# 4.1 FRASER RIVER HYDRAULICS AND MORPHOLOGY

***Fraser River Hydraulics and Morphology – Summary of Assessment***

- The Project is expected to result in very small increases and decreases in flow velocities at various locations immediately upstream and downstream of the new bridge.
- Flow splits at Sapperton Bar, Pattullo Bridge, and the New Westminster Trifurcation are not expected to change due to the Project.
- No material changes to water levels are expected to result from the Project.
- Small to moderate increases and decreases in riverbed levels are expected at locations outside of the navigation channel in the vicinity of the Project.
- Increases in riverbed levels along the southern margin of the main navigation channel may potentially extend a small way into the navigation channel.
- Potential Project-related residual effects can be mitigated through additional scour protection, if required, and refinements to pier positions and configuration during final design will improve their hydraulic performance.
- Cumulative effects with the New Westminster Railway Bridge (NWRB) are possible, which could include decreased velocities and increased sediment deposition downstream of the NWRB piers.
- Project-related residual and cumulative effects on Fraser River Hydraulics and Morphology are expected.

## 4.1.1 Context and Boundaries

### 4.1.1.1 Valued and Intermediate Component Selection

The proposed Project has the potential to change Fraser River hydraulics and morphology; this has implications for Aboriginal, regulatory, scientific, and stakeholder interests. River hydraulics and morphology together were categorized as an IC because their potential Project-related changes have consequent effects on end-of-pathway VCs, including Fish and Fish Habitat (**Section 4.3**), Marine Use (**Section 6.1**) and Heritage Resources (**Section 7.1**).

River hydraulics and river morphology are addressed as separate subcomponents of the IC (**Table 4.1-1**). River hydraulics is the study of flow in rivers, and is most often related to flow patterns, water levels, and velocities. The study of river morphology (i.e., fluvial geomorphology) focuses on river forms and processes, and is primarily concerned with the interaction between fluid flow and the erodible materials in the channel bed and banks (Knighton 1998).

During Project consultation, interest expressed by Aboriginal Groups in relation to river hydraulics and morphology has been primarily related to activities on and near the river, including fishing and navigation, and the existence of important archaeological sites along the river. Potential changes to river hydraulics or morphology could affect fish habitat and/or fish behaviour, in turn affecting Aboriginal fisheries. The Pattullo Bridge area is an important fishing area for Aboriginal Groups, and this importance has been emphasized by several First Nations during consultation (including Musqueam Nation, Kwikwetlem First Nation, Kwantlen First Nation, Tsawwassen First Nation). Concerns that changes to river hydraulics could affect navigation on the river have also been expressed by Aboriginal Groups as well as the potential for sediment deposition or erosion at sites along the foreshore of the river, caused by changes in morphology to have impacts on local archaeological sites.

Stakeholders that could be affected by changes in river hydraulics and morphology include the public, local governments, rail companies, recreational and commercial fisheries, and commercial and industrial marine users; in addition, infrastructure within the Regional Study Area (RSA), including nearby bridges and pipeline crossings, could potentially be affected by these changes.

### Table 4.1-1 Subcomponents of River Hydraulics and Morphology

| Subcomponent | Rationale for Selection |
|---|---|
| River hydraulics | Changes to river hydraulics have the potential to affect commercial, recreational, and Aboriginal fisheries; and navigation; fish habitat and fish behaviour. |
| River morphology | Changes to river morphology have the potential to affect commercial, recreational, and Aboriginal fisheries; navigation; fish habitat and fish behaviour; and in-river infrastructure. |

## 4.1.1.2 Indicators of Potential Effects

Indicators and measurable parameters for the Fraser River Hydraulics and Morphology IC are listed in **Table 4.1-2**.

### Table 4.1-2 Indicators for Assessment of Potential Effects

| Subcomponent | Indicators | Study Approach |
|---|---|---|
| ▪ River hydraulics | ▪ Changes to flow distribution and flow patterns<br>▪ Velocity changes<br>▪ Water level changes | ▪ Review existing information on Fraser River hydraulics<br>▪ Conduct field investigations to gather additional information on existing conditions (to calibrate and validate the models that will be used to assess potential Project effects)<br>▪ Assess Project interactions and related potential adverse effects on flow properties<br>▪ Use physical modelling to assess “near-field” (local) hydraulic (using a 1:80 scale physical model)<br>▪ Also use numerical (i.e., computer) modelling to assess both “near-field” and “far-field” hydraulics<br>▪ Identify measures to mitigate identified potential adverse effects on Fraser River hydraulics<br>▪ Identify and evaluate possible residual and potential cumulative adverse effects (if any) |
| ▪ River morphology | ▪ Changes to river scour<br>▪ Changes to sediment deposition patterns<br>▪ Changes to bathymetry | ▪ Review existing information on Fraser River morphology<br>▪ Conduct field surveys to gather additional information on existing conditions (to calibrate and validate the models that will be used to assess potential Project effects)<br>▪ Assess Project interactions and related potential adverse effects on bed erosion, and sediment deposition<br>▪ Use physical modelling to assess “near-field” (local) sedimentation effects (using a 1:80 scale physical model)<br>▪ Also use numerical (i.e., computer) modelling to assess both “near-field” and “far-field” sediment transport<br>▪ Identify measures to mitigate identified potential adverse effects on Fraser River morphology (as necessary)<br>▪ Identify and evaluate possible residual and potential cumulative adverse effects (if any) |

#### 4.1.1.3 Regulatory Context

Three pieces of legislation (**Table 4.1-3**) are relevant to the Project in the context of river hydraulics and river morphology: the B.C. *Water Sustainability Act* (S.B.C., 2014, c. 15); the federal *Fisheries Act* (R.S.C., 1985, c. F-14); and the *Navigation Protection Act* (R.S.C., 1985, c. N-22).

S. 5(1)(b) of CEAA 2012 applies to changes in environment occurring on federal land which may be tied to Fraser River Hydraulics and Morphology.

#### 4.1.1.3.1 BC Water Sustainability Act

Section 106 of the B.C. *Water Sustainability Act* prohibits "changes in and about a stream" without written approval of the Minister. The Act defines "changes in and about a stream" as:

a) any modification to the nature of a stream including the land, vegetation, natural environment, or flow of water within a stream

b) any activity or construction within the stream channel that has or may have an impact on a stream

#### 4.1.1.3.2 Fisheries Act

Section 35 (1) of the *Fisheries Act* prohibits "any work, undertaking or activity that results in serious harm to fish that are part of a commercial, recreational or Aboriginal fishery, or to fish that support such a fishery." Section 36 (3) prohibits depositing or permitting the deposition of "a deleterious substance of any type in water frequented by fish or in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance may enter any such water." A deleterious substance may include excess concentrations of suspended sediment.

#### 4.1.1.3.3 Navigation Protection Act

Section 3 of the *Navigation Protection Act* (NPA) prohibits anybody to "construct, place, alter, repair, rebuild, remove or decommission a work in, on, over, under, through or across any navigable water that is listed in the schedule except in accordance with this Act or any other federal Act." The Fraser River is listed in the schedule. Any works in a listed waterbody must be submitted to the Minister for approval, except if classified as a "Minor Work." Minor works include erosion protection and dredging. Other in-river works related to the Project, including bridge construction and demolition, will require Approval under the NPA.

**Table 4.1-3 Relevant Regulatory Requirements, Standards, and Best Management Practices and Policies**

| Description | Relevance to Fraser River Hydraulics and Morphology Assessment |
|---|---|
| *Water Sustainability Act* | Changes in and about a stream require approval. |
| *Fisheries Act* | Prohibits any work resulting in serious harm to fish that are part of a commercial, recreational, or Aboriginal fishery, or to fish that support such a fishery.<br>Prohibits deposition of any deleterious substance, which may include excess concentrations of suspended sediment. |
| *Navigation Protection Act* | Works in listed waters require approval, except those designated as "minor works" such as erosion protection and dredging. |

### 4.1.1.4 Assessment Boundaries

The river hydraulics and morphology study was undertaken within the bounds of the spatial, temporal, and technical boundaries described below. These boundaries were established for the modelling work carried out (two numerical models and one physical model; see **Appendix 18.2**) for the Project. No administrative boundaries constrained the study.

##### 4.1.1.4.1 Spatial

The Local Study Area (LSA) encompasses the footprint along with a zone of influence within which most potential project effects are expected to occur (**Figure 4.1-A-1** in **Attachment 4.1-A**). The LSA for river hydraulics and morphology extends 1 km upstream and downstream of the existing Pattullo Bridge, from the downstream end of Sapperton Bar to just upstream of the Phase 3 Trifurcation training wall.

The Regional Study Area (RSA) provides context for the assessment of potential Project effects. The RSA extends from the existing Pattullo Bridge 6 km upstream and 5.5 km downstream in the Fraser River Annieville Channel and the North Arm, and 8 km downstream in the South Arm (**Figure 4.1-A-1**). This includes an area downstream of the Port Mann Bridge to downstream of Alex Fraser Bridge in Annieville Channel and upstream of the Annacis Channel Bridge in Annacis Channel. In the North Arm the RSA extends to downstream of the Queensborough Bridge. The RSA corresponds to the limits of the morphodynamic model.

**Table 4.1-4 Spatial Boundary Definitions for Fraser River Hydraulics and Morphology**

| Spatial Boundary | Description of Assessment Area |
|---|---|
| Local Study Area (LSA) | 1 km upstream and 1 km downstream of Pattullo Bridge |
| Regional Study Area (RSA) | Downstream of Port Mann Bridge to downstream of Alex Fraser bridge (Annieville Channel), upstream of Annacis Channel Bridge (Annacis Channel), and downstream of Queensborough Bridge (North Arm) |

##### 4.1.1.4.2 Temporal

Temporal boundaries for the River Hydraulics and Morphology study incorporated three time periods: existing conditions, Construction Phase and Operations Phase.

The characterization of existing conditions was based on data from recent years and on interpretive geomorphology study. Multibeam bathymetric surveys from 2014 were used to represent existing riverbed conditions, and acoustic doppler current profiler (ADCP) transects measured in 2014 and 2016 were used to assess existing flow splits and velocity distributions. Two numerical models and a physical model were used to assess existing conditions as a baseline for comparison with future modeled conditions.

The Construction Phase comprises the approximately 5-year period when the new bridge is under construction and the existing Pattullo Bridge remains in place. While relatively short-lived, this scenario is important as it represents the time when the largest footprint of instream infrastructure will be in place (i.e. both the existing bridge and new bridge foundations will be present, as well as temporary in-river construction works).

For the purposes of the river hydraulics and morphology study, the Operations Phase begins after decommissioning of the Pattullo Bridge and extends to the end of the new bridge design life. Decommissioning of the existing Pattullo Bridge includes removal of in-river piers and partial removal of the riprap scour protection cones in the navigation channels.

#### 4.1.1.4.3 Technical

The Fraser River at the Project site is a very complex hydraulic and morphological environment. The natural variability in river flow, tidal cycles, and sediment influx, combined with physical conditions (proximity of three bridges, converging flow, etc.), limit the ability to predict future conditions. Assessing potential changes due to the Project requires the application of state-of-the-art modelling tools alongside the judgement and experience of qualified hydrotechnical engineers and geoscientists. The accuracy and precision of the model results are limited by available data for calibration and validation, natural variability and inherent randomness in river systems, and the simplified representation of complex natural systems in numerical and physical models. The three models used in the study (discussed in **Section 4.1.3.2**) provide a robust basis for assessing potential Project effects, but do not deterministically predict future conditions. Instead, comparisons between modelled existing conditions and modelled Project conditions are used to delineate the expected effects of the Project. The numerical modelling approach is consistent with standard practices and state of the science. Details of model validation are given in **Appendix 18.2 – Hydraulic Modelling Report**.

## 4.1.2 Existing Conditions

This section describes the existing conditions for river hydraulics and morphology. Existing conditions were assessed based on field investigations, review of previous studies, and an overview geomorphic assessment.

### 4.1.2.1 Regional Overview and Historical Activities

The hydraulic and morphological conditions in the lower Fraser River have been affected by development activities since at least the early 20th century. Interventions such as flood protection dikes, bank hardening, river training works, and dredging have made significant changes to the river. Similar observations are made in the Musqueam Indian Band Knowledge and Use Study (Musqueam Indian Band 2017). The estuary (downstream of New Westminster Trifurcation) is narrower and deeper than it was pre-development, and its channels have been prevented from migrating laterally as a natural estuary would do on a seasonal basis.

As a result of these interventions, the elevation of the riverbed has decreased over time. Average riverbed levels have declined by approximately 3 m since 1950 and are expected to continue decreasing in the future. This has implications for hydraulics and morphology at the Project site.

Aboriginal Groups use the river extensively for fishing and navigation within the RSA. These activities have the potential to be affected by Project-induced changes to the physical characteristics of the river; potential effects to Aboriginal fisheries and navigation are discussed in **Section 4.1.3**.

### 4.1.2.2 Data Sources and Reliability

#### 4.1.2.2.1 Water Levels and River Discharge

Water levels and river discharges are required as boundary conditions for the numerical and physical models. Local water levels and discharges at the Project site were extracted from the NHC one-dimensional model of the lower Fraser River (NHC 2008a).

#### 4.1.2.2.2 River Velocities and Flow Splits

River velocities and flow splits near the Project were measured on 15 June 2016 by collecting simultaneous paired transects using acoustic doppler current profiling (ADCP) (**Figure 4.1-A-2**). These measurements were used to validate the CFD and morphodynamic models. River discharge varied over the course of the measurements due to tidal influence. Total flow at Sapperton Bar was 8,276 $m^3/s$, with 30% of the flow passing through Sapperton Channel and 70% through Queen's Reach. At the bridge crossings, total flow averaged 7,852 $m^3/s$, with about 60% of the flow passing to the north of New Westminster Railway Bridge (NWRB) Pier 5 and 40% to the south. Total flow at the New Westminster Trifurcation was 7,129 $m^3/s$, split 78% in Annieville Channel, 10% in Annacis Channel, and 12% in the North Arm.

