Appendix IR2020-2.2-A

Stantec Memo: RBT2 Causeway Breach Technical Evaluation

Technical Memo

To: Valerie Spies, P.E.
Manager, Infrastructure Delivery, Technical

Vancouver Fraser Port Authority

2100 The Pointe, 999 Canada Place,
Vancouver, BC V6C 3T4

From: Kip Skabar, P.E., P.Eng., ENV SP
RBT2 Deputy Design Manager

Stantec Consulting Ltd.

1100 – 111 Dunsmuir Street,
Vancouver, BC V6B 6A3

File: 115815019

Date: August 24, 2021

Reference: **RBT2 Causeway Breach Conceptual Technical Evaluation**

INTRODUCTION:

In support of an Information Request (IR) from the Government of Canada to the Vancouver Fraser Port Authority (VFPA or Port Authority) regarding the Roberts Bank Terminal 2 (RBT2 or Project), VFPA has investigated the creation of a breach through the existing Roberts Bank causeway and proposed Widened Causeway, as part of the Project ("Causeway Breach"). The objective of a breach in the causeway is to mitigate potential Project-related disruptions to juvenile salmon movement and to provide a potential juvenile salmon enhancement opportunity.

Stantec has been commissioned by the Port Authority to complete a conceptual technical evaluation regarding the technical feasibility of designing and constructing a Causeway Breach. Functionally, this breach is to accommodate water flows which facilitate fish passage. This Technical Memo has been prepared to summarize this evaluation based on the following scope of work:

- Document the Project's technical requirements, Causeway Breach evaluation criteria, and assumptions ("Technical Parameters");
- Document potential Causeway Breach locations for technical evaluation;
- Identify and describe potential Causeway Breach structure design concepts;
- Provide a technical evaluation of potential Causeway Breach locations and design concepts based on the Technical Parameters;
- Provide a comparison of technically feasible, potential Causeway Breach locations and design concepts;
- Provide a high-level constructability review of those locations and design concepts which are deemed technically feasible; and,
- Provide a summary and conclusions of the findings from this technical evaluation.

TECHNICAL PARAMETERS:

Technical requirements for the Project are defined in the RBT2 Environmental Impact Statement (EIS) Basis of Design (BoD), as updated in 2018[1]. The BoD does not specifically address breach structures but refers to third party technical guidelines and standards for determining applicable design and construction criteria. The adopted hydrotechnical requirements for culvert and bridge structures supporting railway tracks or roadways are based on CN Rail (CN) guidelines[2] or BC Ministry of Transportation and Infrastructure (BC MoTI) standards, respectively.

As such, the Technical Parameters for this technical evaluation of Causeway Breach design and construction concepts include the following:

- Channel alignment shall breach both the existing Roberts Bank causeway and proposed Widened Causeway, connecting the intertidal areas to the north and south (identified with others[3]);
- Channel geometry and hydraulic conditions shall accommodate water flows which facilitate fish passage (determined by others[3]);
- Breach structures (e.g., bridges, culverts) shall accommodate FSLR;
- To promote juvenile salmon passage, daylight penetration through open deck bridge structures should be maximized, or alternatively, interior lighting for daytime illumination should be able to be provided in closed culvert structures;
- Railway track turnouts shall not be located on breach structures or be within 10 m of the breach perimeter to reduce potential railway operating safety risks, in accordance with industry guidelines and best practices;
- Breach structure surface elevations should closely match existing causeway road and track profiles to avoid local grade differentials, and where possible, maximize accommodation of FSLR through a breach;
- Breach alignment shall accommodate safe access and work around live railway traffic, roadway traffic, and other RBT2 construction activities;
- For the purpose of this technical evaluation, breach design concepts shall provide a suitable cross-sectional area defined by a minimum width for fish passage of 10 m (determined by others[3]) and maximum width as defined by safe clearances to surface infrastructure determined by industry standards, guidelines, and best practices, as well as applicable stakeholder(s) requirements. Channel bottom (invert) elevations at evaluated breach locations have also been provided by others[3];

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[1] CIAR Document #1210 From the Vancouver Fraser Port Authority to the Review Panel re: Project Construction Update. Attachment B1: Detailed Tabulated Summary of Changes to Basis of Design (Updated Appendix 4-A) https://www.ceaa-acee.gc.ca/050/documents/p80054/122934E.pdf

[2] General Requirements for Hydrology and Hydraulic Studies for CN Bridge / Culvert Construction Projects, CN Rail, December 2005

[3] Northwest Hydraulic Consultants, RBT2 Roberts Bank Causeway Breach Hydraulic and Geomorphic Assessments Results Report (Appendix IR2020-2.2-C)

- Based on CN guidelines and Stantec's experience on other CN railway bridge design projects, a minimum freeboard (clearance between design high water level, being FSLR, and the underside of a bridge span) allowance of 0.3 m has been assumed;
- CN guidelines for culvert designs recommend comprehensive hydrotechnical and environmental assessments which are not included nor available as part of this conceptual technical evaluation, and as such, potential breach locations and design concepts which carry railway tracks will require further technical evaluation if pursued;
- The roadway along the existing causeway has been assumed as a Rural Arterial Undivided (RAU) road, which is consistent with the BoD for RBT2. The BC MoTI minimum freeboard requirement for RAU roads is 1.0 m;
- BC MoTI follow a similar approach for designing culverts as CN, and as such, potential breach locations and design concepts which carry roadways will require further technical evaluation if pursued further;
- It is assumed construction of a Causeway Breach can be coordinated with the RBT2 overall construction schedule; and,
- Due to not having inputs from existing Terminal Operators and other transportation operations stakeholders at this time, the high-level constructability review has assumed some of the existing Westshore and Deltaport railway tracks can be out of service for extended periods of time (i.e., days or weeks).

This conceptual technical evaluation is based on a 5% level of engineering effort and currently available information. Progression of any technically feasible potential breach locations and design concepts identified from this evaluation will require further engineering analysis and evaluation, which may alter these conclusions regarding technical feasibility.

POTENTIAL CAUSEWAY BREACH LOCATIONS:

Three potential Causeway Breach locations have been identified with others (described by NHC[3]) and technically evaluated by Stantec. Refer to **Appendix A** for a Plan view of the existing causeway and Widened Causeway, identifying these three locations.

- **Location 1** is between the proposed RBT2 DPU (locomotive) setout yard and T-Yard. It was considered because it would allow a shorter overall breach length. This site is in an area along the existing causeway which has a lower surface grade that is relatively close to the level of FSLR. **Appendix B** provides a Plan view of the **Location 1** breach alignment.
- **Location 2** is towards the east end of the RBT2 T-Yard. This site was considered due to its desirable lower intertidal zone location, which would allow for a lower channel invert elevation. A lower invert elevation allows a breach to be inundated for longer periods of time during tidal exchanges. Similar to **Location 1**, **Location 2** is also in an area along the existing causeway which has a lower surface grade that is relatively close to the level of FSLR.
- **Location 3** is towards the west end of the RBT2 T-Yard. Being the most seaward of the three potential Causeway Breach locations, it has the lowest channel invert elevation. This location also has the fewest crossings of existing causeway tracks and its relatively higher surface grade means it is better situated to accommodate FSLR. **Appendix C** provides a Plan view of the **Location 3** breach alignment.

EVALUATION OF BREACH CONCEPTS:

Two breach design concepts at each potential location were considered as part of this technical evaluation:

1) Open deck bridge spans
2) Illuminated precast concrete box culverts

These design concepts were developed in parallel with the hydraulic assessment and while some exceed the minimum width criteria, they can be used for evaluation. A discussion on the technical feasibility of each design concept is provided below.

Open Deck Bridge Spans

The Technical Parameters for minimum freeboard set a minimum elevation for the underside of the bridge spans (bottom chord elevation), relative to existing grade elevations. Further, high railway loadings on railway structures require relatively deep girder sections, resulting in a lower bottom chord elevation relative to existing grade. Operational needs require the top of the bridge structures to closely match the existing causeway roadway and railway grades. For a bridge concept to be technically feasible, the bridge superstructure must be able to be designed with the required freeboard.

Two standard open deck steel railway bridge superstructures were considered as part of this technical evaluation. The first involves a steel Through Plate Girder, consisting of deeper longitudinal girders with an internal steel floor system which directly supports the track, as illustrated in **Figure #1**. As the floor system supports the track, deeper girder sections extend above and below the level of the track. This configuration will preclude the ability to accommodate variable track spacing along the existing causeway. Further, as the girders are located outside the track width, this superstructure would be too wide to accommodate existing track spacing. Therefore, this structural configuration was not considered technically feasible for a design concept. The second involves a steel Beam Span, consisting of multiple, closely spaced, steel beams with the track fastened to the top flange, as illustrated in **Figure #2**. This type of structure allows for flexibility in accommodating variable track spacings and alignment alterations are unimpeded.

Precast concrete box girders were also considered but not pursued further as their need to be ballasted would require a structural depth below the track that is much deeper than a steel Beam Span. As such, an open deck steel Beam Span was considered the most appropriate bridge design concept for this technical evaluation.

Figure #1 – Typical Steel Open Deck Through Plate Girder Bridge

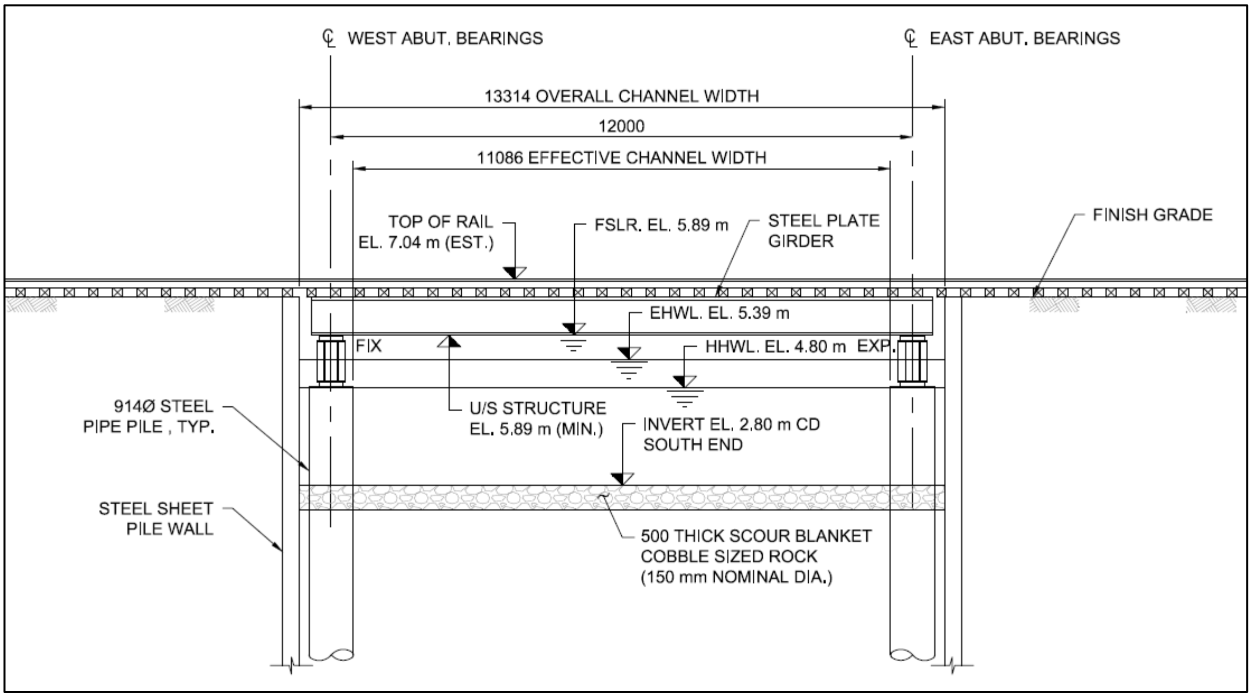


Figure #2 – Location 3 Channel Section (Bridge) Below Existing Causeway Tracks

Based on the Technical Parameters, at **Locations 1 and 2,** FSLR would be above the bottom chord elevation of these steel Beam Spans. Further, for **Location 3**, though the steel spans would be above FSLR, neither the roadway bridge nor railway bridge spans will have sufficient freeboard (as illustrated in **Figure #2** above for the railway bridge span). As such, a bridge span design concept is not technically feasible at any of the three potential breach locations.

Illuminated Precast Concrete Box Culverts

To meet the Technical Parameters while accommodating the imposed railway and roadway live loadings, two double precast concrete box culvert sections would be required. Supporting foundations would also be required; for example, a steel grillage that is cast in place with lean mix concrete, on top of a compacted granular base. Precast concrete segments will need to be longitudinally post-tensioned to ensure proper fit and to avoid separation of adjacent segments. A geotechnical evaluation will need to be completed if this design concept is pursued further to validate proposed foundations and evaluate potential settlements, including differential settlements between the existing and Widened Causeway. Daytime illumination would be provided with semi-submersible fixtures and wiring mounted to the surface of the culvert ceiling.

At **Locations 1 and 2**, the existing causeway grade is lower than the proposed RBT2 design grade, whereas the existing causeway grade at **Location 3** is relatively close to the proposed RBT2 design grade. The elevation of the top of culvert is governed by the lower existing causeway grade. **Figure #3** illustrates a typical culvert section at the existing causeway track at **Locations 1 and 2**, however, elevations shown are for **Location 1** only. At these locations, FSLR will be above the top of the culvert, and relatively close to the top of the existing causeway grade. Potential risks to the track structure due to FSLR should be evaluated if Location 1 or 2 are pursued further. Under extreme high water level (EHWL) conditions, these culverts would flow full.

Though not part of this technical evaluation, scour protection at channel entrances will need to be considered if a breach concept is pursued further[3].

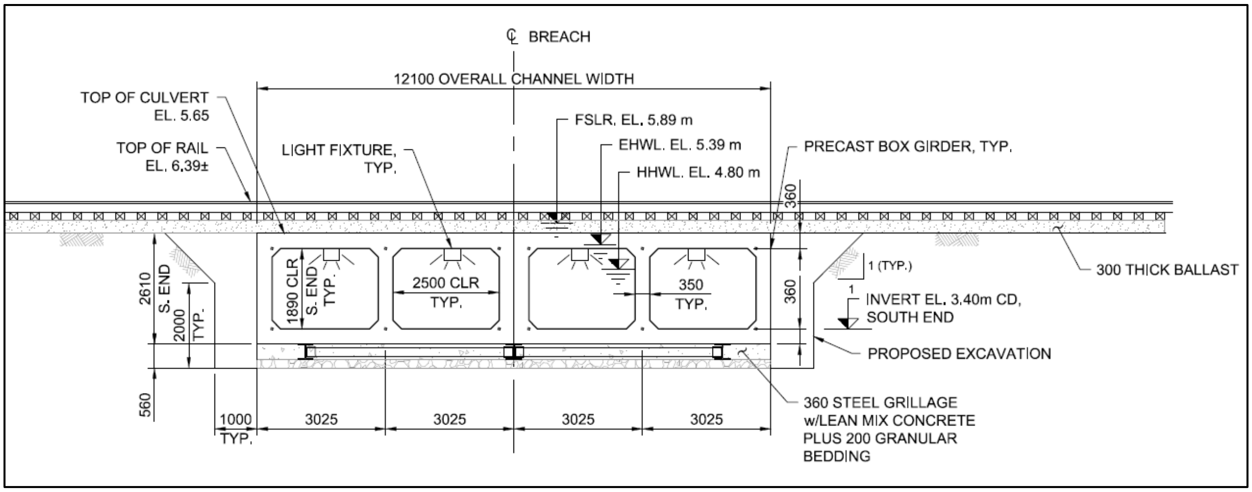


Figure #3 – Typical Location 1 & 2 Channel Section Below Existing Causeway Tracks (Location 1 shown)

Figure #4 illustrates a typical culvert section at existing causeway tracks for **Location 3**. At this location, FSLR is accommodated below the top of the culvert.

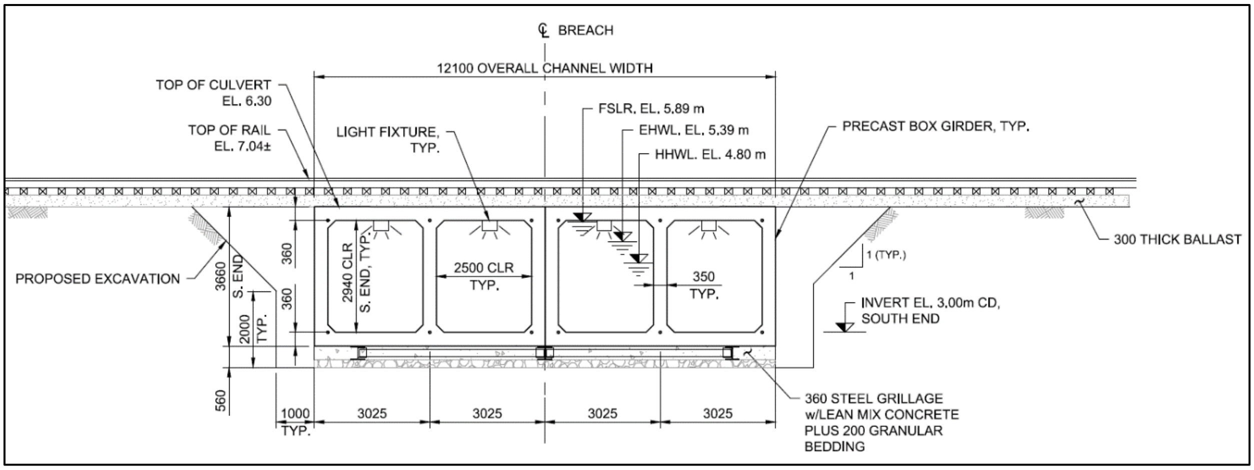


Figure #4 – Location 3 Channel Section (Culvert) Below Existing Causeway Tracks

Based on this conceptual technical evaluation, an illuminated, precast concrete box culvert is considered technically feasible from an engineering design perspective at all three potential breach locations. Although, not all technically feasible concepts and locations are equal; **Location 3** provides a deeper channel, due to its lower invert, and a higher top of culvert elevation, due to the relatively close elevations of the existing causeway and the proposed RBT2 grades, thus providing better accommodation for FSLR with reduced risk to both culvert and track structures from potential future flooding conditions along the existing causeway.

BREACH CONSTRUCTABILITY EVALUATION:

Constructability of a precast concrete box culvert was evaluated at a high-level to help determine if this design concept is also technically feasible to construct. Overall, constructing a precast concrete box culvert breach across two operational railway yards would be very complex. Apart from significant terminal and transportation operational considerations, complicating matters include accommodation of existing and future underground utilities, as well as the fact that much of the land required for a breach is not owned by, or under the control of, the Port Authority. Significant consultation and coordination with stakeholders and third parties (e.g., Terminal Operators, Railway Service Providers [CN, CP, BNSF, TTR, BlueShore], Shipping Companies), Indigenous groups, as well as with the land and infrastructure owners would be essential to the development of an approved construction program. This engagement should begin as soon as practical to help validate the Technical Parameters related to constructability, if a breach concept is pursued further.

Construction activities related to installation of precast concrete box culverts would conceivably involve the following:

- Mobilization of labour, materials, and equipment;
- Construction of temporary berms along the south side of the existing causeway and north side of the proposed Widened Causeway landmasses to allow culvert construction in the 'dry';
- Detouring existing roadways and tracks (by stage);
- Excavation of the breach opening;
- Installation of the culvert foundation (i.e., steel grillage and concrete fill);
- Installation of precast concrete segments and post-tensioning of adjacent segments;
- Backfilling of installed precast concrete segments;
- Returning existing roadways and tracks to original configuration and removing detours (by stage); and,
- Removal of temporary berms.

There are many variables and constraints that impact construction of a potential breach which are not easy to define at this stage of concept development. The primary construction challenge results from the need to maintain rail and road access to the existing terminals while precast concrete box culvert sections are installed. Staged construction would be required in order to minimize disruptions to existing terminal roadway and railway operations. The existing roadway could be accommodated in two stages, while track detours would require multiple stages, balancing workable construction space with geometric track alignment constraints and rail terminal operational requirements.

As highlighted in **Appendices B and C**, there are more track crossings of a potential breach at **Location 1** (and similarly at **Location 2**) than **Location 3**. **Location 3** provides the fewest track crossings, the greatest amount of space for construction activities, and likely the fewest number of stages while accommodating ongoing operations. Overall, of the three potential breach locations, **Location 3** is understood to potentially provide a more efficient and safer working environment during construction. Note any relaxation of railway operational constraints regarding track closures would benefit constructability, although this cannot be reasonably evaluated until applicable consultation is complete.

Based on this conceptual technical evaluation, an illuminated, precast concrete box culvert at any of the three potential breach locations could be considered technically feasible to construct assuming suitable arrangements with the parties defined above could be achieved. However, **Location 3** provides better accommodation for construction activities, with reduced impact to existing terminal and transportation operations. Although **Location 3** is considered the least disruptive to existing operations, it should be noted these impacts are still expected to be substantial, even after being minimized by staging construction work.

SUMMARY AND CONCLUSIONS:

Our conceptual technical evaluation of constructible engineering concepts, to create a Causeway Breach that accommodates water flows which facilitate fish passage, indicates that an illuminated, precast concrete box culvert is the only technically feasible design concept which is compliant with the Technical Parameters. At this stage of conceptual design, and without inputs from existing Terminal Operators and transportation operations stakeholders, it could be considered technically feasible to construct a culvert structure at any of the three potential breach locations. This conclusion is based on the allowance of some track closures over extended periods of time (days and weeks). Resulting impacts to existing terminal and transportation operations could be significant, especially at **Locations 1** and **2,** due to limited space to facilitate safe construction activities. **Location 3** provides the following advantages:

- A deeper channel, which is more conducive to facilitating fish passage, due to its lower invert elevation;
- A higher top of culvert elevation to better accommodate FSLR due to the relatively close elevations of the existing causeway and the proposed RBT2 grades;
- Better accommodation of construction access and activities leading to improved efficiency and safety; and,
- **Reduced impact to existing terminal and transportation operations with fewer existing track crossings.**

Further engineering is required to confirm the Technical Parameters to validate technical feasibility of design concepts and constructability at these potential locations. This additional engineering analysis may alter these conclusions regarding technical feasibility. In accordance with standard practices, this work should include, as a minimum:

- A detailed hydrotechnical analysis and evaluation in accordance with CN guidelines, including industry standard modeling to assess water elevations, waves, flows, velocities, minimum opening requirements (height and width), capacity, and flooding potential. It should also include environmental considerations such as fish passage, sedimentation, debris accumulation, and scour protection;
- A geotechnical evaluation assessing existing foundation conditions as well as, estimates of potential settlement, differential settlement, and settlement mitigation strategies;
- A seismic analysis of the design concept structures;
- Confirmation and accommodation of existing, proposed, and potential future utilities;
- Confirmation of illumination criteria suitable to facilitate fish movement;
- A detailed constructability assessment, including construction staging and temporary works design;
- Assessment of potential flood risks along the existing causeway due to relatively low existing grades and high FSLR elevation, including evaluation of potential mitigation measures; and,
- Identification of inspection and maintenance requirements.

To advance any of these design concepts and locations, consultation will be required with stakeholders and third parties as identified herein, as well as with Indigenous groups and Government Regulators.

DISCLAIMER:

This document entitled RBT2 Causeway Breach Conceptual Technical Evaluation was prepared by Stantec Consulting Ltd. ("Stantec") as subconsultant to Moffatt & Nichol ("M&N"), together providing services as the Owner's Engineer (the "OE"), for the account of the Vancouver Fraser Port Authority (the "Client"). Any reliance on this document by any third party is strictly prohibited. The material in it reflects Stantec's professional judgment in light of the scope, schedule, and other limitations stated in the document and in the contract between the OE and the Client. The opinions in the document are based on conditions and information existing at the time the document was published and do not take into account any subsequent changes. In preparing the document, Stantec did not verify information supplied to it by others (e.g., hydraulic analysis of breach concepts[3]). Any use which a third party makes of this document is the responsibility of such third party. Such third party agrees that Stantec shall not be responsible for costs or damages of any kind, if any, suffered by it or any other third party as a result of decisions made or actions taken based on this document.

CLOSING:

We trust this Technical Memo provides the Port Authority with the information required to move ahead with any future decisions regarding this initiative. Should you have any questions or comments, please contact us at your earliest convenience.

Regards,

STANTEC CONSULTING LTD.

