ROW on private lands in advance of implementation of the private plans, which are anticipated to provide the City a ROW. Inland alternatives could include permanent or demountable floodwalls.

A permanent floodwall could be considered along the existing CN Rail alignment. The footprint of a concrete floodwall could be constructed within the existing CN Rail corridor. This land would need to be acquired from CN. Temporary stop log structures would be required at road crossings. Alternatively, the City could develop plans for a temporary structure that would be mobilized and erected in preparation for anticipated high water events. The alignment for this structure would follow River Road.

It is anticipated that the timeframe for such interim adaptations would be brief and become redundant once the final Duck Island and River Rock solutions are implemented. Assuming a relatively short time-frame for development, minimal investment in the interim adaptation is justified. If the City wishes to implement interim flood protection measures prior to implementation of the private plans, temporary adaptations may be pursued.

Recommendation: Implement as per approved development plans. Plan for temporary dike to protect City assets if required to address sea level rise and climate change prior to implementation of the approved strategy at the Duck Island or River Rock Casino sites.

4.2.9 NORTH DIKE: INDUSTRIAL

The Industrial area spans from the Oak Street Bridge to No. 4 Road. This industrial area includes the Fraser River Terminal, a shipping port and ship repair centre, and the BC Hydro Kidd #2 Substation. The North Arm Bridge carrying the Canada Line and a bikeway was constructed in this area in 2009 with ample clearance for dike works beneath the bridge deck. At the detailed design stage, dike works would need to be verified for confirmation that the footings can withstand additional loading without risk of settling.

Adaptations in this area are constrained by existing waterfront development and uses. This area is anticipated to be industrial for the foreseeable future. Because waterfront lands are constrained by private industrial uses, an alternative dike alignment inland has been considered, as shown in ***Figure 5***.

The comparison of raising the dike at the waterfront versus realigning to an alternate alignment south of the waterfront yards is included in ***Table 9***. The alternate alignment may extend to No. 4 Road or cut through the BC Hydro lands to avoid diking on No. 4 Road.

Table 9: Comparison of Adaptations in Industrial – North Dike

	OPTION 1: RAISE DIKE BY WIDENING FOOTPRINT (LAND SIDE)	OPTION 2: ALTERNATE INLAND ALGINMENT
Environmental Considerations	• No habitat impacts anticipated.	• No habitat impacts anticipated.
Geotechnical	• Ground improvement may be required to meet seismic guidelines	• Inland alignment may reduce ground improvement effort required.
Infrastructure	• Three large transmission towers on the waterfront may be at risk of settlement under additional loading. • Encroachment into parking lots required.	• Alignment on Row requires raising River Road.
Locations for Special Considerations	• North Arm Bridge.	• North Arm Bridge.
Social	• Presently an industrial area, no waterfront trail exists across this area.	• No impact.

	OPTION 1: RAISE DIKE BY WIDENING FOOTPRINT (LAND SIDE)	OPTION 2: ALTERNATE INLAND ALGINMENT
Property	• Waterfront lands are not City owned; cooperation with landowners required. • Easements on private lands may be required.	• If alignment follows municipal ROW, no easement required. • If alignment through BC Hydro lands is selected, easement may be required.
Economic	• Adaptations may limit waterfront access and interfere with waterfront uses.	• Waterfront assets would not have the same level of protection as assets behind the secondary dike.
Operations & Maintenance	• Maintenance of dike on private property will require City access.	• No impact.
Flood Risk Management	• Inherent reliability with traditional trapezoidal dike cross sections.	• Rigid floodwall (concrete or sheetpile) may have increased maintenance costs.

Figure 5: Industrial Area – Alternate Dike Alignment

For the long term flood protection strategy, preferred adaptation is to maintain the dike alignment on the waterfront to protect all infrastructure. The Fraser River Terminal will require a site-specific adaptation at a time when the site is redeveloped, which is not anticipated in the imminent future. In the interim, the Fraser River Terminal site is considered a generally constrained area, discussed further in ***Section 4.3.1***.

Dike works in this area will need to tie in to the adaptations measures approved for the River Rock Casino.

Recommendation: Raise the dike on the existing alignment. Site specific solutions may be required at the Fraser River Terminal site. Plan for temporary dike along the alternate alignment if required to address sea level rise and climate change prior to implementation of a strategy at the Fraser River Terminal site.

4.2.11 NORTH DIKE: INDUSTRIAL NORTH EAST 1

The Industrial North East 1 area spans from Shell Road to the Bath Slough. River Road is adjacent to the waterfront except for a 300 m frontage at Simpson Road, where there is development between River Road and the waterfront.

The adaptations under consideration for all the Industrial North East areas are raising the dike by widening the footprint, or constructing a floodwall. Raising the dike in this area is constrained from existing land uses. These adaptations are compared in *Table 10*.

Table 10: Comparison of Adaptations in Industrial North East 1 – North Dike

	OPTION 1: RAISE DIKE BY WIDENING FOOTPRINT (LAND SIDE)	OPTION 2: FLOOD WALL
Environmental Considerations	• No habitat impacts anticipated.	• No habitat impacts anticipated.
Geotechnical	• Similar for both options.	• Similar for both options.
Infrastructure	• Limited space is available; River Road may be raised concurrently with dike works to meet the target dike crest elevation; however, this would impact access to lots south of River Road. • Waterfront lots would need to be acquired to construct an earth fill dike.	• No impacts anticipated.
Locations for Special Considerations	• None.	• Existing waterfront lots.
Social	• Waterfront trail can be constructed over the dike.	• Limits dike trail options and restricts public access to the waterfront. • Aesthetically, sheet piling or other wall types are consistent with local character.
Property	• Acquisition of property north of Simpson Road required to complete diking. • Additional lands from the private parking lots on the south side of River Road may be acquired if the dike footprint is still highly constrained using only the existing ROW and waterfront as the footprint.	• No acquisition of property required however waterfront businesses must be engaged to improve existing floodwalls on their property.
Economic	• Simpson Road lands will not be returned to commercial or industrial uses once existing businesses are relocated or closed.	• Access to waterfront may be impacted for local business.
Operations & Maintenance	• No impacts anticipated.	• Maintenance of dike on private property will require City access. Limited space available for easements.
Flood Risk Management	• Inherent reliability with traditional trapezoidal dike cross sections.	• Rigid floodwall (concrete or sheetpile) may have increased maintenance costs.

The preferred adaptation is to raise the dike on its existing alignment by expanding the footprint to the land side. The existing lots north River Road would need to be acquired to create a dike with sufficient access to maintain it. The dike could consist of a floodwall or standard trapezoidal section. The floodwall imposes the least physical impacts to the existing landscape however it does not contribute to the long-term goal of a superdike at the waterfront, nor the goal of connecting the entire waterfront with a dike trail.

The acquisition of approximately 2 ha of private lands north of Simpson Road adds significant costs to diking in this area. A floodwall may be implemented at this segment only as an interim solution in advance of the City's acquisition of these lands. Any interim solutions will require cooperation with the existing landowners. Outside this area, there are lands

available from the River Road ROW to the shore to raise the existing dike. At the detailed design stage, if lands are too highly constrained to expand the dike footprint, additional lands from the parking lots on the south side of River Road may be acquired.

Recommendation: Raise the dike on the existing alignment. Acquire the existing lots north of River Road to facilitate construction of a trapezoidal dike. A plan for temporary dike or flood wall adjacent to the waterfront lots may be required to address sea level rise and climate change prior to acquiring all required property.

4.2.12 NORTH DIKE: INDUSTRIAL NORTH EAST 2

The Industrial North East 2 area spans from the Bath Slough to the Knight Street Bridge. This area is exclusively industrial. The River Road alignment at the waterfront is the dike. Drainage ditches on the south side of River Road convey drainage to the Bath Slough pump station. The ditches are adjacent to private parking lots, with buildings generally set back from the ROW. At the Knight Street Bridge, there is ample clearance for dike works beneath the bridge deck, though the footings' capacity to withstand additional loading without risk of settlement should be verified at the detailed design stage.

The adaptations under consideration for all the Industrial North East areas are raising the dike by widening the footprint, or constructing a floodwall. The applicability of these adaptations is compared in ***Table 11***.

Table 11: Comparison of Adaptations in Industrial North East 2 – North Dike

	OPTION 1: RAISE DIKE BY WIDENING FOOTPRINT	OPTION 2: FLOOD WALL
Environmental Considerations	• Ditch on land side is designated RMA; compensation may be required if alterations in habitat cannot be avoided. • Mature trees between River Road and the waterfront for 200 m east of Knight Street Bridge.	• No habitat impacts anticipated.
Geotechnical	• Similar for both options.	• Similar for both options.
Infrastructure	• Ditches at toe of dike may require relocation or infilling to accommodate a wider footprint. • Stormwater storage and conveyance functions must be replicated if reduced. • Revised drainage plans must be compatible with local pump stations. • On street parking may be removed. • River Road may be raised, and accesses to local businesses must be maintained.	• Utility poles on the north side of River Road may need to be relocated; similar for both options.
Locations for Special Considerations	• Knight Street Bridge. • Bath Slough Pump Station.	• Knight Street Bridge. • Bath Slough Pump Station.
Social	• Waterfront trail can be constructed over the dike.	• Limits dike trail options and restricts public access to the waterfront. • Aesthetically, sheet piling or other wall types are consistent with local character.
Property	• Additional lands from the private parking lots on the south side of River Road may be acquired if the dike footprint is too constrained using only the existing ROW and waterfront.	• No additional lands or easements required as the existing ROW is anticipated to be sufficient to erect a floodwall.
Economic	• No impacts anticipated.	• No impacts anticipated.
Operations & Maintenance	• No impacts anticipated.	• No impacts anticipated.
Flood Risk Management	• Inherent reliability with traditional trapezoidal dike cross sections.	• Rigid floodwall (concrete or sheetpile) may have increased maintenance costs.

The preferred adaptation is to raise the dike on its existing alignment. As River Road is currently the dike, it is anticipated that the entire road must be raised as there are insufficient lands available north of the road to raise the dike. No businesses within this area access the waterfront directly from their lots, therefore maintaining waterfront access for these businesses is not required. Public access to the waterfront may be improved by the addition of a trail adjacent to the raised road, in compliance with the City's long term vision of a connected trail system at the waterfront of the entire island. Existing drainage on the land side may need to be modified.

Recommendation: Raise the dike on the existing alignment. Additional studies required to quantify drainage, habitat impacts, and costs associated with land side expansion of a trapezoidal dike. A constrained land side slope may be required to integrate with the existing drainage infrastructure.

4.2.13 NORTH DIKE: INDUSTRIAL NORTH EAST 3

The Industrial North East 3 area spans from the Knight Street Bridge to No. 6 Road, the eastern limit of the study area. River Road is a municipal ROW; however, it is not open to public traffic in this area. It is gated and locked under the Knight Street Bridge, and at the entrance to the lumber yard off No. 6 Road. Industrial equipment is currently occupying sections of the ROW, restricting access.

Adaptations for this area are compared in ***Table 12***.

Table 12: Comparison of Adaptations in Industrial North East 3 – North Dike

	OPTION 1: RAISE DIKE BY WIDENING FOOTPRINT	OPTION 2: FLOOD WALL
Environmental Considerations	• Ditch on land side is designated RMA; compensation may be required if alterations in habitat cannot be avoided. • Mature trees between River Road and the waterfront may be impacted, similar for both options.	• Mature trees between River Road and the waterfront may be impacted, similar for both options.
Geotechnical	• Similar seismic issues with both options.	• Similar seismic issues with both options.
Infrastructure	• River Road is the existing dike, entire roadway must be raised. • Ditches at toe of dike may require relocation or infilling to accommodate a wider footprint. • Stormwater storage and conveyance functions must be replicated if reduced. • Revised drainage plans must be compatible with local pump stations. • On street parking may be removed. • River Road may be raised, and accesses to local businesses must be maintained.	• Utility poles and power transmission tower on south side of ROW may need to be relocated; similar for both options.
Locations for Special Considerations	• Richply lumber yard.	• Richply lumber yard.
Social	• Dike trail at waterfront may be implemented.	• Views and access to the waterfront may be restricted however a floodwall is consistent with the local character in the area.
Property	• City has an existing ROW; no additional lands or easements required as the existing ROW is anticipated to be sufficient without acquiring additional lands.	• No additional lands or easements required as the existing ROW is anticipated to be sufficient to erect a floodwall.
Economic	• Access to the water may be restricted.	• Demountable sections along the lumber yard frontage for water access may be required to avoid impacting operations.

	OPTION 1: RAISE DIKE BY WIDENING FOOTPRINT	OPTION 2: FLOOD WALL
Operations & Maintenance	• River Road is currently gated and locked at Knight Street Bridge; access may be improved concurrently with dike works.	• Similar for both options; access to gated part of ROW may be improved.
Flood Risk Management	• Inherent reliability with traditional trapezoidal dike cross sections.	• Rigid floodwall (concrete or sheetpile) may have increased maintenance costs.

The preferred adaptation is to raise the existing dike by widening the footprint. As River Road is currently the dike, it is anticipated that the entire road must be raised. The dike trail may be extended through the area at the waterfront more easily with a dike than a floodwall. Public access to the waterfront may be improved by the addition of a trail adjacent to the raised road, in compliance with the City's long term vision of a connected trail system at the waterfront of the entire island. The Richply lumber yard site may not be amenable to supporting a trail. This should be investigated at the detailed design stage.

Local businesses, including Richply, should be consulted on their specific water access needs at the detailed design stage. A demountable structure to maintain access at grade may be a suitable adaptation for a small part of the frontage in this area.

Recommendation: Raise the dike on the existing alignment. Additional studies required to quantify drainage, habitat impacts, and costs associated with land side expansion of a trapezoidal dike. A constrained land side slope may be required to integrate with the existing drainage infrastructure.

4.3 SITE SPECIFIC FLOOD PROTECTION STRATEGIES AND CONSIDERATIONS

The area-specific analysis above is appropriate to select adaptations which are valid for those portions of the area subject to similar constraints. Within the study area, there are site specific cases where the overall strategy for an area cannot be implemented. For example, the preferred adaptation for an area may be to raise the existing dike; however this will not be applicable for the site of a low bridge crossing where there is inadequate clearance to raise the dike. Those site-specific special cases are identified and discussed below.

4.3.1 GENERALLY CONSTRAINED AREAS

Some waterfront areas may be severely constrained by development and infrastructure that cannot be impacted or modified at the time when flood protection works are required. This may include roads, bridges, drainage canals & ditches, or buildings. There may also be legal or financial constraints prohibiting the immediate implementation of diking, such as where the City may need to wait to acquire lands. In these areas, interim adaptations may be necessary until such time that the recommended long-term adaptation can be implemented. Any interim adaptation should be designed with consideration for compatibility with the ultimate adaptation.

If any waterfront lands are available, a floodwall or constrained dike can be constructed. The long-term goal should be to plan to remove constrained dikes when feasible by filling lands behind the dike. Where waterfront lands are not available or where implementation of the ultimate adaptation is imminent, temporary demountable structures may be applied.

4.3.2 PUMP STATIONS

There are fourteen existing pump stations in the study area. Typically these have been constructed at a higher elevation than the surrounding area, to provide additional flood protection for this critical infrastructure. Generally they are inset into

the dike with a crest elevation at approximately 4.0 m, where the adjacent dike crest elevations are lower, approximately 3.5 m.

If the dike is raised overtop an existing pump station, the additional loading may cause settlement issues. At the time of detailed design, pump stations should be evaluated for their ability to withstand the required loading. Alternatives may be pursued to avoid settlement, such as constructing a floodwall for the pump station area only to reduce loads. Mitigation plans may also be required to maintain unrestricted outlets to the Fraser River and Georgia Strait from the pump stations throughout construction.

4.3.3 BRIDGES

There are nine existing bridges and one proposed bridge in the study area, as listed in ***Table 12*** and labeled on the key plan in ***Appendix D***.

Only five of these bridges have low decks, which may not provide adequate clearance to raise existing dikes beneath the bridge span. The provincial and TransLink bridges have generally been built with sufficient clearance for all future dike crest increases. If a dike is to be raised under an existing bridge, its footings should be evaluated for their capacity to withstand additional fill at the detailed design stage, to avoid settlement.

The ideal time to implement flood protection adaptations at a bridge is concurrently with bridge rehabilitation or replacement works. Flood protection adaptations should be incorporated into the planning and design for any bridge works in the study area, although interim measures may be implemented when a greater level of flood protection is desired before bridge works will proceed. Flood protection adaptations may be implemented at existing bridges by either raising dikes under the bridge span (where clearances permit the dike crest to be raised), or by tying the dike into the bridge abutments. The recommended adaptation strategies in ***Table 13*** pertain to the existing bridges, for the scenario where adaptations will be implemented in advance of any bridge works. In the case of any proposed bridges, flood protection works should be incorporated at the planning and design stage.

The dike is a continuous waterfront trail. As noted in ***Section 4.1.5***, City staff have identified a preference to maintain the trail at the waterfront, as opposed to a detour route inland around the bridges. Where bridge decks are low and cross over a dike, it may not be feasible to raise the existing dike and maintain adequate clearance for the trail to remain on top of the dike. In those cases, to avoid rerouting the trail inland, a boardwalk may be constructed on the water side of the dike. Options for maintaining the trail at the waterfront under bridge crossings may be investigated at the detailed design stage.

The Marpole Rail Bridge, owned by CP Rail, is the only remaining rail crossing in the study area. The rail bridge connects the Arbutus Corridor in the City of Vancouver to rail lines in Richmond. CP Rail ceased operations on the Arbutus Corridor railroad in 2001, and the City of Vancouver purchased these lands in March 2016. The bridge was formerly connected to the Van Horne Spur. A segment of this spur from No. 2 Road to Capstan Way was acquired by the City in 2006 and has been repurposed as the new River Road alignment. CP Rail maintains ownership of the Marpole Bridge, however it was damaged by fire in 2014 and it is not currently operational. CP Rail's future plans for the bridge and connecting railroads are unknown. At the detailed design stage, CP Rail should be engaged on dike improvements that may impact their rail line if they are still the landowner when plans move forward to construction.

Table 13: Bridges in the Study Area

BRIDGE NAME (OWNERSHIP, BRIDGE TYPE)		
AREA	**CONSTRAINTS AND CONDITIONS**	**RECOMMENDED ADAPTATION STRATEGY**
NO. 2 ROAD BRIDGE (CITY OF RICHMOND, ROAD)		
Oval	• Bridge deck is low. • Footings are under the existing dike. • Bridge crosses over River Road. • Bridge crosses over dike trail. • Bike ramp to bridge from dike trail sensitive to grade changes.	Tied to abutments
DINSMORE BRIDGE (CITY OF RICHMOND, ROAD)		
Oval	• Bridge deck is low. • Footings are under the existing dike. • Bridge crosses over River Road with 4.3m clearance. • Bridge crosses over dike trail.	Tied to abutments
MORAY BRIDGE (CITY OF RICHMOND, ROAD)		
City Centre 1	• Bridge deck is very low. • Existing dike is inland, not under the bridge. • Bridge does not cross any road or trail. • No waterfront trail currently exists under the bridge. • Existing dike is aligned over the bridge.	Tied to abutments
SEA ISLAND CONNECTOR (CITY OF RICHMOND, ROAD)		
City Centre 1	• Bridge deck is very low. • Existing dike is inland, not under a bridge. • Bridge does not cross any road or trail. • No waterfront trail currently exists under the bridge. • Existing dike is aligned over the bridge.	Tied to abutments
MIDDLE ARM CANADA LINE BRIDGE (TRANSLINK, RAIL)		
Duck Island	• None	Under span
MARPOLE RAIL BRIDGE (CP RAIL, RAIL)		
Duck Island	• Bridge deck is low. • Timber trestle bridge; minimal space between footings. • Not currently operational. • Repairs required to return bridge to operational conditions. • CP Rail's intentions for future use are unknown.	Tied to abutments
OAK STREET BRIDGE (BC MINISTRY OF TRANSPORTATION, ROAD)		
Duck Island	• None	Under span
NORTH ARM CANADA LINE BRIDGE (TRANSLINK, RAIL)		
Industrial	• None	Under span
KNIGHT STREET BRIDGE (TRANSLINK, ROAD)		
Industrial NE2	• None	Under span
PROPOSED BURKEVILLE PEDESTRIAN BRIDGE (CITY OF RICHMOND, PEDESTRIAN)		
City Centre 1	• Proposed bridge design has not yet been prepared. • Diking to be incorporated when design proceeds.	N/A

5. Conclusions

The preferred regional and area specific adaptations determined from the analysis presented in this report are summarized in this section.

5.1 REGIONAL APPROACH

A number of regional approaches can be considered to enhance long term flood protection in the City and create resiliency in addressing climate change and sea level rise. These include:

Adopting policies to promote the long-term raising of lands adjacent to and inland of the existing dikes: Amending the FCL bylaw is the preferred regional strategy to achieve this goal and improve flood protection throughout the study area. Specific amendments to mitigate the challenges of implementing the bylaw, such as inconsistent grading and drainage issues, may be further investigated by a team of consultants including architects, planners, environmental consultants and engineers. For larger lots or assembled parcels being redeveloped, the City may continue to negotiate implementation of flood protection measures on a site-specific basis.

Planning for implementation of offshore protection on the Sturgeon Banks: If climate change and sea level rise predictions materialize, increased depths offshore could simultaneously increase wave heights, particularly in the Georgia Strait. Offshore barrier islands are one option to consider to dissipate wave energy prior to reaching the West Dike. Construction of breakwaters or barrier islands at this time may result in adverse impacts on fish habitats. If sea level rise is observed and future tidal conditions reduce or eliminate the existing intertidal marsh, then future barrier islands have the potential to create habitat and be used as a compensation site for other projects.

Consider establishment of a habitat banking program: It is anticipated that for diking projects both within the study area and City-wide, alterations to environmentally sensitive areas may be unavoidable and habitat compensation may be required. The City may consider establishing a formal habitat banking program to allow for flexibility to create habitat. Habitat credits can be applied to multiple projects, or stored for future dike works. A formal habitat banking program may assist with the implementation of long term flood protection infrastructure upgrade programs.

5.2 AREA SPECIFIC APPROACH

Standard earth fill dikes are the preferred option wherever possible. In areas where it is not feasible to raise the dike, alternative strategies may be implemented to achieve the same level of flood protection. The preferred dike alignment is presented in ***Appendix D***; it is generally on the same alignment as the existing dike. The preferred structural adaptation for each area is presented in ***Table 14***.

Table 14: Summary of Preferred Structural Adaptations by Area

FLOOD PROTECTION SEGMENT	PREFERRED OPTION
WEST DIKE	
Steveston & Seafair	Raise the dike on the existing alignment. Additional studies required to quantify drainage impacts of land side expansion, habitat impacts and costs associated with water side or land side expansion, and long term resiliency of a constrained dike solution.
Terra Nova	Raise the dike on the existing alignment. Additional studies required to quantify drainage impacts of land side expansion, habitat impacts and costs associated with water side or land side expansion, and long term resiliency of a constrained dike solution. Consider routing the dike inland through Terra Nova Park.
NORTH DIKE	
Thompson Terra Nova	Raise the dike on the existing alignment with land side expansion. Plan for the long-term raising of River Road.
Thompson Dover	Raise the dike on the existing alignment with land side expansion. Plan to raise River Road.
Oval	Existing area generally redeveloped as a superdike scenario (elevations from 4.0 to 4.5m). Future raisings to 5.5 m can take place on the existing alignments and integrate into the adjacent landscaping.
City Centre 1	Raise a dike with land side expansion. Consider creation of a set-back dike and inland raising (superdike) in conjunction with the future Middle Arm Waterfront Park construction.
City Centre 2	Raise the dike on the existing alignment with land side expansion in conjunction with redevelopment. Ensure any interim dike upgrades are compatible with the long term strategy of constructing superdikes.
Duck Island River Rock	As per approved development plans. Plan for temporary dike to protect City assets if required to address sea level rise and climate change prior to implementation of the approved strategy at the Duck Island or River Rock Casino sites.
Industrial	Raise the dike on the existing alignment. Site specific solutions may be required at the Fraser River Terminal site. Plan for temporary dike along the alternate alignment if required to address sea level rise and climate change prior to implementation of a strategy at the Fraser River Terminal site.
Bridgeport Tait	Existing area generally redeveloped as a superdike scenario (elevation 4.7m). Future raisings to 5.5 m can take place on the existing alignments and integrate into the adjacent landscaping.
Industrial North East 1	Raise the dike on the existing alignment. Acquire the existing lots north of River Road to facilitate construction of a trapezoidal dike. A plan for temporary dike or flood wall adjacent to the waterfront lots may be required to address sea level rise and climate change prior to acquiring all required property.
Industrial North East 2	Raise the dike on the existing alignment. Additional studies required to quantify drainage, habitat impacts, and costs associated with land side expansion of a trapezoidal dike. A constrained land side slope may be required to integrate with the existing drainage infrastructure.
Industrial North East 3	Raise the dike on the existing alignment. Additional studies required to quantify drainage, habitat impacts, and costs associated with land side expansion of a trapezoidal dike. A constrained land side slope may be required to integrate with the existing drainage infrastructure.

6. Next Steps

Parsons has characterized the existing conditions and constraints of the study area, and recommended preferred regional and area specific adaptation measures for the City's consideration. Following receipt of additional City feedback, these adaptation measures will be further refined to establish the Draft Phase 2 Lulu Island Dike Master Plan document.

The recommended next steps in this study are:

1. Internal City Review;
2. Update Strategies per Stakeholder Feedback;
3. Council Review;
4. Agency Stakeholder Review;
5. Public Information Session and Consultation;
6. Final Master Plan Report; and
7. Council adoption of Final Master Plan Report.

7. Closure

We trust the information provided above provides sufficient details of the team's approach to identify, assess, and select the preferred concepts for the Phase 2 LIDMP. The preferred site specific and regional adaptation measures identified in this technical memorandum will form the basis for the Phase 2 LIDMP, establishing the flood protection strategy along the West and North Dikes within the Phase 2 study area.

Regards,

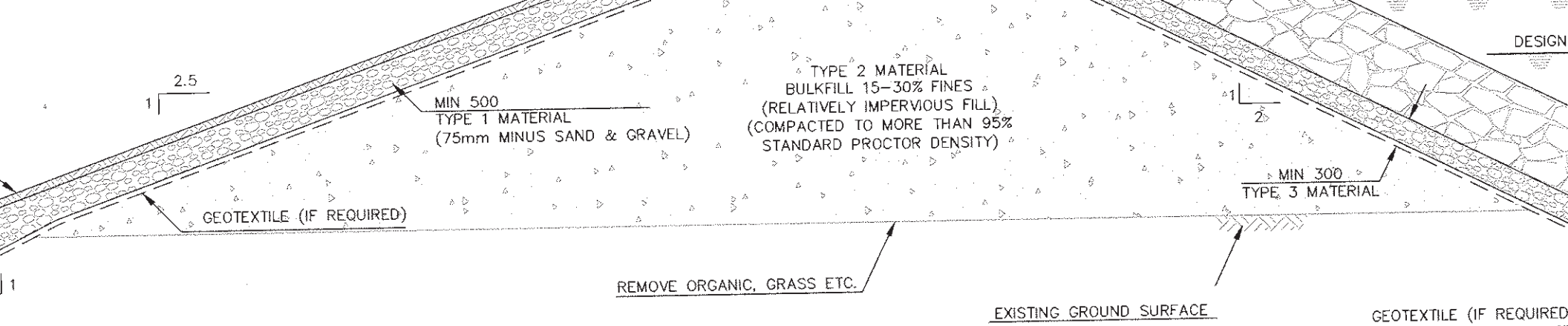
Evelyne Russell, EIT
Project Engineer

Reviewed By:

Todd Bowie, P.Eng
Project Manager

APPENDIX A

Typical Dike Sections



2 MATERIAL (BULK FILL)

2 material shall consist of well-graded sand with 15 percent fines passing the U.S. Standard No. 200 meeting the following gradation limits:

S STANDARD SIEVE SIZE	PERCENTAGE BY WEIGHT PASSING
3/4"	100
#4	80 to 100
#40	25 to 90
#100	18 to 50
#200	15 to 30

TYPE 3 MATERIAL (RIPRAP FILTER)

Type 3 material shall consist of well-graded pit-run or processed sand, gravel and cobbles, or quarried stone meeting the following gradation limits:

US STANDARD SIEVE SIZE	PERCENTAGE BY WEIGHT PASSING
8"	100
3"	60 to 90
3/8"	30 to 65
# 20	5 to 30
# 100	0 to 5

THE CITY OF RICHMOND
IS NOT RESPONSIBLE
FOR ERRORS NOR OMISSIONS

TYPE 4 MATERIAL (RUNNING SURFACE)

Type 4 material shall consist of a clean, well- 19mm minus sand and gravel or road mulch following gradation limits:

US STANDARD SIEVE SIZE	PERCENTAGE WEIGHT PASS
3/4"	100
1/2"	75 to 100
3/8"	60 to 90
#4	40 to 70
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#30	8 to 30
#50	5 to 20
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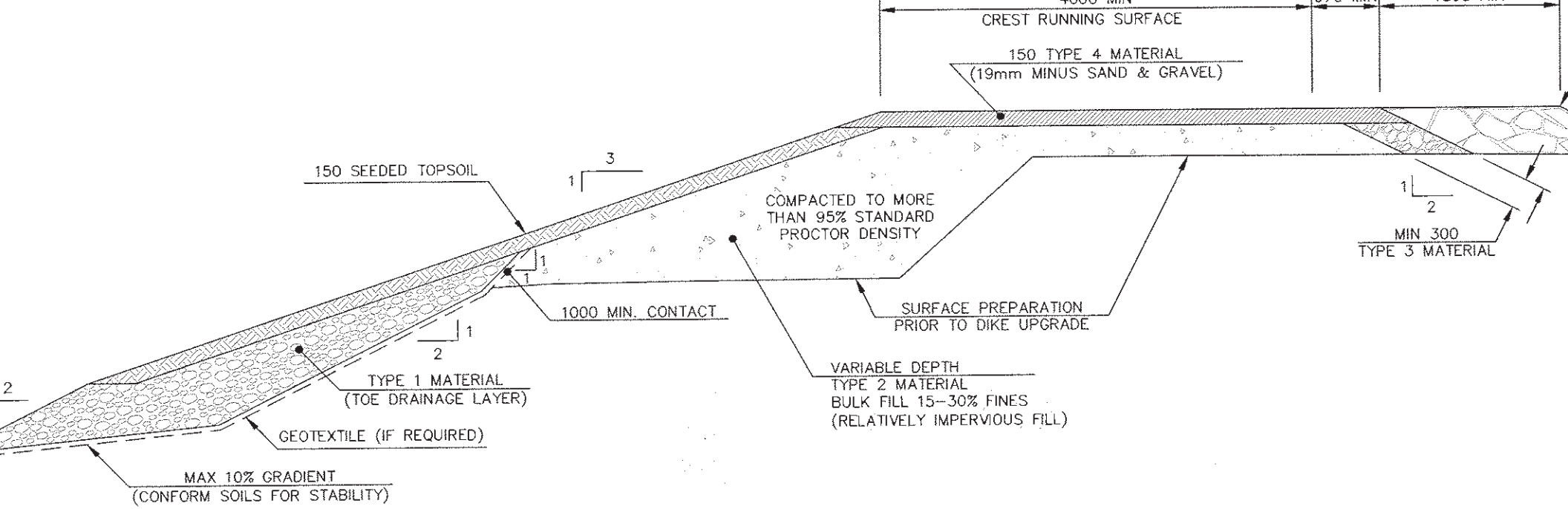

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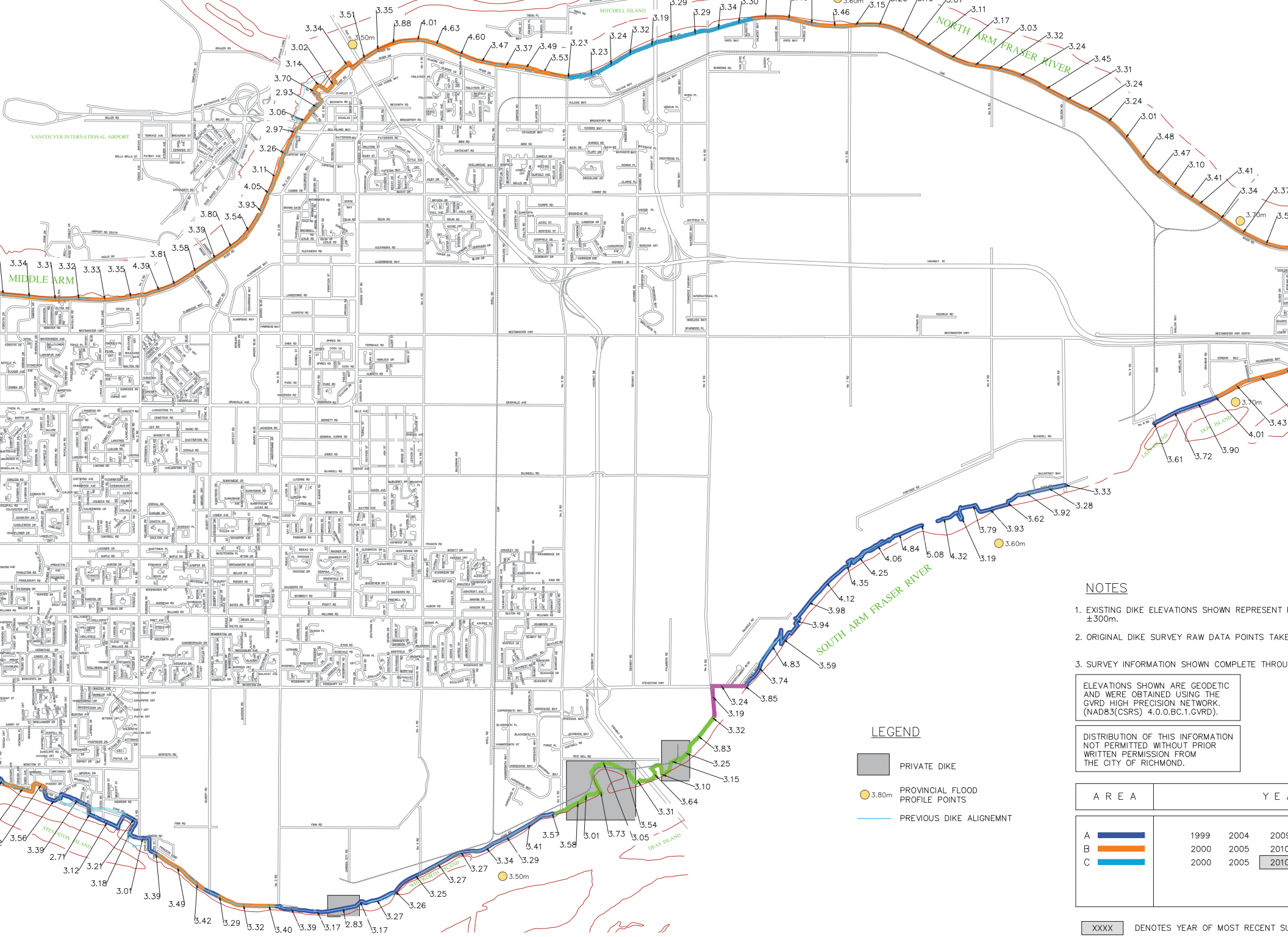
APPENDIX B

Existing Dike Alignment Plans



NOTES

1. EXISTING DIKE ELEVATIONS SHOWN REPRESENT I ±300m.
2. ORIGINAL DIKE SURVEY RAW DATA POINTS TAKE
3. SURVEY INFORMATION SHOWN COMPLETE THROU

ELEVATIONS SHOWN ARE GEODETIC AND WERE OBTAINED USING THE GVRD HIGH PRECISION NETWORK. (NAD83(CSRS) 4.0.0.BC.1.GVRD).