Back-eddies (areas of recirculating flow and slower velocity) are known to occur on the downstream sides of existing bridge piers during some tidal conditions. Musqueam First Nation has indicated that these back-eddies are important for placement of drift nets (Musqueam First Nation 2017).

#### 4.1.2.2.3 Riverbed Substrate

Riverbed sediments were sampled to better characterize the bed material around the Project area. Twelve sites between the proposed new bridge alignment and the SkyTrain Bridge alignment were sampled (**Figure 4.1-A-4**). All but one yielded sediment sizes in the expected range for Fraser River sand. Sample BM7, taken from near the south bank between the Pattullo Bridge and the NWRB, yielded somewhat larger sediments with a median grain size of 7 mm.

#### 4.1.2.2.4 Existing Riprap

The NWRB and Pattullo Bridge piers are protected against scour by extensive riprap installations. Record drawings of both bridges show scour protection being in place in the past, but to a lesser extent than at present. Given that historical records of scour protection upgrades over the lifespan of these bridges are incomplete, the estimated extents, thicknesses, and rock sizes of existing riprap at the two bridges were based on available record drawings, multibeam bathymetry surveys collected between 2005 and 2017, and records of the 2008 scour protection upgrades at Pattullo Piers 4 and 5 (**Figure 4.1-A-4**).

#### 4.1.2.2.5 Bathymetry

Riverbed bathymetry was compiled from available sources[3] including May 2014 multibeam surveys conducted for bi-annual Pattullo Bridge Monitoring, 2014 multibeam surveys from Public Works and Government Services Canada (PWGSC), and 2005 LiDAR from the Fraser Basin Council.

#### 4.1.2.2.6 Previous Studies

Several previous studies were reviewed for information relevant to the Project. Key studies are listed in **Table 4.1-5**; a full list of previous work cited is provided in **Section 4.1.9 References** and in **Appendix 18.2**.

[3] Contours were derived from a TIN created from 2014 bathymetric data in the main channel, 2011 bathymetric data in the Pattullo Sapperton Channel; 2014, May CRA Multibeam around bridges and 2005 LiDAR (FBC) for the bank elevations; 2017 Pattullo Bridge Monitoring Freshet Summary by Northwest Hydraulic Consultants Ltd. All data were prepared using ArcGIS 10.3 or 10.4. Coordinate system: UTM Zone 10, NAD 83, metres.

### Table 4.1-5 Summary of Relevant Studies Related to River Hydraulics and Morphology

| Study Name | Study relevance/purpose |
|---|---|
| Fraser Hydraulic Model Update (NHC 2008a) | Boundary conditions (water level and discharge) for numerical and physical models |
| 2016 ADCP measurements | Flow splits and velocities for model validation |
| Substrate sampling | Characterize bed sediments in the Project area |
| Bi-annual Pattullo Bridge Scour Monitoring (2005 – present) | Changes in bathymetry and scour protection, characterization of seasonal scour and deposition processes |
| Pattullo Bridge Scour Protection Design Basis Report (NHC 2008b) | Previous physical model study results, details of 2008 scour protection upgrades at Pattullo Bridge Piers 4 and 5 |
| McLean et al 2005<br>Nelson et al 2017 | Assessment of long-term riverbed degradation causes and implications for scour protection in the lower Fraser River |
| Cowichan Nation Alliance Strength of Claim Report - Pattullo Bridge Replacement Project (2017) | Traditional knowledge regarding historical changes to the river and traditional use |
| Kwikwetlem First Nation Traditional Knowledge and Cultural Heritage Interests (2017) | Traditional knowledge regarding historical changes to the river and traditional use |
| Kwantlen Land Use and Occupation in the Vicinity of Pattullo Bridge (2017) | Traditional knowledge regarding historical changes to the river and traditional use |
| Lake Cowichan First Nation (2017). Ts'uubaasatx Interests: Pattullo Bridge Replacement Project 2017. | Traditional knowledge regarding historical changes to the river and traditional use |
| Lyackson First Nation Traditional Land Use and Mapping Study for The South Coast British Columbia Transportation Authority's Pattullo Bridge Replacement Project (2017) | Traditional knowledge regarding historical changes to the river and traditional use |
| Musqueam Indian Band Knowledge and Use Study (2017) | Traditional knowledge regarding historical changes to the river and traditional use |
| Tsawwassen First Nation - Pattullo Bridge Replacement: Project Impact Study (2017) | Traditional knowledge regarding historical changes to the river and traditional use |
| Tsleil-Waututh Nation Traditional Use Study (2016) | Traditional knowledge regarding historical changes to the river and traditional use |

Note: Review of reports prepared by Aboriginal Groups was limited to content related to river hydraulics and river morphology.

## 4.1.2.3 Physical Conditions

### 4.1.2.3.1 Hydrology

The Fraser River drains a 232,000 km$^2$ area of southern BC, making it the largest river on the west coast of Canada. The Fraser has a snowmelt-dominated flow regime, with the discharge typically rising in April, peaking between May and July (the freshet period), and then receding during the autumn and winter months. The flood of record occurred on June 5, 1894, reaching 17,000 m$^3$/s at Hope and approximately

19,000 m$^3$/s at Mission. This event was estimated to have a return period of approximately 500 years (NHC 2008a). **Figure 4.1-A-5** shows minimum, mean, and maximum annual flow hydrographs for the Fraser River at Hope, 180 km upstream from the mouth. The year 2012 is also shown because it was selected to represent freshet conditions in the modelling analyses. Average peak flow of the Fraser River at Hope is about 7,000 m$^3$/s in June; the average low flow is approximately 850 m$^3$/s in March.

#### 4.1.2.3.2 River Hydraulics

During low flow conditions, tidal influence in the Fraser River extends to the gravel-sand transition just above Mission. At the Project site, tidal range is approximately 1.8 m during low flow. The tidal salt wedge does not extend upstream as far as the Project site. Tidal flows at the Project site typically reach approximately 8,000 m$^3$/s in both directions, although the duration and magnitude of flood tides are substantially less than that of ebb tides. Average channel flow velocity during flood tides can be 0.5 m/s to 1 m/s (flow moving upstream), while ebb tides range from 1.0 m/s to 1.5 m/s.

The highest water levels, discharges, and velocities in this reach occur during freshet flows. Although flow never reverses at the Project site during freshet, tides continue to influence hydraulics even during high magnitude freshet floods.

About 2.4 km upstream of the crossing, flow diverges around Sapperton Bar; Queen's Reach (the main channel) runs along the south side of the bar, and Sapperton Channel conveys flow to the north of the bar (**Figure 4.1-A-1**). Flow then converges downstream of Sapperton Bar before passing through the NWRB, Pattullo, and SkyTrain bridges. Roughly another 1 km downstream the Fraser River splits into the North Arm, Annacis Channel, and Annieville Channel; this area is referred to as the New Westminster Trifurcation.

Flow converging downstream of Sapperton Bar results in a shear layer[4] between Pattullo Piers 2 and 3. The combination of channel contraction, convergence, and a slight bend in the river causes deep scour here, making this area the deepest part of the channel at the Pattullo Bridge crossing. Riverbed elevations here are normally on the order of El. -23 m.

As flow passes under the NWRB, it plunges over a sill formed by the riprap scour protection around the NWRB piers. The sill is most pronounced on the south side of the channel, where riverbed elevations go from approximate El. -12 m upstream of the NWRB to El. -20 m beneath the Pattullo Bridge. The abrupt drop in riverbed elevations results in turbulent flow and enhanced scour at the Pattullo Bridge.

#### 4.1.2.3.3 River Morphology

##### Scour Conditions

Scour conditions at the Pattullo Bridge location are potentially the most severe in all of the lower Fraser River. The bridge is situated in one of the narrowest sections of the river (Kwikwetlem First Nation 2017), approximately 60 m downstream of the NWRB and just downstream of a long converging left-hand bend. Tidal fluctuations and Fraser River flows combine to yield highly dynamic flow conditions. During winter, flows are fully reversing due to larger tidal influence and smaller Fraser River flows. Flow convergence downstream of Sapperton Bar results in severe scour conditions. General (i.e., contraction) scour adds to

[4] Shear occurs due to friction between fluid particles when flows of differing velocities converge.

the scour potential during extreme floods because of the relatively narrow (about 500 m net) opening at Pattullo Bridge. A weir-like apron of rock is likely present under the NWRB, which results in deep scour around existing Pattullo Piers 4 and 5 when flow plunges over the apron during freshet. Local scour around the existing bridge piers also contributes to, and is augmented by, the angle of pier skew to the flow alignment of about 16° (NHC 2007). The Pattullo Bridge piers are all surrounded by scour protection.

Since construction of the NWRB in the early 20th century, the bed downstream of the bridge has become permanently lower by 10 to 15 m, which has caused large "cones" to form around the existing Pattullo piers. Tide conditions combined with high river flows have been observed to cause local bed levels to fluctuate by up to 7 m over a 24-hour period on both sides of the rail bridge. The hydraulic influence of individual structures, such as piers and scour protection aprons, can extend hundreds of metres upstream and downstream (NHC 2009).

NHC has been monitoring scour at the Pattullo Bridge on behalf of TransLink since 2004; a regular bi-annual monitoring program has been in place since 2011. Bed levels around the bridge piers have been observed to vary by as much as 5 m to 7 m seasonally and on a year-to-year basis. Variations in the order of a few metres are possible in a single tide cycle.

Early monitoring identified scour hazards at Piers 4 and 5, which were addressed by protection upgrades in 2008. NHC and TransLink continue to re-assess scour conditions at the bridge twice per year: once during the large winter tidal cycles and again during spring freshet. No further upgrades have been required since 2008, but riprap at Pier 4 has been launching[5] since at least 2013 (NHC 2013).

## Sediment Loads

The total suspended load averages 16.5 Mt/a (million tonnes per year) and ranges from 12.3 Mt to 31.0 Mt per year. (McLean and Tassone 1988; NHC 2002; Tywoniuk 1972). In the lower Fraser River, fine sediments (also called washload) generally remain in suspension and therefore have little effect on sedimentation patterns. Of primary importance is the bed-material load, which is the bed load and the fraction of sediment load capable of depositing in the river, and therefore exerts an influence on river morphology. The bed-material load averages 2.9 Mt/a, and ranges from 1.2 Mt to 8.9 Mt per year (NHC 2002).

Effects on concentrations of suspended fine sediments (i.e., washload) are excluded from the study. Washload carried in suspension in the water column is flushed through the Fraser River into the Strait of Georgia, and therefore does not affect river morphology. Potential effects on suspended sediment concentrations are discussed in **Section 4.3 Sediment and Surface Water Quality**.

## Riverbed Lowering and Dredging

The lower Fraser River has been subject to extensive human interventions beginning in the early 20th century. Musqueam Indian Band (2017) refers to human interventions including agricultural runoff; residential and industrial development on areas of interest to Musqueam resulting in loss of resources, habitats, and access for rights-based practices; road, bridge, and tunnel construction; river dredging;

[5] Launching refers to the displacement of stone into a scoured bed as the depression develops. Launched stone may continue to protect against scour under certain conditions.

commercial and recreational overfishing; sawmills; canneries; Fraser Port Authority (Port of Vancouver) developments and activities; river port facilities, including cement plants, gravel and sand transport; log booms; and changing habitats. Human interventions which have had reach-scale effects on Fraser River hydraulics and morphology include flood protection dikes, river training, bank hardening, dredging, construction of in-river infrastructure, and construction of riprap scour protection. As a result of these interventions, the Fraser estuary is narrower and deeper than it would be in its natural state. Average riverbed levels have declined by approximately 3 m since 1950 and are expected to continue degrading in the future. As average bed levels decrease, existing riprap protection and other non-alluvial materials begin to project above the riverbed. The increased projection induces turbulence and scour, deepening the lowest parts of the riverbed at a faster rate than average.

Long-term degradation has implications for the Project and nearby infrastructure. The lowering of bed levels at Pattullo Bridge between construction in 1936 and the present day is probably a result of historical deepening in combination with the protrusion of existing riprap at the Pattullo and NWR bridges. Bed levels at the Pattullo crossing alignment have decreased by up to 12 m, with the effect being most pronounced on the south side of the channel.

#### River Infrastructure

The Project is located in an area of the lower Fraser River with a significant amount of in-river infrastructure. The LSA includes three bridges, the existing Pattullo Bridge, the NWRB, and the SkyTrain Bridge; and the RSA includes four others, the Queensborough Bridge, Queensborough Rail Bridge, Annacis Island Rail Bridge, and Alex Fraser Bridge (**Figure 4.1-A-1**).

Within the RSA, Metro Vancouver has three sewer crossings, five water main crossings, and a proposed water supply tunnel (**Figure 4.1-A-6**). The new water supply tunnel (Annacis Main No.5) will be located at the New Westminster Trifurcation. While this proposed crossing lies within the RSA, it is proposed as a deep bored tunnel. As such, it is not expected to be susceptible to hydraulic or morphological changes attributable to the Project.

The hydraulics and morphology of the Fraser River within the RSA have been extensively modified by river training works, including the Annieville and Phase 3 trifurcation dikes; expansion of Annacis Island; two rock sills extending from the north bank; a rock sill across Annacis Channel and the North Arm; two wing dams (pile groins) extending from the south bank of Sapperton Bar; and the Sapperton V-dike.

## 4.1.3 Potential Effects

### 4.1.3.1 Potential Interactions

Potential Project interactions with river hydraulics and morphology will result from the placement of new piers in the river and decommissioning of the existing Pattullo Bridge. These changes could influence hydraulics (water levels, velocities, and flow patterns), which in turn can affect river morphology (scour, sedimentation, and riverbed levels). Morphology can then drive further changes in hydraulics in a complex feedback loop driven by highly variable natural processes.

Construction activities also have the potential to interact with river hydraulics and morphology, as access to in-water construction may involve a combination of barge and temporary trestle. Potential effects of the Project on the Fraser River Hydraulics and Morphology are rated according to the criteria in **Table 4.1-6**.

