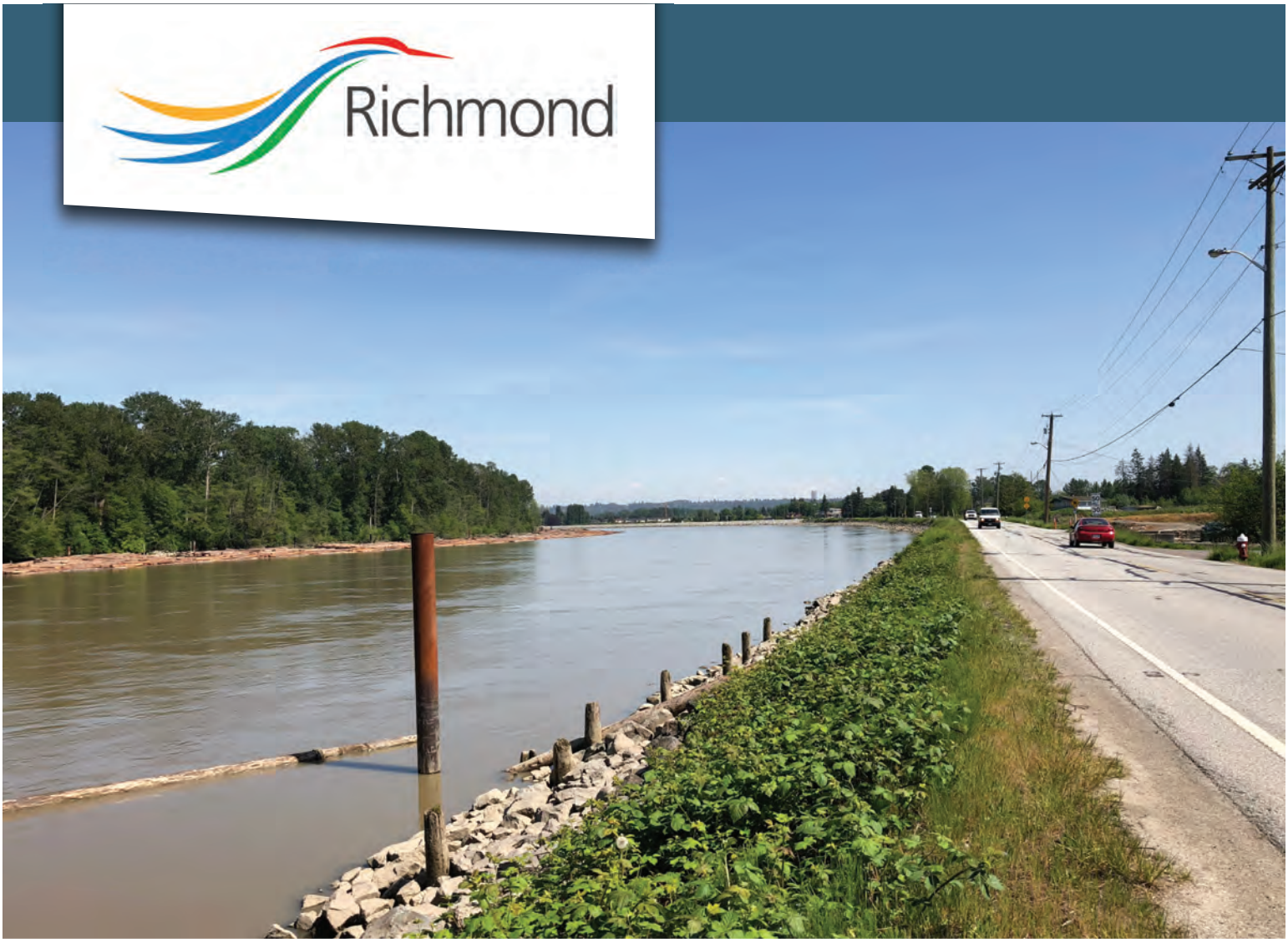
Richmond



Final Report

Richmond Dike Master Plan - Phase 4

April 28, 2023
KWL File No. 0651.122-300

Submitted by:

KERR WOOD LEIDAL
consulting engineers

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Executive Summary

The City of Richmond uses a Dike Master Planning program to guide future dike upgrading projects, and to ensure that land development adjacent to the dike is compatible with flood protection objectives. The program includes 4 phases for the 49 km of the Lulu Island perimeter dike that is within Richmond, plus another phase for Sea Island, Mitchell Island, and Richmond Island. The immediate goal is to raise the dikes to allow for 1 m of sea level rise, and to allow for further upgrading in the future. The ultimate goal is to provide the City with a world class level of flood protection to keep pace with the rapidly growing community that relies on the dikes.

Dike Master Plan Phase 4 covers 9 km of the Lulu Island perimeter dike along the Fraser River North Arm, between No. 6 Road and Boundary Road. The dike within Phase 4 is mainly under River Road, with private property inside and outside of the dike. Phase 4 land use along the dike corridor is primarily industrial in the west, agricultural in the middle, and residential/industrial in the east. Specific features within the Phase 4 area that complicate dike upgrading include River Road on top of the dike, driveways to private property inside and outside the dike, pedestrian and bicycle traffic and safety issues along the dike/road, utilities within the dike, large drainage channels immediately inside the dike, a railway trestle crossing above the dike, the North East Bog Forest, and liquefiable soils beneath the dike.

This report describes existing conditions, develops an ideal vision for dike upgrading, presents design criteria, identifies options for dike upgrading, and presents recommended dike upgrading options that appropriately address the challenges. This work can be used as a basis for design of dike upgrading projects, recognizing that site-specific refinement of recommended options will be required in some areas. This work can also be used to assist with land use planning activities along the dike corridor.

The main recommended upgrading option in Phase 4 involves separating the dike and River Road, and raising River Road to the dike crest elevation. This will produce a total crest (dike plus road) width of over 20 m which will provide robust flood protection, separated multi-use paths and a linear park, and utilities relocated out of the dike.

Some of the additional features of the recommended options in Phase 4 are described below:

- Raise the dike crest to allow for 1 m of sea level rise. West of Nelson Road, the raised dike crest would be 4.7 m (CGVD28). East of Nelson Road, the raised dike crest would increase to 5.1 m at Boundary Road. The plan also allows for longer term upgrading to accommodate a further 1 m of sea level rise (i.e. 2 m of sea level rise).
- Replace the drainage channel immediately inside the dike with storm sewers and swales. This will improve dike stability, and will provide some of the land needed to relocate River Road.
- Raise land and roads immediately inside the dike (during redevelopment) to improve seismic resilience. This will also improve liveability by allowing residents to looking down over the water.
- Construct the north section of a secondary dike near Boundary Road.

It is also recommended that the City prepare a comprehensive implementation plan for dike upgrading that incorporates the elements of the Phase 4 Dike Master Plan, and the elements of the other Dike Master Plans.

To address habitat compensation issues associated with dike upgrading, it is further recommended that the City consider development of a habitat banking program that could provide effective large-scale compensation.

1. Introduction

Flood protection in Richmond is guided by the City's 2008-2031 Flood Protection Management Strategy which includes a comprehensive suite of measures including structural measures (e.g. dikes and pump stations), non-structural measures (e.g. flood construction levels), and flood response and recovery plans.

Dike Master Plans are critical components of the City's 2008-2031 Flood Protection Management Strategy and are used to guide the implementation of long-term dike upgrades.

The City of Richmond (City) has retained Kerr Wood Leidal (KWL) to prepare the Richmond Dike Master Plan Phase 4. The report was essentially completed and a draft report submitted in November 2018. The current final submission includes a summary of some additional stakeholder and public feedback received since the 2018 submission. The Flood Protection Management Strategy Update was submitted in May, 2019 and updates the 2008-2031 Flood Protection Management Strategy. Some of the results of this update may not be reflected in the Dike Master Plan Phase 4 because it was written first. Also, cost estimates were completed in 2018 dollars.

Phase 4 covers the north-eastern portion of the Lulu Island perimeter dike, from No. 6 Road to Boundary Road (City of New Westminster). Figure 1-1 presents the extent of the City's Dike Master Plan phases. Phase 4 has been subdivided into 6 reaches with relatively uniform conditions. Figure 1-2 shows the reaches of the Phase 4 Dike Master Plan.

1.1 Background

Richmond has a population of about 220,000 and is situated entirely on islands within the overlapping Fraser River and coastal floodplains (Lulu Island, Sea Island, Mitchell Island, Richmond Island, etc.). The City's continued success is due in part to its flat, arable land and its strategic location at the mouth of the Fraser River and on the seashore. The low elevation of the land and its proximity to the water comes with flood risks.

Lulu Island is the most heavily developed part of Richmond. Lulu Island is bounded by the Fraser River and the Strait of Georgia and is subject to flood risks from the Fraser River and the sea. Lulu Island is also subject to other flood-related hazards, including dike breach, seismic effects, internal drainage, tsunami, and river instability. The typical natural ground elevation[1] is in the range of 1 m to 2 m as shown on Figure 1-1.

The cornerstone of the Lulu Island flood defenses is a 49 km long perimeter dike. Internal drainage is provided by an integrated system of channels and storm sewers that drain to 39 pump stations / floodboxes. Richmond occupies over 90% of Lulu Island. The balance of Lulu Island (the upstream end) is occupied by the Queensborough neighbourhood of the City of New Westminster.

As Richmond is fully situated within the river/coastal floodplain, there is no option to locate development out of the floodplain. The continued success of the City depends on providing a high level of structural and non-structural flood protection measures. Without continued improvements, the flood risk within the City would progressively rise as a result of rising flood levels (due to climate change), subsiding land, and increasing development.

[1] All elevations in this report refer to the Canadian Geodetic Vertical Datum of 1928 (CGVD28), unless stated otherwise.

The 2008-2031 Flood Protection Management Strategy guides the City's flood risk reduction activities across the City's organizational structure and across the spectrum of structural and non-structural flood protection measures.

The Lulu Island perimeter dike is the most critical structural flood protection measure. With essentially unlimited inflow available from the Fraser River and the sea, significant flood damages and impacts could occur in the event of a dike breach.

1.2 Purpose and Objectives

The purpose of the Dike Master Plan is to guide the implementation of dike upgrades and provide a starting point for the City to work with proposed developments adjacent to the dike. The Dike Master Plan defines the City's preferred and minimum acceptable dike upgrading concepts.

The Dike Master Plan facilitates the City's annual dike upgrading program by providing critical information for the design of dike upgrades, including:

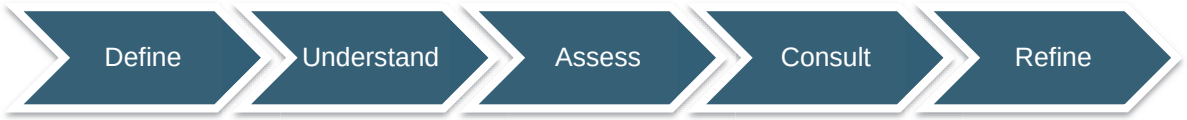
- general design concept;
- alignment;
- typical cross-section (conceptual design);
- footprint and land acquisition and tenure needs;
- design and performance criteria;
- infrastructure changes required for dike upgrading;
- operation and maintenance considerations;
- environmental features and potential impacts;
- social and public amenity considerations;
- guidance for future development adjacent to the dike; and
- guidance on interaction with other structural flood protection measures (e.g. secondary dikes).

The Dike Master Plan is intended to guide dike upgrading over the next 20 to 30 years.

Other flood protection measures, including non-structural measures, are addressed in the City's 2008-2031 Flood Protection Management Strategy.

1.3 Approach and Methodology

The Dike Master Plan has been developed using a 5-step approach presented and described below.



Define: Confirm Dike Master Plan objectives and design/performance criteria.

Understand: Collect and compile relevant information, including spatial data and background reports from the City and several other parties (City of New Westminster, provincial regulators, the port, etc.).

Assess: Develop dike upgrading options and identification of constraints and potential impacts. Desktop and field review of options with City staff to identify preferred options.

Consult: Present to and gather feedback from council and stakeholders on preferred options.

Refine: Develop the master plan informed by consultation and review by the City.

The scope for the Dike Master Plan includes the following main tasks:

- goals and objectives development;
- background data collection and review;
- design criteria development and identification of constraints;
- options development and review;
- site visits;
- drainage impacts assessment;
- desktop habitat mapping and impacts review;
- geotechnical assessment;
- public amenity review;
- stakeholder consultation; and
- report preparation.

1.4 Report Format

This report is organized as follows:

- The executive summary provides a high-level overview of the master plan and key features;
- Section 1 introduces the master plan context and process;
- Section 2 documents the existing conditions;
- Section 3 documents the options development and assessment, and presents the recommended options;
- Section 4 provides implementation strategy, including costs, phasing, and coordination;
- Section 5 is a compilation of 2-page summary sheets highlighting existing conditions and key features of the preferred option for each reach; and
- Section 6 provides general and reach specific recommendations for next steps and implementation.

Appendix A provides figures showing conditions along the existing dike alignment, and the preliminary design footprint for a number of upgrading options discussed in Section 3.

1.5 Project Team

The KWL project team includes the following key individuals:

- Colin Kristiansen, P.Eng., MBA – Project Manager;
- Mike Currie, M.Eng., P.Eng., FEC – Senior Engineer and Technical Reviewer;
- Amir Taleghani, M.Eng., P.Eng. – Project Engineer;
- Laurel Morgan, M.Sc., P.Eng., P.E. – Drainage Engineer;
- Daniel Brown, B.Sc., B.Tech., BIT – Project Biologist; and
- Jack Lau - GIS/CAD Analyst.

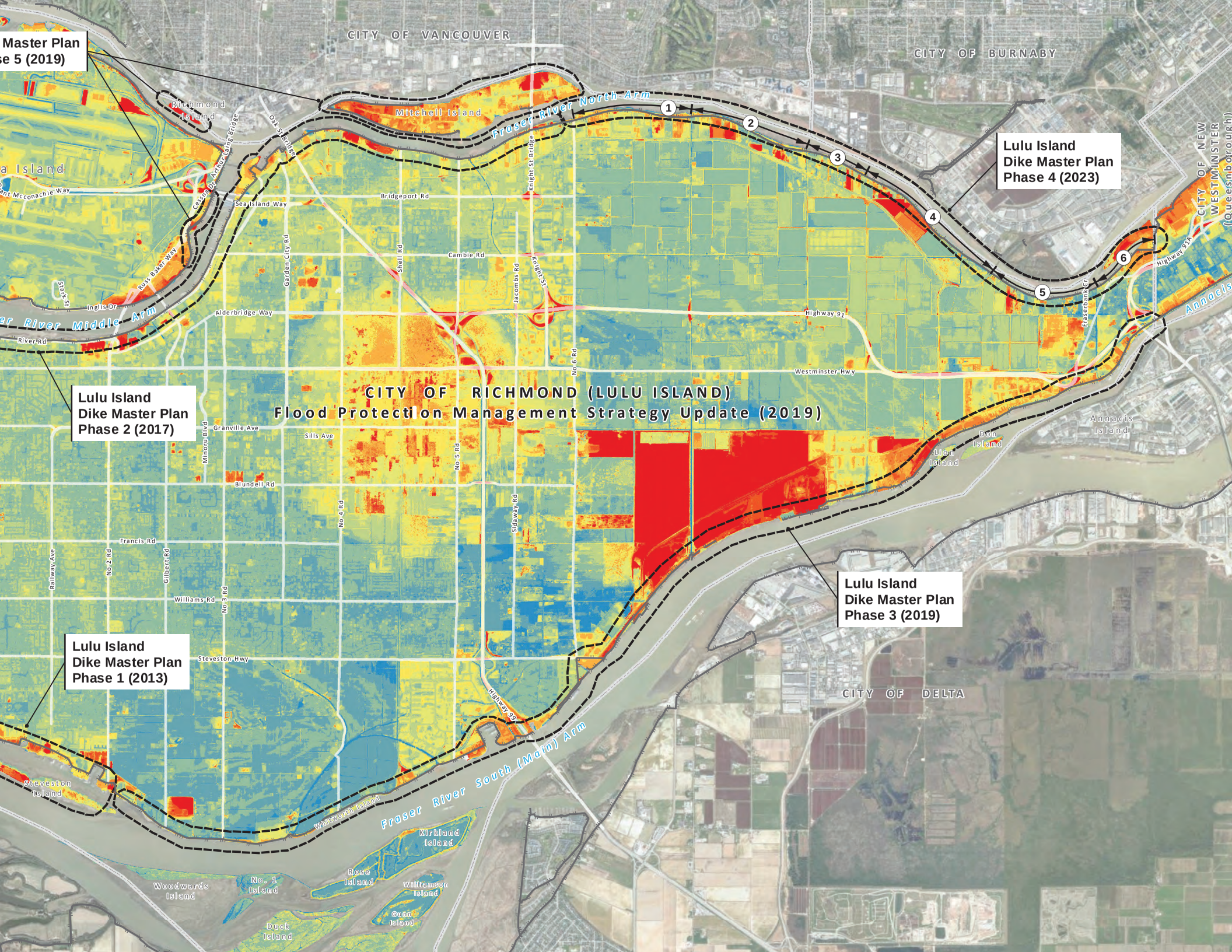
This report was primarily written by Amir Taleghani, and reviewed and updated by Colin Kristiansen. The report was reviewed by Mike Currie.

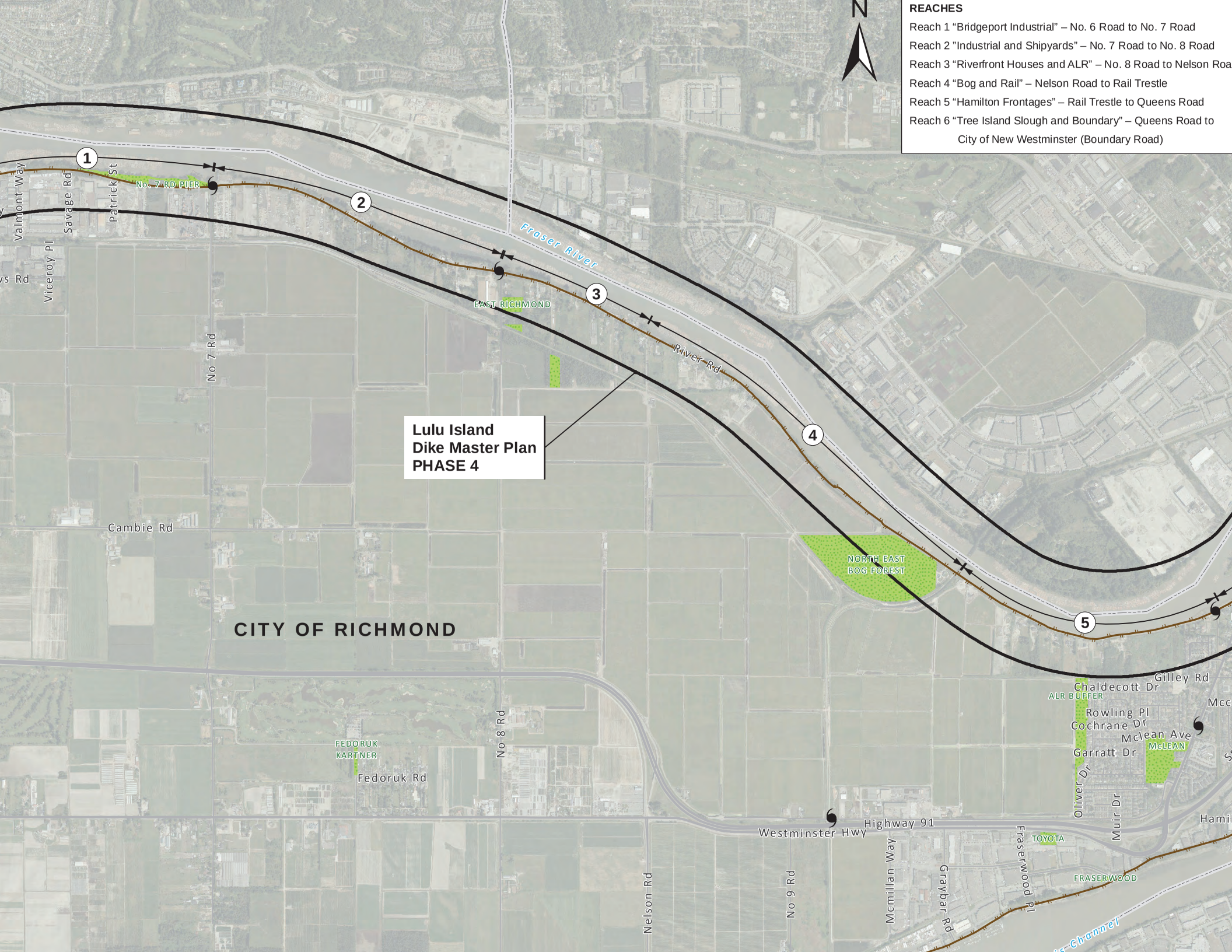
Thurber Engineering Ltd. (Steven Coulter, M.Sc., P.Eng.) provided geotechnical engineering services and Hapa Collaborative (Joseph Fry, BCSLA) provided landscape architecture services.

The project was guided on behalf of the City by:

- Lloyd Bie, P.Eng. – Director, Transportation;
- Corrine Haer, P.Eng. – Project Engineer, Engineering Planning;
- Pratima Milaire, P.Eng., PMP - Project Engineer, Engineering Planning.
- Ridhi Dalla, EIT - Project Manager, Engineering Planning; and
- Eric Sparolin, P.Eng. – Manager, Engineering Planning;

Many additional City staff contributed to the project during workshops, site visits, and in reviewing draft report materials.


Master Plan
se 5 (2019)
CITY OF VANCOUVER
CITY OF BURNABY
Richmond Island
Mitchell Island
Fraser River North Arm
Oak St Bridge
Knight St Bridge
Lulu Island
Dike Master Plan
Phase 4 (2023)
Bridgeport Rd
Sea Island Way
Cambie Rd
Alderbridge Way
Highway 91
Westminster Hwy
Fraser River Middle Arm
Lulu Island
Dike Master Plan
Phase 2 (2017)
CITY OF RICHMOND (LULU ISLAND)
Flood Protection Management Strategy Update (2019)
Granville Ave
Sills Ave
Blundell Rd
Francis Rd
Williams Rd
Steveston Hwy
Annacis Island
Lion Island
Don Island
Lulu Island
Dike Master Plan
Phase 3 (2019)
Lulu Island
Dike Master Plan
Phase 1 (2013)
CITY OF DELTA
Fraser River South (Main) Arm
Steveston Island
Whiskey Island
Kirkland Island
Rose Island
Williamson Island
Gunn Island
No. 1 Island
Woodwards Island
Duck Island
CITY OF NEW WESTMINSTER
(Queensborough)


N
REACHES
Reach 1 "Bridgeport Industrial" – No. 6 Road to No. 7 Road
Reach 2 "Industrial and Shipyards" – No. 7 Road to No. 8 Road
Reach 3 "Riverfront Houses and ALR" – No. 8 Road to Nelson Road
Reach 4 "Bog and Rail" – Nelson Road to Rail Trestle
Reach 5 "Hamilton Frontages" – Rail Trestle to Queens Road
Reach 6 "Tree Island Slough and Boundary" – Queens Road to City of New Westminster (Boundary Road)
1
2
3
4
5
Lulu Island
Dike Master Plan
PHASE 4
Fraser River
No. 7 RD PIER
EAST RICHMOND
River Rd
No 7 Rd
Valmont Way
Savage Rd
Patrick St
Viceroy Pl
Cambie Rd
NORTH EAST
BOG FOREST
CITY OF RICHMOND
Gilley Rd
Chaldecott Dr
ALR BUFFER
Rowling Pl
Cochrane Dr
Mclean Ave
McLEAN
Garratt Dr
Oliver Dr
Muir Dr
FEDORUK
KARTNER
Fedoruk Rd
No 8 Rd
Westminster Hwy
Highway 91
TOYOTA
FRASERWOOD
Fraserwood Pl
Mcmillan Way
Graybar Rd
Nelson Rd
No 9 Rd

2. Existing Conditions

This section summarizes the options development process undertaken, including the following components:

- review of existing conditions;
- design considerations;
- upgrading strategies; and
- preferred options and concepts.

2.1 Reaches and Major Features

River Road is a defining feature of the dike in Phase 4 because the road is located on the dike crest for most of the dike alignment. A variety of land uses, structures, and infrastructure are located on either side of the road/dike. Space is limited along the road corridor, presenting unique challenges for the master plan. City staff have identified road safety, including pedestrian and cyclist safety, as an important consideration for the Dike Master Plan.

Land uses adjacent to the dike in Phase 4 comprise industrial, agricultural, and single family residential. Drainage channels run parallel to River Road on the south side. On the north side of River Road, the setback between the river bank and the dike (road) varies from more than 15 m to none where the edge of the dike/road is the river bank and riprap bank protection is in place. Several industrial and single family residential parcels are located on the river-side (north) of the dike (road), and therefore are not protected by the dike. Much of the dike alignment is adjacent to, or in some places on, the Agricultural Land Reserve (ALR).

Phase 4 has been subdivided into 6 reaches with relatively uniform conditions. The reach extents are presented on Figure 1-2.

Table 2-1 describes the existing conditions and features of each reach. It is anticipated that these defined reaches can be subsequently used for dike upgrading implementation phasing.

Appendix A provides a set of figures showing the existing dike alignment, adjacent land tenure, municipal infrastructure, and existing habitat.

Table 2-1: Phase 4 Reaches and Features

Reach ID and Name	Extent / Length	Existing Dike Alignment	Major Features
1 – Bridgeport Industrial	No. 6 Road to No. 7 Road (1.7 km)	River Road	• Drainage pump station at No. 6 Road • Industrial site (Mainland Sand and Gravel) north of River Road • FortisBC gas pipeline river and facility west of No. 7 Road • Drainage channel and pipe south of road • Riparian area north of road • Potential future tie-in with proposed mid-island dike
2 – Industrial and Shipyards	No. 7 Road to No. 8 Road (1.7 km)	River Road	• Water-oriented industrial parcels located north of road (tug boat operation and Tom-Mac Shipyards) • Residential/storage properties located north of road with minimal setback between road and structures • Large industrial parcels located south of road near No. 7 Road • ALR parcels with houses located south of road • Drainage pump station at No. 8 Road
3 – Riverfront Houses and ALR	No. 8 Road to Nelson Road (0.9 km)	River Road	• Residential/storage properties located north of road with minimal setback between road and structures near Nelson Road • ALR parcels with houses located south of road • Metro Vancouver Tilbury watermain crossing near Nelson Road
4 – Bog and Rail	Nelson Road to Rail Trestle (2.2 km)	River Road	• ALR parcels with cranberry farms south of road • Very large agricultural channel south of dike • North East Bog Forest (City park) • Rail trestle river crossing • No space between road edge and river channel (existing riprap bank protection)

Reach ID and Name	Extent / Length	Existing Dike Alignment	Major Features
5 – Hamilton Frontages	Rail Trestle to Queens Road (1.6 km)	River Road	• ALR parcels south of road with houses located close to road • No space between road edge and river channel (existing riprap bank protection) • Metro Vancouver Big Bend forcemain crossing west of 21920 River Road • Queens North drainage pump station west of Westminster Highway
6 – Tree Island Slough and Boundary	Queens Road to City of New Westminster (1.0 km)	River Road until Westminster Highway Riverbank to Hamilton Transit Centre	• River Road dike alignment from Queens Road to Westminster Highway, then a river-bank dike runs north of Westminster Highway houses to edge of new Hamilton Transit Centre • Tree Island Steel site (3933 Boundary Road) creates a slough north of the dike that shelters the road/dike from the river • Backyards of single family homes located south of dike • Dike alignment not well defined from Hamilton Transit Centre to City of New Westminster river-bank dike • Potential tie-in with proposed secondary dike to separate Richmond and New Westminster

2.2 Land Tenure

Most of the existing dike footprint is located within the City's road dedication, on a right-of-way, or on City-owned land parcels. However, there are several areas where the existing dike footprint encroaches onto private property or where space is very limited such that any upgrading would encroach onto private property.

The existing land tenure in Phase 4 is presented on Figure 2-1 and in more detail in Appendix A.

2.3 Infrastructure

There is considerable infrastructure and utilities associated with the existing dike corridor in Phase 4. In addition to the road that runs along the top of the dike for much of the reach, there are also watermains, drainage channels, and storm sewers that run parallel to the dike, predominantly at the landside toe. This infrastructure may need to be moved to accommodate any increases to the dike footprint.

There are 4 pump stations and 1 PRV (water) station that cross through the dike in Phase 4. The pump stations and the associated reach are summarized in Table 2-2. The condition of each pump station was not assessed as part of preparing the master plan.

Table 2-2: Phase 4 Pump Stations and Reach Locations

Pump Station	Reach
No. 6 Road North	1
No. 7 Road North	1
No. 8 Road North	2
Queens North	6

2.4 Habitat

Desktop Review

A desktop review was conducted to assess the ecological setting along and adjacent to the existing dike alignment. Spatial data were used to identify overlap of known environmental values with the Phase 4 study area.

Spatial data reviewed in the desktop study included:

- Fraser River Estuary Management Program mapping (FREMP 2012, 2007) mapping used to identify riparian and intertidal habitat types and quality;
- iMapBC web application (iMapBC 2017); and
- City of Richmond aerial photographs and Riparian Area Regulation 5 m and 15 m buffer layers (Richmond Interactive Map 2017).

The location and extent of high quality Fraser River riparian and intertidal habitat was identified to inform development of dike upgrade options and their potential impacts. FREMP habitat polygons were assigned the following categories: high quality riparian, high quality intertidal, or other. Deciduous tree woodland polygons were categorized as high quality riparian habitat because these communities provide cover and nutrients to fish using nearshore habitat. Mud, sand, and marsh polygons were

categorized as high quality intertidal habitat because of the foraging and nesting habitat they provide for bird species and the foraging, egg deposition and rearing habitat they provide for fish species. Aquatic and riparian habitat on the land side of the existing dike was identified and mapped using the Riparian Area Regulation buffer layers and interpretation of recent aerial photography (City of Richmond 2017).

Aquatic and Riparian Habitat

High quality intertidal and riparian habitat is present in all six Phase 4 reaches on the Fraser River side of the dike. This important habitat provides forage and cover habitat as well as a staging area for anadromous salmonids transitioning from saltwater to freshwater. Conversely, armoured sections of shoreline on the Fraser River side of the existing dike are present in Reaches 1, 4, 5, and 6. These sections provide limited habitat value and construction here would have less of a negative impact on fish.

On the land-side of the dike, drainage channels are present in all six reaches. These channels provide low to moderate quality aquatic and riparian habitat for fish and amphibians.

Two fish habitat compensation projects are present in the Phase 4 study area. These were created in 1986 and 1989 respectively and included the creation of intertidal marsh habitat to compensate for damage to habitat elsewhere.

Wildlife and Terrestrial Habitat

Terrestrial habitat types in Phase 4 include deciduous tree woodland, tall shrub woodland, low shrub woodland, and vascular plant meadow, as well as uncategorized sections (e.g. paved lots; FREMP 2007). These habitat types have potential to provide nesting habitat to migratory birds in all six reaches of Phase 4. Orthoimagery review identified potential raptor nesting trees in all six reaches of the Phase 4 study area.

The internal drainage channels that are mentioned above and are present in all six reaches of Phase 4 are likely used by native amphibian species as breeding habitat as well as by fish species. It is possible that additional amphibian habitat is present in small ponds or channels along the dike that were not identified in the desktop review.