LEGEND

- PRIVATE DIKE
- 3.80m PROVINCIAL FLOOD PROFILE POINTS
- PREVIOUS DIKE ALIGNEMNT

AREA	YE
A	1999 2004 2009
B	2000 2005 201
C	2000 2005 2010

XXXX DENOTES YEAR OF MOST RECENT SU

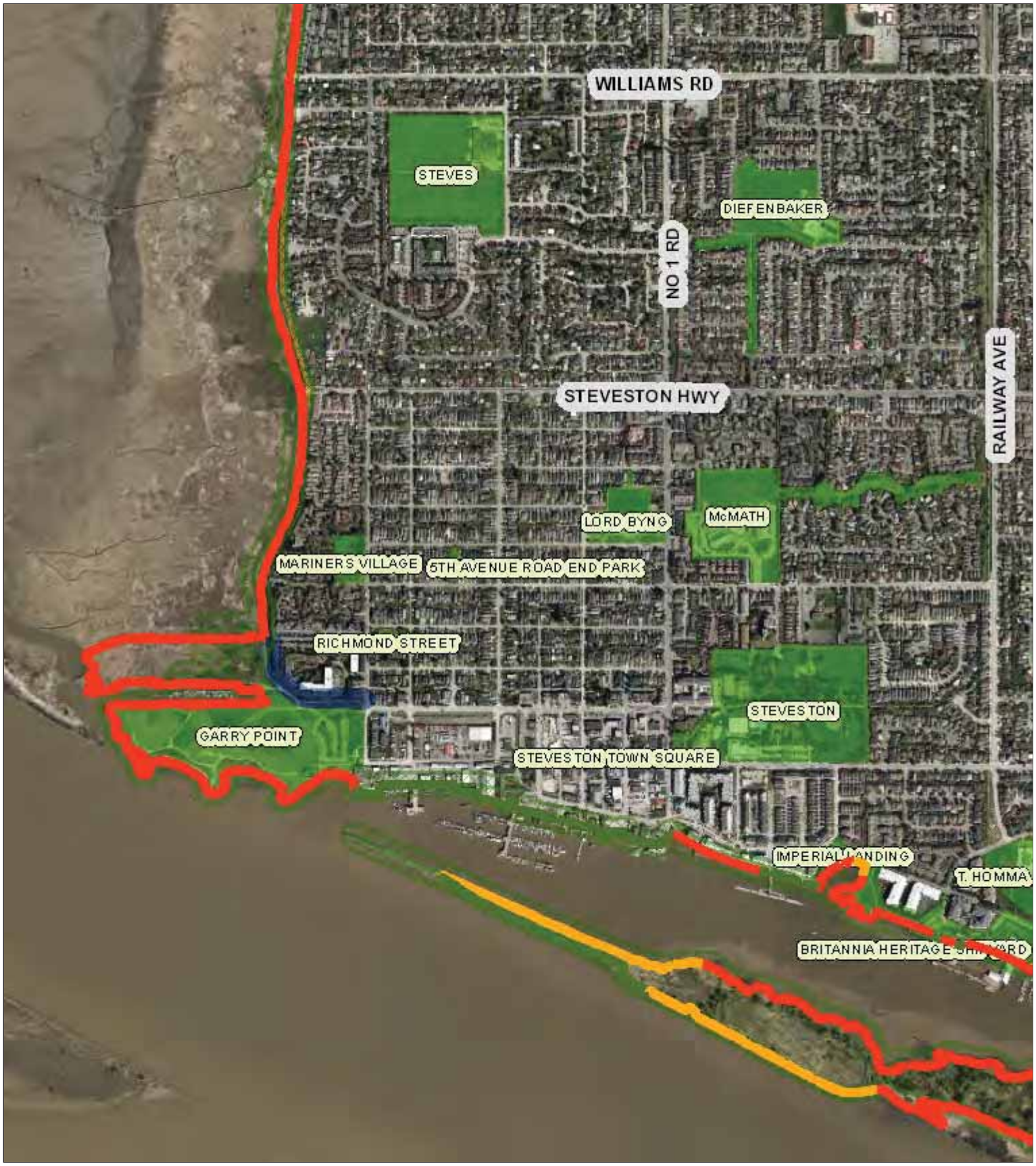
BENCHMARK

REFERENCE DRAWINGS

APPENDIX C

Environmental Constraint Maps

West Dike Steveston

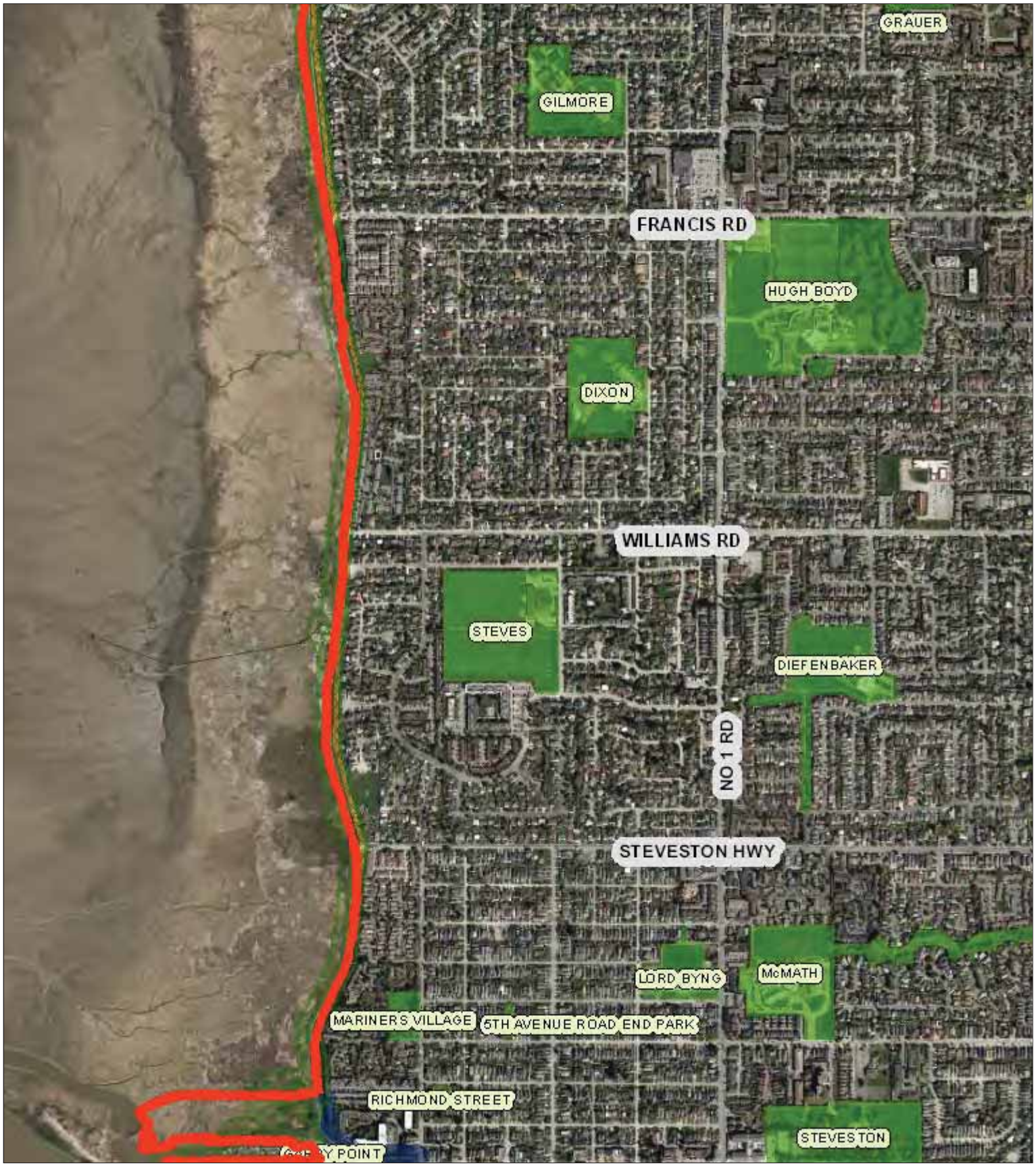


664.0 0 332.00 664.0 Meters

This map is a user generated static output from an Internet mapping site and is for reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable.

THIS MAP IS NOT TO BE USED FOR NAVIGATION

West Dike Williams Road



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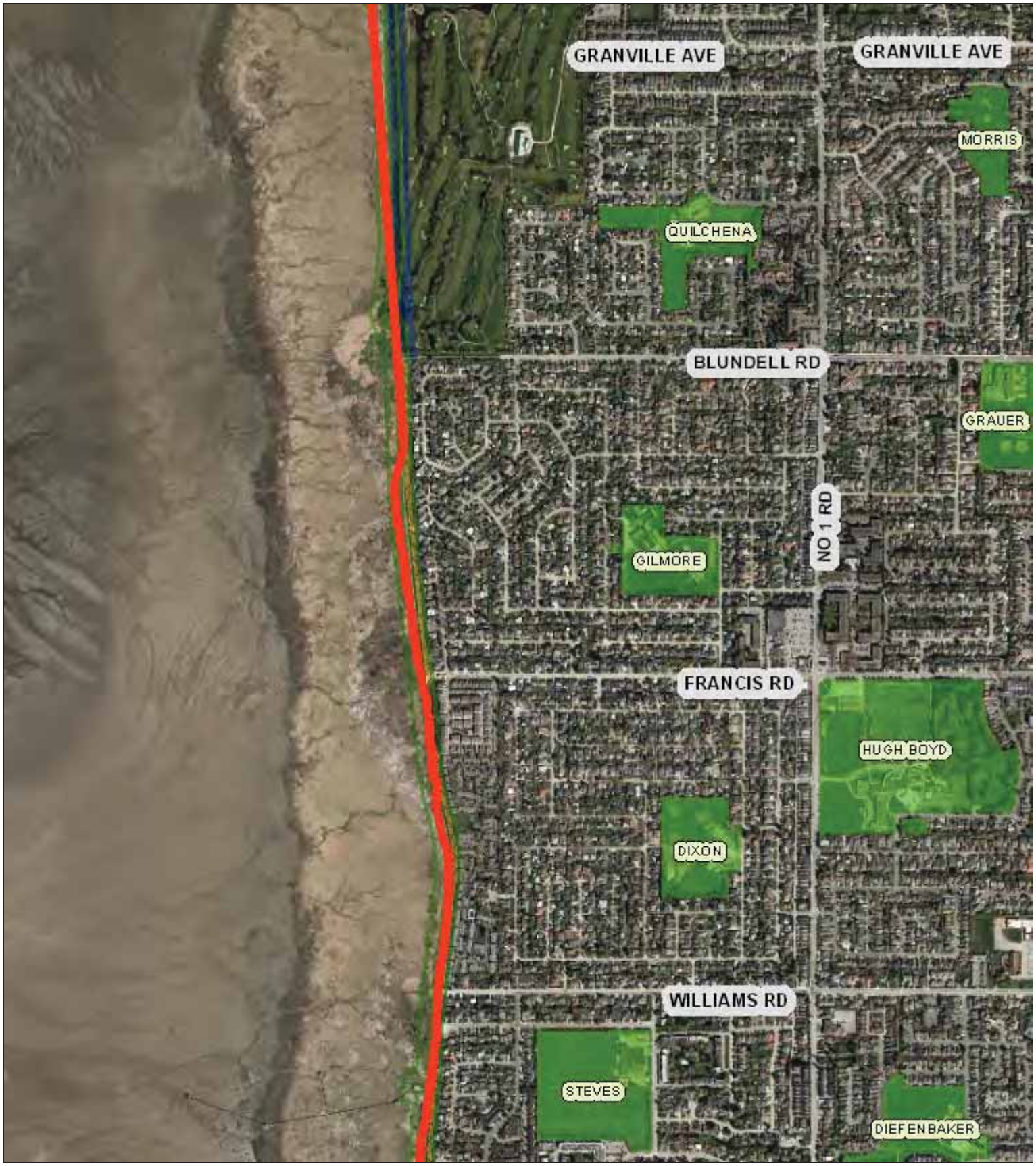
This map is a user generated static output from an Internet mapping site and is for reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable.

THIS MAP IS NOT TO BE USED FOR NAVIGATION

West Dike Francis Road



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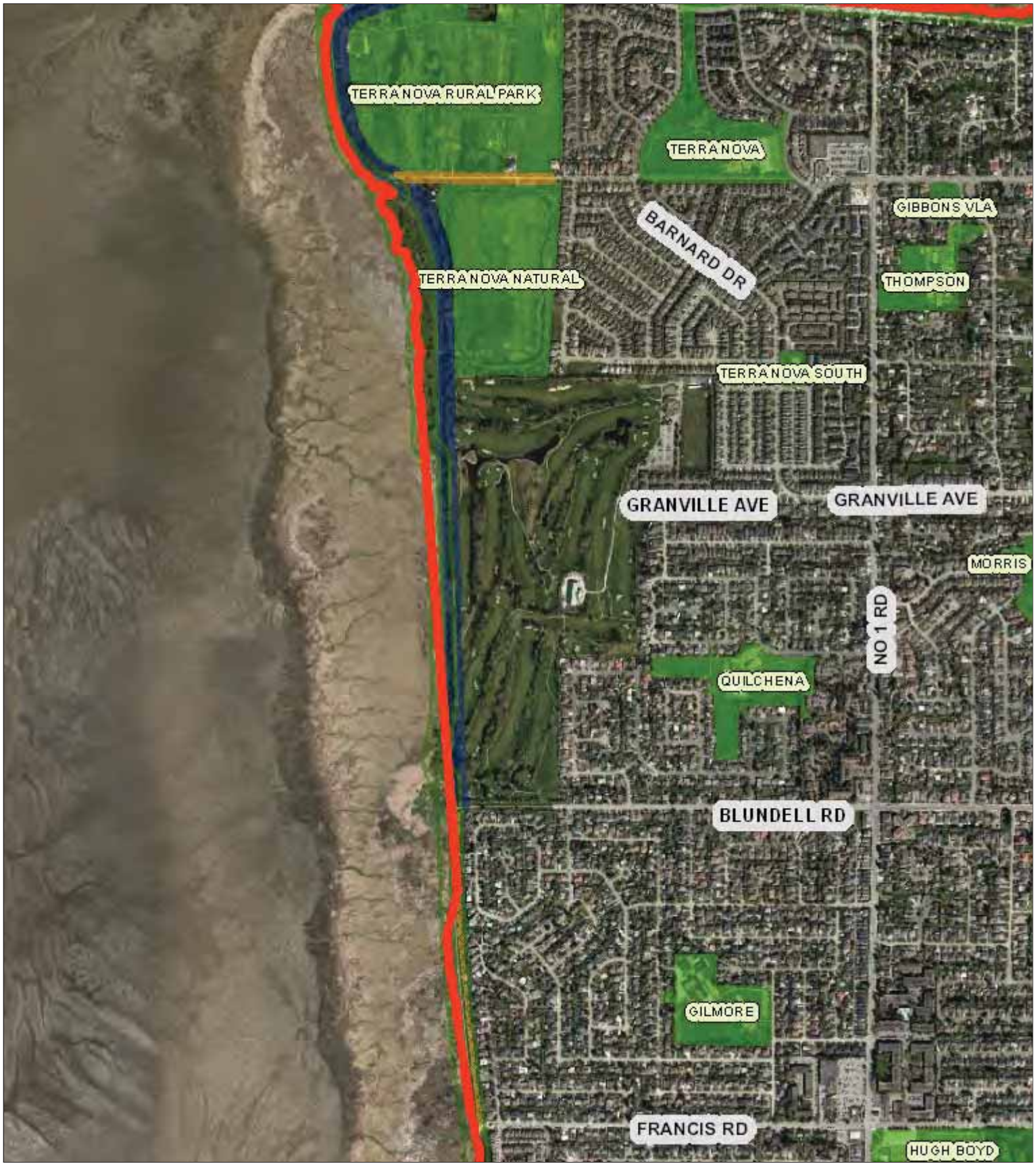
THIS MAP IS NOT TO BE USED FOR NAVIGATION

West Dike Granville Avenue



664.0 0 332.00 664.0 Meters

This map is a user generated static output from an Internet mapping site and is for reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable.

THIS MAP IS NOT TO BE USED FOR NAVIGATION

West Dike Terra Nova

664.0 0 332.00 664.0 Meters

This map is a user generated static output from an Internet mapping site and is for reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable.

THIS MAP IS NOT TO BE USED FOR NAVIGATION

North Dike Terra Nova

508.0 0 254.00 508.0 Meters

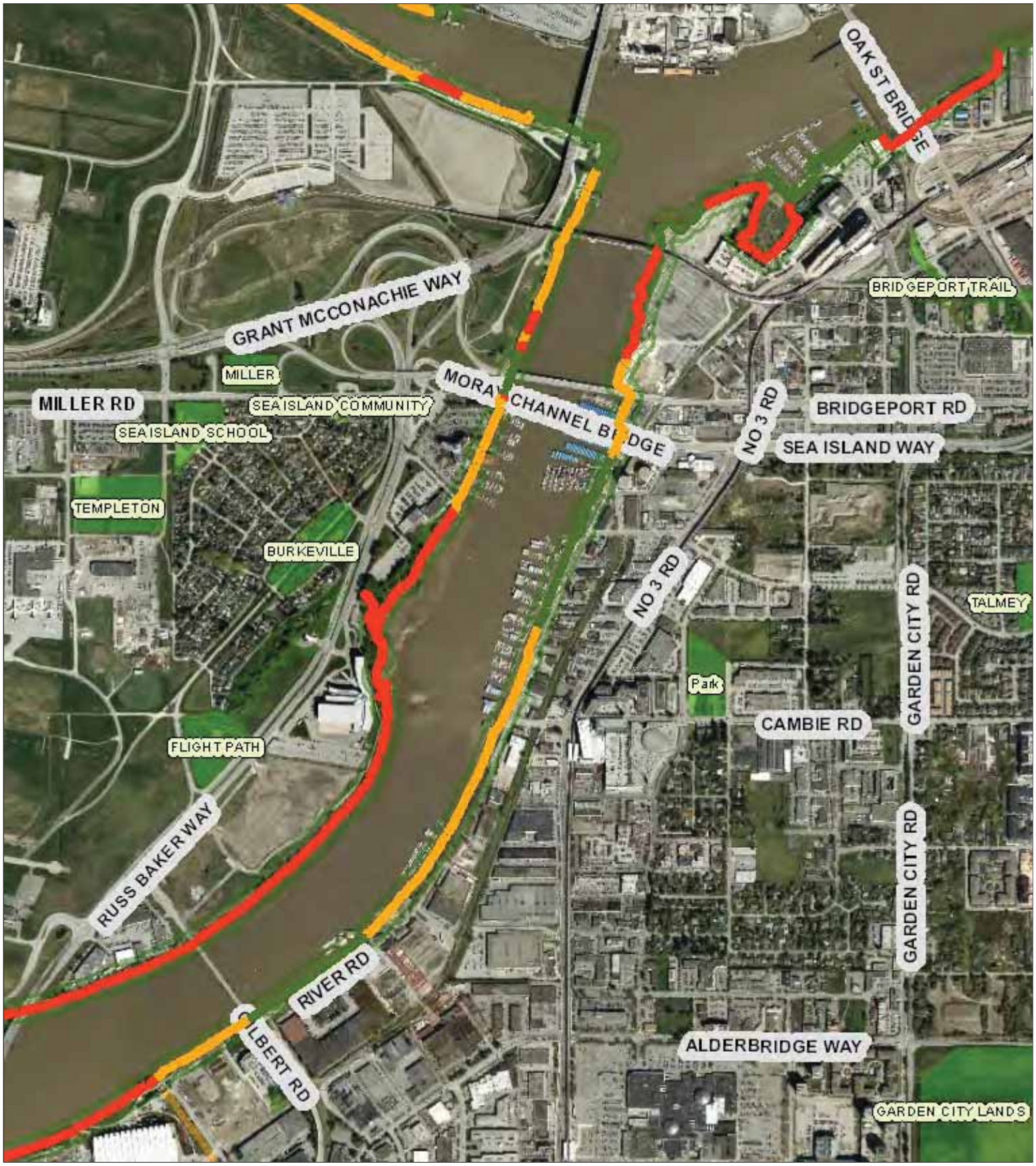
This map is a user generated static output from an Internet mapping site and is for reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable.

THIS MAP IS NOT TO BE USED FOR NAVIGATION

North Dike No 2 Road

508.0 0 254.00 508.0 Meters

North Dike Cambie road



664.0 0 332.00 664.0 Meters

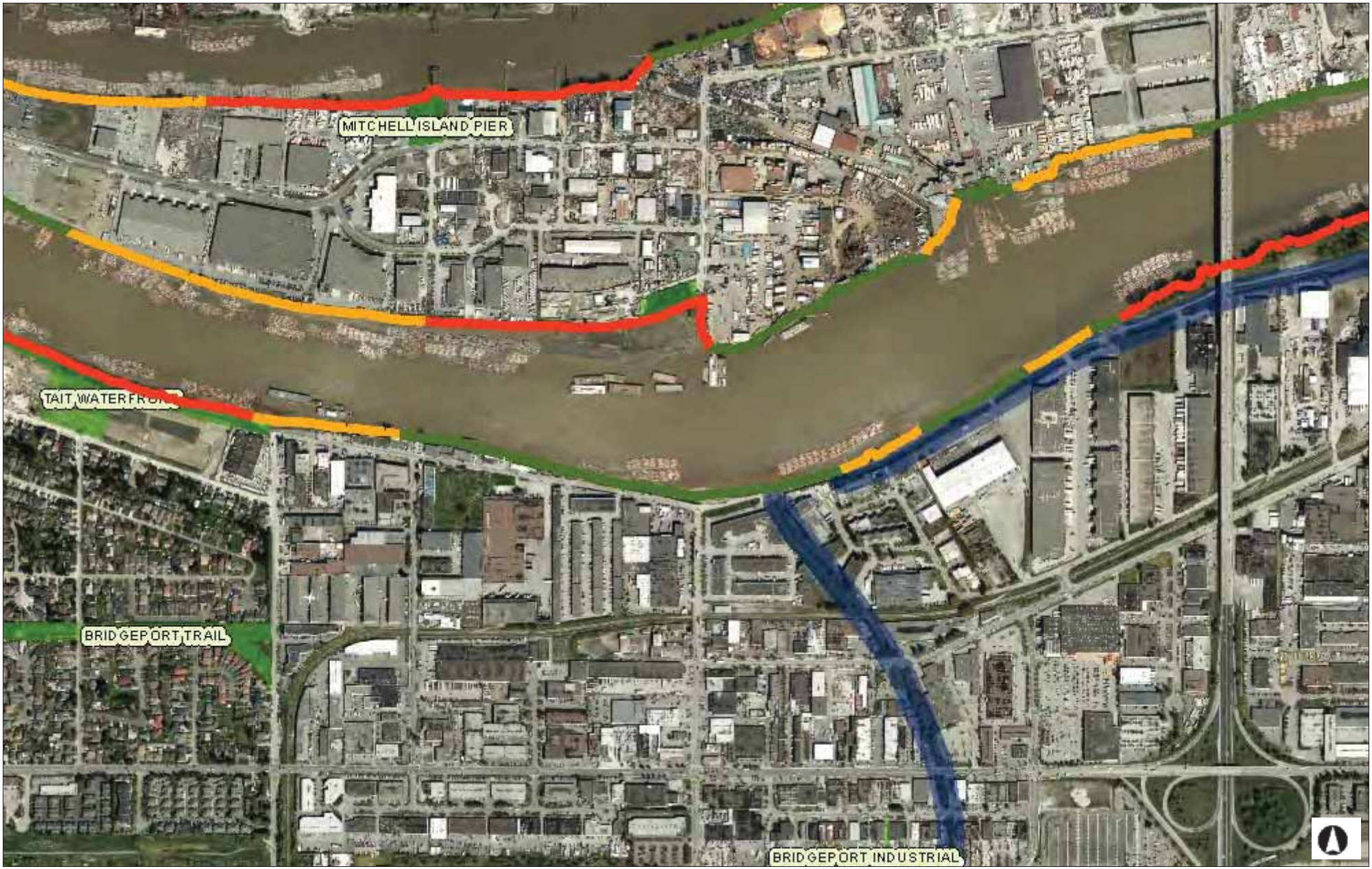
This map is a user generated static output from an Internet mapping site and is for reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable.

THIS MAP IS NOT TO BE USED FOR NAVIGATION

North Dike Oak Street

508.3 0 254.15 508.3 Meters

North Dike (Knight Sreet)



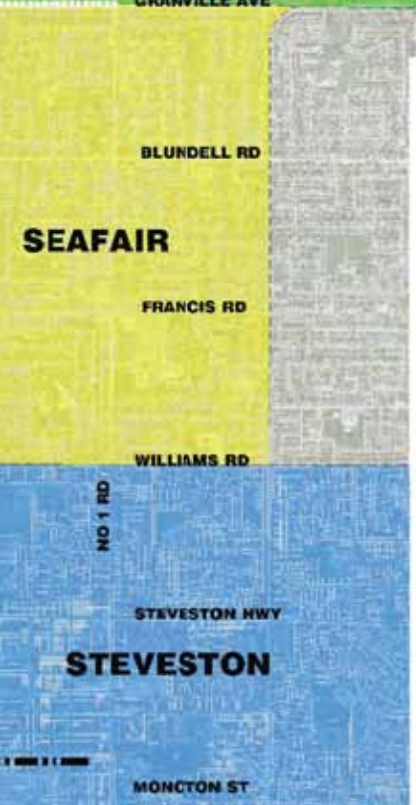
508.0 0 254.00 508.0 Meters

169.4 0 84.72 169.4 Meters

Appendix D

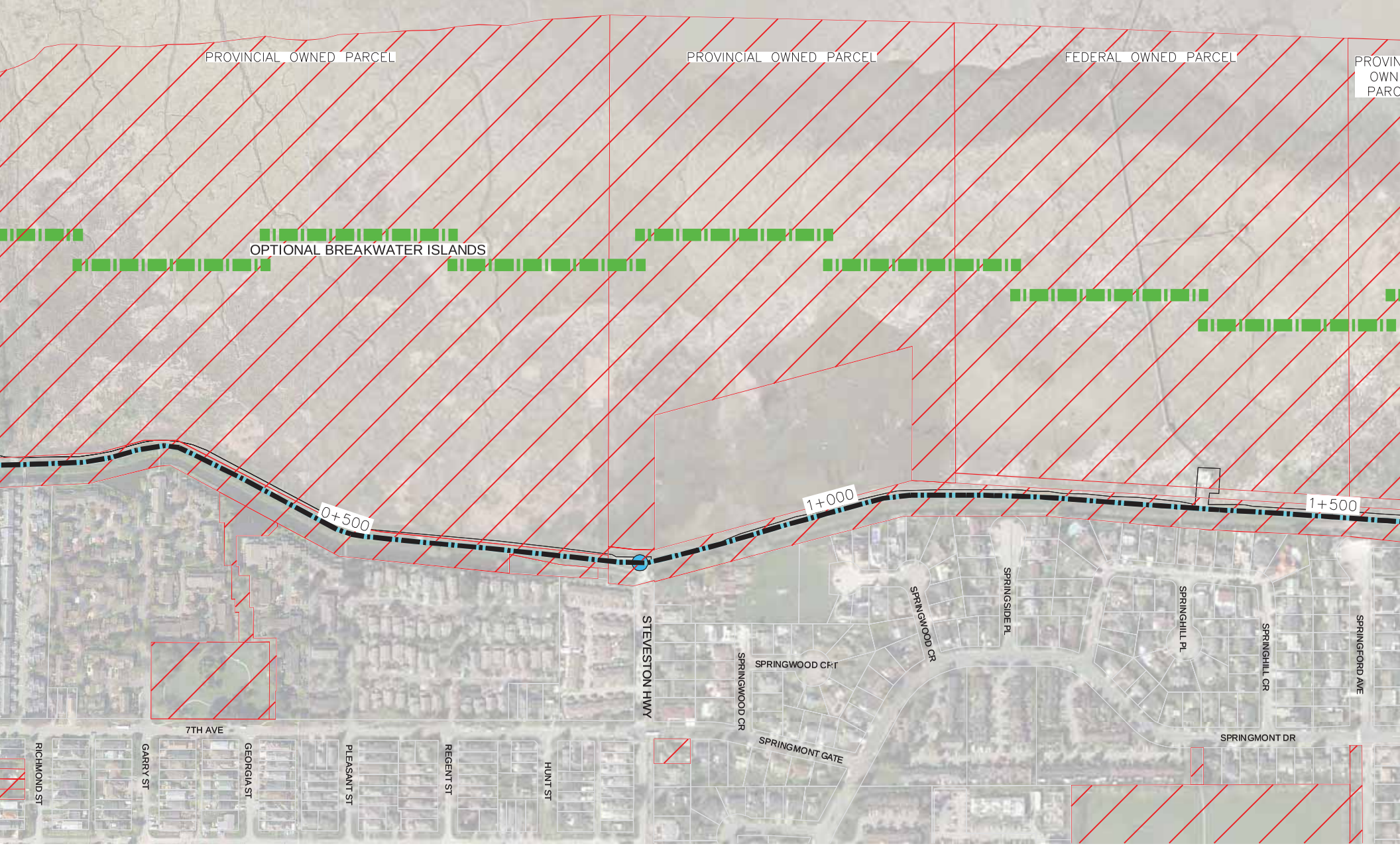
Preferred Dike Alignment Plans

KEY PLAN
N.T.S.