### Table 4.1-6 Preliminary Effects Rating for Project Interactions

| Rating | Description |
|---|---|
| No effect | An interaction with the Project activity is likely to occur but would not be expected to result in a detectable or measurable effect on the Fraser River Hydraulics and Morphology IC. |
| Potential effect | An interaction with the Project activity is likely to occur and would be expected to result in a potential effect on the Fraser River Hydraulics and Morphology IC. |

The Fraser River Hydraulics and Morphology IC has the potential to induce changes in end-of-pathway VCs including Fish and Fish Habitat (**Section 4.3**), Economic Activity (**Section 5.1**), Marine Use (**Section 6.1**), and Archaeological Heritage Resources (**Section 7.1**).

Statutory requirements under CEAA 2012 were integrated into the assessment and are summarized in **Section 11**.

### 4.1.3.2 Methodology

Several tools were employed to yield a robust assessment of potential changes due to the Project. Three types of model studies were used to assess hydraulic and morphologic changes due to the Project - two numerical models and a mobile-bed physical model. The models are briefly described below; further details are provided in **Appendix 18.2**.

The potential effects of the Project on near-field flow hydraulics were investigated using Flow-3D (www.Flow3D.com), a three-dimensional computational fluid dynamics (CFD) model with special capabilities for modelling complex geometries and free surface flows. CFD models are well suited to complex, local-scale hydraulic modelling, but are limited in scope because of extensive computational requirements and are not a preferred tool for sediment transport modelling. To reduce computational time, all simulations were performed assuming steady flow with constant discharge and water level. This steady-state assumption is acceptable when assessing the hydraulic effects of the Project. The CFD model assessed five scenarios: existing conditions, the Reference Concept with and without NWRB upgrades, and the Pattullo Bridge Decommissioning scenario with and without NWRB upgrades. All scenarios were modelled at three flows: the 1894 flood of record, a typical freshet condition, and an incoming winter flood tide. The flood of record is the largest flood known to have occurred on the Fraser River, and has been adopted as the standard design flood for major infrastructure on the Fraser River. The typical freshet condition was selected to assess potential changes during normal high flow conditions. The incoming winter flood tide was used to assess potential effects (primarily upstream of the proposed bridge) during flow reversals.

The TELEMAC SYSTEM, a three-dimensional morphodynamic model, was used to assess far-field hydraulics and river morphology (changes to bed elevation). Three-dimensional morphodynamic models can cover larger spatial areas than CFD models, and are capable of modelling sediment transport and changes in riverbed levels. However, the larger spatial scope of the Pattullo morphodynamic model limits

its ability to assess small-scale hydraulics and local scour around the bridge piers. The morphodynamic model assessed existing conditions, the Reference Concept, and the Decommissioning scenario. The 2012 freshet flows were selected to assess potential changes in bed elevations under a typical (but larger than average) freshet.

A mobile-bed 1:80 scale physical model was used to assess existing conditions and two earlier iterations of the proposed replacement crossing. Although the Reference Concept was not tested in the physical model, observations from the physical model have been incorporated where relevant. Physical models are capable of capturing detailed and reach-scale hydraulics, local scour around bridge piers, and larger-scale changes in sediment transport; this is the most robust tool available for assessing near-field changes to hydraulics and morphology. However, these models are limited in spatial coverage and have a finite lifespan.

Results of the three model studies were synthesized to provide a concise summary of the changes to river hydraulics and morphology expected as a result of the Project. Except where specifically noted otherwise, river hydraulics results are from the CFD model and changes in bed elevation are from the morphodynamic model.

The accuracy and precision of the model results are limited by available data for calibration and validation, natural variability and inherent randomness in river systems, and the representation of complex natural systems in simplified models. The three models in combination provide a robust basis for assessing potential Project effects, but do not deterministically predict future conditions.

#### 4.1.3.3 Effects Assessment

Project effects on River Hydraulics and Morphology could result particularly from the placement of new piers in the water. Relevant aspects of the IC that could be affected include current velocities, water levels, flow splits, and riverbed levels. Musqueam First Nation (2017) indicated that placement of new bridge piers is important, as it can affect water flow, the placement of drift nets, and marine traffic.

Potential effects have been assessed by comparing results for existing conditions with those from the construction and Operations Phases. The characterization of existing conditions was based on data from recent years and on the interpretive geomorphology study. Multibeam bathymetric surveys from 2014 were used to represent existing riverbed conditions, and acoustic doppler current profiler (ADCP) transects measured in 2014 and 2016 were used to assess existing flow splits and velocity distributions. Both numerical models and the physical model assessed existing conditions as a baseline for comparison with future conditions.

For the Construction Phase, potential effects due to the proposed new Pattullo Bridge with the existing Pattullo Bridge still in place were assessed using the CFD model for hydraulics and the morphodynamic model for changes in bed levels. Within the Construction Phase, potential effects from temporary construction works were assessed qualitatively. Since the location, orientation, extents, and design of temporary works are not known at this stage, the potential effects have not been modelled.

Potential effects for the Operations Phase, after decommissioning of the Pattullo Bridge, were also assessed using the CFD and morphological models. The Operations Phase represents the long-term condition after the new bridge has been constructed and the existing bridge has been decommissioned.

The existing Pattullo piers were removed from the model and, based on input from the Vancouver Fraser Port Authority (VFPA), the riprap scour protection cones were truncated at El. -10.0 m GD in the local navigation channel and at El. -14.35 m GD in the main navigation channel.

#### 4.1.3.3.1 Potential Effect #1: Changes in Current Velocities

##### Construction Phase

***Effects of Temporary Construction Works***

Temporary construction works may affect local current velocities and flow distribution where trestles or other obstructions to flow are introduced to the channel. If a temporary trestle were to obstruct flow on one side of the channel, then a larger proportion of flow may be diverted to the opposite side. The local change in flow split could potentially affect the flow splits upstream at Sapperton Island and downstream at the Trifurcation.

Potential effects of construction works have not been modelled; however, any effects are expected to be temporary and may be minimized by limiting the footprint of temporary obstructions (e.g., trestle) in the channel. Barges, cranes, and other mobile vessels are not expected to affect current velocities.

***Effects of the New Bridge***

The Project as currently proposed is not expected to result in any notable increase in average velocities. Inclusion of the piers as identified in the Reference Concept in the CFD model increased depth-averaged velocities in the main navigation channel by 0.1 m/s for the 1894 flood of record (**Figure 4.1-A-7**) and the typical freshet flows (**Figure 4.1-A-8**). These differences are considered negligible because they are within the numerical accuracy of the model and the natural variability of the Fraser River. There was no change in velocities in the local navigation channel. These effects are corroborated by the morphodynamic modeling (**Appendix 18.2 Hydraulic Modelling Report, Appendix B**), with the exception that an increase in velocity of less than 0.2 m/s was predicted for the local navigation channel.

A low-velocity shadow occurred downstream of the South Tower. Immediately downstream of the pylon, depth-averaged velocity was reduced from 2.7 m/s to 0.4 m/s under flood of record conditions (**Figure 4.1-A-7**), and from 1.6 m/s to 0.3 m/s under typical freshet conditions (**Figure 4.1-A-8**). The decrease in depth-averaged velocities is attenuated downstream of the South Pylon but persists as far downstream as the SkyTrain Bridge. Near-bed velocities closer to the pylon are also reduced. Similar but more moderate effects occurred at the North Tower. The morphodynamic model suggests the attenuated velocity decrease could extend as far downstream as the Trifurcation Phase III Training Wall at RK 35 (shown in **Figure 4.1-A-1**).

Velocities between the South Tower and Pier S0 increased by 0.3 m/s and 0.4 m/s for the typical freshet and flood of record flows, respectively. A localized region of high velocity developed on the upstream-north side of the South Tower.

Velocity changes for the winter flood (incoming) tide condition were less pronounced (**Figure 4.1-A-9**). Velocities at the South Tower increased from 1.3 m/s under existing conditions to 1.5 m/s for winter flood tide conditions. In the lee of the South Tower, velocities reduced to 0.4 m/s, compared with 1.4 m/s for existing conditions. Similar but weaker low-velocity areas were observed behind the remaining Reference Concept piers.

### *Flow Splits*

The river flow splits upstream and downstream of Pattullo Bridge, where the river channel divides around islands. Upstream, the Sapperton V-dike bifurcates the flow into Queen's Reach and Sapperton Reach. Downstream, flow divides into the North Arm, Annacis Channel, and Annieville Channel (South Arm) at an area known as the New Westminster Trifurcation.

Flow splits are not expected to change due to the Project. **Table 4.1-7** shows modelled flow splits for the existing conditions, the Construction Phase (Pattullo still in place), and the Operations Phase (Pattullo decommissioned). Modelled flow splits for existing conditions (morphodynamic validation run) were within 2% of measured flow splits (**Appendix 18.2 Hydraulic Modelling Report**, **Appendix B**).

### Table 4.1-7 Modelled Flow Splits for Existing Conditions, Construction Phase (with Pattullo still in place), and Operations Phase (Pattullo decommissioned)

| Location | Existing Conditions | Construction Phase | Operations Phase |
|---|---|---|---|
| **Sapperton V-Dike** | | | |
| Sapperton Channel | 30% | 30% | 30% |
| Queen's Reach | 70% | 70% | 70% |
| **Pattullo Bridge** | | | |
| North of NWRB Pier 5 | 65% | 66% | 66% |
| South of NWRB Pier 5 | 35% | 34% | 34% |
| **Trifurcation** | | | |
| North Arm | 12% | 12% | 12% |
| Annacis Channel | 9% | 9% | 9% |
| Annieville Channel | 79% | 79% | 79% |

Notes:

1 Modelled flow splits from typical freshet flow (2012).
2 Flow splits at Sapperton V-Dike and Pattullo Bridge from CFD model.
3 Flow split at New Westminster Trifurcation from morphodynamic model.

## Operations Phase

Minor changes in current velocities are expected in the Operations Phase (new bridge in place, Pattullo Bridge decommissioned) compared with the Construction Phase (new bridge and the existing Pattullo Bridge both in place). For the flood of record (**Figure 4.1-A-10**) and typical freshet conditions (**Figure 4.1-A-11**), the reduction in main navigation channel velocities after removing the existing piers was negligible. The riprap cones of the Pattullo Bridge continue to cause a contraction in flows even after the piers are removed, although velocities near the riprap cones were 0.2 m/s to 0.3 m/s higher after decommissioning.

Local regions of high velocity caused by flow acceleration around Pattullo Piers 3 and 4 are no longer present after decommissioning, resulting in a velocity reduction in these regions of approximately 0.5 m/s for the flood of record and of 0.3 m/s for typical freshet conditions.

For the winter flood (incoming) tide scenario, shown in **Figure 4.1-A-12**, the absence of a low-velocity shadow from the existing piers results in local velocity increases. The greatest increase in velocity was 0.2 m/s directly west of NWRB Piers 3 and 4.

#### 4.1.3.3.2 Potential Effect #2: Changes in Water Levels

### Construction Phase

***Effects of Temporary Construction Works***

Temporary construction works entailing the presence of barges, other large vessels, and temporary trestles in the river are expected to have localized effects on water levels. Water levels at the upstream ends of these obstructions will be slightly elevated while the obstruction remains in place. The effects are expected to be temporary and will not affect reach-scale water levels.

***Effects of the New Bridge***

Modelled water levels are shown in **Table 4.1-8**. No significant effects to water levels are expected to result from the new bridge; the differences indicated in the table are small in comparison to the natural variability of the Fraser River at the Project area.

**Table 4.1-8 Modelled Water Levels for Existing Conditions, Construction Phase (Pattullo still in place), and Operations Phase (Pattullo decommissioned) during Typical Freshet Flow**

| Location | Existing Conditions | Construction Phase | Operations Phase |
|---|---|---|---|
| **Water Surface El. (m)** | **Typical Freshet** | **Typical Freshet** | **Typical Freshet** |
| Primary navigation channel at Pattullo | 0.68 | 0.66 | 0.68 |
| Secondary navigation channel at Pattullo | 0.68 | 0.69 | 0.68 |
| Navigation channel at SkyTrain Bridge | 0.65 | 0.64 | 0.64 |
| Navigation channel at Sapperton Channel | 0.87 | 0.83 | 0.85 |
| Navigation channel at Queen’s Reach | 0.88 | 0.87 | 0.87 |
| South of NWRB Pier 5 | 0.64 | 0.62 | 0.64 |

### Operations Phase

No significant effects to water levels are expected to result from decommissioning of the existing Pattullo Bridge. The water level differences in **Table 4.1-8** are small in comparison to the natural variability of the Fraser River at the Project area.

#### 4.1.3.3.3 Potential Effect #3: Bed Level Changes

The effects of the new bridge on riverbed elevations were assessed using the morphodynamic model, with additional insight provided by the physical and CFD model results. Modelled changes to bed elevations are indicative of the expected trends and relative magnitudes in bed elevations, but should not be interpreted as quantitative predictions. Rather, they represent a likely outcome given a set of assumed inputs. The modelled bed level changes should also be understood in the context of the river's natural variability. Bed levels at the Pattullo Bridge crossing can change by several meters in the span of a single tide cycle.

Bed elevation changes due to the new bridge piers are expected in the area near the existing Pattullo Bridge, the NWRB, and proposed new bridge, with minor changes as far downstream as the New Westminster Trifurcation. Various "points of interest" were identified by VFPA, Metro Vancouver, and the Archaeology team. Sites of interest to VFPA and pipeline crossings are identified in **Appendix 18.2**. Bed level changes for existing, Reference Concept, and Decommissioning scenarios are illustrated in **Figures 4.1-A-13** and **4.1-A-14**.

## Construction Phase

### *Effects of Temporary Construction Works*

Construction of temporary trestles could potentially induce changes in riverbed levels. Local scour around the trestle and existing adjacent bridge piers is likely and may cause sedimentation downstream (or upstream during flow reversals). Far-field changes to bed levels are also possible due to the potential for the temporary trestles to affect current velocities and flow splits. These effects would be temporary and would likely dissipate within one freshet after removal of the temporary construction works.