Prepared by:

Richard Lanyi, P. Eng.
RBT2 OE Rail Lead
Phone: (780) 917-7119
richard.lanyi@stantec.com

Reviewed by:

Glenn McIntyre, E.I.T., ENV SP
Assistant Project Manager
Phone: (604) 696-8264
glenn.mcintyre@stantec.com

Approved by:

Kip Skabar, PE, P.Eng., ENV SP
RBT2 Deputy Design Manager
Phone: (604) 363-1690
kip.skabar@stantec.com

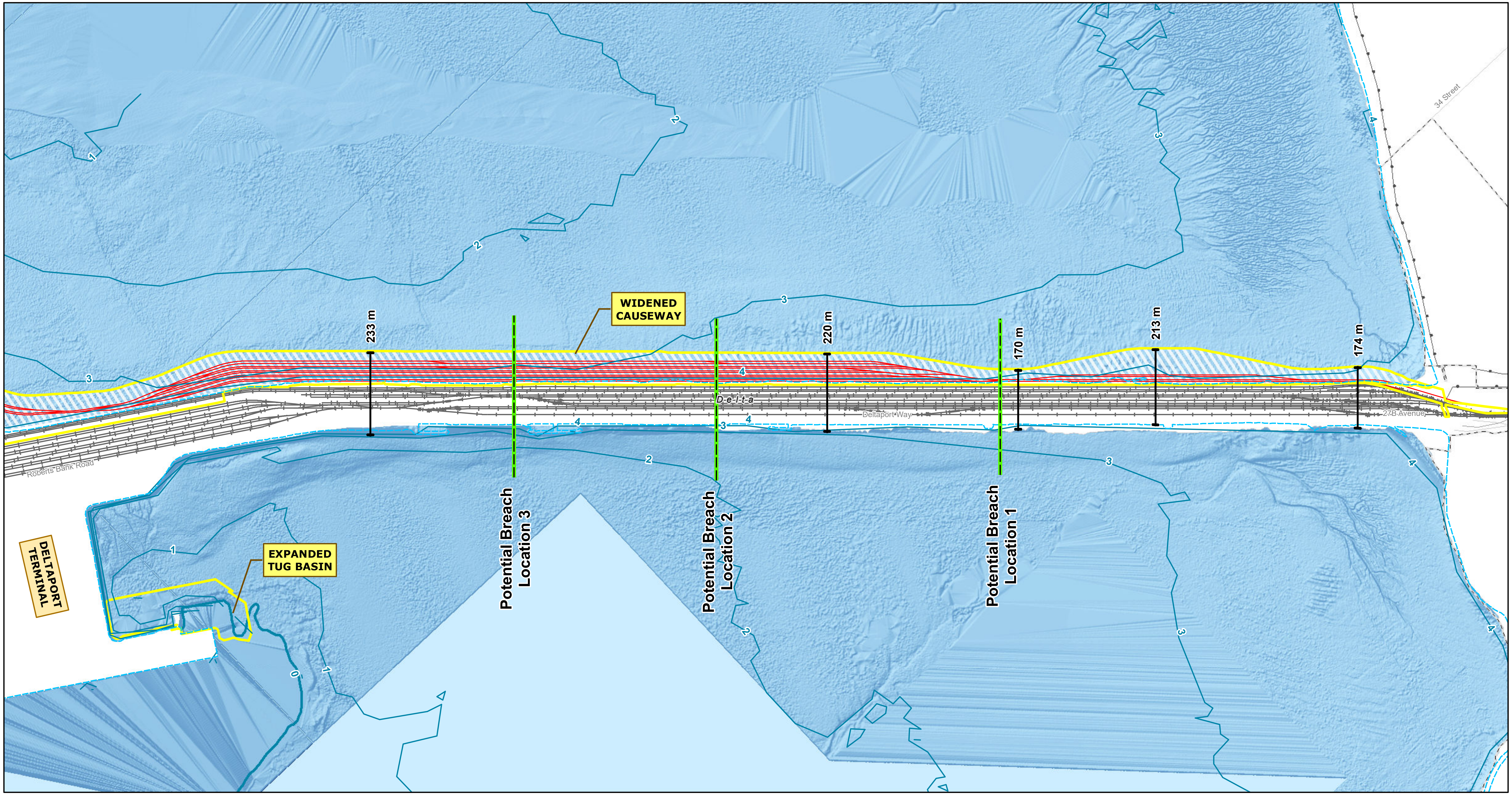
Attachments:

1. Appendix A – Potential Causeway Breach Location Plan
2. Appendix B – Location 1 Plan
3. Appendix C – Location 3 Plan

cc. Michael Cho, Moffatt & Nichol

APPENDIX A

Potential Causeway Breach Location Plan



Legend

- ▭ BOUNDARY OF PROJECT AREA
- ├─┤ WIDTH DIMENSIONS
- ╌ POTENTIAL CAUSEWAY BREACH CENTRELINE
- ╌ HIGH WATER MARK (2015)
- ─ BATHYMETRIC CONTOUR (METRES)
- ─ PROPOSED RBT2 RAIL
- ┼ EXISTING RAIL

Notes:
1. Accuracy of existing conditions has not been verified by Stantec

0 100 200 400
Meters
1:10,000
NAD 1983 UTM Zone 10N

PROJECT COMPONENT

EXISTING LANDMARK

PORT of vancouver

ROBERTS BANK TERMINAL 2

POTENTIAL CAUSEWAY BREACH LOCATIONS

DATE: 03/30/2021

FIG No. 1

APPENDIX B

Location 1 Plan

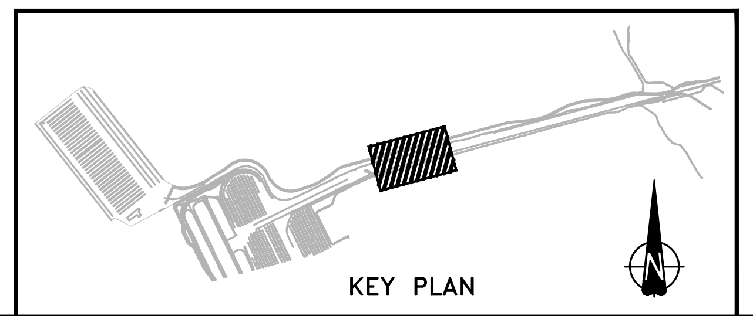
PLAN – PROPOSED CAUSEWAY BREACH

H 1:1000

SYMBOLS / LEGEND	
PROP RBT2 TRACK CL	🟥
PROPWESTSHORE TRACK CL (BY OTHERS)	🟦
PROP IY YARD TRACK CL	🟩
EXISTING TRACK CL	━
PROP TRACK REMOVAL CL (BY OTHERS)	— — —
FUTURE TRACK (BY OTHERS)	— —
PROP LIMIT OF CAUSEWAY	▬ ⁞ ▬
REDUCED LIMIT OF CAUSEWAY	— - - —
PROP ACCESS ROAD	▨
PROP PAVED YARD SURFACE	■
PROP RETAINING WALL	—x—x—
PROP ROADWORK	—
PROP WALL ALONG ROADWORK	⋀⋀⋀
PROP SWITCH POINT	◐
PROP SWITCH POINT (BY OTHERS)	◐
EXISTING SWITCH POINT	◇
PROP BUMPER POST	⋈

m 0 10 20 30 40 50 m

1:1000



NOTES:

1. DIMENSIONS IN METRES UNLESS STATED OTHERWISE
2. TOP OF RETAINING WALL MATCHES M4 TOP OF RAIL PROFILE

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Ref.No.	REFERENCE

moffatt & nichol

IN ASSOCIATION WITH:

Stantec

No.	Date	REVISION	Dr'n	Ch'd
A	APR05/21	FOR DISCUSSION – LOCATION 1	DK	RL

PORT of vancouver

VANCOUVER FRASER PORT AUTHORITY
ENGINEERING DEPARTMENT

DESIGN BY	–
DRAWN BY	–
APPROVED	–
DATE	–
SCALE	SHOWN
PMV SITE	34

CONTAINER CAPACITY IMPROVEMENT PROGRAM
ROBERTS BANK TERMINAL 2
PROPOSED CAUSEWAY BREACH
LOCATION 1

SIZE	DWG.	SHEET	REV.
D	34–347–RL–1395	A	A

APPENDIX C

Location 3 Plan

TITLE BLOCK: DL-TB.dwg

SYMBOLS / LEGEND

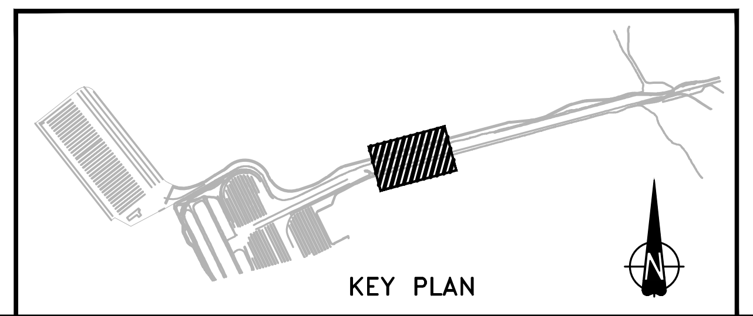
PROP RBT2 TRACK CL	🟥
PROPWESTSHORE TRACK CL (BY OTHERS)	🟦
PROP IY YARD TRACK CL	🟩
EXISTING TRACK CL	―
PROP TRACK REMOVAL CL (BY OTHERS)	— — —
FUTURE TRACK (BY OTHERS)	— —
PROP LIMIT OF CAUSEWAY	▬ ⁞ ▬ ⁞ ▬
REDUCED LIMIT OF CAUSEWAY	— - - —
PROP ACCESS ROAD	▨
PROP PAVED YARD SURFACE	▬
PROP RETAINING WALL	—x—x—
PROP ROADWORK	―
PROP WALL ALONG ROADWORK	﹏
PROP SWITCH POINT	◐
PROP SWITCH POINT (BY OTHERS)	◐
EXISTING SWITCH POINT	◊
PROP BUMPER POST	⋈
OVERHEAD POWER CABLE	—E—
UNDERGROUND TEL CABLE	—T—
WATER MAIN PIPE	—W—
FIBER CABLE	—FOC—

PLAN - PROPOSED CAUSEWAY BREACH

H 1:1000

m 0 10 20 30 40 50 m

1:1000



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DO NOT USE FOR CONSTRUCTION
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Ref.No. REFERENCE

moffatt & nichol

IN ASSOCIATION WITH:

Stantec

No.	Date	REVISION	Dr'n	Ch'd
A	APR05/21	FOR DISCUSSION – LOCATION 3	DK	RL

PORT of vancouver

VANCOUVER FRASER PORT AUTHORITY
ENGINEERING DEPARTMENT

DESIGN BY –
DRAWN BY –
APPROVED –
DATE –
SCALE SHOWN
PMV SITE 34

CONTAINER CAPACITY IMPROVEMENT PROGRAM
ROBERTS BANK TERMINAL 2
PROPOSED CAUSEWAY BREACH
LOCATION 3

SIZE D
DWG. 34–347–RL–1396
SHEET –
REV. A

DATE: 2021/04/05 – 10:16am
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Appendix IR2020-2.2-B

Stantec Memo: RBT2 Marine Terminal Breach Technical Evaluation

Technical Memo

To: Valerie Spies, P.E.
Manager, Infrastructure Delivery, Technical

Vancouver Fraser Port Authority

2100 The Pointe, 999 Canada Place,
Vancouver, BC V6C 3T4

From: Kip Skabar, P.E., P.Eng., ENV SP
RBT2 Deputy Design Manager

Stantec Consulting Ltd.

1100 – 111 Dunsmuir Street,
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File: 115815019

Date: August 24, 2021

Reference: **RBT2 Marine Terminal Breach Conceptual Technical Evaluation**

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- Document and describe a potential Marine Terminal Breach location;
- Identify and describe potential Marine Terminal Breach structure design concepts;
- Provide a technical evaluation of potential design concepts based on the Technical Parameters;
- Provide a comparison of technically feasible Marine Terminal Breach design concepts;
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As such, the Technical Parameters for this technical evaluation of Marine Terminal Breach design and construction concepts include the following:

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[1] CIAR Document #1210 From the Vancouver Fraser Port Authority to the Review Panel re: Project Construction Update. Attachment B1: Detailed Tabulated Summary of Changes to Basis of Design (Updated Appendix 4-A) https://www.ceaa-acee.gc.ca/050/documents/p80054/122934E.pdf

[2] General Requirements for Hydrology and Hydraulic Studies for CN Bridge / Culvert Construction Projects, CN Rail, December 2005

[3] Northwest Hydraulic Consultants, RBT2 Marine Terminal Breach Hydraulic Assessment Results Report (Appendix IR2020-2.2-D)

technical evaluation, and as such, design concepts which carry railway tracks will require further technical evaluation if pursued;

- The proposed roadway to/from the RBT2 Marine Terminal is a Rural Arterial Undivided (RAU) road, which is consistent with the BoD. The BC MoTI minimum freeboard requirement for RAU roads is 1.0 m;
- BC MoTI follow a similar approach for designing culverts as CN, and as such, design concepts which carry roadways will require further technical evaluation if pursued further; and,
- It is assumed construction of a Marine Terminal Breach can be coordinated with the RBT2 overall construction schedule.

This conceptual technical evaluation is based on a 5% level of engineering effort and currently available information. Progression of any design concepts at the potential location identified will require further engineering analysis and evaluation, which may alter these conclusions regarding technical feasibility.

BREACH LOCATION:

The identified, potential Marine Terminal Breach alignment is based on the need to integrate it with the current RBT2 roadway and track alignment Reference Concept Designs (2021). To reduce impacts on terminal and railway infrastructure, the alignment also had a goal of minimizing the number of road and rail crossing structures. **Figure #1** illustrates the identified, potential Marine Terminal Breach location.

Figure #1 – Potential Marine Terminal Breach Location

Based on this, and to preclude the impact of having a track turnout on or adjacent to a breach structure, the potential Marine Terminal Breach location is identified to have a structural segment east of the proposed RBT2 intermodal yard (IY) and IY Storage track turnouts, crossing three rail tracks and three lanes of roadway. The Marine Terminal Breach then turns south into an open channel segment (i.e., no structural crossings) along the west perimeter of Westshore Terminals, through to the southwest corner of the existing landmass. **Figure #2** shows a more detailed Site Plan highlighting the conceptual alignment of the Marine Terminal Breach. A preliminary hydraulics analysis of this channel alignment has been competed by others[3] for the purpose of supporting the biological assessment.

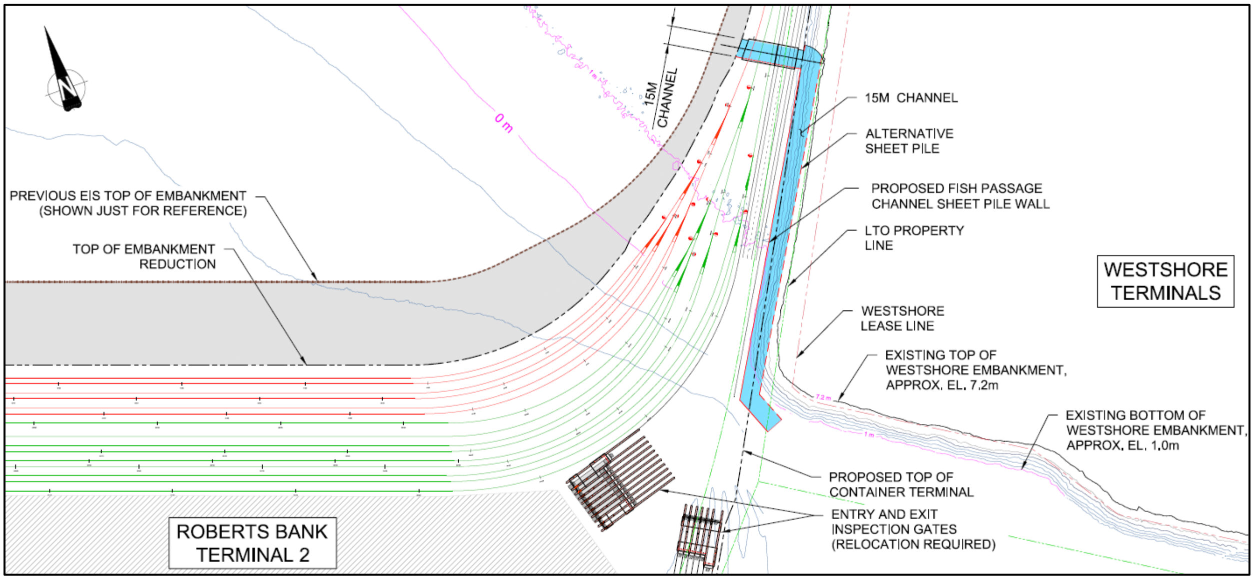

Figure #2 – Marine Terminal Breach Conceptual Site Plan

EVALUATION OF BREACH CONCEPTS:

Two breach design concepts were considered at the potential location as part of this technical evaluation:

1) Illuminated, precast concrete box culvert with open channel segment
2) Open deck bridge spans with open channel segment

These design concepts were developed in parallel with the hydraulic assessment and while they exceed the minimum width criteria, they can be used for evaluation. A discussion on the technical feasibility of each design concept is provided below.

Illuminated Precast Concrete Box Culvert with Open Channel Segment

Precast Concrete Box Culvert Segment

To meet the Technical Parameters while accommodating the imposed railway and roadway live loadings, two double precast concrete box culvert sections would be required. Supporting foundations would also be required; for example, steel grillage that is cast in place with lean mix concrete, on top of a compacted granular base. Precast concrete segments will need to be longitudinally and laterally post-tensioned to ensure proper fit and to avoid separation of adjacent segments. A geotechnical evaluation will need to be completed if this design concept is pursued further to validate proposed foundations and evaluate potential settlements. Day-time illumination would be provided with semi-submersible fixtures and wiring mounted to the surface of the culvert ceiling.

Figure #3 illustrates a typical culvert section at the track crossing segment of the breach, with FSLR accommodated below the top of culvert. General Arrangement plans for this concept have been provided in **Appendix A**. Based on the Technical Parameters and this conceptual technical evaluation, an illuminated, precast concrete box culvert is considered technically feasible as a design concept.

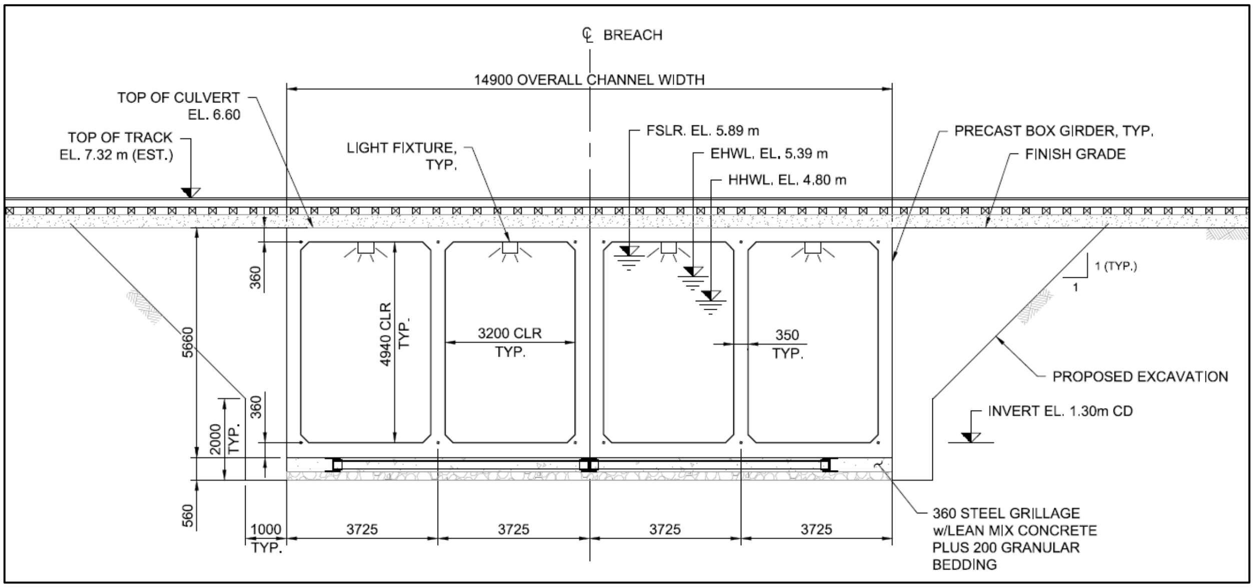

Figure #3 – Culvert Structure Section Below Tracks

Open Channel Segment

Figure #4 shows a typical cross section of the open channel segment positioned parallel to the perimeter of the existing Westshore landmass. The open channel geometry and streambed and side-slope treatments, intended to offer enhanced conditions for fish, were provided by others[3]. An alternative sheet pile wall is illustrated in **Figure #4** with the intent to reduce potential impacts to existing usable land, for future consideration.

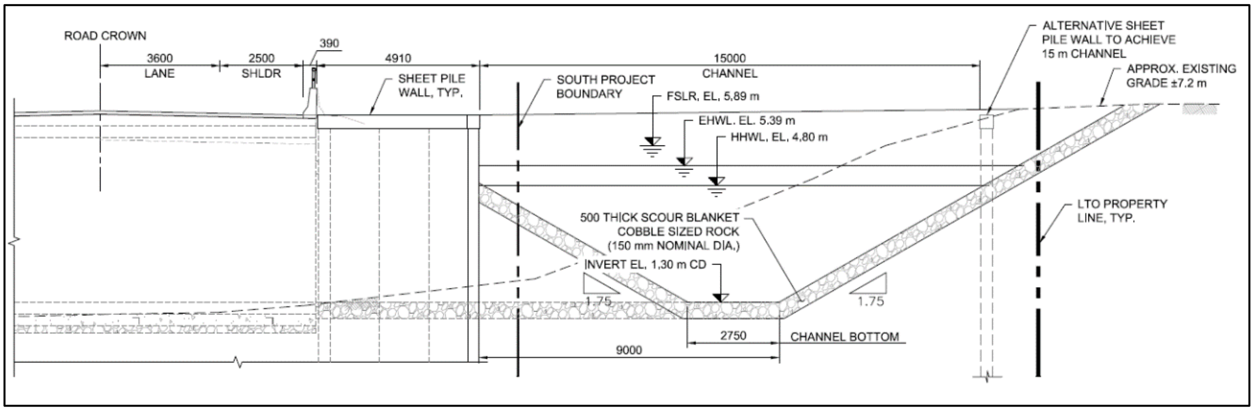

Figure #4 – Open Channel Section Near Culvert Structure (Section B from Figure #5)

Figure #5 shows a Plan view of the Marine Terminal Breach at the area of transition between culvert structure and open channel segments.

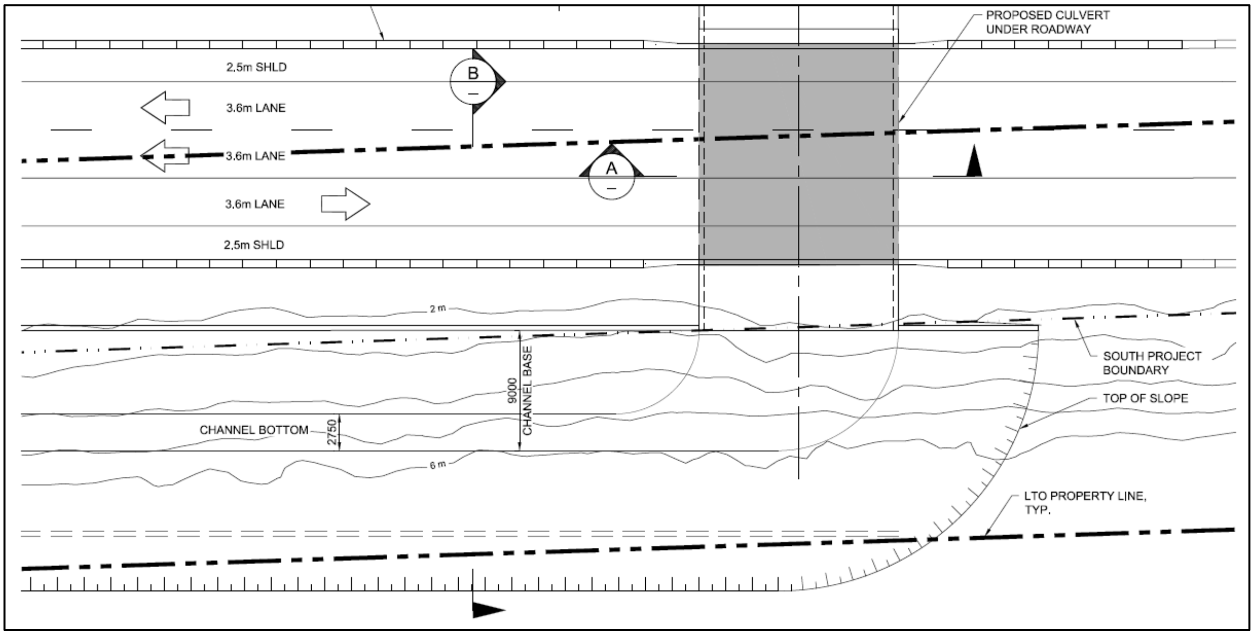

Figure #5 – Culvert to Open Channel Transition Plan

This concept is not expected to impact the adjacent Terminal Operator (i.e., Westshore Terminals) operations or lands, currently leased from the Port Authority. Consultation with Westshore Terminals should be considered to review the alignment and design of the open channel segment of a Marine Terminal Breach, should this design concept be pursued further. As well, scour protection at channel entrances will need to be designed[3]. As such, this open channel design concept is also considered technically feasible relative to the Technical Parameters.

Open Deck Bridges with Open Channel Segment

Open Deck Bridge Segment

The Technical Parameters for minimum freeboard set a minimum elevation for the underside of the bridge spans (bottom chord elevation), relative to proposed RBT2 grade elevations. Further, high railway loadings on railway structures require relatively deep girder sections, resulting in a lower bottom chord elevation relative to proposed grade. For a bridge concept to be technically feasible, the bridge superstructure must be able to be designed with the required freeboard.

Two standard open deck steel railway bridge superstructures were considered as part of this technical evaluation. The first involves a steel Through Plate Girder, consisting of deeper longitudinal girders with an internal steel floor system which directly supports the track, as illustrated in **Figure #6**. As the floor system supports the track, deeper girder sections extend above and below the level of the track. This configuration will preclude the ability to accommodate variable track spacing. Further, as the girders are located outside the track width, this superstructure would be too wide to accommodate proposed RBT2 track spacing. Therefore, this structural configuration was not considered technically feasible for a design concept. The second involves a steel Beam Span, consisting of multiple, closely spaced, steel beams with the track fastened to the top flange, as illustrated in **Figure #7**. This type of structure allows for flexibility in accommodating variable track spacings and alignment alterations are unimpeded.

Precast concrete box girders were also considered but not pursued further as their need to be ballasted would require a structural depth below the track that is much deeper than a steel Beam Span. As such, an open deck steel Beam Span was considered the most appropriate bridge design concept for this technical evaluation.

Figure #6 – Typical Steel Open Deck Through Plate Girder Bridge

Figure #7 illustrates a typical bridge section at the track crossing segment of the breach which does not accommodate minimum freeboard requirements for a railway bridge when experiencing FSLR. **Figure #8** illustrates a typical bridge section at the road crossing segment of the breach which also does not accommodate minimum freeboard requirements for a roadway bridge. As these bridge concept designs are not considered technically feasible, the open channel segment of this design concept does not need to be assessed as it would be similar to the culvert design concept detailed earlier.

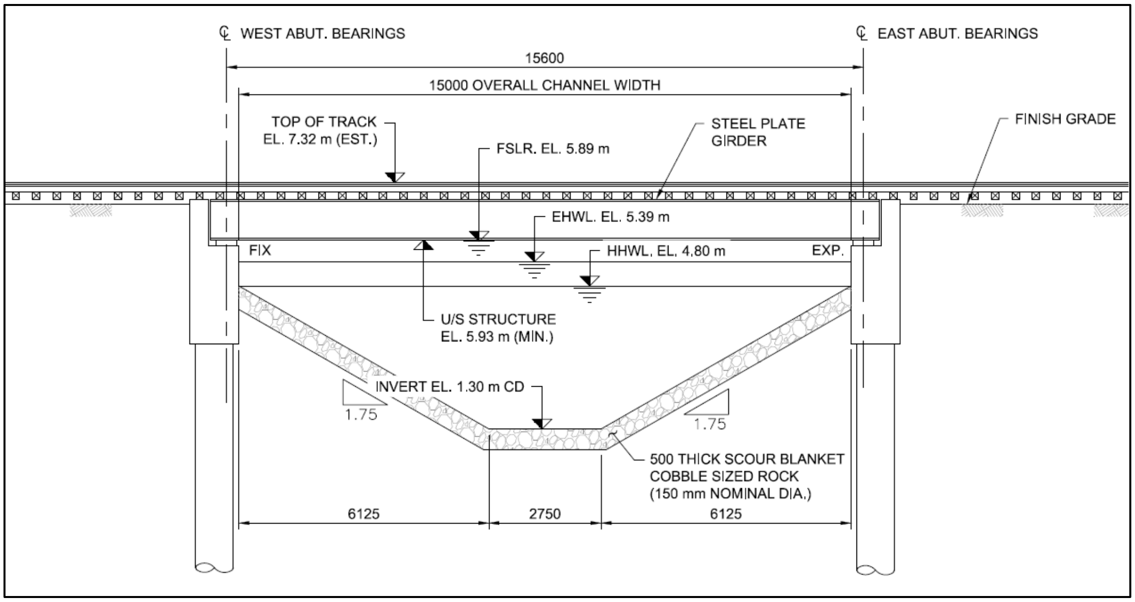

Figure #7 – Bridge Structure Section Below Tracks

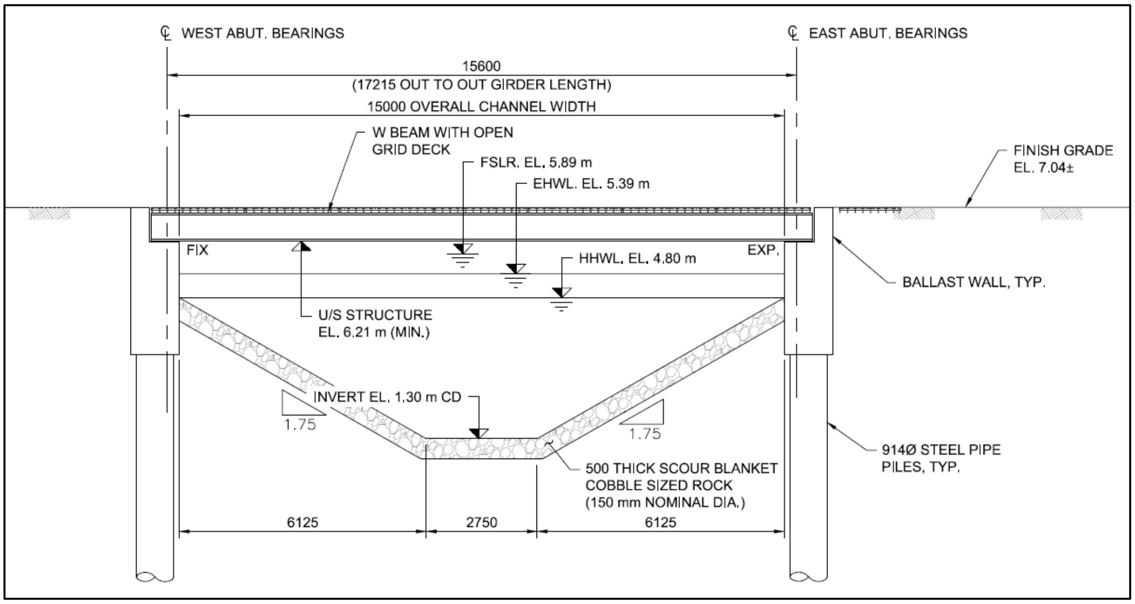

Figure #8 –Bridge Structure Section Below Roadway

Based on this conceptual technical evaluation only the Culvert with Open Channel Segment configuration, comprising the identified alignment at the potential Marine Terminal Breach location, is considered technically feasible.