DESIGN AREAS	
SEGMENT	SEGMENT NAME
1A	WEST DIKE: STEVESTON
1B	WEST DIKE: SEAFAIR
2	WEST DIKE: TERRA NOVA
3	NORTH DIKE: THOMPSON TERRA NOVA
4	NORTH DIKE: THOMPSON DOVER
5	NORTH DIKE: OVAL
6	NORTH DIKE: CITY CENTRE 1
7	NORTH DIKE: CITY CENTRE 2
8	NORTH DIKE: DUCK ISLAND
9	NORTH DIKE: INDUSTRIAL
10	NORTH DIKE: BRIDGEPORT TAIT
11	NORTH DIKE: INDUSTRIAL NORTH EAST 1

Lulu Island Dike M
Flood P



KEY PLAN
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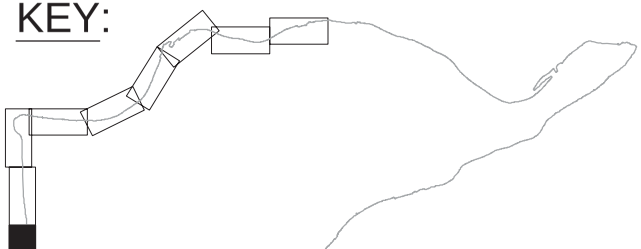
ND:

RED DIKE ALIGNMENT
ATE DIKE ALIGNMENT
PUMP STATION
GMENT

KEY:



Lulu Island Dike M

PARCEL

PROVINCIAL OWNED PARCEL

GRAUER LANDS HABI

GRAUER LAND

3+000

2+500

FRANCIS RD

FAIRFAX PL

FAIRDELL PL

FAIRDELL CR

SEAFAIR DR

FAIRFAX CR

FAIRWAY RD

FAIRLANE RD

FAIRHURST RD

WARDMORE PL

FAIRBROOK CR

NEWMORE AVE

BLUNDELL RD

WELLMOND RD

BARMOND AVE

OAKMOND RD

SALTSPRING CI

GABR

KEY PLAN
1: 5,000

SEAFAIR | WEST DIKE TERRA NOVA

ND:

RED DIKE ALIGNMENT

ATE DIKE ALIGNMENT

PUMP STATION

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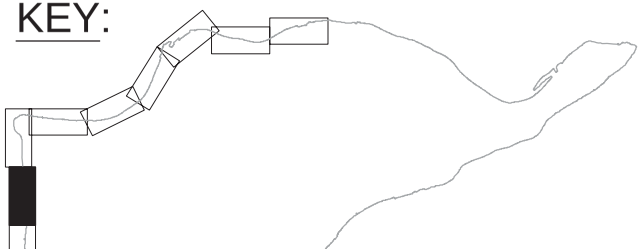

Lulu Island Dike M

AL WETLAND)

GRAUER LANDS HABITAT (TIDAL WETLAND)

m BUFFER)

GRAUER LANDS HABITAT (70m BUFFER)

+000

4+500

5+000

5+500

WESTMINSTER HWY

GRANVILLE A

SEMLIN DR

PEARKES DR

MUSGRAVE CR

KEY PLAN
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RED DIKE ALIGNMENT

ATE DIKE ALIGNMENT

PUMP STATION

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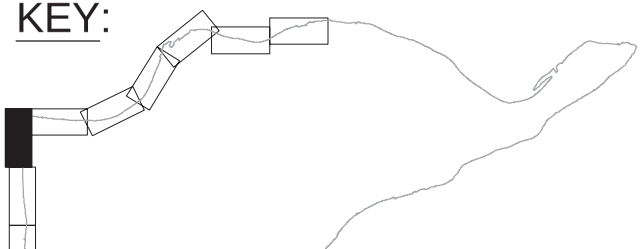

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THOMPSON TER

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ATE DIKE ALIGNMENT

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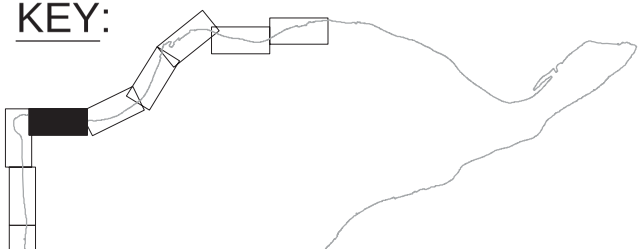

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RED DIKE ALIGNMENT
ATE DIKE ALIGNMENT
PUMP STATION
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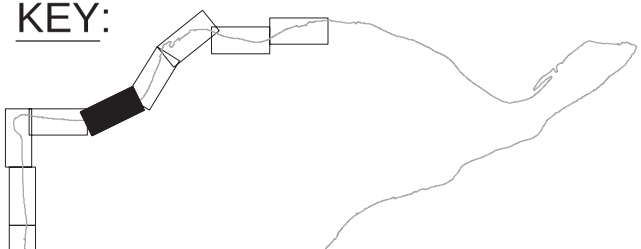

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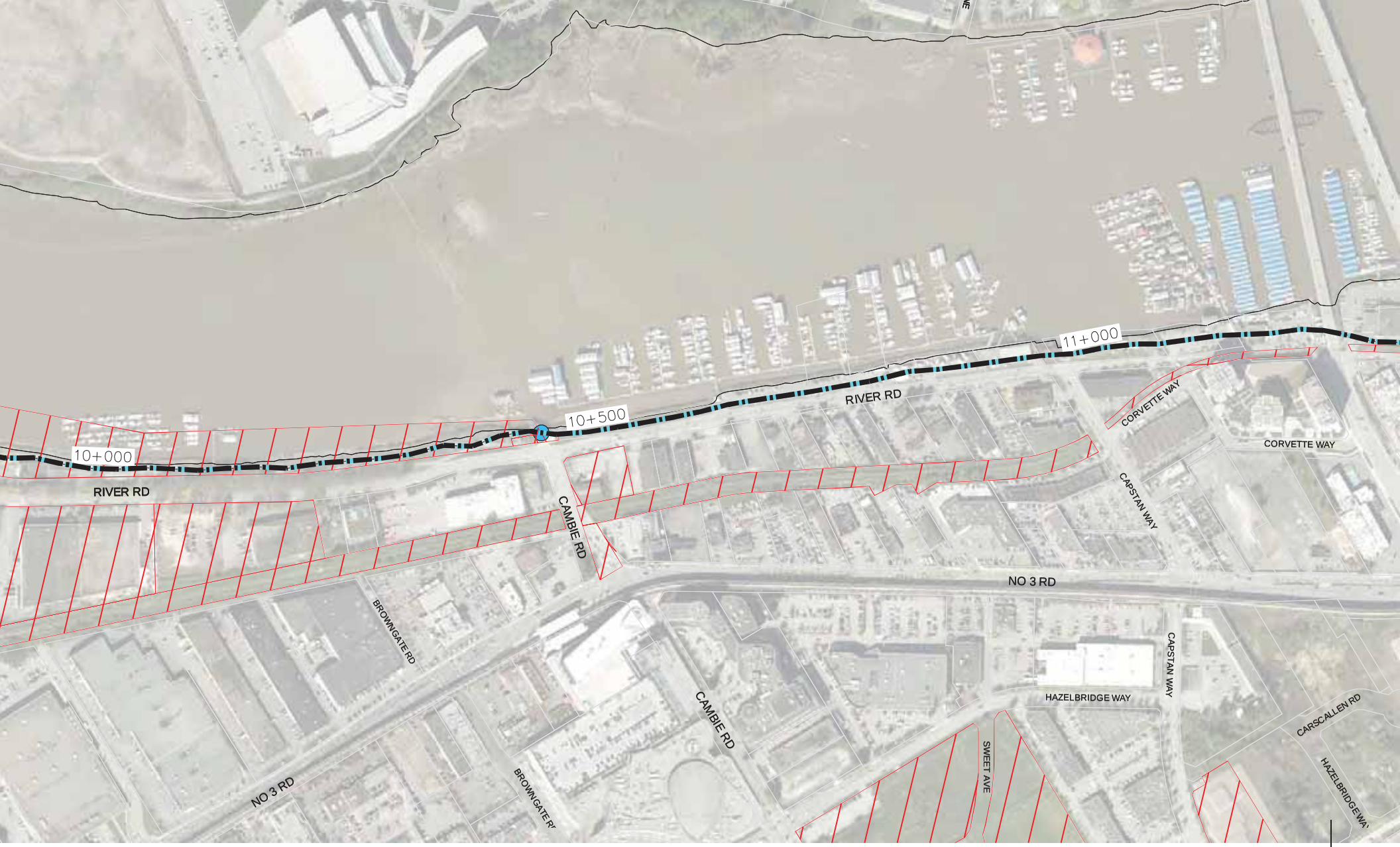

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ATE DIKE ALIGNMENT

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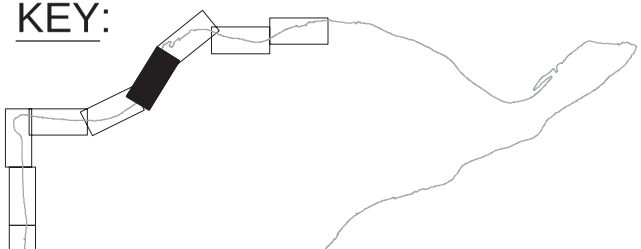

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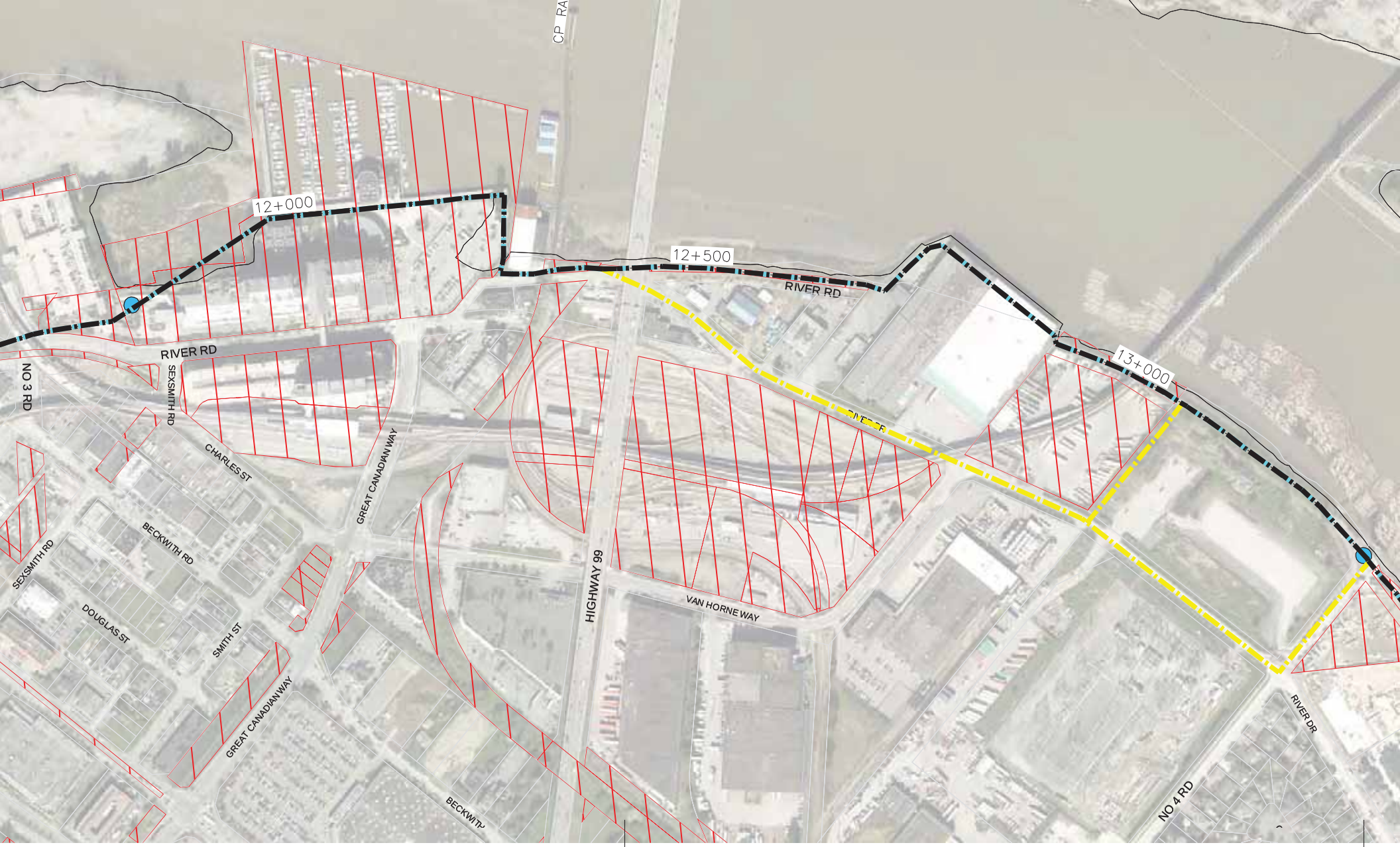

KEY PLAN
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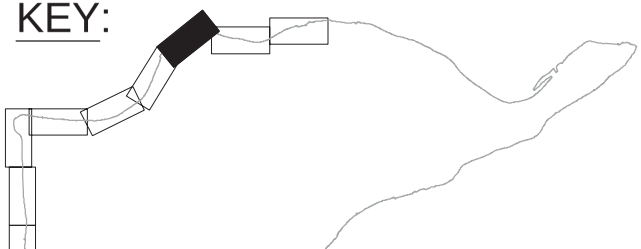
ND:

RED DIKE ALIGNMENT
ATE DIKE ALIGNMENT
PUMP STATION
GMENT

KEY:



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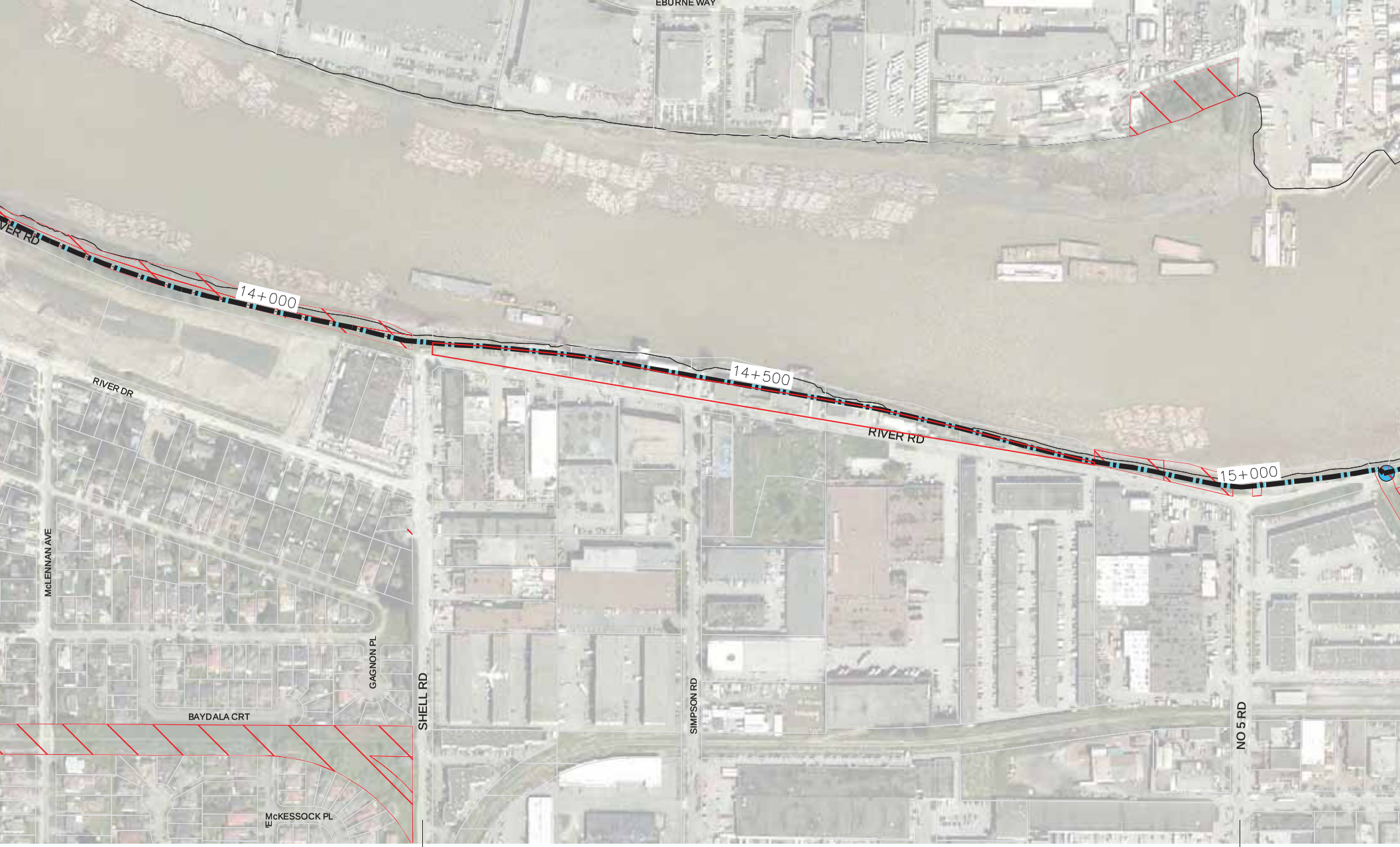

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PUMP STATION

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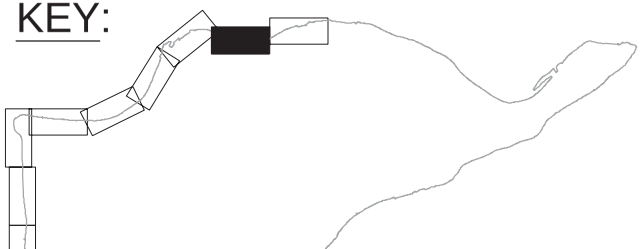

Lulu Island Dike M

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RED DIKE ALIGNMENT

ATE DIKE ALIGNMENT

PUMP STATION

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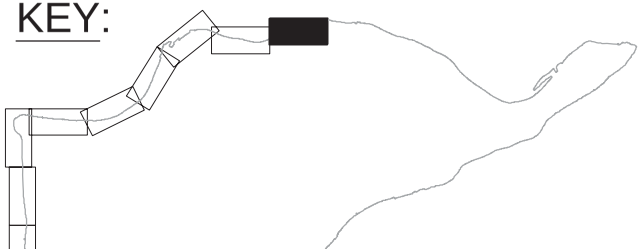
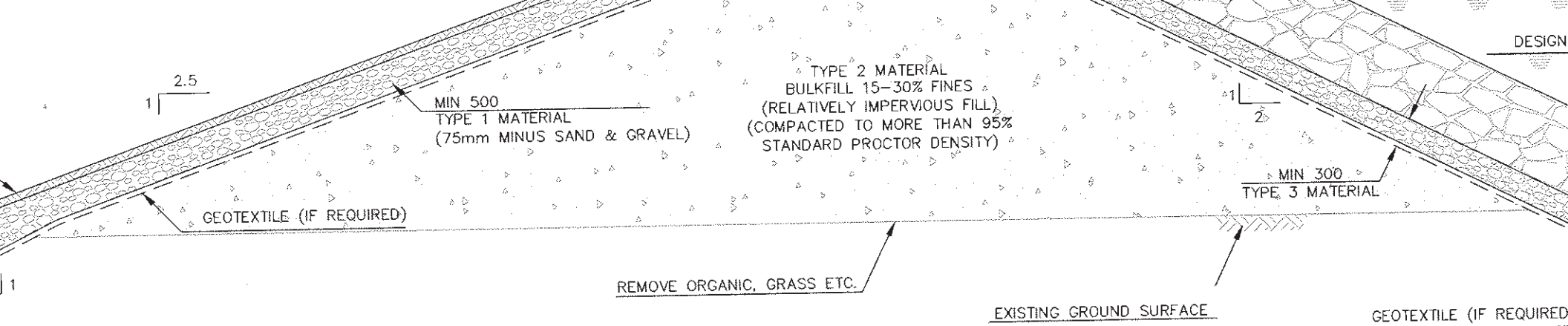


Lulu Island Dike M



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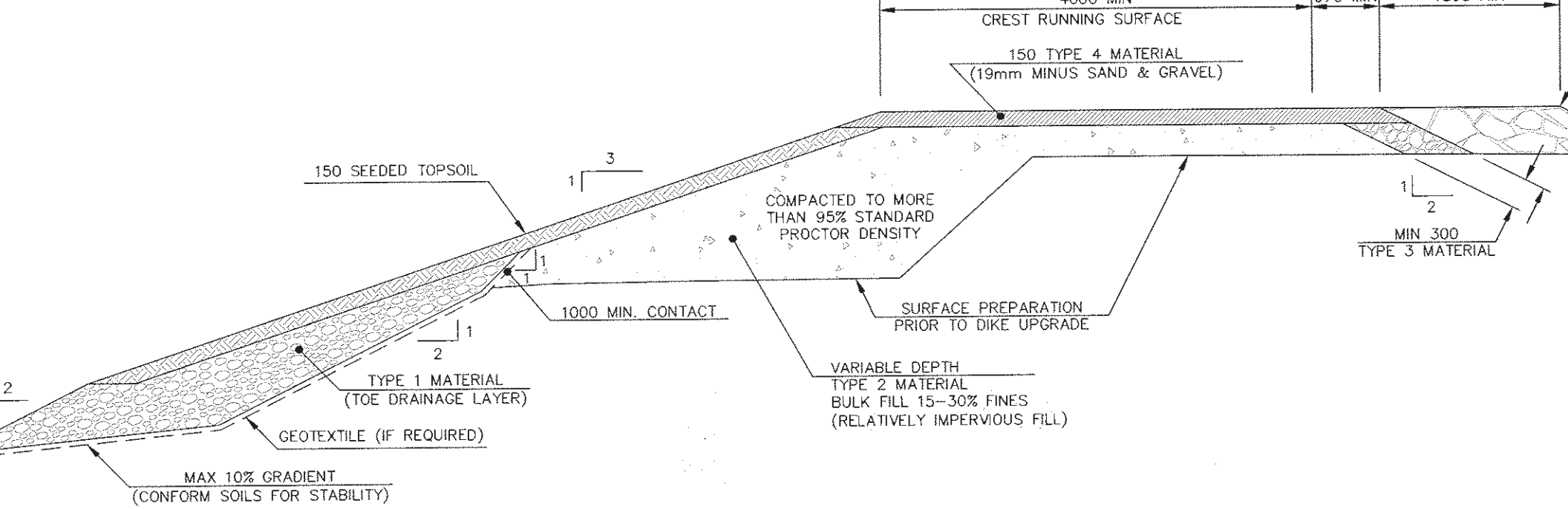

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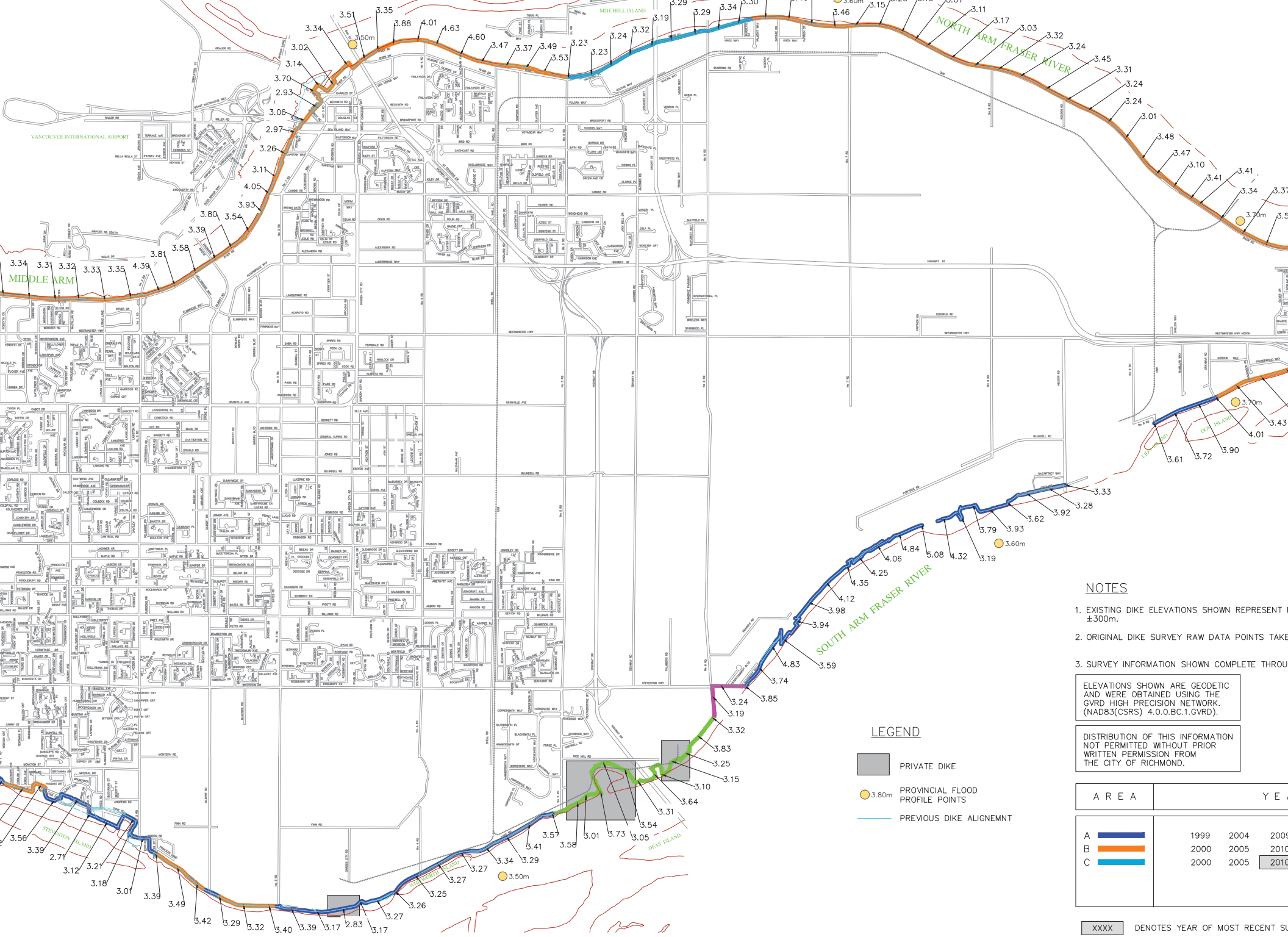
US STANDARD SIEVE SIZE	PERCENTAGE BY WEIGHT PASSING
8"	100
3"	60 to 90
3/8"	30 to 65
# 20	5 to 30
# 100	0 to 5

THE CITY OF RICHMOND
IS NOT RESPONSIBLE
FOR ERRORS NOR OMISSIONS

TYPE 4 MATERIAL (RUNNING SURFACE)

Type 4 material shall consist of a clean, well-g 19mm minus sand and gravel or road mulch n following gradation limits:

US STANDARD SIEVE SIZE	PERCENTAGE E WEIGHT PASSI
3/4"	100
1/2"	75 to 100
3/8"	60 to 90
#4	40 to 70
#8	27 to 55
#16	16 to 42
#30	8 to 30
#50	5 to 20
#200	2 to 8



NOTES

1. EXISTING DIKE ELEVATIONS SHOWN REPRESENT I ±300m.
2. ORIGINAL DIKE SURVEY RAW DATA POINTS TAKE
3. SURVEY INFORMATION SHOWN COMPLETE THROU

ELEVATIONS SHOWN ARE GEODETIC AND WERE OBTAINED USING THE GVRD HIGH PRECISION NETWORK. (NAD83(CSRS) 4.0.0.BC.1.GVRD).