### *Effects of the New Bridge*

*Bed Level Changes in the Navigation Channels*

Placement of the piers of the proposed bridge is expected to induce minor changes in the navigation channels. Up to 1 m of bed lowering is expected in the main navigation channel upstream of the proposed new bridge. About 0.5 m of aggradation is expected along the margin of, and encroaching slightly into, the primary navigation channel near the SkyTrain Bridge. Downstream of the SkyTrain Bridge, about 0.5 m of bed lowering is expected in the main navigation channel. The Project as reflected by the Reference Concept is not expected to induce any significant changes in the local navigation channel.

*Bed Level Changes at the Bridges*

At the location of the proposed new crossing, an increase of 3 m to 4 m in the bed level is expected immediately downstream of the South Tower. Approximately 1 - 2 m of aggradation is expected downstream of Pier S0 between Pier S0 and the existing Pattullo Bridge. About 1.5 m of bed lowering is expected between the South Tower and Pier S0.

At the existing Pattullo Bridge, about 1 m of bed lowering is expected between Piers 5 and 6, extending upstream to between NWRB Piers 9 and 10 and downstream for about 100 m. Up to 2 m of infilling was noted downstream of existing Pattullo Bridge Piers 1 and 2.

The physical model tested two replacement concepts along the same alignment as the Reference Concept. These concepts both incorporated two pylons and several other piers upstream of the NWRB. Test results suggested that the placement of new piers in these areas has the potential to cause deep local scour at the NWRB piers, and to a lesser degree at the existing Pattullo Bridge (**Appendix 18.2 Hydraulic Modelling Report**, **Appendix C**). These results indicate that downstream scour and sediment deposition are sensitive to upstream pier placement, and that the Reference Concept, or other future design, will influence the degree of scour at the NWRB and existing Pattullo Bridge piers.

*Bed Level Changes Elsewhere*

The bed level is expected to increase by approximately 2 m to 3 m along the south border of the main navigation channel between km 35 and km 36. As mentioned above, only minor deposition, on the order of 0.5 m, is expected in a limited area within the navigation channel.

Bed lowering of about 0.5 m to 1 m is expected near the upstream end of the Trifurcation Phase 3. At the New Westminster Trifurcation, the model showed about 0.5 m of bed lowering in Annieville Channel along the Annieville Dike, and 0.5 m to1.0 m of lowering downstream of the sheet pile wall at the tip of Annacis Island, where there is an existing deep scour hole.

The Project is not expected to result in bed level changes at any of the pipeline crossings within the RSA. The relevant crossings, owned by Metro Vancouver, Fortis BC Energy, and Kinder Morgan, are listed in **Section 3.4.1**. of **Appendix 18.2**.

Aboriginal Groups have identified numerous sites in the river with archaeological importance. The locations of these sites were compared with plots of modelled velocity and bed level changes from the morphodynamic model sites (**Figure 4.1-A-13**, **4.1-A-14** and **Appendix 18.2**, **Figure 21**). The Project is not expected to result in any significant changes in river velocity or bed elevations at the sites of interest. Hydraulic and morphological modeling applicable to archaeological sites of interest is discussed in the assessment of the Heritage Resources VC (**Section 7.1.3.4**).

A number of constructed tidal marshes have been identified as areas that would potentially be sensitive to bed level changes. Constructed tidal marshes reviewed for potential Project effects are shown in **Figure 4.1-A-15**. These were compared with modelled velocity and bed level changes from the morphodynamic model (**Figure 4.1-A-13, 4.1-A-14** and **Appendix 18.2**, **Figure 21**). No Project-induced changes in velocity or bed levels are expected at any of these sites.

Based on concerns raised by Aboriginal Groups, potential for the Project to affect hydraulic or morphological conditions at the South Arm Marshes Wildlife Management Area was considered. The wildlife management area is located at the mouth of the Fraser River, approximately 20 km downstream of the Project, outside of the RSA. Results of modelling confirmed that no Project-related influences on the hydraulic or morphological conditions of the river are expected outside of the RSA boundary, including at the South Arm Marshes Wildlife Management Area.

## Operations Phase

To represent conditions during the Operations Phase after the new bridge has been constructed and the existing Pattullo Bridge has been decommissioned, the existing Pattullo piers were removed from the model and the riprap scour protection cones were truncated at El. -10.0 m GD in the secondary navigation channel and at El. -14.35 m GD in the primary navigation channel. In general, bed level changes associated with the Operations Phase are expected to be similar to those expected during construction. Potential differences are discussed below. Modelled bed level differences for the Operations Phase compared with existing conditions are shown in **Figure 4.1-A-14**.

*Bed Level Changes in the Navigation Channels*

Removal of the existing Pattullo bridge piers and truncation of the riprap cones is expected to cause minor changes in bed level. The bed lowering between Piers 5 and 6 resulting from the placement of the new bridge piers is expected to be reversed. Deposition on the order of 4 m to 5 m is expected south of the navigation channel near the SkyTrain Bridge alignment, and deposition in the order of 1 m may extend a few metres into the navigation channel further downstream.

With the Pattullo Bridge decommissioned, about 0.5 m of aggradation is expected in the navigation channel in Annieville Channel around km 34.

*Bed Level Changes Elsewhere*

Modelled bed lowering around the flow splitter at the upstream end of Annacis Island was reduced under the Decommissioning scenario.

## 4.1.4 Mitigation Measures

This section describes the mitigation approach, relevant management plans, and the Project-specific mitigation measures proposed to avoid or reduce potential adverse effects of the Project on River Hydraulics and Morphology.

### 4.1.4.1 Mitigation Approach and Relevant Management Plans

#### 4.1.4.1.1 Mitigation Approach

The approach to the identification of mitigation measures subscribed to the mitigation hierarchy as described in the Environmental Mitigation Policy for British Columbia. Consideration of mitigation measures followed a hierarchical approach:

- Avoidance: preventing, controlling, or minimizing adverse effect by changing the location, method. or design of a Project component or activity
- Minimization: minimizing or reducing the extent of the adverse effect through standard mitigation measures, best management practices or specific mitigation measure
- Restoration or Habitat Enhancement: where a potential adverse effect is unavoidable, restoration or habitat enhancement is considered, which aims to restore the affected component on site to pre-Project conditions
- Offsetting: where an adverse effect is unavoidable, and restoration or habitat enhancement is not practicable, compensation or offsetting is considered to reduce the effect through compensatory actions, resulting in a neutral or beneficial net effect on the community or ecosystem

Mitigation has been proposed only for effects that are considered adverse. Effects with neutral or positive influences on habitat, infrastructure, and navigation are not proposed to be mitigated. The latter include riverbed lowering in the navigation channel, riverbed level increases outside the navigation channel and away from sensitive habitat, and current velocity changes local to the piers or outside the navigation channels.

#### 4.1.4.1.2 Relevant Management and Monitoring Plans

**Scour Monitoring**

TransLink currently monitors the area surrounding the Pattullo and NWR bridges for scour impacts twice annually: once during the spring freshet and once during the large winter tidal swings in December–January. Multibeam bathymetry is collected for the entire channel width during freshet and for only the southern half of the channel during the winter survey. Freshet surveys also include cross-sections within about 900 m upstream and downstream of Pattullo Bridge. This monitoring program will be continued to the start of construction. Leading up to construction, a baseline multibeam bathymetry survey should be undertaken, extending upstream to the middle of Sapperton Bar in Sapperton Channel and Queen's Reach, and downstream of the Trifurcation to RK 33 in the main channel. During construction, regular monitoring around the bridges should be undertaken more frequently. Depending on the stage of construction and the nature of instream work, frequency could range from daily to monthly. Following construction, regular monitoring should continue on a weekly to monthly basis, reducing to bi-annually over time if scour effects to the bridges are minor.

Scour issues identified through monitoring would be addressed through procedures established in a response plan which is under development.

### 4.1.4.2 Avoidance

Effects of temporary construction works on current velocities, water levels, flow splits, and bed levels may be avoided if construction can be accomplished without the use of temporary trestles or other flow obstructions. The feasibility of construction by barge and crane, without trestles, will be determined based on the detailed design of the new bridge.

### 4.1.4.3 Minimization

#### 4.1.4.3.1 Mitigation Measure #1: Scour Protection Upgrades

Scour at the existing Pattullo and NWR bridge piers will be mitigated by upgrading existing riprap scour protection if required based on detailed Project analysis to be completed during final design. Upgrades to existing scour protection have not been designed for the Reference Concept but would be incorporated into the detailed design based on results of future hydrotechnical assessment. The new bridge is not expected to require scour protection as the pile depth should be sufficient to withstand scour down to the deepest levels seen in the model studies (minimum El. -38 m in the physical model; **Appendix 18.2 Hydraulic Modelling Report, Appendix C**).

Protecting the existing Pattullo and NWR bridges from additional scour induced by the new bridge piers may reduce the extent and/or magnitude of bed level increases expected downstream by eliminating or reducing the amount of sediment mobilized by local scour around piers. However, velocity reductions downstream of the proposed new piers would still occur and would be expected to result in bed level increases.

Scour protection upgrades are expected to be highly effective at mitigating local scour around the existing Pattullo and NWR bridge piers, with moderate certainty. The effectiveness of the upgrades at mitigating downstream bed level increases is considered low to moderate, with a low degree of certainty.

#### 4.1.4.3.2 Mitigation Measure #2: Pier Location and Configuration

To ensure the most severe conditions were assessed, piers were placed in areas with substantial flow and not aligned to the flow in the model. Aligning the piers could reduce the effects on current velocities, local scour, and downstream sediment deposition. Moving piers closer to shore and aligning them with flow direction would also mitigate some of the expected reduction in downstream velocities caused by the skew which in turn could reduce the tendency for sediment deposition and bed level increases downstream.

### 4.1.4.4 Summary of Proposed Mitigation Measures

The proposed mitigation measures are summarized in **Table 4.1-9**. The mitigation measures apply only to the River Morphology Subcomponent as no potential adverse effects were identified for the River Hydraulics Subcomponent.

## Table 4.1-9 Summary of Proposed Mitigation Measures for River Hydraulics and Morphology

| IC Subcomponent | Potential Effect | Mitigation Measure | Project Phase | Effectiveness | Certainty | Relevant Management Plan | Residual Effect (Y/N) |
|---|---|---|---|---|---|---|---|
| River Morphology | Local scour around existing Pattullo and NWR bridge piers | Upgrade existing scour protection;<br>Pier location and configuration | Construction<br>Operations | High | Moderate | Erosion and Sediment Control Plan<br>Emergency Response and Spill Prevention Plan | N |
| River Morphology | Bed level increases in downstream navigation channel | Upgrade existing scour protection | Construction<br>Operations | Low to Moderate | Low | Erosion and Sediment Control Plan | Y |
| River Morphology | Bed level increases downstream of North and South pylons | Pier location and configuration | Construction<br>Operations | Moderate | Moderate | Erosion and Sediment Control Plan | Y |
| River Morphology | Bed level decrease between Pattullo Piers 5 and 6 | Pier location and configuration | Construction<br>Operations | Low | Low | Erosion and Sediment Control Plan | Y |

## 4.1.5 Residual Effects

Three residual effects have been identified: bed level increases in the navigation channel downstream of the SkyTrain Bridge, bed level increases downstream of the North and South pylons (Reference Concept), and bed level decreases between existing Pattullo Piers 5 and 6.

### 4.1.5.1 Characterization of Residual Effects

#### 4.1.5.1.1 Residual Effect # 1: Bed Level Increases in Downstream Navigation Channel

Bed level increases are expected along the south margin of the main navigation channel downstream of the SkyTrain Bridge following decommissioning of the Pattullo Bridge (**Figure 4.1-A-14**). The residual effect is characterized below.

- **Context** for this effect is neutral: The Fraser River may or may not adjust to this deposition over time.
- The **extent** of the effect is regional: Expected deposition within the navigation channel covers an area approximately 900 m long and up to 40 m wide within the RSA.
- **Magnitude** for most of this area: Expected to be on the order of 1 m in a limited area. Within the context of natural variability in this reach of the Fraser River, a bed level increase of 1 m is considered moderate.
- **Duration** of the increase is long term: It is expected to persist over the operational life of the new bridge.
- The effect is considered **reversible**.
- **Frequency** of the effect is regular: Bed levels will vary substantially with seasonal and tidal changes, but the increase is expected to recur regularly.
- **Likelihood** of increased bed levels: Expected to occur; however, the encroachment of this effect on the navigation channel is only moderately likely.

#### 4.1.5.1.2 Residual Effect # 2: Bed Level Increases Downstream of North and South Towers

Bed level increases are expected downstream of the North and South Towers of the proposed new bridge following decommissioning of the Pattullo Bridge (**Figure 4.1-A-14**). The residual effect is characterized below.

- **Context** for this effect is neutral: The Fraser River may or may not adjust to this deposition over time.
- The **extent** of the effect is regional: Expected bed level increases downstream of the North Tower cover an area approximately 100 m long and 20 m wide between the NWRB and the SkyTrain Bridge. Downstream of the South Tower the expected bed level increases cover the area immediately downstream of the pylon (upstream of NWRB), an area about 4 m long by 100 m wide downstream of the decommissioned Pattullo Pier 4, and an area about 1,200 m long and 40 m to 80 m wide along the south margin of the navigation channel.

- **Magnitude** for most of this area: Expected to be less than 1 m; however, up to 5 m of deposition is possible in a limited area (approximately 350 m by 40 m) straddling the SkyTrain Bridge alignment. Within the context of natural variability in this reach of the Fraser River, a bed level increase of 5 m is considered high.
- **Duration** of the increase is long term: It is expected to persist over the operational life of the new bridge.
- The effect is considered **reversible**: Removal of the pylons at the end of the operating life of the new bridge could eliminate the bed level increase.
- **Frequency** of the effect is regular: Bed levels will vary substantially with seasonal and tidal changes, but the increase is expected to recur regularly.
- **Likelihood** of increased bed levels: Likely to occur.