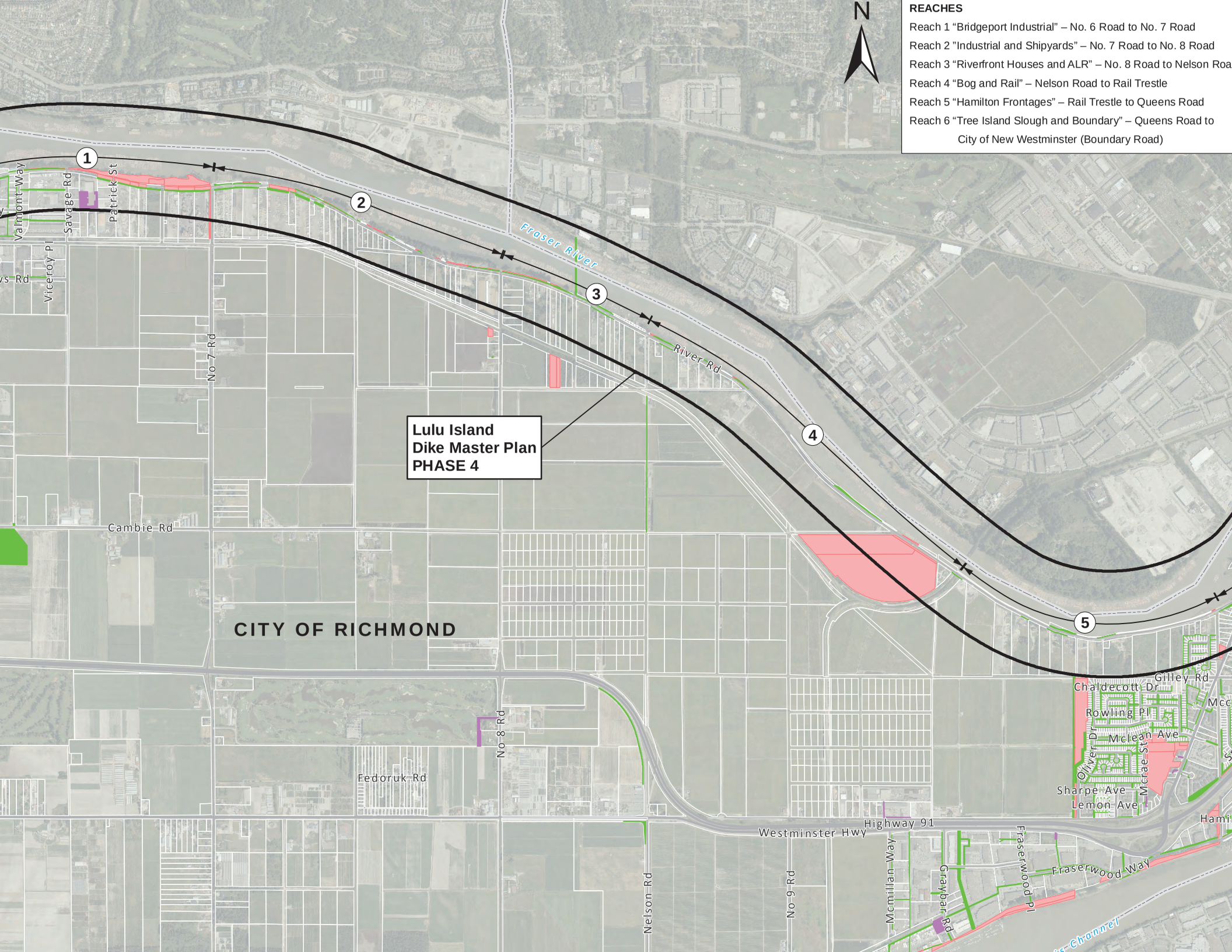
Species and Ecological Communities at Risk

No known occurrences of terrestrial wildlife species at risk are present in the Phase 4 study area, but several occurrences exist on nearby islands in the Fraser River or on the river banks across from Richmond. It is possible that individuals of these species also occur on the Richmond side of the Fraser River. The Lower Fraser River population of White Sturgeon (*Acipenser transmontanus* pop. 4) is known to occur in the Fraser River next to the dike. Mapped critical habitat for at-risk species is not present within 500 m of the Phase 4 study area.

FREMP mapping (2007) indicates the presence of intertidal marsh communities in all six reaches of the Phase 4 study area. Many of these communities in British Columbia are considered at-risk (i.e. Blue-Listed; special concern, or Red-Listed; threatened, or endangered). No ecological communities at-risk are shown in either the study area on BC iMap (2017), but it is likely that some are present in the Phase 4 study area.

Table 2-3 presents the findings of the desktop review on a reach-by-reach basis and separates Fraser River side results from land-side results.

	Environmental Setting	Construction Constraints	Construction Opportunities	FREMP Habitat Types	Known Species at Risk Occurrence Near Dyke Alignment	Potential Raptor Nesting Trees	M Ne
	• Sections of channelized watercourse (amphibian habitat) • Sections of moderate quality low shrub woodland	Drainage channels and moderate quality habitat	Limited sections without drainage channels or shrub woodland	Low shrub woodland Deciduous tree woodland Meadow	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	
ide	• Low-quality habitat, gravel lot and armoured bank at west end • High quality deciduous treed woodland riparian habitat along east 3/4 of reach • High Quality marsh and mudflat habitat along east 3/4 of reach	High quality riparian and aquatic habitat in east 3/4 of reach	Low quality habitat at west end of reach	Marsh Deciduous tree woodland Mudflats Meadow			
	• Channelized watercourse adjacent to dike (amphibian habitat) along full length of reach	Drainage channels along full length of reach	n/a	Deciduous tree woodland Meadow	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	
ide	• High-quality deciduous tree woodland riparian habitat along 75% of reach • High-quality marsh and mudflats habitat along 90% of reach	High quality habitat along >90 % length of reach	n/a	Deciduous tree woodland Marsh Mudflats Meadow			
	• Channelized watercourse adjacent to dike (amphibian habitat) along full length of reach	Drainage channels along full length of reach	n/a	Deciduous tree woodland Meadow	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	
ide	• High-quality deciduous tree woodland riparian habitat along 75% of reach • High-quality marsh habitat along full length of reach	High quality habitat along full length of reach	n/a	Marsh Deciduous tree woodland			
	• Channelized watercourse adjacent to dike (amphibian habitat) along full length of reach • High-quality shrubland habitat connected to North East Bog Forest in east end of reach	Drainage channels along full length of reach	n/a	Deciduous tree woodland Meadow Low shrub woodland Tall shrub woodland	Green-fruited Sedge (Carex interrupt)	Y	
ide	• High quality deciduous tree woodland riparian habitat along west 60% of reach. • High-quality marsh habitat along west 60% of reach • Low quality armoured bank habitat in east 40% of reach	High quality habitat along west 60% of reach	Low quality habitat at least 40% of reach	Deciduous tree woodland Marsh	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)		
	• Channelized watercourse adjacent to dike (amphibian habitat) along full length of reach • Moderate quality low shrub woodland and meadow in middle of reach	Drainage channels along full length of reach	n/a	Meadow Low shrub woodland Tall shrub woodland	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	
ide	• High-quality mudflat habitat and small patches of marsh at east end of reach • Low quality armoured bank habitat along full length of reach	High quality habitat along east half of reach	Low quality habitat at west end of reach	Mudflat Marsh			
	• Channelized watercourse adjacent to dike (amphibian habitat) along west end of reach • Mostly low-quality habitat, paved or maintained lawn	Drainage channels along west end of reach	Low quality habitat along most of reach	Tall shrub woodland Deciduous tree woodland	White Sturgeon (Lower Fraser River population) (Acipenser transmontanus pop. 4)	Y	
ide	• High quality mudflat habitat and small patches of marsh at west end of reach • Low quality habitat armoured bank at west half of reach	High quality habitat along full length of reach	Low quality habitat at west end of reach	Mudflat Marsh Meadow			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1
2
3
4
5
Lulu Island
Dike Master Plan
PHASE 4
Fraser River
River Rd
Valmont Way
Savage Rd
Patrick St
Viceroy Pl
No 7 Rd
Cambie Rd
CITY OF RICHMOND
No 8 Rd
Fedoruk Rd
Gilley Rd
Chaldecott Dr
Rowling Pl
Mclean Ave
Oliver Dr
Mcrae St
Sharpe Ave
Lemon Ave
Highway 91
Westminster Hwy
Mcmillan Way
Graybar Rd
Fraserwood Pl
Fraserwood Way
Nelson Rd
No 9 Rd

3. Options Assessment

This section summarizes the options development process, including the following components:

- design considerations and design criteria;
- upgrading strategies;
- upgrading options and concepts;
- options evaluation; and
- recommended options for implementation.

The next version of the draft report will include a summary of external stakeholder engagement results.

3.1 Design Considerations

This section summarizes the main themes and issues that have informed the development of upgrading strategies and options for Phase 4.

Dike Performance, Maintenance, and Upgrading

Dike performance, maintenance, and upgrading are the most important design considerations for the Dike Master Plan.

The following themes define an ideal vision for dike upgrading:

1. **Level of Protection:** The City's 2008-2031 Flood Protection Management Strategy sets a target level of protection for structural measures. The City is presently developing an updated flood protection management strategy that will have an even more ambitious flood protection level target. The level of protection translates to a hazard-based design flood scenario to be incorporated into the Dike Master Plan. At this time, the proposed design flood scenario for the Lulu Island perimeter dike is the 500-year return period flood event (0.2 % annual exceedance probability, AEP) with climate change allowances including 1 m of sea level rise. However, the Dike Master Plan should be flexible to accommodate a future change in the design flood scenario in the future.
2. **Form and Performance:** The preferred form of the dike is a continuous, compacted dike fill embankment with standard or better geometry. Walls and other non-standard forms are less reliable and are not preferred. The level of performance of the Lulu Island perimeter dike should be in line with the significant population and assets that the dike protects. The dike should meet all relevant design guidelines of the day and in some cases, exceed guidelines to provide a higher level of performance. Dike performance can be expressed in terms of freeboard above the design flood scenario water level, and factors of safety against various failure processes, including flood conditions and internal erosion (piping).
3. **Passive Operation:** Minimal human or mechanical intervention or operation should be required to achieve full dike performance. To achieve this, the dike should not have any gaps, gates, or stop log structures.
4. **Enhance Performance** (slow failure)**:** The likelihood of a catastrophic dike failure causing significant flood damages can be reduced by design features that aim to slow down failure processes, provide redundancy, and provide time to implement emergency repairs. In general, failure can be slowed or controlled with additional setback, crest width, and armouring of the river-side slope, crest, and land-side slope. Such measures can slow the impacts of river erosion, overtopping erosion, and stability failures. Increased monitoring approaches and technology may also be helpful.

5. **Post-earthquake Protection:** The dike should provide adequate protection following a major earthquake until permanent repairs can be implemented. In general, this means avoiding dike conditions where a major earthquake results in a sudden and full failure of the dike cross-section into the river, referred to as a 'flowslide failure'. Other conditions where the dike crest settles, but still provides sufficient freeboard and factors of safety until repairs can be conducted may be acceptable. In general, increased crest width, crest elevation, and setback from the river may be undertaken to help achieve adequate post-earthquake protection. In some cases, improved seismic performance will also require ground improvement and densification works.
6. **Future Upgrading:** Uncertainty in climate change, particularly sea level rise timing, may require the City to further upgrade the dike sooner or higher than anticipated by current guidelines and policies. Sufficient space should be reserved under secured land tenure for future upgrading based on standard geometry. Conceptual design is provided for design flood levels which incorporate 1 m of sea level rise, and proof-of-concept design is provided for design flood levels which incorporate another 1 m water level increase for further climate change impacts (i.e. 2 m of sea level rise).

Some specific design considerations related to the above principles are presented in Table 3-1.

Table 3-1: Ideal Dike Design Principles and Considerations

Design Principle	Ideal Design Principles and Considerations
Level of Protection	• Based on 2008-2031 Flood Protection Management Strategy • Currently proposed: 500-year return period (0.2% AEP) with climate change allowances as per provincial studies
Form and Performance	• Continuous, compacted dike fill with standard or better geometry • Crest elevation and adequate freeboard • Factors of safety against stability • Minimal infrastructure within the dike corridor • Adequate bank protection or setback
Passive operation	• No gaps, gates, or stop logs • Passive monitoring (e.g. SCADA water levels)
Enhance Performance (slow failure)	• Wide dike crest • Armoured river-bank slope to resist erosion • Paved/armoured crest and/or land-side slope to resist overtopping • Wide setback from the river
Post-earthquake Protection	• No loss of full dike geometry into the river ("flowslide failure") up to a return period to be determined • Adequate post-earthquake freeboard and stability until repairs • Wide dike crest and/or wide setback from the river
Future upgrading	• Space and tenure for upgrading (standard or better geometry) • Avoid need for future infrastructure relocation or land acquisition

River Road Safety and Access

The safety of drivers, cyclists, and pedestrians using River Road is a significant consideration in Phase 4. City transportation engineering staff were consulted during the master plan development to provide input on dike upgrading concepts that will also improve road safety. The City's preferred concept for River Road is to provide wider vehicle travel lanes and separated multi-use paths, which may be located on the dike crest. Preferred travel lane and multi-use path widths are documented in the design criteria in Section 3.2. Additionally, the City's goal is to create a continuous path around Lulu Island along the river/on the dike system.

Vehicle access to properties located on both sides of River Road is also a significant consideration. Dike raising along River Road will impact driveway access in some areas. Land use on these properties includes industrial / port-related uses, residential, and agricultural. As such, a variety of vehicles, including semi-trailer trucks, need safe access from River Road to these properties. Currently, these properties are generally at grade with or slightly below River Road, and access is provided via asphalt or gravel driveways. For properties located south of River Road, the driveway crosses the existing drainage channel via a culvert. In some areas where the channel is large, the driveway crossing culvert has a large lock block headwall.

Driveway access was considered in options development by identifying several access upgrading concepts including upgrading driveways with retaining walls, land filling to raise sites to the dike/road level, and providing vehicle parking at the dike/road level. Retaining walls should consider the need for handrails for safety, in accordance with applicable regulations.

Internal Drainage System

As with any diked area, the drainage for the interior protected area must be integrated with the flood protection measures such that the protected area does not experience flooding due to conflicting functions between the drainage of water from the interior area and prevention of flooding from water exterior to the dike system.

In this part of Lulu Island, there are large drainage channels adjacent to the interior (land) side of the existing dike and River Road through much of this area. Most upgrading options (discussed in Section 3.4) will impact these drainage channels throughout Phase 4.

The master plan assesses the potential drainage impacts of filling in the existing channel adjacent to River Road and installing a piped drainage system. The assessment was conducted using East Richmond hydraulic model (MIKE URBAN software) provided to KWL by the City.

Land Raising and Acquisition

Land acquisition is an important consideration for the development and evaluation of dike upgrading options. In many areas, the River Road dike corridor is confined on both sides by private property with no room for expansion of the dike footprint.

The figures in Appendix A present the overlap between the proposed dike footprint and private property for select upgrading options discussed in this section. This overlap can be used to produce a land acquisition plan.

In some locations, an alternative to land acquisition may be to raise private property lots up to the dike elevation to create a much wider land raising platform (similar to recent developments along the Middle Arm (e.g. Olympic Oval).

Environmental Considerations

City of Richmond Bylaws

The City's Official Community Plan (OCP) bylaw (2011) includes an Ecological Network Management Strategy (ENMS) that identifies ecologically important areas in the City's Ecological Network (EN). These areas include Environmentally Sensitive Areas (ESAs), Riparian Management Areas (RMAs), and EN components (hubs, sites, and corridors, shoreline, city parks).

ESAs are designated as Development Permit Areas (DPAs) with specific restrictions and guidelines for development controlled through a review and permitting process (HB Lanarc-Golder and Raincoast Applied Ecology 2012). There are five ESA types, based on habitat, each with specific management objectives. These are summarized in Table 3-2 and more detailed guidelines can be found in HB Lanarc-Golder and Raincoast Applied Ecology (2012). According to Richmond's OCP, dike maintenance is exempt from development permits in ESAs. However, the guidelines provide useful direction that can be used to minimize impacts to these areas and provincial and federal legislation (see below) still applies to these areas.

RMAs are setbacks that were implemented in accordance with the provincial *Riparian Areas Protection Act* and act as pre-determined Streamside and Protection Areas (SPEAs) under the Act. They extend 5 m or 15 m back from the top of bank of the City's higher value drainage channels or more natural watercourses and are to remain free from development unless authorized by the City (City of Richmond, 2017). RMAs are present in all six Phase 4 reaches.

Hubs, sites, and corridors are components of the City of Richmond's EN, which aren't specifically afforded protection, but often overlap ESAs and RMAs, which are protected. These components are present in all 6 reaches of Phase 4.

Dike upgrade options will consider the potential impacts to these areas.

Table 3-2: City of Richmond ESA Type Management Objectives

ESA Type	Reaches Where Present	Management Objectives
Intertidal	All	• Prevent infilling or direct disturbance to vegetation and soil in the intertidal zones • Maintain ecosystem processes such as drainage or sediment that sustain intertidal zones
Shoreline	1, 2, 3, 4, 6	• Preserve existing shoreline vegetation and soils, and increase natural vegetation in developed areas during development or retrofitting
Upland Forest	1	• Maintain stands or patches of healthy upland forests by preventing or limiting tree removal or damage, and maintaining ecological processes that sustain forests over the long-term
Old Fields and Shrublands	None	• Maintain the extent and condition of old fields and shrublands, while recognizing the dynamic nature of these ecosystems • Preservation should recognize the balance between habitat loss and creation with the overall objective of preventing permanent loss of old fields and shrublands

ESA Type	Reaches Where Present	Management Objectives
Freshwater Wetland	None	• Maintain the areal extent and condition of freshwater wetland ESAs by preserving vegetation and soils, and maintaining predevelopment hydrology, drainage patterns, and water quality
		Modified from HB Lanarc-Golder and Raincoast Applied Ecology 2012

Fish Habitat and Offsetting

Fish and aquatic habitat is protected by the federal *Fisheries Act*. Under the Act, *serious harm to fish* must be authorized by the Minister of Fisheries and Oceans and impacts that cannot be avoided or mitigated must be balanced through offsetting. Offsetting plans are negotiated on a case-by-case basis and may require consultation with aboriginal groups and the Province. Offsetting measures include habitat restoration or enhancement and habitat creation and must be proportional to the loss caused by the project.

Often, the amount of offsetting habitat created is greater than the area of habitat impacted. The area of offsetting may need to be increased to account for uncertainty of effectiveness and time lag between impacts and offsetting. Selecting offsetting locations and beginning habitat creation works prior to all impacts occurring can help to reduce requirements for additional offsetting area required due to lag time. Creation of a smaller number of larger area habitat restoration, enhancement, or creation sites would allow for a more efficient use of resources and potentially reduce uncertainty.

Wildlife Considerations

Migratory birds, their eggs, and active nests are protected by the *Migratory Birds Convention Act* and appropriate measures must be taken to avoid incidental take. The most effective and efficient of these measures includes scheduling vegetation clearing outside of the migratory bird nesting season. If this is not possible, bird nest surveys can be completed immediately prior to vegetation clearing to identify active nests and delay vegetation clearing until the nest is no longer active.

The nests of Bald Eagles, herons and other raptors (both active and inactive) are protected under the provincial *Wildlife Act*. It is also prohibited under the *Wildlife Act* to disturb or harm birds and their eggs. The detailed design stage for dike upgrading should attempt to avoid the removal of trees where bald eagle nests are located.

Native amphibian species may use the drainage channels on the land side of the dike at certain times of year. These species are protected by the provincial *Wildlife Act* and detailed design should also consider potential impacts to these species.

Tie-in with City of New Westminster Dike

The Phase 4 dike needs to tie into the City of New Westminster portion of the Lulu Island perimeter dike.

As shown in the Appendix A, the dike alignment within the tie-in area is not well-defined. The alignment crosses between industrial sites including the Tree Island Steel property (3933 Boundary Road) and the recently developed Translink Hamilton Transit Centre property (4111 Boundary Road) to reach the border (Boundary Road) with the City of New Westminster.

The dike alignment on the City of New Westminster side of the boundary also doesn't appear well defined. Coordination between the City and the City of New Westminster is important to confirm the dike tie-in design at the boundary.

Potential Future Secondary Dikes

The City's 2008-2031 Flood Protection Management Strategy identifies potential secondary dike concepts which are important considerations for Phase 4, including the proposed mid-island dike and the proposed Richmond-New Westminster boundary dike. The purpose of these secondary dikes would be to limit flood damage by creating flood cells on Lulu Island which would contain flooding to smaller areas, and prevent complete flooding of the island if dike breaches were to occur.

The Phase 4 Dike Master Plan has been developed to allow tie-ins with the proposed mid-island dike and the proposed Richmond-New Westminster boundary dike. It is understood that the City is also considering implementation of both of these proposed dikes through gradual land raising through development as opposed to a dedicated dike corridor. The City's 2008-2031 Flood Protection Management Strategy provides additional information regarding potential future secondary dikes.

Public Realm and Ecological Enhancement

The dike is a major existing public realm feature providing a variety of recreation opportunities. The Dike Master Plan provides an opportunity to significantly enhance the public amenity of the dike system, particularly in the Phase 4 project area where walking, biking, and resting opportunities along River Road are limited. Additionally, the dike upgrading provides an opportunity to enhance ecological value through the landscaping treatments that will define the dike surface and edges.

Appendix B presents a suite of landscape concepts prepared by Hapa landscape architects to supplement the Dike Master Plan. These include landscape design principles, an overall network connectivity concept for the Lulu Island perimeter dike trail, and design toolkits for ecological enhancement and public realm features. Additionally, the Appendix B also includes descriptions of landscape concepts associated with the upgrading options presented in this section.

3.2 Design Criteria

This section describes the main design criteria used in the Dike Master Plan.

Table 3-3 presents a summary of the design criteria, and is followed by additional discussion. The criteria are presented in terms of both a minimum acceptable level, and a preferred level.

Table 3-3: Design Criteria Summary

Item	Value and Description	
	Minimum Acceptable	Preferred
Proposed Dike Crest Elevation	4.7 m CGVD28 downstream of Nelson Road 4.7 m CGVD28 to 5.0 m CGVD28 between Nelson Road and Boundary Road	
Future Dike Crest Elevation (for proof-of-concept design)	5.5 m CGVD28 downstream of Nelson Road 5.5 m CGVD28 to 6.0 m CGVD28 between Nelson Road and Boundary Road	
Geometry and Stability	4 m wide crest with dike fill core 3H:1V land-side slope 3H:1V river-side slope (or 2H:1V with riprap revetment) Retaining walls minimized Sheetpile walls acceptable only with minimum 4 m wide dike fill core behind wall No standalone flood walls Meet minimum geotechnical factors of safety	Meets or exceed provincial dike standard and City dike standard
Land Tenure	Registered right-of-way	Dike located on City-owned land
Infrastructure in Dike	Crossings designed with seepage control Locate parallel infrastructure to land-side outside of dike core	No infrastructure in dike
Land Adjacent to Dike	Land is raised as much as is practical	Land is raised to meet or exceed dike crest elevation
Seismic Performance	Minimum 3.2 m CGVD28 post-earthquake dike crest elevation and maintain dike core integrity	No damage to dike from earthquakes up to a return period to be determined

Item	Value and Description	
	Minimum Acceptable	Preferred
River-side Slope and Setback	2H:1V bank slope with riprap revetment designed for freshet flow velocities and vessel-generated waves	>10 m setback between river top of bank and dike river-side slope toe 3H:1V river-side bank slope with acceptable vegetation
Crest Surfacing and Land-side Slope Treatment	Crest surfacing: 150 mm thick road mulch Land-side slope treatment: hydraulically seeded grass	Meet or exceed provincial dike standard and City dike standard Consider paved crest and land-side slope vegetation/armouring to add robustness against overtopping
River Road Design Width	From river-side to land-side: 4.0 m multi-use path 0.5 m allowance for barrier 0.6 m min horizontal clearance Two 3.7 m travel lanes 0.6 m min horizontal clearance 0.5 m allowance for barrier Total width: 9.6 m	From river-side to land-side: 4.0 m multi-use path 0.5 m min horizontal clearance 0.5 m allowance for barrier 0.6 m min horizontal clearance Two 3.7 m travel lanes 0.6 m min horizontal clearance 0.5 m allowance for barrier 2.0 m pedestrian walkway Total width: 16.1 m

Dike Crest Elevation

At this time, the Province has not established a Fraser River flood profile and dike design profile that considers sea level rise and climate change. It is understood that the Fraser Basin Council's Lower Mainland Flood Management Strategy project may produce a recommended flood profile in the near future. The most recent available flood profile information is provided in the Province's 2014 study of climate change and sea level rise effects on the Fraser River flood hazard.

The designated flood profile for the purpose of developing the Dike Master Plan is proposed as the maximum of the following flood scenarios:

- 500-year return period coastal water level with 1 m of sea level rise (no wave effects); and
- 500-year return period freshet with moderate climate change impacts and 1 m of sea level rise.

Figure 3-1 shows the estimated flood profile water levels (in CGVD28 vertical datum, excluding freeboard) along the river in the study area. As shown on the figure, the coastal flood scenario governs from the Ocean upstream to approximately Nelson Road.

Design dike crest elevations are derived by adding freeboard and an allowance for land subsidence to the flood level. Table 3-4 presents the components that sum to the proposed dike crest elevation.

Table 3-4: Flood Levels and Dike Crest Elevations

Item	Downstream of Nelson Road (flat profile)	Upstream of Nelson Road (sloped profile)		
		Nelson Road	Boundary Road (Border with City of New Westminster)	Eastern Tip of Lulu Island
Governing Flood Hazard	tide + storm surge	Fraser River freshet		
Level of Performance	500-year return period (0.2% annual exceedance probability)			
Climate Change Allowance	1 m sea level rise	1 m sea level rise and 20% freshet flow increase		
Design Flood Level (m, CGD28)[1]	3.8		4.2	4.6
Wave Effects Allowance	None			
Freeboard (m)	0.6			
Land Subsidence Allowance (m)	0.2			
Dike Crest Elevation[2] (m)	4.6		5.0	5.4

Notes:
1. From (BC MFLNRO, 2014).
2. The City's adopted downstream design crest elevation (4.7 m) exceeds the minimum required elevation (4.6 m). This is a result of updated coastal water level analysis methods (joint probability analysis) that result in a discrepancy when compared to previous methods (additive method).

The Dike Master Plan also allows for further upgrading by providing proof of concept for raising to between 5.5 m downstream of Nelson Road, and 6.0 m at the boundary with the City of New Westminster.

Seismic Performance

The current provincial seismic performance criteria for dikes are difficult to meet without costly and complex ground improvement works. Additionally, the guidelines are considered very conservative in some situations because they require performance under extremely rare scenarios. For example, the guidelines require dikes to maintain 0.3 m freeboard in the event of a 10-year return period flood occurring following a 2,475-year return period earthquake which has a probability of 0.004% in a 1-year period. This is significantly rarer than the design event for the dike crest elevation (500-year return period event has a 0.2% annual exceedance probability). It is understood that the Province is conducting a review of the current criteria and associated guidelines.

For the purpose of the Dike Master Plan, an alternative seismic performance approach that focuses on failure mechanisms and post-earthquake level of protection is proposed. The alternative criteria are presented below.

Table 3-5: Proposed Alternative Seismic Performance Criteria

Criteria	Description / Value
Failure Mechanisms	Flowslides (resulting in full loss of dike cross-section into the river or channel) are not acceptable up to a return period to be determined (e.g. 2475-year return period).
Maximum post-earthquake overtopping probability	0.2% annual exceedance probability Calculate probability through comparison of various post-earthquake dike crest elevations and future flood levels + 0.3 m freeboard. Assume a minimum 1-year exposure period for dike repairs, or longer if local site conditions warrant. In general, this results in a minimum post-earthquake dike crest elevation of 3.2 m which corresponds to the governing scenario of an average annual maximum coastal water level (1.9 m) with 1 m of sea level rise occurring within 1 year of a 475-year return period earthquake. The post-earthquake dike crest would need to provide adequate dike performance and static stability (i.e. no major deformations and cracks).

This approach would make the service level of the dike in a seismic scenario consistent with the service level for the dike crest elevation which is set based on a 500-year return period flood or a 0.2% annual exceedance probability.

For the coastal design dike crest elevation of 4.7 m CGVD28, this approach would allow for up to 1.5 m of vertical settlement, as long as core dike integrity is maintained.

The length of time between earthquake and dike repair will be a critical assumption for analysis to support this approach. The City may wish to specify consistent assumptions through the Dike Master Plan to ensure consistent analyses. For example, reconstruction of a dike that has failed into the river channel following a flowslide failure from an extreme earthquake may take up to 2 years or more, whereas more straightforward compaction and raising of a settled dike could be done in less than a year after an earthquake.

In addition, it should be noted that meeting the seismic performance criteria through increasing the dike crest elevation, as opposed to ground densification, has the added benefit of increasing the level of protection against flood events.

The seismic performance criteria may need to be further reviewed if/when the Province issues updated guidelines for seismic performance of dikes.

3.3 Alternative Upgrading Strategies

Several high-level upgrading strategies, summarized in Table 3-6, were considered to inform the development of specific options for the Dike Master Plan.

Table 3-6: High-level Dike Upgrading Strategies

Strategy	Advantages	Disadvantages
Road Dike *Raise road to dike crest elevation*	• Smaller footprint • Wider crest (more robust) • Smaller impacts to habitat	• Operation and maintenance challenges • Infrastructure within dike • High cost to raise dike in the future
Separated Dike and Road *Conventional dike adjacent to road*	• Operation and maintenance separated from road • No infrastructure within dike	• Larger footprint and impact to infrastructure and habitat
Raise Riverbank Dike *Conventional dike along riverbank*	• Minimize footprint	• Limited space • Impacts to river side riparian and intertidal habitat and land side riparian and aquatic habitat • Reduced seismic performance • Erosion hazard
Fill River-side Dike *Build into river to achieve conventional dike*	• Less impacts to existing development and on-shore infrastructure	• Larger impacts to river side riparian and intertidal habitat • Reduced seismic performance • Erosion hazard
Setback Dike *Realign significantly away from river*	• Increased seismic performance • Reduced erosion hazard • Increased opportunities for riparian and intertidal habitat enhancement	• Increase in unprotected development • High infrastructure impacts • High cost to construct new dike alignment • Would result in 2 dikes (existing and setback) to maintain
Land Raising (“superdike”) *Raise development and roads adjacent to dike*	• Wider crest (more robust) • Reduced grading issues (after implementation) • Less impacts to raise a dike in the future	• Timing and phasing depends on development • High cost to raise large lots with low-density land use • Grading and access issues for water-oriented developments

3.4 Options and Concepts

Through a series of meetings and site visits with City staff, the high-level upgrading strategies have been narrowed down to a set of options and concepts for each reach.

The options developed for Phase 4 include:

- Option 1: Raise dike and road, extend land-side (Figure 3-2);
- Option 2: Raise dike and road with retaining walls (Figure 3-3);
- Option 3: Raise dike only and extend river-side (Figure 3-4); and
- Option 4: Raise dike only and extend land-side.

In addition to the above options, the following options have been developed to address site-specific issues at the rail trestle (Reach 4) and at the tie-in with the City of New Westminster (Reach 6):

- Option 6: Rail trestle – raise road/dike under trestle (Figure 3-5);
- Option 7: Rail trestle – fill in between trestle piles (Figure 3-6);
- Option 8: City of New Westminster tie-in – raise Boundary Road (Figure 3-7);
- Option 9: City of New Westminster tie-in – fill Tree Island Steel property to dike level (Figure 3-8); and
- Option 10: City of New Westminster tie-in – new alignment across Tree Island Slough (Figure 3-9).

Table 3-7 presents a summary of the options as applied to each reach based on discussions with City staff and is followed by a discussion of the options. Appendix B includes landscape concepts prepared by Hapa associated with the cross-section options.

Table 3-7: Major Dike and Road Alignment and Cross-section Options

Reach ID and Name	Alignment and Cross-section Options
1 – Bridgeport Industrial	• Option 1: Raise dike and road, extend land-side**
2 – Industrial and Shipyards	• Option 1: Raise dike and road, extend land-side**
3 – Riverfront Houses and ALR	• Option 1: Raise dike and road, extend land-side**
4 – Bog and Rail	• Option 1: Raise dike and road, extend land-side • Option 2: Raise dike and road with retaining walls • Option 3: Raise dike only and extend river-side** *Specific options for rail trestle:* • Option 6: Rail trestle – raise road/dike under trestle • Option 7: Rail trestle – fill in between trestle piles
5 – Hamilton Frontages	• Option 1: Raise dike and road, extend land-side** • Option 3: Raise dike only and extend river-side
6 – Tree Island Slough and Boundary	• Option 3: Raise dike only and extend river-side** • Option 4: Raise dike only and extend land-side *Specific options for tie-in with City of New Westminster dike:* • Option 8: City of New Westminster tie-in – raise Boundary Road • Option 9: Fill Tree Island Steel property to dike level • Option 10: City of New Westminster tie-in – new alignment across Tree Island slough
Notes: ** Option footprint is presented in Appendix A plan figures.	

Raise Dike and Road, and Extend Land-side

The preferred option developed for Reaches 1 to 3 involves separating the dike and River Road, raising both to the dike crest elevation, and extending the footprint of the fill towards the land-side. Figure 3-2 presents a typical cross-section for this option.

Figure 3-2 shows a 10 m wide dike crest to allow for additional future dike raising without the need to reconstruct the road. An alternative approach to reduce the overall footprint at first would be to have a 4 m wide dike crest and to extend the footprint and reconstruct the road in the future.

This option addresses several of the main design considerations including providing a substantially wide dike and improving River Road safety by separating vehicles and cyclists/pedestrians.