BREACH CONSTRUCTABILITY EVALUATION:

To determine if the Culvert with Open Channel Segment design concept is also technically feasible to construct, constructability matters (including construction staging) were also evaluated at a high-level. There are many variables and constraints that impact construction of a potential breach which are not easy to define at this stage of concept development. It is envisioned the Widened Causeway landmass and the landmass in the immediate area of the East Basin would first be fully constructed prior to starting construction of a Marine Terminal Breach. Other Marine Terminal construction activity would be occurring around the potential Marine Terminal Breach location concurrently. As such, construction would need to be coordinated with overall RBT2 construction activities to ensure the breach work can progress without compromising the consistent need for construction access between the Widened Causeway and Marine Terminal.

Breach construction would conceivably be completed in multiple phases, beginning with the portion of the structural segment supporting the three future RBT2 railway tracks. If this design concept is pursued further, the precast concrete box culvert section configuration would be confirmed relative to fabrication, transportation, and constructability constraints, with regards to either the current two double section configuration or a four single section configuration. Construction activities related to installation of precast concrete box culverts would involve the following:

- Mobilization of labour, materials, and equipment;
- Construction of a temporary berm along the north side of the Widened Causeway landmass in order to allow culvert construction in the 'dry';
- Excavation of the breach opening;
- Installation of the culvert foundation (i.e., steel grillage and concrete fill);
- Installation of precast concrete segments and post-tensioning of adjacent segments; and,
- Backfilling of installed precast concrete segments.

The next phase would involve completion of the portion of the precast concrete box culvert supporting the future RBT2 roadway. Construction would follow the same procedure as the first phase, excluding installation of the temporary berm but including its removal. The open channel segment of the breach could be constructed concurrently with the structural segment. This would involve the following:

- Construction of a temporary berm along the southern end of the open channel in order to allow construction in the 'dry';
- Installation of steel sheet piling along the eastern side of the Marine Terminal;
- Trimming of the existing slope along the west side of the existing Westshore Terminal landmass;
- Completing the side slopes and channel bottom with the required granular surface protection; and,

- Removal of the temporary berm.

Based on this conceptual technical evaluation, the Culvert with Open Channel Segment design concept is considered technically feasible to construct at the potential breach location.

SUMMARY AND CONCLUSIONS:

Our conceptual technical evaluation of constructible engineering concepts, to create a Marine Terminal Breach that accommodates water flows which facilitate fish passage, indicates that a breach at the potential location is considered technically feasible to design and construct. An illuminated, precast concrete box culvert structural segment is the only technically feasible design concept which is compliant with the Technical Parameters, when paired with an open channel segment.

Further engineering is required to confirm the Technical Parameters to validate technical feasibility of design concepts and constructability at this potential location. This additional engineering analysis may alter these conclusions regarding technical feasibility. In accordance with standard practices, this work should include, as a minimum:

- A detailed hydrotechnical analysis and evaluation in accordance with CN guidelines, including industry standard modeling to assess water elevations, waves, flows, velocities, minimum opening requirements (height and width), capacity, and flooding potential. It should also include environmental considerations such as fish passage, sedimentation, debris accumulation, and scour protection;
- A geotechnical evaluation assessing existing foundation conditions as well as, estimates of potential settlement and settlement mitigation strategies;
- A seismic analysis of the design concept structures;
- Confirmation and accommodation of existing, proposed, and potential future utilities;
- Confirmation of illumination criteria suitable to facilitate fish passage;
- A detailed constructability assessment, including construction staging and temporary works design; and,
- Identification of inspection and maintenance requirements.

Although this design concept and potential location is not expected to impact Westshore Terminals operations or their leased land, consultation should be considered to review alignment and design of the open channel segment of a Marine Terminal Breach. Further, to advance this design concept, consultation will be required with other stakeholders and third parties as identified herein, as well as with Indigenous groups and Government Regulators.

DISCLAIMER:

This document entitled RBT2 Marine Terminal Breach Conceptual Technical Evaluation was prepared by Stantec Consulting Ltd. ("Stantec") as subconsultant to Moffatt & Nichol ("M&N"), together providing services as the Owner's Engineer (the "OE"), for the account of the Vancouver Fraser Port Authority (the "Client"). Any reliance on this document by any third party is strictly prohibited. The material in it reflects Stantec's professional judgment in light of the scope, schedule, and other limitations stated in the document and in the contract between the OE and the Client. The opinions in the document are based on conditions and information existing at the time the document was published and do not take into account any subsequent changes. In preparing the document, Stantec did not verify information supplied to it by others (e.g., hydraulic analysis of breach concepts[3]). Any use which a third party makes of this document is the responsibility of such third party. Such third party agrees that Stantec shall not be responsible for costs or damages of any kind, if any, suffered by it or any other third party as a result of decisions made or actions taken based on this document.

CLOSING:

We trust this Technical Memo provides the Port Authority with the information required to move ahead with any future decisions regarding this initiative. Should you have any questions or comments, please contact us at your earliest convenience.

Regards,

STANTEC CONSULTING LTD.

Prepared by:

Richard Lanyi, P. Eng.
RBT2 OE Rail Lead
Phone: (780) 917-7119
richard.lanyi@stantec.com

Reviewed by:

Glenn McIntyre, E.I.T., ENV SP
Assistant Project Manager
Phone: (604) 696-8264
glenn.mcintyre@stantec.com

Approved by:

Kip Skabar, PE, P.Eng., ENV SP
RBT2 Deputy Design Manager
Phone: (604) 363-1690
kip.skabar@stantec.com

Attachments:

1. Appendix A – Precast Concrete Box Culvert Concept Plans
2. Appendix B – Open Deck Bridge Concept Plans

cc. Michael Cho, Moffatt & Nichol

APPENDIX A

Precast Concrete Box Culvert Concept Plans

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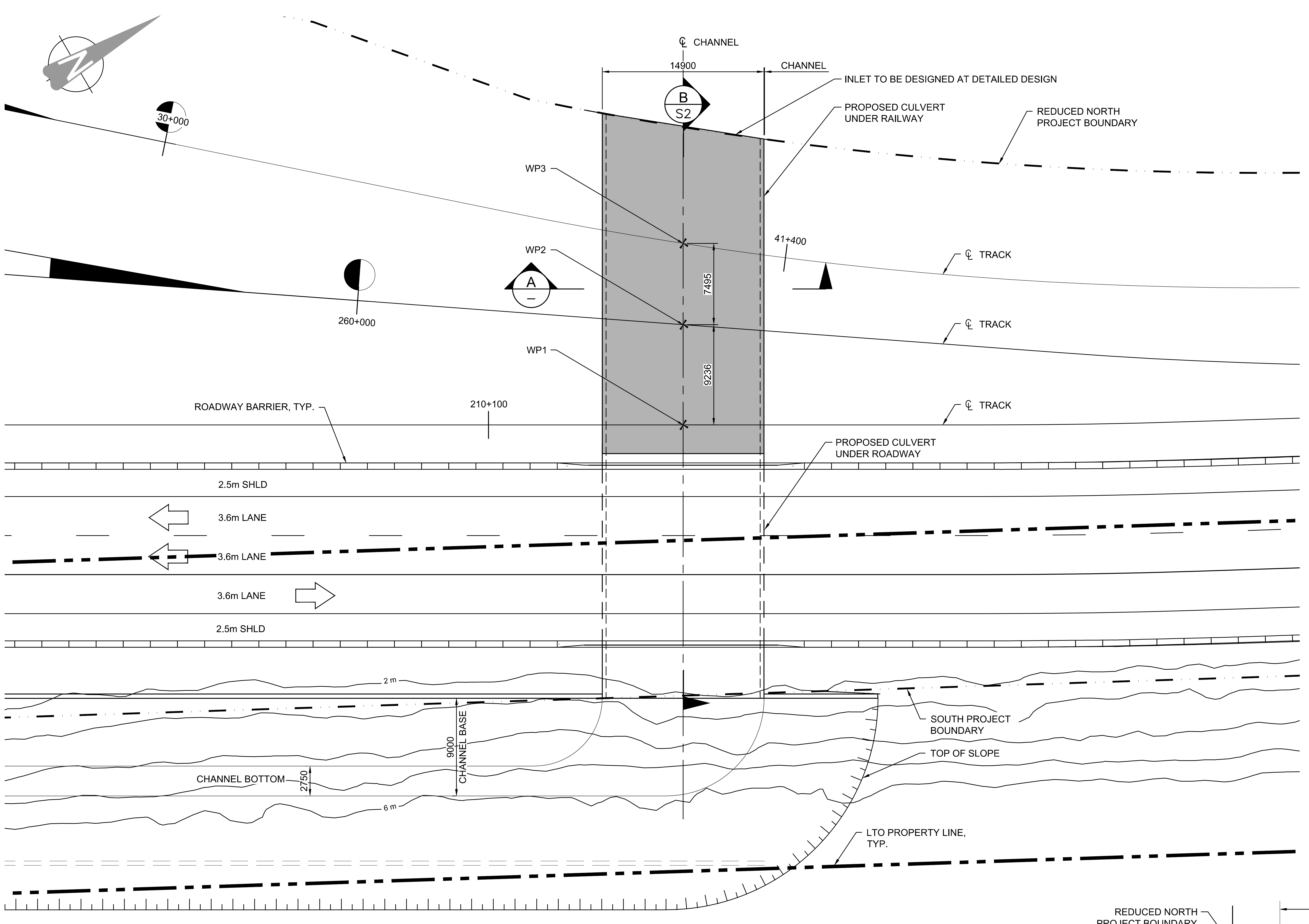

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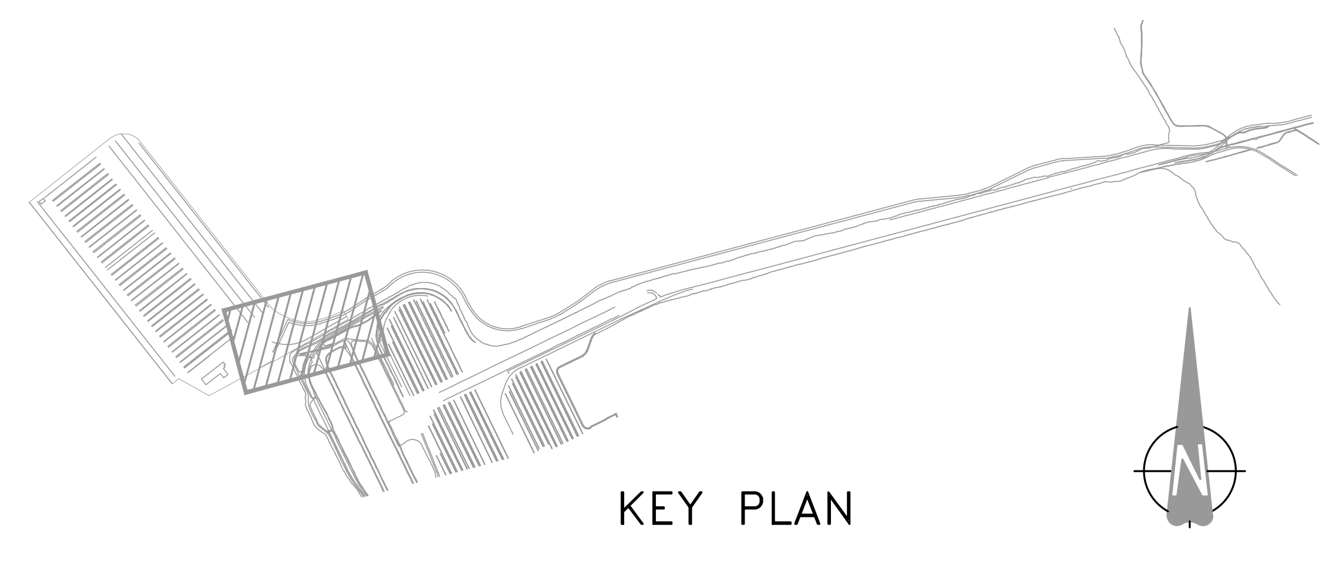

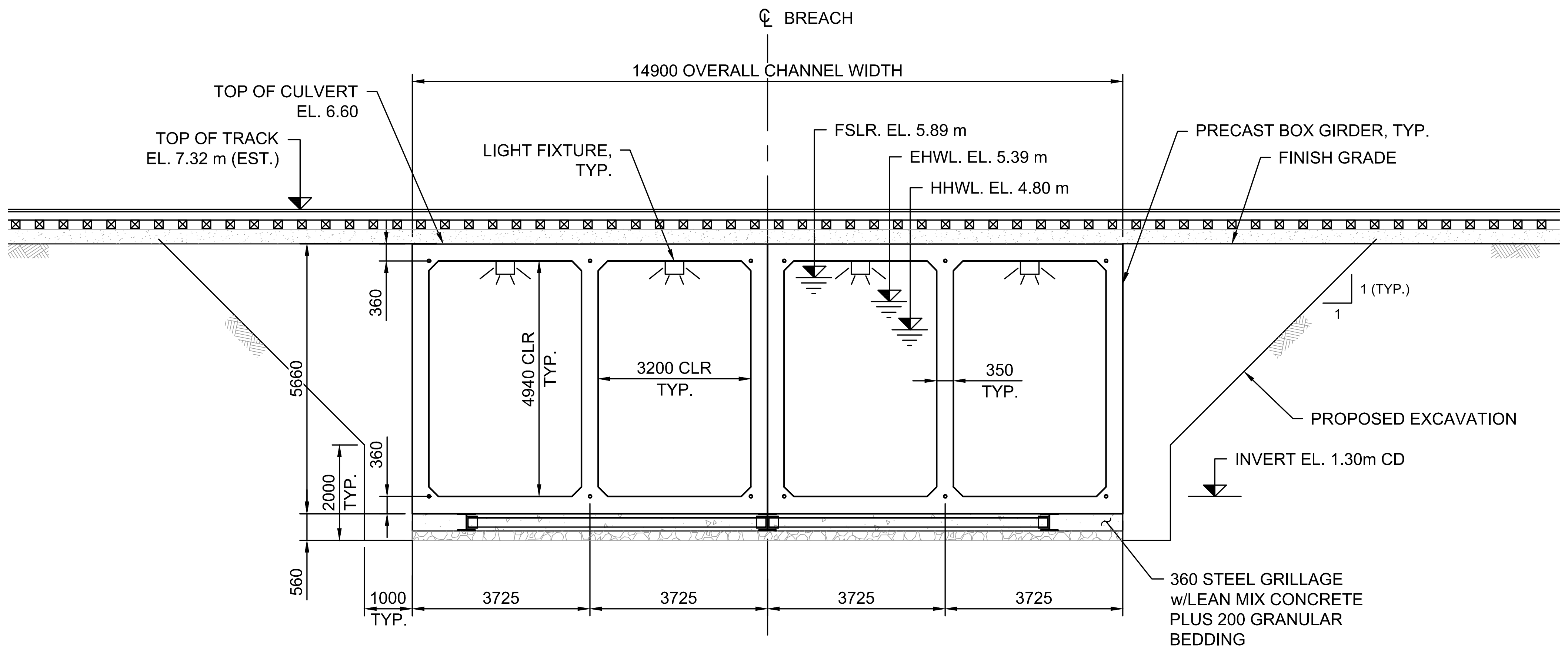

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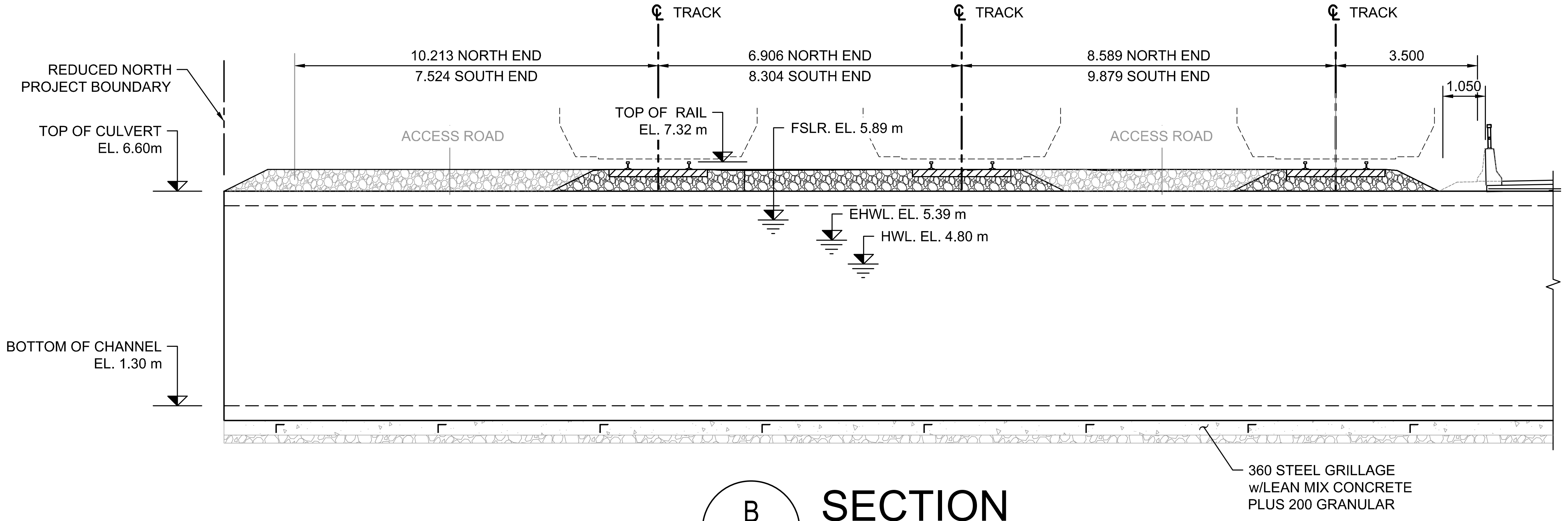

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APPROVED	J.PHILP
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CONTAINER CAPACITY IMPROVEMENT PROGRAM
ROBERTS BANK TERMINAL 2
MARINE TERMINAL BREACH
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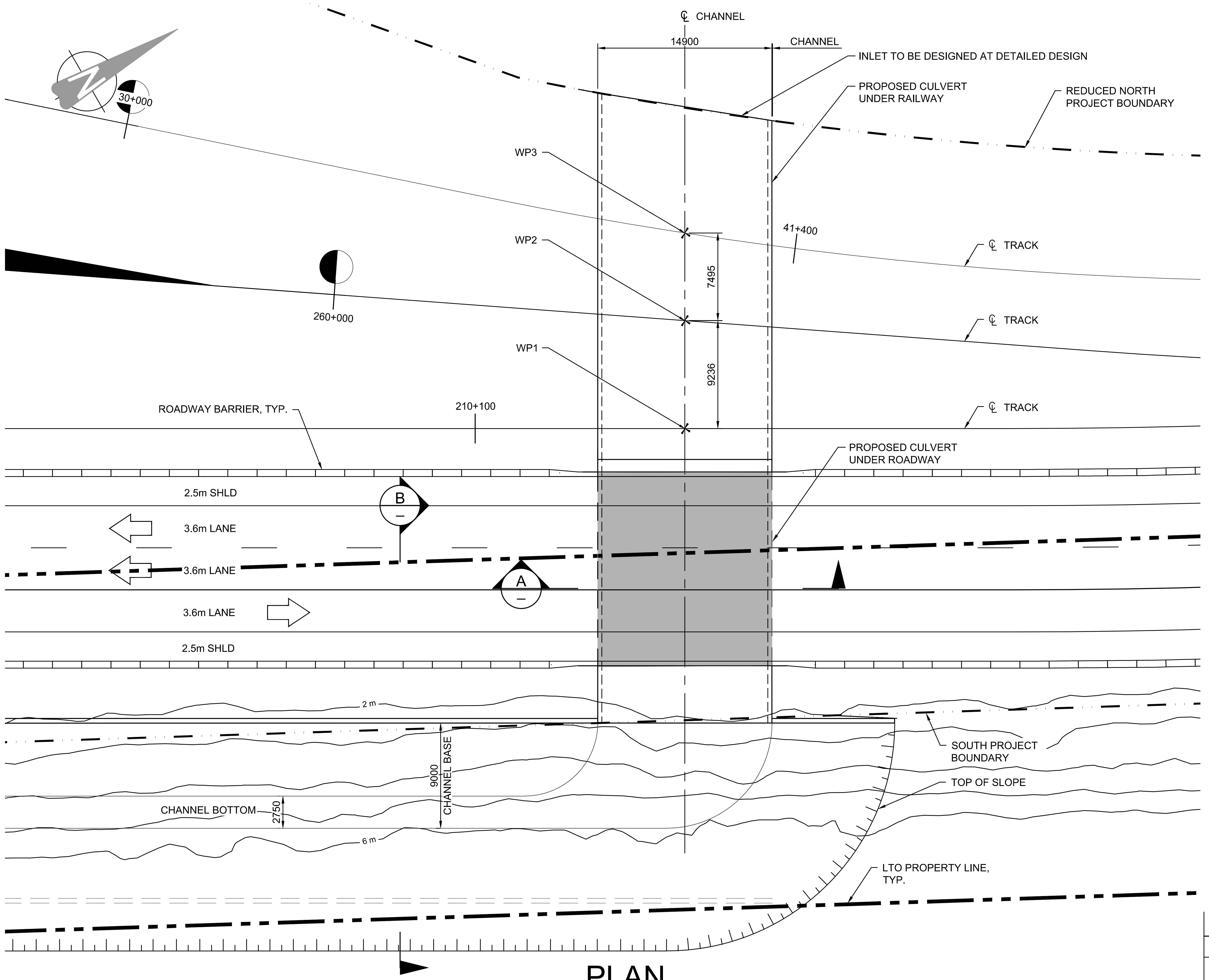

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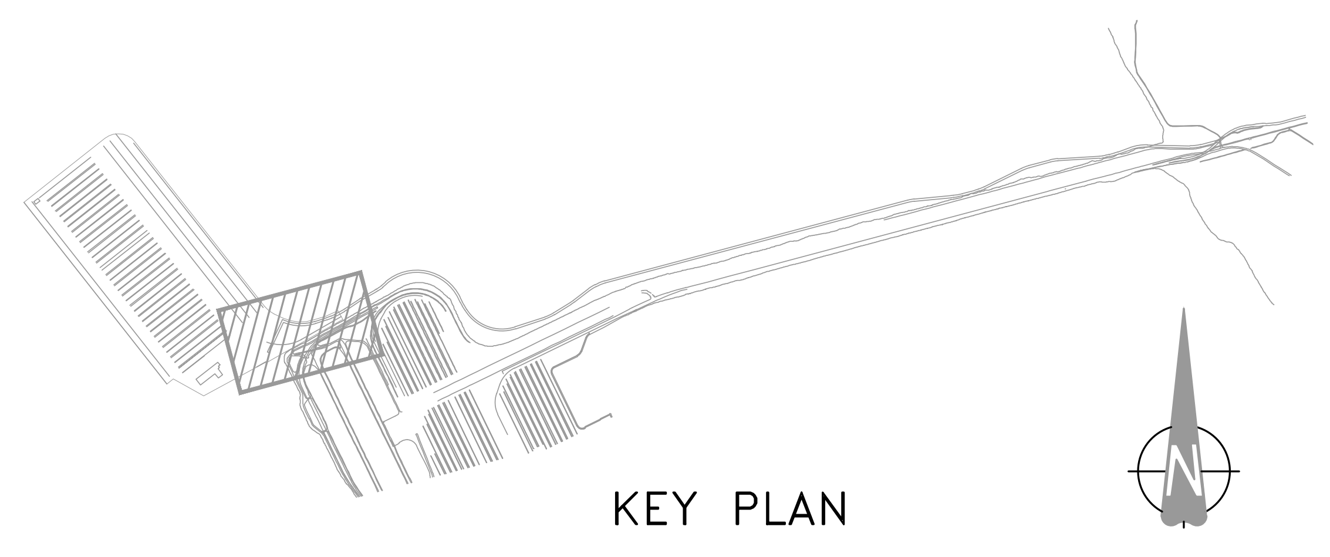