LEGEND

- PRIVATE DIKE
- 3.80m PROVINCIAL FLOOD PROFILE POINTS
- PREVIOUS DIKE ALIGNEMNT

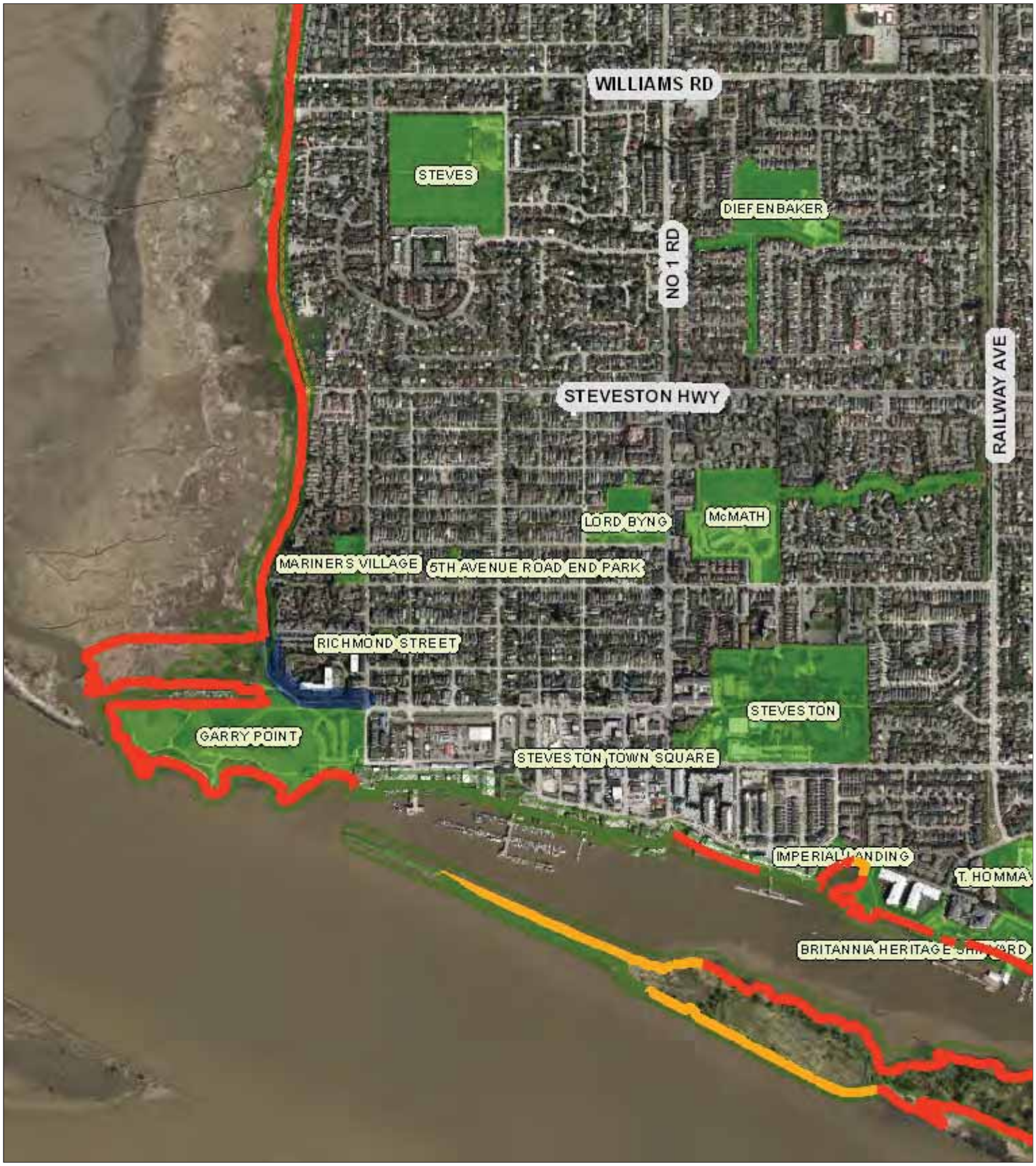
AREA	YE
A	1999 2004 2009
B	2000 2005 201
C	2000 2005 2010

XXXX DENOTES YEAR OF MOST RECENT SU

BENCHMARK

REFERENCE DRAWINGS

West Dike Steveston

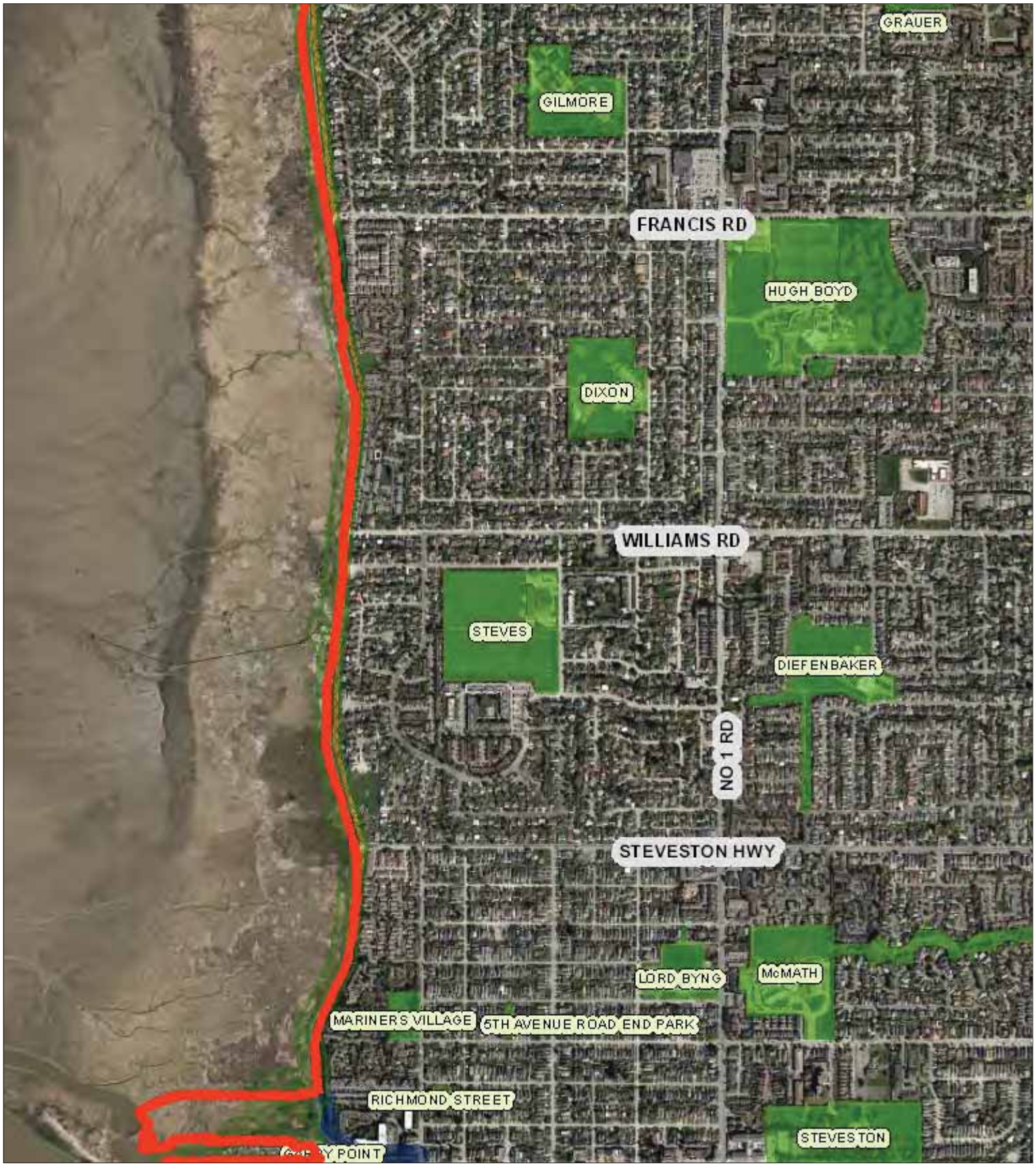


664.0 0 332.00 664.0 Meters

This map is a user generated static output from an Internet mapping site and is for reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable.

THIS MAP IS NOT TO BE USED FOR NAVIGATION

West Dike Williams Road



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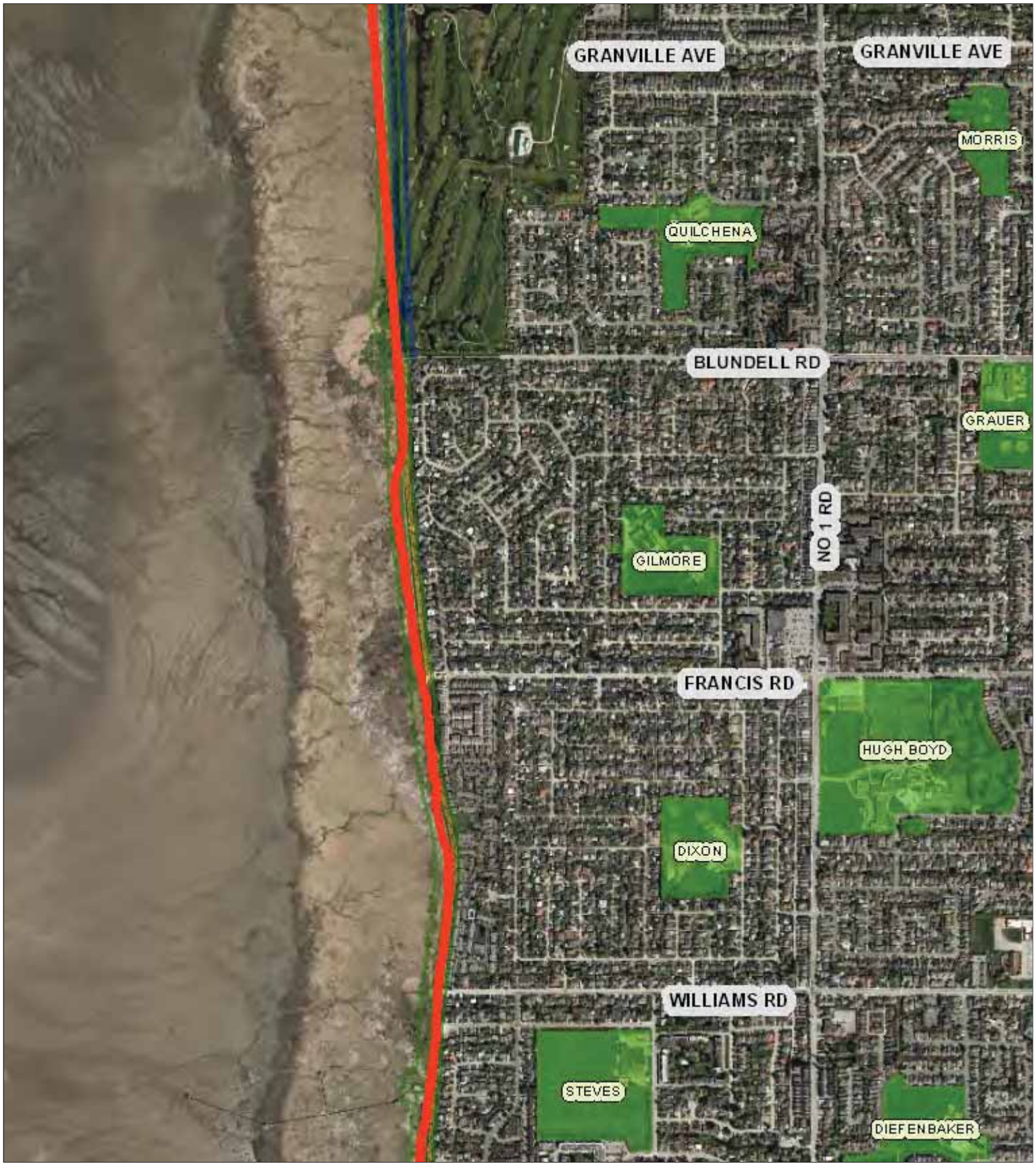
THIS MAP IS NOT TO BE USED FOR NAVIGATION

West Dike Francis Road



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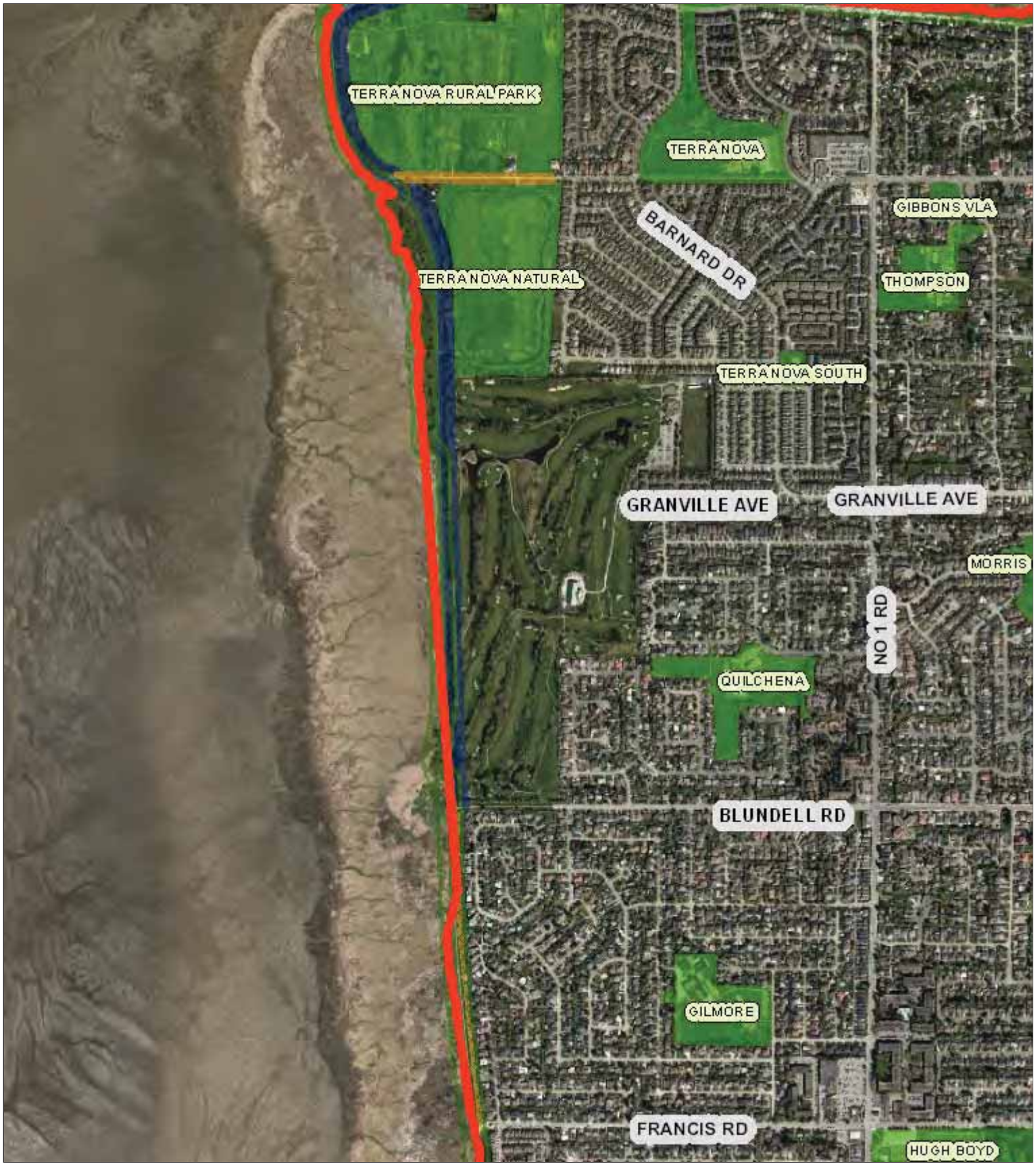
THIS MAP IS NOT TO BE USED FOR NAVIGATION

West Dike Granville Avenue



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This map is a user generated static output from an Internet mapping site and is for reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable.

THIS MAP IS NOT TO BE USED FOR NAVIGATION

West Dike Terra Nova

664.0 0 332.00 664.0 Meters

This map is a user generated static output from an Internet mapping site and is for reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable.

THIS MAP IS NOT TO BE USED FOR NAVIGATION

North Dike Terra Nova

508.0 0 254.00 508.0 Meters

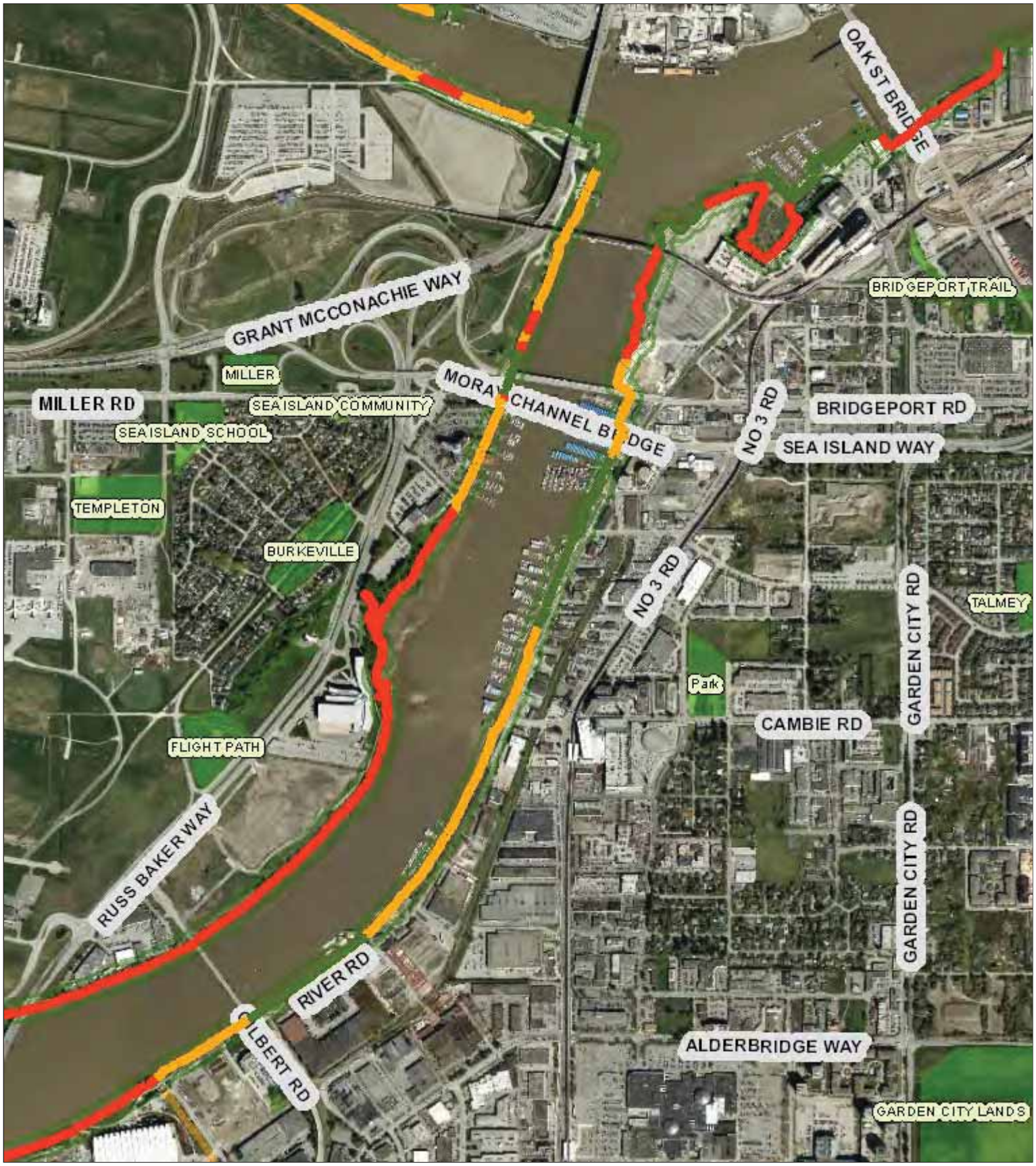
This map is a user generated static output from an Internet mapping site and is for reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable.

THIS MAP IS NOT TO BE USED FOR NAVIGATION

North Dike No 2 Road

508.0 0 254.00 508.0 Meters

North Dike Cambie road



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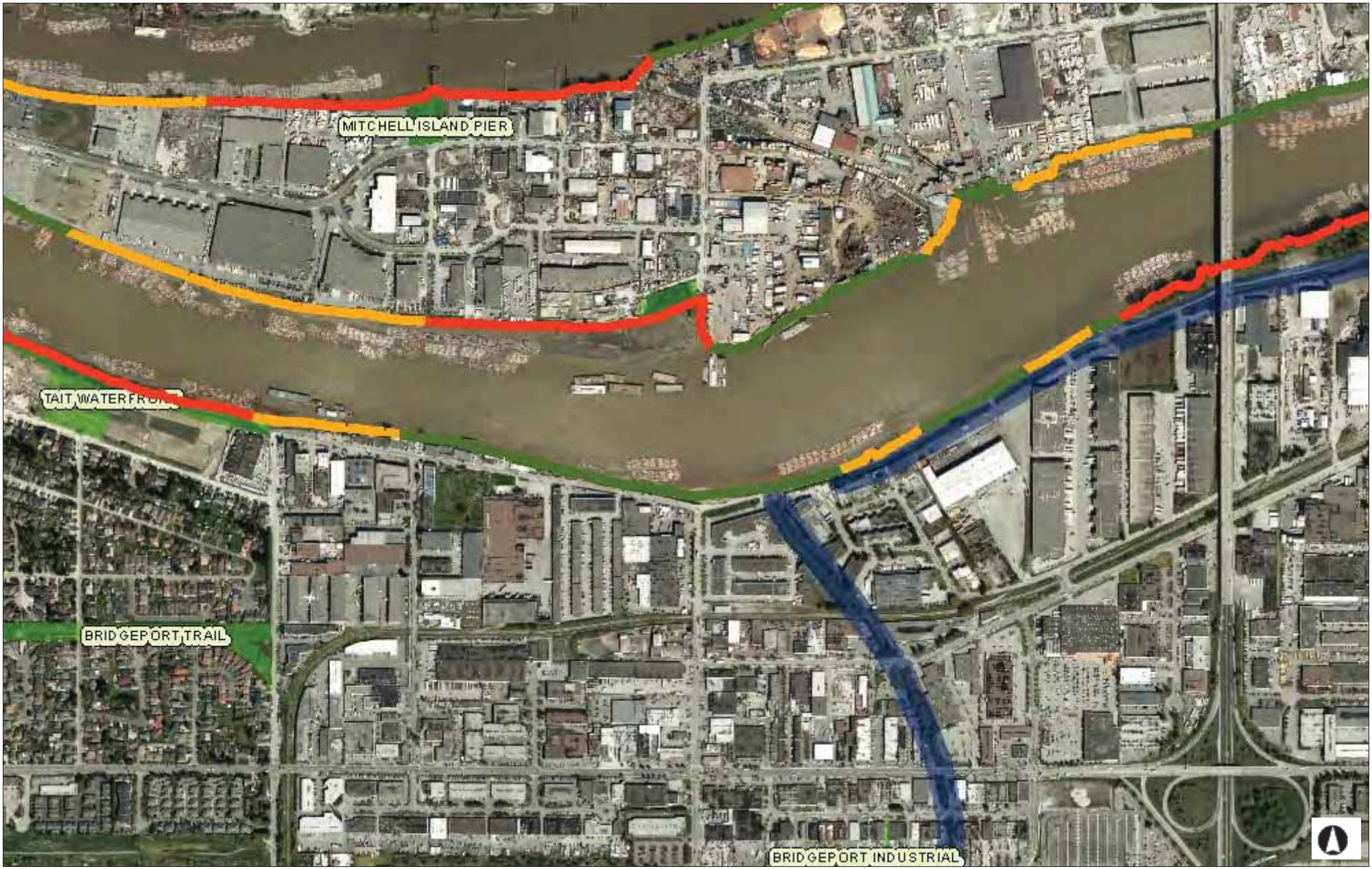
This map is a user generated static output from an Internet mapping site and is for reference only. Data layers that appear on this map may or may not be accurate, current, or otherwise reliable.

THIS MAP IS NOT TO BE USED FOR NAVIGATION

North Dike Oak Street

508.3 0 254.15 508.3 Meters

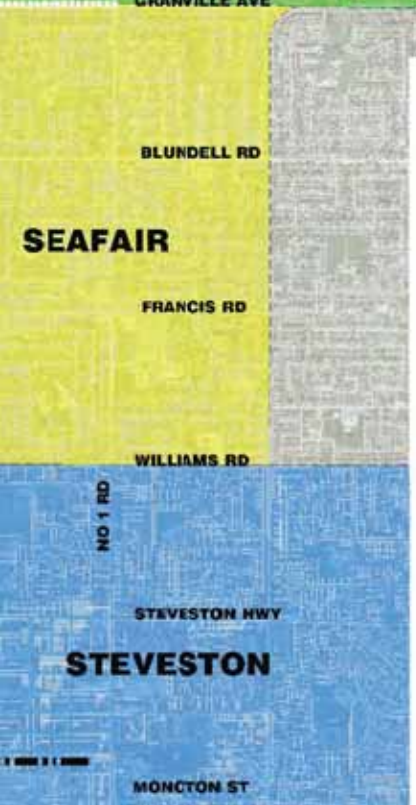
North Dike (Knight Sreet)



508.0 0 254.00 508.0 Meters

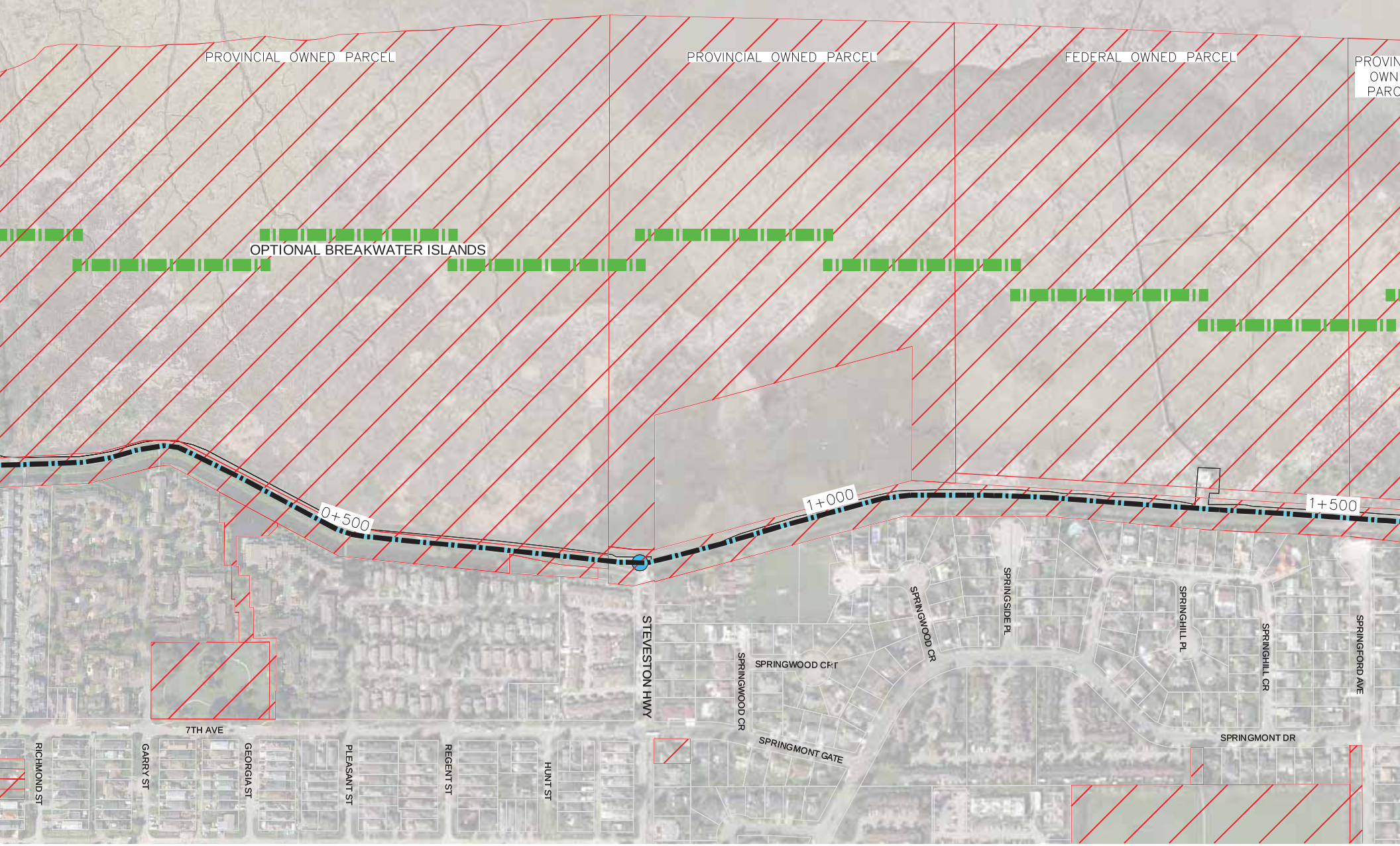
169.4 0 84.72 169.4 Meters

KEY PLAN
N.T.S.