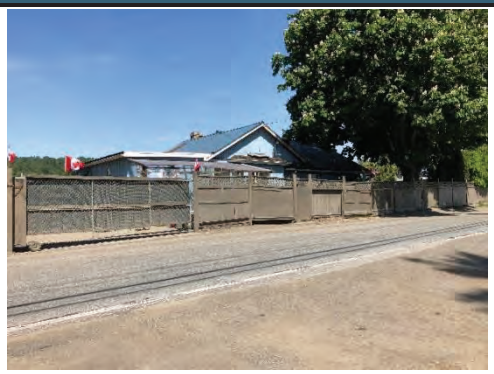
Extending the footprint towards the land-side takes advantage of the space currently occupied by drainage channels. This option requires filling in the existing channel and replacing or relocating the drainage conveyance and storage. The preferred approach is to replace the channels with pipes. This will result in a loss of aquatic and riparian habitat and will require habitat creation or enhancement to be completed elsewhere to offset the loss. Drainage modification options are discussed separately below.

Extending the footprint towards the land-side will also require land acquisition where the existing corridor width is insufficient. In general, this would affect a narrow strip of land on the frontage of large lots and should be feasible to implement.

However, there are also areas on both the land-side and the river-side where the upgrade will result in access issues. The areas with the most severe space limitations and potential options to address the access issues are presented in Table 3-8.

Table 3-8: Space Limitations and Access Issues

Reach / Location / Description	Photo	Options to Address Footprint and Access
Reach 1 No. 7 Road Pump Station		• Retaining walls and steeper driveway access • Replace pump station during dike upgrades
Reach 1 15700 River Road FortisBC gas pipeline facility		• Retaining walls and steeper driveway access • Coordinate with FortisBC to raise parcel during next major upgrade

Reach / Location / Description	Photo	Options to Address Footprint and Access
Reach 2 16291 River Road Residential / Office Space		• Retaining walls • Provide parking on land-side (instead of driveway down to lot) • Raise parcel of land at time of redevelopment • Land acquisition / managed retreat (buy-out, relocate, or do not allow redevelopment)
Reach 2 16971 River Road Tom-Mac Shipyard on water side, Residential on inland side		• Retaining walls • Provide parking on land-side (instead of driveway down to lot) • Raise parcel of land at time of redevelopment • Managed retreat (buy-out, relocate, or do not allow redevelopment)
Reach 3 17740 River Road No. 8 Road North Drainage Pump Station		• Retaining walls • Replace pump station during dike upgrades
Reach 3 18871 River Road Storage, and Residential lots (Water Side) Large Channel (Inland Side)		• Retaining walls • Provide parking on land-side (instead of driveway down to lot) • Raise parcel of land at time of redevelopment • Land acquisition / managed retreat (buy-out, relocate, or do not allow redevelopment)

Reach / Location / Description	Photo	Options to Address Footprint and Access
Reach 3 19051 River Road Metro Vancouver Tilbury Watermain Crossing		• Retaining walls and steeper driveway access • Coordinate with Metro Vancouver to raise parcel during next major upgrade
Reach 4 21200 River Road CN Rail Trestle Bridge		• Refer to rail trestle discussion paragraph in this section (page 3-18)
Reach 5 22760 River Road Queen Road North Drainage Pump Station		• Retaining walls and steeper driveway access • Replace pump station during dike upgrades

Filling in Drainage Channels (Extending Land-side)

The interior channels along River Road will generally be filled in the preferred option which involves raising the dike and River Road, and extending the footprint towards the land-side. Options considered to replace the conveyance and storage capacity provided in the channels are described in Table 3-9.

Table 3-9: Options for Replacing Existing River Road Drainage Channels

Option	Comments
1. Relocate channels further inland to new River Road toe	• Would impact the adjacent properties, requiring acquisition of right-of-way or, potentially, of whole lots (depending on extent of impact to the lot) • New channels may not need to be as wide as the existing channel • New channels would be located at the toe of the road and outside the dike section • It is not ideal to have a channel near the toe of the dike and the option of locating a channel near the toe of the dike would need to be evaluated by a geotechnical engineer for seepage concerns
2. Replace channels with pipe	• Would involve replacing the channel functions with a pipe below the road • Pipe would be located within the road base but must be outside of the dike cross-section or toe of the dike • The size of pipe that could be fit into the available space in the road cross-section is a potential limitation • Would result in a loss of land side aquatic and riparian habitat
3. Reconstruct channels at rear of lots along River Road	• Would require re-grading of lots and re-connection of lot drainage to rear of lot • Property acquisition for drainage right-of-way would be required • Road drainage would need to be accommodated in additional infrastructure – likely a pipe below the road on the inland side

The option expected to be both the simplest to implement and the least cost is to replace the existing channels along River Road with pipes. As noted, this option is limited by the size of the pipe that can fit within the road cross-section and outside of the dike cross-section in the preferred option for the dike upgrades. It is estimated that maximum pipe size is approximately 1.2 m diameter, and a circular pipe will fit better than a box section in the available space.

Drainage from both River Road and the interior lots adjacent to the road would be directly connected to the new drainage pipes. The new pipes would drain to the existing north-south channels that convey runoff to the pump stations.

A preliminary assessment of the replacing the drainage channel with a piped system was done to determine whether it could provide the necessary conveyance and storage functions to replace the existing channels along River Road. The existing hydraulic model of the east Richmond drainage system was provided to KWL for this purpose by the City. The preliminary assessment indicates that replacement of the existing River Road channels with 1.2 m diameter concrete pipes would provide adequate conveyance and storage for drainage of the design storms from the interior drainage system.

The internal drainage system in the eastern part of Lulu Island provides irrigation service as well as drainage service. The system of channels allows water from intakes on the Fraser River to flow into Lulu Island and distribute through the drainage conveyance system to provide irrigation water to the farmlands in eastern Lulu Island. This use of the drainage conveyance system relies on the storage capacity within the channels to provide adequate water to the farmlands. The system was reviewed relative to the impacts on irrigation functions with the proposed removal of the large storage channels along River Road and their replacement with pipe infrastructure. The function of these channels for the irrigation system was discussed with City staff (Derek Hunter, Pump Station Manager). From an irrigation perspective, these changes to the system along River Road are not expected to impact the irrigation functions of the system. The east-west running channels along River Road have one-way flow gates at the junctions with the north-south running channels that convey flow to and from the pump stations and the irrigation intake points. These one-way gates allow the water to drain out of the east-west channels along River Road to flow to the pump stations, but they block irrigation water from entering the east-west channels when the irrigation function of the channels is in use during the growing season. Therefore, the proposed replacement of the channels along River Road with pipe infrastructure should not impact the irrigation system. Similar one-way gates should be used on the new pipe infrastructure to allow the irrigation flow in the north-south channels to continue to bypass the drainage infrastructure that will provide drainage service along the new River Road.

Infilling drainage channels will remove a large amount of aquatic and riparian habitat important for fishes and amphibians. This will require a significant amount of habitat creation, restoration, and/or enhancement to offset this loss.

North East Bog Forest (Reach 4)

In Reach 4, raising both the dike and River Road to the design dike elevation and extending the footprint towards the land-side (Option 1) would encroach onto the north-east Bog Forest, and is generally not preferred from an environmental perspective. The bog is a unique feature on Lulu Island, and impacts to the bog need to be carefully considered.

To avoid encroaching onto the bog, the following additional options are considered for Reach 4:

- Option 2: Raise dike and road with retaining walls; and
- Option 3: Raise dike only and extend river-side.

Option 2 would limit the encroachment onto the bog by retaining the road land-side slope using retaining walls. Settlement may be a significant concern with Option 1 and Option 2 because the soils adjacent to the bog may experience significant settlement.

By filling towards the river-side instead of the land-side, Option 3 would avoid encroachment and filling in the bog. Building into the river would cause an impact to existing riparian and aquatic habitat and require offsetting. However, the desktop habitat review (Section 2.4) shows that there are existing areas of low quality riparian and aquatic habitat in the eastern portion of Reach 4. As such, building into the river provides an opportunity to replace the low quality riparian habitat with higher quality riparian habitat. One concept to achieve this is to build out a shallow river-side slope with riparian and marsh benches, as shown in Figure 3-4. A shallow river-side slope would also reduce the erosion concern and reliance on riprap bank protection. Aquatic habitat loss will have to be offset elsewhere.

Since this option would involve filling in a portion of the river channel, it may have some impact on channel conveyance or navigation. However, the existing trestle piles and piers located upstream already limit the conveyance and navigation in this area. These impacts should be considered further if this option is preferred.

Rail Trestle (Reach 4)

The existing rail trestle structure at eastern end of Reach 4 is an obstacle to conventional dike upgrading due to limited space for widening the dike and road, and due to limited overhead clearance space for raising the road – as shown on the photo below.

The existing maximum road clearance below the structure is posted at 5.88 m. Raising the road/dike would reduce the clearance.

The following options have been developed for dike upgrading at the rail trestle:

- Option 6: Rail trestle - raise road/dike under trestle; and
- Option 7: Rail trestle – fill in between trestle piles.

To achieve Option 6, the trestle structure may need to be modified to achieve a minimum acceptable overhead clearance (to be confirmed with City staff).

Option 7 would avoid reducing the overhead clearance by leaving the road as-is and constructing a new dike on the river-side filling in between the trestle piers. The feasibility of this option needs to be confirmed from geotechnical engineering and constructability perspectives. Additionally, this option would involve filling in a portion of the river channel and may have an impact on channel conveyance or navigation. However, the existing trestle piles and piers already limit the conveyance and navigation in this area. These impacts should be considered further if this option is preferred.

Hamilton Frontages (Reach 5)

Upstream of the rail trestle, in Reach 5, the primary option is the same as Reach 1 to 3. This involves raising the road and the dike to the design dike elevation, and extending the footprint to the land-side (Option 1). This will remove a large amount of aquatic and riparian habitat and will require a significant amount of habitat creation, restoration and/or enhancement to offset the loss.

However, Option 3, raise dike and extend to river-side, is also considered because of the opportunity to convert the existing low quality riparian and aquatic habitat into higher quality habitat (see Section 2.4). One concept to achieve this is to build out a shallow river-side slope with riparian and marsh benches, as shown on Figure 3-4. A shallow river-side slope would also reduce the erosion concern and reliance on riprap bank protection. Additionally, this option is considered in both Reach 4 and Reach 6, and would allow for continuity in alignment. This option would involve filling in a portion of the river channel and may have an impact on channel conveyance or navigation.

Tree Island Slough and Tie-in with City of New Westminster Dike (Reach 6)

Near the western end of Reach 6, River Road intersects Westminster Highway. The existing dike runs along the river bank, and is separated from River Road. The existing dike runs east until it reaches the recently developed Hamilton Transit Centre. The existing dike alignment is not well defined from the Hamilton Transit Centre to Boundary Road where jurisdiction of the Lulu Island perimeter changes to the City of New Westminster.

The following options have been developed for Reach 6:

- Option 3: Raise dike only and extend river-side; and
- Option 4: Raise dike only and extend land-side.

The following specific options have been developed for tie-in with the City of New Westminster dike:

- Option 8: City of New Westminster tie-in – raise Boundary Road;
- Option 9: Fill Tree Island Steel property to dike level; and
- Option 10: City of New Westminster tie-in – new alignment across Tree Island Slough.

Options 3 and 4 address dike upgrading along the existing dike alignment from Reach 5 to the Hamilton Transit Centre, from which there are 2 compatible options for tie-in with the City of New Westminster dike:

- construct a dike along the right-of-way north of the Hamilton Transit Centre and raise Boundary Road (Option 8); and
- fill the Tree Island Steel property (3933 Boundary Road) up to the dike elevation through redevelopment.

Option 3 (extend river-side) would involve impacts to existing intertidal habitat, but also presents the opportunity to improve river side riparian habitat, while Option 4 would have private property impacts.

Raising Boundary Road (Option 8) may be difficult to achieve through a standard dike design because there is a railroad access line to the Tree Island Steel property that crosses Boundary Road. This may require a rail gate, which is not desired.

Raising the land elevation of the Tree Island Steel property (Option 9) would create a wide and robust dike at the tie-in, but this option is dependent on redevelopment of the site and may have feasibility issues due to access requirements.

Option 10 provides an alternative approach that realigns the dike to cross over the slough and runs along the Tree Island Steel property and directly connects to the City of New Westminster dike along the river bank. Option 10 would involve partially or completely closing off the slough and presents the opportunity to construct a large habitat enhancement project. One concept for this is to create an intertidal marsh in the slough and have a tide gate installed on the dike crossing at the outlet of the slough.

3.5 Stakeholder Engagement

Stakeholder engagement for Phase 4 was completed in four stages. This included internal (City) stakeholder review, Council review, external stakeholder engagement, and then public engagement.

Prior to City Council review, initial stakeholder engagement included meetings with internal City departments and some regulatory agencies. This initial stakeholder engagement provided input from City groups on options developed, additional background, and future coordination, with the goal of

informing the preferred upgrade options. City departments included Transportation, City of Richmond Parks, Planning, and Sustainability.

Following Council review, additional stakeholder engagement was conducted, including meetings with specific stakeholder groups.

External stakeholder feedback was received originally received in 2018 from the City of New Westminster and the Ministry of Forests, Lands, Natural Resource Operations, and Rural Development (MFLNRORD), including Inspector of Dikes, Flood Safety, and Water Authorizations staff. In 2022 and 2023, additional feedback was received from the Department of Fisheries and Oceans, Ministry of Transportation, Fortis BC, and the Ministry of Forests, Richmond's Advisory Committee on the Environment, and Richmond's Food Security and Agricultural Advisory Committee.

The Department of Fisheries and Oceans (DFO) originally declined to meet with the City in 2018, stating that input would be provided during later stages in the established review and approvals process. However, at a later date City staff met with the Fish and Fish Habitat Protection Program team at the Department of Fisheries and Oceans to discuss the dike-raising initiative and how impacts on fish and fish habitat are planned to be mitigated or compensated, where impact cannot be avoided. They encourage the implementation of more nature-based solutions. Staff are in discussion with the Department of Fisheries and Oceans to implement a habitat bank, per council direction.

Richmond's Advisory Committee on the Environment generally supported dike-raising and noted that New Westminster's dike-raising plans should align with Richmond's. The City is coordinating with the City of New Westminster to ensure that east Richmond will be protected from flood risks.

Richmond Food Security and Agricultural Advisory Committee noted that implementing a continuous trail network along the perimeter dike and tree planting for habitat compensation should be prioritized. Additionally, opportunities for accessing the river for water activities should be investigated. The dike cross-section recommended in the Dike Master Plan includes a continuous multi-use pathway for dike trail continuity and

The Ministry of Transportation does not have any infrastructure in the Dike Master Plan Phase 4 study area; however, they noted their request to be notified and engaged wherever Richmond's dike project may intersect with Ministry infrastructure. Staff will consult with the Ministry staff for any dike reaches where their infrastructure is located.

Fortis BC requested to be notified in advance of dike upgrades along Reach 1 of Dike Master Plan Phase 4, which is between No. 6 Road and No. 7 Road, to relocate or regrade one of their critical pump stations. They also noted the potential impact to their DP gas main along the rest of Reach 1. A preload and impact memo was requested during design to determine if there are impacts and mitigative measures needed.

Ministry of Forests expressed concerns about habitat impact from potential Riparian Management Area (RMA) ditch infills along River Road. They also noted that Land Act authorizations would be required for any potential dike infrastructure that may stretch over the river or aquatic areas. Staff will obtain all required authorizations and work closely with a Qualified Environmental Professional, in collaboration with the Ministry, during the detailed design phase of the different dike sections to limit impacts where possible and provide adequate habitat compensation, as necessary.

Public Feedback

The City sought and received feedback from the public. The engagement is described in the November 2022 report by the City titled City of Richmond Flood Protection What We Heard Report. The

engagement was conducted by the City over a five month period from May to September, 2022. "Approximately 1,000 people attended in-person engagement activities and events. Over 2,000 people participated online, both through the City's flood protection webpage and Let's Talk Richmond project page that was set up to support community outreach." The received feedback included:

- Strong support for the accelerated flood protection program with a 50-year implementation timeline;
- Support for the actions being taken with regard to community safety;
- Support for environmental considerations in the Dike Master Plan;
- Support for coordination with development to create superdikes;
- Support for improved cyclist experience along River Road;
- Support for amenity upgrades along the dike corridor, including delineated bike lanes, multi-use pathways, benches, washrooms, perimeter dike trail continuity, and traffic calming features;
- Concern regarding the removal of trees and habitat along the dike. Once staff explained how trees in the dike could impact its overall structural integrity, the participants understood why tree removal may be necessary for some situations;
- Concern regarding the uncertainty in sea level rise trends. The participants were assured that the City is continuously monitoring and reviewing the evolving climate change science and adjusting the City's flood protection plans to protect the City well ahead of the sea-level rise;
- Concern regarding New Westminster's dike-raising plans. Staff are coordinating with New Westminster to ensure their dike upgrade plans are in alignment with Richmond's;
- Appreciation for the flood protection public engagement campaign and desire for more similar initiatives in the future;
- Appreciation for all materials available to provide information to residents, including the webpage, online StoryMaps, hand-out flyers, and poster boards; and
- Appreciation for being able to communicate directly with City staff regarding their flood protection concerns.

3.6 Options Evaluation and Selection

The options described in Section 3.4 have been evaluated based on the design considerations and feedback from the stakeholder meetings held to date.

Recommended options have been identified and are described below. Environmental impacts and geotechnical considerations associated with the recommended options are also summarized below.

It is understood that the recommended options will be confirmed through Council and additional stakeholder consultation.

Recommended Options

In general, the recommended option is to separate River Road from the dike, and have both the road and the dike at the dike crest elevation. This is referred to as the "separated dike and road" option and is presented as Option 1 in Section 3.4.

The main features of this option are described below.

- Separate the dike and roadway such that there is an over-wide dike and separate travel areas for vehicles and cyclists/pedestrians.
- Raise the dike crest and road surface to the design dike crest elevation and extend the footprint of fill towards the land-side.
- Retain the land-side toe of the road with retaining walls (e.g. MSE) where necessary (e.g. to minimize impact to North East Bog Forest).
- Fill existing land-side drainage channel and replace with a piped drainage system.
- Modify driveways and access ramps into adjacent properties where reasonable (some constrained areas may require major modifications, redevelopment, or property acquisition).
- Incorporate public space, linear park, and multi-use path features appropriate for a dike crest.
- Install bank protection works on the river-side to match existing (may not be required where the alignment is setback from the river-bank).

The dike portion of the overall crest would be 10 m wide to accommodate future dike raising without having to modify the road. This option is recommended because it is the most robust of the options considered as it produces an earth fill embankment (dike and road) that would be approximately 22 m wide at the crest. This is a significant increase above the standard dike crest width of 4 m and is expected to reduce the likelihood of failure for a variety of processes. Additionally, separating the dike and road would provide several community benefits including improved pedestrian, cyclist, and vehicle safety, and the opportunity for a linear park/multi-use path.

Other options are recommended below in areas which are constrained and do not allow for the separated dike and road option.

- **Riverbank Dike** (Option 4):
  - Use in eastern end of Phase 4 where there is no road associated with the dike.
  - Raise the dike crest to the design height and extend the footprint of fill towards the land-side.
  - Install bank protection works on the river side to match existing.
- **Combined Dike and Road Below Trestle** (Option 6):
  - Use only at the CP rail trestle crossing where there is not enough space for a separated dike and road.
  - There is sufficient clearance to raise the road to the design dike elevation based on discussion with City transportation staff.
  - Install bank protection works on the river side to match existing.
- **Construct Dike Between Tree Island Steel and Hamilton Transit Centre, and Raise Boundary Road** (Option 8):
  - Use to tie-in with the City of New Westminster's portion of the Lulu Island perimeter dike.
  - Use existing right-of-way between Tree Island Steel property (3933 Boundary Road) and the Hamilton Transit Centre (4111 Boundary Road).
  - Raise Boundary Road from Tree Island Steel property towards river bank to tie into City of New Westminster's portion of the Lulu Island perimeter dike.

- Boundary Road raising will require road and possible intersection changes.
- The existing rail spur line servicing Tree Island Steel will need to be addressed (e.g. rail dike gate, raise rail spur, etc.).
- Alternatively, if redevelopment of the Tree Island Steel property occurs during the implementation period of the Dike Master Plan, then the recommended alternative option is raise the property (or a portion of it) to the dike crest elevation as per Option 9.

In addition to the options listed above, another recommendation for flood protection in all areas of Phase 4 is to target land raising of the areas behind the dike.

Table 3-10 below presents a summary of the recommended options for each reach.

Table 3-10: Recommended Dike Upgrading Options

Reach # and Name	Recommended Options
1 – Bridgeport Industrial	• Option 1: Separated dike and road
2 – Industrial and Shipyards	• Option 1: Separated dike and road
3 – Riverfront Houses and ALR	• Option 1: Separated dike and road
4 – Bog and Rail	• Option 1: Separated dike and road[1] *Site specific option at rail trestle crossing:* • Option 6: Combined dike and road below trestle
5 – Hamilton Frontages	• Option 1: Separated dike and road
6 – Tree Island Slough and Boundary	• Option 4: Riverbank dike *Site specific option for tie-in with City of New Westminster dike:* • Option 8: Raise boundary road
1. Retaining walls (Option 2) may be required to minimize impacts to the bog.	

Environmental Impacts of Recommended Options

In total, the estimated impact for the selected Phase 4 options is 3,300 m^2 of high quality Fraser River intertidal habitat, 1,900 m^2 high quality Fraser River riparian habitat, 28,500 m^2 drainage channel aquatic habitat, and 106,200 m^2 drainage channel riparian habitat. These areas represent an estimate based on FREMP habitat mapping (2007), and City of Richmond orthoimagery interpretation (2017). Not all Fraser River riparian and intertidal habitat was quantified. The desktop review only quantified high-quality riparian and intertidal habitat types on the Fraser River side of the existing dike. The remaining habitat area, while not calculated here, would also be required in calculations for determining offsetting requirements. Calculation of the exact area of impact of selected options will require an aquatic habitat survey and aquatic effects assessment.

Table 3-11 presents the summary of habitat impacts for the recommended options by reach.

Table 3-11: Reach-by-Reach Summary of Habitat Impacts

Reach # and Name	High-Quality Fraser River Intertidal (m^2)	High Quality Fraser River Riparian (m^2)	Drainage Channel Aquatic (m^2)	Drainage Channel Riparian (m^2)
1 - Bridgeport Industrial	-	500	3,300	14,800

Reach # and Name	High-Quality Fraser River Intertidal (m²)	High Quality Fraser River Riparian (m²)	Drainage Channel Aquatic (m²)	Drainage Channel Riparian (m²)
2 - Industrial and Shipyards	-	800	5,900	28,000
3 - Riverfront Houses and ALR	50	300	3,000	16,100
4 - Bog and Rail	100	300	10,200	23,500
5 - Hamilton Frontages	900	-	5,900	23,700
6 - Tree Island Slough and Boundary	2,200	-	-	-

Geotechnical Considerations for Recommended Options

The proposed dike improvements were assessed with consideration for the BC Seismic Design Guidelines for Dikes.

Thurber Engineering Ltd. (Thurber) assessed 3 sample cross-sections to estimate the potential deformation resulting from seismic events. The cross-sections were based on the preferred cross-section at what was judged to be the most susceptible areas for deformation. Soil conditions were determined by cone penetration tests. Seismic performance was assessed on the basis of existing foundation conditions, (i.e. no additional ground improvement/densification) to determine the need for ground improvement or alternative approaches. The analysis included seismic events representing 100, 475 and 2475-year return period events. Seismic performance was assessed using 2 methods: 1-D (i.e. flat ground) liquefaction assessment to estimate reconsolidation settlements, and 2-D numerical deformation assessment to estimate dynamic deformations. The methods are complimentary, and the results are interpreted together.

The preliminary geotechnical report is attached in Appendix C.

The key results of the geotechnical analysis are summarized below.

- Proposed dike cross-sections will not meet the performance requirements of the seismic design guidelines, without ground improvement or alternative approaches, based on the results of both assessment methods.
- The liquefaction hazard is considered insignificant for earthquakes up to the 100-year return period event.
- The liquefaction hazard is considered moderate and high for the 475 and 2475-year return period events respectively. The resulting deformations would be large.
- Liquefaction may result in a flowslide into the river for dike alignments along the river-bank due to lateral spreading, whereas it would result only in vertical deformation for dike alignments significantly set back from the river bank.
- The deformation analysis indicates that dikes may meet the performance requirements of the seismic design guidelines if they are typically set back 50 m to 100 m from the river-bank and have flat slopes or some localized ground improvement.

Options to address seismically induced deformations, and opinions on each, include:

- **Densification** – The typical approach to densification is to install stone columns. To be effective against the liquefaction expected to follow the 2475-year return period event, densification would have to extend the depth of the liquefaction zone, and for a similar width. In a typical scenario, this can be considered as a 30 m (width) by 30 m (depth) densification located at the river-side toe of

the dike. Densification can be very costly (e.g. $9,000 to $18,000 per lineal metre of dike). Alternate experimental techniques are being tested by the City that may offer a more economic solution.

- **Higher Crest** – For the 100-year return period event, additional crest elevation may compensate for deformations caused by settlement. For events that cause liquefaction, added height just results in added deformation, so it would be less effective. This is not an effective strategy by itself for return periods above 100-year due to lateral spreading and large vertical deformations.
- **Setback and Slope** – Flatter side slopes on the dike improves seismic stability. However, to prevent large deformations in the 2475-year return period event, the maximum acceptable slope between the river channel invert and the dike crest would need to be approximately 2%, which would require a significant setback between the dike and river.
- **Wide Crest** ("superdikes") – A very wide dike (e.g. crest width of 100 m to 200 m) could be used to extend the dike beyond the limit of significant lateral spreading due to liquefaction. A portion of the wide crest could be considered sacrificial in the even to major lateral spreading. Raising the land for approximately 200 m inland of the dike is desirable for related flood protection reasons, and may be desired by the City for other reasons such as land use planning. It has already been done as part of multiple family, commercial, and industrial development projects along the waterfront. Buildings within this area must already account for liquefaction in their foundation design.
- **Dike Relocation / Secondary Dikes** – Place the dike inland of the liquefaction lateral spreading zone (similar to set back approach) or place a secondary dike inland of the liquefaction lateral spreading zone. The wider option above would essentially include a secondary dike. Relocating the primary dike inland would be a form of retreat and would leave property and buildings exposed outside of the dike.
- **Post-earthquake Dike Repair** – Dike reach specific plans could be developed for post-earthquake dike repairs. These would need to consider the feasibility of dike repair construction following a major earthquake. In general, it is likely not feasible to quickly repair a dike that has failed due to a flowslide induced by liquefaction lateral spreading, especially if the breach results flooding from regular high tides. However, it may be feasible to prepare dike repair plans for dikes where a flowslide is not anticipated.

Additionally, the City may wish to use alternative seismic performance criteria, such as the criteria discussed in Section 3.2 which aims to develop a consistent level of performance between seismic scenarios and flood level scenarios (i.e. an overall 0.2% annual exceedance probability of failure across all hazards).

Recommendations to manage the seismic risk include:

- Consider the proposed alternative seismic performance criteria provided in Section 3.2. Review the criteria if/when the Province issues updated guidelines for seismic performance of dikes.
- Fill land for approximately 200 m inland of the dike to dike crest elevation. Buildings in this zone should be built above the dike crest elevation and have densified foundations capable of withstanding liquefaction. The required distance requires some additional evaluation and may be addressed in the pending updated to the Flood Protection Management Strategy.
- Continue to investigate practical densification options and consider earthquake induced dike deformations in emergency response and recovery planning.

3.7 Cost Opinions

Cost opinions for the recommended option in each reach are provided to help the City consider the financial implications for planning and comparing options. A breakdown is provided to help understand the proportional cost for recommendations such as separating and raising the road.

Costs are based on unit rate cost estimates and tender results for similar works. Costs are presented in 2018 dollars. They have not been updated between the original draft submission in 2018 and the current final report. The most relevant rates are from the City's Gilbert Road dike project. The City provided a summary of the cost estimate prepared by WSP for this project.

Rates from recent tenders for diking on the Lower Fraser River and other locations within the Lower Mainland were used to check the reasonableness of the rates and estimate other features such as sheet piles or large diameter drain pipes.

The costs were broken down by reach so that unit rates could be applied to similar typical cross-sections. They were also broken down into the main features that coincide with options that the City may wish to consider further. These features are described below.

- **Dike Raising** – this is the core element required to provide flood protection. It includes a 10 m crest width that can be raised while still achieving a 4 m crest width. This includes site preparation, fill, and erosion protection.
- **Road Structure and Utilities** – this includes stripping, subgrade preparation, pavement structure, drainage and utilities. Where the existing road is atop the dike, most of this cost would be incurred regardless of where it gets relocated.
- **Road Raising To Dike Crest** – this includes the additional fill required to raise the road to the dike crest elevation.
- **Other** –This category was used to capture pathways and utilities if the option did not include road construction.
- **Contingency** – A 40% contingency is provided because the costs are based on concept plans only.

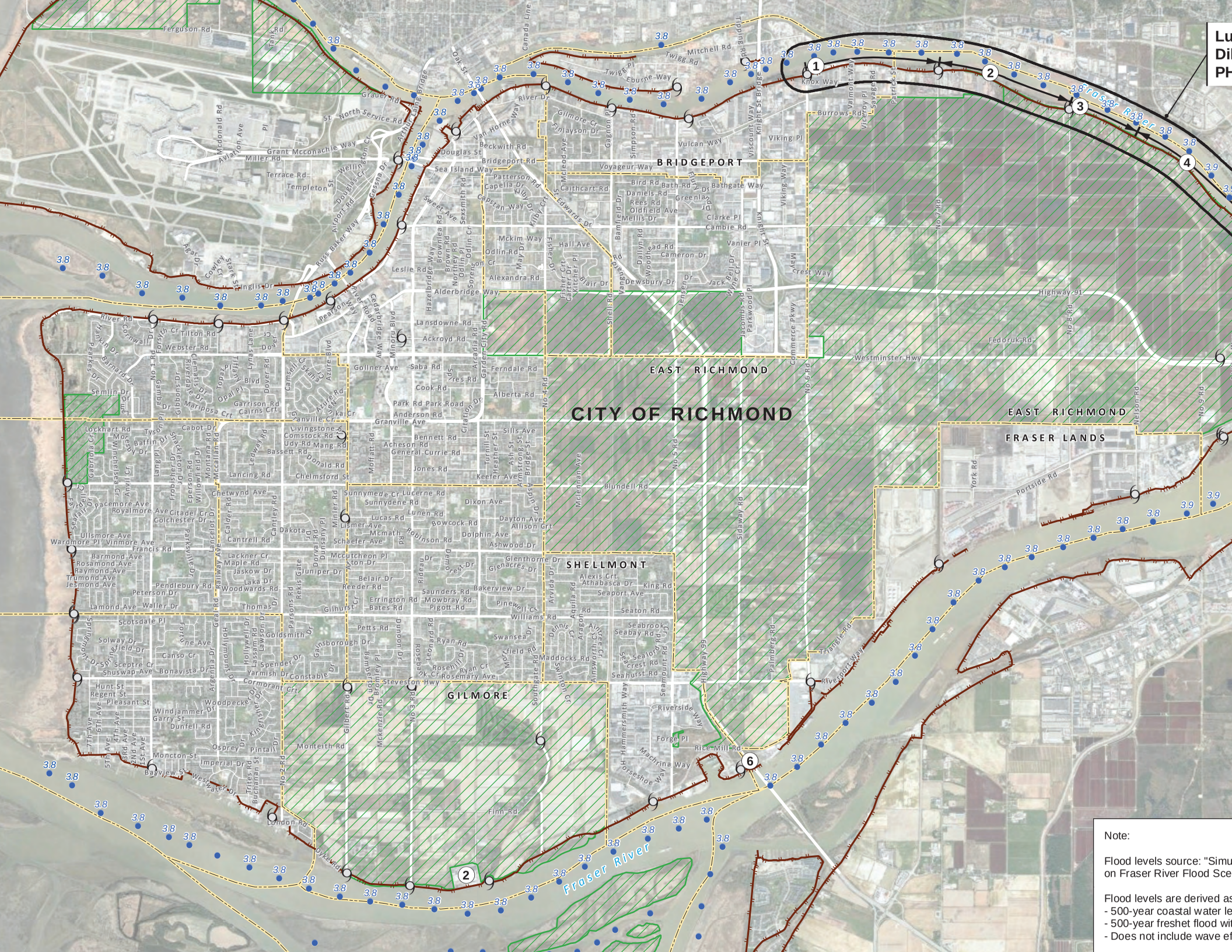
Table 3-12 presents a summary of all reaches with cost breakdowns for the items described above. Costs for each reach are also provided in the Reach Summary Sheets in Section 5.