#### 4.1.5.1.3 Residual Effect # 3: Bed Level Decreases Between Pattullo Piers 5 and 6

Bed levels are expected to decrease between Pattullo Piers 5 and 6 by approximately 1.5 m during the Construction Phase and approximately 1.2 m during the Operations Phase (with a lesser spatial extent) (**Figures 4.1-A-13** and **4.1-A-14**). Aligning the new piers to the flow may reduce the hydraulic effects of the new bridge and thereby reduce the amount of bed lowering in this area. The residual effect is characterized below.

- **Context** for this effect is neutral: The Fraser River may or may not adjust to this deposition over time.
- The **extent** of the effect is local: Bed lowering extends from the NWRB about 180 m downstream in the Construction Phase, and from the Pattullo bridge about 50 m downstream in the Operations Phase.
- **Magnitude** for most of this area: Expected to be on the order of 1 m. Within the context of natural variability in this reach of the Fraser River, a bed level increase of decrease of 1 m is considered moderate.
- **Duration** of the increase is long term: It is expected to persist over the operational life of the new bridge.
- The effect is considered **reversible**: Removal of the pylons at the end of the operating life of the new bridge could eliminate the bed level decrease.
- **Frequency** of the effect is regular: Bed levels will vary substantially with seasonal and tidal changes, but the increase is expected to recur regularly.
- **Likelihood** of bed lowering: likely to occur.

#### 4.1.5.2 Confidence and Risk

There is a high degree of confidence that riverbed levels will change downstream of the proposed new bridge. However, there is only moderate confidence in predicting the exact locations and magnitude of the changes, including the degree (if any) of encroachment on the navigation channel and in context of the natural variability in this reach of the Fraser River. The degree of encroachment in the morphodynamic model is limited and represents a potential outcome from a given set of conditions (2012 freshet flows, Reference Concept pier geometry, decommissioning and removal of existing Pattullo Bridge). The natural variability in Fraser River flows and sediment transport yields regular changes of several metres in bed levels and introduces a high degree of inherent uncertainty in model predictions.

Regular monitoring of riverbed bathymetry will be sufficient to track the magnitude and extents of bed level increases.

#### 4.1.5.3 Summary of Residual Effects Assessment

The assessment of residual effects is summarized in **Table 4.1-10**.

## Table 4.1-10 Summary of the Residual Effects Assessment for River Hydraulics and Morphology

| IC Subcomponent | Residual Effect | Project Phase | Mitigation Measure | Characterization of Residual Effect | Likelihood | Confidence |
|---|---|---|---|---|---|---|
| River Morphology | Bed level increase in the downstream navigation channel | Construction<br>Operations | Upgrade existing scour protection, pier location and configuration | Context: neutral<br>Extent: regional<br>Magnitude: moderate<br>Duration: long term<br>Persistence: reversible<br>Frequency: regular | Moderate | Moderate |
| River Morphology | Bed level increase downstream of North and South pylons | Construction<br>Operations | Upgrade existing scour protection, pier location and configuration | Context: neutral<br>Extent: regional<br>Magnitude: high<br>Duration: long term<br>Persistence: reversible<br>Frequency: regular | Moderate | Moderate |
| River Morphology | Bed level decrease between Pattullo Piers 5 and 6 | Construction<br>Operations | Pier location and configuration | Context: neutral<br>Extent: local<br>Magnitude: moderate<br>Duration: long term<br>Persistence: reversible<br>Frequency: regular | High | Moderate |

## 4.1.6 Cumulative Effects

This section describes potential interactions with other past, present, and reasonably foreseeable projects, and rates the cumulative interaction as "no cumulative effect" or "potential cumulative effect," as defined in **Table 4.1-11**. Certain and reasonably foreseeable projects are provided in **Section 3.0 Methodology**. Two of the foreseeable projects have the potential for cumulative effects: the Bosa 660 Quayside development and the NWRB seismic upgrade (**Figure 4.1-A-16**). The remaining projects listed in the table do not have potential for cumulative effects with regard to River Hydraulics and Morphology.

### 4.1.6.1 Cumulative Effects Assessment Boundaries

The spatial boundary for River Hydraulics and Morphology cumulative effects assessment coincides with the RSA (**Figure 4.1-A-1**). Temporal boundaries incorporate the Construction and Operations Phases of the Project.

### 4.1.6.2 Interactions with Other Projects

#### 4.1.6.2.1 Bosa 660 Quayside Development

The Bosa 660 Quayside development proposes the construction of multiple residential buildings and a tower, partial infill of the existing piled wharf on the north bank of the Fraser River, and the construction of a new pedestrian wharf in the Fraser. This development could potentially interact with the Project by changing river hydraulics and morphology downstream of the Project and consequently altering the assessed potential effects of the Project on Fraser River Hydraulics and Morphology. The extent of encroachment into the river proposed by the Quayside development is relatively small in comparison with the overall river width, however, and effects on river hydraulics and morphology would probably be limited to local changes. For these reasons, no cumulative effect with the Project changes to Fraser River Hydraulics and Morphology is expected.

#### 4.1.6.2.2 NWR Bridge Seismic Upgrade

CN Rail proposes to strengthen the NWRB. At the time of this environmental assessment, CN planned to add two new 2.5 m diameter piles at the upstream and downstream ends of NWRB Piers 6 to10 and pile caps to tie the new piles to the existing piers. The plan also includes the removal of the Pier 6 protection and the addition of two more 2.5 m diameter piles in its place. Given the proximity of the NWRB to the Project, local-scale changes in the river could potentially result in cumulative effects on Fraser River Hydraulics and Morphology.

#### 4.1.6.2.3 Annacis Island Wastewater Treatment Plant Outfall Project

Metro Vancouver is proposing a new outfall location and diffuser system to release treated effluent from the Annacis Island Wastewater Treatment Plant into the Fraser River, which will involve constructing a one-kilometre long tunnel (approximately) from the plant to the river. Construction on this project, located approximately 6.5 km downstream of the Project, is anticipated to start in 2019. Potential effects of the Outfall project are not yet known, but would be local in extent. The Project is not expected to result in any effects on Fraser River hydraulics or morphology this far downstream and in any case the Pattullo Bridge

Replacement Project would not affect the new tunnel which will be deeply buried. Therefore, no cumulative effects with this project are anticipated.

### Table 4.1-11 Preliminary Rating for Cumulative Interactions

| Rating | Description |
|---|---|
| No cumulative effect | A cumulative interaction with residual effects of other certain and reasonably foreseeable projects is likely to occur but is expected to result in relatively minimal contribution to cumulative effects that is negligible. |
| Potential cumulative effect | A cumulative interaction with residual effects of other certain and reasonably foreseeable projects is likely to occur and is expected to result in a potential cumulative effect on the VC/IC. |

#### 4.1.6.3 Potential Cumulative Effects and Mitigation Measures

Potential cumulative effects resulting from the NWRB upgrades include changes in flow distribution; changes in flow patterns; changes in velocities; local scour at piers on the NWRB, existing Pattullo Bridge, and/or proposed new bridge; reach-scale changes to riverbed levels; and sediment deposition. Local scour and deposition could be effectively mitigated by upgrading the existing scour protection or placing scour protection at the proposed new bridge. The shape of NWRB piers is already streamlined; changing their shape is unlikely to mitigate any cumulative effects on hydraulics. Removal of NWRB Pier 6 protection could affect velocities, flow patterns, and flow distribution, and possibly morphology. If necessary, mitigation could involve leaving the Pier 6 protection structure in place or rebuilding a similar flow deflector after pile installation.

#### 4.1.6.4 Residual Cumulative Effects Assessment

The CFD model was used to assess potential changes to river hydraulics resulting from the proposed NWRB upgrades. Based on preliminary designs for the NWRB upgrades, effects were limited to local increases in the size of back-eddies forming downstream of the NWRB piers, particularly at NWRB Pier 6 (**Figures 4.1-A-7** through **4.1-A-12**; **Appendix 18.2 Hydraulic Modelling Report**, **Appendix A**, **Figures A3–A11**). The decrease in velocity downstream of NWRB piers is likely to lead to deposition.

The residual cumulative effect of the proposed NWRB upgrades is characterized as follows:

- **Context** for this effect is neutral: the Fraser River may or may not adjust to this deposition over time
- The **extent** of the effect is local: Expected changes to hydraulics and morphology are within the LSA
- **Magnitude** for most of this area: Considered moderate
- **Duration** of the increase is long term: It is expected to persist over the operational life of the proposed new bridge and the NWRB
- The effect is considered **reversible.** Removal of the piers at the end of the operating life of the new Pattullo Bridge and/or removal of the NWRB (or the upgrades) could eliminate the changes

- **Frequency** of the effect is regular: Bed levels will vary substantially with seasonal and tidal changes, but the increase is expected to recur regularly
- **Likelihood** of the cumulative effect: Moderately likely

Further assessment of the proposed NWRB upgrades is recommended once the detailed designs for the Project piers and the NWRB upgrade are substantially complete. The CFD model was developed for the purpose of assessing changes due to the placement of new bridge piers; a finer local mesh may be required to fully examine the local near-field effects of the NWRB upgrades.

### 4.1.7 Follow-up Strategy

Regular scour monitoring is recommended, incorporating an assessment of cumulative changes to River Hydraulics and Morphology due to the NWRB upgrades. Distinguishing the effects of the Project from those of the NWRB upgrade and the cumulative effects of the two may be difficult or impossible. Future modelling assessment of the cumulative effects, based on the detailed designs for the Project and NWRB upgrades, can be used to compare with surveyed bed elevation changes to evaluate the accuracy of the original effects prediction and the effectiveness of proposed mitigation measures.

### 4.1.8 Conclusions

The following measures are proposed to mitigate potential effects of the project:

- Scour protection upgrades at the existing Pattullo Bridge and NWRB
- Aligning piers on the new bridge with the river flow

Scour protection upgrades at Pattullo Bridge and NWRB will be required to mitigate expected local scour at the existing bridge piers caused by the Reference Concept piers. It may also reduce the extent and/or magnitude of downstream sediment deposition. Aligning the new piers with river flow could reduce the effects on current velocities, local scour, and downstream sediment deposition.

The modelling undertaken indicates a potential for the following residual effects to River Hydraulics and Morphology:

- The Project is not expected to result in any significant changes to average velocities in the navigation channels.
- Velocities are expected to be reduced downstream of the South Tower, and to a lesser extent, downstream of the North Tower.
- Velocities are expected to increase by less than 0.5 m/s between the South Tower and Pier S0.
- Flow splits at Sapperton Bar, Pattullo Bridge, and the New Westminster Trifurcation are not expected to change due to the Project.
- No significant changes to water levels are expected to result from the Project.
- Increases in the riverbed levels of up to 1 m may be experienced along the south margin of the main navigation channel, potentially extending a small way into the navigation channel.

- Increases in riverbed levels of up to 3 m during the Construction Phase and up to 5 m during the Operations Phase are expected downstream of the South Tower outside the southern border of the main navigational channel.
- Increases in the riverbed levels of approximately 0.5 m are expected in the southern part of the main navigation channel downstream of the Trifurcation. A similar degree of bed lowering is also expected across the channel.
- Bed lowering is expected between Pattullo Piers 5 and 6, on the order of 1 m. The spatial extents of this lowering are expected to decrease during the Operations Phase.
- Cumulative effects with the NWRB are possible and could include decreased velocities and increased sediment deposition downstream of the NWRB piers.

## 4.1.9 References

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Kwikwetlem First Nation Traditional Knowledge and Cultural Heritage Interests Relating to the Pattullo Bridge Rehabilitation Project, July 2017.

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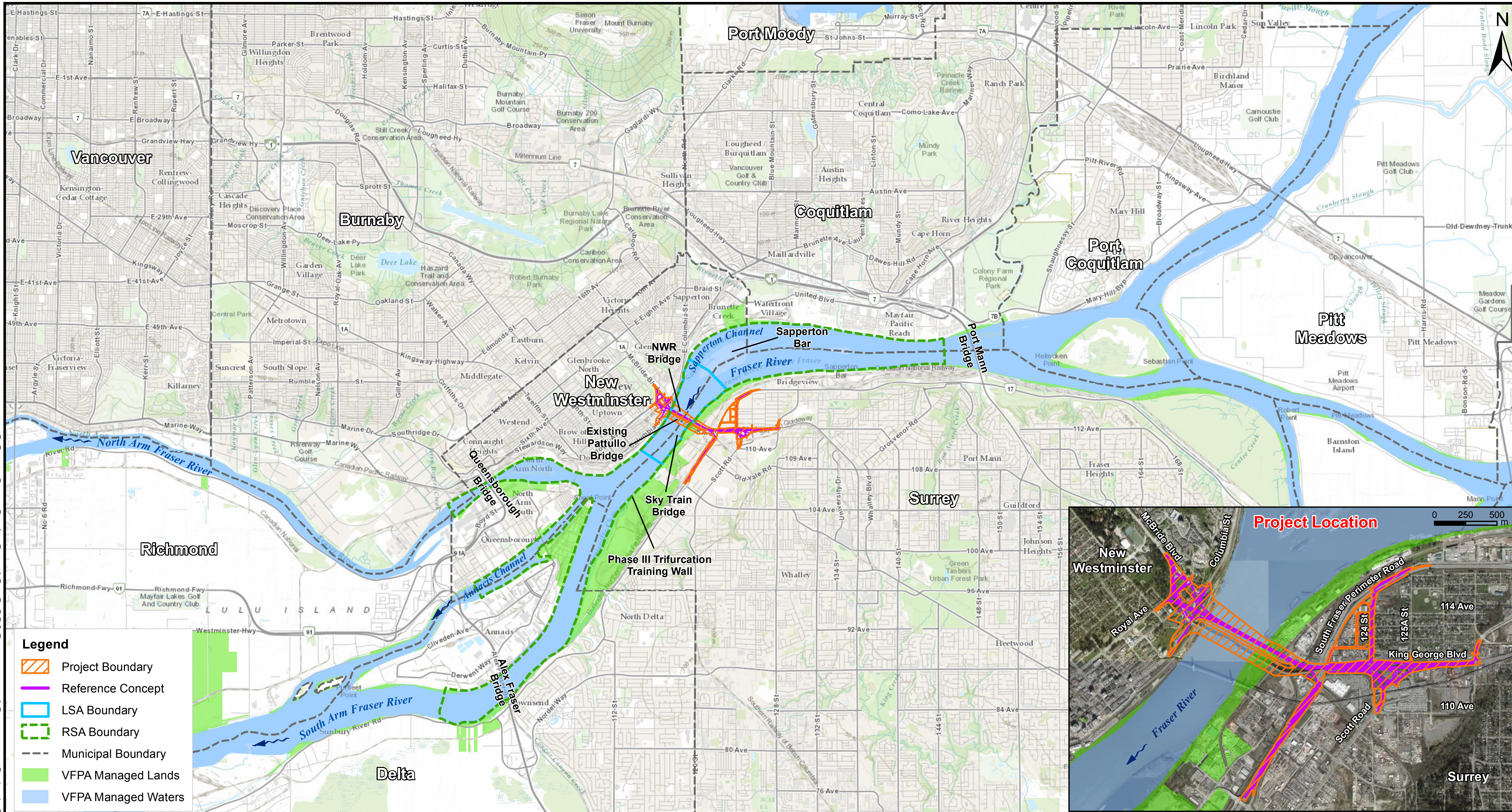
# ATTACHMENTS