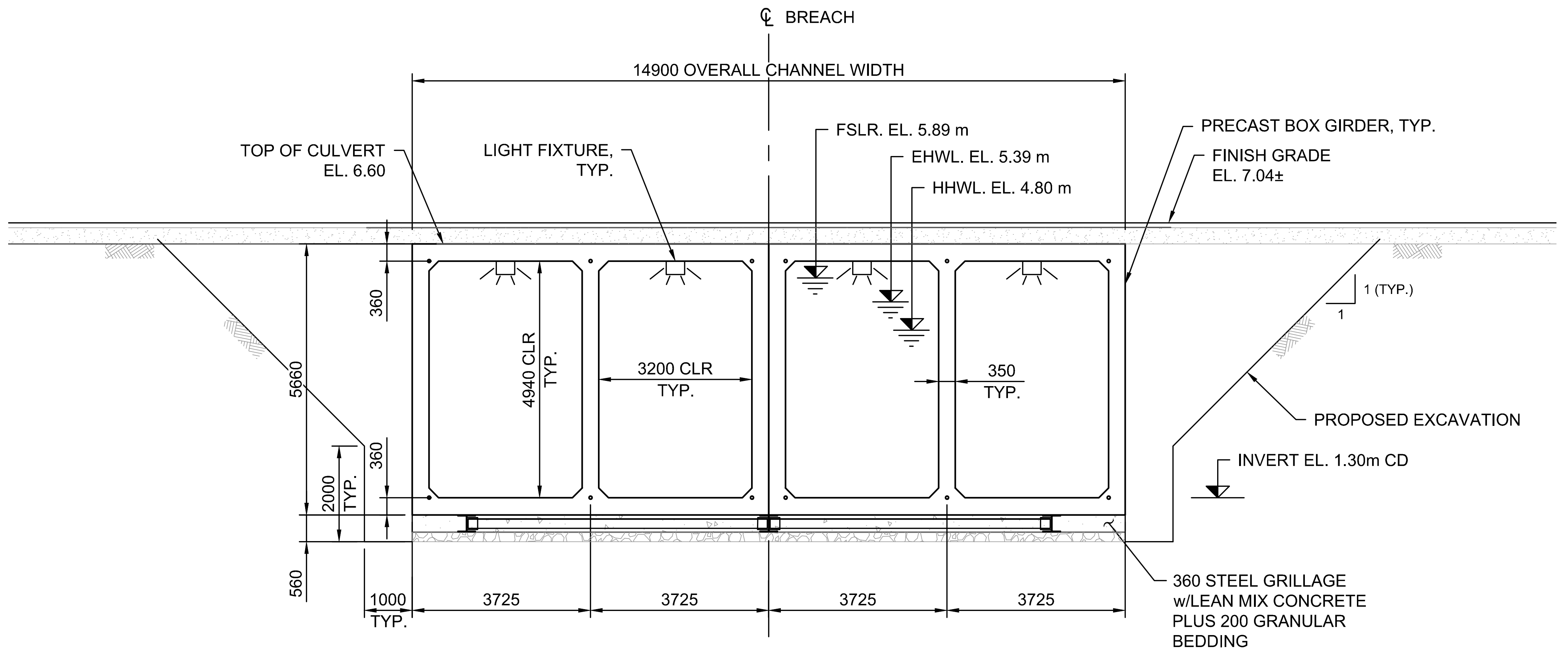

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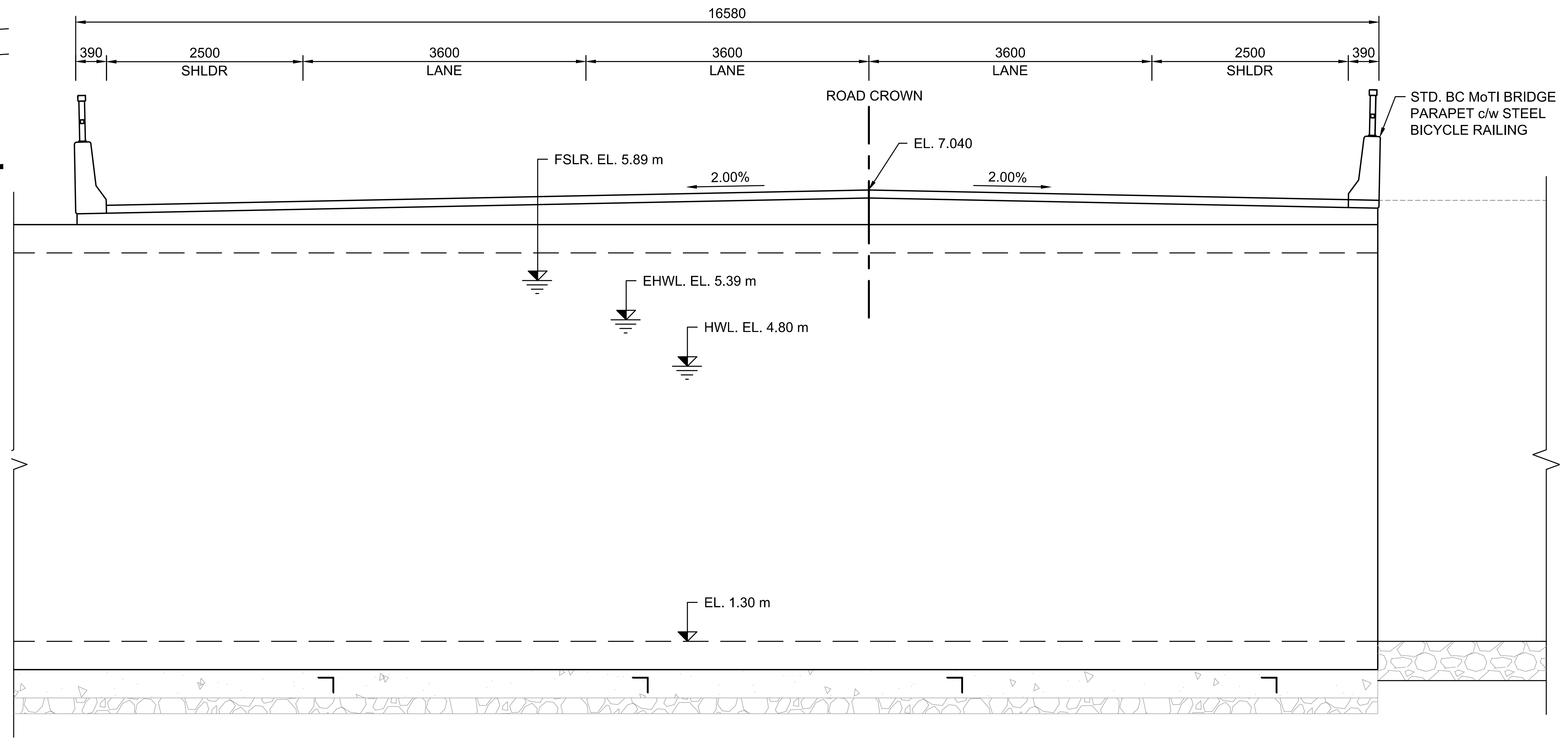

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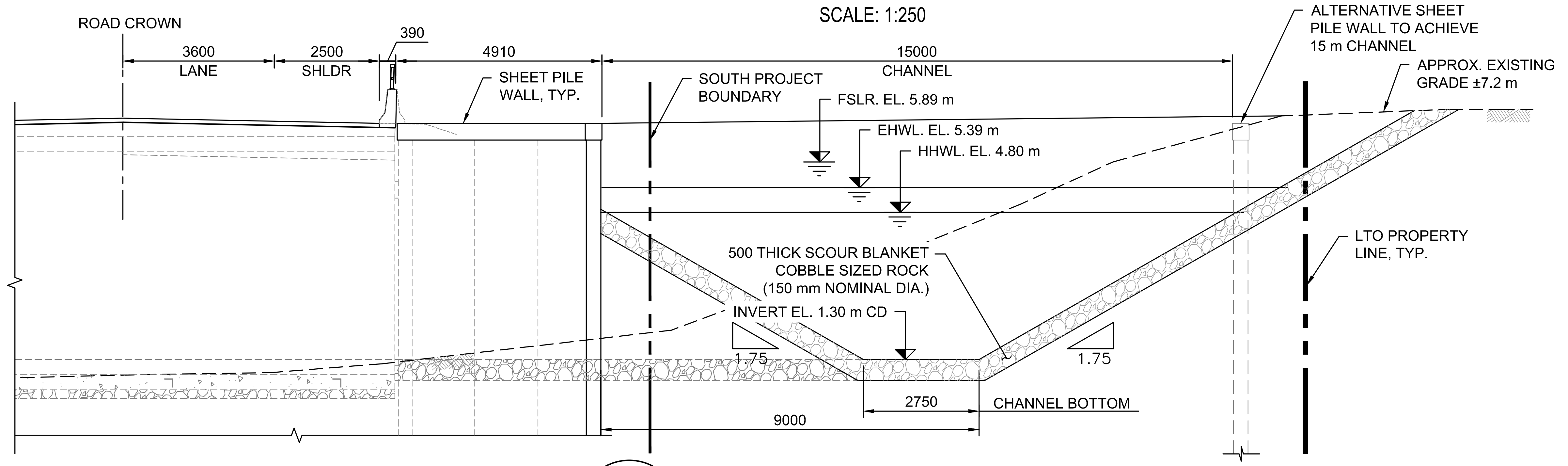

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CONTAINER CAPACITY IMPROVEMENT PROGRAM
ROBERTS BANK TERMINAL 2
MARINE TERMINAL BREACH
GENERAL ARRANGEMENT – ROAD CULVERT

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APPENDIX B

Open Deck Bridge Concept Plans

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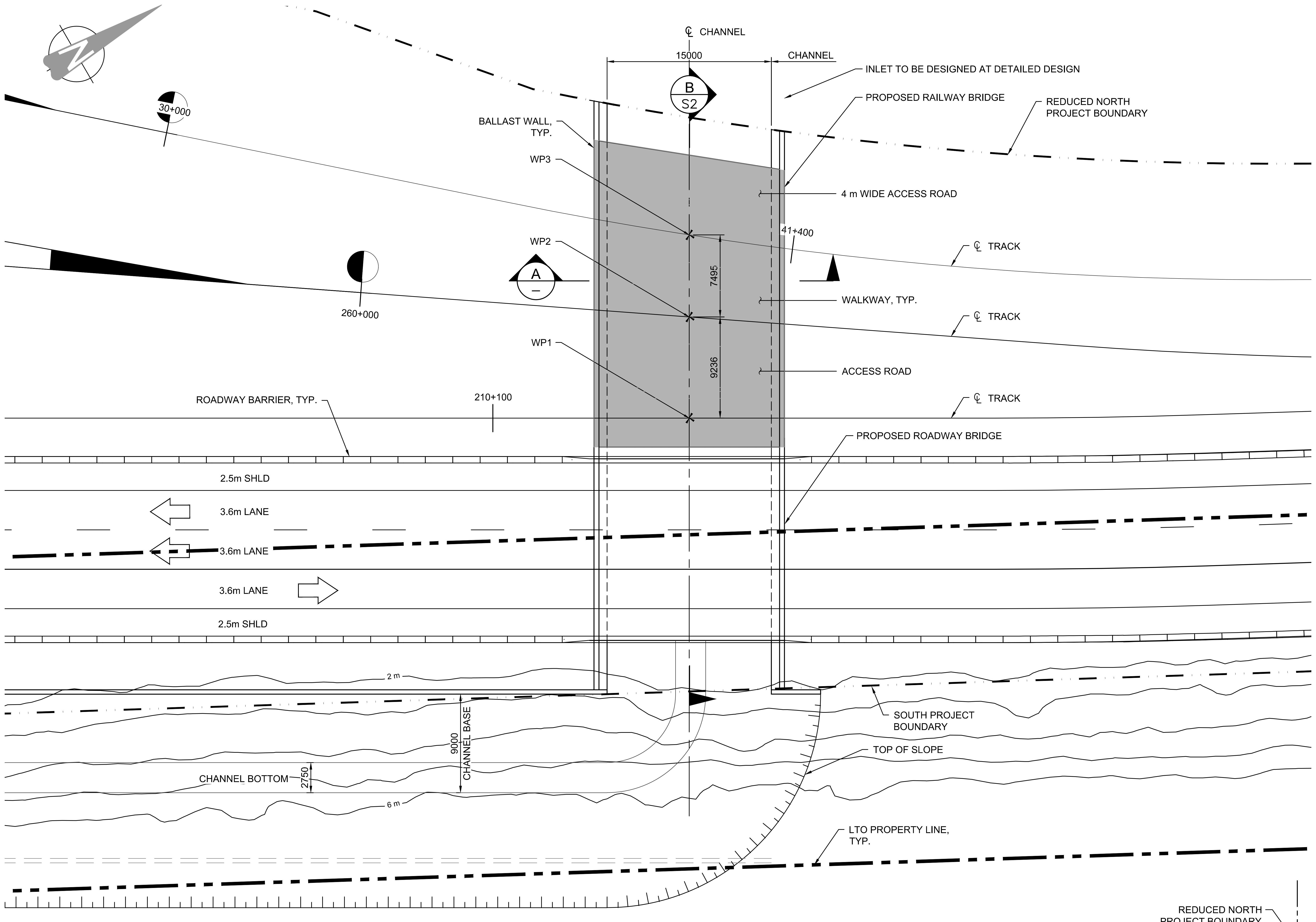

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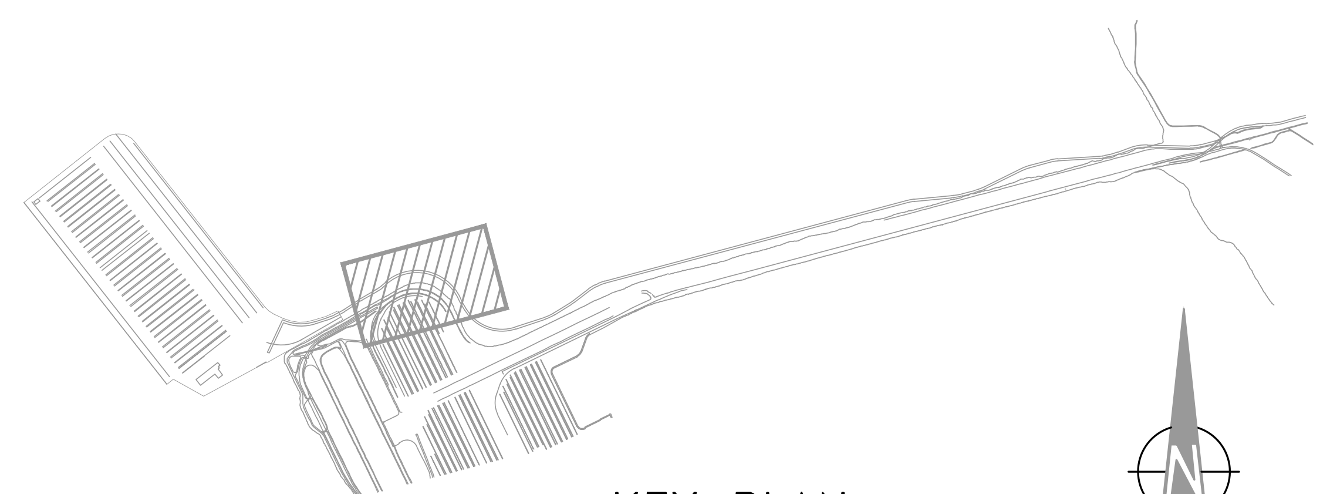

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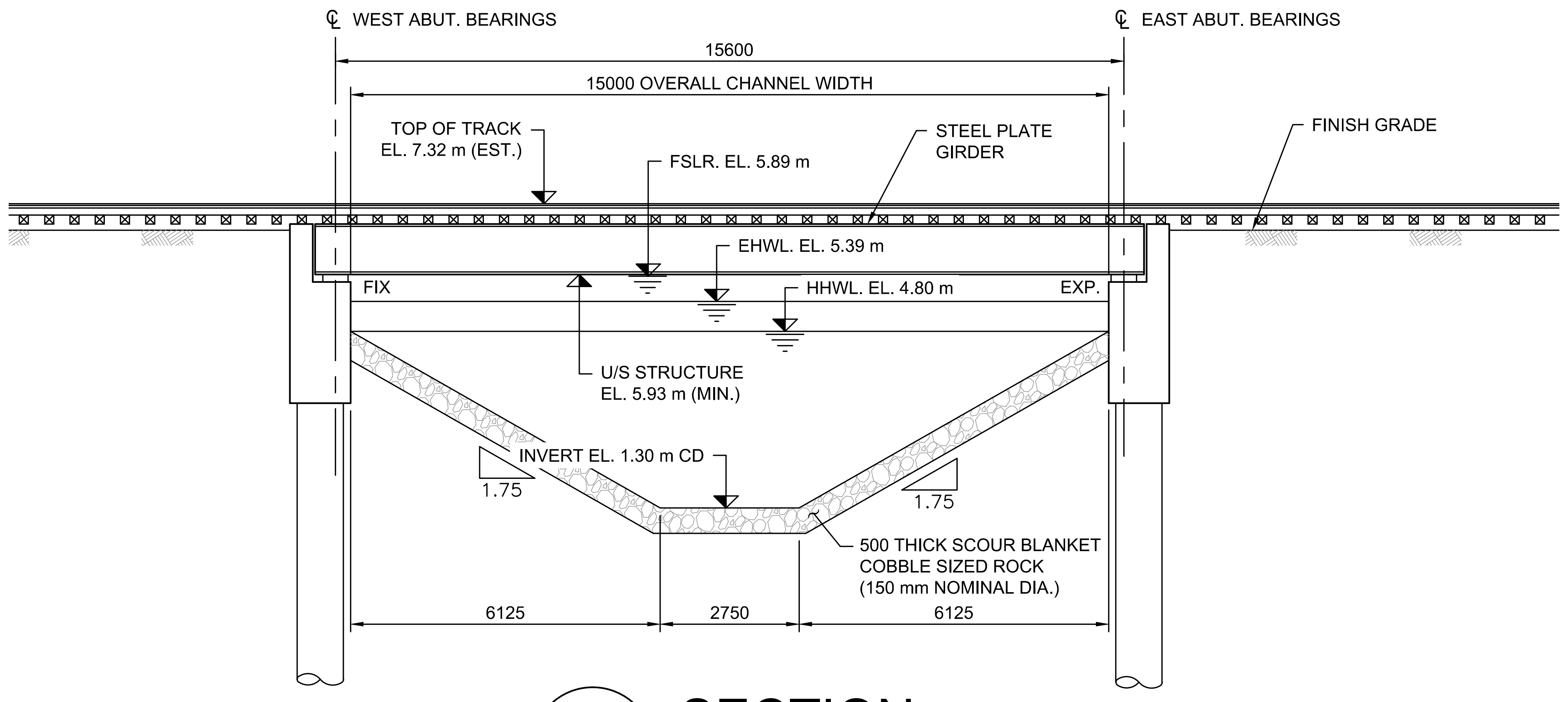

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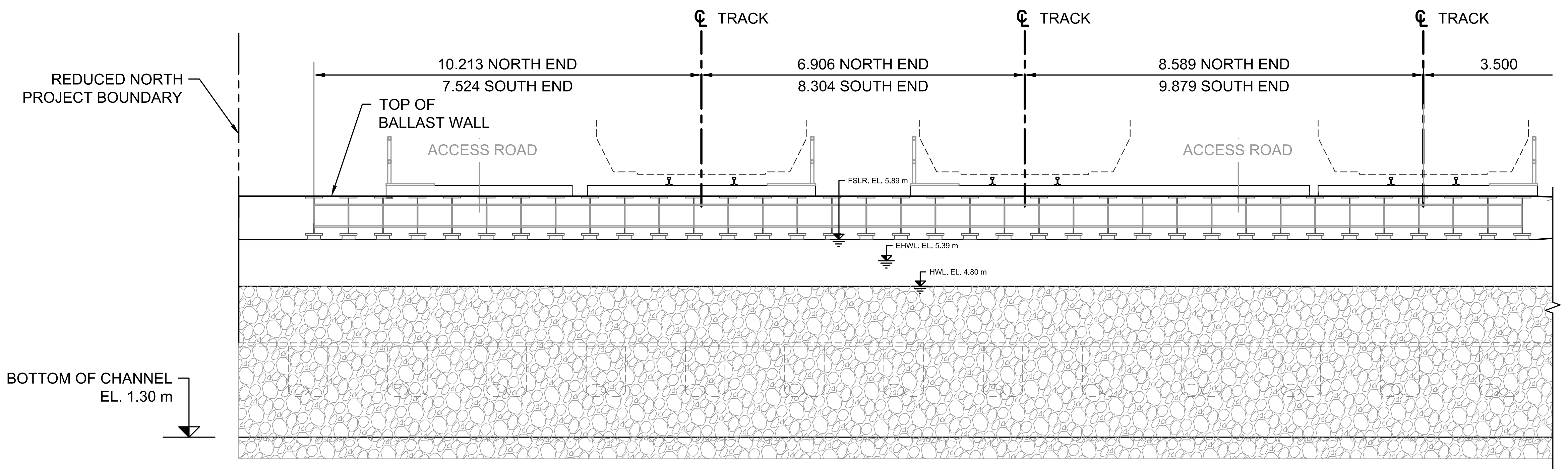

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CONTAINER CAPACITY IMPROVEMENT PROGRAM
ROBERTS BANK TERMINAL 2
MARINE TERMINAL BREACH
GENERAL ARRANGEMENT – RAILWAY BRIDGE

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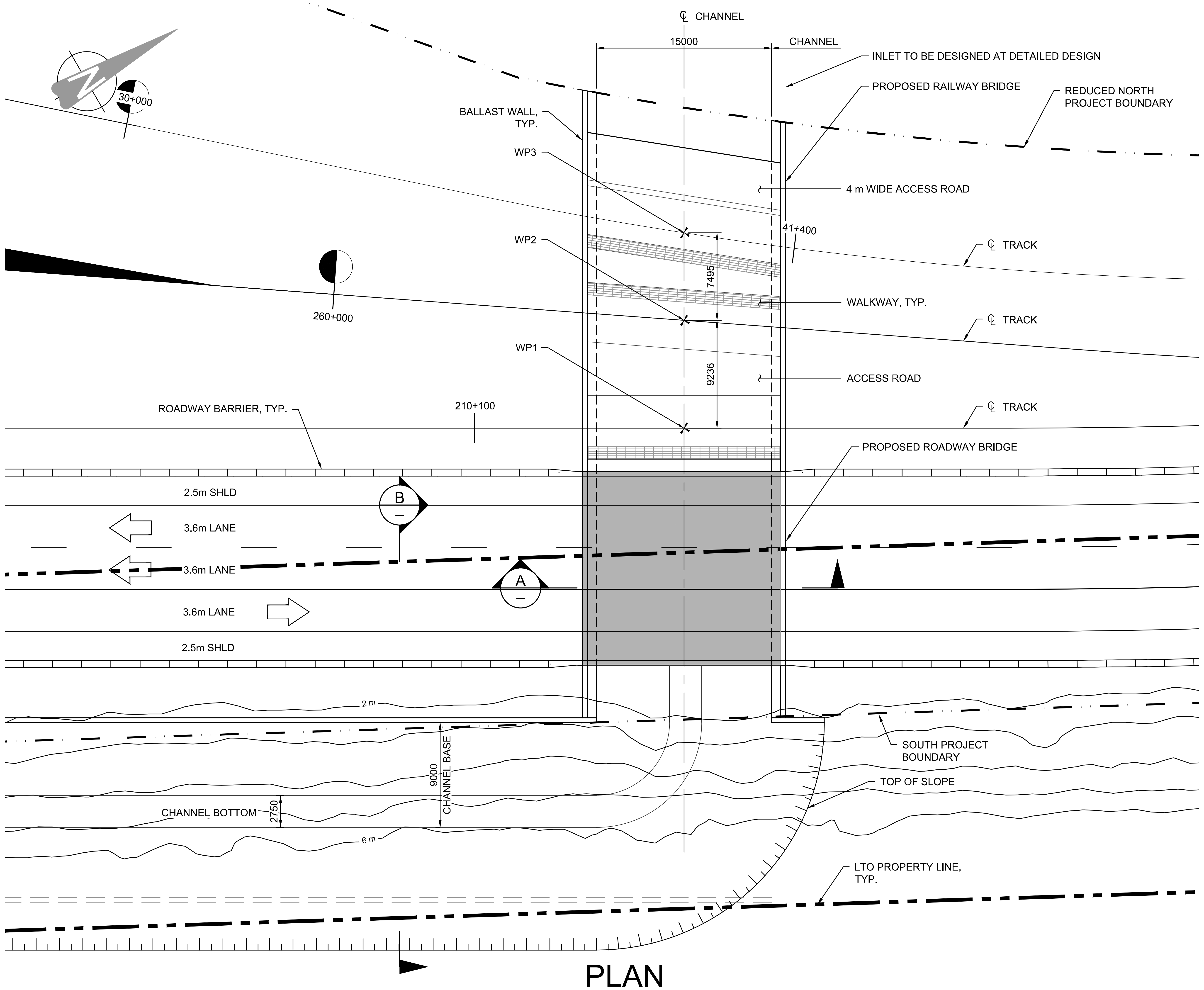

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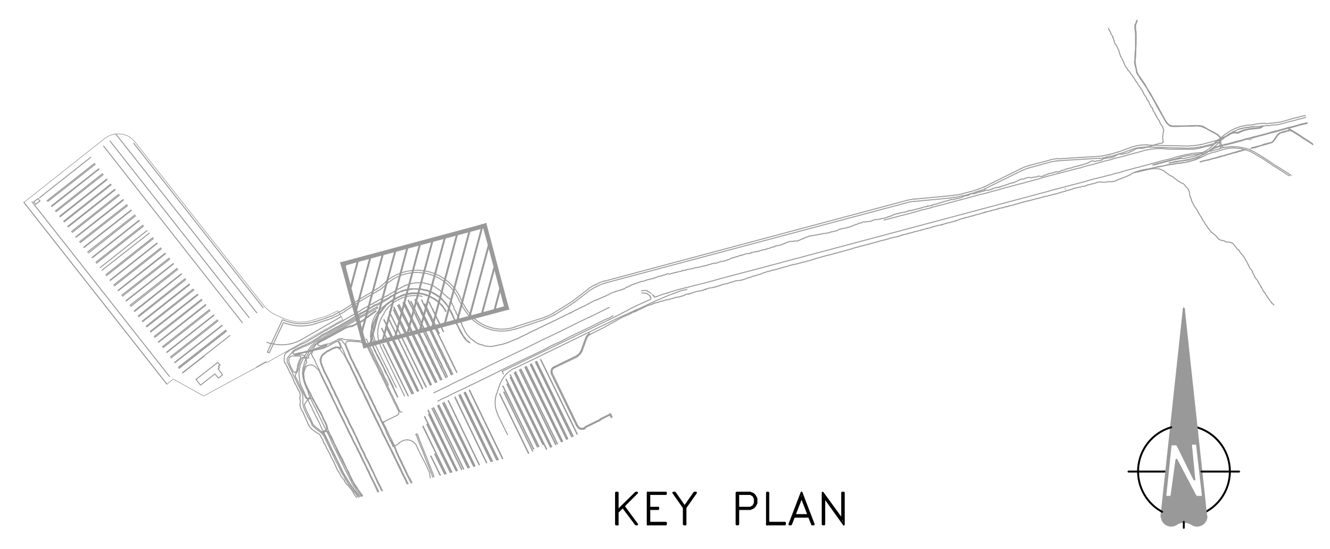