Table 3-12: Summary of Construction Costs ($ in Millions)

Item	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 6	Total
Dike Raising	$7.6	$7.7	$4.1	$10.5	$7.3	$4.7	$41.9
Road Structure & Utilities	$12.3	$12.6	$6.6	$16.8	$11.8	$1.5	$61.4
Raise Road to Dike Height	$3.2	$3.3	$1.7	$4.3	$3.1	$1.6	$17.2
Other*	$1.5	$2.0	$1.1	$2.0	$1.5	$4.6	$12.8
Contingency (40%)	$9.8	$10.2	$5.4	$13.5	$9.5	$5.0	$53.3
Total	$34.3	$35.8	$18.9	$47.1	$33.1	$17.4	$186.6
*Other - includes utilities if there is no road							

Costs that are not included are noted below.

- Land acquisition is not included. Ideally, land will be acquired during redevelopment. Similarly, there may be opportunities to have dike improvements tied to adjacent development.
- Densification is not included. The recommendation is to fill 200 m back from the dike face as a preferred strategy to deal with liquefaction. If the road and land behind the dike is not raised, then densification is recommended. Current techniques such as stone columns would cost approximately $9,000 to $18,000 per metre of dike.
- Off-site habitat projects (that may be needed beyond the habitat enhancement provided along the dike corridor) are not included. Such cost could be roughly 5% of the construction cost. It is understood that a separate Dike Master Plan may be prepared to address habitat compensation by identifying and developing medium to large habitat compensation concepts.
- Raising the land behind the dike is not included. This is proposed to be a condition of development behind the dike, with the cost and benefit attributed to the property owner.
- Professional fees (engineering, surveying, environmental, archeological, etc.) are not included. Such costs could be in the range of 10% to 15% of the construction cost.
- Inflation since 2018.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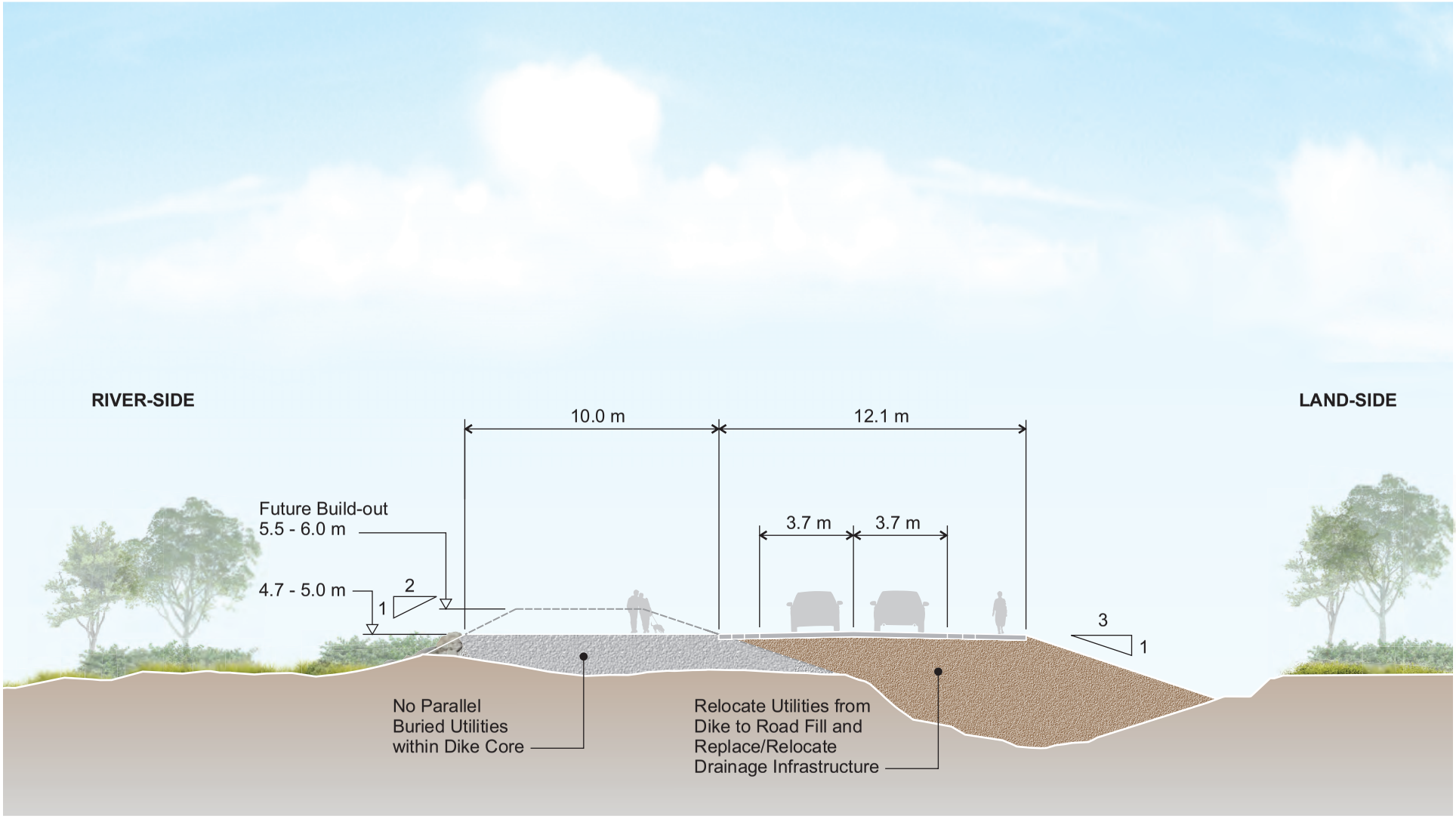
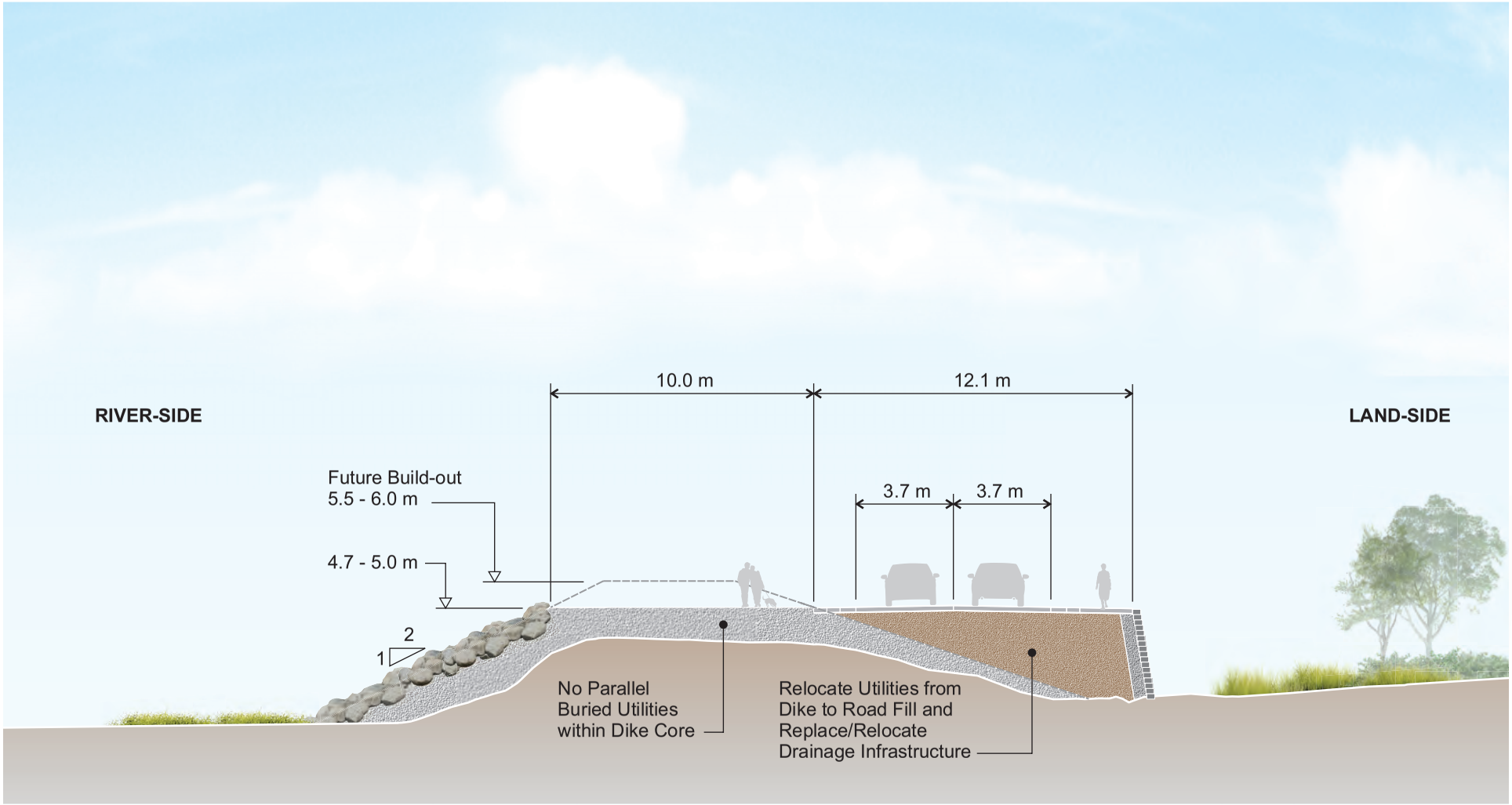


Project No.	651.122
Date	April, 2023
Scale	Not to Scale

Option 1: Raise Dike and Road and Extend Land-side (Reaches 1-5)

Figure 3-2



Project No.	651.122
Date	April, 2023
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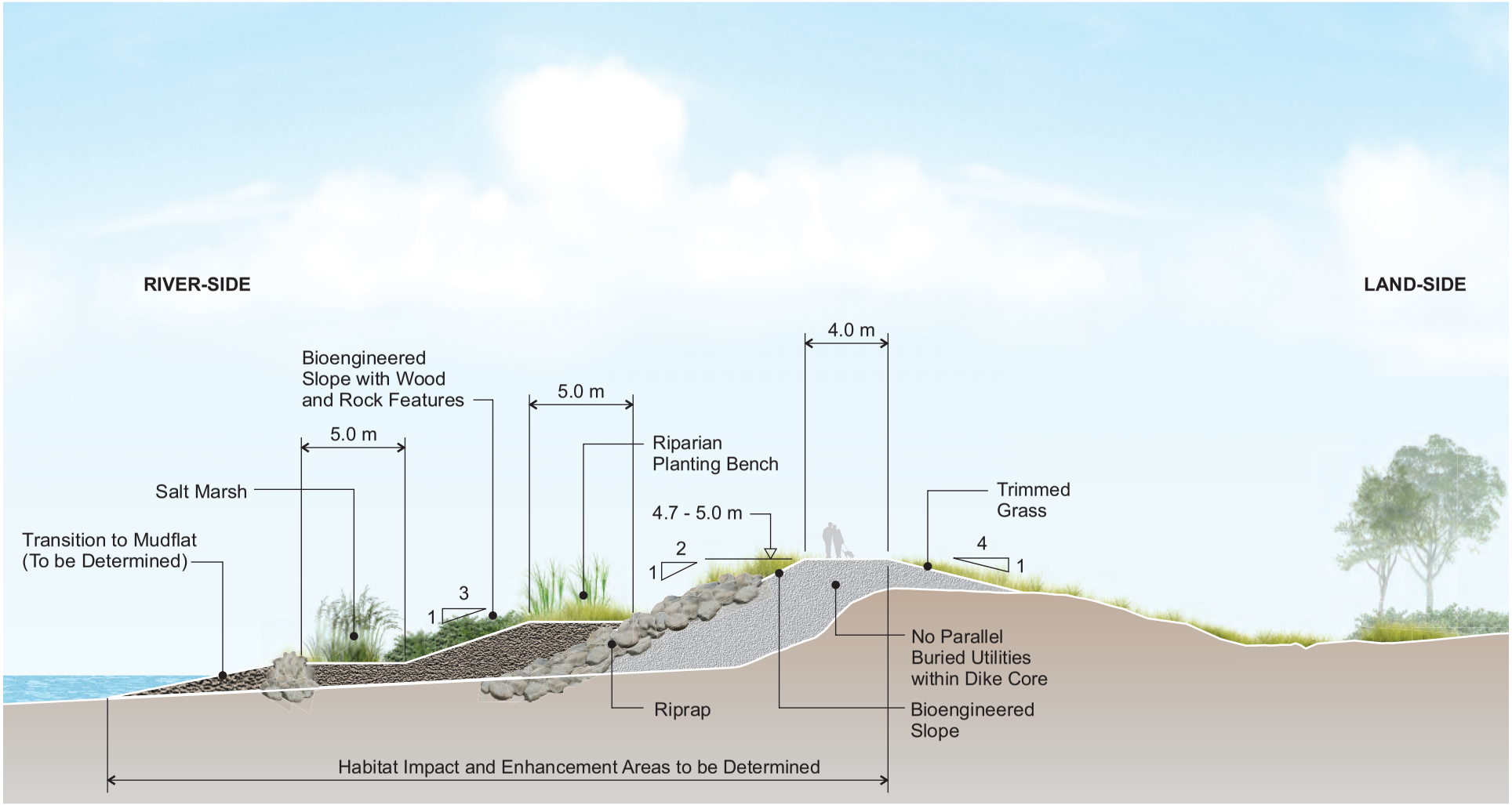
Option 2: Raise Dike and Road with Retaining Walls (Reach 4)

Figure 3-3

City of Richmond
Lulu Island Dike Master Plan - Phase 4

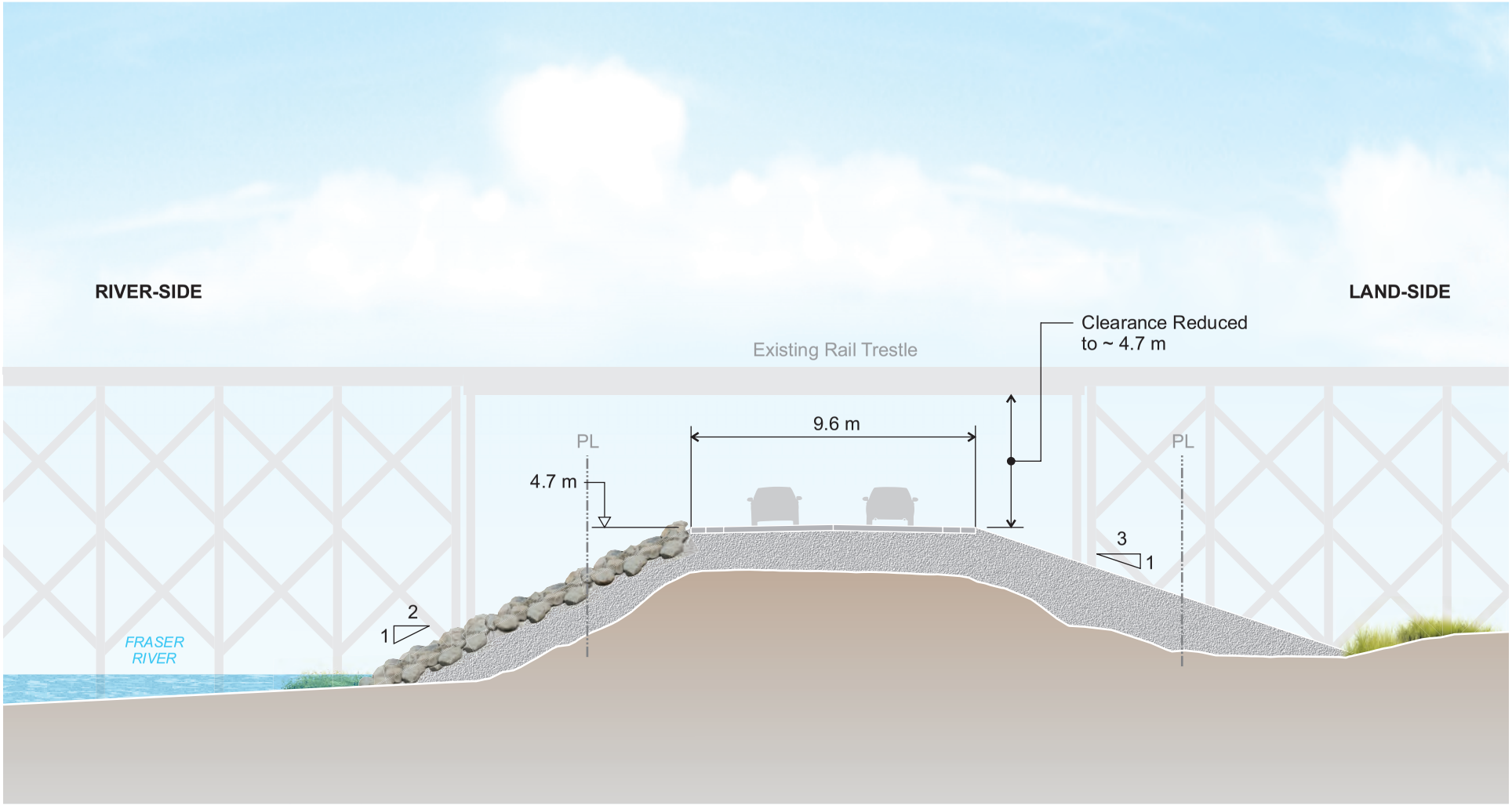
KERR WOOD LEIDAL
consulting engineers



Project No.	651.122
Date	April, 2023
Scale	Not to Scale

Option 3: Raise Dike Only and Extend River-side (Reaches 4-6)

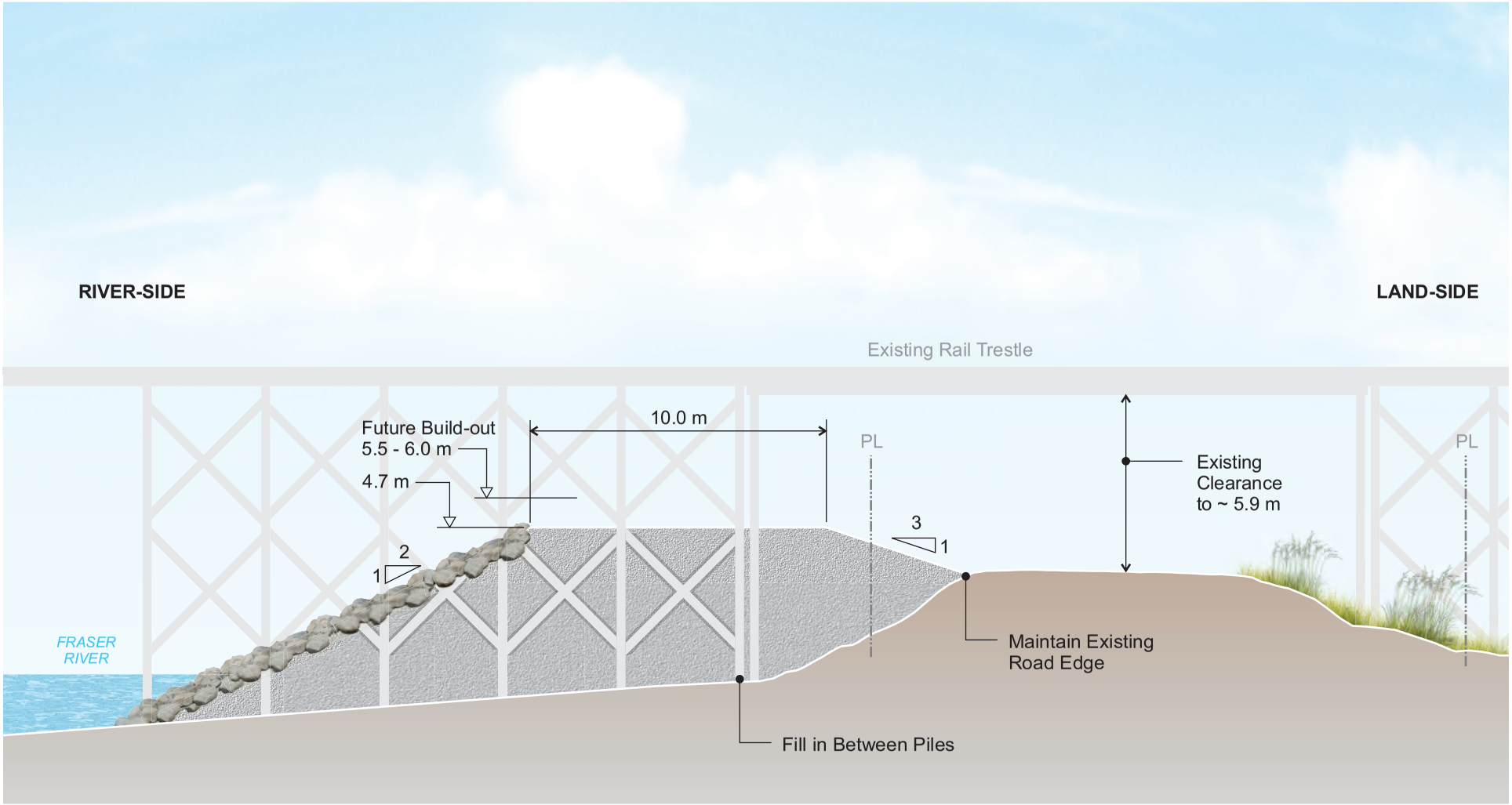
Figure 3-4



Project No.	651.122
Date	April, 2023
Scale	Not to Scale

Option 6: Rail Trestle - Raise Road/Dike Under Trestle (Reach 4)

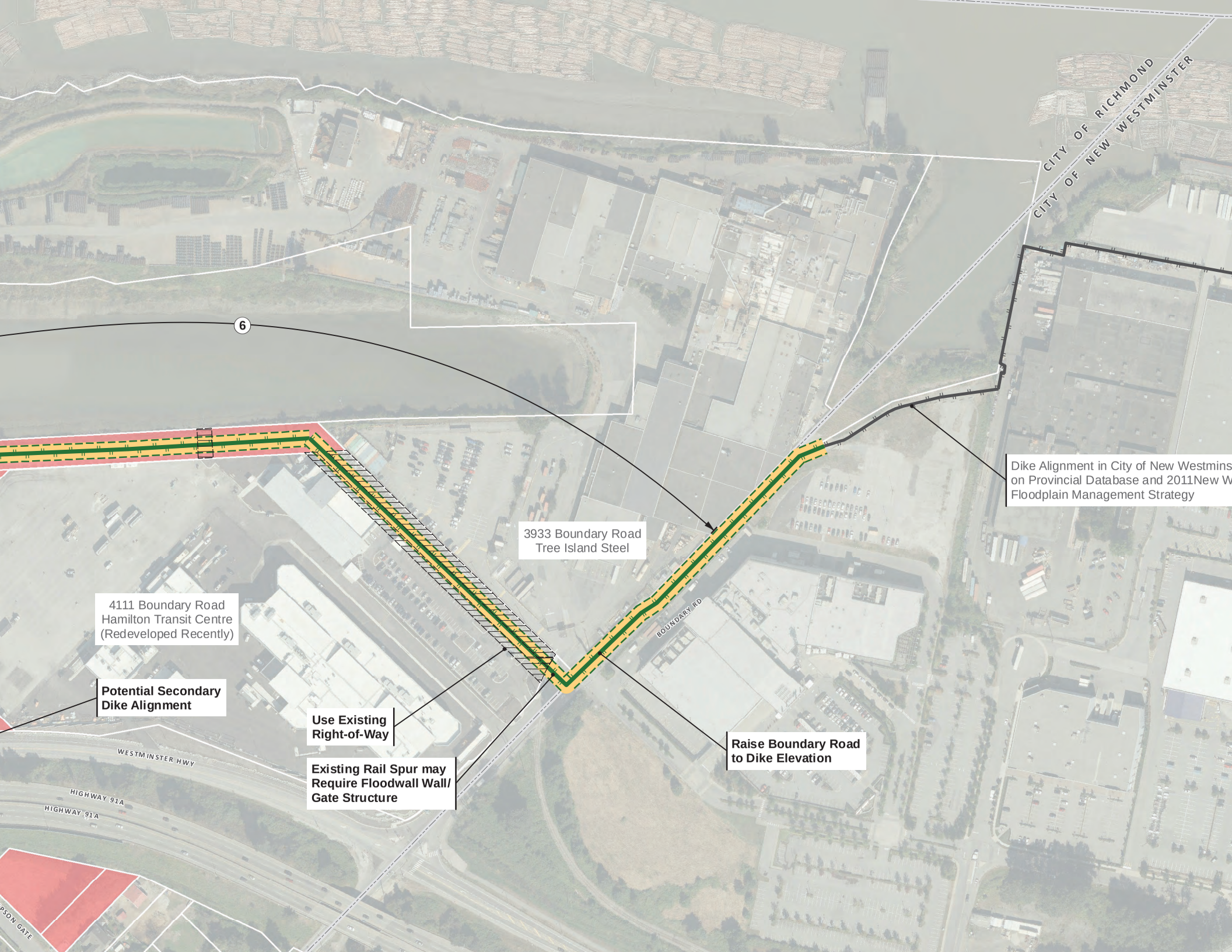
Figure 3-5

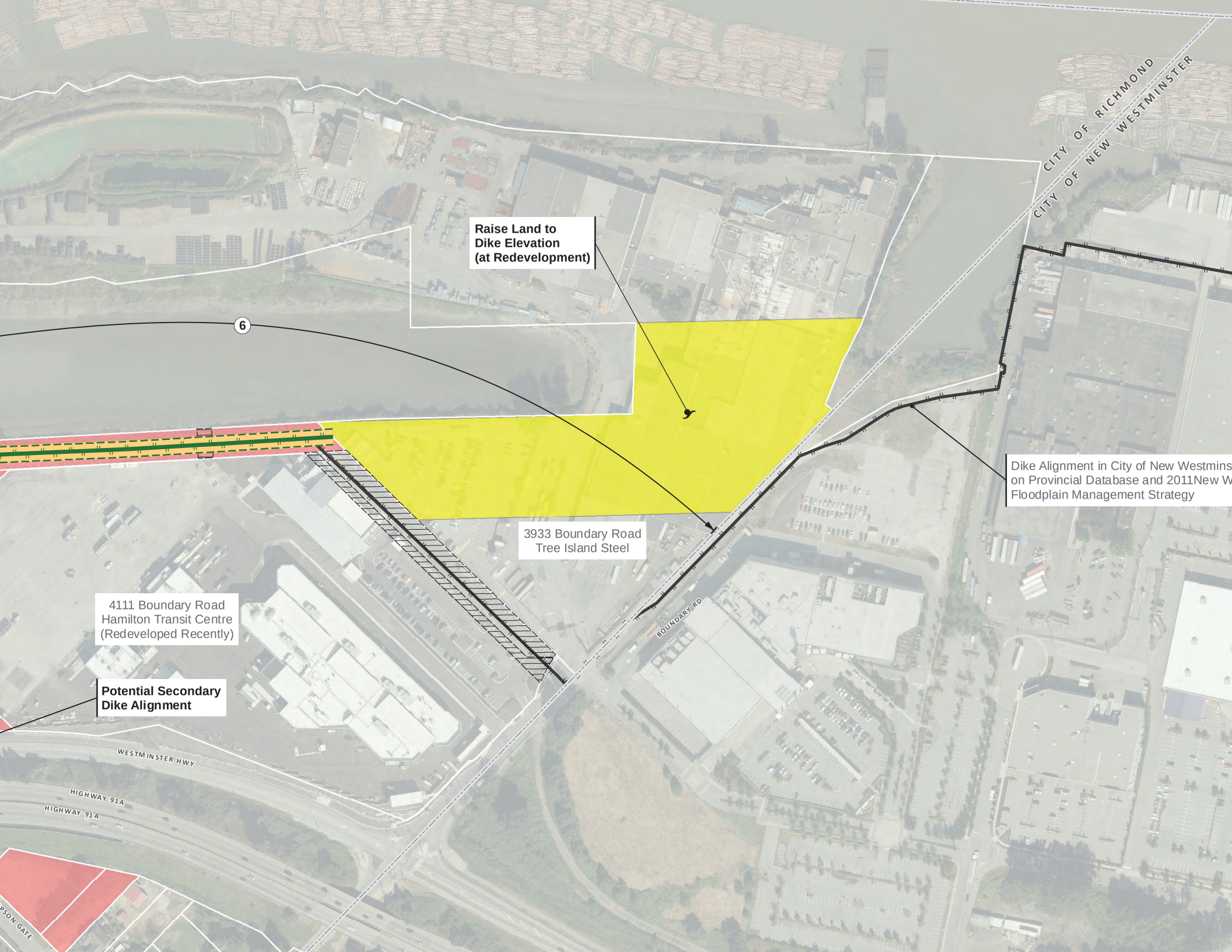


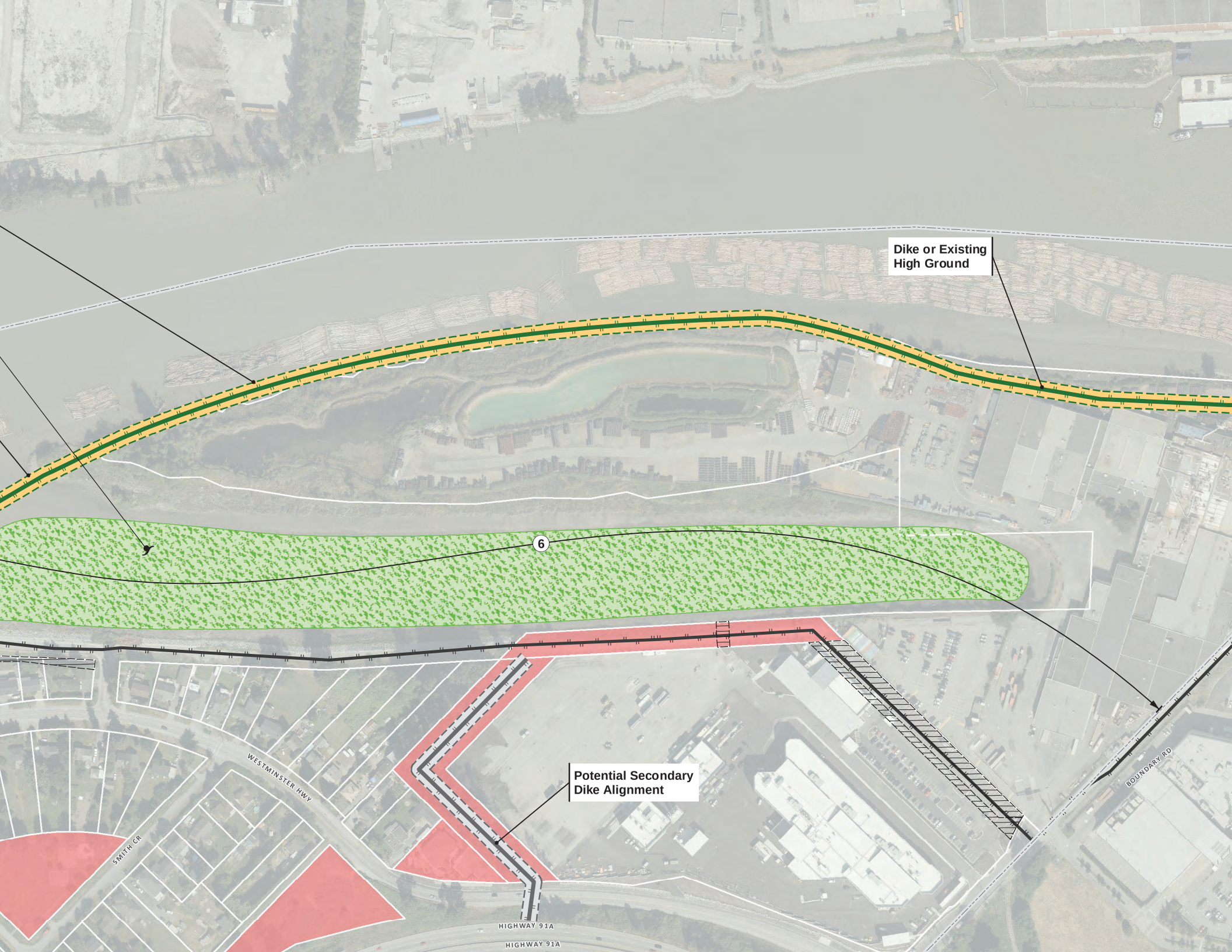
Project No.	651.122
Date	April, 2023
Scale	Not to Scale

Option 7: Rail Trestle - Fill In-between Trestle Pile (Reach 4)

Figure 3-6


CITY OF RICHMOND
CITY OF NEW WESTMINSTER
6
Dike Alignment in City of New Westmins
on Provincial Database and 2011New W
Floodplain Management Strategy
3933 Boundary Road
Tree Island Steel
4111 Boundary Road
Hamilton Transit Centre
(Redeveloped Recently)
BOUNDARY RD
Potential Secondary
Dike Alignment
Use Existing
Right-of-Way
Existing Rail Spur may
Require Floodwall Wall/
Gate Structure
Raise Boundary Road
to Dike Elevation
WESTMINSTER HWY
HIGHWAY 91A
HIGHWAY 91A


Raise Land to
Dike Elevation
(at Redevelopment)
6
CITY OF RICHMOND
CITY OF NEW WESTMINSTER
Dike Alignment in City of New Westmins
on Provincial Database and 2011New W
Floodplain Management Strategy
3933 Boundary Road
Tree Island Steel
4111 Boundary Road
Hamilton Transit Centre
(Redeveloped Recently)
BOUNDARY RD
Potential Secondary
Dike Alignment
WESTMINSTER HWY
HIGHWAY 91A
HIGHWAY 91A


Dike or Existing High Ground
6
Potential Secondary Dike Alignment
WESTMINSTER HWY
SMITH CR
HIGHWAY 91A
HIGHWAY 91A
BOUNDARY RD

4. Implementation Strategy

The implementation strategy has three parts:

- pre-design measures;
- construction sequencing for a typical reach; and
- prioritization of reaches for construction.