DESIGN AREAS	
SEGMENT	SEGMENT NAME
1A	WEST DIKE: STEVESTON
1B	WEST DIKE: SEAFAIR
2	WEST DIKE: TERRA NOVA
3	NORTH DIKE: THOMPSON TERRA NOVA
4	NORTH DIKE: THOMPSON DOVER
5	NORTH DIKE: OVAL
6	NORTH DIKE: CITY CENTRE 1
7	NORTH DIKE: CITY CENTRE 2
8	NORTH DIKE: DUCK ISLAND
9	NORTH DIKE: INDUSTRIAL
10	NORTH DIKE: BRIDGEPORT TAIT
11	NORTH DIKE: INDUSTRIAL NORTH EAST 1

Lulu Island Dike M
Flood P



KEY PLAN
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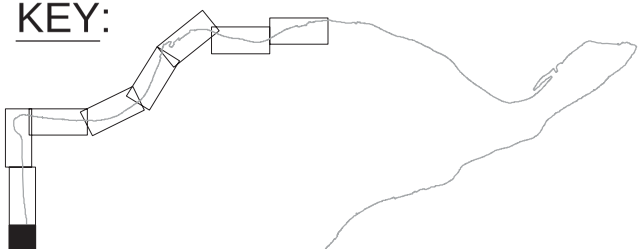
ND:

RED DIKE ALIGNMENT
ATE DIKE ALIGNMENT
PUMP STATION
GMENT

KEY:



Lulu Island Dike M

PARCEL

PROVINCIAL OWNED PARCEL

GRAUER LANDS HABI

GRAUER LAND

3+000

2+500

FRANCIS RD

FAIRFAX PL

FAIRDELL PL

FAIRDELL CR

SEAFAIR DR

FAIRFAX CR

FAIRWAY RD

FAIRLANE RD

FAIRHURST RD

WARDMORE PL

FAIRBROOK CR

NEWMORE AVE

BLUNDELL RD

WELLMOND RD

BARMOND AVE

OAKMOND RD

SALTSPRING CI

GABR

KEY PLAN
1: 5,000

SEAFAIR | WEST DIKE TERRA NOVA

ND:

RED DIKE ALIGNMENT

ATE DIKE ALIGNMENT

PUMP STATION

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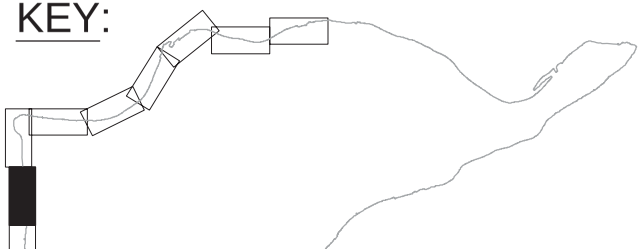

Lulu Island Dike M

AL WETLAND)

GRAUER LANDS HABITAT (TIDAL WETLAND)

m BUFFER)

GRAUER LANDS HABITAT (70m BUFFER)

+000

4+500

5+000

5+500

WESTMINSTER HWY

GRANVILLE A

SEMLIN DR

PEARKES DR

MUSGRAVE CR

KEY PLAN
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ND:

RED DIKE ALIGNMENT

ATE DIKE ALIGNMENT

PUMP STATION

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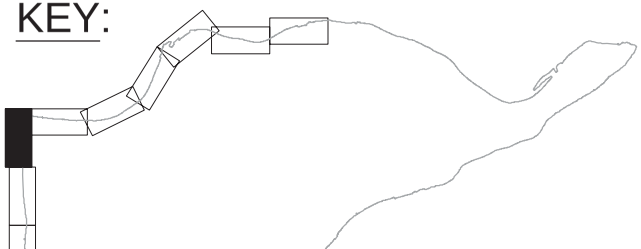

Lulu Island Dike M

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THOMPSON TER

ND:

RED DIKE ALIGNMENT

ATE DIKE ALIGNMENT

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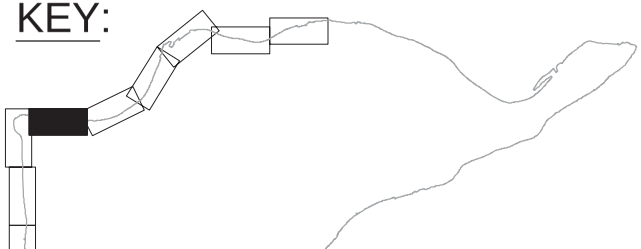

Lulu Island Dike M

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ATE DIKE ALIGNMENT
PUMP STATION
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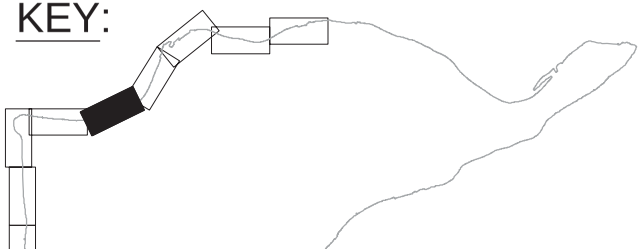

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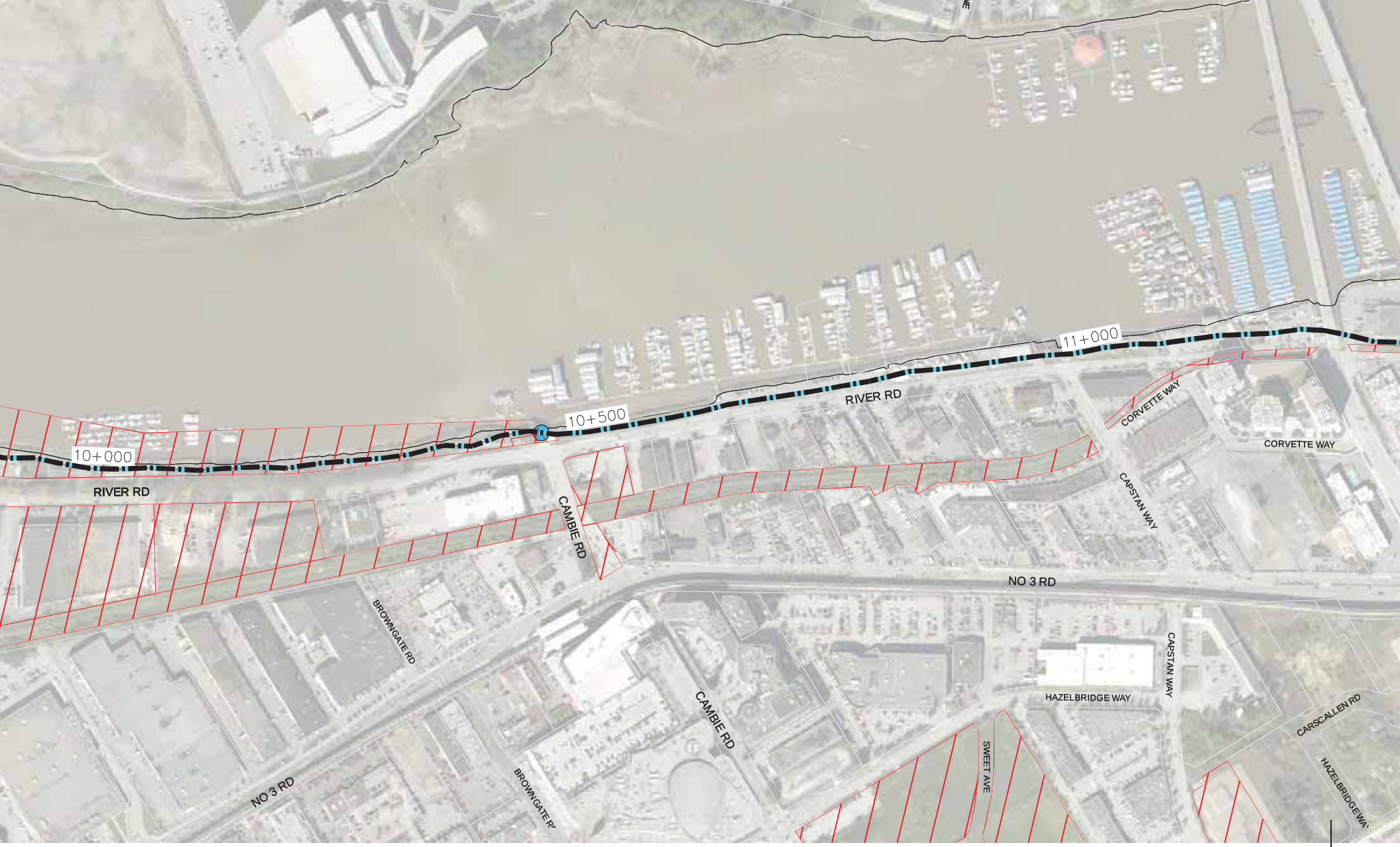

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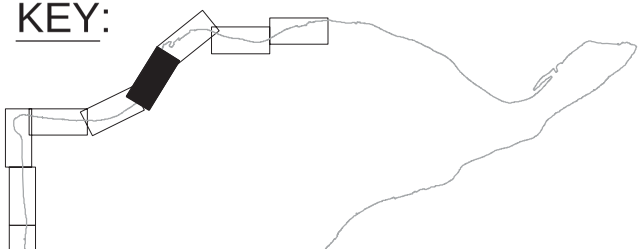

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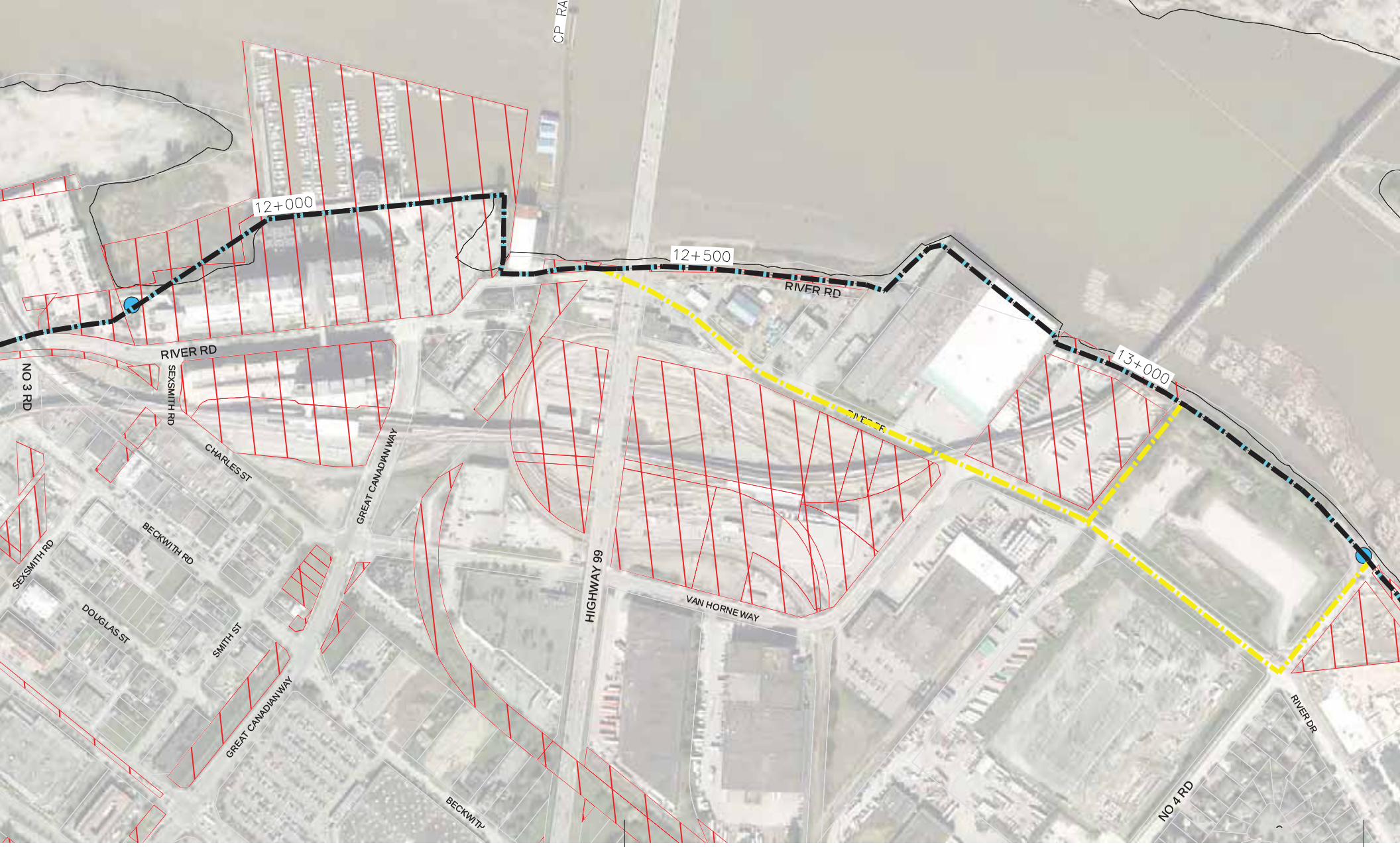

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RED DIKE ALIGNMENT
ATE DIKE ALIGNMENT
PUMP STATION
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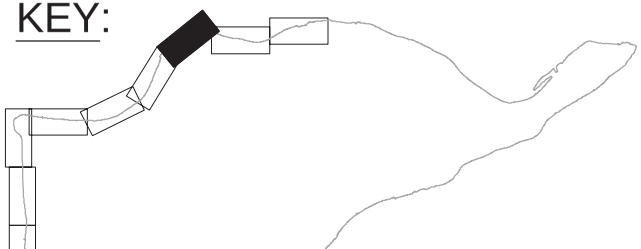

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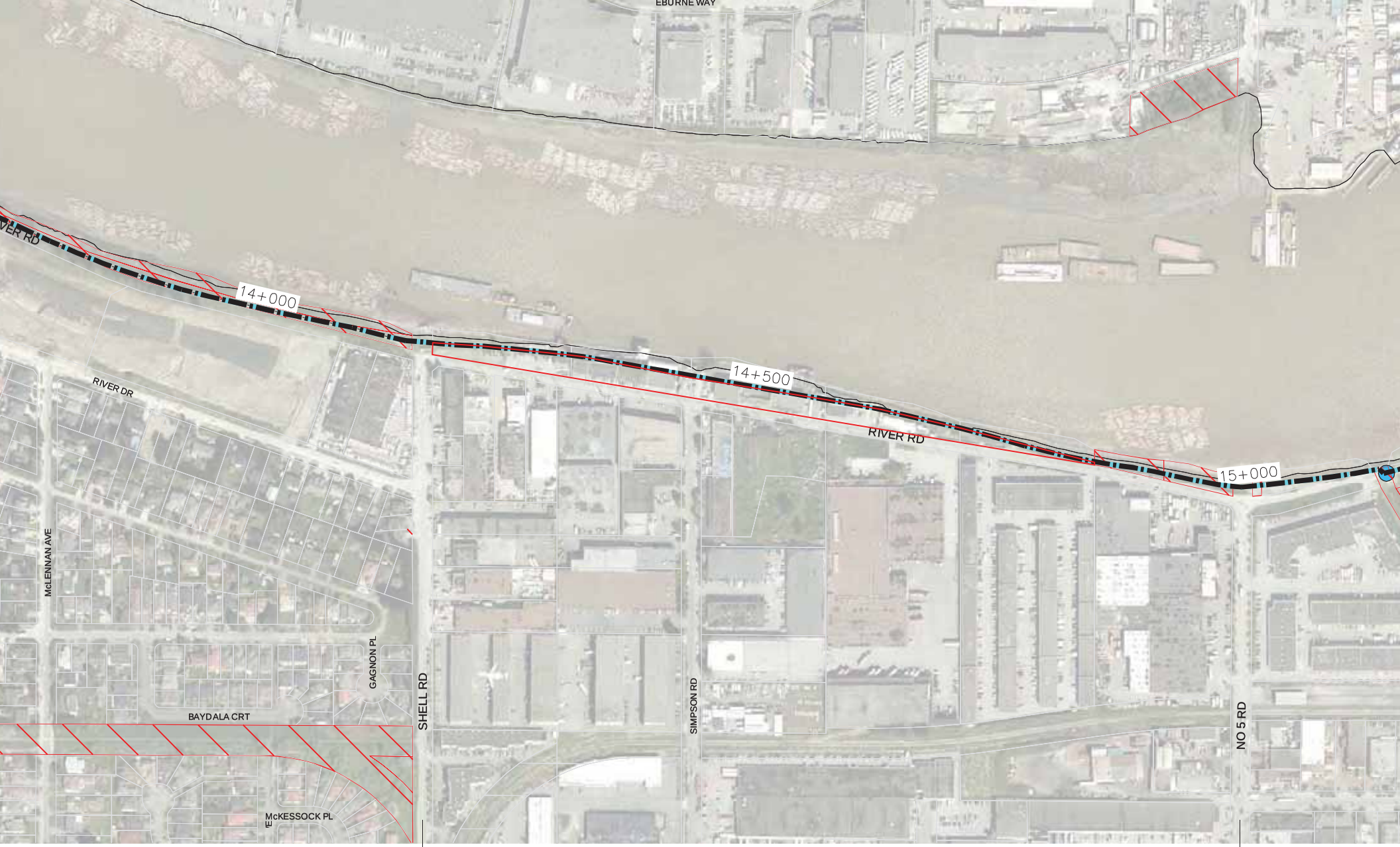

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ATE DIKE ALIGNMENT

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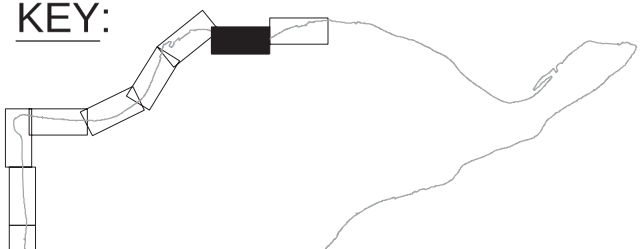

Lulu Island Dike M

KEY PLAN
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RED DIKE ALIGNMENT

ATE DIKE ALIGNMENT

PUMP STATION

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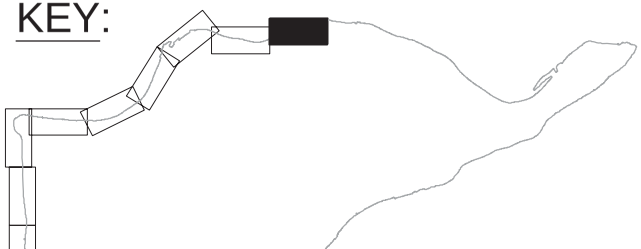


Lulu Island Dike M

Attachment 3

Geotechnical Input Memo - Thurber

THURBER ENGINEERING LTD.

MEMORANDUM

To: Todd Bowie, P.Eng.
Parsons

Date: October 6, 2016

From: Steven Coulter, P.Eng.
(Reviewed by David Regehr, P.Eng.)

File: 19-5538-20

LULU ISLAND DIKE MASTER PLAN - PHASE 2
GEOTECHNICAL INPUT

As requested, this memorandum provides preliminary geotechnical input for Phase 2 of the Lulu Island Dike Master Plan. It is a condition of this memo that Thurber's performance of its professional services is subject to the attached Statement of Limitations and Conditions.

1. BACKGROUND

The City of Richmond (the City) requires input to identify dike upgrade options for Phase 2 of the Lulu Island Master Plan. Phase 2 of the plan includes the West Dike and the west section of the North Dike. These dikes have a total length of about 16 km and extend from the west end of Steveston Highway to the No. 6 Road North Pump Station. Preliminary drawings showing the existing dike alignment and sections were provided by Parsons. The dike sections show ground surface profile and include bathymetry of the North Arm and Middle Arm of the Fraser River.

We understand that existing dike generally has a crest elevation of about El 3.3 m, although there are areas where it is higher. The Lulu Island Dike Master Plan requires a dike crest elevation of El. 4.7 m for current flood protection requirements, with consideration to raise the dike crest to El. 5.5 m in the future. The City has also requested that consideration be given to infilling ditches on the landside of the dike.

Our assessment assumes that the dike upgrades will generally comprise the Ministry of Forests, Lands and Natural Resources' (MFLNRO's) standard dike section. This dike section has 3H:1V and 2.5H:1V landside and waterside slopes, respectively, and a minimum 4.0 m wide dike crest. Further, we understand that the MFLNRO classifies the dikes within the scope of this study as "high consequence" dikes.

2. GEOTECHNICAL CONDITIONS

Based on available information and information in our files, the subsurface conditions are anticipated to comprise fill overlying alluvial Fraser River deposits. Underlying the fill there is typically a layer of silt that is near the surface and becomes sandier with depth. This layer is generally about 2 to 4 m thick, although it ranges from about 1 m to 6 m thick. Below the silt, there is a zone that transitions from silt to sand at a depth of about 7 m. The sand layer below a depth of about 7 m becomes cleaner and coarser with depth and is typically 8 to 25 m thick.

Below the sand there is a sequence of silt and sand layers. Underlying the silt and sand sequence, there is a thick deposit of silt, which is underlain by dense till-like soil at depths of 50 m or more.

The B.C. Geological Survey's map "Geoscience Quaternary Geology of Richmond, British Columbia" (Quaternary Geology map) is attached for reference. This map provides descriptions of the near-surface deltaic deposits, which are often referred to as the topset deposits. In the study area, the topset deposits generally comprise the 8 to 25 m thick sand layer described above. This sand layer is susceptible to seismically induced liquefaction.

3. DIKE UPGRADE ISSUES

As described in the MFLNRO's document "Best Management Practices for Dike Design and Construction", July 2003, the major geotechnical design considerations for future upgrades include: 1) seepage control through and under the dike, 2) dike slope stability and 3) dike crest settlement. Additionally, the MFLNRO's document "Seismic Design Guidelines for Dikes", June 2014, (2014 Seismic Guidelines) includes seismic performance criteria for high consequence dikes.

3.1 Seepage

The existing dike crest elevation is at about El. 3.3 m and, as shown on the PDF file "Bathymetry Sections" provided by Parsons on September 14, 2015, the ground elevation on the landside of the dike is generally at about El. 2.0 m. Accordingly, the current design flood height (i.e. the height of water above the landside ground surface) for this dike section is about 0.7 m (assuming 0.6 m of freeboard). Raising the dike to Els. 4.7 m and 5.5 m will provide protection from design flood heights of 2.1 m and 2.9 m respectively. These increases in flood height are significant and will increase the risk of 1) landside heave of the less permeable surficial silt layer above the sand and 2) piping through the dike, the dike foundation, and the surficial silt layer. These increased seepage demands are likely one of the most significant design considerations for future upgrades.

Piping occurs when excessive seepage forces cause the migration of soil particles through the soil matrix resulting in internal erosion and eventually retrogressive failure. Heave can occur when there are excessive hydraulic pressures on the landside of the dike caused by a lower permeability soil layer forming a cap over a more permeable layer near the ground surface. Heave can lift and fracture the cap resulting large localised seepage volumes and internal erosion, which could cause a dike breach if it occurs near the dike.

We assume that that most of the dikes have been constructed without including filters to control seepage. (I.e. they are unfiltered). Evaluating the potential for piping in unfiltered dikes is difficult to analyse and predict. Accordingly, piping is one of the leading causes of failure of earth dams and dikes that have unfiltered seepage exits. Based on the current dike configuration and a 0.7 m flood height, the typical dike is subject to an average hydraulic gradient of about 0.08. The hydraulic gradient represents the seepage force through the dike, and higher hydraulic gradients

are more likely to cause piping. Raising the dike crest elevation to 4.7 m will result in an average hydraulic gradient of about 0.2. This is a significant increase, and although the current unfiltered dike appears to be performing acceptably, the risk of piping under higher design floods is much greater.

An important parameter to assess the potential for heave or piping of the surficial silt layer is the average hydraulic gradient through the surficial silt layer. Heave occurs when the water pressure exceeds the weight of soil above it and is anticipated to initiate when the average hydraulic gradient through the silt layer exceeds 0.8. Based on the current design flood height of 0.7 and a minimum 1.0 m thick layer of surficial silt, the average hydraulic gradient through the silt could be as high as 0.7, which is nominally below the value of 0.8 at which heave could initiate (i.e. the current dike is probably "safe" considering heave). The average hydraulic gradient would be less for a thicker silt layer. Based on typical 2 to 4 m thick silt layer, heave is a concern for flood heights above about 1.6 to 3.2 m

Where the silt is thick enough that heave is not a concern, piping could still be a problem. As recommended in U.S. Army Corps of Engineers' document "Design and Construction of Levees" (EM 1110-2-1913), the average hydraulic gradient through the silt layer should be limited to 0.3 to prevent piping under sustained flood heights. Accordingly, assuming that the surficial silt layer is 7 m thick (the thickest generally expected), piping of the surficial silt still may be a concern for flood heights greater than 2.1 m.

To provide reliable protection from higher design flood heights, a system of seepage control measures will probably be required for almost all of the dike. The potential for heave and piping could be mitigated using relief wells, drainage blankets or trenches. Relief wells and trenches should have filters designed to prevent piping and internal erosion and have filtered seepage exits. Retaining the existing landside ditches increases the risk of piping as they shorten the seepage path length and increase the hydraulic gradient. Accordingly, these ditches may need to be filled in order to provide the required level of flood protection.

3.2 Stability

We do not anticipate any significant stability issues associated with construction of a standard dike section to a dike crest elevation of 5.5 m provided high quality dike fill materials are used and placed in accordance with accepted engineering practice. The standard dike section is also anticipated to be generally stable under these higher floods (although it will be less stable than the lower height configuration). In areas where stability is a concern, minor modifications to the standard dike section may be required, such as flattening the landside slope, constructing a toe berm on the landside of the dike or providing a seepage cut-off and filter within the dike.

The stability of dikes will be improved where ditches near the landside toe are infilled. Dikes where the ditch is at the toe will have the largest increase in stability from infilling. As the distance between the toe of the dike and the ditch increases, the benefit of infilling the ditch decreases. Accordingly, dike stability could also be improved by moving ditches away from the toe of the

landside slope. The effect of the ditch location on dike stability depends on the site-specific geotechnical conditions and the dike and ditch configuration. In general, we anticipate that ditches located a minimum distance equal to the width of the dike (i.e. the distance between the landside toe and the waterside toe) from the landside toe will have a minimal destabilizing effect.

3.3 Settlement

Raising the dikes will induce primary consolidation settlement of the surficial silt layers. This settlement could be up to about 5% of the increase of the thickness of new dike fill placed and could potentially be compensated for by nominally overbuilding the dike. Also, settlement where construction is over peat or highly organic soils will be higher. The dike and surrounding area are experiencing secondary compression settlement due to on-going long-term compression of deeper silt layers. This on-going settlement is in the range of a 1 to 2 mm per year and is not anticipated to be significantly affected by raising the dike by the amounts considered. The effects of settlement on nearby infrastructure such as buildings and utilities should be considered. Potentially damaging differential settlement will be mostly due to consolidation of the surficial silt layer. Differential settlements are generally anticipated to be small at a distance greater than the thickness of the surficial silt layer (i.e. 1 to 6 m) from new dike fill.

Infilling ditches is not anticipated to significantly affect settlement.

3.4 Seismic Performance

The 2014 Seismic Guidelines recommend designing high consequence dikes to control seismic deformations within prescribed limits. The seismic deformation limits vary depending on the earthquake return period as shown in the table below.

Earthquake Return Period (year)	Maximum Allowable Displacement (m)	
	Vertical	Horizontal
1 in 100	<0.03	<0.03
1 in 475	0.15	0.3
1 in 2,475	0.5	0.9

Based on our experience in Richmond, and as shown on the B.C. Geological Survey's Geoscience Map "Liquefaction Hazard Map of Richmond, British Columbia", the dikes in the scope of this study are anticipated to be underlain by sand with a high susceptibility to liquefaction. Under the 1 in 100 year return period earthquake, liquefaction could be limited, although it may be significant in areas where there are significant site amplification effects, such as along the edges of the delta. Under the 1 in 2475 year return period earthquake, extensive liquefaction of the topset sand is almost certain.

Based on our experience with dike projects in the lower mainland, it is our opinion that much of the dike (and raised dike) could meet the displacement criteria in 2014 Seismic Guidelines for the 1 in 100 year return period earthquake without ground improvement. Ground improvement might

be required to meet the displacement criteria for the 1 in 475 year return period earthquake and is likely to be required to meet the displacement criteria for the 1 in 2,475 year return period earthquake.

Higher dikes and riverside dikes will have larger seismic deformations than lower dikes and setback dikes. Seismic deformations are anticipated to be smaller where the surficial silt layer is thicker and larger where more extensive liquefaction is anticipated

Along the west side of Lulu Island, the mud bank is relatively flat and extends out a significant distance. This mud bank will mitigate seismic deformations. However, we anticipate that the dike will still experience lateral spreading and liquefaction reconsolidation settlements that could potentially exceed the 2014 Seismic Guidelines displacement limits for the 1 in 2475 year return period earthquake.

Along the North Arm and Middle Arm of the Fraser River, where the dike comprises a “riverside” dike with steeper slopes (i.e. on the riverbank without a setback), flow slides caused by liquefaction during the 1 in 2475 year return period earthquake are more likely. A flow slide is a slide with large, uncontrolled deformations (i.e. greater than a meter) caused by the sand losing strength in its liquefied state. Accordingly, extensive ground improvement will be required to meet the displacement criteria in the 2014 Seismic Guidelines.

Where the dikes comprise “setback” dikes they might be far enough away from the riverbank to be outside of the flow slide zone. For conceptual planning purposes, we suggest considering dikes with a 50 to 100 m setback to be far enough away from most of the influence of riverbank flow slides. Setback dikes will still experience lateral spreading and liquefaction reconsolidation settlements that could potentially exceed the displacement limit in the 2014 seismic guidelines. The setback required to be outside of the flow slide zone depends on factors including the steepness of the riverbank and the depth of the river channel. The required setback could be in the order of 10 times the channel depth.

Riverside dikes where there are steeper slopes and where liquefaction is anticipated are likely to require extensive seismic remediation measures, such as reinforcement or densification of the foundation soils, to meet the deformation limits of the 2014 Seismic Guidelines. For conceptual purposes, a 15 m high by 15 m wide zone of ground improvement below the waterside toe of the dike could be required.

It is our opinion that a numerical deformation analysis provides better understanding of seismic deformation than empirical or limit equilibrium analytical methods and accordingly is better suited for assessing the suitability of ground improvement or the implementation of other seismic mitigation options. Carrying out PLAXIS numerical deformation analyses on representative dike sections during detailed design would provide an understanding of the extent and distribution of the seismic deformation and help to provide some guidance and insight into the level of measures that may be required in order to meet the 2014 Seismic Guidelines.

THURBER

4. OTHER FLOOD CONTROL MEASURES

Other flood control measures include floodwalls, foreshore structures to reduce wave run-up and construction of "superdikes". Superdikes comprise very wide earth fill dikes and can allow for construction of infrastructure and development on top of them. The concept of a superdike is to make the dike wide enough to provide a very long seepage path resulting in a very low hydraulic gradient, effectively eliminating the risk of piping or landside heave. Superdikes could also be constructed to extend beyond the areas near the river that are anticipated to be affected by large lateral deformations (i.e. flow slides). This configuration would maintain the required dike crest elevation for at least a part of the dike and would meet the intent of the 2014 Seismic Guidelines, although the dikes would have to be overbuilt to accommodate post-liquefaction reconsolidation settlement, which could be about 0.5 m or more under the 1 in 2475 year return period earthquake.

We trust that this information is sufficient for your needs. Should you require clarification of any item or additional information, please contact us at your convenience.

REFERENCES

B.C. Geological Survey Geoscience Map 2010-2: Quaternary Geology of Richmond, British Columbia, by P.A. Monahan, V.M. Levson and B. Kerr

B.C. Geological Survey Geoscience Map 2010-3: Liquefaction Hazard Map of Richmond, British Columbia, by P.A. Monahan, V.M. Levson and B. Kerr

Attachments

Statement of Limitations and Conditions

THURBER

STATEMENT OF LIMITATIONS AND CONDITIONS

1. STANDARD OF CARE

This Report has been prepared in accordance with generally accepted engineering or environmental consulting practices in the applicable jurisdiction. No other warranty, expressed or implied, is intended or made.

2. COMPLETE REPORT

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment are a part of the Report, which is of a summary nature and is not intended to stand alone without reference to the instructions given to Thurber by the Client, communications between Thurber and the Client, and any other reports, proposals or documents prepared by Thurber for the Client relative to the specific site described herein, all of which together constitute the Report.

IN ORDER TO PROPERLY UNDERSTAND THE SUGGESTIONS, RECOMMENDATIONS AND OPINIONS EXPRESSED HEREIN, REFERENCE MUST BE MADE TO THE WHOLE OF THE REPORT. THURBER IS NOT RESPONSIBLE FOR USE BY ANY PARTY OF PORTIONS OF THE REPORT WITHOUT REFERENCE TO THE WHOLE REPORT.

3. BASIS OF REPORT

The Report has been prepared for the specific site, development, design objectives and purposes that were described to Thurber by the Client. The applicability and reliability of any of the findings, recommendations, suggestions, or opinions expressed in the Report, subject to the limitations provided herein, are only valid to the extent that the Report expressly addresses proposed development, design objectives and purposes, and then only to the extent that there has been no material alteration to or variation from any of the said descriptions provided to Thurber, unless Thurber is specifically requested by the Client to review and revise the Report in light of such alteration or variation.

4. USE OF THE REPORT

The information and opinions expressed in the Report, or any document forming part of the Report, are for the sole benefit of the Client. NO OTHER PARTY MAY USE OR RELY UPON THE REPORT OR ANY PORTION THEREOF WITHOUT THURBER'S WRITTEN CONSENT AND SUCH USE SHALL BE ON SUCH TERMS AND CONDITIONS AS THURBER MAY EXPRESSLY APPROVE. Ownership in and copyright for the contents of the Report belong to Thurber. Any use which a third party makes of the Report, is the sole responsibility of such third party. Thurber accepts no responsibility whatsoever for damages suffered by any third party resulting from use of the Report without Thurber's express written permission.