# Attachment 4.1-A

# Figures

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| CHECKED | | | | | |
| APPROVAL | | | | | |

**REFERENCE DRAWING**

| NO. | DESCRIPTION |
|---|---|
| 1 | Reference Concept, Parsons 2018. |

British Columbia — Ministry of Transportation and Infrastructure

Hatfield Consultants

**Proposed Pattullo Bridge Replacement Project**

**Fraser River Hydraulics and River Morphology - Overview of the Study Area**

**Contract No. 0906-14/SC001110CA**

| SCALE | FIGURE NO. | REV NO. |
|---|---|---|
| 1:75,000 (0 1 2 Km) | 4.1-A-1 | 3 |

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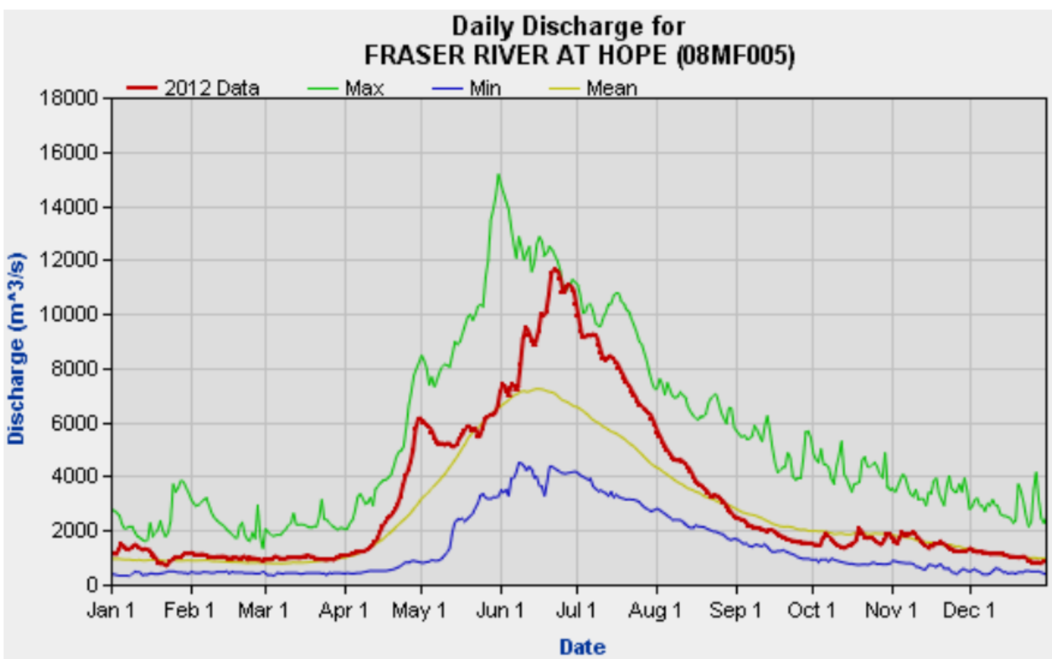
## Figure 4.1-A-2 ADCP Transects Collected 15 June 2016. Paired Transects are Designated by Colour

## Figure 4.1-A-3 Sediment Sample Locations

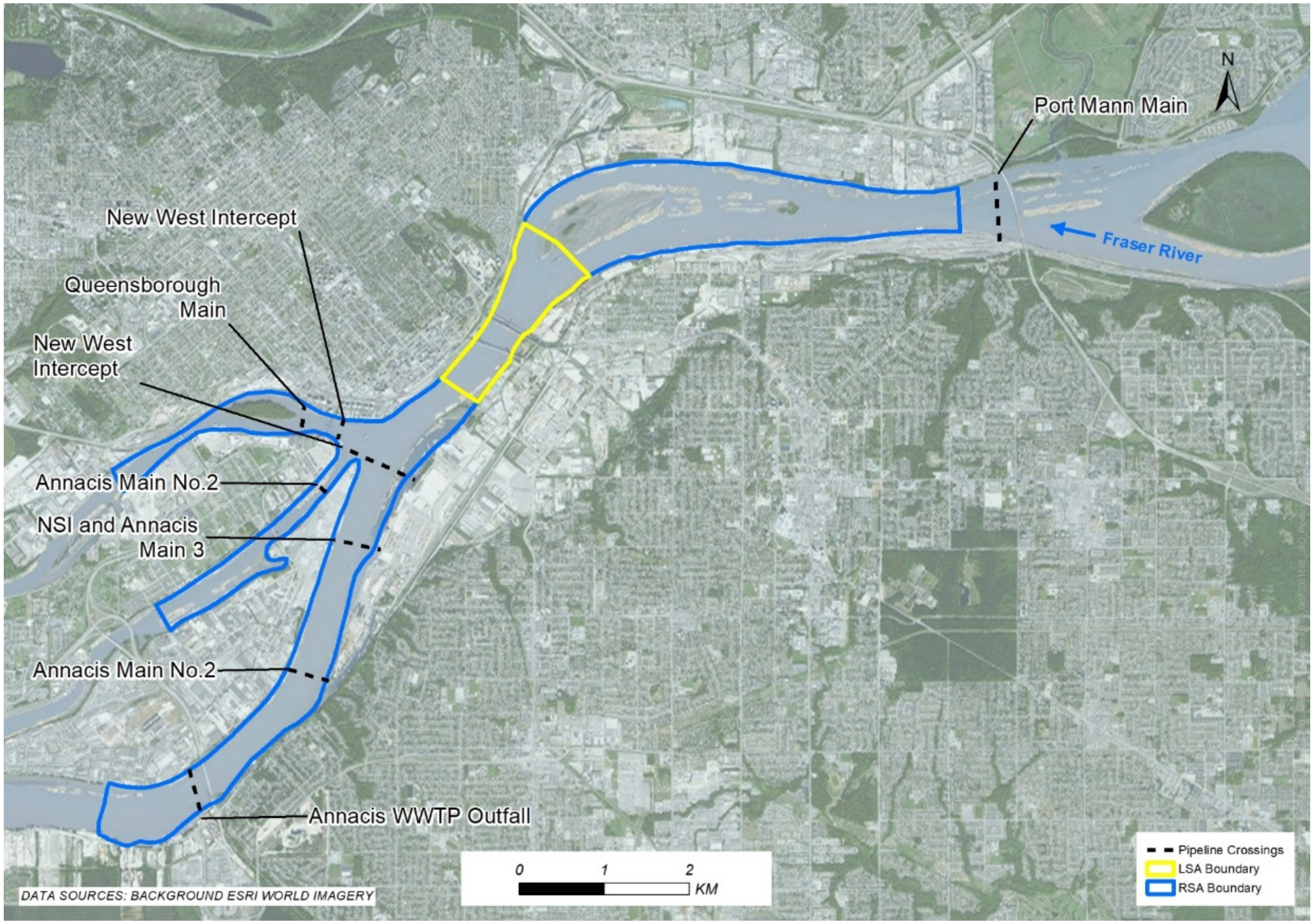
## Figure 4.1-A-4 Piers of the Skytrain Bridge, Pattullo Bridge, New Westminster Rail Bridge, and Proposed Replacement Bridge


## Figure 4.1-A-5 Annual Hydrograph for the Fraser River at Hope (from Water Survey of Canada)




Statistics corresponding to 101 years of data recorded from 1912 to 2012.*

## Figure 4.1-A-6 Pipeline Crossings in the RSA



## Figure 4.1-A-7 Depth-Averaged Velocities from the CFD Model for the 1894 Flood of Record

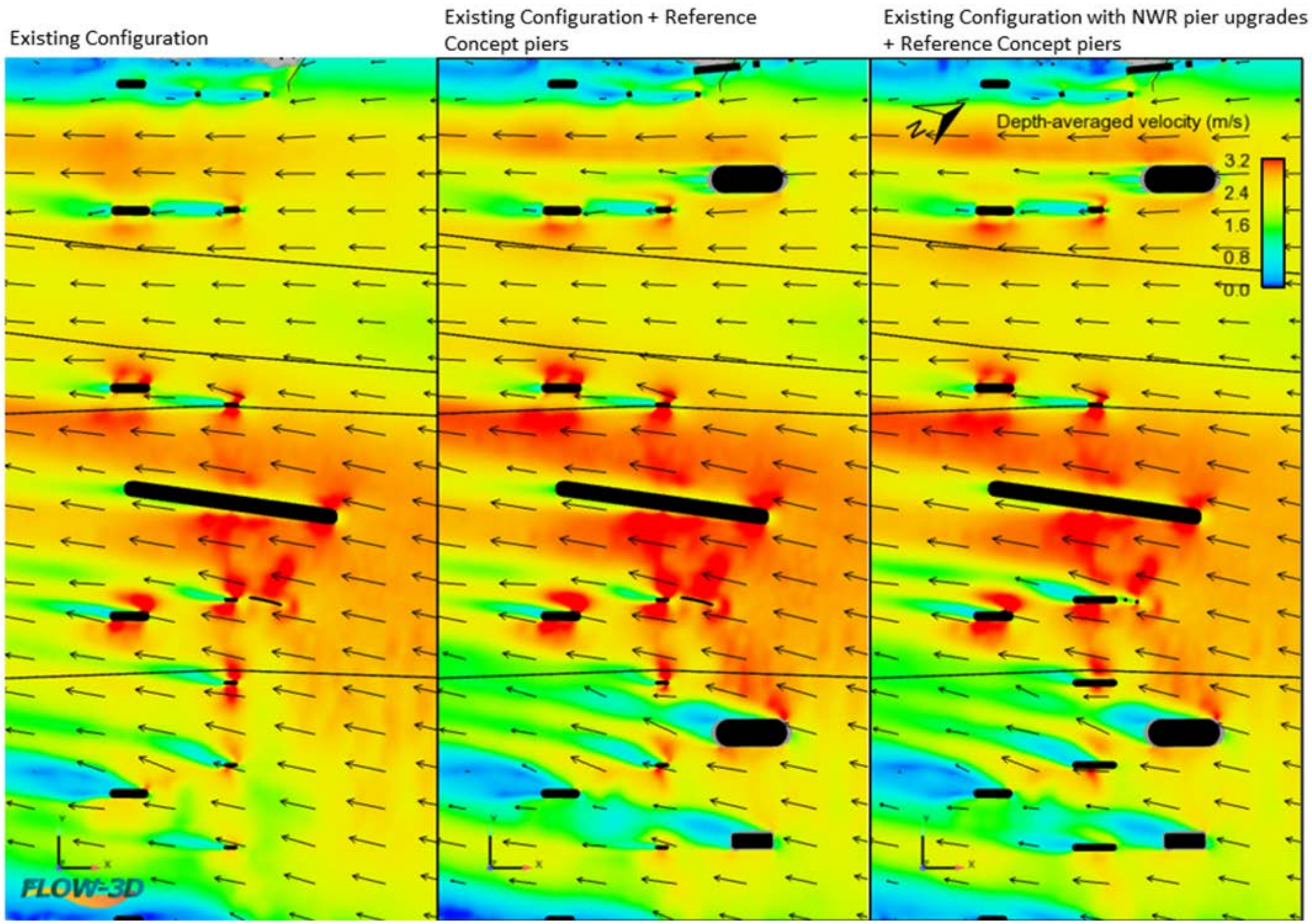
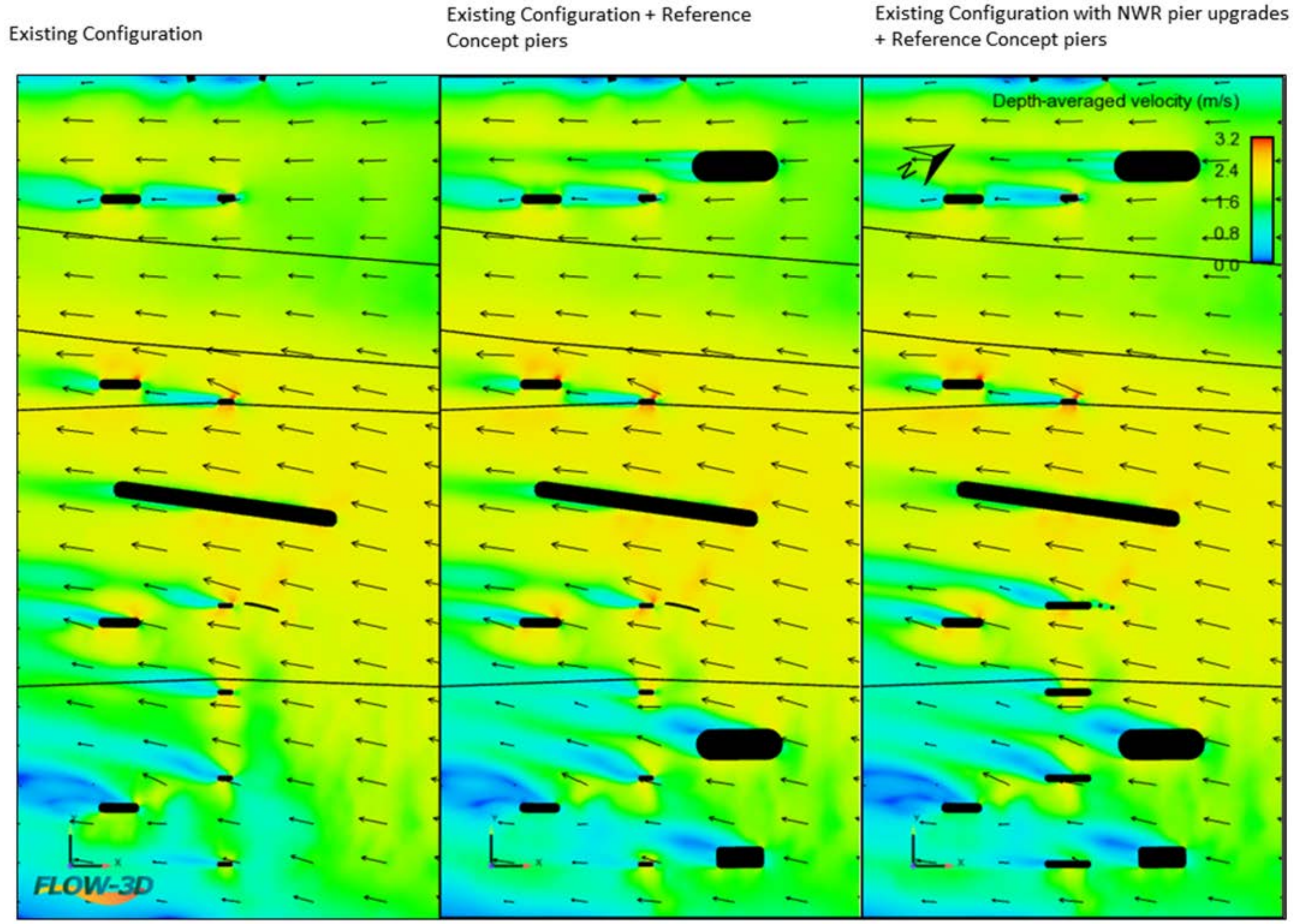