4.1 Pre-design Measures

Before construction can be implemented, the following steps are recommended.

- Use the Dike Master Plan as a planning tool with City land use planning to acquire land during redevelopment, and to rezone land with conditions for land raising inland of the dike.
- Acquire land prior to construction.
- Seek habitat compensation projects to bank credits in preparation for drainage channel and associated riparian area impacts. A separate mater plan for habitat compensation could be prepared to identify and develop medium to large habitat enhancement concepts to serve as compensation for multiple reaches.
- Assess required drainage system modifications (e.g. filling drainage channels and constructing a piped drainage system) in additional detail.
- Design with consideration for construction sequencing noted below.
- Advance public space and multi-use path design concepts further.
- Consider the need for an appropriate building setback from the land-side toe of any future flood protection works in view of the current BC setback guideline of 7.5 m. This should consider the planned dike upgrade to 4.7 m CGVD28, as well as future buildout to 5.5 m CGVD28. This may require consultation with the Inspector of Dikes.

4.2 Construction Sequence

The construction sequence for a typical reach is provided below. A typical reach currently has a road atop the dike, and utilities within the dike.

1. Secure land.
2. Coordinate third party utility relocations. This is mainly hydro on poles. Coordination with rail needed at trestle.
3. Install storm sewer (approximately 1200 mm dia., to be confirmed through at design) in proximity to existing channel.
4. Fill over storm sewer to underside of road structure. The fill placement may be followed by a settlement period depending on geotechnical recommendations. If so, this fill may include a preload depth in excess of the road fill.
5. Install new utilities (typically water and hydro, with some sewer).
6. Construct new road with parking where access outside the dike will be impacted.

7. Divert traffic to new road.
8. Remove existing road and utilities. Don't abandon utilities within dike.
9. Fill dike to crest elevation. Excavation of sub-grade may be required to remove unsuitable materials.
10. Complete armouring, trail, and landscaping.

Larger projects will result in less temporary road diversion works. As an alternate, the entire road could be reconstructed first, in phases, before the dike is built later. This would work with the new road being raised to dike crest elevation.

4.3 Prioritization

Priority for construction will depend on which section is the lowest and therefore most urgent to raise, opportunities such as site development or road improvement plans, level of preparedness for issues such as land acquisition and habitat offsets, and adjacent residents' receptiveness to a higher dike. A preliminary priority list is provided below. Opportunities may shift the order, and the reaches may be broken down into smaller or larger projects.

Table 4-1: Priority by Reach

	Reach ID and Name	Extent / Length	Notes
1	3 – Riverfront Houses and ALR	No. 8 Road to Nelson Road	• Low section and road safety issues.
2	4 – Bog and Rail	Nelson Road to Rail Trestle	• Low section and road safety issues. Rail coordination takes time.
3	5 – Hamilton Frontages	Rail Trestle to Queens Road	• Relatively straightforward.
4	2 – Industrial and Shipyards	No. 7 Road to No. 8 Road	• Seek redevelopment opportunities for land acquisition and to resolve access issues.
5	1 – Bridgeport Industrial	No. 6 Road to No. 7 Road	• Seek redevelopment opportunities for land acquisition and to resolve access issues.
6	6 – Tree Island Slough and Boundary	Queens Road to City of New Westminster	• Coordinate with planned park, road realignment, and redevelopment. Seek revised alignment with Tree Island Steel site, and further investigate Tree Island Slough habitat enhancement.

5. Reach Summary Sheets

This section contains 2-page, reach-by-reach summary sheets that summarize the existing conditions, design considerations and potential constraints for each reach of Phase 4. The second sheet will summarize the features of the master plan through each reach including typical cross-sections, plan features, costs and priority for upgrade.

Reach 1: Bridgeport Industrial

Existing Conditions

The existing dike in this reach is located in River Road. A watermain and overhead utilities run along the southern portion of the road.

This reach has wide vegetated channels on the inland side of the dike, and a wide vegetated riparian zone on the riverside.

Industrial lots and associated infrastructure exist throughout the reach, including warehouses and container storage.

No. 6 Road is the tie-in location with Phase 2 of the Dike Master Plan, and is also a potential tie-in location for the proposed mid-island dike.

Unique Features

- Drainage pump station at No. 6 Road.
- Industrial sites with water access north of River Road (e.g. Mainland Sand and Gravel).
- FortisBC gas pipeline river crossing and facility west of No. 7 Road.
- Drainage channel and pipe south of road.
- Riparian area north of road.
- Potential future tie-in location with proposed mid-island dike.

Considerations

Flood Protection

- Dike alignment
- Dike crest elevation
- Erosion protection
- Seismic performance
- Static stability and seepage
- River toe stability and setbacks
- Boat waves

Industrial

- Water access industrial sites north of road/dike
- Road design and driveway grade to accommodate large trucks

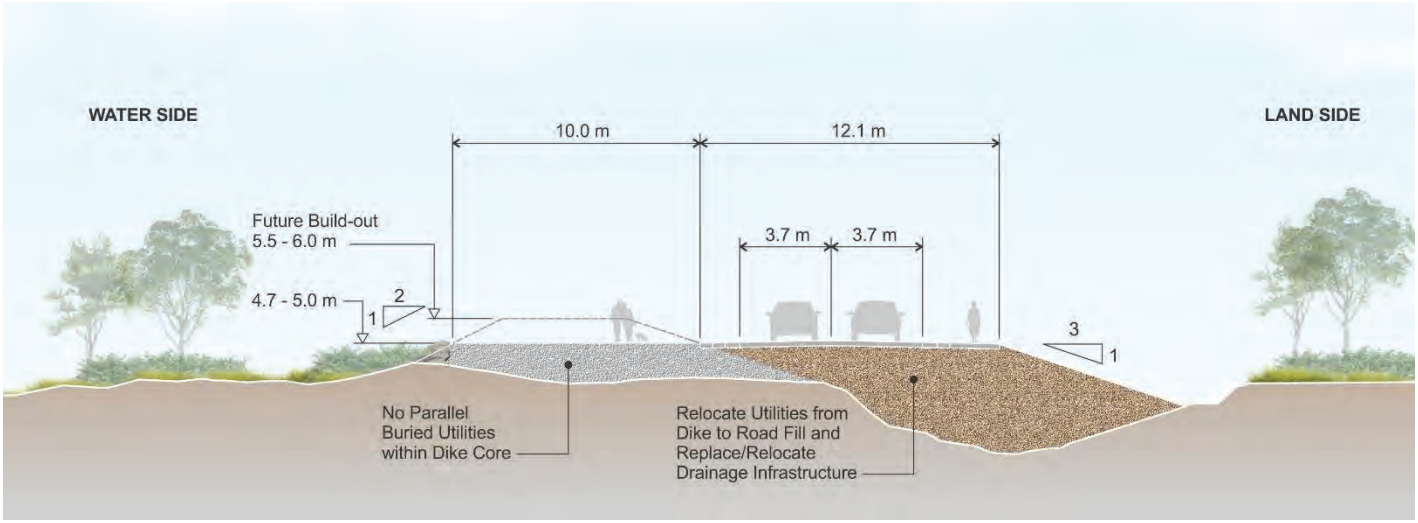
Social

- No. 7 Road Pier Park
- Align with 2009 Waterfront Strategy
- Connect to existing and planned trails and public amenities
- Wayfinding and public information signs

Environmental

- Fraser River side habitat includes high quality intertidal habitat and high quality riparian habitat
- Land side includes drainage channels adjacent to dike
- No. 7 Road Pier Park

Reach 1: Bridgeport Industrial - Recommended Improvements



Master Plan Features

Flood Protection

Raise dike to 4.7 m and separate and raise road inland of the dike as illustrated above.

Dike alignment will typically extend up from the current face of dike, and widen inland.

Provide erosion protection along the face of the dike, typically consisting of rip rap revetment.

Raise properties 200 m inland to 4.7 m or densify to the depth of potential liquefaction.

Replace channels with storm sewers and swales to improve stability and reduce seepage.

Industrial

Raise road to dike crest elevation to permit access over tide to industrial sites north of dike.

Raise industrial sites to dike crest elevation during redevelopment.

For lower sites, driveway ramps may need to extend into lots with grades that accommodate large trucks. Ramps may require retaining walls to limit footprint.

Social

Construct multi-use path on top of dike, separate from road. Link to parks, trails, public amenities, and wayfinding.

Environmental

The proposed footprint would impact an estimated 500 m^2 of high quality Fraser River riparian habitat, 14,800 m^2 of drainage channel riparian habitat, and 3,300 m^2 of drainage channel aquatic habitat

NOTE: This is an estimate based on 2007 FREMP mapping and 2017 orthoimagery interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Priority

Priority is ranked 5th out of 6 reaches.

This is one of the lower priority reaches due to relatively good existing height, and benefits to coordinating with future land redevelopment. The dike is at a higher elevation than the high priority reaches. Required land may be secured through redevelopment opportunities. Land raising during redevelopment will also reduce the width required for dike and road work, and the need for interim access ramps.

Construction Cost

Costs below are for 1.7 km of dike similar to cross-section above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$7.6 Million
Road Structure & Utilities	$5,300	$8.9 Million
Raise Road to Dike Height	$1,900	$3.2 Million
Pathway	$600	$1 Million
Other (Driveways, Ramps or Road Reconstruction)		$.5 Million
Utilities (Drainage, Water)	$2,000	$3.3 Million
Contingency (40%)		$9.8 Million
Total		$34.3 Million

Cost opinions are in 2018 Canadian Dollars.

Reach 2: Industrial and Shipyards

Existing Conditions

The existing dike alignment in this reach is a dike in River Road. This reach has industrial lots, shipyards and a narrow riparian strip on the water side of the dike.

The inland side of the dike has access to industrial lots and residential lots to the east side of the reach.

Currently, there is parking along the dike for the shipyard employees.

Unique Features

- Water-oriented industrial parcels located north of road (tugboat operation and Tom-Mac Shipyards).
- Residential/storage properties located north of road with minimal setback between road and structures.
- Large industrial parcels located south of road near No. 7 Road.
- ALR parcels with houses located south of road.
- Drainage pump station at No. 8 Road.

Considerations

Flood Protection

- Dike alignment
- Dike crest elevation
- Erosion protection
- Seismic performance
- Static stability and seepage
- River toe stability and setbacks
- Boat waves

Industrial

- Water access for tugboats, and shipyards.
- Road design and driveway grade to accommodate large trucks
- Drainage pump station at No. 8 Road
- Parking for shipyards is along River Road

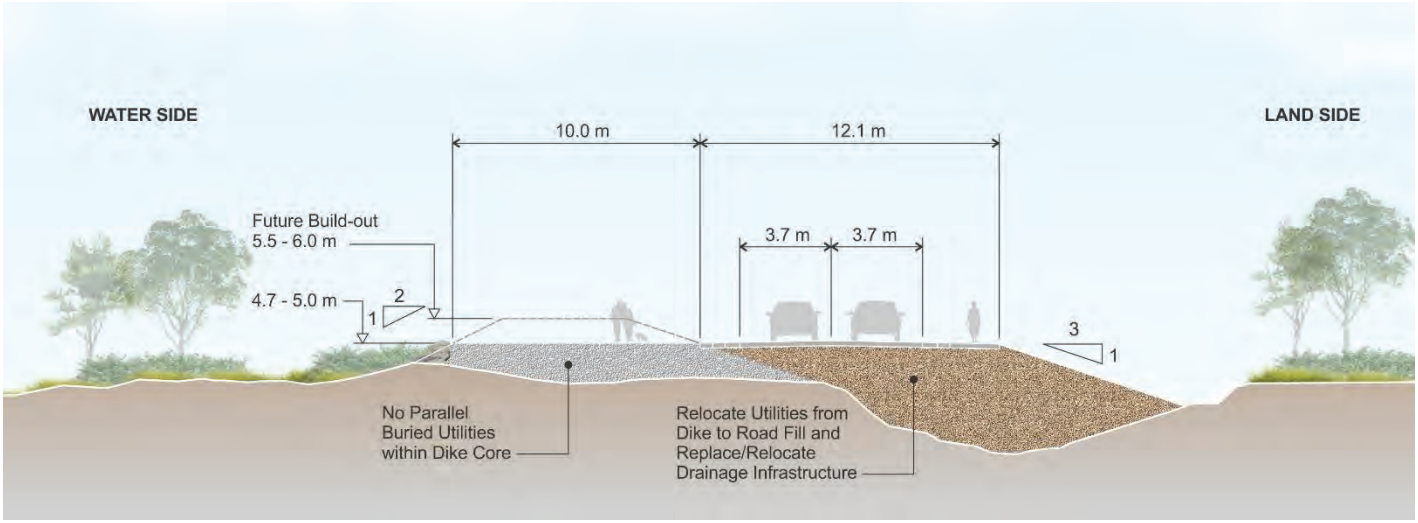
Social

- Align with 2009 Waterfront Strategy
- Connect to existing and planned trails and public amenities
- Wayfinding and public information signs

Environmental

- Fraser River side habitat includes narrow deciduous treed woodland high-quality habitat
- Western portion of Land side includes drainage channels adjacent to dike; eastern portion of land side has trees/hedges along residential lots

Reach 2: Industrial and Shipyards - Recommended Improvements



Master Plan Features

Flood Protection

Raise dike to 4.7 m and separate and raise road inland of the dike as illustrated above.

Dike alignment will typically extend up from the current face of dike, and widen inland.

Provide erosion protection along the face of the dike, typically consisting of rip rap revetment.

Raise properties 200 m inland to 4.7 m or densify to the depth of potential liquefaction.

Replace channels with storm sewers and swales to improve stability and reduce seepage.

Industrial

Raise road to dike crest elevation to permit access over tide to industrial sites north of dike.

Raise industrial sites to dike crest elevation during redevelopment.

For lower sites, driveway ramps may need to extend into lots with grades that accommodate large trucks.

Social

Construct multi-use path along dike, separate from road. Link to parks, trails, public amenities, and wayfinding.

Environmental

The proposed footprint would impact an estimated 800 m^2 of high quality Fraser River riparian habitat, 28,000 m^2 of drainage channel riparian habitat, and 5,900 m^2 of drainage channel aquatic habitat

NOTE: This is an estimate based on 2007 FREMP mapping and 2017 orthoimagery interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Priority

Priority is ranked 4th out of 6 reaches.

This is one of the lower priority reaches due to relatively good existing height, and benefits to coordinating with future land redevelopment. The dike is at a higher elevation than the high priority reaches. Required land may be secured through redevelopment opportunities. The adjacent industrial land is less developed than Reach 1, so opportunities for land acquisition and land raising through redevelopment may arise earlier than for Reach 1. Land raising during redevelopment will also reduce the width required for dike and road work, and the need for interim access ramps.

Construction Cost

Costs below are for 1.7 km of dike similar to cross-section above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$7.7 Million
Road Structure & Utilities	$5,300	$9.1 Million
Raise Road to Dike Height	$1,900	$3.3 Million
Pathway	$600	$1 Million
Other (Driveways, Ramps or Road Reconstruction)		$1 Million
Utilities (Drainage, Water)	$2,000	$3.4 Million
Contingency (40%)		$10.2 Million
Total		$35.8 Million

Cost opinions are in 2018 Canadian Dollars.

Reach 3: Riverfront Houses and ALR

Existing Conditions

The dike in this reach is a dike in River Road, with a combination of residential and industrial lots on either side of the dike.

The inland side of the dike has large residential lots separated from the road by a large channel and hedges. The water side of this reach has access to docks, storage, drainage pump station.

There is a major Metro Vancouver pipe river crossing in this reach.

Unique Features

- Residential/storage properties located north of road with minimal setback between road and structures near Nelson Road.
- ALR parcels with houses located south of road.
- Metro Vancouver Tilbury watermain crossing near Nelson Road.

Considerations

Flood Protection

- Dike alignment
- Dike crest elevation
- Erosion protection
- Seismic performance
- Static stability and seepage
- River toe stability and setbacks
- Boat waves

Industrial

- Drainage pump station at east side of the reach
- Storage and water access on the north side of River Road
- Metro Vancouver watermain crossing
- Road design and driveway grade to accommodate large trucks

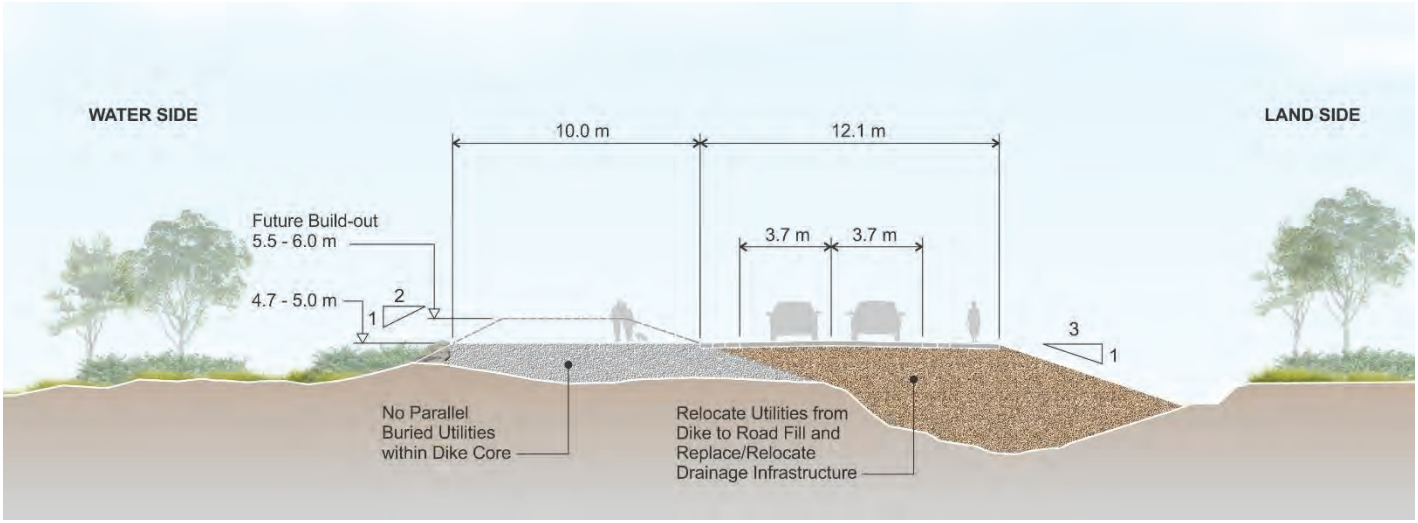
Social

- Align with 2009 Waterfront Strategy
- Connect to existing and planned trails and public amenities
- Wayfinding and public information signs

Environmental

- Fraser River Side habitat includes narrow deciduous treed woodland high-quality habitat along the 75% of the reach
- Land side has tree/hedges along residential lots and drainage channels

Reach 3: Riverfront Houses and ALR - Recommended Improvements



Master Plan Features

Flood Protection

Raise dike to 4.7 m and separate and raise road inland of the dike as illustrated above.

Dike alignment will typically extend up from the current face of dike, and widen inland.

Provide erosion protection along the face of the dike, typically consisting of rip rap revetment.

Raise properties 200m inland to 4.7m or densify to the depth of potential liquefaction.

Replace channels with storm sewers and swales to improve stability and reduce seepage.

Industrial

Raise road to dike crest elevation to permit access over tide to properties north of dike.

Parking for properties north of dike to be provided at side of road, or with driveways and ramps or raised parking on private property.

Social

Construct multi-use path along dike, separate from road. Link to parks, trails, public amenities, and wayfinding.

Environmental

The proposed footprint would impact an estimated 300 m^2 of high quality Fraser River riparian habitat, 50 m^2 of high quality Fraser River intertidal habitat, 16,100 m^2 of drainage channel riparian habitat, and 3,000 m^2 drainage channel aquatic habitat

NOTE: This is an estimate based on 2007 FREMP mapping and 2017 orthoimagery interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Priority

Priority is ranked 1st out of 6 reaches.

This is highest ranked priority due to low crest elevations and road safety issues.

Land acquisition may be required, but the large agricultural/residential lots typically include adequate setbacks to provide enough space without redevelopment.

Land raising during redevelopment will also reduce the width required for dike and road work, and the need for interim access ramps.

Construction Cost

Costs below are for 0.9 km of dike similar to cross-section above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$4 Million
Road Structure & Utilities	$5,300	$4.8 Million
Raise Road to Dike Height	$1,900	$1.7 Million
Pathway	$600	$.5 Million
Other (Driveways, Ramps or Road Reconstruction)		$.6 Million
Utilities (Drainage, Water)	$2,000	$1.8 Million
Contingency (40%)		$5.4 Million
Total		$18.9 Million

Cost opinions are in 2018 Canadian Dollars.

Reach 4: Bog and Rail

Existing Conditions

The dike in this reach is within River Road.

There are environmental and agricultural constraints along either side of the dike. Outside of the dike on the riverside, there is a narrow strip of riparian zone and riprap along the Fraser River.

Informal agricultural (cranberry) dikes are located along the south edge of the road/dike. The drainage channel in this reach is very wide.

The North East Bog Forest is a city park/conservation area located south of the road/dike.

The east side of the reach includes a rail trestle bridge that crosses the dike and Fraser River.

Unique Features

- ALR parcels with cranberry farms south of road.
- Very large agricultural channel south of dike.
- North East Bog Forest (City park).
- Rail trestle river crossing.
- No space between road edge and river channel (existing riprap bank protection).

Considerations

Flood Protection

- Dike alignment
- Dike crest elevation
- Erosion protection
- Seismic performance
- Static stability and seepage
- River toe stability and setbacks
- Boat waves
- Soft soils (bog)

Industrial

- Water access and parking for docks.
- Road and Driveway access will need to be regraded.
- Train rail trestle located at east side of reach.
- Farm dike on the inside of the current dike.

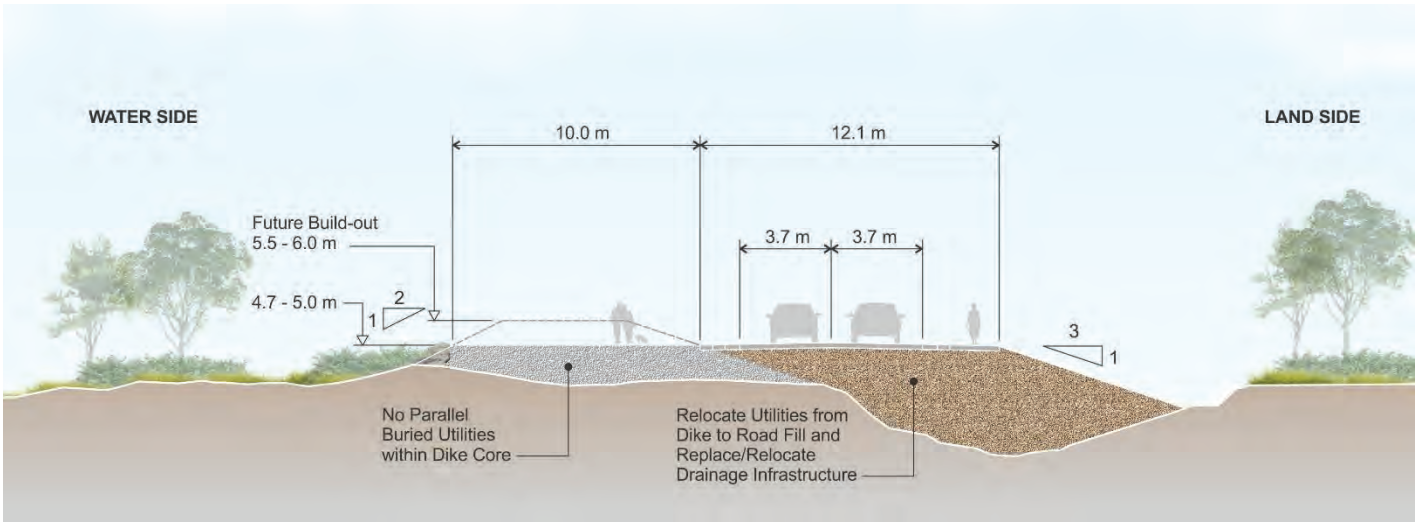
Social

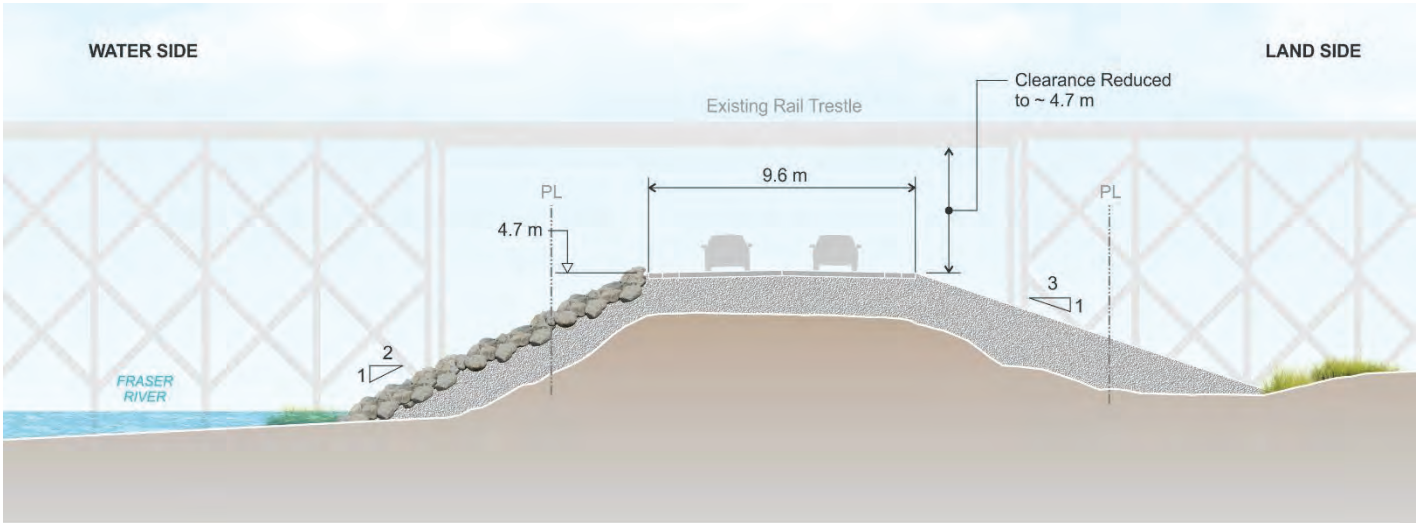
- North East Bog Forest
- Align with 2009 Waterfront Strategy
- Connect to existing and planned trails and public amenities
- Wayfinding and public information signs

Environmental

- Fraser River side habitat includes narrow low-brush riparian zone on ½ of reach
- Land side includes drainage channels adjacent to and North East Bog Forest at eastern end of the reach

Reach 4: Bog and Rail - Recommended Improvements





Master Plan Features

Flood Protection

Raise dike to 4.7 m and separate and raise road inland of the dike as illustrated above.

Dike alignment will typically shift into the river, with some widening inland.

Provide erosion protection along the face of the dike, typically consisting of rip rap revetment.

Industrial

Coordinate work around rail trestle with rail company.

Social

Construct multi-use path along dike, separate from road. Link to parks, trails, public amenities, and wayfinding, per Lululoop concept developed in Phase 3. Ensure barriers are in place where the road and path narrow into closer proximity at the rail trestle.

Environmental

The proposed footprint would impact an estimated 300 m^2 of high quality Fraser River riparian habitat, 100 m^2 of high quality Fraser River intertidal habitat, 23,500 m^2 drainage channel riparian habitat, and 10,200 m^2 drainage channel aquatic habitat

NOTE: This is an estimate based on 2007 FREMP mapping and 2017 orthoimagery interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Reach 4: Bog and Rail - Recommended Improvements

Priority

Priority is ranked 2nd out of 6 reaches.

This is ranked high due to low crest elevations and road safety issues.

Regulatory and rail company approvals may take extra time due to proposed widening into river and work around the trestle structure.

Land acquisition may be required, but the large agricultural/residential lots typically include adequate setbacks to provide enough space without redevelopment.

Land raising during redevelopment will also reduce the width required for dike and road work, and the need for interim access ramps.

Construction Cost

Costs below are for 2.2 km of dike similar to cross-section above.

Item	Cost per metre	Cost
Option 1		
Dike Raising	$4,500	$10.3 Million
Road Structure	$5,300	$12.1 Million
Raise Road to Dike Height	$1,900	$4.3 Million
Pathway	$600	$1.4 Million
Other (Driveways, Ramps or Road Reconstruction)		$.6 Million
Utilities (Drainage, Water)	$2,000	$4.8 Million
Option 6 Only at Rail Trestle Crossing		
9.6 m wide Dike Crest at 4.7 m c/w riprap with 15-20 m widening at base	$4,500	$.3 Million
9.6 m wide asphalt road with 2x1.1 m shoulder	$1,900	$1 Million
Contingency (40%)		$13.5 Million
Total		$47.1 Million

Cost opinions are in 2018 Canadian Dollars.

Reach 5: Hamilton Frontages

Existing Conditions

This reach of the dike is located on a narrow strip of right-of-way between the Fraser River, and agricultural/residential lots.

On the Fraser River side of the dike, there is a strip of riprap for bank protection. The inland side of the dike includes a minor drainage channel, agricultural land and residential lots at the east side of the reach.

There is a major Metro Vancouver pipe crossing in this reach.

Unique Features

- ALR parcels south of road with houses located close to road.
- No space between road edge and river channel (existing riprap bank protection).
- Metro Vancouver Big Bend forcemain crossing west of 21920 River Road.
- Queens North drainage pump station west of Westminster Highway.