5. INTERPRETATION OF THE REPORT

a) Nature and Exactness of Soil and Contaminant Description: Classification and identification of soils, rocks, geological units, contaminant materials and quantities have been based on investigations performed in accordance with the standards set out in Paragraph 1. Classification and identification of these factors are judgmental in nature. Comprehensive sampling and testing programs implemented with the appropriate equipment by experienced personnel may fail to locate some conditions. All investigations utilizing the standards of Paragraph 1 will involve an inherent risk that some conditions will not be detected and all documents or records summarizing such investigations will be based on assumptions of what exists between the actual points sampled. Actual conditions may vary significantly between the points investigated and the Client and all other persons making use of such documents or records with our express written consent should be aware of this risk and the Report is delivered subject to the express condition that such risk is accepted by the Client and such other persons. Some conditions are subject to change over time and those making use of the Report should be aware of this possibility and understand that the Report only presents the conditions at the sampled points at the time of sampling. If special concerns exist, or the Client has special considerations or requirements, the Client should disclose them so that additional or special investigations may be undertaken which would not otherwise be within the scope of investigations made for the purposes of the Report.

b) Reliance on Provided Information: The evaluation and conclusions contained in the Report have been prepared on the basis of conditions in evidence at the time of site inspections and on the basis of information provided to Thurber. Thurber has relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, Thurber does not accept responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of misstatements, omissions, misrepresentations, or fraudulent acts of the Client or other persons providing information relied on by Thurber. Thurber is entitled to rely on such representations, information and instructions and is not required to carry out investigations to determine the truth or accuracy of such representations, information and instructions.

c) Design Services: The Report may form part of design and construction documents for information purposes even though it may have been issued prior to final design being completed. Thurber should be retained to review final design, project plans and related documents prior to construction to confirm that they are consistent with the intent of the Report. Any differences that may exist between the Report's recommendations and the final design detailed in the contract documents should be reported to Thurber immediately so that Thurber can address potential conflicts.

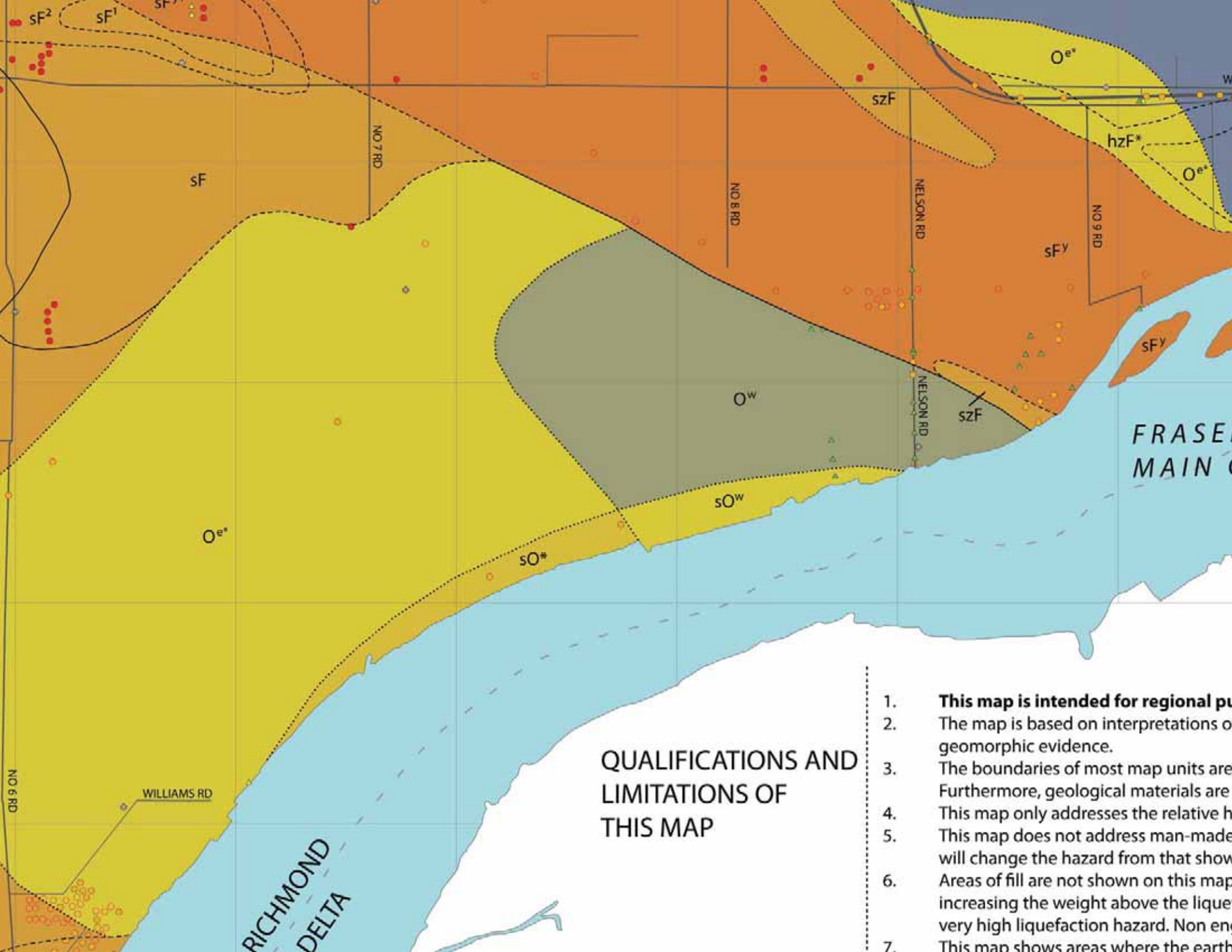
d) Construction Services: During construction Thurber should be retained to provide field reviews. Field reviews consist of performing sufficient and timely observations of encountered conditions in order to confirm and document that the site conditions do not materially differ from those interpreted conditions considered in the preparation of the report. Adequate field reviews are necessary for Thurber to provide letters of assurance, in accordance with the requirements of many regulatory authorities.

6. RELEASE OF POLLUTANTS OR HAZARDOUS SUBSTANCES

Geotechnical engineering and environmental consulting projects often have the potential to encounter pollutants or hazardous substances and the potential to cause the escape, release or dispersal of those substances. Thurber shall have no liability to the Client under any circumstances, for the escape, release or dispersal of pollutants or hazardous substances, unless such pollutants or hazardous substances have been specifically and accurately identified to Thurber by the Client prior to the commencement of Thurber's professional services.

7. INDEPENDENT JUDGEMENTS OF CLIENT

The information, interpretations and conclusions in the Report are based on Thurber's interpretation of conditions revealed through limited investigation conducted within a defined scope of services. Thurber does not accept responsibility for independent conclusions, interpretations, interpolations and/or decisions of the Client, or others who may come into possession of the Report, or any part thereof, which may be based on information contained in the Report. This restriction of liability includes but is not limited to decisions made to develop, purchase or sell land.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QUALIFICATIONS AND LIMITATIONS OF THIS MAP
1. **This map is intended for regional pu**
2. The map is based on interpretations o geomorphic evidence.
3. The boundaries of most map units are Furthermore, geological materials are
4. This map only addresses the relative h
5. This map does not address man-made will change the hazard from that show
6. Areas of fill are not shown on this map increasing the weight above the lique very high liquefaction hazard. Non en
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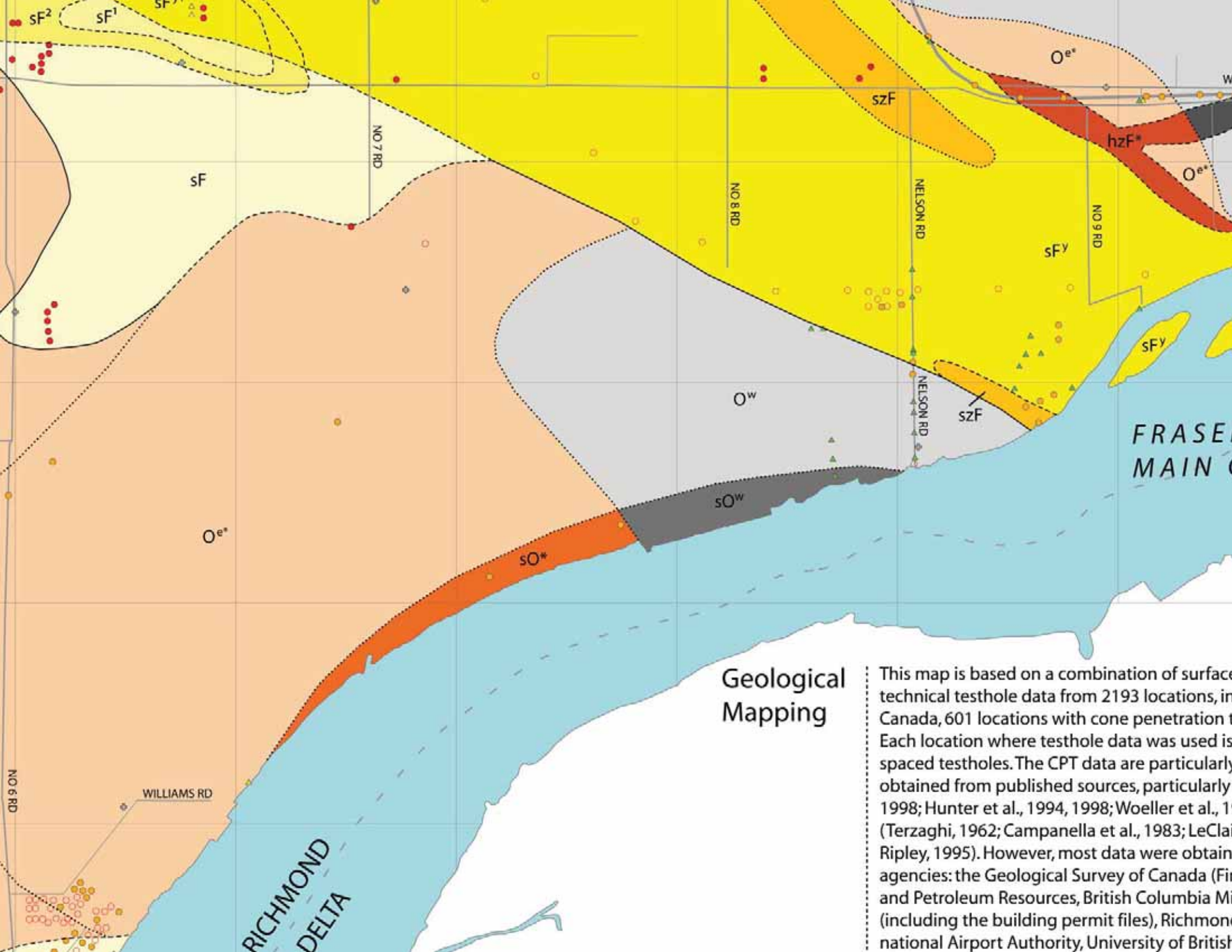

Geological Mapping

This map is based on a combination of surface technical testhole data from 2193 locations, in Canada, 601 locations with cone penetration t Each location where testhole data was used is spaced testholes. The CPT data are particularly obtained from published sources, particularly 1998; Hunter et al., 1994, 1998; Woeller et al., 1 (Terzaghi, 1962; Campanella et al., 1983; LeClai Ripley, 1995). However, most data were obtain agencies: the Geological Survey of Canada (Fi and Petroleum Resources, British Columbia Mi (including the building permit files), Richmon national Airport Authority, University of British

Attachment 4

Environmental Technical Brief - Envirowest

November 2, 2016

Mr. Todd Bowie, P.Eng.
Parsons
Suite 2300, 4710 Kingsway
Burnaby, BC V5H 4M2

Dear Sir,

RE: LULU ISLAND DIKE MASTER PLAN PHASE 2
TECHNICAL BRIEF

Envirowest Consultant Inc. (Envirowest) respectfully submits the following technical brief for the above referenced project. This brief provides an overview of the environmental values within the study area and the applicable legislative context that is anticipated for the project. Refinement of design scenarios will not be undertaken during this phase of the project.

Project Overview

The City of Richmond intends to implement flood protection upgrades as part of the Phase II Lulu Island Dike Master Plan (LIDMP) to the existing dikes extending along the west and north perimeters of Richmond. The north dike extends along the south bank of the North and Middle arms of the Fraser River from No. 6 Road to Terra Nova. The west dike extends along the west edge of Richmond from Terra Nova to Steveston.

The City of Richmond encompasses most of Lulu Island within the Fraser River estuary. Land use within the City is primarily urban and agricultural. The City's juxtaposition with the high ecological values of the estuary is reflected by the Ecological Network Management Strategy (ENMS). The ENMS provides context for the protection, enhancement and connectivity of an interconnected system of natural areas that make up Richmond's distinctive landscape. The ENMS recognizes the essential ecosystem services integral to the subtidal, intertidal and upland riparian areas within the LIDMP area, such as water storage and filtration, wave energy attenuation, temperature mitigation and prevention of soil erosion. Green infrastructure, which refers to components of the natural and built environment that provide ecosystem services, are also promoted within the ENMS.

Ecological lands within the LIDMP study area include City parks, Riparian Management Areas (RMAs) and Environmentally Sensitive Areas (ESAs) designated in the City's Official Community Plan (OCP), as well as other ecologically valuable lands such as the provincially designated Sturgeon Bank Wildlife Management Area (City of Richmond, Official Community

Plan (OCP) Chapter 9, Island Natural Environment). The LIDMP study area is includes 6 of the 10 geographic strategy areas identified within the ENMS: Traditional Neighbourhoods, City Centre, West Dike, Wildlife Management Areas, Industrial Area and the Fraser River. The ENMS and associated Strategy Areas will inform the Lulu Island Dike Master Plan.

Subtidal, Intertidal and Upland Riparian Ecological Values

The ENMS encompasses all ecological lands in the City, regardless of tenure. Priorities to reduce the fragmentation of natural habitats are central to the ENMS principles. The LIDMP study area covers some of the City's highest ecological values within the Fraser River estuary. The following paragraphs provide an overview of the City and non-City designated ecological attributes within the study area.

Riparian Management Areas and Channelized Watercourses

Richmond, unlike most other Metro Vancouver municipalities, has interconnected drainage catchments that are delineated by the operation of pump stations that feed into the receiving waters into the Fraser River. Being in the Fraser River floodplain, there is no significant grade change and the inland watercourses are slow moving and wetted the majority of the time. The high ground water table that feeds the City's watercourse and sloughs contains naturally occurring dissolved iron and other metals, and low levels of dissolved oxygen. These water quality conditions are generally inhospitable to salmon and trout; however, other species of fish, reptiles and amphibians may utilize the inland aquatic areas.

The City's watercourses flow into and contribute to fish and wildlife resources sustained by the Fraser River. As such the watercourses are designated fish habitat under the federal Fisheries Act, the provincial Water Sustainability Act, and the provincial Riparian Areas Protection Act. While the majority of these watercourses have been historically realigned into road grid to support agricultural development, they are identified by the City as channelized watercourses and not storm water ditches as they are fed with a significant source of groundwater. To support the form and function of these channelized watercourses, pre-designated riparian setbacks of 5 metres and 15 metres are designated by the City on minor and major watercourses, respectively. The setbacks are identified by the City as Riparian Management Areas, and are protected from development. Channelized watercourses, and their associated Riparian Management Areas (RMAs), are interspaced on the landside of the West and North dikes within the LIDMP study area.

Environmentally Sensitive Areas

The City has designated Environmentally Sensitive Areas (ESA) across the City. As identified in Chapter 9 of the OCP, intertidal and shoreline ESA Development Permit (DP) is in place around the island perimeter, extending 30 metres out into the intertidal/subtidal, and 30 metres inland of the shoreline into upland riparian habitat from the High Water Mark This ESA recognizes the

estuarine values surrounding Richmond and provide direction for application of the DP through DP permit guidelines.

City Parks

The West Dike trail and Terra Nova parks are both City park attributes contained within the study area. Consideration of habitat functionality and ecological values comprised within these lands must be integrated within the LIDMP.

Bath Slough

The North East Industrial study areas include the Bath Slough that forms part of the historical watercourse complex that stretched across Lulu Island, and acts as a catchment area for over 750 hectares of industrial and residential land in the Bridgeport area. The Bath Slough Revitalization Initiative, adopted in 2014 the City, has conducted a number of innovative ecological initiatives along Bath Slough including water quality improvements, riparian enhancements and native pollinator pasture initiatives. The Bath Slough Revitalization Initiative should be considered in the design construction phase of dike upgrades in the Bridgeport Tait study area.

ENMS Strategy Areas

Both inland and foreshore ecological values are embedded within the 6 ENMS Strategy Areas identified above. The ENMS and associated Strategy Areas provide key ecological context within the study area.

Wildlife Management Area – Sturgeon Bank

Sturgeon Bank is a provincially designated Wildlife Management Area (WMA) established in 1998 and is located on the waterside of the West Dike to protect and conserve internationally significant habitat for year-round migration and wintering waterfowl populations and important fish habitat. It is comprised primarily of near shore and intertidal brackish marsh, sandflats, mudflats, and open water. The WMA foreshore marsh and mudflat habitats provide critical ecological values as well as significant ecosystem services for wave energy attenuation and shoreline stabilization. Consideration and clear understanding of these key climate change adaptation and resiliency attributes along Sturgeon Bank are pivotal to future dike and off shore barrier island considerations.

Fraser River Estuary Management Program (FREMP) Mapping

Habitat productivity mapping has been undertaken since the mid-1980s along the Fraser River shoreline from the mouth of the Fraser River Delta upstream to the Pitt River/Maple Ridge area. This mapping was undertaken by the former Fraser River Estuary Management Program (FREMP). FREMP was a cooperative agreement amongst member agencies, including Environment Canada, Fisheries and Oceans Canada, Transport Canada, Fraser River Port

Authority, North Fraser Port Authority, BC Ministry of Environment, and the Greater Vancouver Regional District.

Though FREMP ceased to exist in 2013, the City continues to utilize this valuable data resource to inform activities in and along the City's Fraser River foreshore. The FREMP classification system comprises a three tiered colour-coded system: habitats are colour-coded red, yellow or green. Red-coded shorelines sustain highly productive fish and wildlife habitats. Yellow-coded shorelines sustained moderately productive habitats, while green-coded shorelines were characterized by habitats of low productivity. Generally development constraints are greatest within red-coded habitats, while development within green-coded habitats is constrained the least. Constraints within yellow-coded habitats are intermediate between those for red-coded and green-coded habitats.

Habitat productivity within the LIDMP study area includes a majority of red –coded reaches along the West and North Dike. Below is a further break down of the FREMP coding within the study area.

High productivity (red coded) habitat is depicted to extend along the north dike generally from No. 6 Road to the Knight Street bridge, along the Tait Waterfront Park, from No.4 Road to the Canada Line bridge, under the Oak Street Bridge, immediately west of the River Rock casino, south of the Canada Line YVR line, and west of Hollybridge Way to the Terra Nova Rural Park. High productivity habitat is depicted to continue along the entire sea-ward edge of the West Dike fronting Sturgeon Bank and Terra Nova Park.

Moderate (yellow coded) and Low (green coded) productivity habitats are interspersed along this shoreline between Hollybridge Way and Knight Street bridge.

Fraser River Fish and Species at Risk Values

The Fraser River Estuary provides habitat for many species of fish and wildlife. The estuarine marshes provide critical rearing and feeding opportunities for migrating birds and juvenile salmon. While the inland watercourses are considered to be generally not hospitable to salmon and trout species, they do flow into and support fish life in the Fraser River and are therefore considered as nutrient providing fish habitat.

A desktop review for species of management concern (i.e. included in Schedule 1 of the Federal Species at Risk Act and Provincial Conservation Data Centre red- and blue-listed species) was undertaken on the Provincial Conservation Data Centre web map. The search provided a single result, specifically utilization of the Fraser River by white sturgeon. The search did not provide any results along the seaward extent of the west dike, or along inland channelized watercourses. The absence of search results does not indicate that species at risk or of management concern are absent, but that they have either not been observed and /or recorded within these areas. A detailed species at risk assessment will need to be undertaken at the time of design construction

as the potential for listed species such as white sturgeon, Vancouver Island beggarticks, streambank lupine etc. within the study area is high.

Proposed Work

The study area extends approximately 16 kilometres along the west and north shorelines of Richmond from Garry Point to No. 6 Road. Upgrades to the West and North Dikes are recommended by Parsons to be implemented generally along the existing alignments. Several structural design scenarios have been presented by Parsons, including:

i) Raise the existing dike by widening its footprint;
ii) Construct a Superdike (elevations landward of the dike are raised in conjunction with the dike);
iii) Raise the existing dike within the existing footprint with retaining walls (i.e. constrained dike);
iv) Install temporary special structures (e.g. floodwalls);
v) Install permanent floodwalls;
vi) Install demountable floodwalls (where access to waterfront lands beyond the floodwall is required); and
vii) Maintain and Enhance intertidal habitat including l breakwaters and barrier islands.

Evaluation of the structural design scenarios, and recommended variations thereof, are presented in the Parsons Technical Memo 2: Analysis of Flood Protection Alternatives. Environmental values described in the Technical Memo will be considered for each identified design scenario.

Legislative Overview

Several federal and provincial acts protecting environmental resources may be engaged by the implementation of any or a combination of the recommended dike adaptations. An overview of federal and provincial acts relevant to this project is provided below.

Federal Legislation

- Canada *Fisheries Act*

The protection of fish and fish habitat in Canadian Waters is administered by Fisheries and Oceans Canada (DFO) under the auspices of the Federal *Fisheries Act*.

The determination by Fisheries and Oceans Canada of project impacts to fish and fish habitat are outlined by the Fisheries Protection Policy Statement (October 2013). The objectives of this document are to:

i) set out how DFO and its regulatory partners will apply the fisheries protection provisions of the Fisheries Act and guide the development of regulations, standards and directives; and
ii) provide guidance to proponents on the application of fisheries protection provisions of the Fisheries Act.

An interpretation of 'serious harm' included in the *Fisheries Act* is provided by DFO as:

a) the death of fish
b) a permanent alteration of fish habitat on spatial scale, duration or intensity that limits or diminishes the ability of fish to use such habitats as spawning grounds, or as nursery, rearing or food supply areas, or as a migration corridor, or any other area in order to carry out one or more of their life processes; and
c) the destruction of fish habitat of a spatial scale, duration or intensity that limits or diminishes the ability of fish to use such habitats as spawning grounds, or as nursery, rearing or food supply areas, or as a migration corridor, or any other area in order to carry out one or more of their life processes.

Any proposed works would be submitted to DFO as an 'Application for Environmental Review'. DFO review of the submitted information will culminate in a determination of whether or not the project will result in 'serious harm' to fish. This review by DFO will

a) determine that the project will not result in serious harm to fish and fish habitat and as such the project may proceed without an authorization pursuant with Section 35(2)(b) subject to implementation of proposed impact avoidance and mitigation measures, or
b) determine that the project will result in serious harm to fish and fish habitat and require that the project submit an application for authorization pursuant to Section 35(2)(b) of the *Fisheries Act* .

The submission of a request for authorization will allow DFO to undertake additional reviews of the project effects. The request for authorization will also include the development of offset measures to render residual project impacts (i.e. those impacts that cannot be fully avoided or mitigated) to fish and fish habitat insignificant. The Minister will, on the basis of the submission, determine if an authorization is to be issued or refused.

It is expected that improvements not engaging the estuarine (west dike) and or riverine (north dike) shorelines would not require *Fisheries Act* Authorization, whereas an authorization would likely be required for works engaging these estuarine and riverine shorelines. The implementation of impact mitigation features or strategies to minimize serious harm to fish and fish habitat would be integral to development of a design that engages the shorelines.

Section 36 of the *Fisheries Act* also prohibits impacts to fish and fish habitat by deleterious substances. This aspect of the *Act* is addressed by Environment Canada rather than by DFO.

The DFO project review duration for works not requiring Authorization will likely extend between 1 and 2 months. The review period will however be increased to up to 12 months in the

event that an authorization is required. A request for project authorization would trigger review of the proposed works by the Minister of Fisheries and Oceans pursuant with the *Canada Environmental Assessment Act*.

- Canada *Navigation Protection Act*

This *Act* provides for the protection of navigation within waterbodies identified in the Schedule, including '*all waters from the outer limit of the territorial sea up to the higher high water mean tide water level and includes all connecting waters up to an elevation intersecting with that level'* of the Pacific Ocean.

Proposed works located within navigable waters (e.g. the offshore breakwater islands) would require review by the Minister to ensure that navigation is not adversely affected. Review by the Minister of Transportation of works requiring *Navigation Protection Act* approval would trigger review of the proposed works by the Minister pursuant with the *Canada Environmental Assessment Act*.

- Canada *Species At Risk Act*

The primary objective of the Canada *Species At Risk Act* (SARA) is to prevent Canadian indigenous species, subspecies and distinct population of wildlife from becoming extirpated or extinct; to provide for the recovery of species that are extirpated, endangered or threatened; and to manage species of special concern to prevent them from becoming endangered or threatened. Through collaboration with provinces, territories, other federal departments, local governments, Aboriginal peoples, and other groups, all SARA listed species should be protected from development impact.

- Canada *Migratory Birds Convention Act* 1994

The *Migratory Birds Convention Act* and Regulations provides for the project of migratory birds and their nests. Section 5 of the *Act* prohibits, except where authorized by regulations, a) possession of a migratory bird or nest or b) buying, selling, exchange or giving of a migratory bird or nest or make it a subject of a commercial transaction.

Displacement of a migratory bird or nest as a result of the proposed works would require authorization by the Minister of Environment. The *Act* does not distinguish active nest (i.e. occupied by a bird or its egg) from an inactive nest. The request for such an authorization would trigger review of the proposed application by the Minister of Environment under the auspices of the *Canada Environmental Assessment Act*.

- *Canada Environmental Assessment Act*

The *Canada Environmental Assessment Act* (CEAA) provides a comprehensive and exhaustive review process of environmental issues at the federal level of government. Review of a project

pursuant to CEAA is triggered in the event that a) the proposed works are located on federal land, b) the proposed works require approval by other federal legislation (e.g. *Fisheries Act*), and c) the proposed works have received partial or full funding from the Government of Canada.

Project review pursuant with CEAA is the responsibility of the respective federal department undertaking the review (e.g. Minister of Fisheries and Oceans). It is the responsibility of the Proponent to provide information relevant to the project to the respective Minister to facilitate review of the project.

Works and undertakings associated with projects that trigger federal approval will require review pursuant with CEAA.

Provincial Legislation

- British Columbia *Environmental Assessment Act* (BCEAA)

Projects that may have significant adverse environmental, economic, social, heritage, and or health effects may be considered as candidates for review pursuant with this Act. The Reviewable Projects Regulation of the BCEAA requires the review of proposed dike improvements resulting in *'(1) modification of an existing facility if (a) the existing facility, were it a new facility, would meet the criteria set out opposite in Column 2* (i.e. a new dyke facility that protects for flooding an area of ≥ 10 square kilometres), *and (b) the modification results in the raising of the entire length of the dyke*'. Phase 2 of the dike improvement project fulfills this assessment requirement.

The BCEAA allows for the exemption of projects from review under this legislation. An application for exemption would be reviewed and accepted if the Executive Director of the Environmental Assessment Office considers that the proposed works will not have significant adverse effects. The determination that the project will not have significant adverse effects may be provided by either the provincial or federal governments through other acts and their respective review processes.

- British Columbia *Water Sustainability Act*

The *Water Sustainability Act* (WSA) replaced the *Water Act* on March 1, 2016. Section 11 of the WSA requires that changes in and about a stream be undertaken in accordance with *(a) the terms and conditions of a change approval, (b) the regulations, (c) the terms and conditions of an authorization, or (d) an order.*

'Stream' is defined by this act as *(a) a natural watercourse, including a natural glacier course, or a natural body of water, whether or not the stream channel of the stream has been modified, or (b) a natural source of water supply, including, without limitation, a lake, pond, river, creek, spring, ravine, gulch, wetland or glacier, whether or not usually containing water, including ice, but does not include an aquifer'.*

Modifications to channelized watercourses will require review and acceptance pursuant with this *Act*.

River bottom comprising the Middle and North Arms of the Fraser River is identified as Crown Land and is managed by the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO). Modification of Crown Land by the proposed dike will require review and acceptance by MFLNRO pursuant with this *Act*.

- British Columbia *Dike Maintenance Act*

This *Act* provides for the establishment of drainage, diking or development districts and the appointment of commissioners to oversee the districts. The commissioners are responsible for the development, management, and maintenance of flood protection measures.

Works affecting an existing dike will require authorization from the Inspector of Dikes.

- British Columbia *Riparian Areas Protection Act*

This *Riparian Areas Protection Act (2016)* replaced the *Fish Protection Act (1997)*. The act enables the Riparian Area Regulation, which is a directive to local governments to protect and enhance riparian habitat from industrial, residential and commercial development.

In response to the Riparian Area Regulation, the City of Richmond adopted the Riparian Response Strategy in 2006. Following the Provincial Ombudsperson review of local government's riparian protection methods in 2012, the City is collaborating with the Province to implement new legislated protection and enhancement measures that is compliant with the provincial directive. The Provincial Riparian Area Regulation applies to the City's inland watercourses, but not the foreshore of the Fraser River. The Fraser River foreshore is also part of the City's Ecological Network and is designated Environmentally Sensitive Area in the City's OCP protected under development permit.

It is anticipated that raising the crest of a dike may expand the dike footprint and potentially enclose or relocate adjacent existing channelized watercourses. Unavoidable loss of RMA designated fish habitat would need to be compensated for following a net gain approach.

- British Columbia *Wildlife Act*

The British Columbia *Wildlife Act* provides for the protection of vertebrate species. Adverse effects to vertebrate species, except those excluded by regulation, resulting in death or injury of the species is prohibited except as permitted by the Minister. Section 34 of the *Act* prohibits harm to specific birds (i.e. eagle, peregrine falcon, gyrfalcon, osprey, heron, and or burrowing owl) and their nests, as well as other birds and their nests when the nest is occupied.

Displacement of an active nest to allow for construction will require submission of a request for a general *Wildlife Act* permit. This application typically occurs during the construction phase of a project.

The Sturgeon Bank Wildlife Management Area (WMA) was established in 1998 under the legislative auspices of the *Wildlife Act*. The objective of this WMA as stated by the Ministry of Forests, Lands and Natural Resource Operations is to provide for the 'conservation of critical internationally significant habitat for year round, migrating and wintering waterfowl populations, along with important fish habitat'. Modifications of environmental attributes sustained within the Sturgeon Bank WMA would require consent from the Ministry.

- British Columbia *Environmental Management Act* and Regulations

The *Environmental Management Act* (EMA) generally protects the quality of air, soil, and water in the Province by regulation the discharge of emissions of effluent, waste, or contaminants. A component of the Act includes the Spill Reporting Regulation that requires reporting of discharges of certain contaminants to the environment exceeding regulated volumes.

The application of the EMA and the Spill Reporting Regulation would be expected during the construction phase of a project.

- British Columbia *Land Act*

The *Land Act* is administered by the Ministry of Forests, Lands and Natural Resource Operations. The *Act* provides for the management of Crown land by the Ministry that is not in the administration of another minister, branch, or agency or government.

Engagement of Crown land by the proposed works would, as a minimum, require submission of an application for Crown Land tenure to the Ministry in the event that prior agreements and / or right-of-way permitting engagement of Crown Land are absent.

Dike Design and Costruction Considerations

The existing dike alignments are, for the most part, constrained on either side by ecological assets identified in the City's Ecological Network Management Strategy. While generally waterside habitat within the Fraser River Estuary will have a higher habitat value, this may not always be the case if for example the landside of the dyke has a high value Riparian Management Area, and the adjacent foreshore is disturbed.

Implementation of area specific flood protection strategies will have an environmental impact regardless of the strategy put forth for a given area. Environmental assessments identifying the impacts will be undertaken in the design phase. Identified impacts will be mitigated to the greatest extent practical both during the design and construction phases of the project. Residual (i.e. unmitigated) impacts will require the development of compensation measures to off-set the

loss of productive capacity of the affected habitats. The development of compensation habitats will pursue a 'net gain' approach of habitat and productive capacity.