**Figure 4.1-A-8 Depth-averaged Velocities from the CFD Model for the Typical Freshet Flow**



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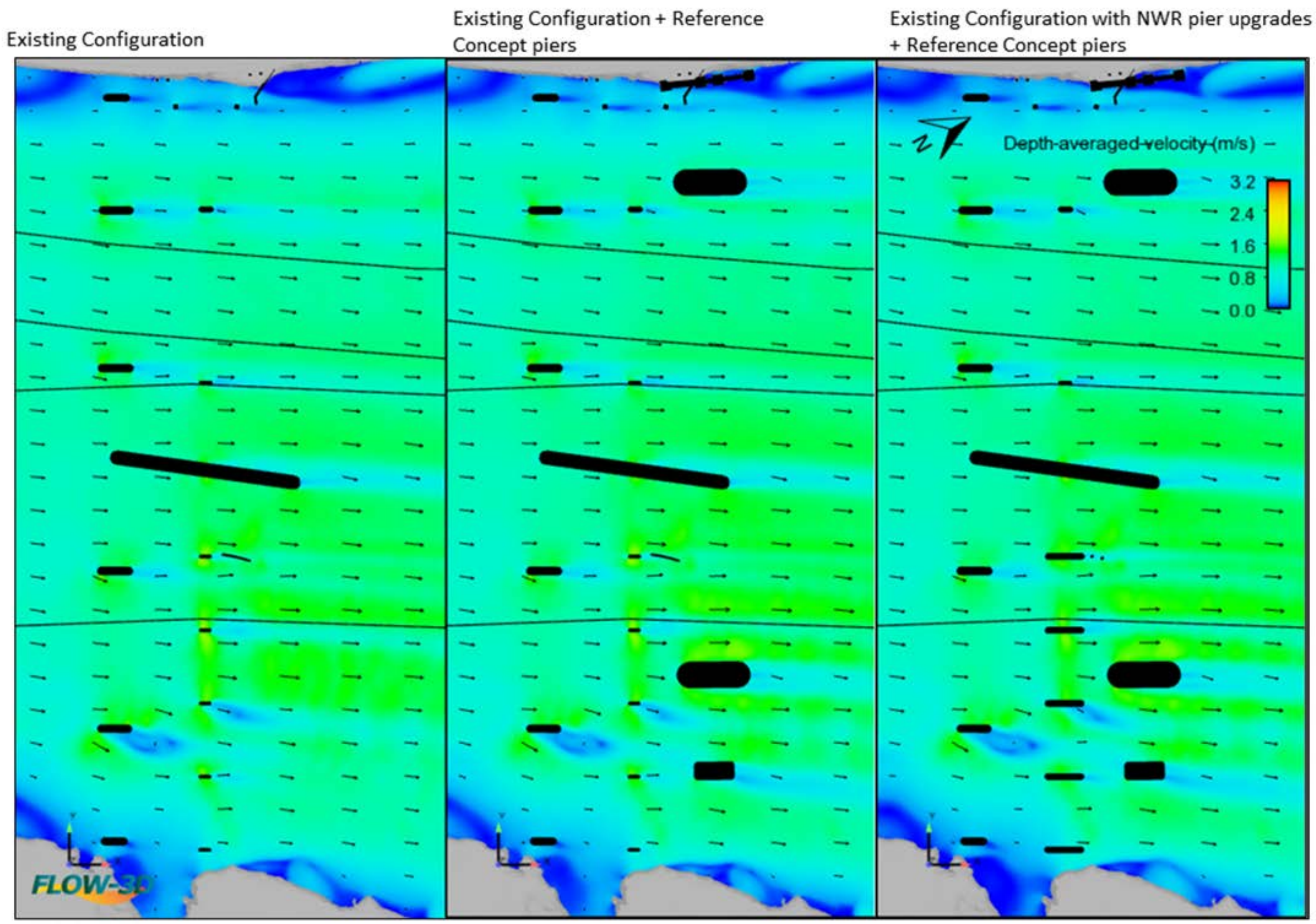
## Figure 4.1-A-9 Depth-averaged Velocities from the CFD Model for the Winter Flood Tide



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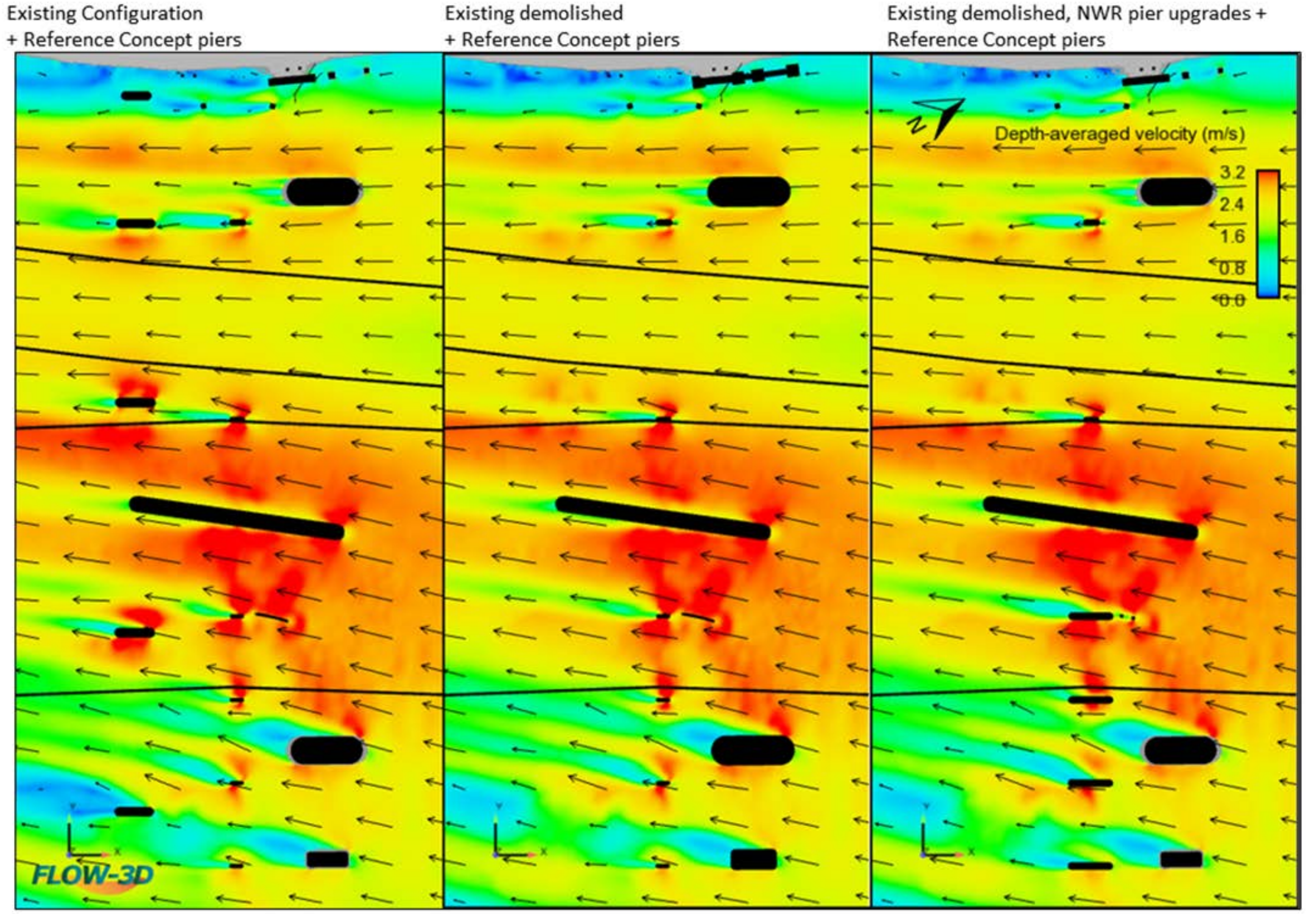
## Figure 4.1-A-10 Depth-averaged Velocities from the CFD Model for the Flood of Record, Including Post-decommissioning of Pattullo Bridge



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## Figure 4.1-A-11 Depth-averaged Velocities from the CFD Model for Typical Freshet Condition, Including Post-decommissioning of Pattullo Bridge

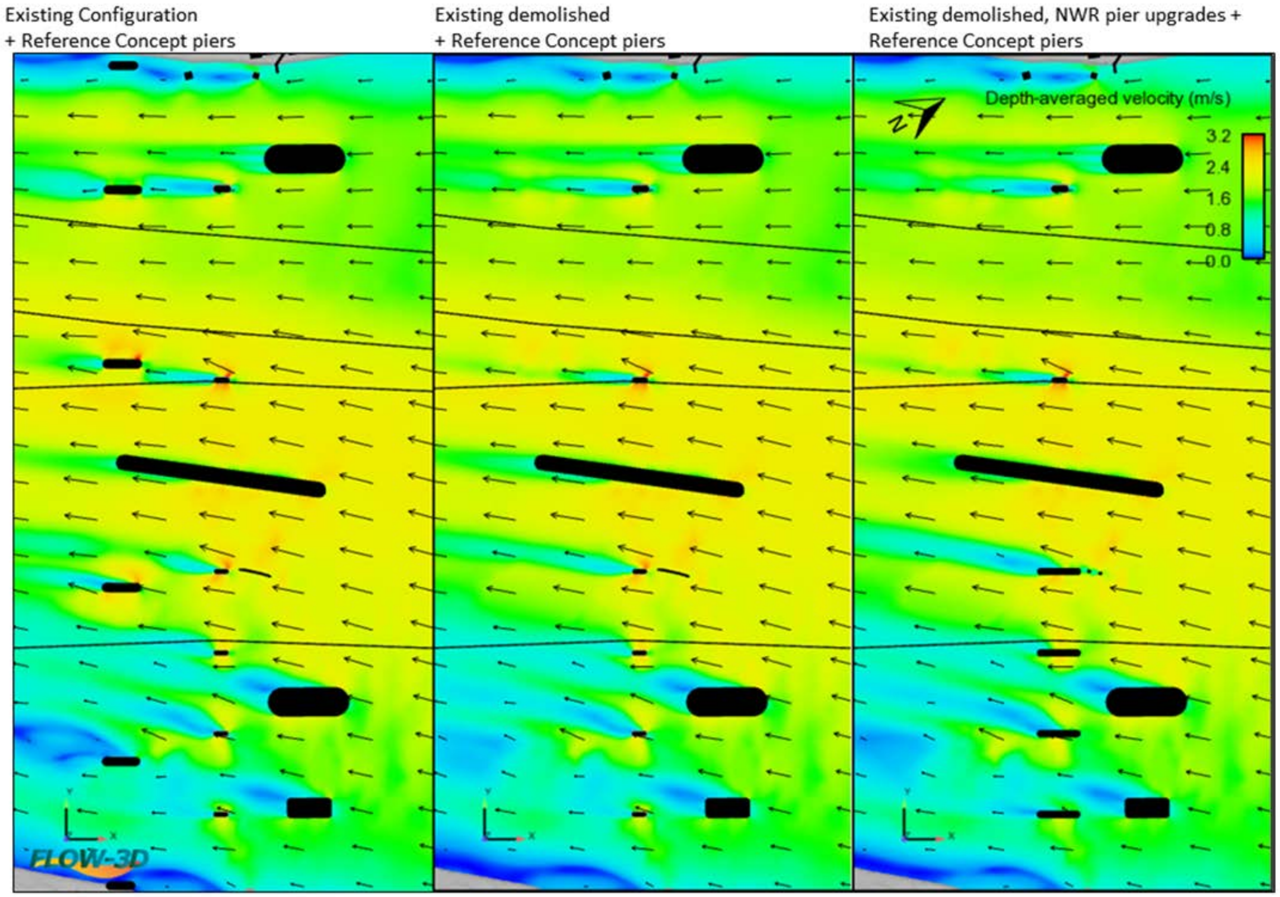
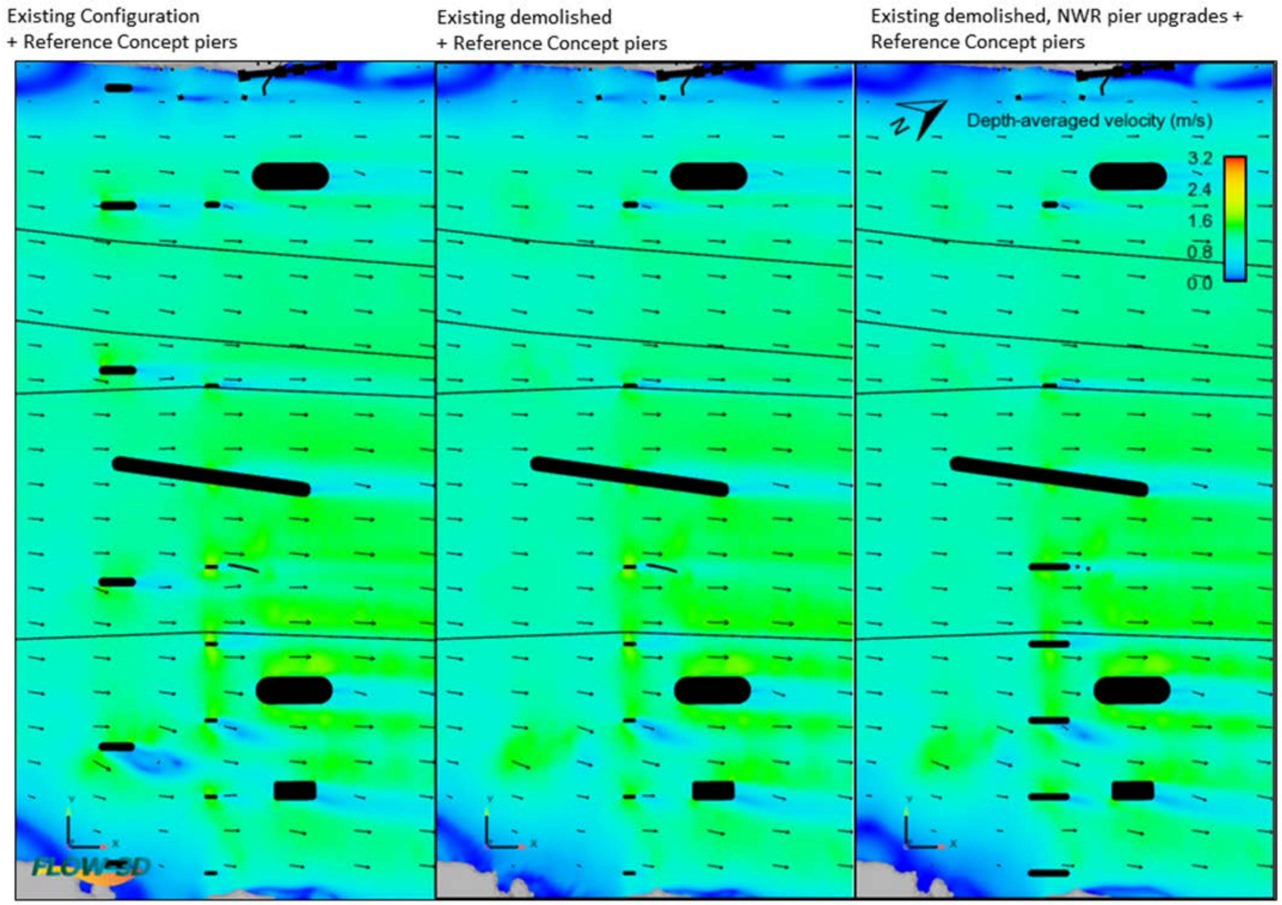