Considerations

Flood Protection

- Dike alignment
- Dike crest elevation
- Erosion protection
- Seismic performance
- Static stability and seepage
- River toe stability and setbacks
- Boat waves

Industrial

- Pump station on waterside of dike
- Road design and driveway grade

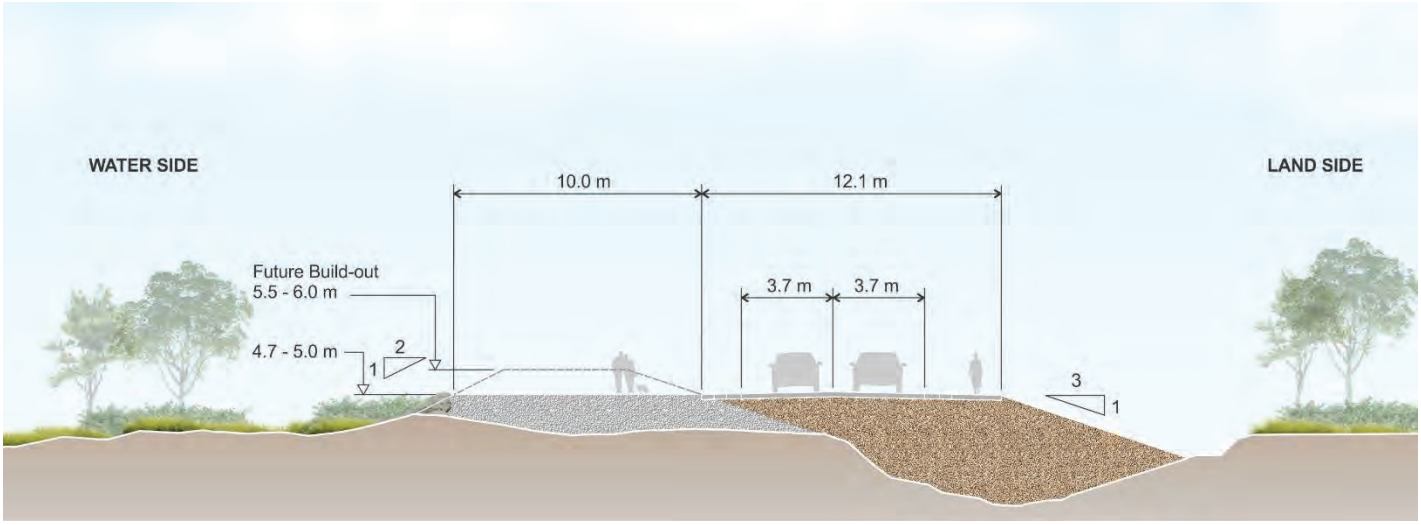
Social

- Align with 2009 Waterfront Strategy
- Connect to existing and planned trails and public amenities
- Wayfinding and public information signs

Environmental

- Fraser River side has narrow riprap slope, with low-quality habitat
- Land side includes agricultural land for ½ of reach, and low-quality habitat and maintained lawn (residential) for remainder of reach. Drainage channels and associated riparian and aquatic habitat area present along the full length of the reach

Reach 5: Hamilton Frontages - Recommended Improvements



Master Plan Features

Flood Protection

Raise dike to 4.7 m and separate and raise road inland of the dike as illustrated above.

Dike alignment will typically extend up from the current face of dike, and widen inland.

Provide erosion protection along the face of the dike, typically consisting of rip rap revetment.

Raise properties 200 m inland to 4.7 m or densify to the depth of potential liquefaction.

Replace channels with storm sewers and swales to improve stability and reduce seepage.

Industrial

Driveway ramps required to extend to access private properties until properties raised.

Social

Construct multi-use path along dike, separate from road. Link to parks, trails, public amenities, and wayfinding.

Environmental

The proposed footprint would impact an estimated 900 m^2 of high quality Fraser River intertidal habitat, 23,700 m^2 of drainage channel riparian habitat, and 5,900 m^2 of drainage channel aquatic habitat

NOTE: This is an estimate based on 2007 FREMP mapping and 2017 orthoimagery interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Priority

Priority is ranked 3rd out of 6 reaches.

This is ranked just above average high due to moderate elevations, but relatively straightforward implementation.

There are some active redevelopment plans for the area, including road realignment at the east end of the reach. Road and development changes may change the priority of this reach.

Land acquisition may be required, but the large agricultural/residential lots typically include adequate setbacks to provide enough space without redevelopment.

Land raising during redevelopment will also reduce the width required for dike and road work, and the need for interim access ramps.

Construction Cost

Costs below are for 1.6 km of dike similar to cross-section above.

Item	Cost per metre	Cost
Dike Raising	$4,500	$7.3 Million
Road Structure & Utilities	$5,300	$8.6 Million
Raise Road to Dike Height	$1,900	$3. Million
Pathway	$600	$1. Million
Other (Driveways, Ramps or Road Reconstruction)		$.6 Million
Utilities (Drainage, Water)	$2,000	$3.2 Million
Contingency (40%)		$9.5 Million
Total		$33.1 Million

Cost opinions are in 2018 Canadian Dollars.

Reach 6: Tree Island Slough and Boundary

Existing Conditions

The dike system in this reach is between a slough and the backyards of single family residential homes. Riprap bank protection exists along the river-side slope.

The slough on the Fraser River side of the dike provides high-quality marsh and mudflat habitat.

The existing dike alignment is not well-defined east of the Hamilton Transit Centre. It is understood that the current tie-in with the City of New Westminster's portion of the dike is along Boundary Road. The Tree Island Steel property (3933 Boundary Road) has rail access across Boundary Road which may be an obstacle to dike raising.

Existing city-owned lots provide an opportunity for a Richmond-New Westminster boundary secondary dike.

Unique Features

- River Road dike alignment from Queens Road to Westminster Highway, then a river-bank dike runs north of Westminster Highway houses to edge of new Hamilton Transit Centre.
- Tree Island Steel site (3933 Boundary Road) creates a slough north of the dike that shelters the road/dike from the river.
- Backyards of single family homes located south of dike.
- Dike alignment not well defined from Hamilton Transit Centre to City of New Westminster river-bank dike.
- Potential tie-in with proposed secondary dike to separate Richmond and New Westminster.

Considerations

Flood Protection

Dike alignment
Dike crest elevation
Erosion protection
Seismic performance
Static stability and seepage
River toe stability and setbacks
Boat waves

Industrial

Hamilton Transit Centre
Tree Island Steel with rail connection

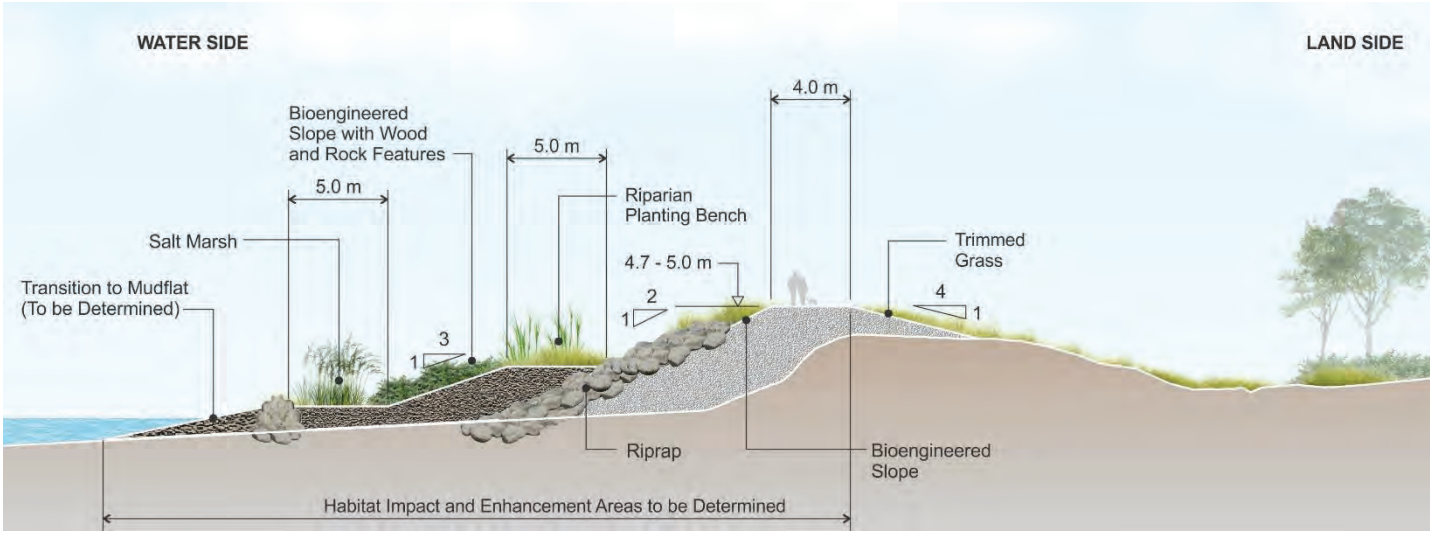
Social

Align with 2009 Waterfront Strategy
Connect to existing and planned trails and public amenities
Wayfinding and public information signs

Environmental

Slough located on the Fraser River side of the dike
High-quality mud flats and marsh found within the slough
Land side of dike includes maintained backyards for the western portion of the reach

Reach 6: Tree Island Slough and Boundary



Master Plan Features

Flood Protection

Raise dike to 4.7 m as illustrated above.

Dike alignment will typically extend up from the current face of dike, and widen inland.

Provide erosion protection along the face of the dike, typically consisting of rip rap revetment.

Raise properties 200 m inland to 4.7 m or densify to the depth of potential liquefaction.

Construct north section of secondary dike near Boundary Road.

Industrial

Seek shift of dike alignment to include the Tree Island Steel side and Tree Island Slough if and when this site redevelops.

Raise the dike through the Hamilton Transit Centre during future redevelopment.

Social

Construct multi-use path along dike. Link to parks, trails, public amenities, and wayfinding, per Lululoop. Develop trail link to south dike at Boundary Road, plus links to New Westminster dike trail.

Environmental

The proposed footprint would impact an estimated 2,200 m^2 of high quality Fraser River intertidal habitat

NOTE: This is an estimate based on 2007 FREMP mapping and 2017 orthoimagery interpretation. Exact numbers will require an aquatic habitat survey and aquatic effects assessment

Reach 6: Tree Island Slough and Boundary

Priority

The is the lower ranked priority reach. This dike is higher than other sections. Stalling construction increases the chance that a realignment opportunity could arise with Tree Island Steel. Alternatively, Hamilton Neighbourhood Plan implementation may provide early opportunities to raise the dike along with road realignment, park development, and some property development.

Construction Cost

Costs below are for 1 km of dike similar to cross-section above.

Item	Cost per metre	Cost
Option 4		
Dike Raising	$4,500	$3.6 Million
Pathway	$600	$.5 Million
Bioengineering Slopes	$1,000	$.8 Million
Marsh Benches	$100	$.08 Million
Utilities (Drainage, Water)	$2,000	$1.6 Million
Other (Driveways, Ramps or Road Intersection Reconstruction)		$.3 Million
Option 8 – Through ROW between Hamilton Transit Centre and Tree Island Slough		
Dike Raising	$4,500	$1.1 Million
Pathway	$600	$.1 Million
Retaining Walls	$1,500	$.8 Million
Utilities (Drainage, Water)	$2,000	$.5 Million
Option 8 – Raise Boundary Road from ROW between Hamilton Transit Centre and Tree Island Steel River Bank		
Raise boundary road to become dike	$5,400	$1.6 Million
Road Structure	$2,850	$.9 Million
Utilities (Drainage, Water)	$2,000	$.6 Million
Contingency (40%)		$5 Million
Total		$17.4 Million

Cost opinions are in 2018 Canadian Dollars.

6. Recommendations

It is recommended that the City adopt the Phase 4 Dike Master Plan as documented in this report, including the main features described below.

- Raise the dike crest to allow for 1 m of sea level rise. West of Nelson Road, the raised dike crest would be 4.7 m (CGVD28). East of Nelson Road, the raised dike crest would increase to 5.1 m at Boundary Road. The plan also allows for longer term upgrading to accommodate a further 1 m of sea level rise (i.e. 2 m of sea level rise).
- Widen the dike on the land side rather than into the Fraser River North Arm.
- Move River Road inside the dike to facilitate short-term and long-term dike upgrading. This will require the road to be reconfigured and reconstructed, with some additional need for land tenure. Moving the road will allow removal of utilities within the dike.
- Raise the relocated River Road to the dike crest elevation. This will facilitate driveway access over the dike to riverside properties. It will also be compatible with the desire to raise land inside the dike.
- Replace the drainage channel immediately inside the dike with storm sewers and swales. This will improve dike stability, and will provide some of the land needed to relocate River Road.
- Raise land and roads immediately inside the dike (during redevelopment) to improve seismic resilience. This will also improve liveability by allowing residents to looking down over the water, rather than at the backside of a dike.
- Improve pedestrian and cyclist safety by constructing a separate multi-use path along the dike. This would be consistent with the City Parks vision for a perimeter trail system (Appendix B)
- Construct the north section of a secondary dike near Boundary Road.

It is also recommended that the City prepare a comprehensive implementation plan for dike upgrading that incorporates the elements of the Phase 4 Dike Master Plan, and the elements of the other Dike Master Plans.

To address habitat compensation issues associated with the Dike Master Plans, it is further recommended that the City consider development of a habitat banking program that could provide effective large-scale compensation for the environmental impacts of dike upgrading. This could include the potential Tree Island Slough project identified in this report.

For all phases of the Dike Master Plan, continue to research alternative densification strategies for seismic stability, consider the proposed alternative seismic performance criteria in Section 3.2, and plan to fill land for approximately 200 m inland of the dike to crest elevation. The required fill distance requires additional evaluation and may be addressed in the pending update to the Flood Protection Management Strategy.

Report Submission

KERR WOOD LEIDAL ASSOCIATES LTD.

Colin Kristiansen, MBA, P.Eng.
Project Manager

Reviewed by:

Mike V. Currie, M.Eng., P.Eng., FEC
Project Director and Technical Reviewer

Statement of Limitations

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This document represents KWL's best professional judgment based on the information available at the time of its completion and as appropriate for the project scope of work. Services performed in developing the content of this document have been conducted in a manner consistent with that level and skill ordinarily exercised by members of the engineering profession currently practicing under similar conditions. No warranty, express or implied, is made.

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Revision History

Revision #	Date	Status	Revision	Author
0	April 28, 2023	Final	Add stakeholder and public engagement summary	CAK

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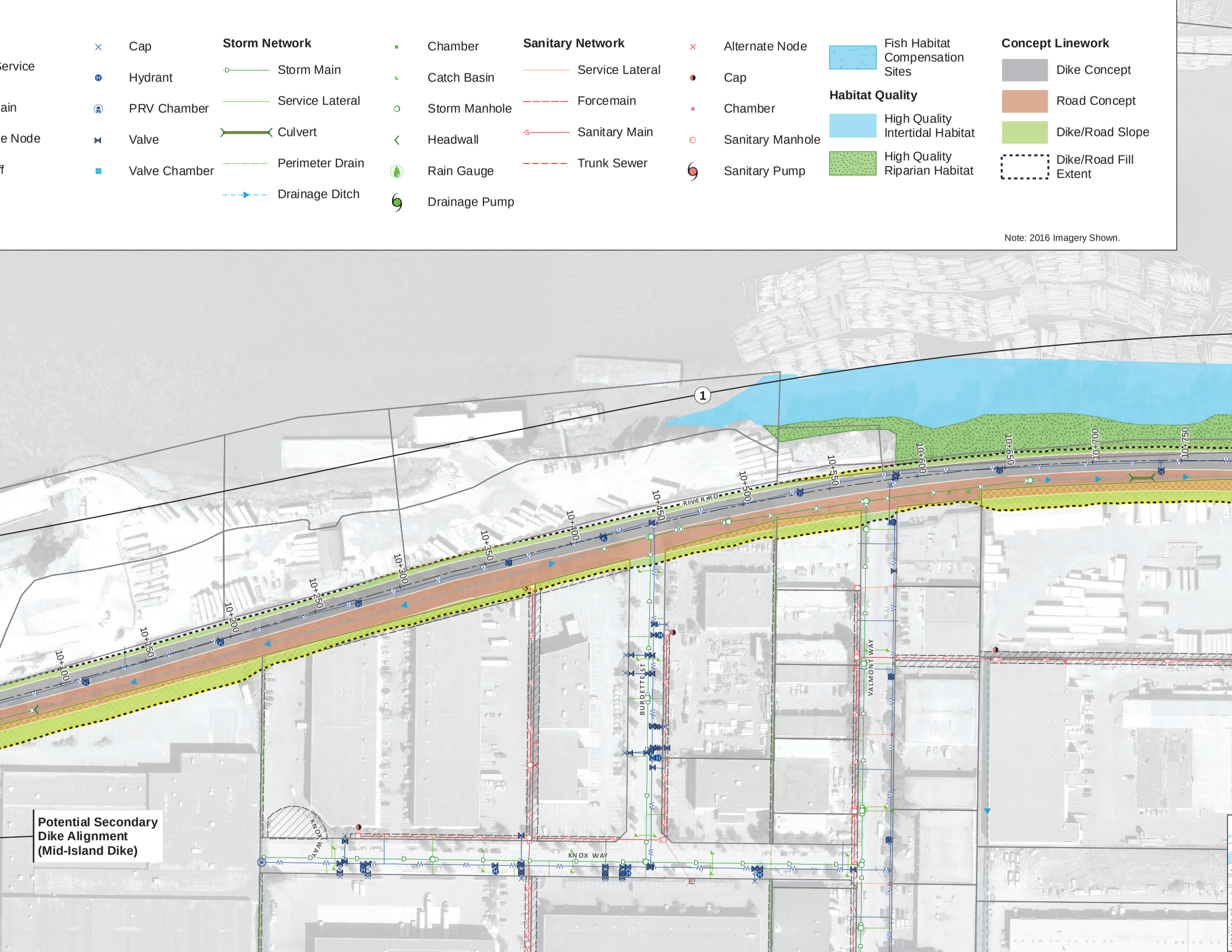
Appendix A