Intertidal habitat such as barrier islands, sand flats, mud flats, salt marsh and eelgrass beds can provide erosion and wave energy attenuation by dissipating wave energy before it engages the shore. Intertidal habitat can work in combination with a constructed flood control structures like dikes and floodwalls, to mitigate flood risk. Monitoring existing intertidal habitat, and identifying opportunities to maintain and enhance productivity within this area should be considered as a part of the LIDMP.

Please contact me at 604-944-0502 or at sickmuller@envirowest.ca should you have any questions regarding this correspondence.

Sincerely,
ENVIROWEST CONSULTANTS INC.

Rolf Sickmuller, R.P.Bio.
Senior Biologist

RWS

Attachment 5

Seismic Deformation Analysis - Thurber

THURBER ENGINEERING LTD.

September 12, 2016 File: 19-5538-20

City of Richmond c/o
Parsons
Suite 2300, 4710 Kingsway
Burnaby, BC V5H 4M2

Attention: Evelyne Russell, EIT

LULU ISLAND DIKE MASTER PLAN - PHASE 2
SEISMIC DEFORMATION ANALYSIS

Dear Evelyne:

As requested, Thurber Engineering Ltd. (Thurber) has carried out a seismic deformation analysis for the above project using the software program PLAXIS. This report presents the results of the deformation analysis.

It is a condition of this report that Thurber's performance of its professional services is subject to the attached Statement of Limitations and Conditions.

1. INTRODUCTION

Thurber provided preliminary geotechnical input for Phase 2 of the City of Richmond's (the City's) Lulu Island Dike Master Plan in a memorandum dated September 25, 2015. This memorandum included a high-level discussion of the anticipated seismic performance of the West Dike and the North Dike. We understand that these dikes are classified as high-consequence dikes by Ministry of Forests, Lands and Natural Resources Operations (MFLNRO) and accordingly any upgrades must conform to the MFLNRO's "Seismic Design Guidelines for Dikes", dated June 2014, (2014 Seismic Guidelines). For reference, the displacement criteria of the 2014 Seismic Guidelines are provided in the table below.

Earthquake return period (year)	Maximum allowable displacement (mm)	
	Horizontal	Vertical
1 in 100	<30	<30
1 in 475	300	150
1 in 2,475	900	500

In our preliminary report we indicated that ground improvement might be required to meet the displacement criteria for the 1 in 475 year return period earthquake and will almost certainly required to meet the displacement criteria for the 1 in 2,475 year return period earthquake.

Ground improvement is generally not anticipated be required to meet the performance criteria of the 1 in 100 year return period earthquake as liquefaction is generally anticipated to be limited.

To better understand the potential seismic deformations, Thurber carried out a seismic deformation analyses on three dike section at the following locations:

1) No. 1 Road
2) No. 4 Road
3) Bath Slough

This report presents the results of our numerical seismic deformation analysis using the software program PLAXIS 2D.

2. RESULTS OF THE ANALYSIS

We carried out seismic deformation analyses to assess the anticipated deformations of the pump station using the software program PLAXIS 2D. PLAXIS 2D is an advanced finite element modelling program that allows for complex modelling of cyclic soil behaviour similar to the software program FLAC, but with a faster computation routine. The deformation analyses incorporated complex cyclic soil behaviour using the UBCSand soil model, which is the same model used in FLAC for similar numerical deformation analysis.

The analyses used the earthquake time-histories from the Lion's Gate Waste Water Treatment Plant project for crustal, in-slab and interface earthquakes. These time-histories were scaled to the peak ground acceleration at the site for each component (i.e. crustal, in-slab and interface) earthquake provided by Natural Resources Canada for the 1 in 475 and 1 in 2,475 year return period earthquakes.

The analysis used cone penetration test (CPT) data and seismic CPT data provided by the City. Sections showing the bathymetry and topography were prepared by Parsons. The locations the dikes are shown on Dwg. 19-5538-20-1 and the sections analysed are shown on Dwg. 19-5538-20-3. The results of the analysis indicates that the most extensive liquefaction and largest seismic deformations occur under the 1 in 2,475 year return period earthquakes. Summary tables providing the maximum displacements for the all of the 1 in 475 and 1 in 2,475 year return period earthquakes for each dike section is attached. The table below summarize the maximum displacements of the landside crest of each dike sections. PLAXIS output from the earthquakes that resulted in these maximum displacements are attached.

1 in 2475 year return period earthquake			
Dike Section	Earthquake motion	Maximum displacement (mm)	
		Horizontal	Vertical
No 1. Road[A]	Interface	500	600
Bath Slough[A]	Interface	450	1000
No. 4 Road	In-slab	300	500

[A] - Displacement exceeds the 2014 Seismic Guidelines

As shown in the above table, the estimated vertical displacement of the dike at No. 1 Road and at Bath Slough under the 1 in 2,475 year return period interface earthquake are anticipated nominally exceed the deformation criteria of the 2014 Seismic Guidelines. We note that these deformations do not include post-liquefaction reconsolidation settlements. Accordingly, total vertical displacements will be higher. For conceptual design purposes, vertical reconsolidation settlements could be in the order of 0.3 m. The horizontal deformation criteria were met for all three dike sections. This suggests that overbuilding the dike to provide sufficient post-earthquake freeboard could potentially be an acceptable way to meet the 2014 Seismic Guidelines.

These results are only applicable at the sections analysed and larger seismic deformations may occur at other dike locations. Site-specific seismic deformations will depend on the slope of the riverbank and the bottom of the river channel. The slopes of the bottom of the river channel are about 1% at the No. 1 Road dike and about 10% at the No. 4 Road and Bath Slough dikes. Larger seismic deformations are likely where slopes are steeper.

In addition to the site-specific topography and bathymetry, deformations will also depend on the soil type and strength. In general, we anticipate that smaller deformations will occur where there is more silt in the soil profile and where there is less liquefiable sand. Flow slides could potentially occur where there is extensive liquefaction and a steeper riverbank and river channel bottom. With flows slides, large uncontrolled deformations of several metres or more could be anticipated.

THURBER

We trust that this report provides sufficient information for your needs at this time. Should you require clarification of any item or additional information, please do not hesitate to contact us.

Yours truly,
Thurber Engineering Ltd.
David Regehr, P.Eng.
Review Principal

Steven Coulter, P.Eng.
Project Engineer

Attachments:
Statement of Limitations and Conditions (1 page)
Dwgs. 19-5538-20-1, 19-5538-20-3 (2 pages)
Plaxis results summary tables (1 page)
Plaxis output (6 pages)
CPT/SCPT data (6 pages)

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STATEMENT OF LIMITATIONS AND CONDITIONS

1. STANDARD OF CARE

This Report has been prepared in accordance with generally accepted engineering or environmental consulting practices in the applicable jurisdiction. No other warranty, expressed or implied, is intended or made.

2. COMPLETE REPORT

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment are a part of the Report, which is of a summary nature and is not intended to stand alone without reference to the instructions given to Thurber by the Client, communications between Thurber and the Client, and any other reports, proposals or documents prepared by Thurber for the Client relative to the specific site described herein, all of which together constitute the Report.

IN ORDER TO PROPERLY UNDERSTAND THE SUGGESTIONS, RECOMMENDATIONS AND OPINIONS EXPRESSED HEREIN, REFERENCE MUST BE MADE TO THE WHOLE OF THE REPORT. THURBER IS NOT RESPONSIBLE FOR USE BY ANY PARTY OF PORTIONS OF THE REPORT WITHOUT REFERENCE TO THE WHOLE REPORT.

3. BASIS OF REPORT

The Report has been prepared for the specific site, development, design objectives and purposes that were described to Thurber by the Client. The applicability and reliability of any of the findings, recommendations, suggestions, or opinions expressed in the Report, subject to the limitations provided herein, are only valid to the extent that the Report expressly addresses proposed development, design objectives and purposes, and then only to the extent that there has been no material alteration to or variation from any of the said descriptions provided to Thurber, unless Thurber is specifically requested by the Client to review and revise the Report in light of such alteration or variation.

4. USE OF THE REPORT

The information and opinions expressed in the Report, or any document forming part of the Report, are for the sole benefit of the Client. NO OTHER PARTY MAY USE OR RELY UPON THE REPORT OR ANY PORTION THEREOF WITHOUT THURBER'S WRITTEN CONSENT AND SUCH USE SHALL BE ON SUCH TERMS AND CONDITIONS AS THURBER MAY EXPRESSLY APPROVE. Ownership in and copyright for the contents of the Report belong to Thurber. Any use which a third party makes of the Report, is the sole responsibility of such third party. Thurber accepts no responsibility whatsoever for damages suffered by any third party resulting from use of the Report without Thurber's express written permission.

5. INTERPRETATION OF THE REPORT

a) Nature and Exactness of Soil and Contaminant Description: Classification and identification of soils, rocks, geological units, contaminant materials and quantities have been based on investigations performed in accordance with the standards set out in Paragraph 1. Classification and identification of these factors are judgmental in nature. Comprehensive sampling and testing programs implemented with the appropriate equipment by experienced personnel may fail to locate some conditions. All investigations utilizing the standards of Paragraph 1 will involve an inherent risk that some conditions will not be detected and all documents or records summarizing such investigations will be based on assumptions of what exists between the actual points sampled. Actual conditions may vary significantly between the points investigated and the Client and all other persons making use of such documents or records with our express written consent should be aware of this risk and the Report is delivered subject to the express condition that such risk is accepted by the Client and such other persons. Some conditions are subject to change over time and those making use of the Report should be aware of this possibility and understand that the Report only presents the conditions at the sampled points at the time of sampling. If special concerns exist, or the Client has special considerations or requirements, the Client should disclose them so that additional or special investigations may be undertaken which would not otherwise be within the scope of investigations made for the purposes of the Report.

b) Reliance on Provided Information: The evaluation and conclusions contained in the Report have been prepared on the basis of conditions in evidence at the time of site inspections and on the basis of information provided to Thurber. Thurber has relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, Thurber does not accept responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of misstatements, omissions, misrepresentations, or fraudulent acts of the Client or other persons providing information relied on by Thurber. Thurber is entitled to rely on such representations, information and instructions and is not required to carry out investigations to determine the truth or accuracy of such representations, information and instructions.

c) Design Services: The Report may form part of design and construction documents for information purposes even though it may have been issued prior to final design being completed. Thurber should be retained to review final design, project plans and related documents prior to construction to confirm that they are consistent with the intent of the Report. Any differences that may exist between the Report's recommendations and the final design detailed in the contract documents should be reported to Thurber immediately so that Thurber can address potential conflicts.

d) Construction Services: During construction Thurber should be retained to provide field reviews. Field reviews consist of performing sufficient and timely observations of encountered conditions in order to confirm and document that the site conditions do not materially differ from those interpreted conditions considered in the preparation of the report. Adequate field reviews are necessary for Thurber to provide letters of assurance, in accordance with the requirements of many regulatory authorities.

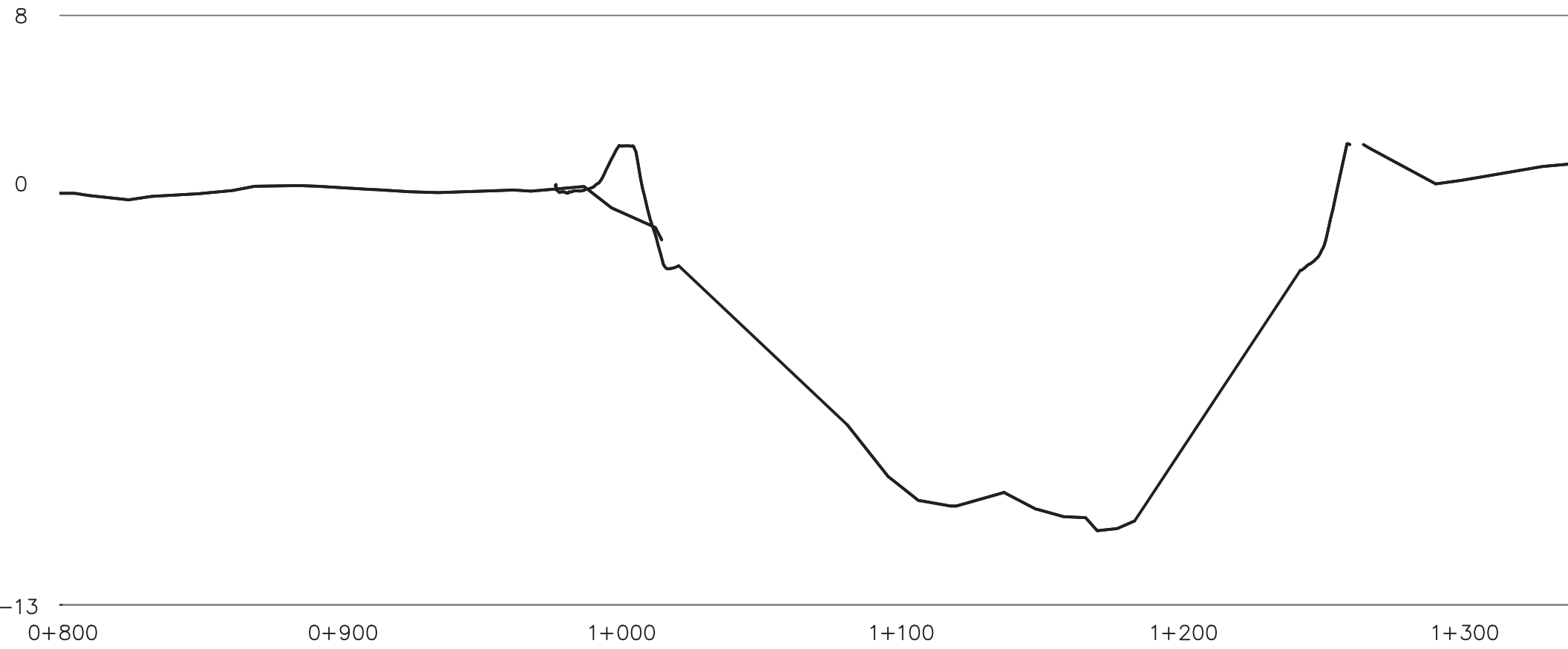
6. RELEASE OF POLLUTANTS OR HAZARDOUS SUBSTANCES

Geotechnical engineering and environmental consulting projects often have the potential to encounter pollutants or hazardous substances and the potential to cause the escape, release or dispersal of those substances. Thurber shall have no liability to the Client under any circumstances, for the escape, release or dispersal of pollutants or hazardous substances, unless such pollutants or hazardous substances have been specifically and accurately identified to Thurber by the Client prior to the commencement of Thurber's professional services.

7. INDEPENDENT JUDGEMENTS OF CLIENT

The information, interpretations and conclusions in the Report are based on Thurber's interpretation of conditions revealed through limited investigation conducted within a defined scope of services. Thurber does not accept responsibility for independent conclusions, interpretations, interpolations and/or decisions of the Client, or others who may come into possession of the Report, or any part thereof, which may be based on information contained in the Report. This restriction of liability includes but is not limited to decisions made to develop, purchase or sell land.


GREAT CANADIAN WAY
HEMSLEY RD
GARDEN CITY RD
NO 4 RD
BRIDGEPORT RD



SECTION 2 – NO. 4 ROAD

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No. 1 Road

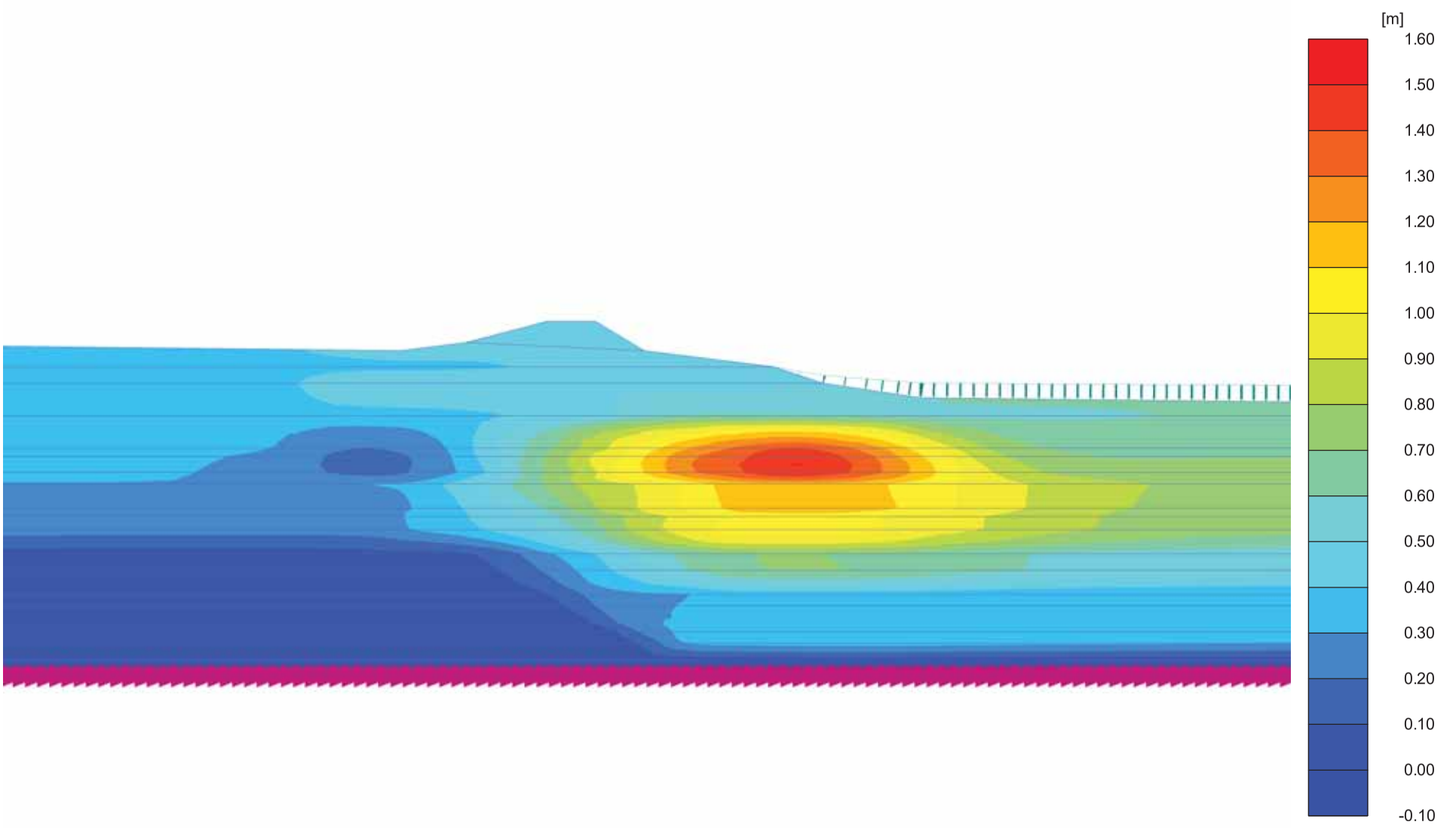
Eathquake motion	Maximum displacement (mm)	
	Horizontal	Vertical
1 in 475 year return period earthquake		
Interface	10	10
Crustal	5	10
In-slab	45	20
1 in 2475 year return period earthquake		
Interface	500	600
Crustal	10	20
In-slab	75	60

Bath Slough

Eathquake motion	Maximum displacement (mm)	
	Horizontal	Vertical
1 in 475 year return period earthquake		
Interface	50	25
Crustal	35	20
In-slab	70	35
1 in 2475 year return period earthquake		
Interface	450	1000
Crustal	80	40
In-slab	80	60

No. 4 Road

Eathquake motion	Maximum displacement (mm)	
	Horizontal	Vertical
1 in 475 year return period earthquake		
Interface	60	125
Crustal	10	30
In-slab	100	100
1 in 2475 year return period earthquake		
Interface	125	150
Crustal	125	150
In-slab	300	500



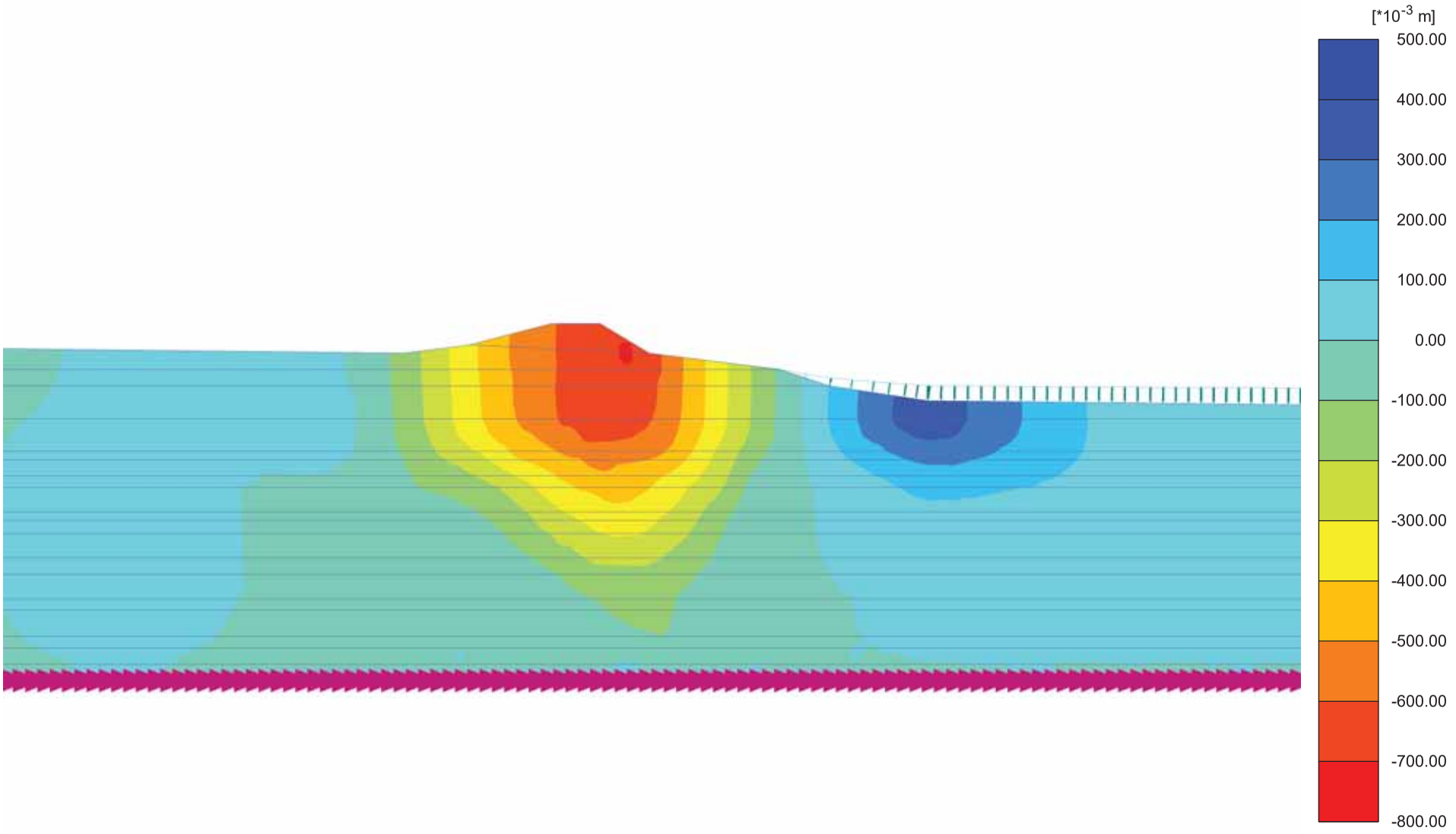
Phase displacements Pu_x

Maximum value = 1.503 m (Element 1755 at Node 11487)

Minimum value = -0.06041 m (Element 1651 at Node 16072)

THURBER ENGINEERING LTD.

Project description		Date
1 Road_2475 Interface_Horizontal displ.		9/8/2016
Project filename	*Step*	*User name*
1Road EQ3	19000	Thurber Engineering Ltd

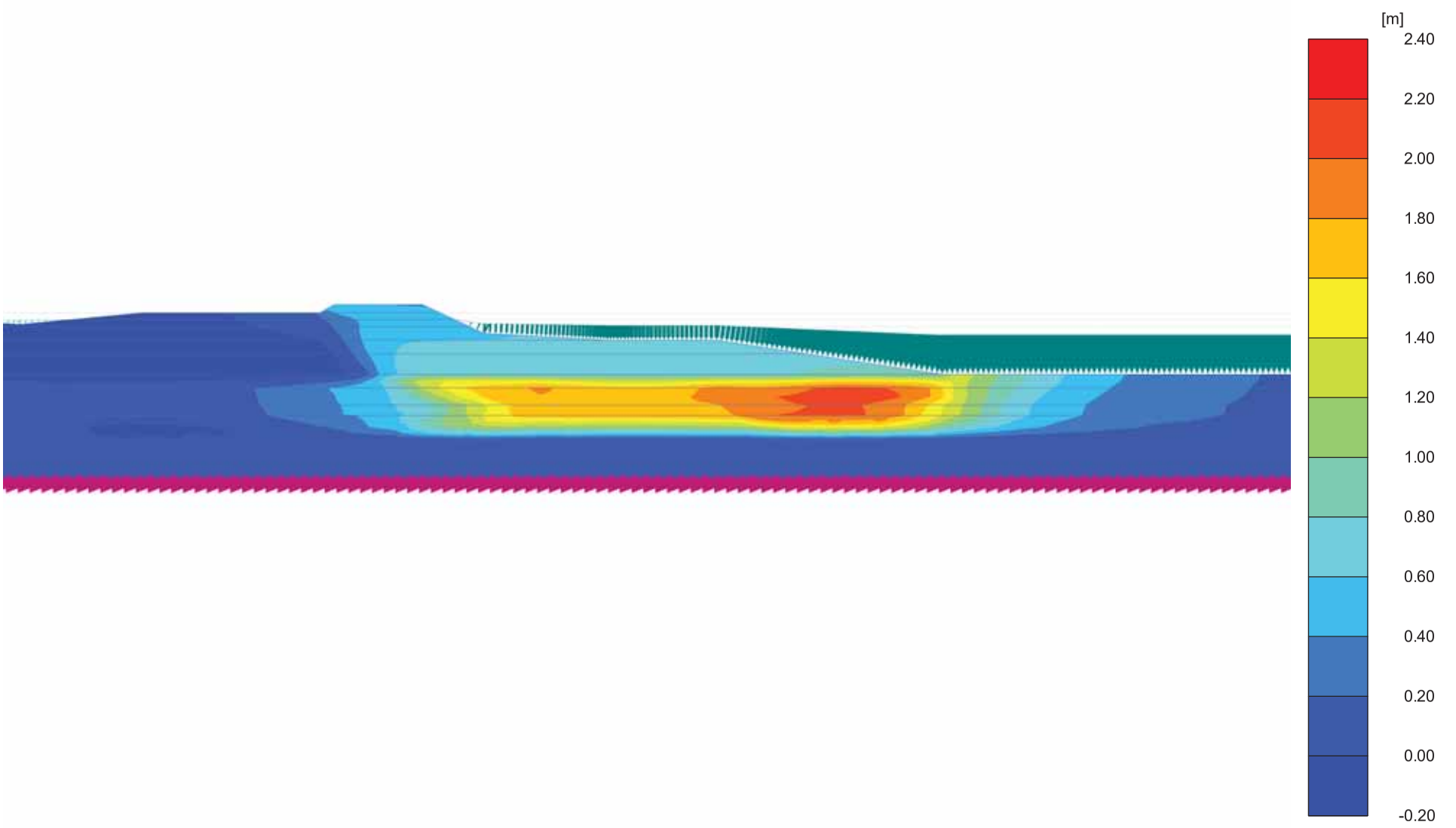


Phase displacements Pu_y

Maximum value = 0.4078 m (Element 807 at Node 2122)

Minimum value = -0.7062 m (Element 9 at Node 12272)

THURBER ENGINEERING LTD.	*Project description* 1 Road_2475 Interface_Vertical displ.		*Date* 9/8/2016
	Project filename 1Road EQ3	*Step* 19000	*User name* Thurber Engineering Ltd

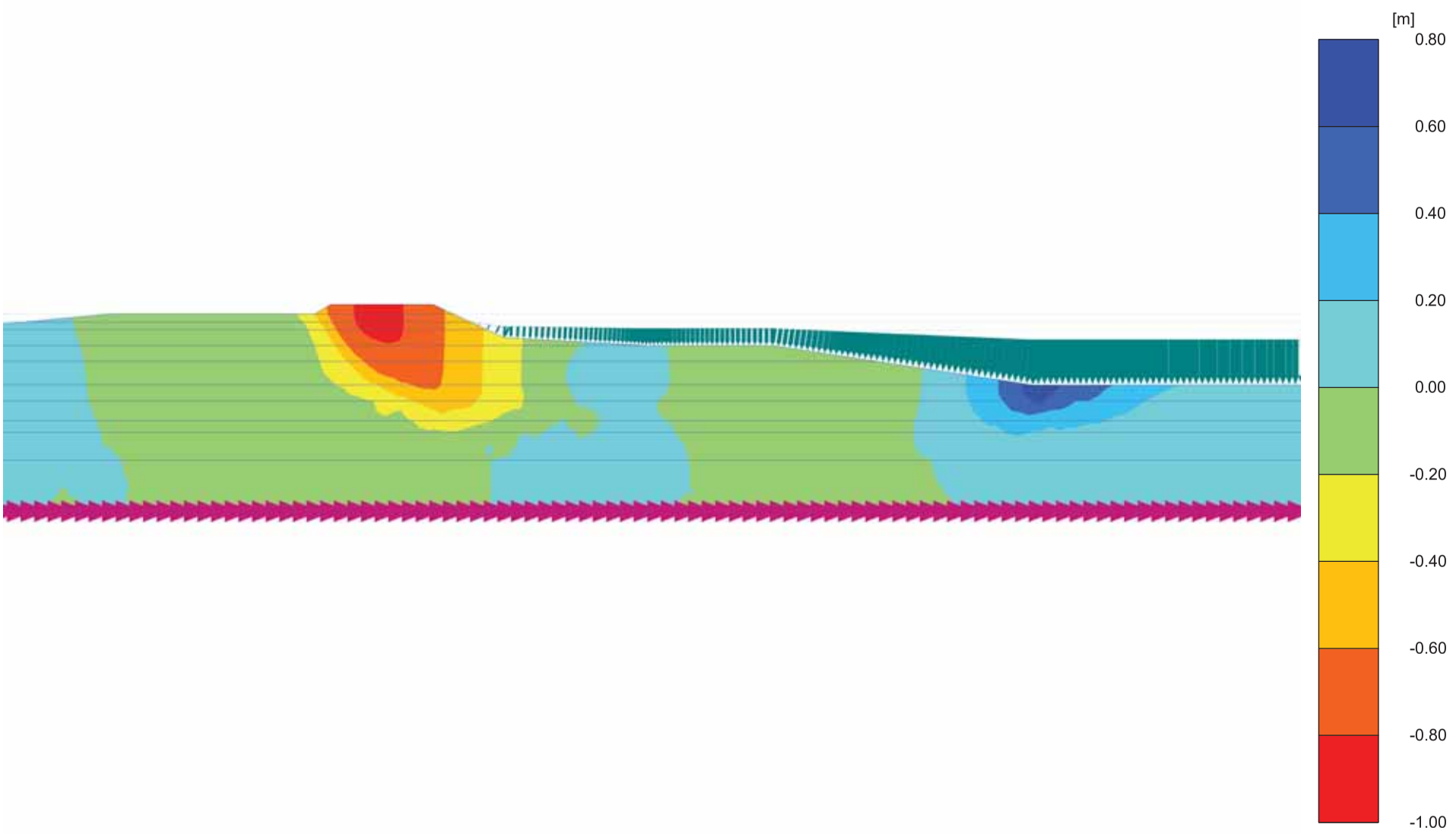


Phase displacements Pu_x

Maximum value = 2.120 m (Element 4233 at Node 7015)