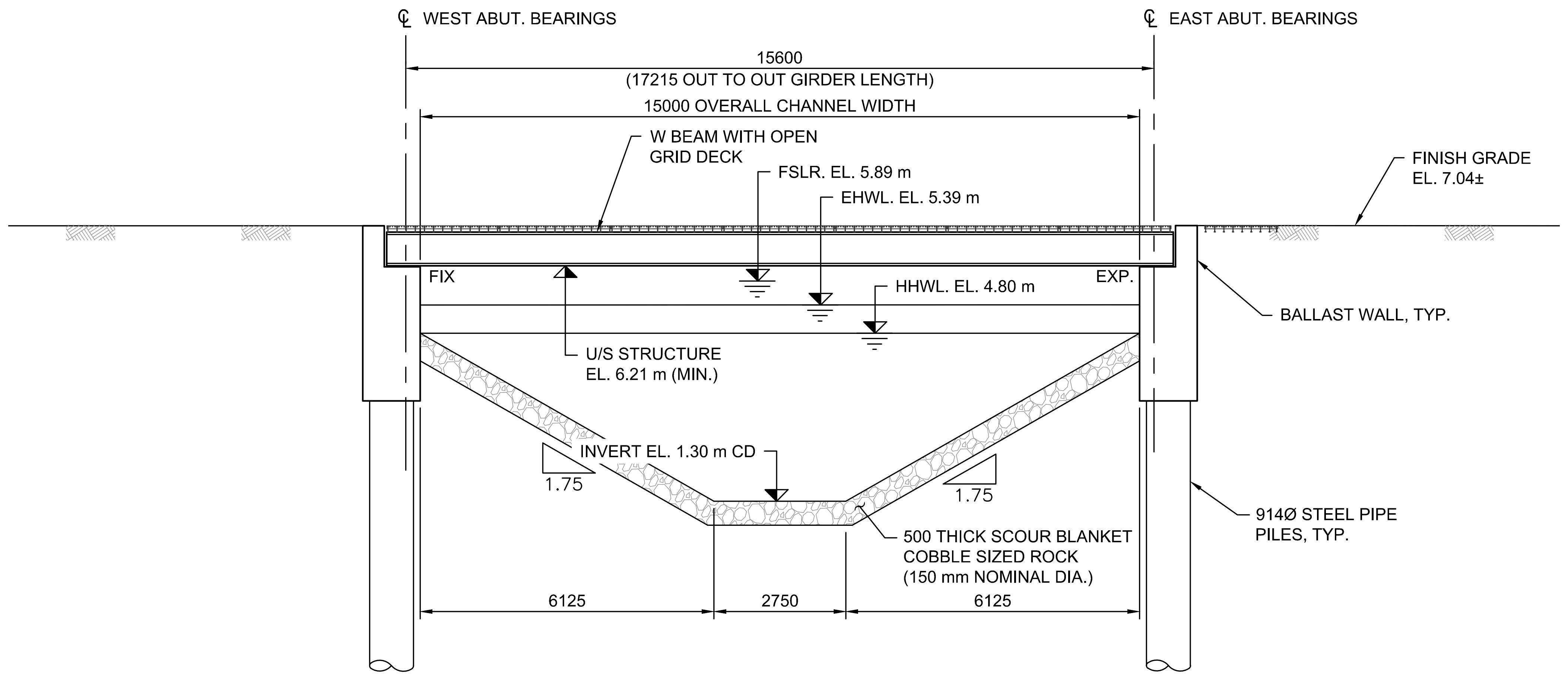

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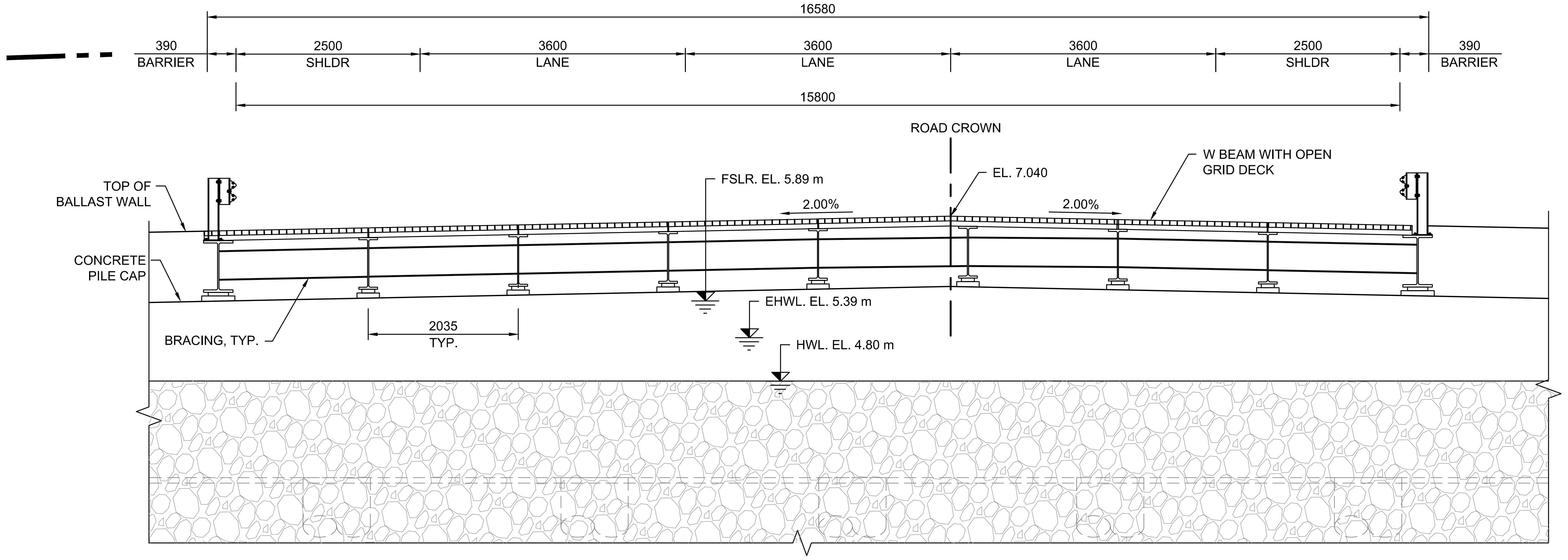

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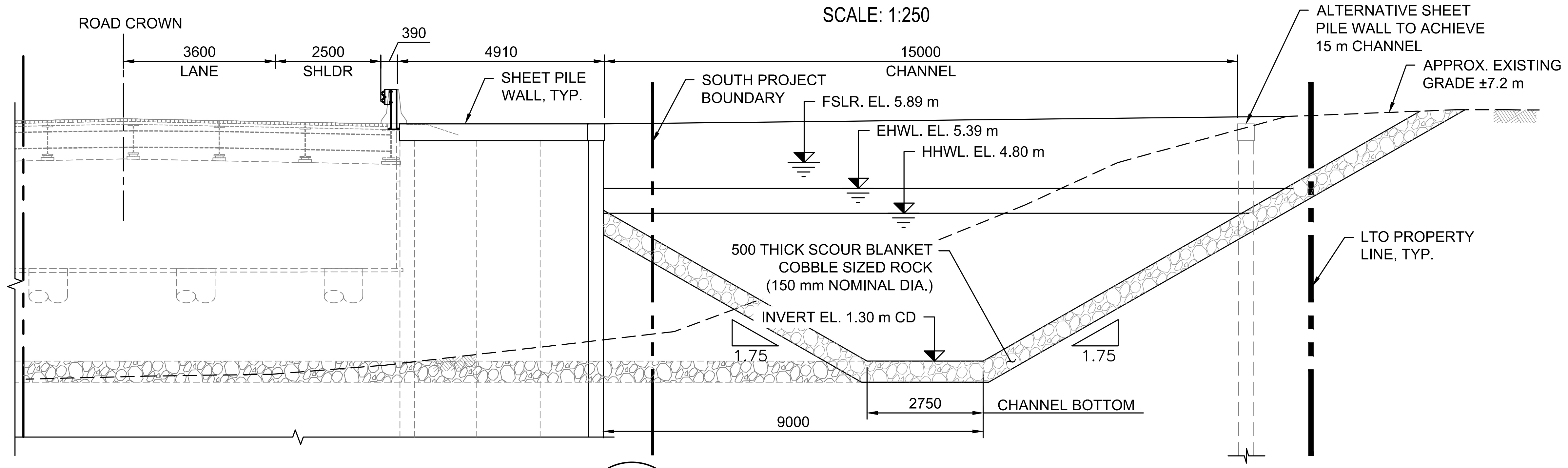

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CONTAINER CAPACITY IMPROVEMENT PROGRAM
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MARINE TERMINAL BREACH
GENERAL ARRANGEMENT – ROADWAY BRIDGE

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Appendix IR2020-2.2-C

Northwest Hydraulic Consultants Report: RBT2 – Roberts Bank Causeway Breach Hydraulic and Geomorphic Assessments

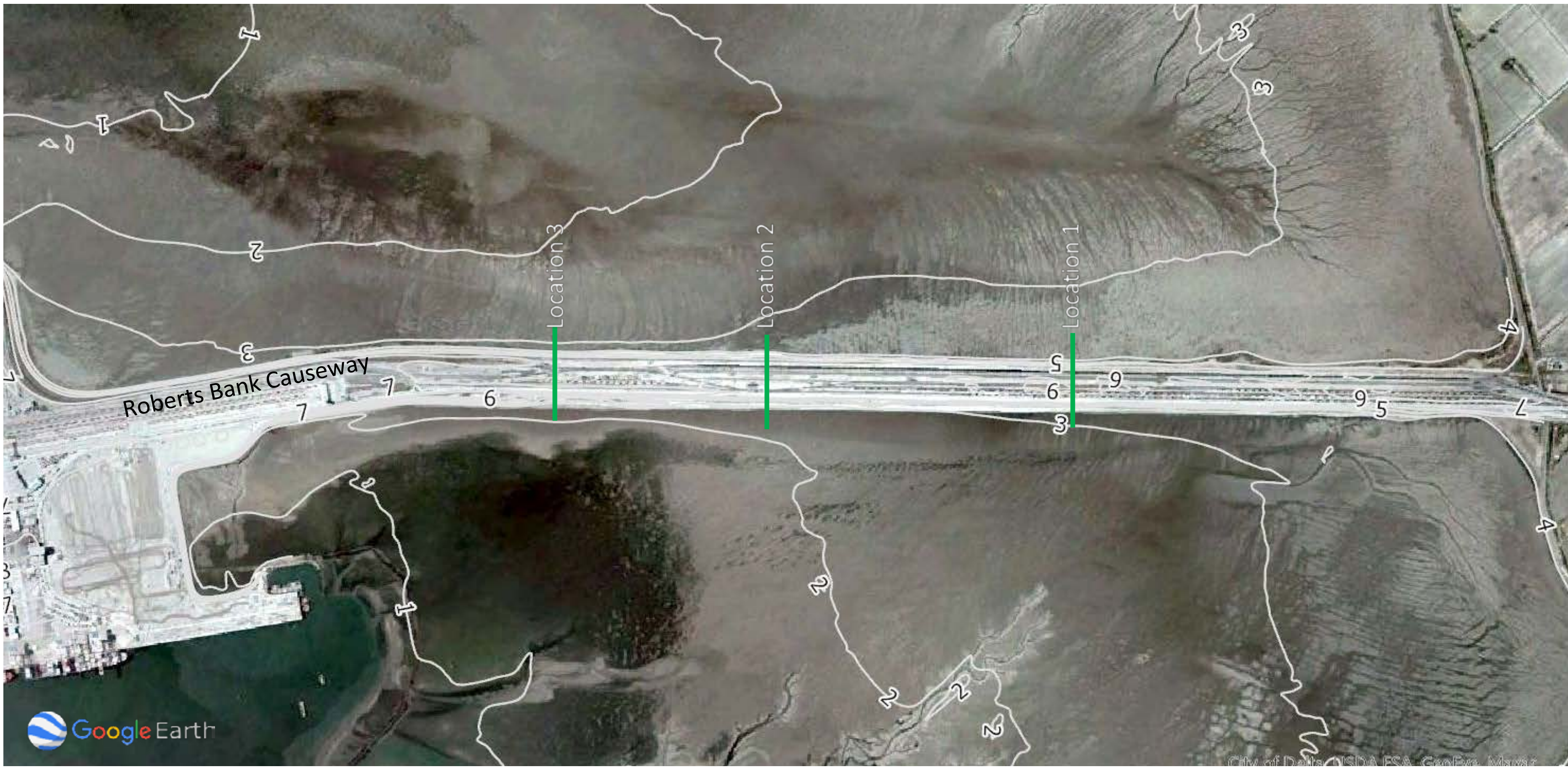

Photo source: Google Earth

RBT2 Roberts Bank Causeway Breach Hydraulic and Geomorphic Assessments Results Report – Revised Final

Prepared by:

Northwest Hydraulic Consultants Ltd.
30 Gostick Place
North Vancouver, BC V7M 3G3
Tel: (604) 980-6011
www.nhcweb.com

NHC Project Contact:
Derek Ray, P.Geo.
Principal

Prepared for:

Vancouver Fraser Port Authority
100 The Pointe, 999 Canada Place Vancouver, BC
V6C 3T4

July 27, 2021
Final Report, Rev. 2

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Date	Revision No.	Reviewer	Issued for
4th March 2021	0	Derek Ray	Client Review
6th April 2021	1	Derek Ray	Final Report
27th July 2021	2	Derek Ray	Revised Final Report[1]

[1] Final report was revised to correct minor errors in the text in Section 4.2.

Report prepared by:

E. C. WANG
29366

Aug 12, 2021

Edwin Wang, P.Eng.
Senior Hydrotechnical Engineer
Coastal Numerical Modelling

Report reviewed by:

D. A. RAY
#23833

Aug. 12, 2021

Derek Ray, P.Geo.
Senior Coastal Geomorphologist - Principal

DISCLAIMER

This report has been prepared by **Northwest Hydraulic Consultants Ltd.** for the benefit of Vancouver Fraser Port Authority for specific application to the RBT2 Roberts Bank Causeway Breach Hydraulic Assessment. The information and data contained herein represent **Northwest Hydraulic Consultants Ltd.** best professional judgment in light of the knowledge and information available to **Northwest Hydraulic Consultants Ltd.** at the time of preparation, and was prepared in accordance with generally accepted engineering and geoscience practices.

Except as required by law, this report and the information and data contained herein are to be treated as confidential and may be used and relied upon only by Vancouver Fraser Port Authority, its officers and employees. **Northwest Hydraulic Consultants Ltd.** denies any liability whatsoever to other parties who may obtain access to this report for any injury, loss or damage suffered by such parties arising from their use of, or reliance upon, this report or any of its contents.

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APPENDIX SECTIONS

Appendix A Overview of Existing Tidal Channels in the Fraser River Delta

1 INTRODUCTION

The Roberts Bank Terminal 2 Project (RBT2 or Project) is a proposed new container terminal located in Delta, B.C. The Project consists of three main components: 1) a new multi-berth marine container terminal; 2) a widened causeway and 3) an expanded tug basin.

The Vancouver Fraser Port Authority (VFPA) received an Information Request (IR) from the Government of Canada to provide any additional terminal and causeway design options (e.g., breaches) that could avoid or reduce habitat loss and potential disruption of juvenile salmon migration (IR2020-2.2). Northwest Hydraulic Consultants Ltd. (NHC) has been tasked with undertaking hydraulic and geomorphic analyses of breach concepts, located at the marine terminal or along the causeway, that could reduce the potential disruption of migrating juvenile salmon. Three causeway breach locations were found to be technically feasible from an engineering design and construction perspective. (Appendix IR2020-2.2-B). These breach locations would connect the tidal waters of the portion of Roberts Bank on the north side of the causeway with the tidal waters of the inter-causeway area. The objective of connecting tidal waters is to allow juvenile salmon to move between the north side of the project and the inter-causeway area. This report summarizes our findings of the hydraulic analysis and geomorphic evaluation for three causeway breach locations. A separate report summarizes our findings for a marine terminal breach location (Appendix IR2020-2-2-C).

Note that standard practice in coastal engineering is to reference elevations to Chart Datum (CD), which has a variable conversion factor to Geodetic Datum (GD) across the various regions within the model domain. As a result, the model results are referenced to GD, which for the purposes of this assessment, has a conversion adjustment factor of 3.0 m below CD.

1.1 Background

The port authority has previously investigated the potential installation of a breach in the Roberts Bank causeway as a means of transmitting tidal waters between the two sides to address concerns about water quality in the inter-causeway area. Two culvert configurations were analysed to estimate the potential volume of water that would be exchanged via tidal forcing: a 1 m diameter circular culvert and a 1.5 m high by 4 m wide box culvert, each approximately 150 m in length with the culvert invert set at 1.0 m below the Higher High Water (HHW), approximately 1,000 m from the shoreward end of the causeway. The results of the hydraulic analysis are summarised in a memo prepared by NHC (2005); this memo forms the basis of the port authority's response to the Review Panel's Information Request IR1-13[1]. The circular culvert and the box culvert maximum discharges were predicted to be less than 0.5 m^3/s and 1.0 m^3/s, respectively. The amount of tidal flow draining from the inter-causeway area was measured in the field to be 1,600 m^3/s and calculated from the model to be more than 2,000 m^3/s

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[1] For more information refer to VFPA responses to Information Request Package 1 (https://www.ceaa-acee.gc.ca/050/evaluations/document/116534), which includes the specific response to IR1-13 (https://www.ceaa-acee.gc.ca/050/documents/p80054/116545E.pdf)

during peak flows on a December 2004 mean tide, more than two thousand times the proposed culvert discharges.

In addition to estimating the potential volume of flow exchange through the two culvert configurations, the NHC (2005) memo offered comment on the likelihood of tidal channel formation that could result from flow passing through the structure and concluded that there would be a “substantial risk” that a flow passage structure could initiate a sequence of morphological changes on the tidal flats (e.g., tidal channel development). Given that there would be no measurable benefit to water quality because the volume exchanged through a culvert would be insignificant compared to the volume of water exchanged through ongoing tidal movements, there was an implied assumption that the risks of detrimental changes to the physical habitat far outweighed the benefits.

The topic of a causeway breach was also addressed during the public hearings of the Review Panel and summarised in VFPA’s Closing Remarks submitted to the Panel[2]. Based on the previous breach design configurations, the VFPA’s assessment indicated that it was unlikely that juvenile salmon would swim through a dark culvert and that the installation of a breach will not mitigate potential losses in juvenile salmon productivity from potential disruption to juvenile salmon migration.

In consideration of the recent IR from the Government of Canada, NHC’s assessment of breach locations presented below is based on design configurations that would facilitate direct access by juvenile salmon from one side of the Roberts Bank causeway to the other. The intent of NHC’s hydraulic and geomorphic analyses are to inform subsequent evaluations (by others; see response to IR2020-2.2) regarding reducing the potential disruption of juvenile salmon mitigation.

2 CAUSEWAY BREACH LOCATIONS

As described in the Stantec memo *RBT2 Causeway Breach Technical Evaluation* (Appendix IR2020-2.2-B), three causeway breach locations, with either bridge or culvert crossing structures, were identified with others for evaluation (Figure 2.1). These locations are representative of the range of constraints along the causeway where a breach could potentially be installed, and do not necessarily represent an ultimate installation location (should one of these locations be pursued further). A concrete box culvert configuration was found to be the only structure that is technically feasible from an engineering design and constructability standpoint at all three locations. The open deck bridge structure is not feasible at any of the locations, as there is insufficient elevation to satisfy the freeboard design criteria[3] (see Appendix IR2020-2.2-B for details about the freeboard requirements).

The technically feasible conceptual culvert design at locations 1, 2, and 3 (from an engineering and constructability standpoint) consist of two double precast concrete box culverts (Appendix IR2020-2.2-

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[2] Environmental Assessment of The Roberts Bank Terminal 2 Project Closing Submission of the Vancouver Fraser Port Authority (https://www.ceaa-acee.gc.ca/050/documents/p80054/132546E.pdf)

[3] Freeboard is defined as the clearance above the design high water level (including future sea level rise) to the underside of the bridge span.

B). For location 1 (Figure 2.2), each box culvert has inner dimensions of 2,500 mm (width) x 1,890 mm (height), and for the purposes of the hydraulic assessment it was assumed that location 2 had the same culvert dimensions[4]. For location 3, the inner dimension of each of the four concrete box culverts is assumed to be 2,500 mm (width) x 2,940 mm (height). Based on the inner culvert dimensions for all locations, the effective width[5] is about 10 m. For the purposes of this hydraulic assessment, an effective channel width of approximately 10 m was considered to provide suitable cross-sectional area to accommodate migration by juvenile salmon (see response to IR2020-2.2 for more information).

For the purposes of this hydraulic assessment, which was carried out in parallel with the engineering evaluation of breach locations, a multi-box culvert structure has been assumed for locations 1 and 2 and a bridge structure at location 3. A conceptual 12 m clear span bridge design (Figure 2.3) at location 3 has an effective opening of about 11 m wide. Although the engineering evaluation concluded (after the hydraulic analysis was complete) that a bridge structure is not technically feasible at any of the causeway locations (based on an engineering design and constructability standpoint; Appendix IR2020-2.2-B), the model results for a bridge structure at location 3 can be used to determine the hydraulic characteristics of a box culvert structure at location 3, as described subsequently.

The effective width and channel bottom (invert) elevations modelled for each causeway breach location are summarised below in Table 2.1. Based on available topographic information, channel invert elevations were set at the natural bed elevation of the adjacent tidal flats on Roberts Bank on both the north and south sides of the causeway. Since the invert elevations differ across the length of the channel for each location, this results in the channel sloping southward for locations 1, and northward for locations 2 and 3.

Table 2.1 Summary of physical parameters for each modelled causeway breach location

	Crossing Solution	Effective Width (m)	North Invert El. (m CD / GD)	South Invert El. (m CD / GD)
Location 1	Box Culverts	10	3.7 / 0.7	3.4 / 0.4
Location 2	Box Culverts	10	3.1 / 0.1	3.6 / 0.6
Location 3*	Clear-span Bridge	11	2.8 / -0.2	3.0 / 0

* Based on the clear-span bridge (open deck) structural concept. Effective width for the culvert concept would be 10 m and hydraulic parameters were determined based on modelling results for the clear-span bridge.

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[4] Appendix IR2020-2.2-B outlines that section drawings for location 2 were not created given similarities to location 1. Based on its location in deeper waters, location 2 could accommodate a greater inner dimension height, but was assumed for the purposes of this assessment to have the same configuration as location 1.

[5] Effective width refers to the portion of the channel that is available to convey flow.

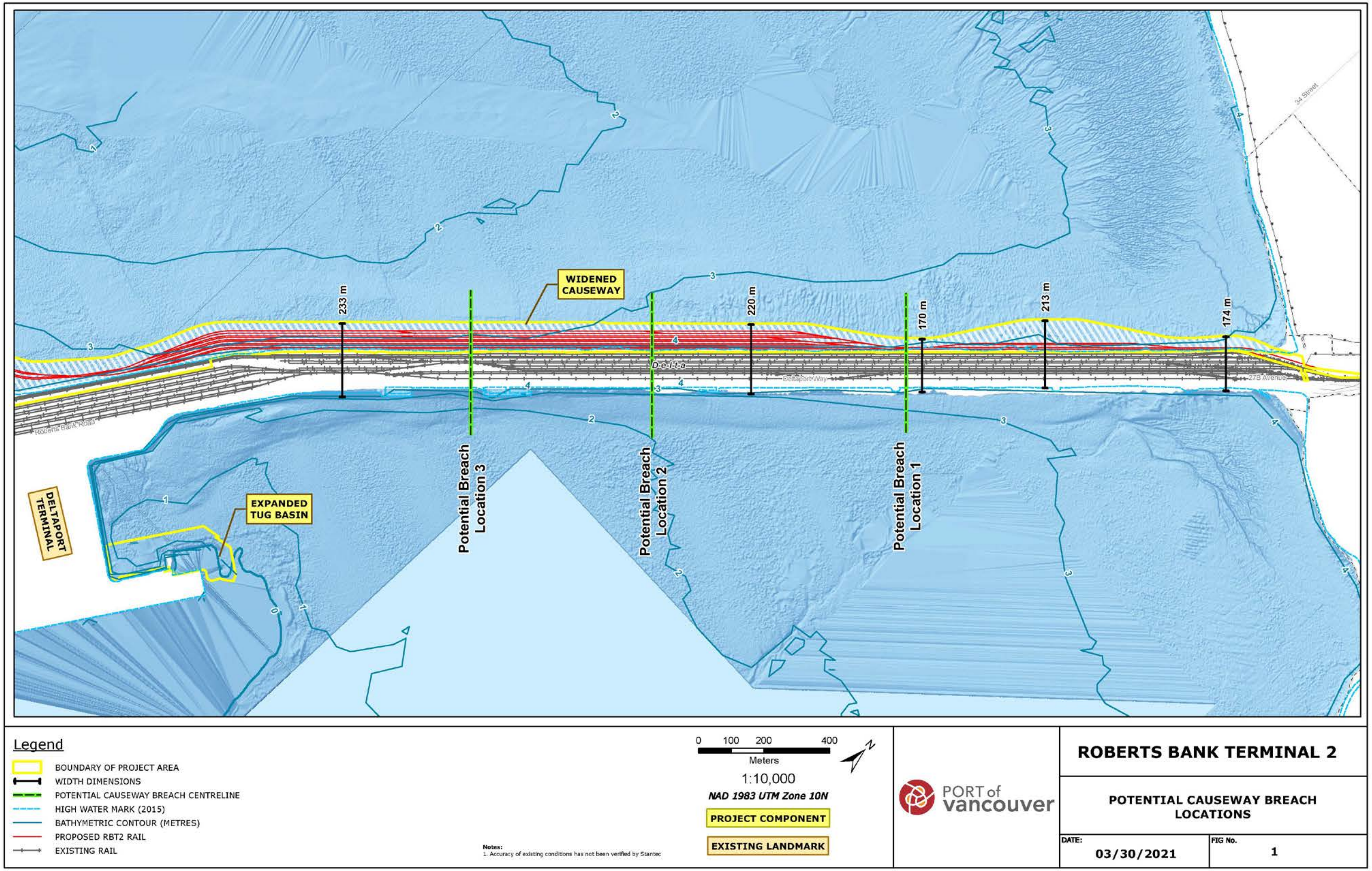

Figure 2.1 Assessed causeway breach locations (from Appendix IR2020-2.2-B, Appendix A).

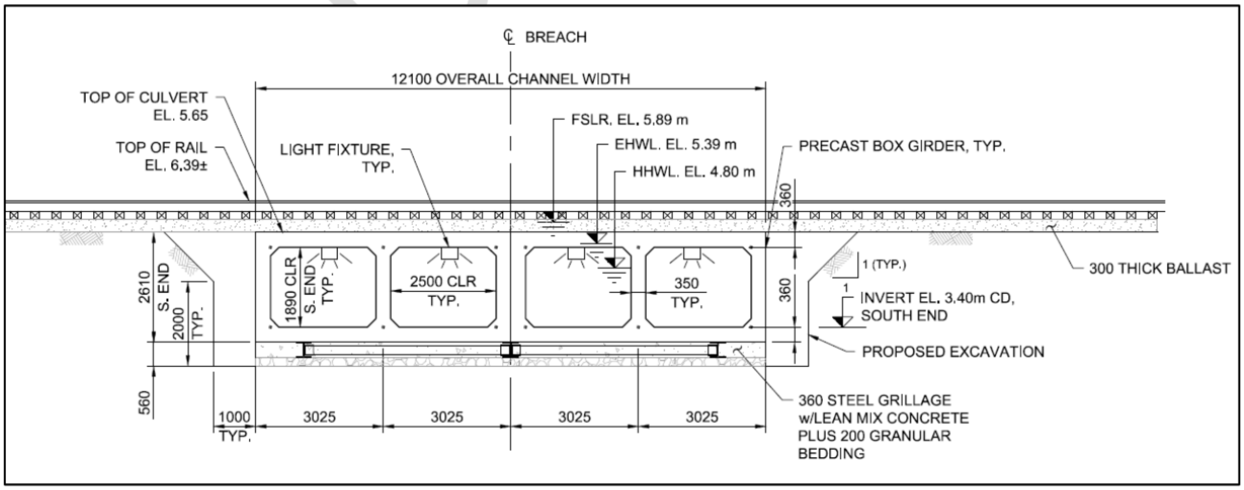

Figure 2.2 Conceptual concrete box culvert geometry under existing causeway tracks at causeway breach location 1 (from Appendix IR2020-2.2-B). Note that elevations are preliminary.