Plans and Sections for Richmond Dike Master Plan – Phase 4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Fish Habitat Compensation Sites
Habitat Quality
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Concept Linework
Dike Concept
Road Concept
Dike/Road Slope
Dike/Road Fill Extent
Note: 2016 Imagery Shown.
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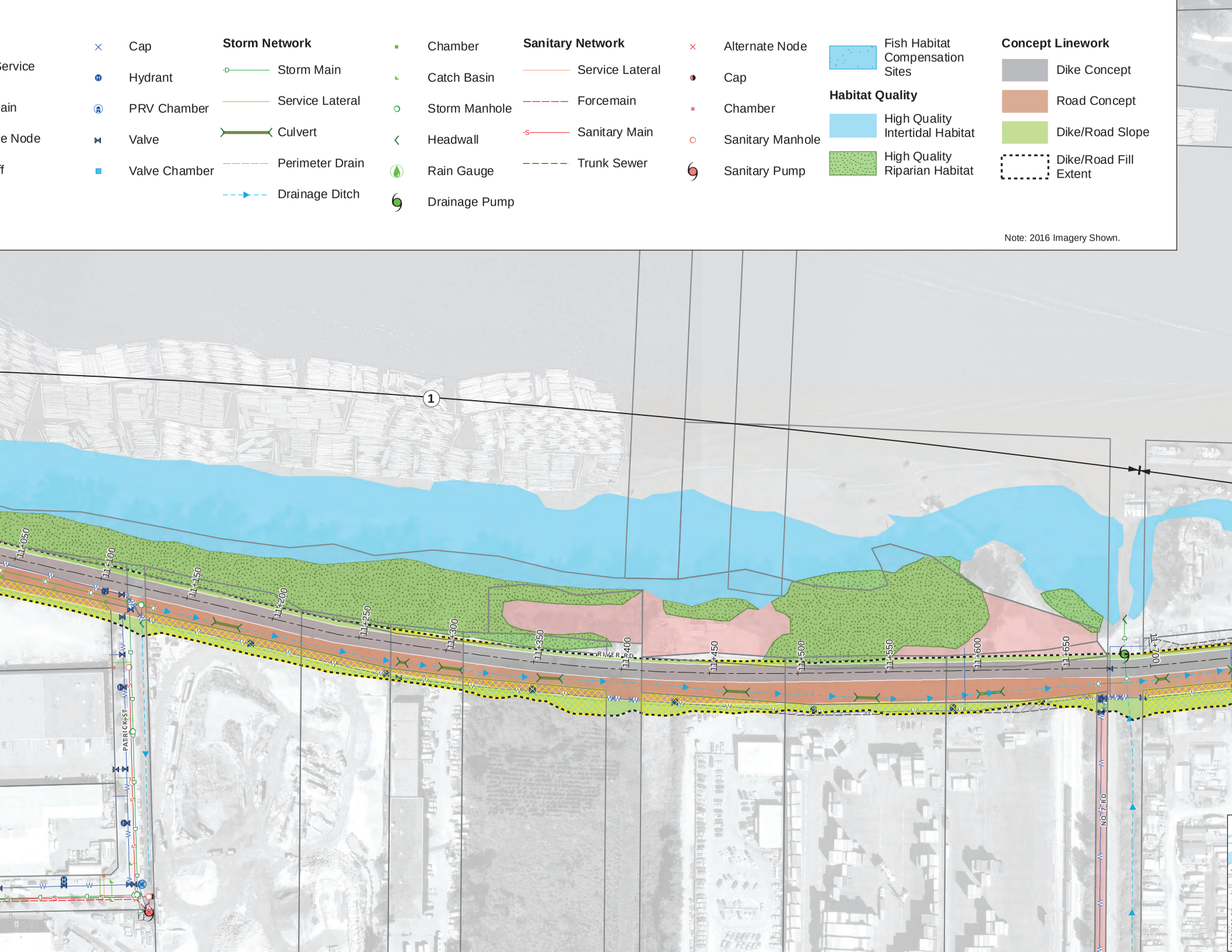
KNOX WAY
Potential Secondary Dike Alignment (Mid-Island Dike)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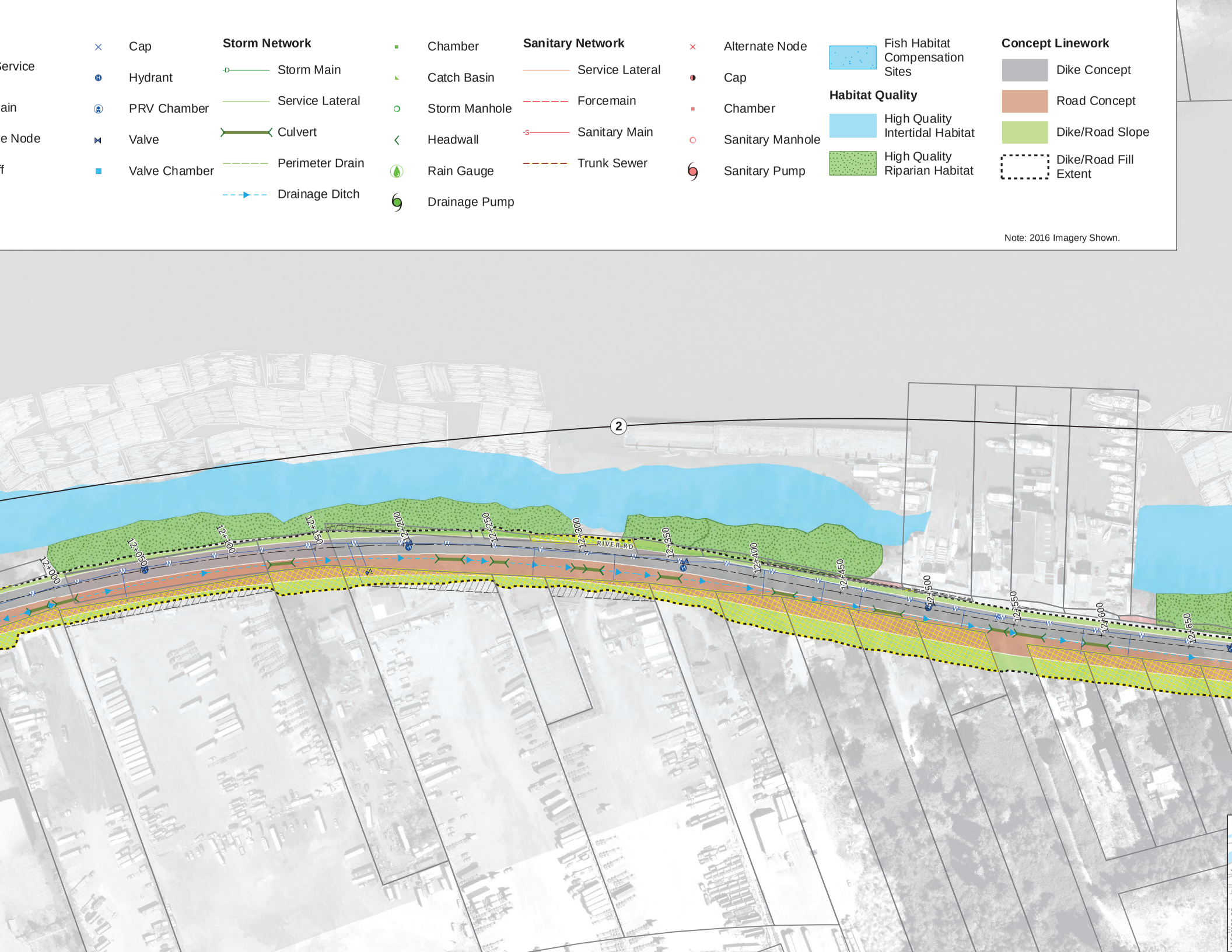
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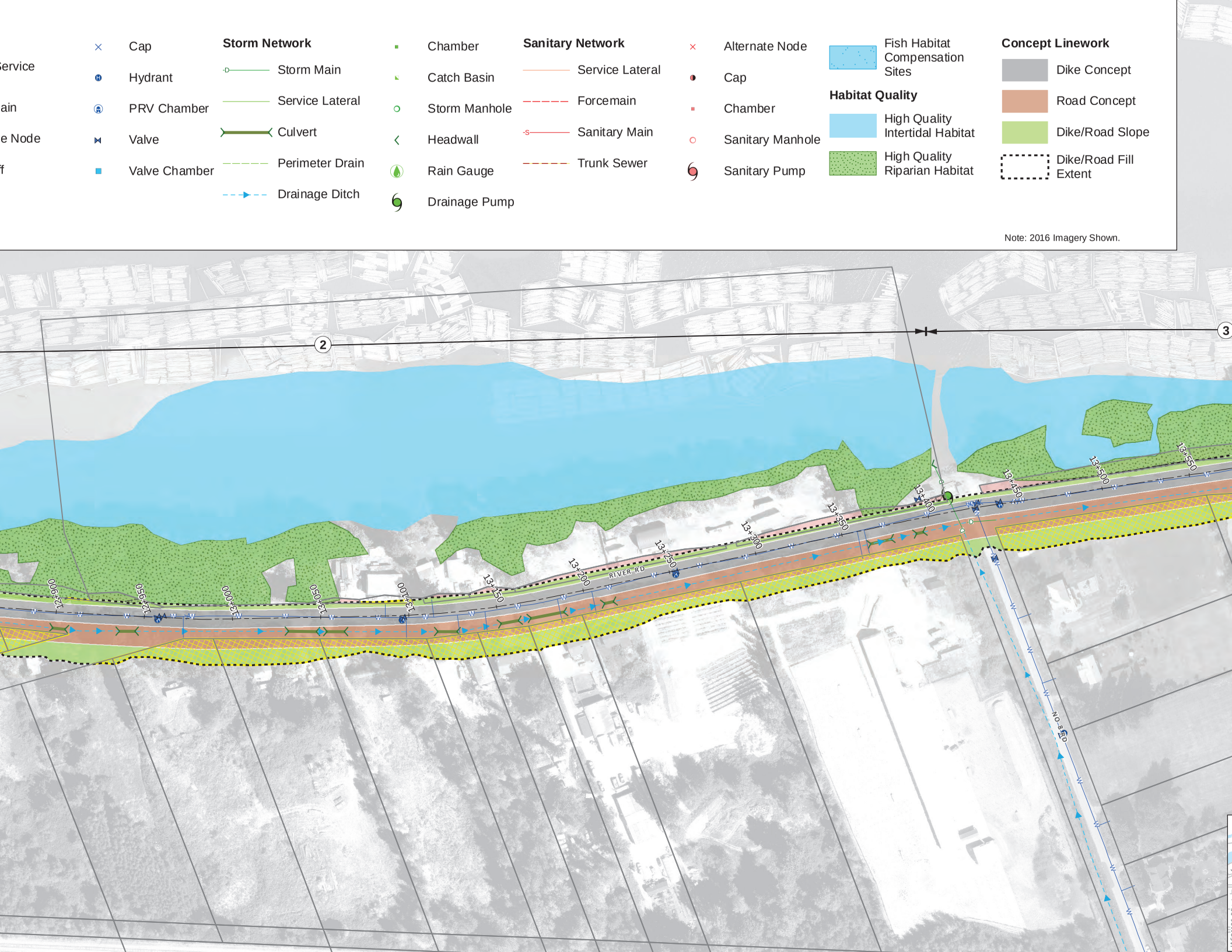
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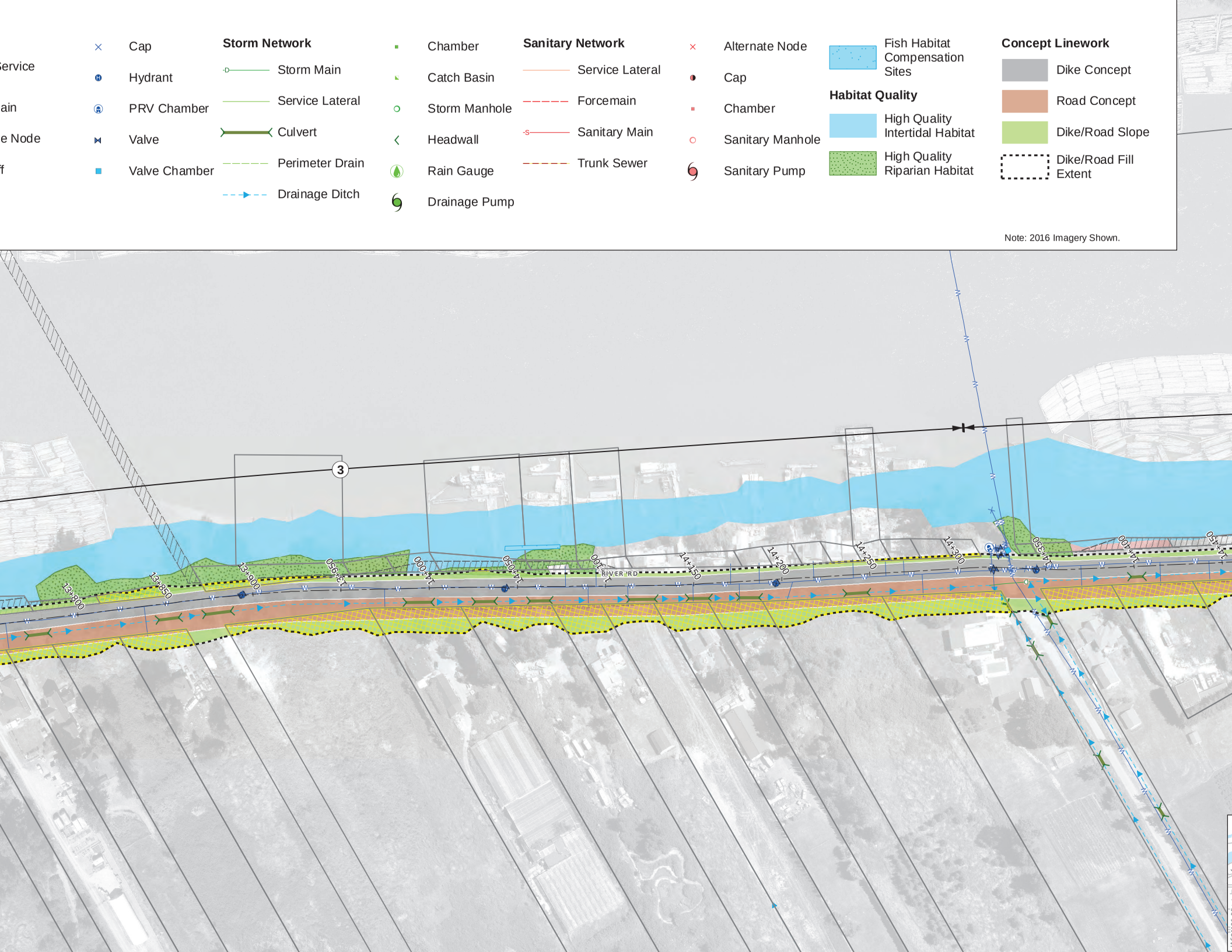
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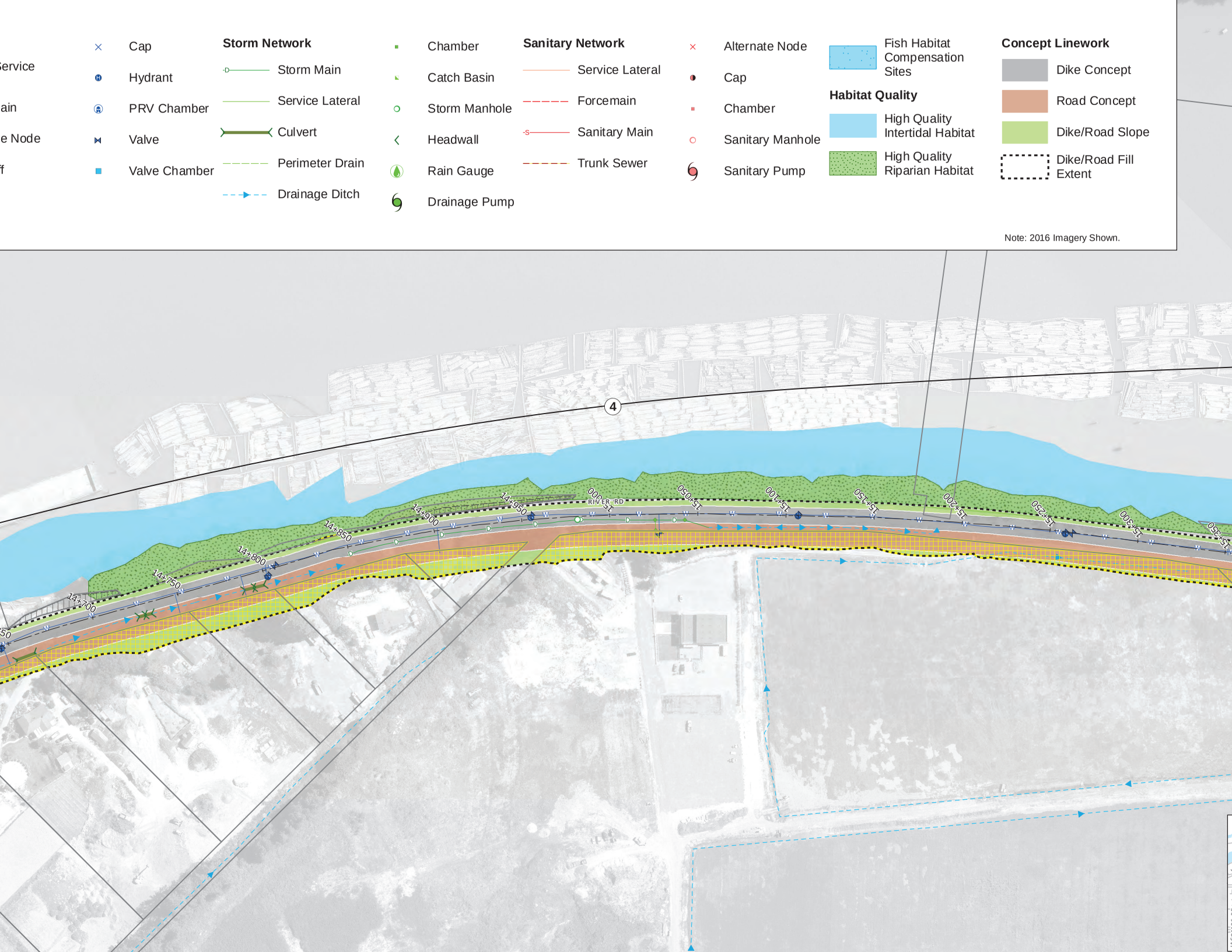
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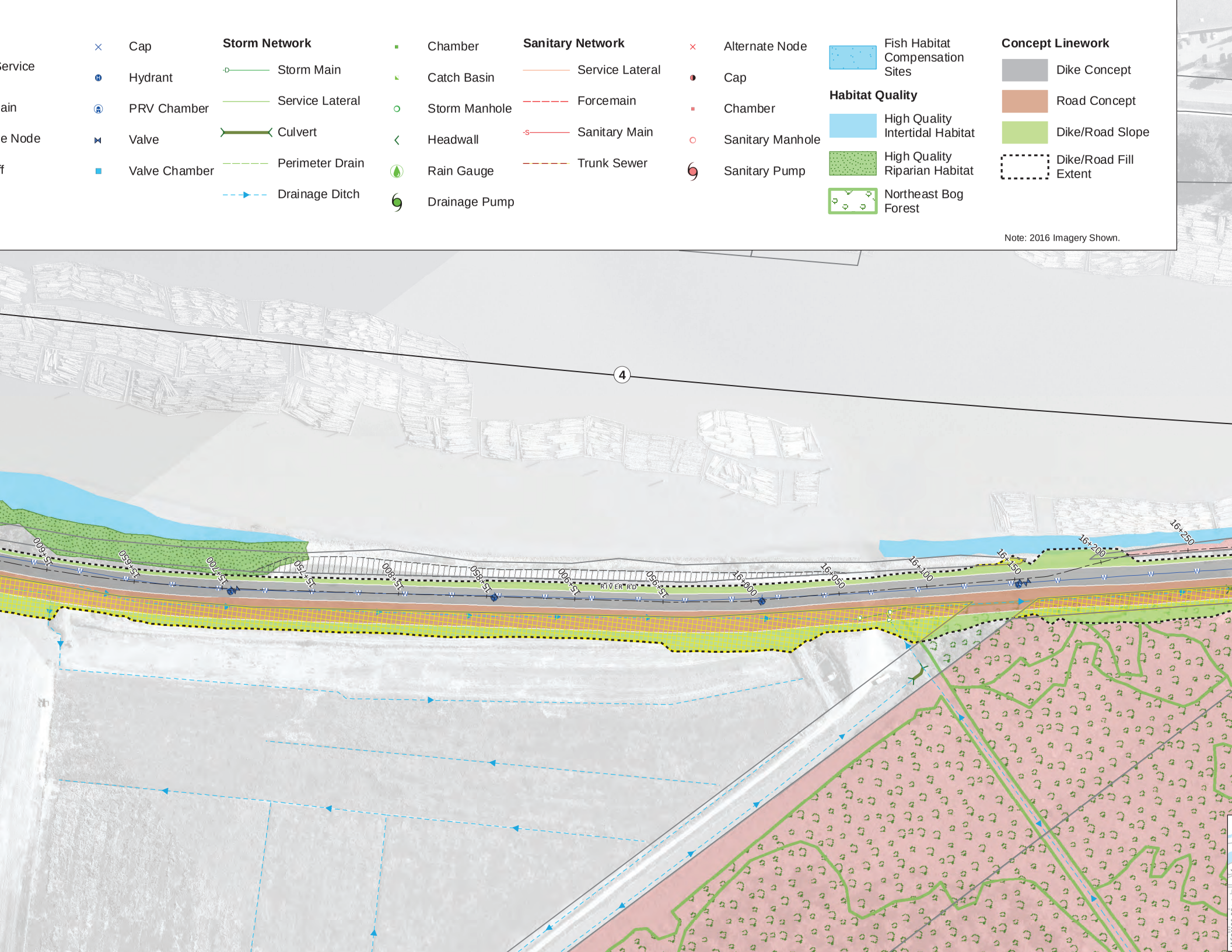
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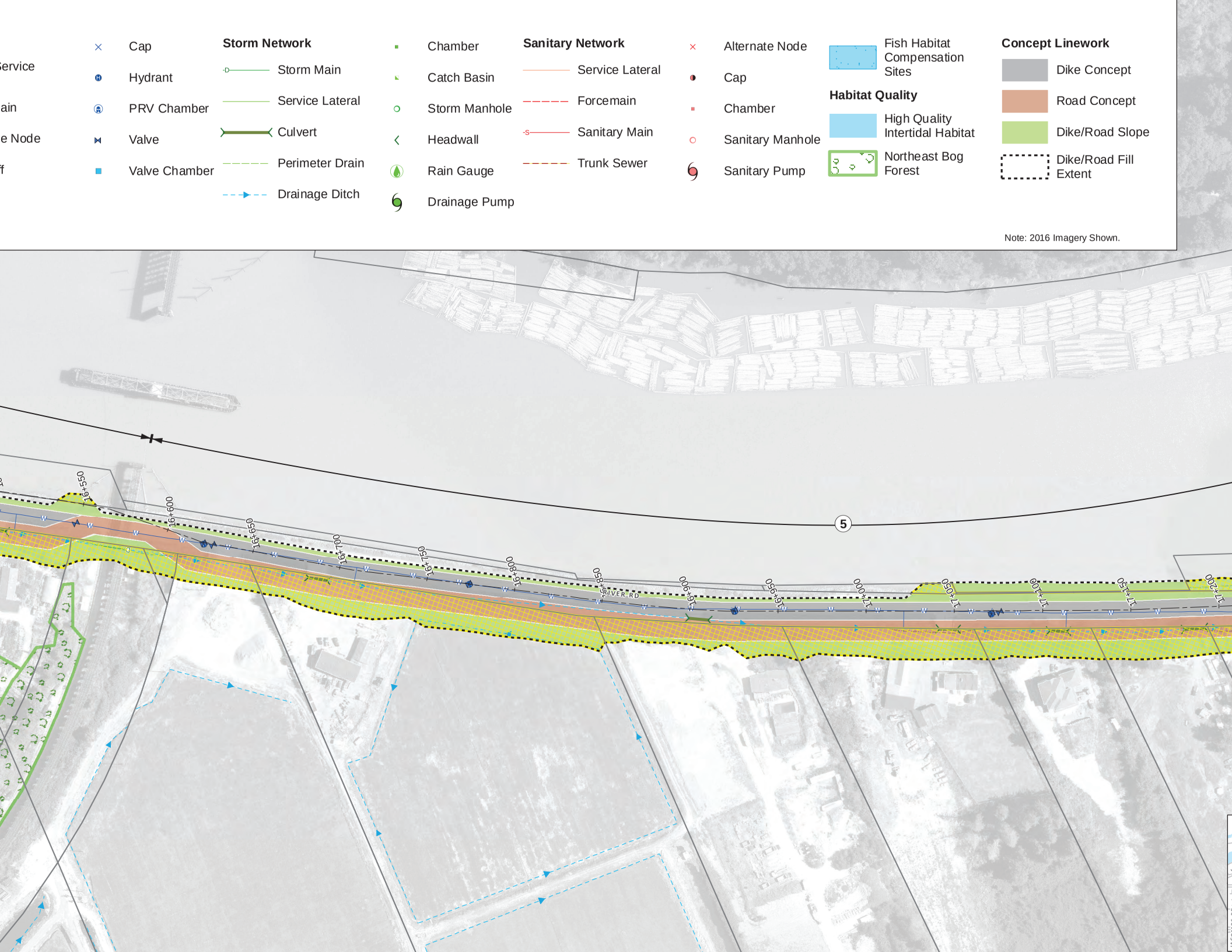
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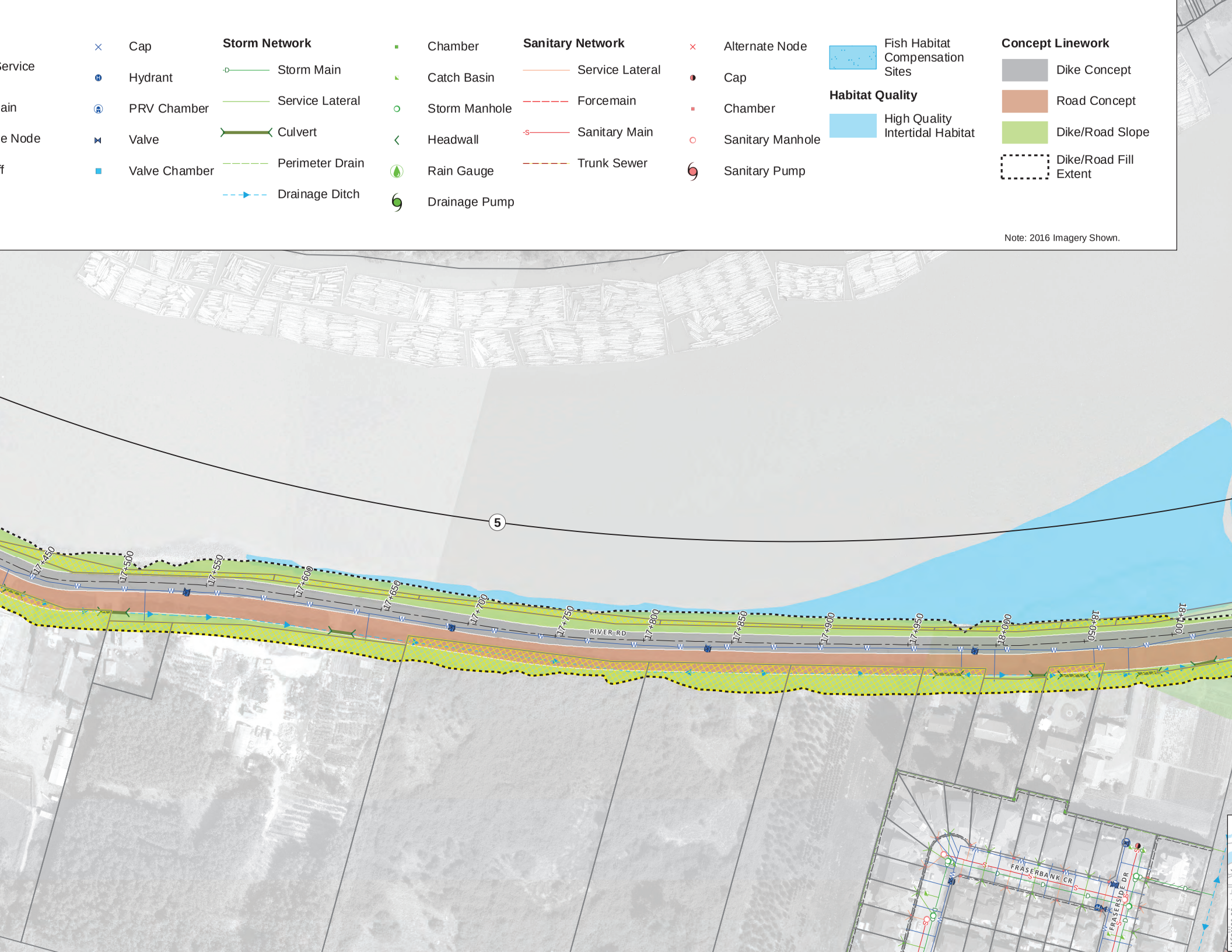
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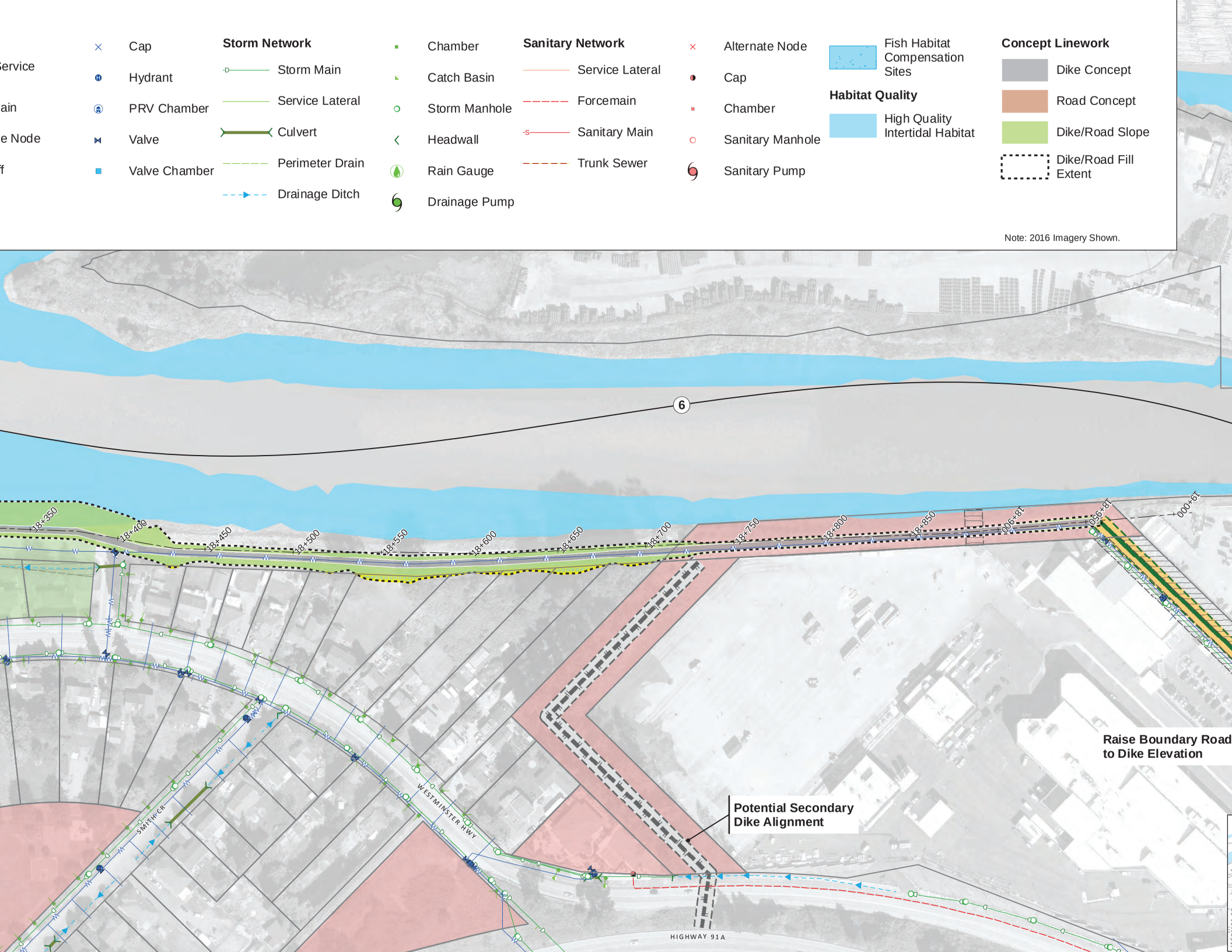
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Raise Boundary Road to Dike Elevation
Potential Secondary Dike Alignment
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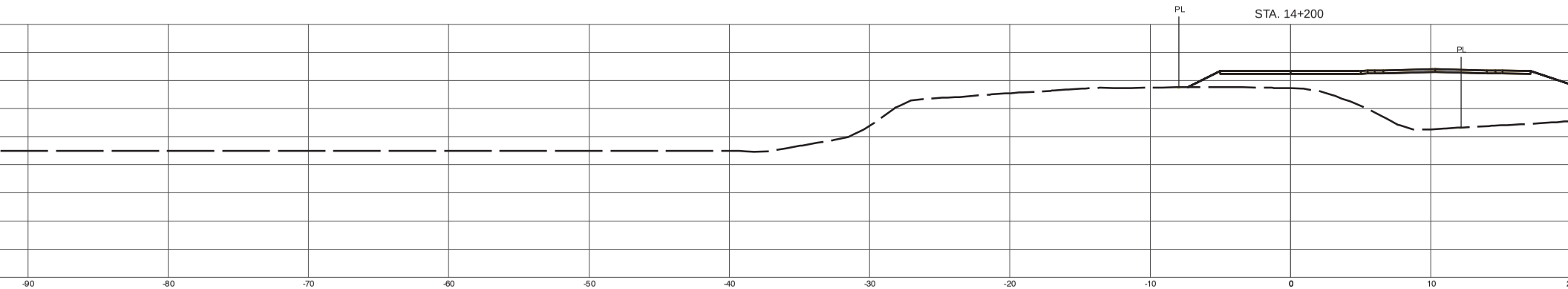
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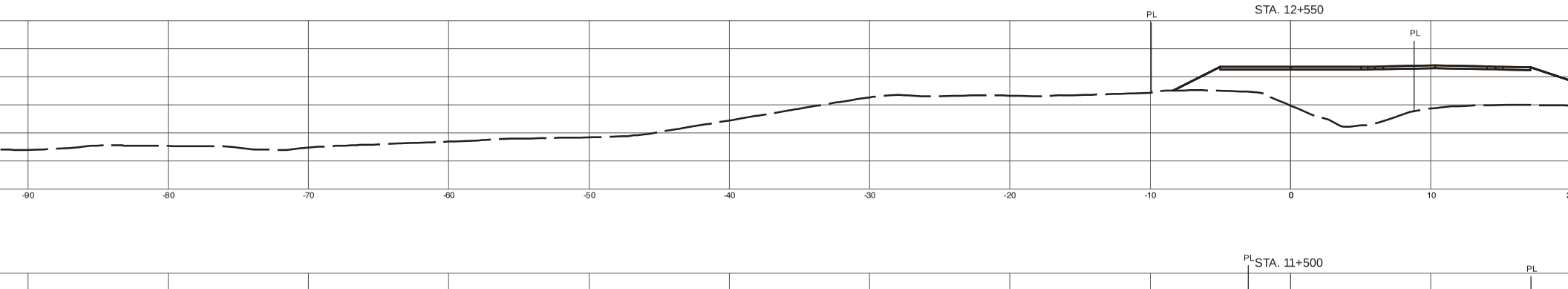
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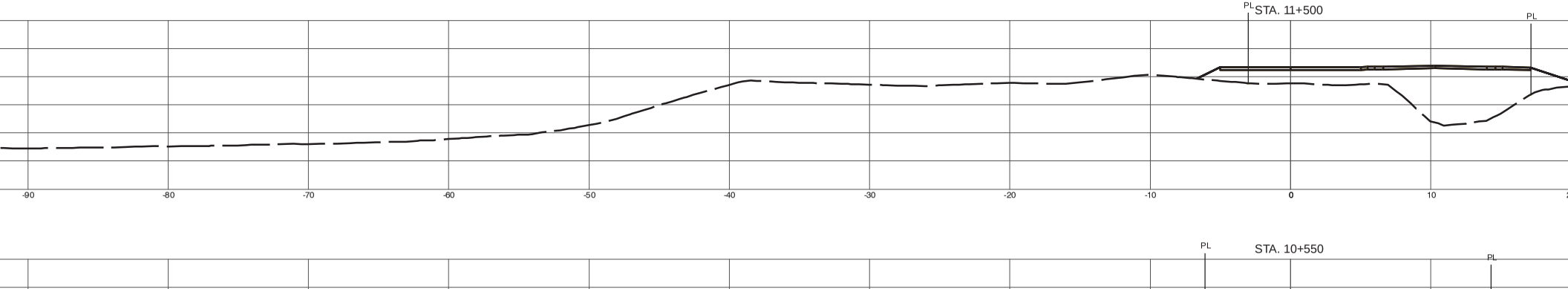
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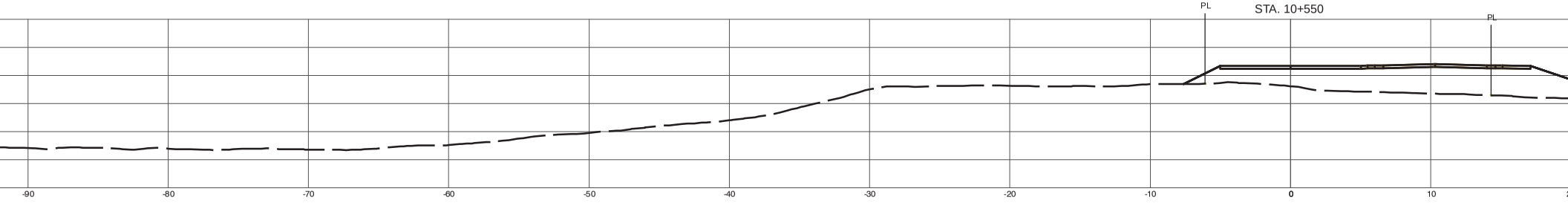
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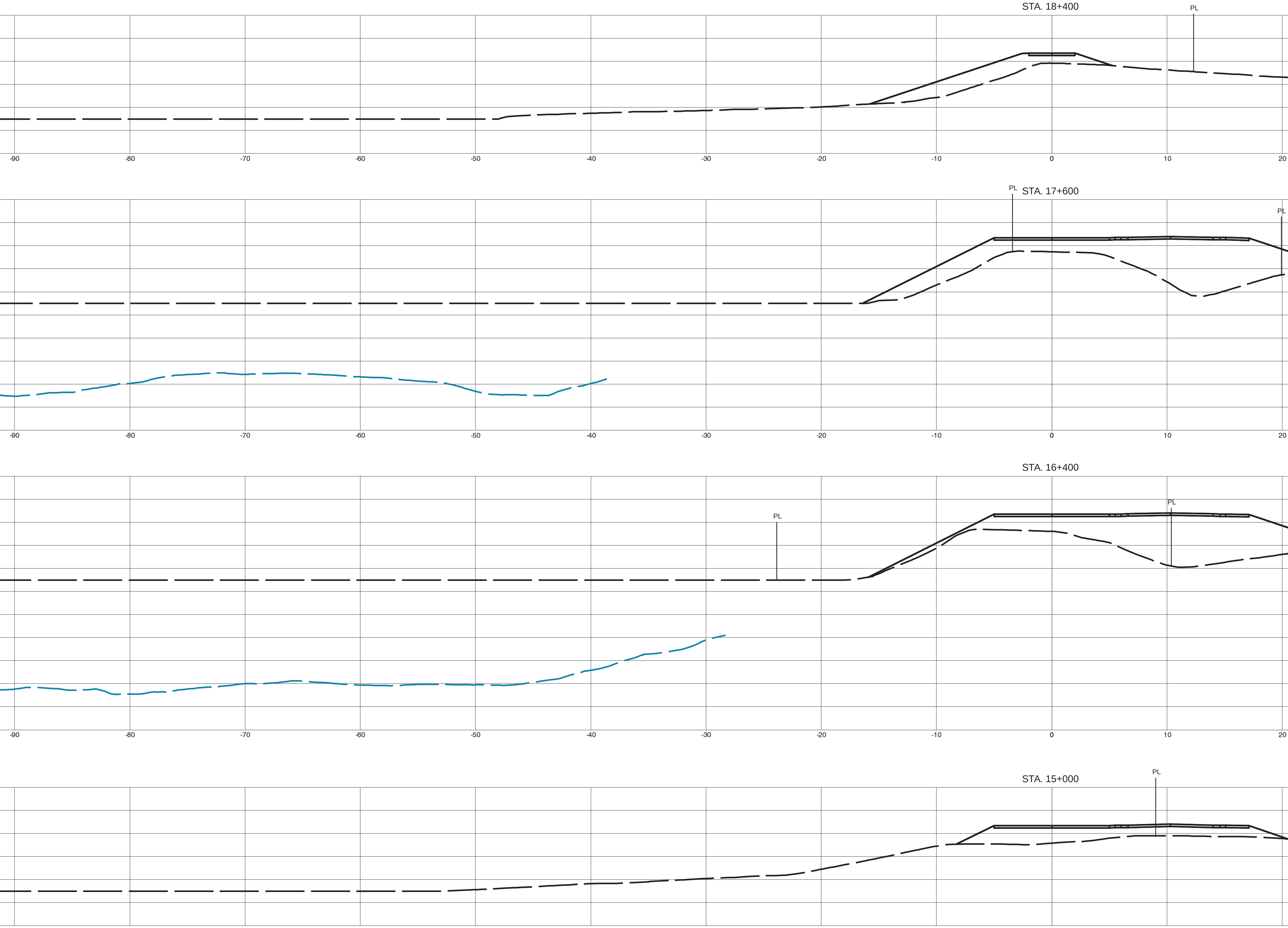
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Appendix B

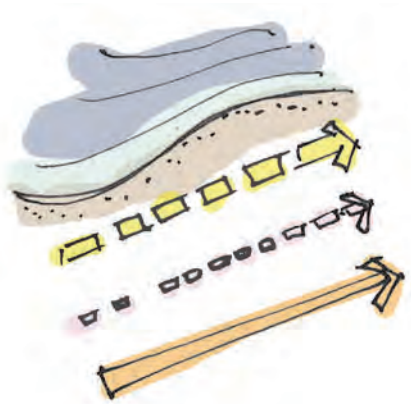
Richmond Dike Master Plan
Landscape Concepts and Dike Typologies

P

DIKE MASTER PLAN

E CONCEPTS

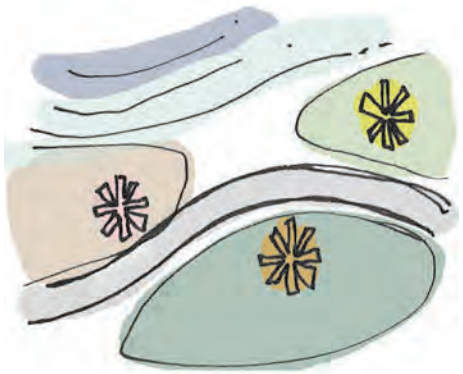
DESIGN PRINCIPLES



ALL TOGETHER NOW

Integrate the movement of pedestrians, bikes, and vehicles safely and respectfully:

- mark out pedestrian areas with bollards, lighting, and furnishings;
- ensure the safety of cyclists by separating paths or providing safe road shoulders;
- include parking where appropriate and allow accessible transitions between modes of travel.



A PATH WORTH TAKING

Enhance the edges of roads, trail, and river with durable, maintainable materials that are also beautiful:

- utilize planting to soften hardscape and infiltrate stormwater;
- look for opportunities for street trees to provide a rhythm and buffer to roads;
- provide furnishings as points of rest, observation, and wayfinding.

ISLAND INTEREST

Activate special areas of public realm with a deployable toolskit sharing a consistent design language:

- determine best locations for public space based on context, connectivity, and distribution;
- leverage areas of ecological, industrial, and cultural value for social connection;
- find opportunities for wonder in constrained spaces.


AN
VANCOUVER
BURNABY
RICHMOND
DELTA
SEA ISLAND
SKYTRAIN
KNIGHT
ARTHUR LAING
No.7 Road
Pier Park
North East
Bog Forest
Richmond
Oval
FRASER RIVER NORTH ARM
FRASER RIVER SOUTH ARM
WESTMINSTER HWY
RAILWAY AVE
NO. 3 RD
SHELL RD/ TRAIL
HWY 99
Lafarge
Finn Slough
Crown Packaging
Dyke Trail
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ENHANCEMENT

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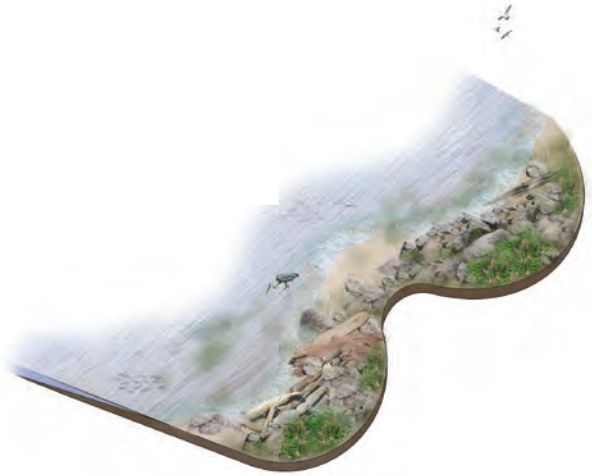

SUB-AQUATIC

At or in the water, sometimes interspersed in rip-rap or driftwood:

- aquatic and semi-aquatic plants;
- low-lying and submersive, following the water's edge;
- home to fish including salmon and sturgeon, and the foraging grounds of wading birds.

INTERTIDAL

Frequently inundated by water, characteristic of river's edge:

- bullrushes and shrubs with small trees at the edges;
- long and with variable width;
- teeming with song birds and hunting hawks, a common sight along the dike.

RIPARIAN

Interface between
ecological value:

- rich variety of
- expanding widt
- sensitive habita
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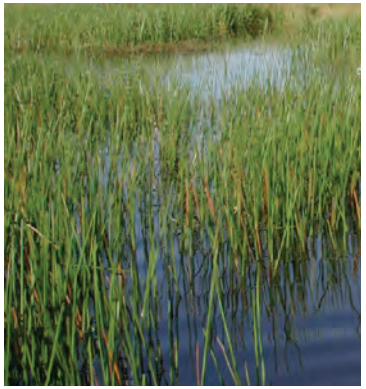
PRECEDENTS



ENHANCEMENT

along road edge,
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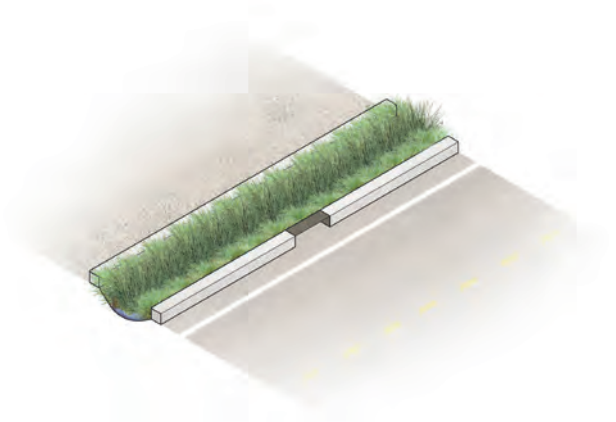

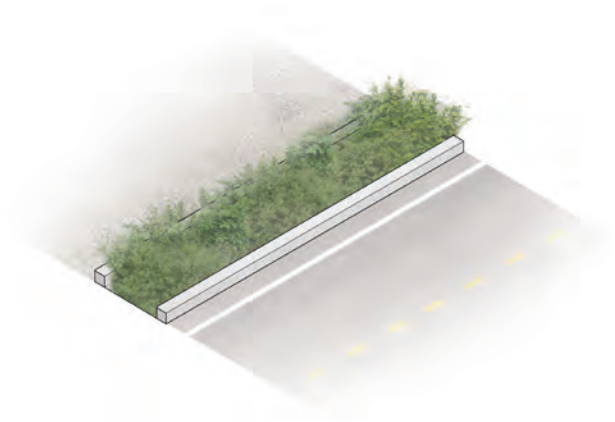

RAINGARDEN

Roadside infiltration of stormwater with grasses, sedges, and shrubs :

- native plant species that can withstand inundation but also summer drought;
- linear with suitable sloped depressions;
- permeable function but clean, maintainable design.