**Figure 4.1-A-12 Depth-averaged Velocities from the CFD Model for Winter Flood Tide Condition, Including Post-decommissioning of Pattullo Bridge**



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## Figure 4.1-A-13 Bed-difference Map – Reference Concept Minus Existing Conditions

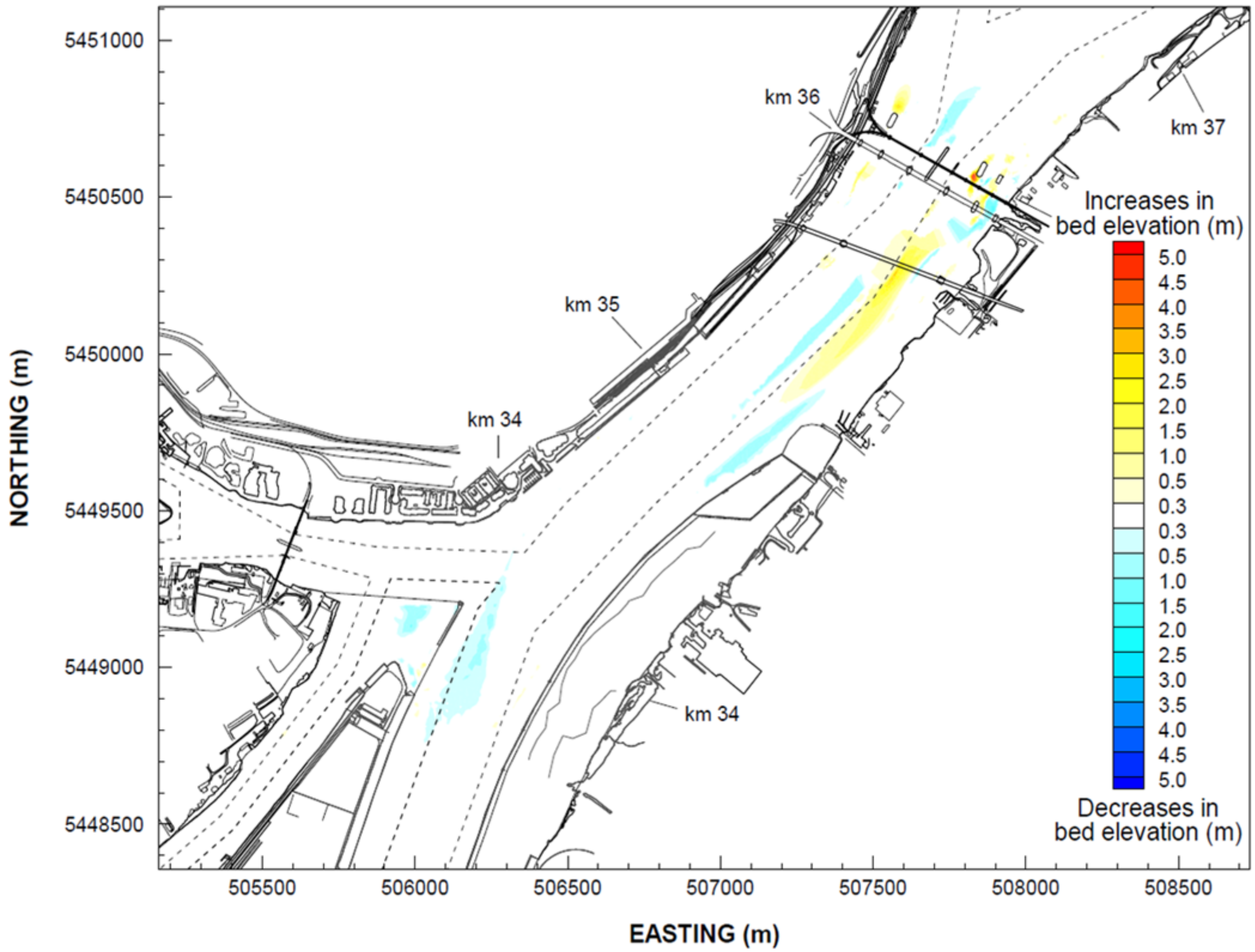
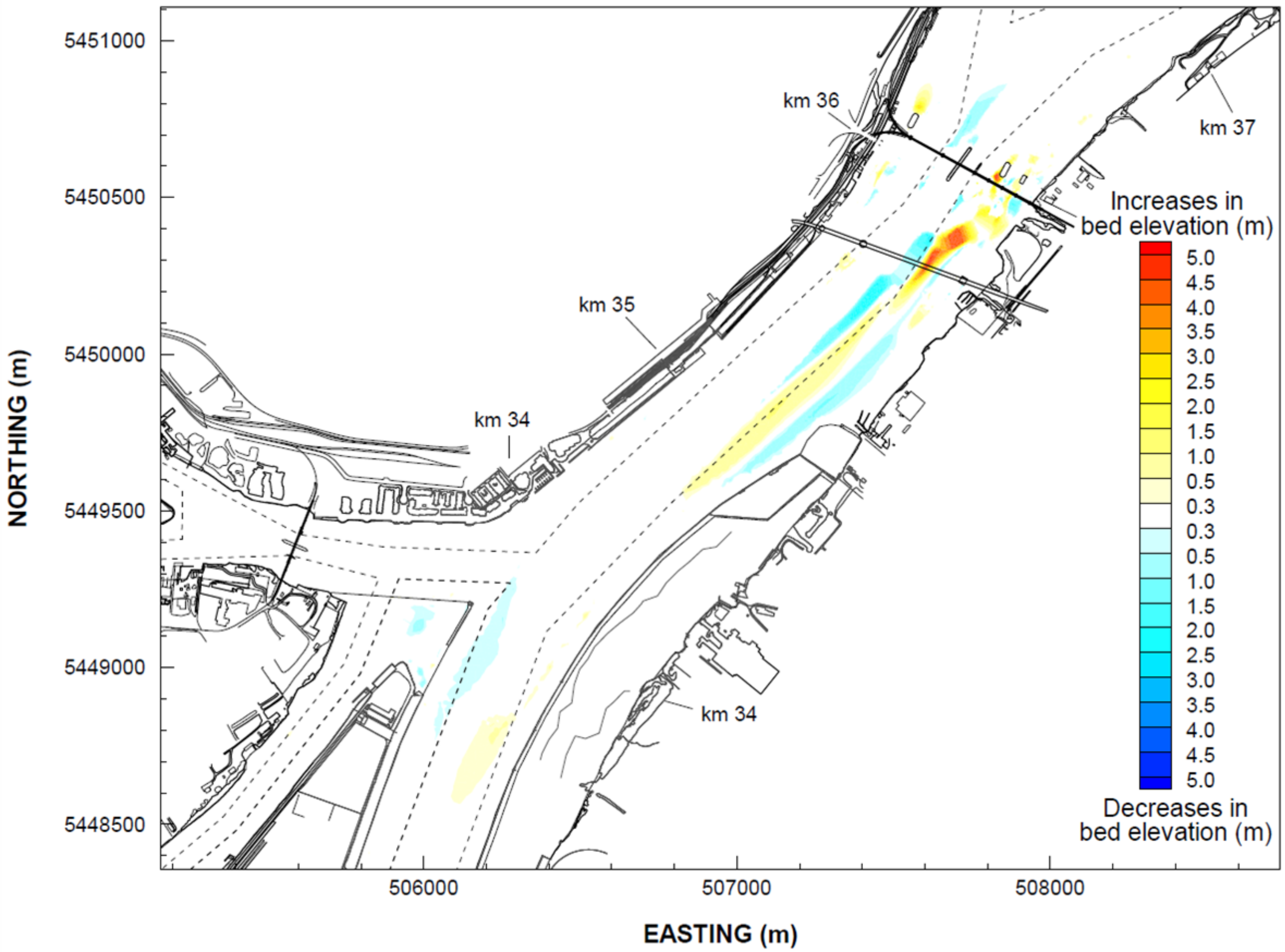
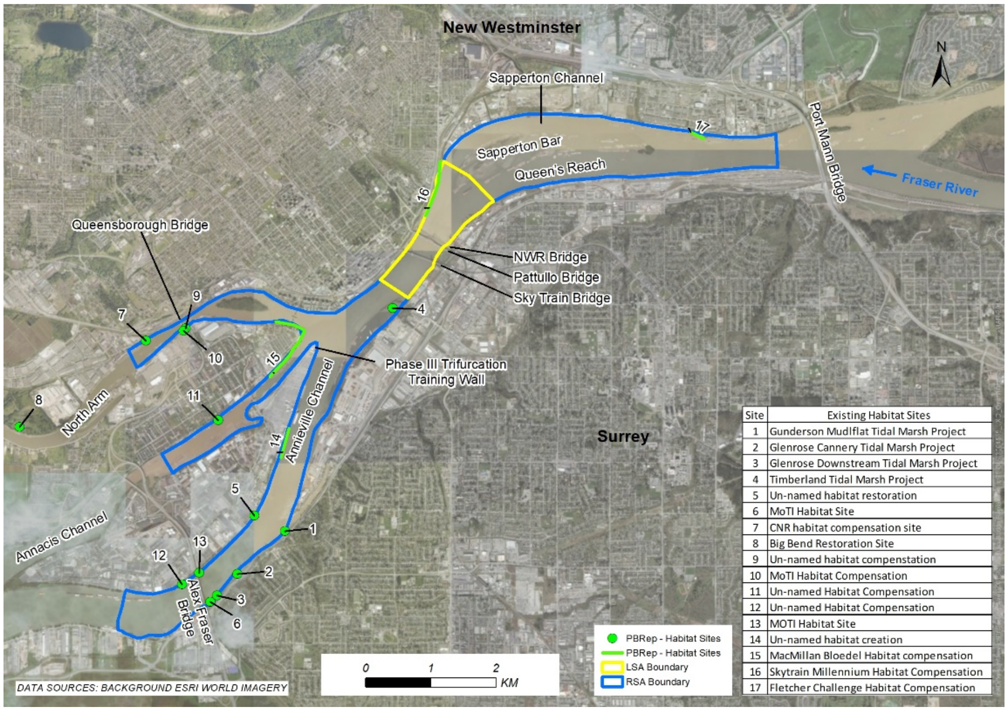


**Figure 4.1-A-14 Bed Difference Map – Decommissioning Scenario Minus Existing Conditions**



## Figure 4.1-A-15 In-river Habitat Sites with Potential to be Affected by the Project




## Figure 4.1-A-16 Reasonably Foreseeable Projects with Potential Cumulative Effects

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