Minimum value = -3.178 m (Element 4548 at Node 2173)

THURBER ENGINEERING LTD.	*Project description* Bath Slough_2475 Interface_Horizontal displ.		*Date* 9/8/2016
	Project filename Bath Slough_Rev0-Resav ...	*Step* 29015	*User name* Thurber Engineering Ltd



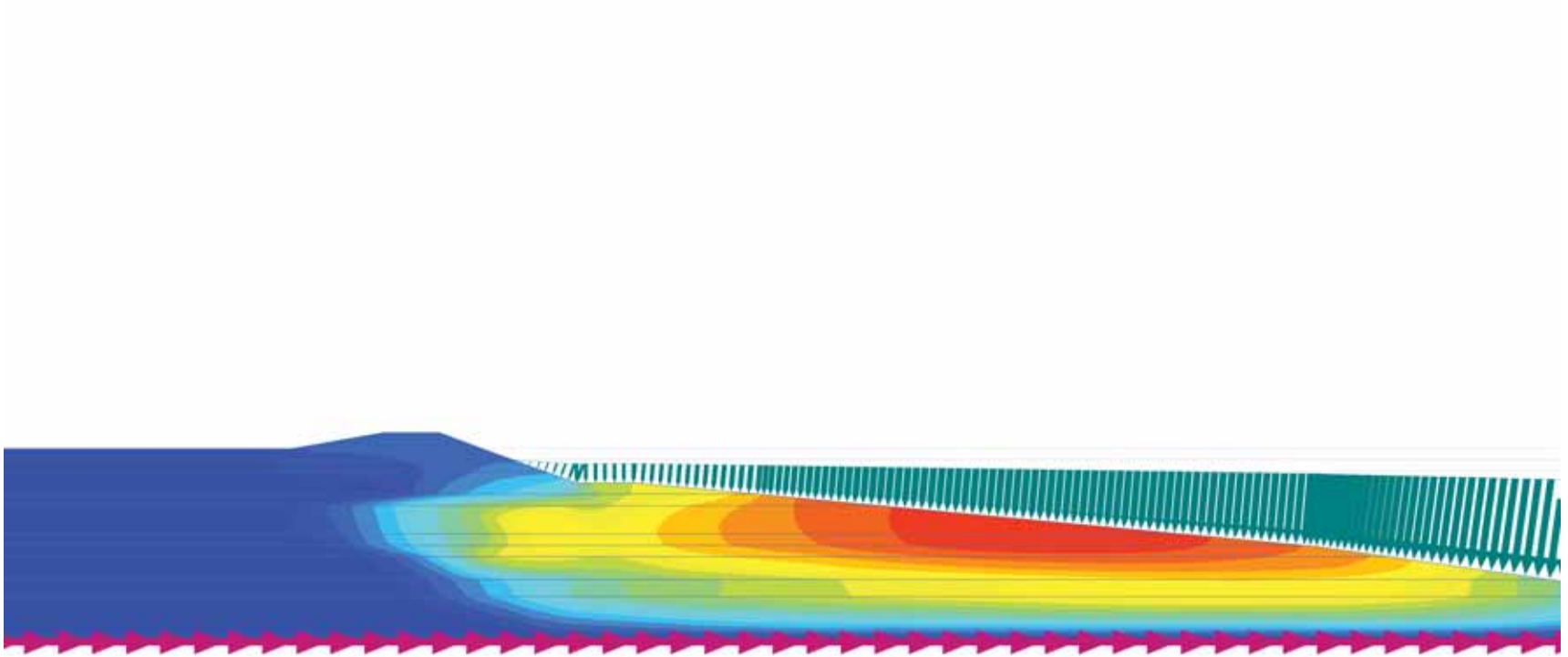
Phase displacements Pu_y

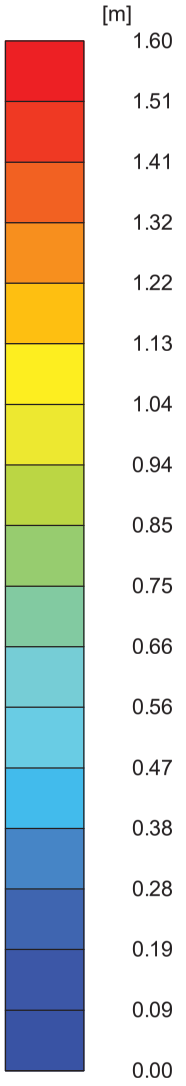
Maximum value = 1.321 m (Element 4097 at Node 2427)

Minimum value = -0.8717 m (Element 8 at Node 8586)

THURBER ENGINEERING LTD.

Project description		Date
Bath Slough_2475 Interface_Vertical displ.		9/8/2016
Project filename	*Step*	*User name*
Bath Slough_Rev0-Resav ...	29015	Thurber Engineering Ltd





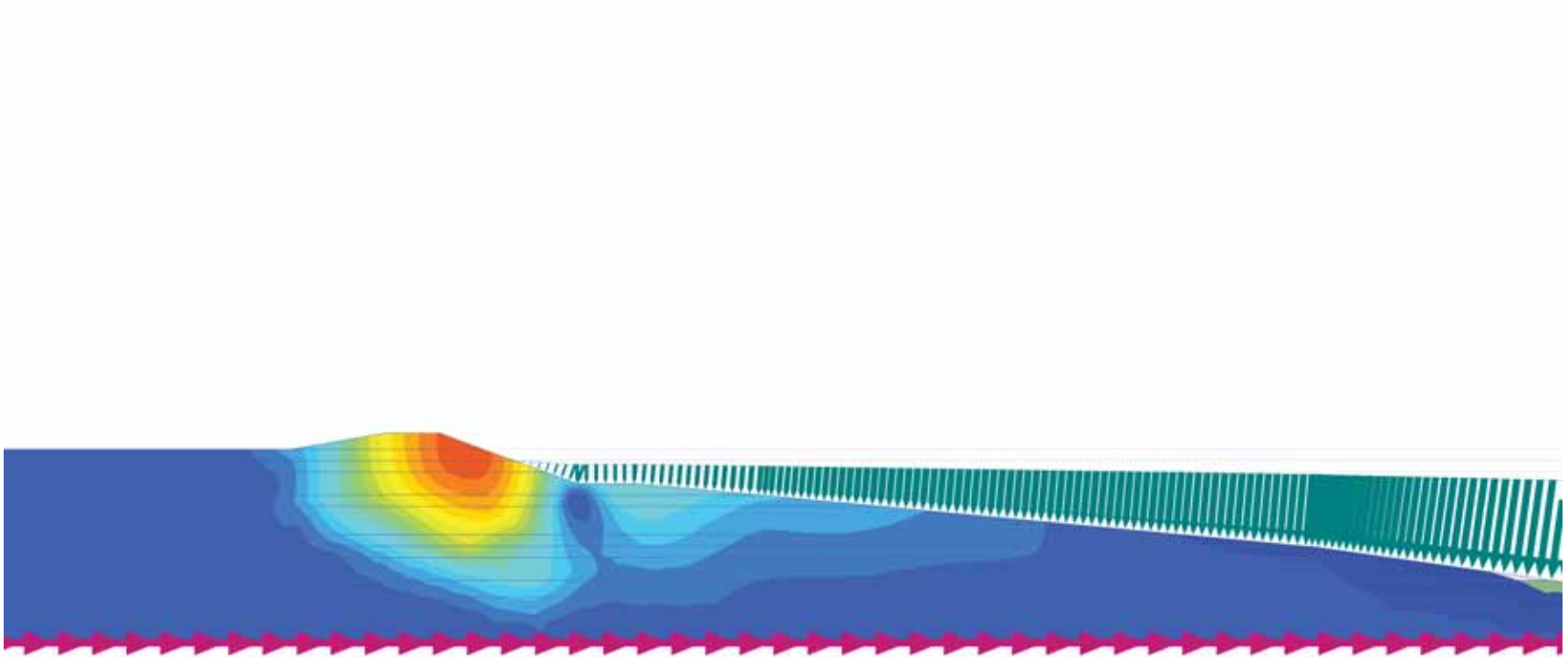
Phase displacements Pu_x

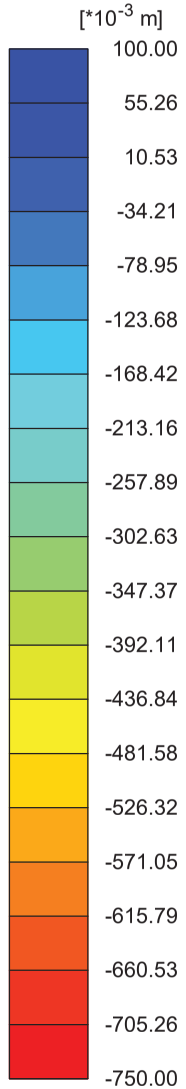
Maximum value = 1.494 m (Element 3764 at Node 4722)

Minimum value = -1.760 m (Element 4049 at Node 9726)

THURBER ENGINEERING LTD.

Project description		Date
No 4 Road_2475 In-slab_Horizontal displ.		9/8/2016
Project filename	*Step*	*User name*
No4 Road_r1-Crustal and ...	20091	Thurber Engineering Ltd





Phase displacements Pu_y

Maximum value = 0.1634 m (Element 5843 at Node 9150)

Minimum value = -0.6995 m (Element 495 at Node 10028)

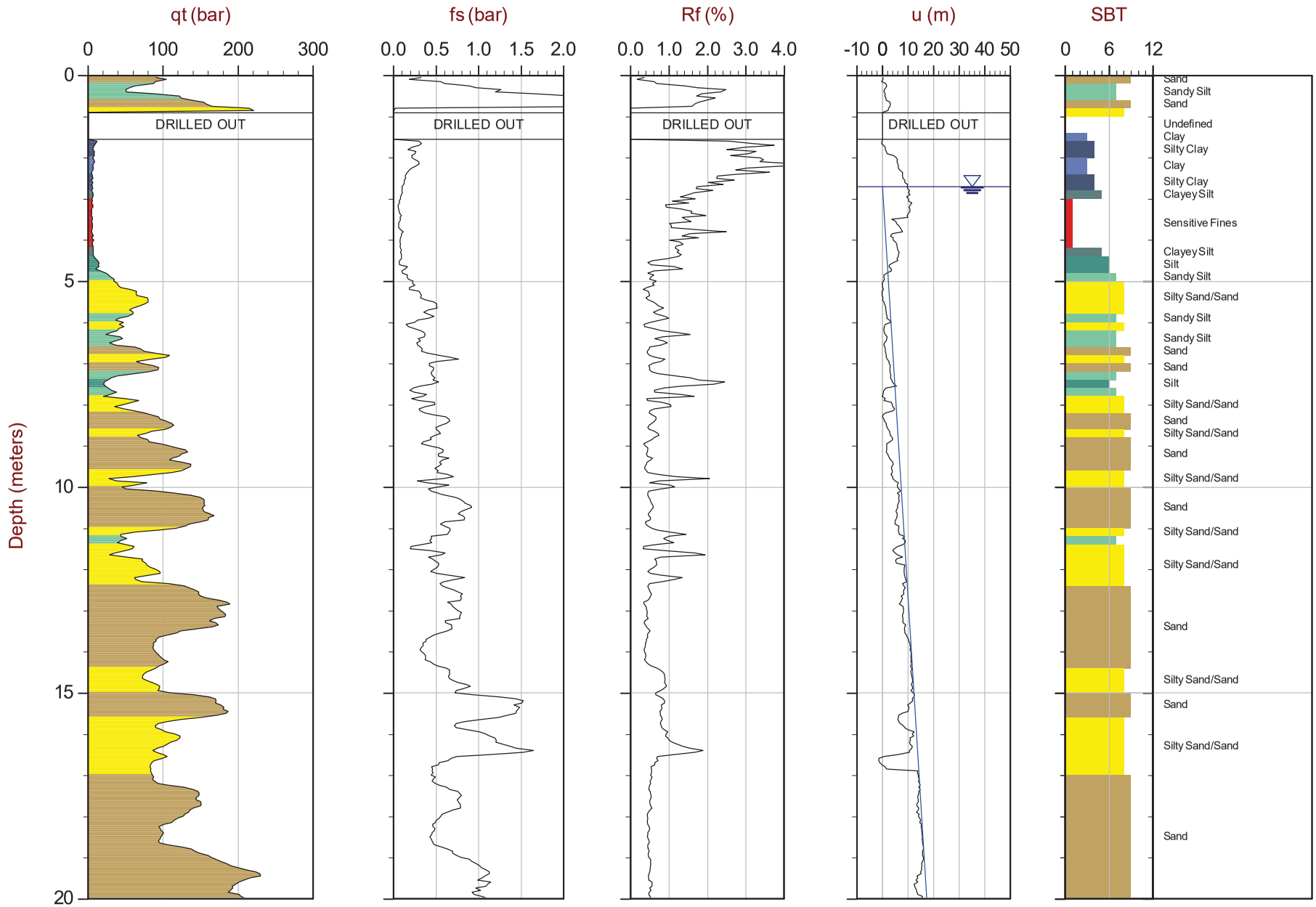
THURBER ENGINEERING LTD.	*Project description* No 4 Road_2475 In-slab_Vertical displ.		*Date* 9/8/2016
	Project filename No4 Road_r1-Crustal and ...	*Step* 20091	*User name* Thurber Engineering Ltd

CONETEC

MEG Consulting

Job No: 11-278
Date: 12:13:11 12:13
Site: No. 1 Road Pumphouse, Richmond, BC

Sounding: CPT11-06
Cone: 334:T1500F15U500



Max Depth: 24.700 m / 81.04 ft
Depth Inc: 0.050 m / 0.164 ft
Avg Int: 0.200 m

File: 278CP06.COR
Unit Wt: SBT Chart Soil Zones

SBT: Lunne, Robertson and Powell, 1997
Coords: UTM 10U N: 5446831m E: 486780m
Page No: 1 of 2

The reported coordinates were acquired from hand-held GPS equipment and are only approximate locations. The coordinates should not be used for design purposes.

CONETEC

MEG Consulting

Job No: 11-278
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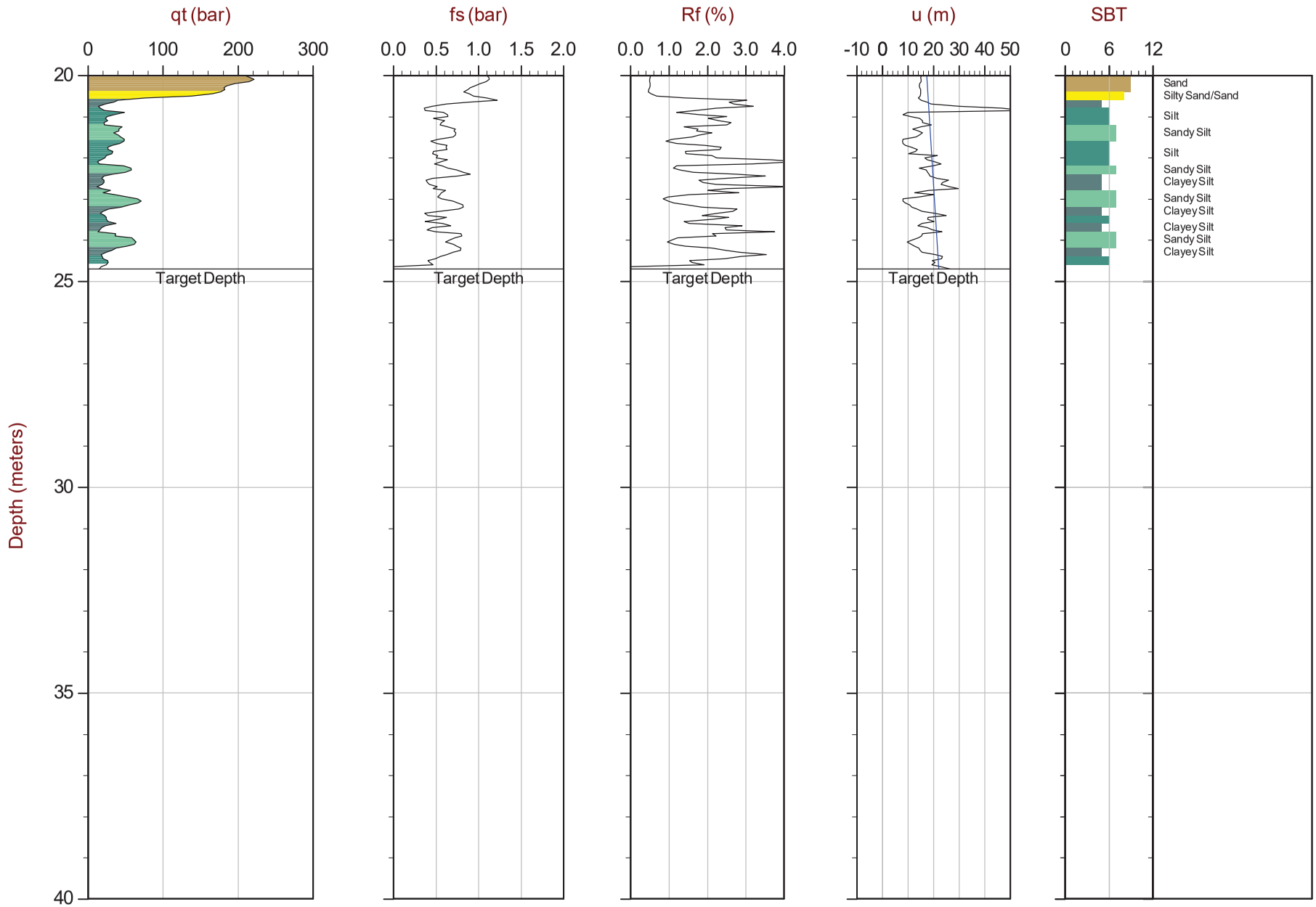
Cone: 334:T1500F15U500



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SBT: Lunne, Robertson and Powell, 1997
Coords: UTM 10U N: 5446831m E: 486780m
Page No: 2 of 2

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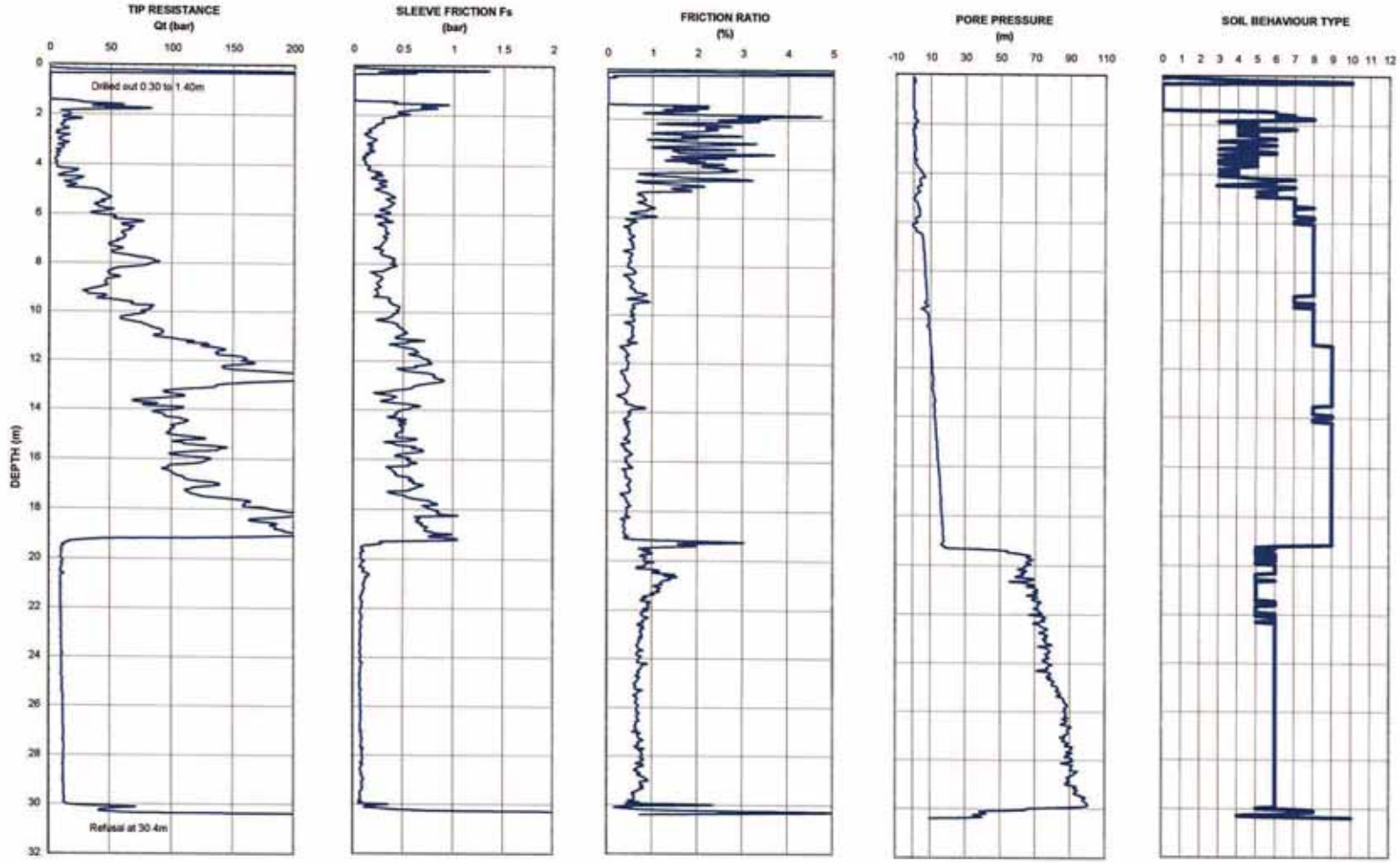
GeoPacific Consultants Ltd.	28-Mar-09	City of Richmond Engineering	GeoPacific Project #: 8081
	Sounding: SCPT09-01	No. 4 Rd. Pump Station at River Road, Richmond, BC	Figure: B.01



** Based on Robertson et. al 1986

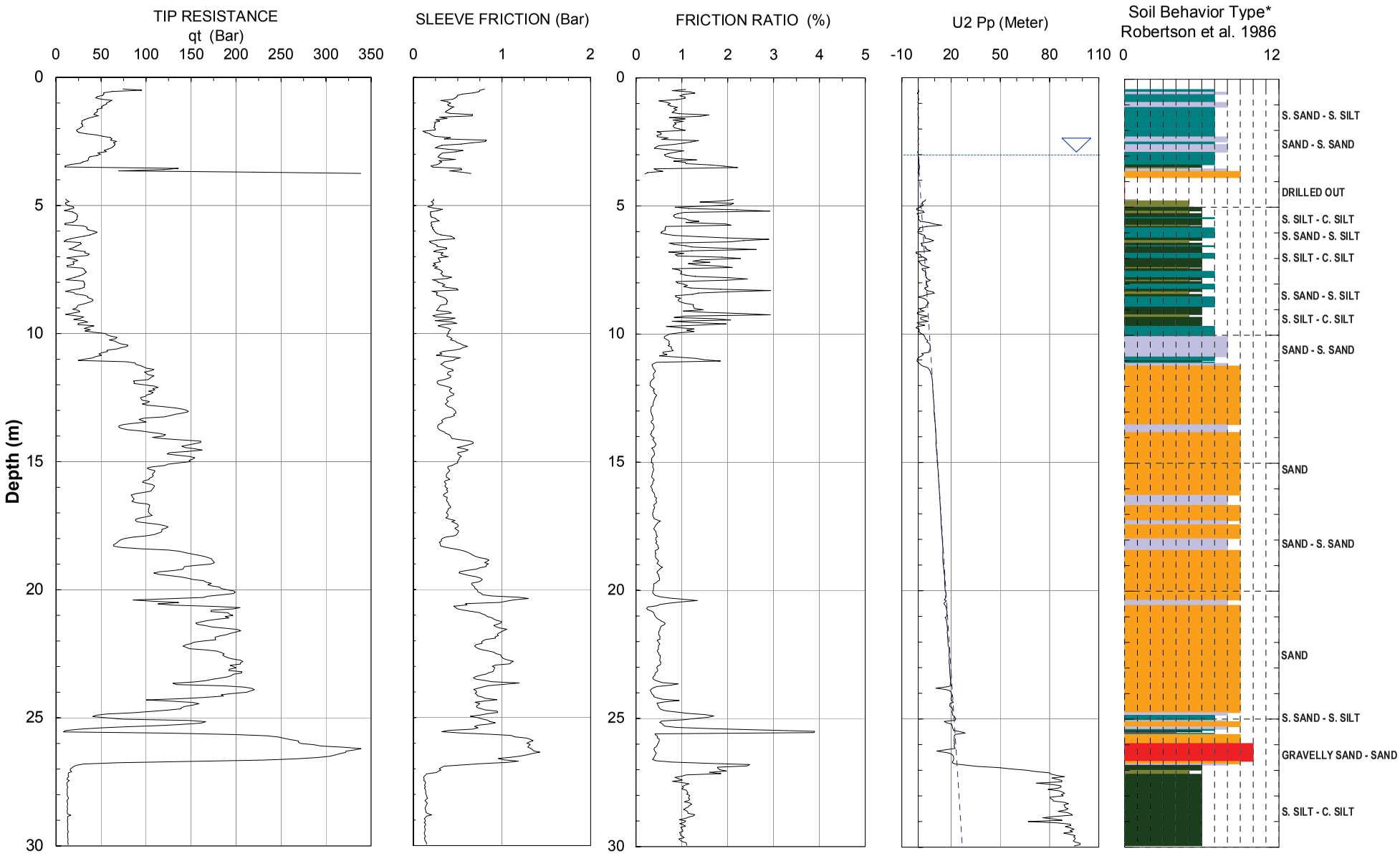
1 Sensitive Fine Grained
2 Organic Material
3 Clay
4 Silty Clay to Clay
5 Clayey Silt to Silty Clay
6 Sandy Silt to Clayey Silt
7 Silty Sand to Sandy Silt
8 Sand to Silty Sand
9 Sand
10 Gravelly Sand to Sand
11 Very Stiff Fine Grained
12 Sand to Clayey Sand

Marine + Earth MEG Geosciences

Operator: Schwartz Soil Technical
Sounding: SCPT13 - 01
Cone ID: DPG1110 10 Ton

Date: June 27, 2013
Site: Bath Slough Pump Station, Rmd
MEG Project No: 13 - 195 - 01

Schwartz SOIL TECH

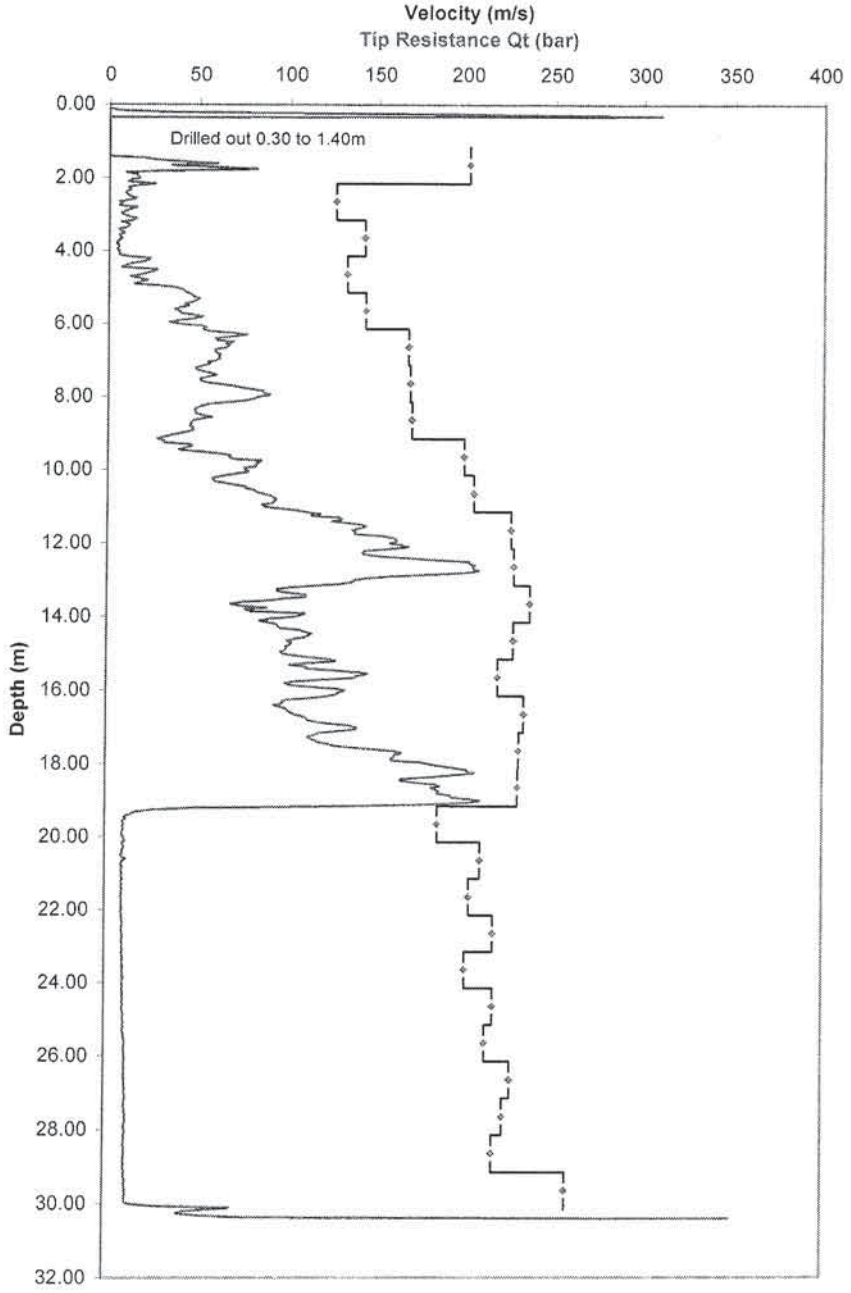


Maximum Depth = 29.95 meters

Depth Increment = 0.05 meters

1 sensitive fine grained
2 organic material
3 clay
4 silty clay to clay
5 clayey silt to silty clay
6 sandy silt to clayey silt
7 silty sand to sandy silt
8 sand to silty sand
9 sand
10 gravelly sand to sand
11 very stiff fine grained (*)
12 sand to clayey sand (*)

File: 8081
Project: Proposed Pump Station Upgrade
Client: City of Richmond Engineering
Site: No. 4 Rd. and River Rd., Richmond, BC
Sounding: SCPT09-01



Schwartz SOIL TECH

SHEAR WAVE VELOCITY PROFILE

Client: MEG
Test: SCPT13 - 01
Site: Bath Slough Pump Station
Richmond, B.C.

Date: June 27, 2013
Cone ID: DPG1110 10 Ton
Source offset: 0.80 m
Source: Beam