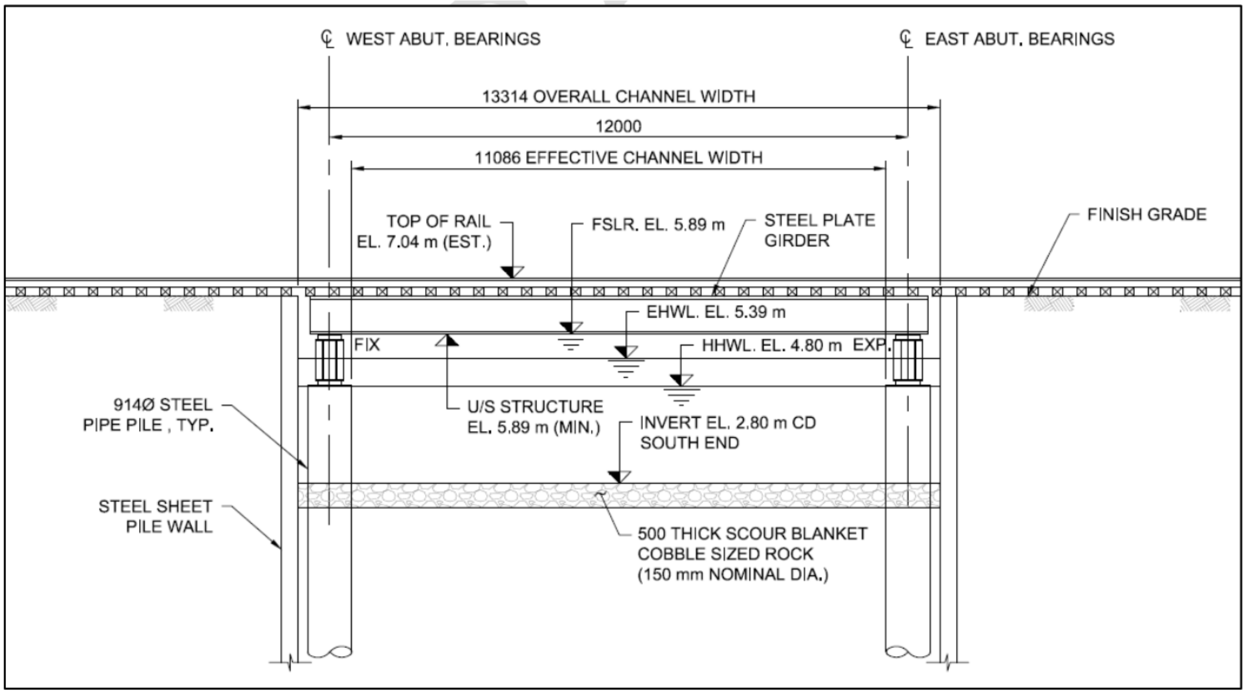

Figure 2.3 Conceptual geometry with 12 m clear span bridge structure for areas under existing causeway tracks at causeway breach location 3 (from Appendix IR2020-2.2-B). Note that elevations are preliminary.

3 HYDRAULIC ASSESSMENT

An assessment was conducted for the purposes of evaluating hydraulic characteristics for each of the three potential breach locations to support further environmental evaluations. Parameters of primary concern to assessing each location that could influence juvenile salmon migration include:

- percentage time wetted;
- flow velocity;
- flow rate (volume over time); and
- potential changes to salinity.

Flow through the breach concepts is driven by tide height differences on either side of the causeway, while the amount of time that the channel will be wetted is essentially a function of tide height and channel bottom elevation. Therefore, the assessment was conducted using a combination of empirical analysis and numerical modelling.

The numerical modelling was conducted using the TELEMAC SYSTEM to evaluate changes in hydraulics associated with the causeway breach concepts. TELEMAC is a suite of finite element computer programs developed by the Laboratoire National d'Hydraulique et Environnement (LNHE), a department of Electricité de France's Research and Development Division.

3.1 Model Implementation

For the purposes of this assessment on the three breach concepts, a few minor modifications were made to the existing Roberts Bank TELEMAC model that was previously used to assess project interactions with coastal geomorphology processes, as reported in the Environmental Impact Statement (EIS). Minor modifications to the model and simplifying assumptions incorporated in this assessment are summarised as follows:

1. Updated Telemac version v8p0r0 is used instead of Telemac version r3356;
2. Mesh refinement in the inter-causeway region and near the potential breach locations to improve model resolution at key locations;
3. 2D depth averaged model is used instead of 3D model;
4. Wind forcing is not considered; and
5. The following simplifying assumptions were made:
    - Concrete box culvert configurations at location 1 and location 2 are represented as open channels in the model using an adjustment for the effective width. Tides are not anticipated to reach the full clear height of the culverts over the course of the December 2012 simulation period, which was chosen to be representative of general water level conditions.
    - Representative period excludes storm surge and future sea level rise.

- Modelled flows within the clear-span channel at location 3 are scaled down by 10% to account for the reduction in cross-sectional area for the alternative concrete box culvert structure configuration at location 3.

The 2D model is appropriate for the level of this hydraulic analysis. It is computationally more efficient than the 3D model, permitting faster model run-times and therefore more model run tests but a key limitation of a 2D model is that it does not provide insight into the vertical flow (z-axis) direction. Thus, it may not accurately predict the tidal hydraulics in a highly stratified environment, such as typically governed over the adjacent tidal flats or where deep, complex circulations occur. Nevertheless, for the purpose of evaluating the hydraulic characteristics of each breach location (in which highly stratified waters are not expected), the 2D model provides an appropriate approximation of the tidal hydraulics during juvenile salmon migration. Wind forcing was not considered because it would not be expected to affect the dominant hydraulic conditions in the assessed channels.

The TELEMAC model mesh used for the study extends from Ballenas Island to Port Renfrew and south into Puget Sound (Figure 3.1). The model also includes the Fraser River up to km 36, upstream of New Westminster and downstream of the Skytrain Bridge. The model mesh contains approximately 83,000 nodes and 160,000 elements. The element lengths vary from approximately 500 m in the Strait of Georgia to about 3 m in the vicinity of the potential breaches. Model geometry and model mesh resolution for location 3 is shown in Figure 3.2.

The model bathymetry was derived using the following distinct datasets:

1. In the vicinity of the existing Roberts Bank terminals and surrounding areas, 2011 bathymetric surveys and LiDAR were used;
2. In the Fraser River, 2004 Public Works and Government Service Canada (PWGSC) bathymetric surveys and 2005 Fraser Basin Council LiDAR were used; and
3. In Puget Sound, the Strait of Georgia and Juan de Fuca Strait, the coarse dataset comprising Canadian Hydrographic Service (CHS) bathymetry data used in the Deltaport Third Berth (DP3) project was used.

Tides (on the ocean boundary) are simulated with amplitudes and phases of dominant tidal constituents along the open boundaries obtained from the TPXO model (Egbert and Erofeeva, 2002). Inflows (on the upstream boundary) to the Fraser River were obtained from the hydraulic model of the lower Fraser River that uses the MIKE11 one-dimensional hydrodynamic software developed by the Danish Hydraulic Institute. NHC developed the lower Fraser River MIKE11 model for the Fraser Basin Council in 2006 (NHC, 2006) and updated it for BC Ministry of Environment two years later (NHC, 2008).

The model simulation utilized December 2012 conditions for both ocean water levels and Fraser River flow. This period offers good representation of typical hydraulic conditions for assessing the causeway breach concepts that would be used in the spring-summer period during juvenile salmon migration. The December 2012 period was selected because of the availability of data that was used to calibrate and validate a Strait of Georgia and Roberts Bank hydrodynamic-morphodynamic model that NHC previously developed as part of the EIS assessment on coastal geomorphology processes.

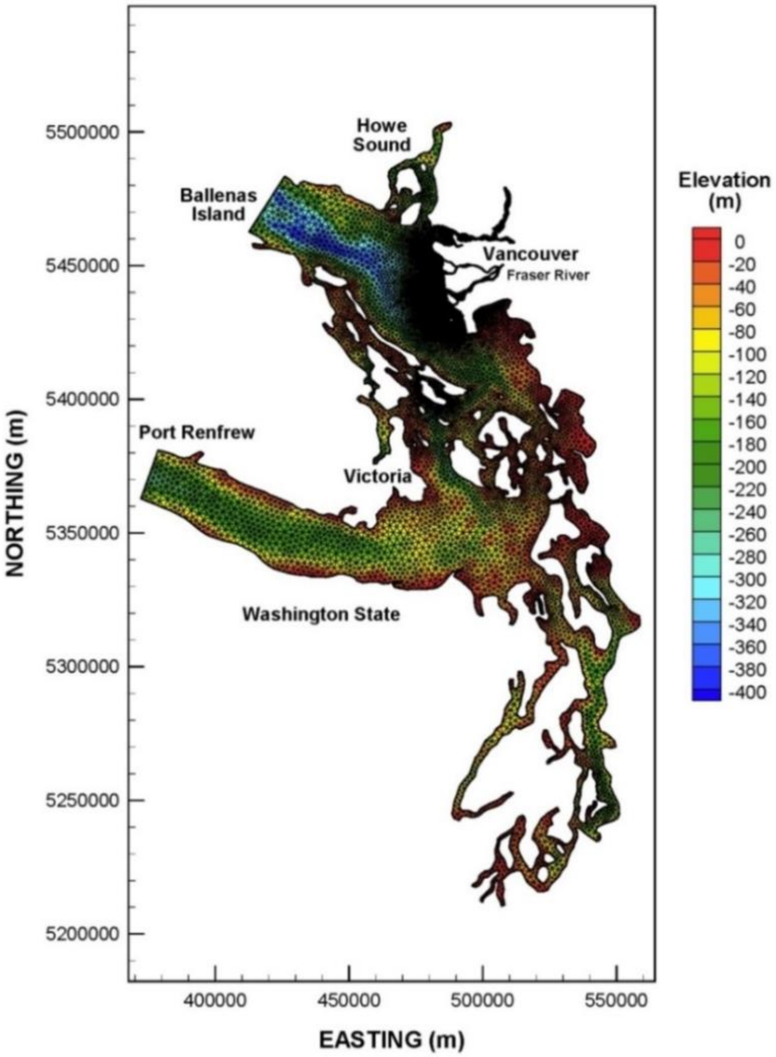

Figure 3.1 TELEMAC model domain used for the hydraulic assessment.

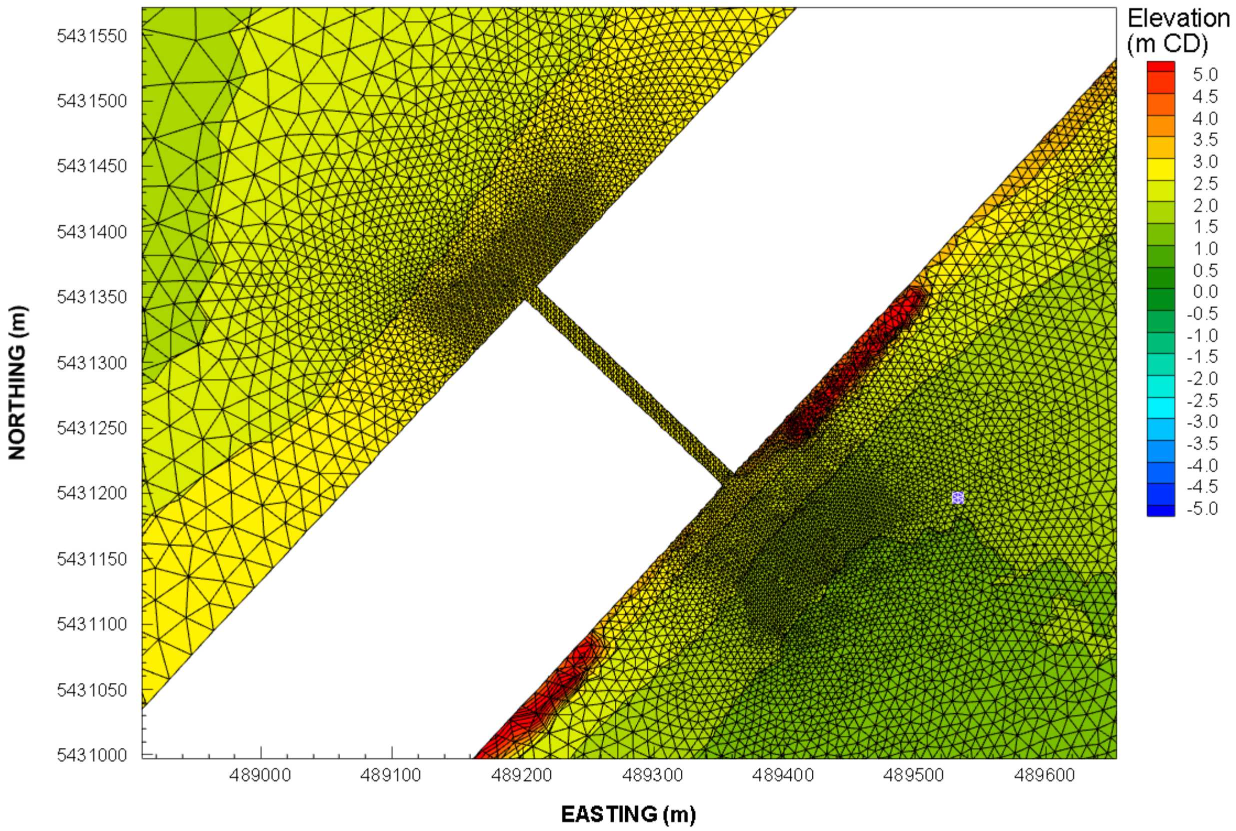

Figure 3.2 **TELEMAC model geometry and model mesh resolution at and near causeway breach location 3. The causeway boundaries (shown in white) correspond with the limits of the model mesh.**

3.2 Tidal Analysis

Table 3.1 summarizes the percentage exceedance of tide level above specific intertidal bed elevations based on predicted 2020 Point Atkinson water levels. Considering minimum depth criteria of 50 cm and channel invert elevation ranges presented in Table 2.1, the breach concept at location 1 would be adequately wetted to facilitate fish migration about 9% of the time, at location 2 approximately 12% of the time, and the breach at location 3 would be adequately wetted about 37% of the time[6]. The criterion of 50 cm of depth was assumed as the minimum water depth at which juvenile salmonids could be expected to move freely and unimpeded, based on habitat use data on juvenile chinook from the Fraser River estuary (Mesa, 1985) and the Columbia River estuary (Hering et al., 2010).

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[6] For each breach location, the percentage is based on the average adequately wetted time (greater than 0.5 m) at the highest elevation entrance (north or south side).

Table 3.1 Tide level percentage exceedance based on 2020 Point Atkinson tide level

Tide Level (m GD)	Tide Level (m CD)	% Exceedance
1.5	4.5	1.9%
1.0	4.0	15.8%
0.5	3.5	36.5%
0.0	3.0	57.4%
-0.5	2.5	70.8%
-1.0	2.0	80.9%
-1.5	1.5	89.3%
-2.0	1.0	95.7%

3.3 Hydraulic Analysis

The local change from the causeway breach locations on hydraulics at Roberts Bank was assessed by examining the hydrodynamic model simulation over the December 2012 flow conditions, which include a series of typical spring and neap tide cycles and so offer a reasonable representation of typical conditions[7]. The Fraser River flow at Hope and Point Atkinson tidal conditions over the simulation period are shown in Figure 3.3. Variations in Fraser River discharge will have essentially no influence on the hydraulics of the breach locations because flow across the breach is driven by tide height, which is independent of Fraser River flow at this location. Two analyses were conducted:

1. Flow rate and speed in the channel plotted as a time-series over the representative simulation period; and
2. Maximum velocity predicted over the representative simulation period and displayed spatially on a map.

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[7] For additional information that describes how tides and Fraser River flows are representative, please refer to Sections 4.1 and 4.2 of EIS Appendix 9.5-A (CIAR Document #181) and VFPA's responses to IR3-41 and IR12-09 (CIAR Document #934).

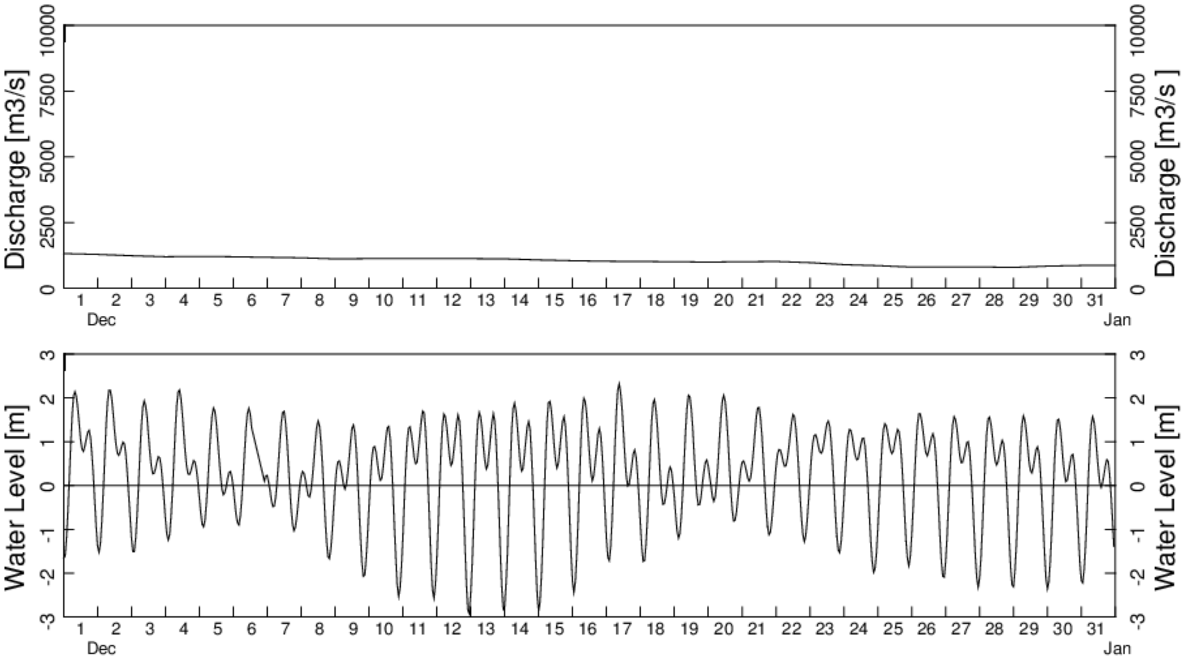

Figure 3.3 Hydraulic conditions for the representative period - Fraser River discharge (top) and tide height (bottom). Tide height (water level in meters) referenced to Geodetic Datum.

3.3.1 Flow Analysis

Key criteria for the causeway breaches (in addition to water depth) include flow rate and velocity (speed) over time. The flow rate to and from the north side of the causeway through the breach also provides an indicator of the potential impact the breach concept might have on salinity patterns in the inter-causeway area. For reference, the tidal flow exchange into and out of the inter-causeway area that passes between the Roberts Bank terminals and the BC Ferries terminal to the south was previously assessed to be between 1,600 m^3/s and 2,000 m^3/s, based on both field measurements and numerical modelling (NHC, 2005)[8]. As discussed below, the flow volume that is expected to pass through each of the breach concepts is very small in comparison.

Location 1

Figure 3.4 shows the time series of selected key hydraulic parameters for location 1 (based on the representative simulation period). The first panel shows the water level at the north and south ends of the breach (note the water levels are quite similar and differences are not resolvable at the scale of the figure). The second panel shows the water level difference between the two entrances. The third panel

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[8] For more information, refer to CIAR #540, From the Review Panel Secretariat to the Review Panel re: Potential Effects of Opening the Causeway Document (Available at: https://www.ceaa-acee.gc.ca/050/documents/p80054/115549E.pdf) and CIAR #934, Vancouver Fraser Port Authority response to Review Panel IR1-13 Causeway Design (Available at: https://www.ceaa-acee.gc.ca/050/documents/p80054/122026E.pdf

shows the flow rate across the breach. Positive values indicate flow into the north side of the causeway (i.e., flood) and negative values indicate flow into the inter-causeway area (i.e., ebb). The bottom panel shows the water velocity (speed) at the midway point of the breach.

The results shown in Figure 3.4 indicate:

- The water level differences between the two entrances of the location 1 channel are generally less than 0.3 m. The maximum water level difference occurs during a large rising tide;
- Maximum flow exchange through location 1 is about ±3.2 m^3/s. As noted above, this flow rate is very small compared to the exchange of tidal flow into and out of the inter-causeway area and the overall volume of water exchanged through the channel is not expected to influence the broader salinity distribution in the inter-causeway area, though there may be a localised effect in the zone proximal to the south entrance (see Section 3.3.3);
- The tidal exchange across the breach is asymmetric. Inflows (from the inter-causeway area to the north side of the causeway) are typically short-lived (about an hour) before the flow reverses in direction. The outflows (into the inter-causeway area) are typically 4-5 hours long in duration.
- The water velocity (speed) in the breach is generally less than 0.3 m/s. Speeds greater than 1.0 m/s occur during the large tidal swing periods. Maximum speed over the course of the simulation period is 1.1 m/s but the duration is short-lived.

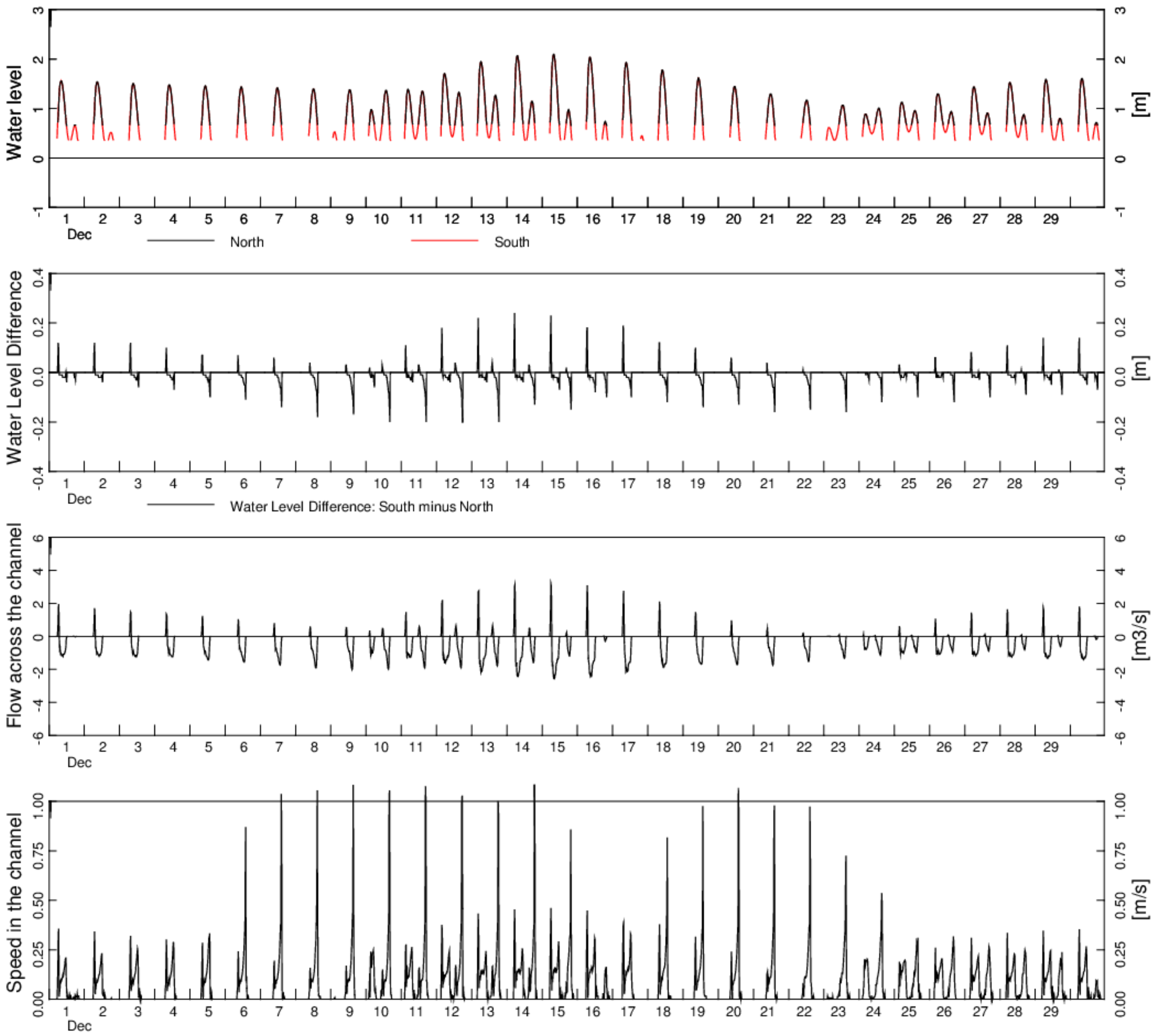


Figure 3.4 **Time series of selected hydraulic parameters at location 1 (based on representative simulation period). Tide height (water level in meters) referenced to Geodetic Datum.**

<u>Location 2</u>

Figure 3.5 shows the time series of selected key hydraulic parameters for location 2 based on the representative simulation period. The findings are similar to that for location 1. The maximum flow exchange rate is about ±2.6 m^3/s, which is lower than the predicted rate at location 1. The reason for the larger peak flow exchange at location 1 compared to location 2 is because of the delay in tide height rising in the upper foreshore region between the inter-causeway area and the north side of the causeway. This delay results in a larger surface gradient between the two ends of the breach and hence a somewhat higher maximum flow rate.

As with location 1, maximum speed in the channel is generally quite low (typically less than 0.2 m/s) but, maximum speeds are briefly somewhat higher, peaking at 1.4 m/s during the largest tidal exchange.

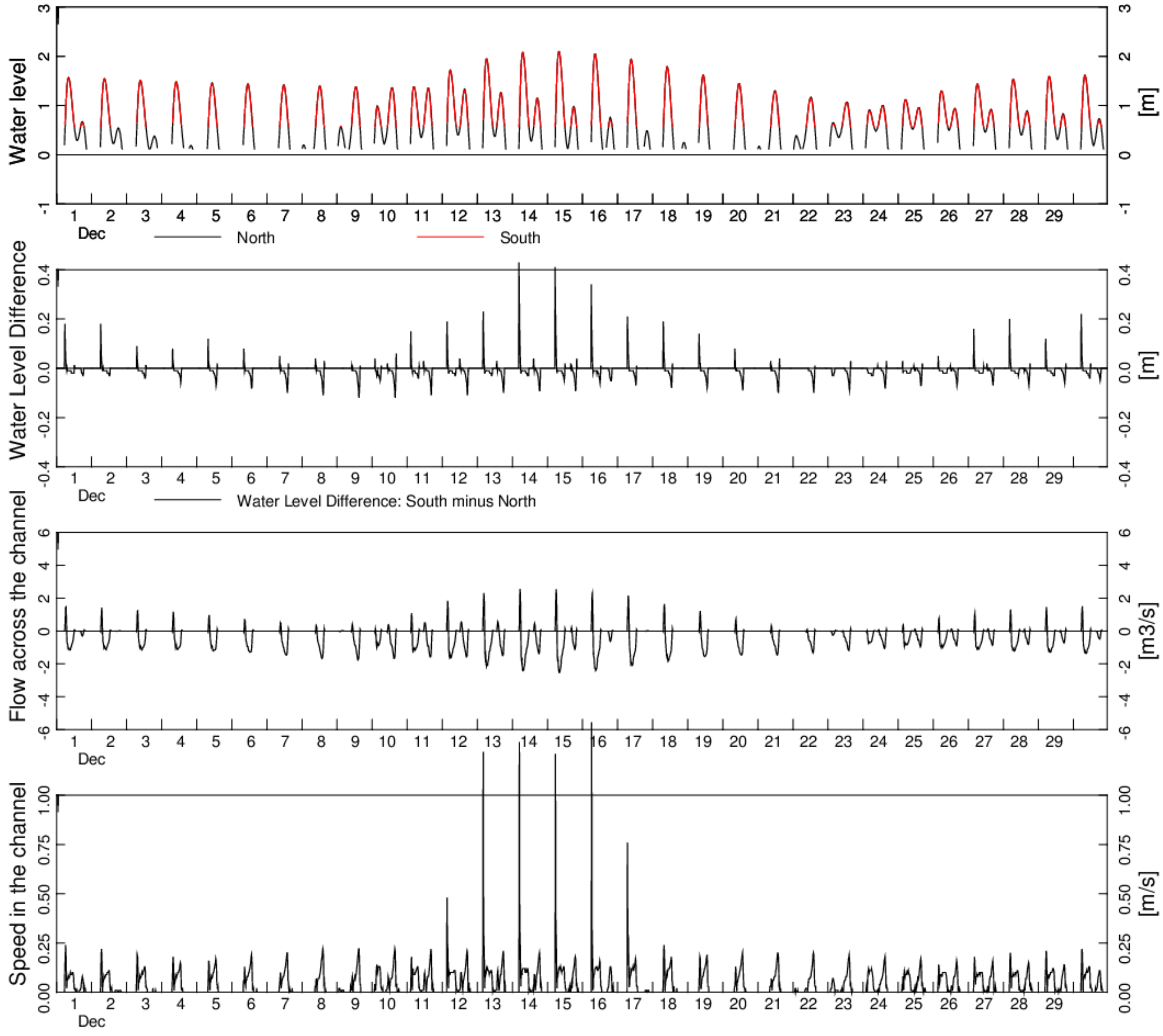


Figure 3.5 Time series of selected hydraulic parameters at location 2 (based on representative simulation period). Tide height (water level in meters) referenced to Geodetic Datum.