HARDY SHRUB BUFFER

Durable shrub planting suited to high-use areas:

- heavy duty shrubs that are resistant to damage;
- below waist height for clear sightlines but as soft, barrier swathes;
- planted median between road and path through shrub density.

STREET TREES

Providing consiste
along urban edges

- urban tolerant
- tightly spaced
straight leader
- species selecte
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PRECEDENTS

ENHANCEMENT

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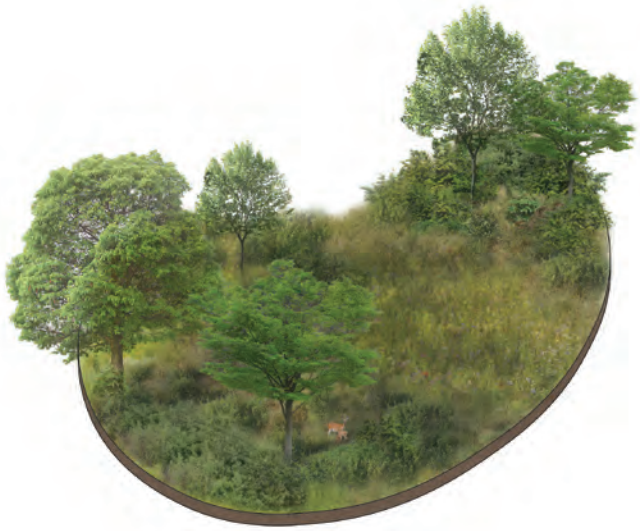

MEADOW

Open grassland with seasonal flowering interest:

- native grasses and forbs with pollinator-favoured species;
- flowing, elongated shapes accented with blooms;
- idyllic and appealing planting with low impact on ground and sightlines.

WOODLAND

Layered plant community with texture and small trees:

- native grasses, shrubs, and deciduous trees;
- more concentrated and concentric than meadow and with clusters of short trees and shrubs;
- less penetrable, but ecologically important to nesting birds and small mammals.

FOREST

Densest, most ver
wildlife corridor:

- native deciduou
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- tight and some
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- occuring in spe
suitable space.

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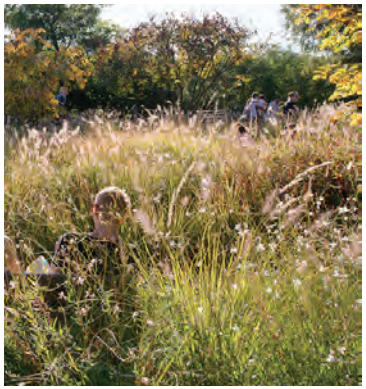

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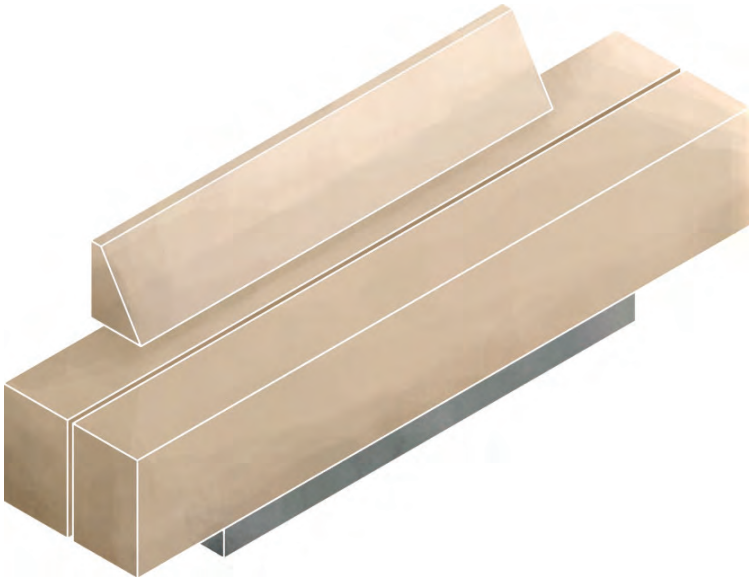

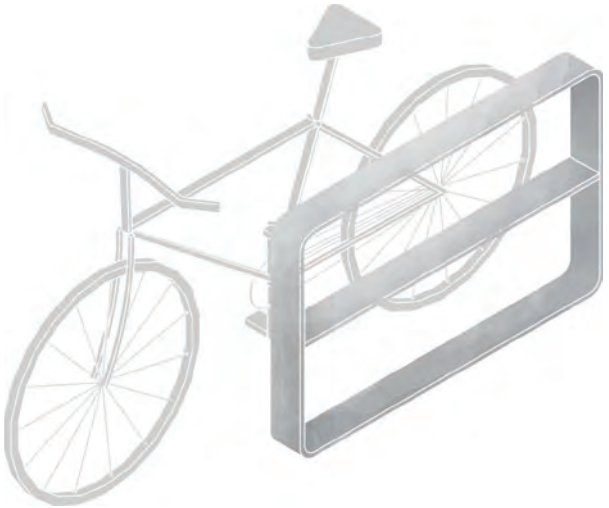

BENCH

Heavy timber wood benches spaced to provide frequent resting:

- cedar timbers with powdercoated exposed steel and galvanized components;
- heavy, durable form but comfortably tuned to human body;
- references logs washed up on river bank.

BIKE RACK

Steel bike rack for two bikes, side by side:

- powdercoated steel;
- simple, functional form easy to manufacture and difficult to vandalize;
- industrial character but obviously legible as a place to lock your bike.

LONG TABLE

The ultimate picni
form of the trail:

- cedar timber ta
powdercoated
components;
- long, linear for
- evocative of riv

PRECEDENTS

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RAMP

Graded wood ramp for rolling accessibility to lower area:

- tight, level wood members run lengthwise;
- unobtrusive form but securely constructed on foundation and drain rock;
- practical, functional feature without ornament.

STEPS

Heavy timber steps for access to area of interest:

- cedar timbers marked for slip resistance;
- simple form with guardrails where appropriate, and securely embedded in landscape;
- characteristically familiar to bench and table furnishings.

SEAT STEPS

Stone or heavy tim
context allows:

- granite stone c
- cascading form
comfortale dep
- industrial or ge
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PRECEDENTS

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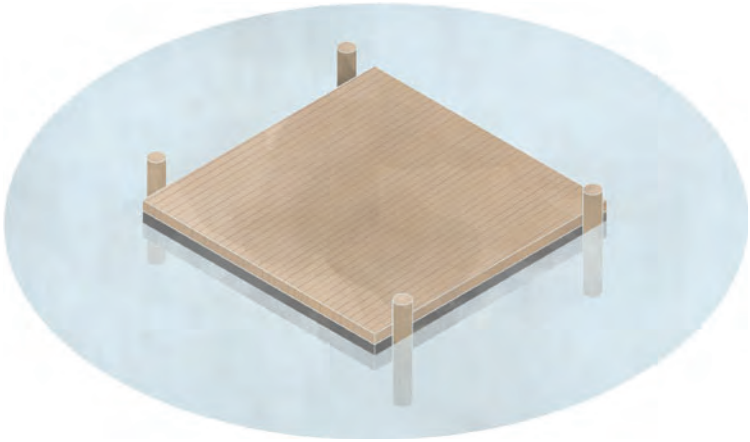

SHELTER

A shaded or warming respite from the weather and place of gathering:

- post and beam structure with tin roof;
- simple form with sloped roof and seating around a hearth;
- contemporary boathouse feel.

VIEWPOINT

Deck and boardwalk to allow viewing of the river from its banks:

- cedar boards with simple guardrail;
- geometric alignment of boards or slats into different planes for sitting and leaning;
- appearing like a deconstructed boat deck oriented to bridge the river and bank.

TOWER

Vantage point up a
birdwatching:

- cedar posts, de
- zig-zagging or
shielded bird b
- referencing the
Sturgeon Bank

PRECEDENTS

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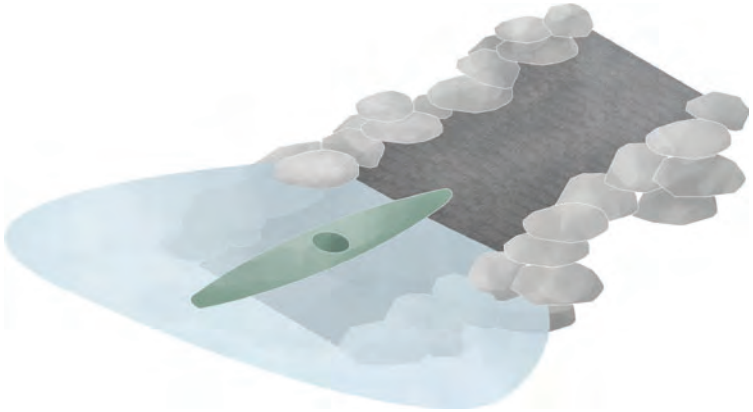

KAYAK LAUNCH

For launching and landing small self-propelled water craft:

- wood with stainless steel details;
- floating pier or slip with covered area;
- clean, minimal intrusion into the water that adapts to ebb and flood of tide.

BIKE JUMPS

Short ramps for small thrills along the path:

- graded dirt or asphalt with bright warnings;
- height geared towards younger rides or the young at heart;
- undeniable features for the aspiring daredevil.

LOG JUMP + CR

Nature play featur

- dried timbers s
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PRECEDENTS

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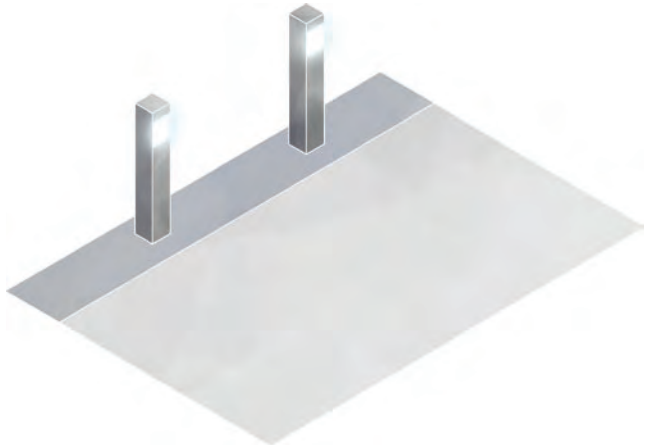
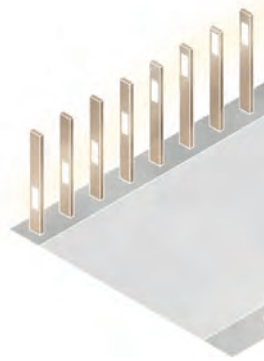




PEDESTRIAN LIGHT POLE

Highest output lighting for urban edges and darkest zones:

- wooden pole or light gray steel;
- 5m high with dual lumenaire design between bike and walking pathes;
- wooden pole or light gray steel and sleek, modern fixture.

BOLLARD

Vertical separation of paths with option for safety lighting:

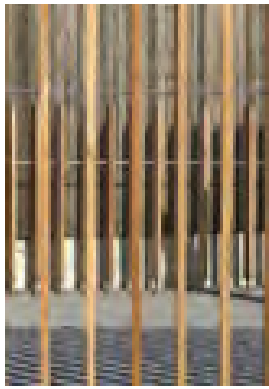
- heavy timber with powdercoated steel;
- simple design with stable, secure presence;
- industrial or shipbuilding aesthetic through contemporary lens.

SCREEN/BARRIE

For creating a safe
between two cond

- vertical wood s
- 1.1m high with
- simple, contem

PRECEDENTS



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infrastructure as

WAYFINDING
Mapboard with clear, legible graphics and consistent design language:

- cedar with steel or resin board;
- post-like and visible from a distance but human-scaled;
- simple character with bold colour allowing quick reading by diverse groups.

BIKE REPAIR/WATER FOUNTAIN
Refill with air or water from a multi-use checkpoint:

- concrete and powdercoated steel construction;
- durable, tamperproof design with overflow water well-drained;
- utilitarian industrial aesthetic with discrete design accents.

WEATHER/TIDE
Marker reflecting
analog form:

- stainless or po
- simple, legible
- inspiring curio
river's changes

PRECEDENTS

TION 1

EXTEND LAND-SIDE (REACHES 1-5)

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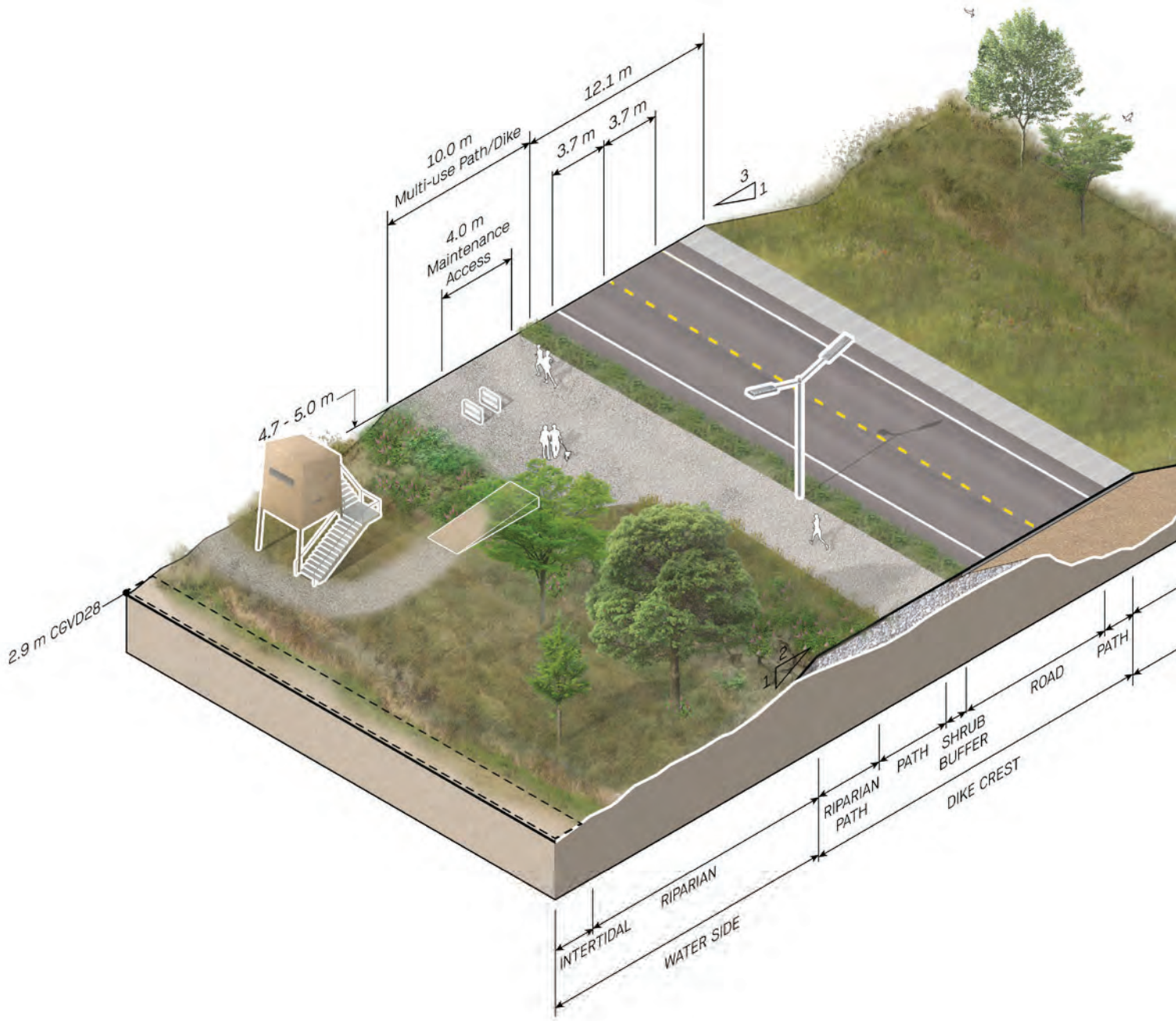

TION 2

RETAINING WALLS (REACH 4)

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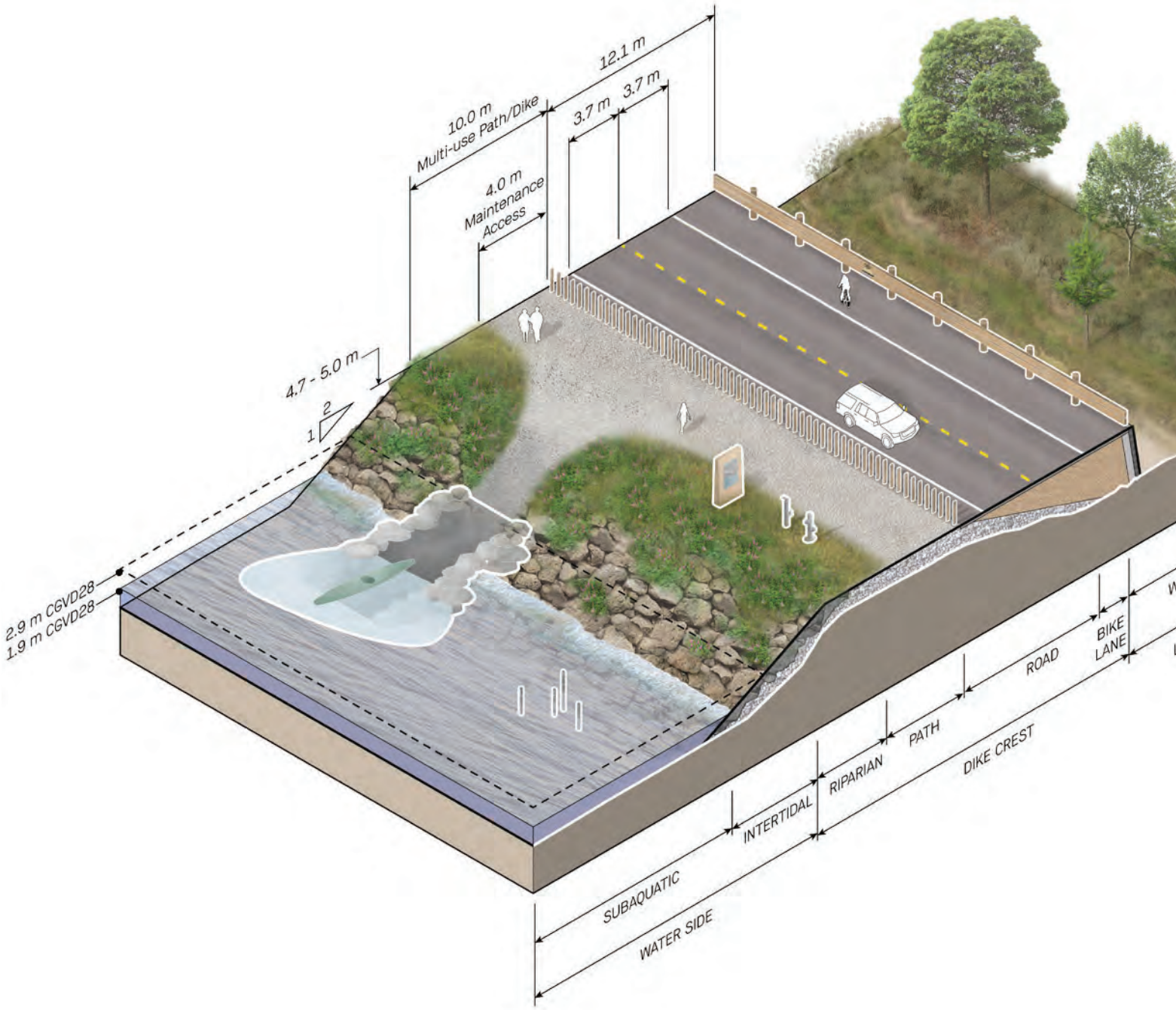

TION 3

ID RIVER-SIDE (REACHES 4-6)

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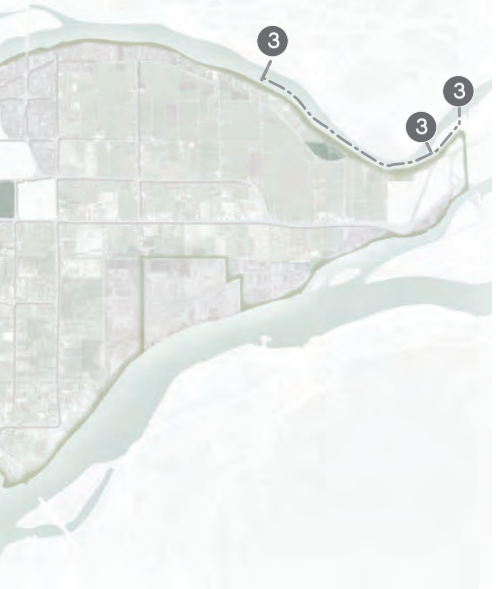

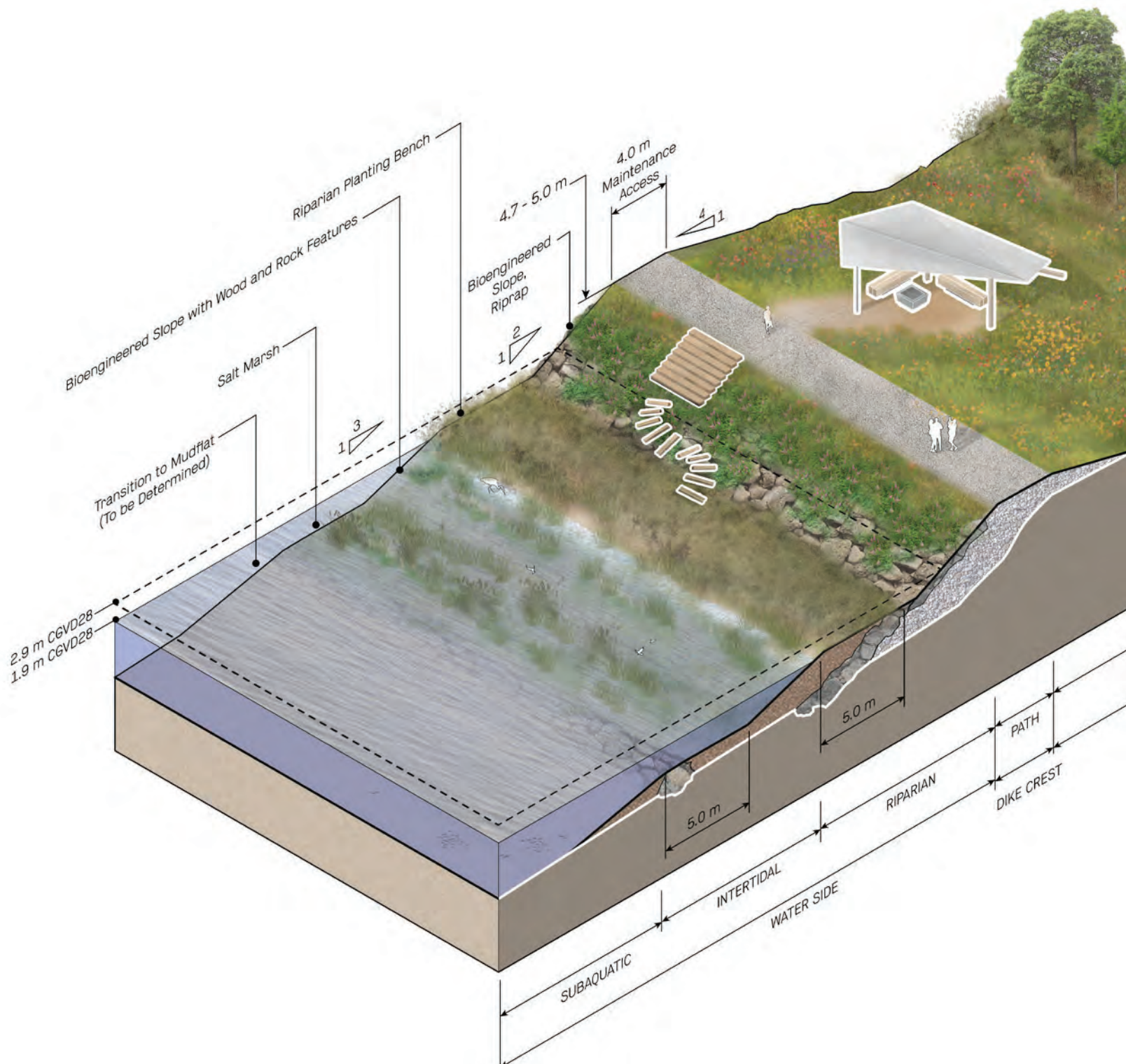

TION 6

/ DIKE UNDER TRESTLE (REACH 4)

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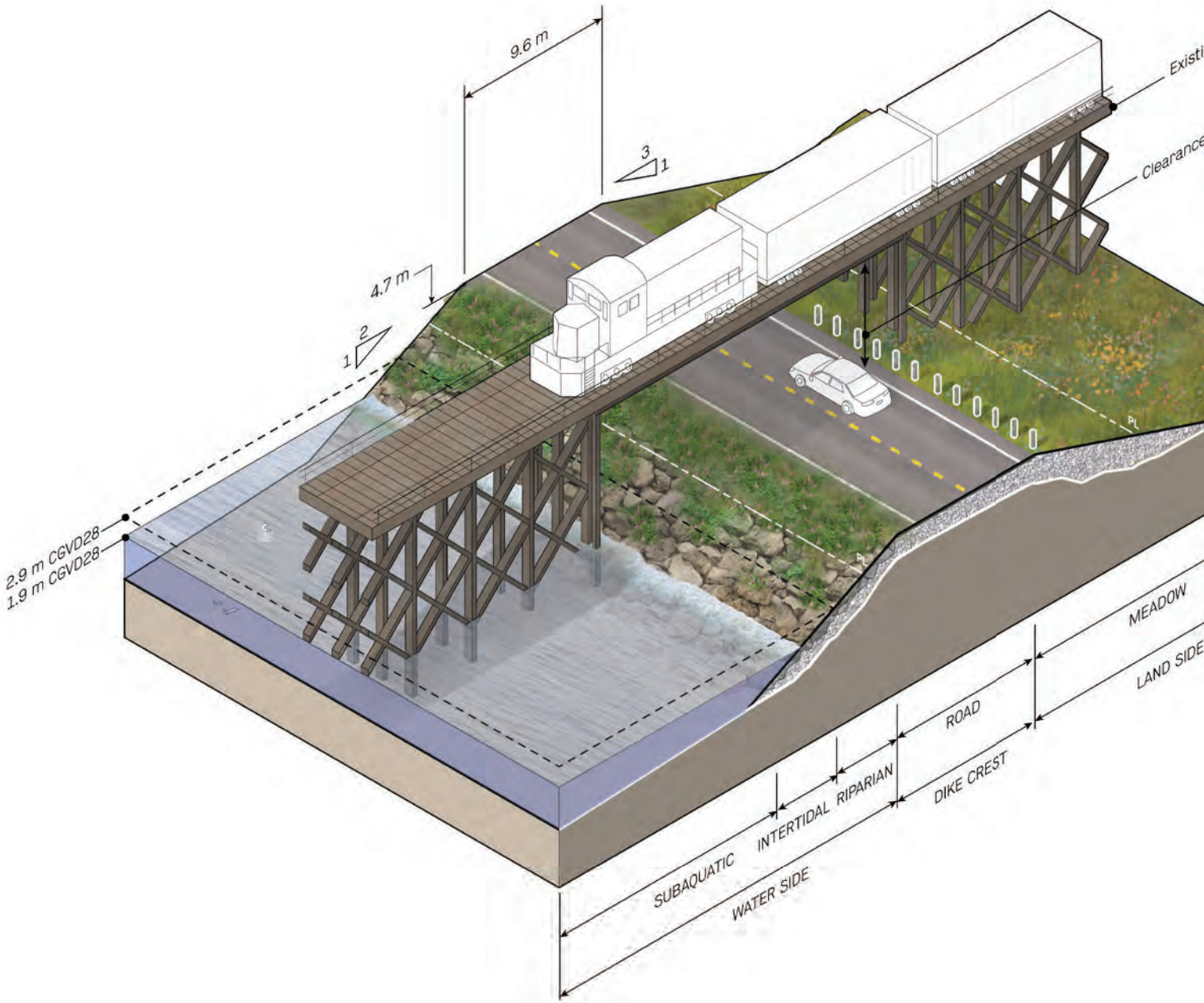

TION 7

WEEN TRESTLE PILE (REACH 4)

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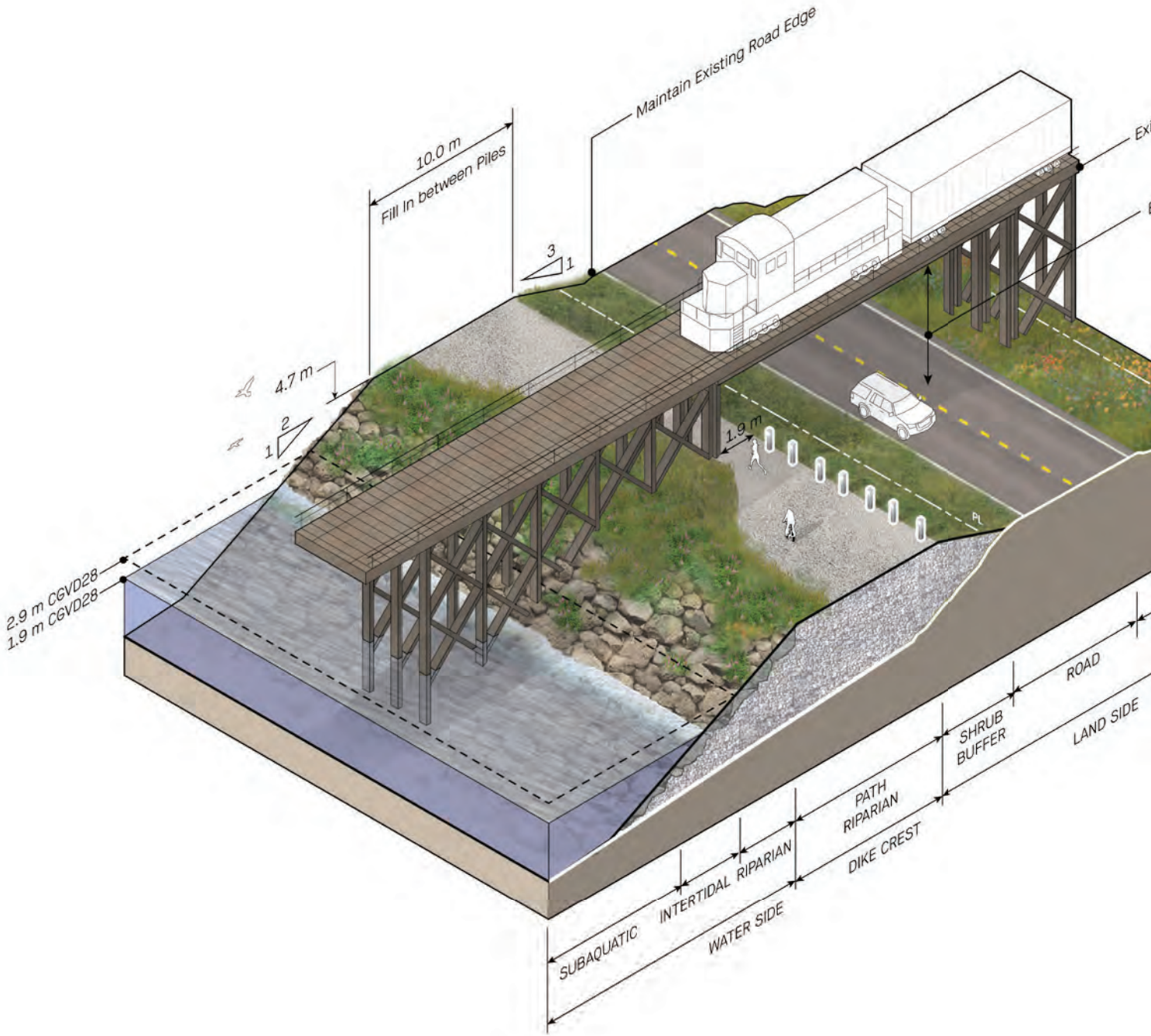

KERR WOOD LEIDAL
consulting engineers

Appendix C

Geotechnical Engineering Analysis Report (Thurber)