<u>Location 3</u>

Figure 3.6 shows the time series of selected key hydraulic parameters for location 3 based on the representative simulation period. The findings are similar to that for locations 1 and 2. The maximum flow exchange rate for an open channel is about ±3.7 m^3/s (or about 3.3 m^3/s for the culvert configuration) which is greater than the predicted exchange rate for locations 1 and 2. The larger flow exchange is expected as the invert (bottom) elevation of location 3 is lower than the invert elevations at locations 1 and 2. The water velocity in the breach is typically less than 0.3 m/s with higher values

occurring during large spring tides. The maximum velocity is about 1.0 m/s but occurs only during brief periods during some of the tide swings.

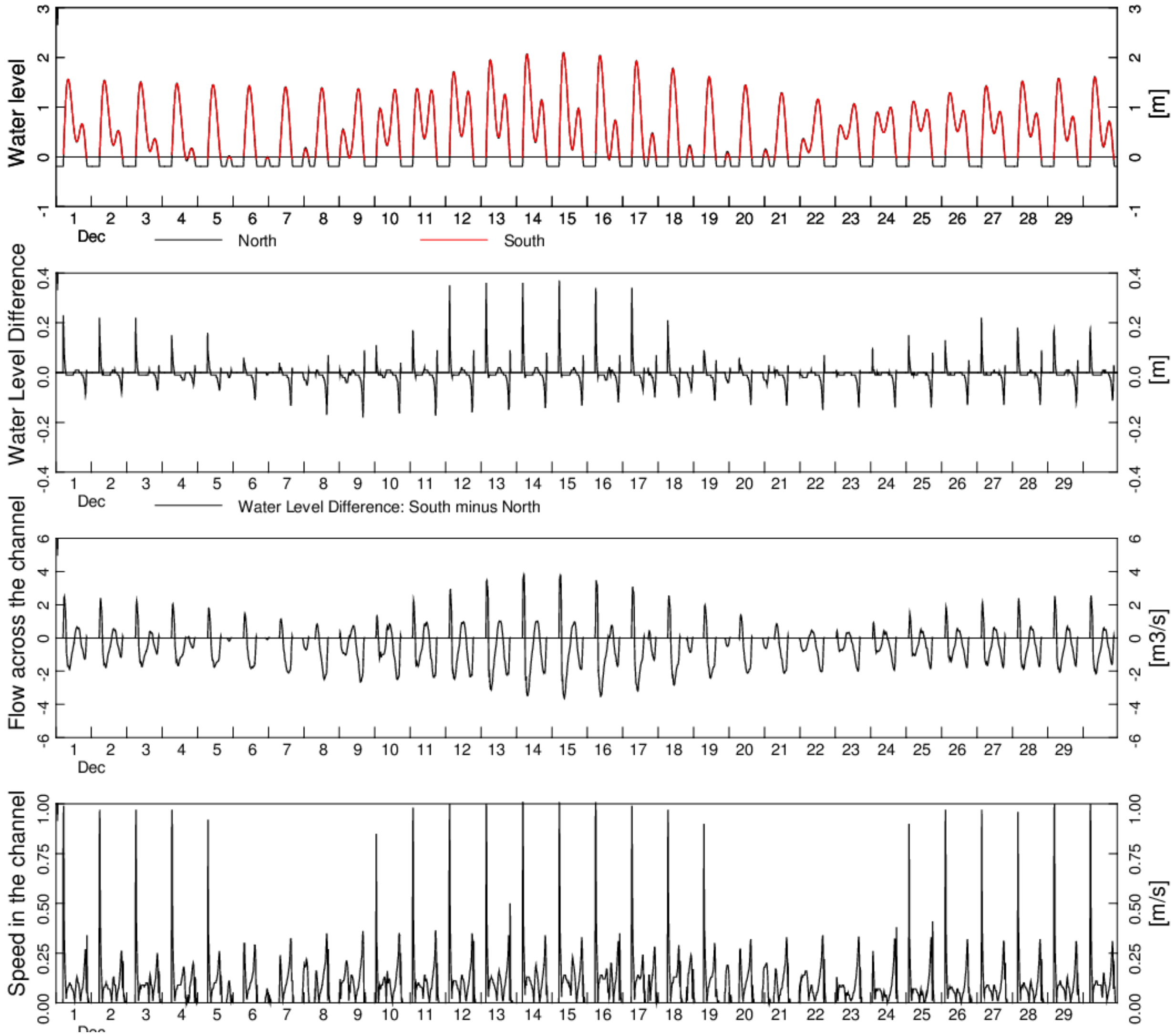


Figure 3.6 **Time series of selected hydraulic parameters at location 3 (based on representative simulation period). Tide height (water level in meters) referenced to Geodetic Datum.**

3.3.2 Flow Velocity Distribution

Figure 3.7, Figure 3.8 and Figure 3.9 show the maximum depth-averaged flow velocity distribution based on 15-minute interval time-steps over the course of the representative 30-day simulation period for location 1, location 2 and location 3, respectively. Maximum speeds of up to 1.2 m/s are predicted at the north entrance of each of the location 1 and location 3 breaches. At location 2 the changes in current velocity at the ends of the channel are predicted to be greater on the inter-causeway tidal flats than on the tidal flats on the north side of the causeway.

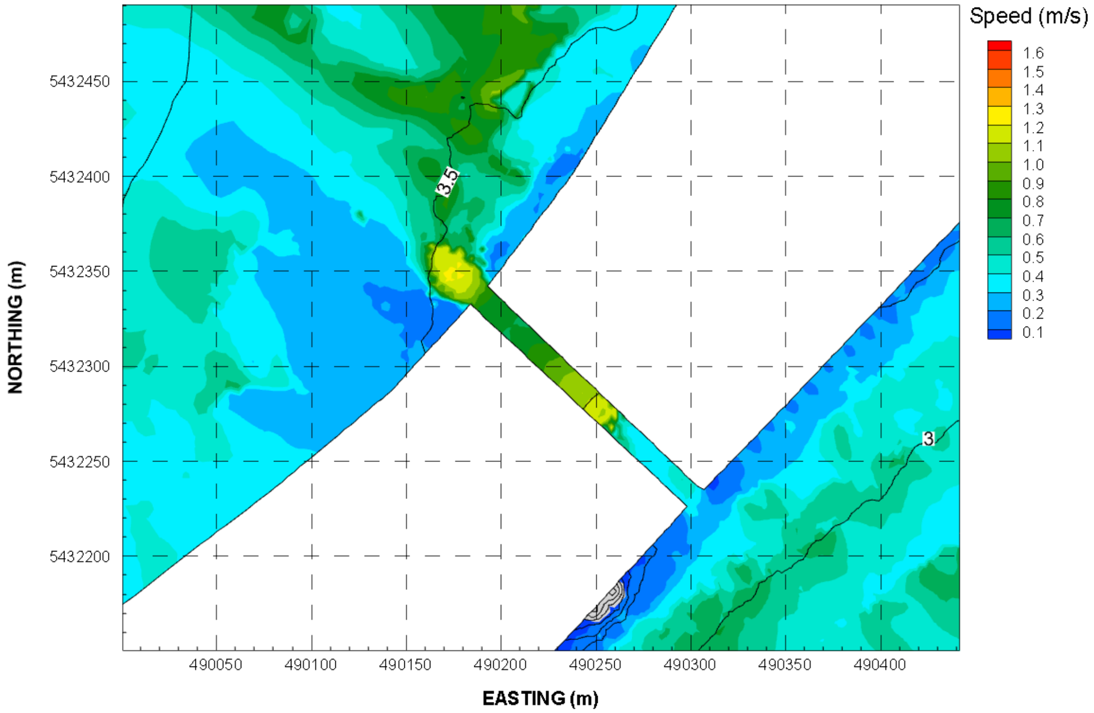


Figure 3.7 Maximum velocity distribution at location 1 based on representative simulation period.

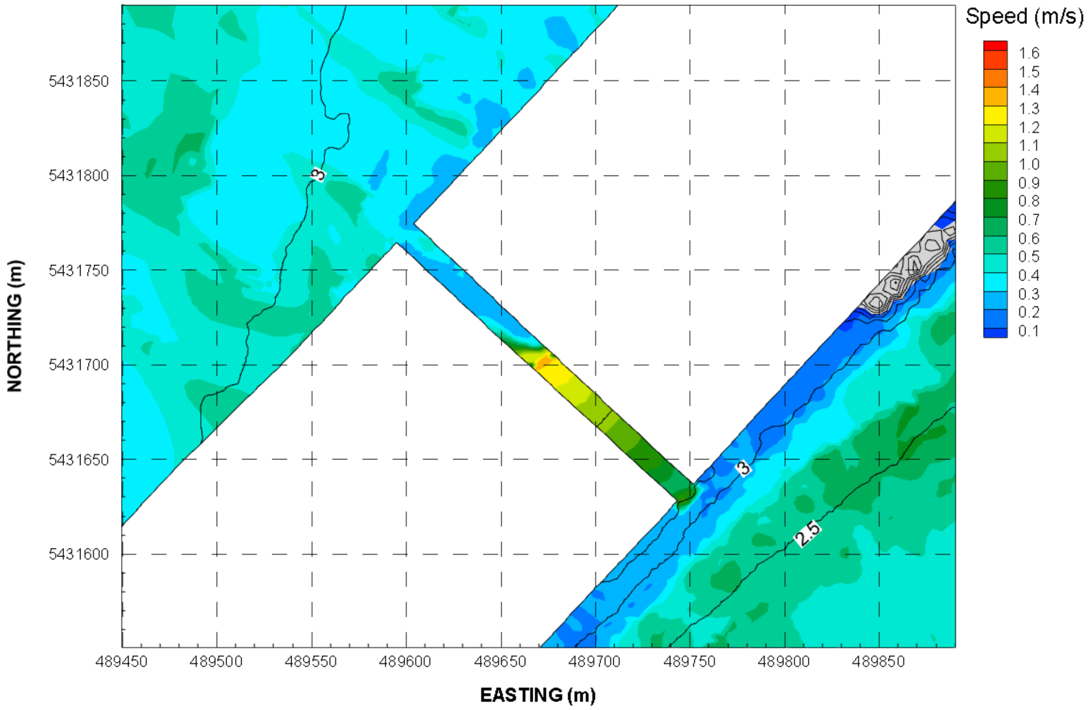


Figure 3.8 Maximum velocity distribution at location 2 based on representative simulation period.

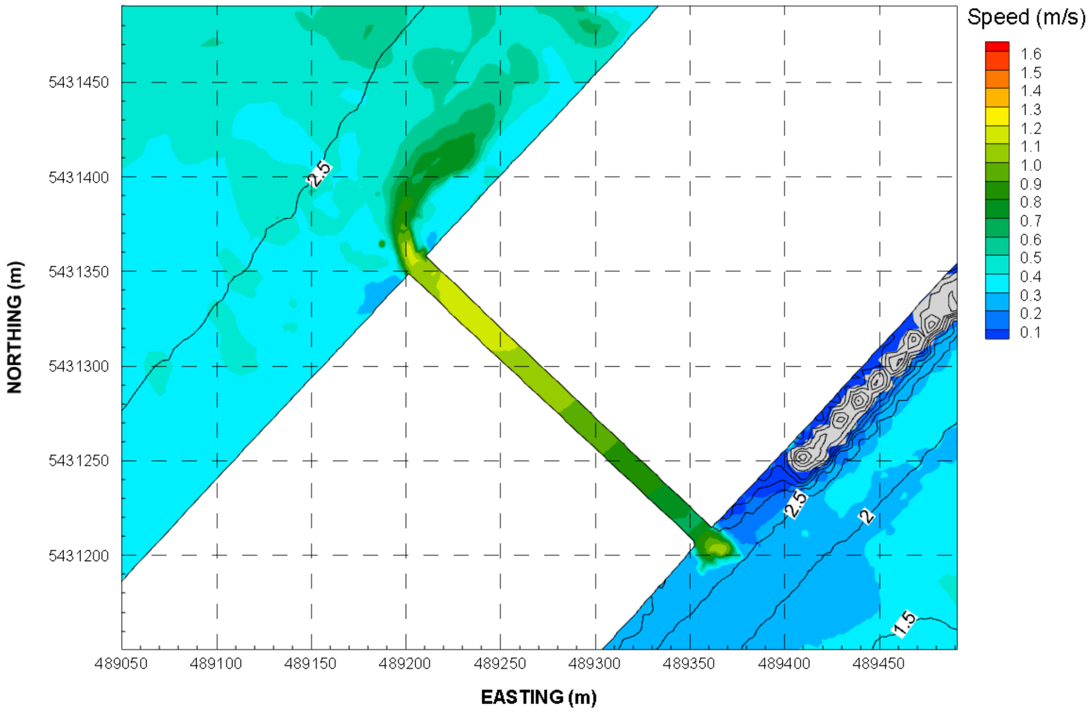


Figure 3.9 Maximum velocity distribution at location 3 based on representative simulation period.

3.3.3 Potential Changes to Salinity

The inter-causeway area presently receives minimal freshwater inputs from the Fraser River while the area on the north side of the causeway experiences daily and seasonal fluctuations in water column salinity in response to tides and Fraser River discharge. Flow exchange across a potential breach in the causeway has the potential to alter the salinity regime on both sides. As noted above, the overall volume of water passing through each potential breach location is very small compared to the total volume of water exchanged over the tidal flats.

In order to assess the relative influence that each potential breach location might have on salinity, the TELEMAC model was run in 2D mode for the representative simulation period. Two key points about this approach are noted:

i. The 2D model does not represent stratified (layered) flow and so the results should not be interpreted in any absolute sense; and

ii. The period of time that is represented in the model run is reflective of low Fraser River winter discharge. Therefore, the difference in salinity on either side of the causeway is much lower during this period than during the summer freshet period and so professional judgement is applied to assessing the potential influence that a breach would have on salinity during freshet conditions.

As described below, 50th percentile salinity maps under the existing conditions case (based on representative December 2012 tidal conditions), with a potential breach in place, are used to assess the potential changes that each breach location might have on salinity. The 50th percentile value is a statistical representation that is computed based on modelled salinity values at 15-minute intervals during the simulation period. Fifty percent of the time, salinities are higher than that value at a given location, and 50% of the time, they are lower. It is a useful way to illustrate the general change from each proposed breach location on salinity under the full range of water levels and Canoe Passage discharges during the simulation period as it focuses on the median (50th percentile) salinity.

Figure 3.10, Figure 3.11, and Figure 3.12 show the 50th percentile salinity distribution over the course of the simulation period for location 1, location 2 and location 3, respectively. The top image on each figure shows the large-scale view and the bottom image shows the close-up view of the salinity distribution near each breach location. The figures indicate that the potential breach locations have a subtle influence on the 50th percentile salinity distribution in the inter-causeway area, and that this influence is experienced over a relatively small area. This is not unexpected as the flow rate analysis (Section 3.3.1) has shown that the flow rates across the breaches are small compared to tidal flow into and out of the inter-causeway area. Furthermore, flow rates from the inter-causeway area to the area north of the causeway are lower and northward flows have a much shorter duration.

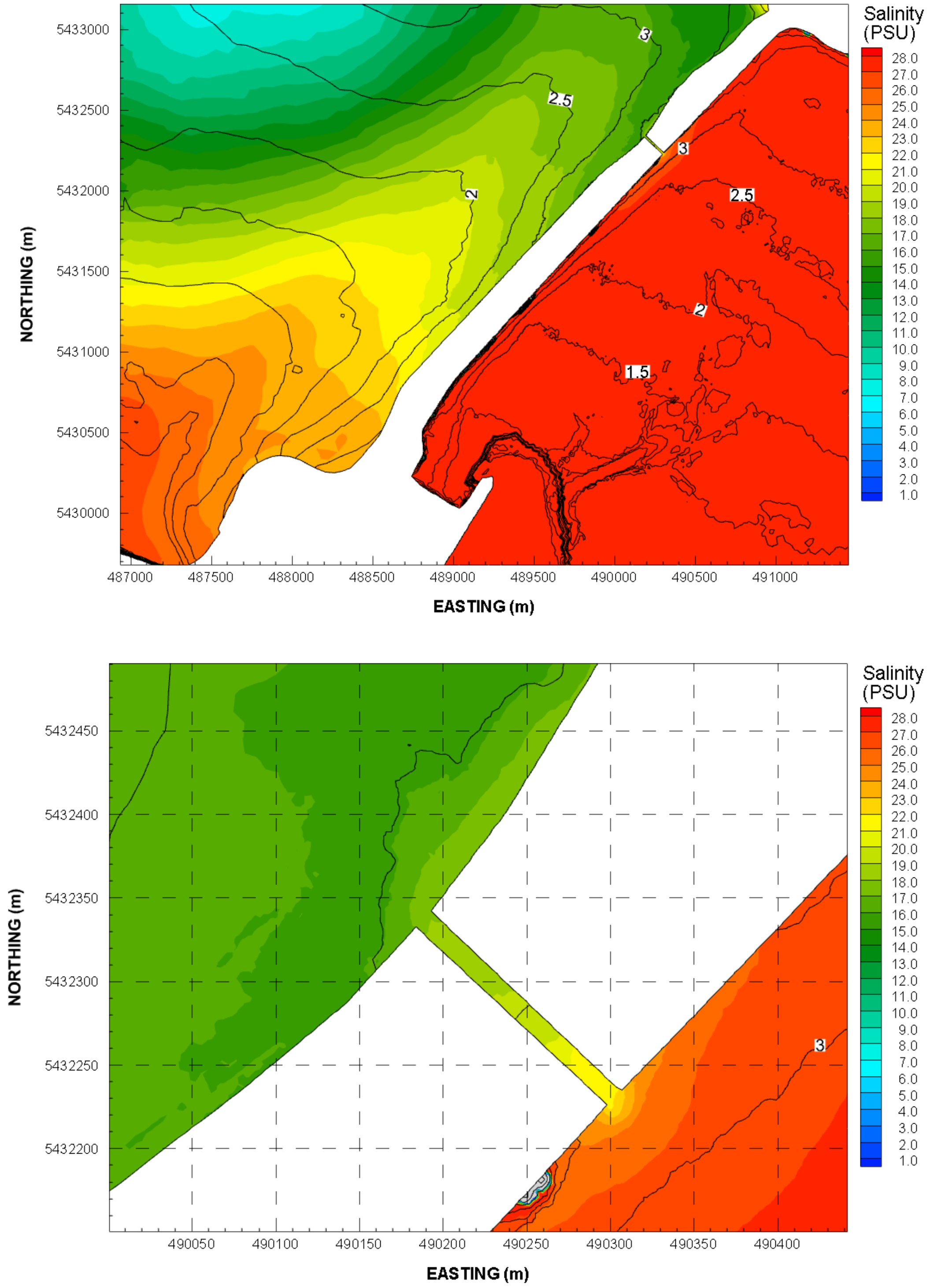


Figure 3.10 50th percentile Salinity distribution at location 1 based on representative simulation period.

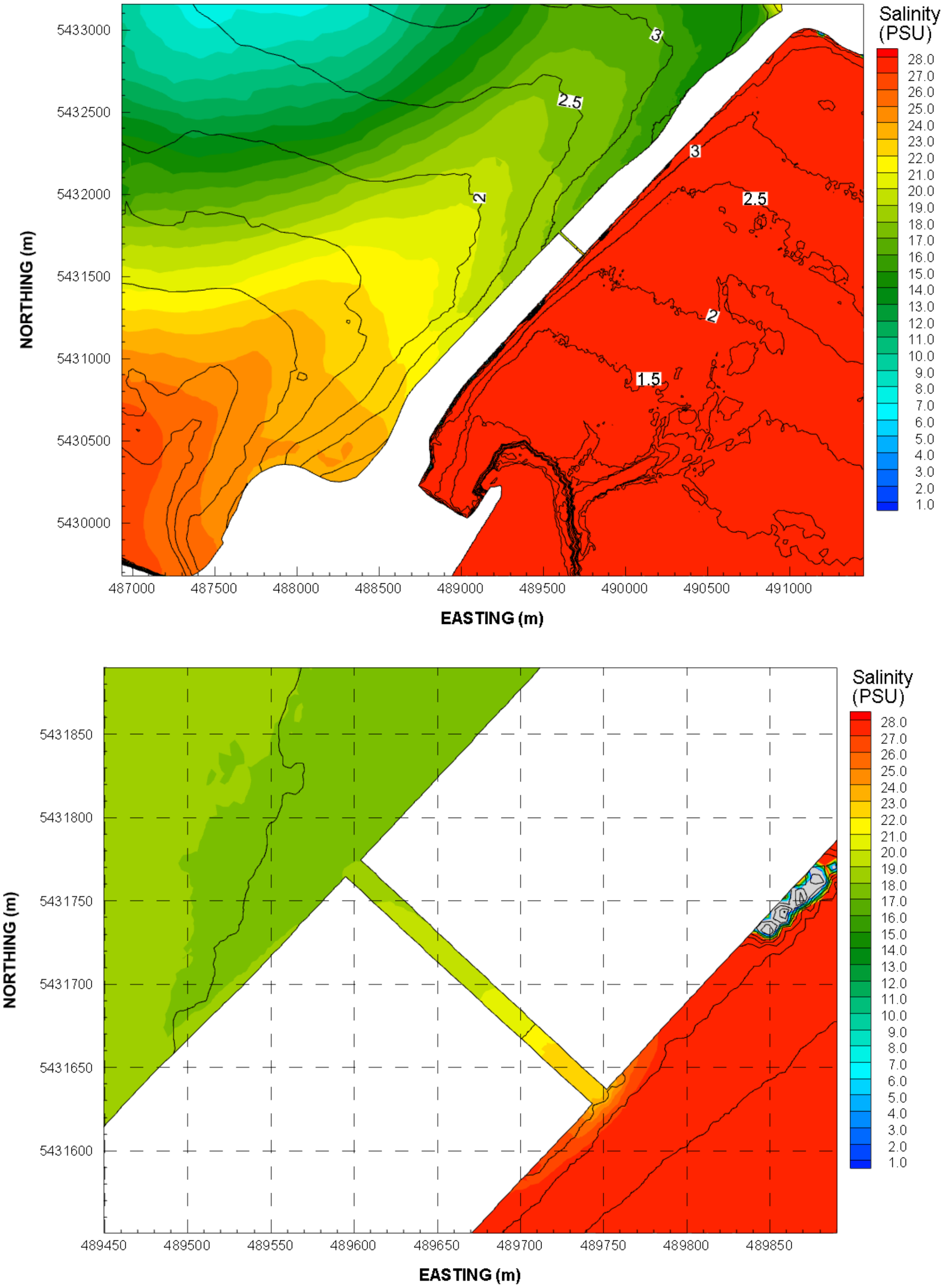
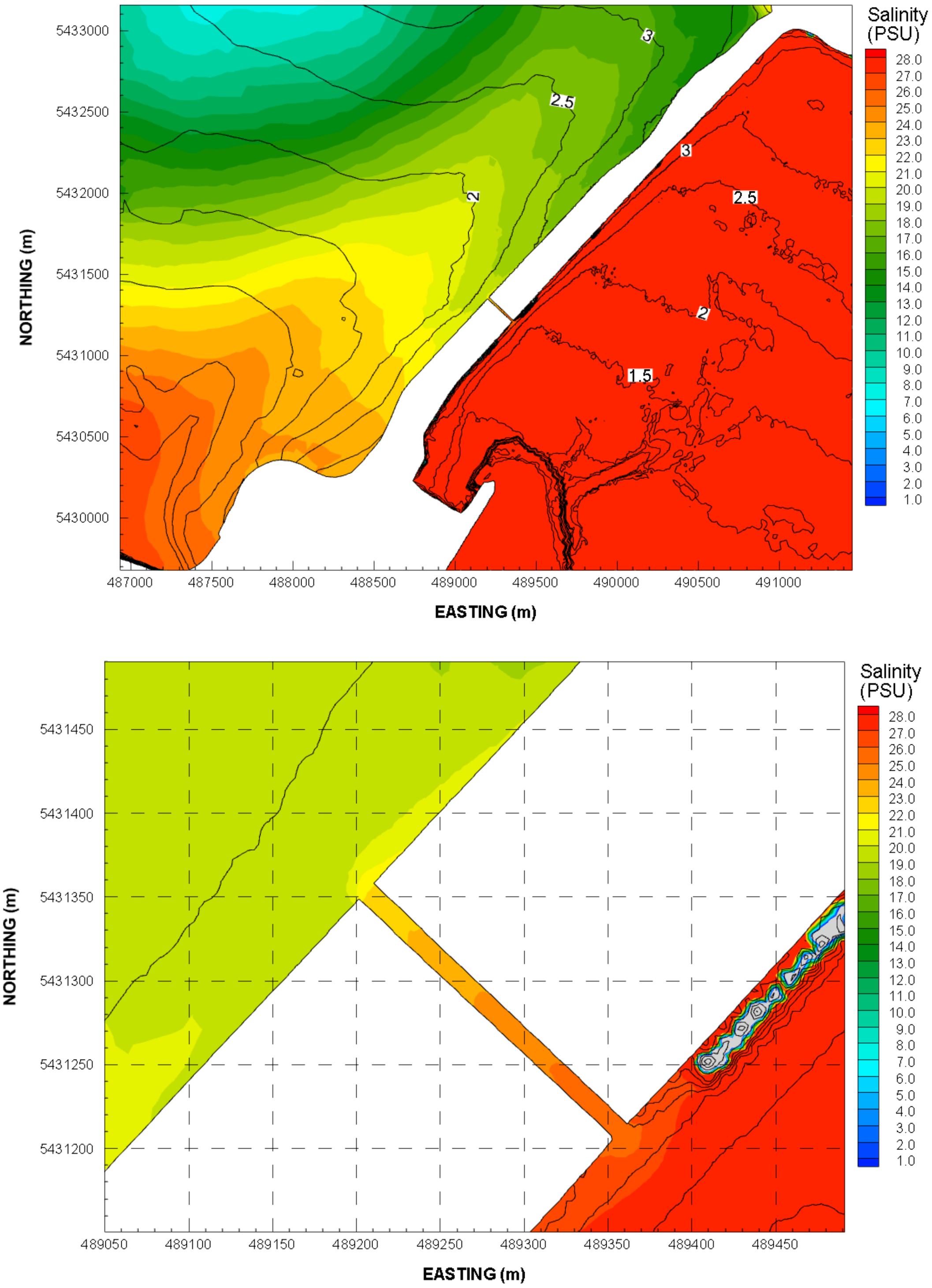


Figure 3.11 50th percentile Salinity distribution at location 2 based on representative simulation period.



Note: the zone of higher tidal flats adjacent to the south side of the causeway is related to habitat compensation features.

Figure 3.12 50th percentile Salinity distribution at location 3 based on representative simulation period.

4 TIDAL CHANNEL FORMATION

The tidal flats of Roberts Bank are generally characterised by gently sloping soft sediments with a fairly even grade. Prior to the construction of the Roberts Bank and BC Ferries causeways, regular exposure to waves and tidal currents maintained this form, but various physical interventions related to development have resulted in the formation of a number of tidal channels occurring at a range of scales. The root causes of tidal channel formation in the inter-causeway area were investigated in detail as part of the technical studies for the Deltaport Third Berth (DP3) terminal expansion project (NHC and Triton, 2004) and include the following factors that are relevant to the potential breach concepts:

- Concentration of flow; and
- Temporary storage of water and delay of flow that is released over the tidal flats at shallow tide stages or during emergent conditions when the tidal flats are fully exposed.

Based on these factors, there is a potential for tidal channels to form at the entrances to each of the three causeway breach locations.

4.1 Tidal Channel Prediction

Prediction of tidal channel formation at Roberts Bank is inherently uncertain, in part because the natural physical system that forms and maintains the tidal flats contains inherent uncertainty, for example with respect to the timing of storms, evolving vegetation patterns, and heterogeneous sediment characteristics. The mechanisms of channel initiation (e.g., the physical processes that cause the channel to begin to form) are reasonably well understood, permitting a reasonable degree of prediction at the macroscale; however, tidal channels can change in unpredictable ways in response to a range of physical factors, making fine-scale predictions much less certain. As discussed below, in the absence of proven predictive tools such as numerical models, a predictive approach has been developed based on the known mechanisms of channel initiation and the subsequent observed behaviour of numerous tidal channels within the Fraser River estuary.

While there exist a number of approaches to modelling tidal channel formation, the academic research has primarily focused on gaining an understanding of the physical processes (D’Alpaos et al., 2005; Fagherazzi et al., 2004; Fagherazzi and Priestas, 2010; Fagherazzi and Sun, 2004) rather than on developing predictive tools. Previous studies of tidal channel formation at Roberts Bank (NHC and Triton, 2004) have relied primarily on observations of existing tidal channels to understand the various mechanisms of channel initiation, as well as tracking their evolution using historical aerial imagery, as the basis for making predictive assessments. The preferred approach to making a prediction in relation to a causeway breach location relies on the understanding of the underlying causes of channel formation from ongoing development that was gained from past analytical work at Roberts Bank. Appendix 1 contains an overview of existing Fraser River delta channels, including descriptions of major inter-causeway tidal channels, tidal drainage channels, and DP3 tidal channels. The characteristics of existing tidal channels described in Appendix A informed the prediction of potential tidal channel development resulting from a causeway breach.

4.2 Tidal Channel Development from Potential Causeway Breach Locations

Based on a comparison with the various examples of past tidal channel formation on the Fraser River delta described in Appendix A, it can be concluded that there is a high probability that a tidal channel will initiate at breach entrances on either side of the causeway, regardless of the breach location. A conservative estimate of tidal channel dimensions would be a total width of up to 15 m and an incised depth below the surrounding sediment elevation of between 0.3 m and 0.5 m, and would form in a generally perpendicular direction away from the breach within the apron area described below. This prediction is made based on the following observed physical characteristics and expected processes:

- As illustrated by the contours shown in Figure 4.7, the slope of the tidal flats was previously modified by the construction of the Roberts Bank causeway such that currently an apron of sediment forms a steeper slope adjacent to the causeway[9] compared to the overall slope of the tidal flats that runs parallel to the causeway. This current apron extends approximately 150 m from the south side of the causeway and between 300 – 500 m from the north side of the causeway (Figure 4.7). The result is that water flowing through a breach will run approximately perpendicular to and away from the causeway until it reaches the base of this apron to meet the portion of the tidal flats that dominantly slopes seaward. On the north side of the causeway this apron terminates at a shallow drainage swale (Figure 4.7).
- Flow may be temporarily stored within the sediments or shallow depression to drain after the tide has receded to expose the tidal flats adjacent to the breach location. Two potential mechanisms for this process exist:
    - Flow through a potential breach will occur when water depths over the adjacent tidal flats are shallow. It is expected that a shallow basin will form on the tidal flats immediately offshore of each entrance as a result of scour caused by concentrated flow from the breach. This shallow basin has the potential to temporarily store water that will continue to discharge over the exposed tidal flats after the tide recedes.
    - Flow through a potential breach will generally drop to near zero as the tide level drops below its invert elevation (e.g., Figure 3.4, Figure 3.5, and Figure 3.6). However, it can be reasonably expected that there will be water temporarily retained within the sediments or substrate fill in the causeway breach that will continue to discharge as residual flow after the tide has receded from the adjacent tidal flats.
- Once initiated, tidal channels become preferential flow paths for water seeping from the surrounding soft sediments that would otherwise drain as shallow sub-surface flow, leading to an ongoing concentration of flow and continued evolution and development of the tidal channel feature.

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[9] A comparison of bathymetric surveys completed in 1967 and 2011, presented in EIS Figure 9.5-18, shows sediment deposition along the north edge of the Westshore Terminals and along the causeway. Since construction of the Westshore Terminals was completed in 1969, this comparison reflects a combination of both natural and human induced bathymetric changes. Based on airphoto evidence (see Figure 10 of EIS Appendix 9.5-A), methods of construction for the Roberts Bank causeway resulted in significant dispersal of sediment over the tidal flats which persists to the present day in the form of an apron of material that slopes away from the causeway, as previously described in EIS Table 9.5-3 and EIS Appendix 9.5A: Section 3.4.2.

There are a number of secondary factors that affect the extent (length) of tidal channel development. Physical processes that counteract channel formation include tidal currents and wave processes that move the sediments of the tidal flats and thus have the tendency to obscure the form of the channel, particularly in zones where channelized flow processes are less dominant; the north side of the causeway is more exposed to waves than the inter-causeway zone. A secondary factor that promotes channel extension is the potential for interactions with other tidal channel systems. As shown by the example of the upper tidal flat channel in the inter-causeway area that was eventually captured by the BC Ferries channel (see Appendix A), a tidal channel forming from one of the causeway breach concepts could be captured into one of the existing tidal channel systems. Should this occur, it has the potential to accelerate the tidal channel development processes, leading to further extension across the tidal flats.

As noted in Section 4.1, there is uncertainty in whether a tidal channel will form at any of the breach location entrances and the extent to which it will develop. Predictions are made on the basis of probability as follows:

- There is a very high probability that a shallow basin will form at each end of a breach, regardless of location. The basin could extend up to 50 m from the entrance.
- There is a high probability that a tidal channel will form at each entrance of a breach and extend across the tidal flats within the apron zone indicated on Figure 4.7. As noted above, the apron extends further on the north side of the causeway (between 300 – 500 m from the causeway) than the south side (up to 150 m from the causeway).
- There is a moderate probability that a tidal channel would extend beyond the apron zone and it is unlikely that a tidal channel would extend seaward all the way across the tidal flats to the low tide zone (between 1 m CD and 0 m CD).
- Tidal channel capture by an existing system of channels would result in a greater tidal channel length. The south entrance of breach location 1 is closest to an existing drainage channel network (feature indicated by white arrow on Figure 4.7) so the likelihood of this occurring is potentially greatest at this location. This potential process is relevant to channel formation on the south side of the causeway only, as the presence of the shallow drainage swale on the north side of the causeway (Figure 4-7) limits channel formation. However, the degree of uncertainty about how channels will form means that it is not possible to differentiate between the three breach locations based on this process.

Figure 4.1 Major tidal flat features of relevance to potential channel formation at potential causeway breach locations (Google Earth imagery date April 2009). Arrow on south side of causeway indicates location of an existing channel network.

4.3 Tidal Channel Mitigation

Historically, efforts to mitigate tidal channel formation have not been successful. As noted in Appendix A, the crest protection structure was installed around the ship turning basin in the early 1980s to limit channel development. Subsequently, smaller rock berms were installed across two other smaller channels, with the result that the channel simply migrated around the structure. These past uses of 'hard' engineered structures to control channels that form in the very soft sediments of the tidal flats demonstrate the very real challenge of applying structural controls in a highly dynamic environment. Furthermore, the installation of materials such as rock or gravel that is meant to offer additional resistance to erosion has the effect of altering the substrate characteristics. Should tidal channel development be initiated by a breach installation in the causeway, there is no feasible means to mitigate further development.

5 SUMMARY

Table 5.1 provides a summary of the hydraulic characteristics for each of the modelled breach location s. In addition, hydraulic characteristics for a box culvert structure at location 3 is provided in Table 5.1, based on the modelled bridge structure concept at this location. Flow and velocity are based on modelling of tidal forcing during the representative simulation period, while the percent time wetted[10] is based on empirical analysis of tides during the 2020 period.

Table 5.1 Summary of hydraulic parameters for each causeway breach location assessed

	Max. Flow (m^3/s)	Typical Velocity (m/s)	Max. Velocity (m/s)	% Time Wetted (at min. 0.5 m depth)
Location 1 culvert	3.2	< 0.3	1.1	9%
Location 2 culvert	2.6	< 0.2	1.4	12%
Location 3 bridge	3.7	< 0.3	1.0	37%
Location 3 culvert*	3.3	< 0.3	1.0	37%

* Culvert structure at location 3 not modelled; hydraulic characteristics are based on modelled bridge structure concept at this location. As the channel bottom elevations are the same for both structure types, the percent time wetted is also the same.

These results show that the overall volume of water that would be exchanged between the inter-causeway area and the area to the north of the causeway is relatively very small compared to the very large volumes of water that exchange over the tidal flats via direct connection with the Strait of Georgia. Flow velocities are nearly identical at the three locations and the major difference between these

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[10] For each breach location, the percentage is based on the average wetted time (greater than 0.5 m) at the highest elevation entrance (north or south side).

locations is the much higher percentage of time that the breach would be wetted at location 3 because it would be possible to set the invert elevation of the breach up to 0.7 m lower than at location 1 and up to 0.8 m lower than at location 2.

The influence that a breach would have on salinity is predicted to be relatively subtle and experienced over a relatively small area. The influence that a breach would have on salinity in the inter-causeway area is greater compared to the area north of the causeway because of the strongly asymmetrical flows that predominantly discharge from north to south.

For any of the causeway breach locations, a breach has a high probability of initiating the development of a tidal channel at both entrances. This probability is considered to be similar for all three locations. With existing tools and models, it is not possible to accurately predict the extent of channel formation (length) or the overall dimensions (width, depth), but based on professional experience in this region, it is expected that tidal channels up to 15 m wide and 0.3 to 0.5 m deep will develop at any of the three breach locations. Tidal channel development is expected to initiate from each end of the breach and extend seaward across the tidal flats within the existing apron zone outlined in Figure 4.7. There is a moderate probability that a channel would extend beyond this zone, and if a new tidal channel was to interact with one of the existing systems of tidal channels within the inter-causeway area, tidal channel forming processes would be accelerated and result in a greater extent of the tidal flat being affected. Given the uncertainty in how channels will develop, the likelihood of formation and extent of tidal channel development is considered similar for all three locations.

Once formed, it would not likely be possible to control a tidal channel. Past efforts to mitigate channels have demonstrated that installation of armouring material or berms is not successful due to the highly dynamic nature of the environment and the fact that the sediments of the tidal flats are very easily eroded. Installation of armour material on the seabed would change the physical characteristics of the substrate.

6 REFERENCES

D’Alpaos, A., Lanzoni, S., Marani, M., Fagherazzi, S., and Rinaldo, A. (2005). Tidal network ontogeny: Channel initiation and early development. *Journal of Geophysical Research*, 110, F02001.

Egbert, G. D., and Erofeeva, S. Y. (2002). Efficient Inverse Modeling of Barotropic Ocean Tides. *Journal of Atmospheric and Oceanic Technology*, 19(2), 183–204. doi:10.1175/1520-0426(2002)019<0183:EIMOBO>2.0.CO;2.

Fagherazzi, S., Gabet, E. J., and Furbish, D. J. (2004). The effect of bidirectional flow on tidal channel planforms. *Earth Surface Processes and Landforms*, 29, 295–309.

Fagherazzi, S., and Priestas, A. M. (2010). Sediments and water fluxes in a muddy coastline: interplay between waves and tidal channel hydrodynamics. *Earth Surface Processes and Landforms*, (35), 284–293.

Fagherazzi, S., and Sun, T. (2004). A stochastic model for the formation of channel networks in tidal marshes. *Geophysical Research Letters*, 31.

Hemmera, NHC, and Precision (2008). *Deltaport Third Berth Adaptive Management Strategy 2007 Annual Report*. Report prepared by Hemmera Envirochem Inc., Northwest Hydraulics Consultants and Precision Identification for Port Metro Vancouver, Vancouver, BC. 216 pp pp.

Hering, D. K., Bottom, D. L., Prentice, E. F., Jones, K. K., and Fleming, I. A. (2010). Tidal movements and residency of subyearling Chinook salmon (Oncorhynchus tshawytscha) in an Oregon salt marsh channel. *Canadian Jounral of Fisheries and Aquatic Sciences*, 67, 524–533.

Mesa, K. A. (1985). *The influence of temperature, salinity, and dissolved oxygen on juvenile salmon distributions in a nearshore estuarine environment*. Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, University of British Columbia (Department of Zoology), Vancouver, B.C.

NHC (2005). *Questions on Coastal Geomorphology*. Memo prepared by Northwest Hydraulic Consultants Ltd. for Vancouver Port Authority. 8 pp.

NHC (2006). *Lower Fraser River Hydraulic Model Final Report*. Prepared by Northwest Hydraulic Consultants and Triton Consultants for Fraser Basin Council.

NHC (2008). *Fraser River Hydraulic Model Update* (Final Report). Report prepared for the BC Ministry of Environment by Northwest Hydraulic Consultants Ltd. 227 pp.

NHC, and Triton (2004). *Roberts Bank Container Expansion Coastal Geomorphology Study*. Prepared by Northwest Hydraulic Consultants Ltd. and Triton Consultants Ltd. for Vancouver Port Authority. 116 pp.

APPENDIX A

OVERVIEW OF EXISTING TIDAL CHANNELS IN THE FRASER RIVER DELTA

OVERVIEW OF EXISTING TIDAL CHANNELS IN THE FRASER RIVER DELTA

A broad survey of existing tidal channels that have formed as a result of a number of triggering mechanisms was used to inform the assessment of tidal channels that was part of the environmental assessment of the Deltaport Third Berth (DP3) Project (see Figure A-1 reproduced from NHC and Triton, 2004). In addition, a more recent example of tidal channel formation, described in Hemmera *et al.* (2008), which occurred when water and supernatant flowed through the containment berm during construction of the DP3 Project onto the adjacent exposed tidal flats (see Figure A-2), is also instructive. The following is a brief overview of the characteristics of various tidal channels, grouped based on the process that initiated the feature.

Major Inter-Causeway Tidal Channels

Tidal channels formed in the central portion of the inter-causeway area, initially in response to construction of the ship turning basin that was dredged in 1984 that caused an abrupt change in the slope (or knickpoint) within the intertidal portion of the tidal flats. Channels began to form almost immediately in response to a process of headward erosion (or headcutting) and have subsequently evolved into a complex system of tributary channels that are connected to a main trunk channel; the planform resembles that of a tree and so is often described as having a dendritic form. The largest system of dendritic channels is labelled 1 in Figure A-1, while two smaller, less developed channel systems are labelled 2 and 3.

Figure A-3 (a) shows dendritic channel systems 1 and 2 in an oblique aerial view. The larger trunk channel is approximately 90 m wide and has a residual depth below lowest tide elevation of approximately 1.5 m. The trunk channel terminates at its landward end in a mobile sand bar covering an area of over 10 ha. Also visible in this photo is a linear feature at the seaward end of the channels, which is a rock berm (crest protection structure) that was installed in the early-1980s in an attempt at controlling the tidal channel formation. At present, the currents within the trunk channel, which are driven by tidal forcing with similar velocities during both the rising and falling tides, have formed a physical feature that appears to be in equilibrium with the governing processes. In contrast, the dendritic channels connecting with the main trunk channel (via the large sand bar) are essentially driven by currents that are strongest on the ebbing tide and so are acting as tidal drainage channels.

Another major inter-causeway channel system is shown in Figure A-3 (b) and labelled 6 in Figure A-1. It formed initially in response to expansion of the BC Ferries terminal, which resulted in tidal flow concentration. Although the initiation mechanism is different, it is of a similar scale to the dendritic channels and has been the subject of past efforts to halt the channel using a rock berm that, similar to the crest protection structure, was not effective. Also similar to the dendritic channels, is that fact that the seaward end of the channel flows quite fast on both the rising and falling tides, while the upper channels are mainly driving by flows that occur during the ebbing tide.

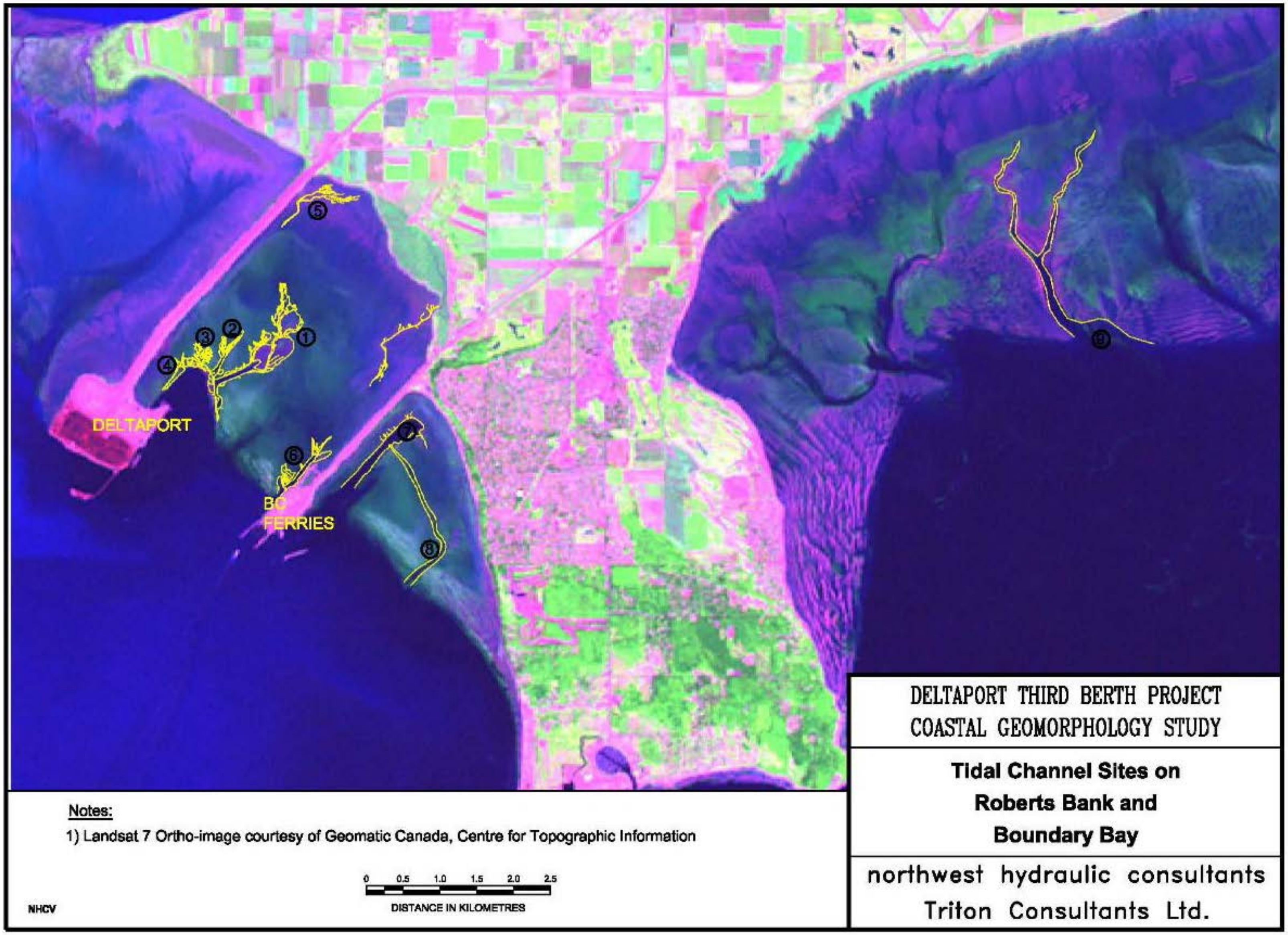

Figure A-1 Tidal channel sites at Roberts Bank and Boundary Bay, as identified in NHC and Triton (2004).

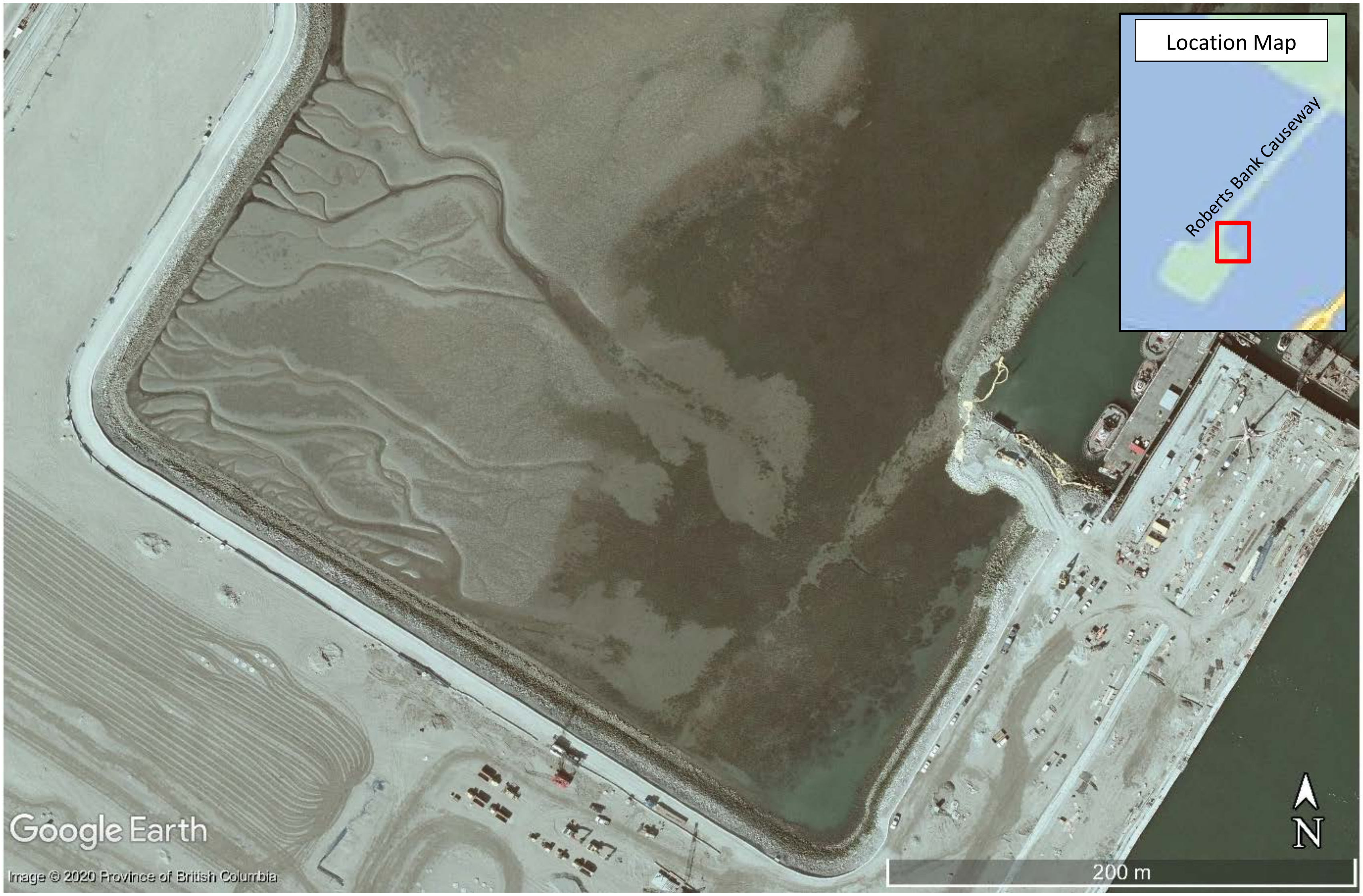

Figure A-2 Tidal channels adjacent to the Deltaport Third Berth terminal (Google Earth imagery date April 2009).

Figure A-3 a) Inter-Causeway dendritic channels – numbered 1 and 2 in Figure A-1 (photo taken 7 June 2004); b) BC Ferries channels – numbered 6 in Figure 1-1; located within orange oval (photo taken 22 April 2004).

Tidal Drainage Channels

Tidal channels that are mainly formed by water draining over the tidal flats after the dropping tide has exposed the soft sediments appear across the Fraser River delta. In some cases, the source of water is an upland stream or drainage system, while in many others the source is tidal water that inundates an area of soft sediments and/or tidal marsh and then drains in a delayed release for up to many hours after the tide has receded. An example of the latter channel form is labelled 5 in Figure A-1, and shown in the oblique aerial views in Figure A-4. Another example of this type of channel exists in the vicinity of Brunswick Point where flow is released from the extensive marsh system as well as from Canoe Passage (Figure A-5).

Tidal channels that form in the upper intertidal zone tend to be relatively subtle features, having a maximum depth below the surrounding tidal flats of not more than 20-30 cm, and often terminate within the mid elevation zone of the tidal flats because the volume of water available to maintain the channel has been exhausted by the time the tide recedes to this elevation. A notable exception to this tendency is the channels adjacent to the BC Ferries causeway – the lower elevation channels (those labelled 6 in Figure A-1) continued to evolve throughout the 2000s, extending shoreward to connect with the drainage channels that had formed decades earlier on the upper tidal flats. Once connected, the rate of channel evolution accelerated markedly.

Figure A-4 Tidal drainage channel in the upper inter-causeway area (photo a) taken 26 July 2013; b) taken 12 March 2008).

Figure A-5 Tidal drainage channel near Brunswick Point (photo taken 6 June 2012).

Deltaport Third Berth Tidal Channels

A sub-set type of tidal drainage channels formed in the inter-causeway area adjacent to the DP3 Project during the construction phase (Figure A-2 and Figure A-6). The source of water was tidal, which was temporarily impounded within the project containment berm and seeped through the rock berm for several hours after the tide had dropped. The seepage on the exposed adjacent mudflats initiated tidal channel development. Supernatant was also temporarily released when sediments were pumped into the containment area to develop the terminal. As described in Hemmera *et al.* (2008), once the area behind the containment berm was filled with sediment, the volume of water released through the berm was reduced to nearly zero and the channels became inactive, though the features remain visible because the area is not exposed to sufficient waves and currents to remobilise the sediments and fill in the channels.

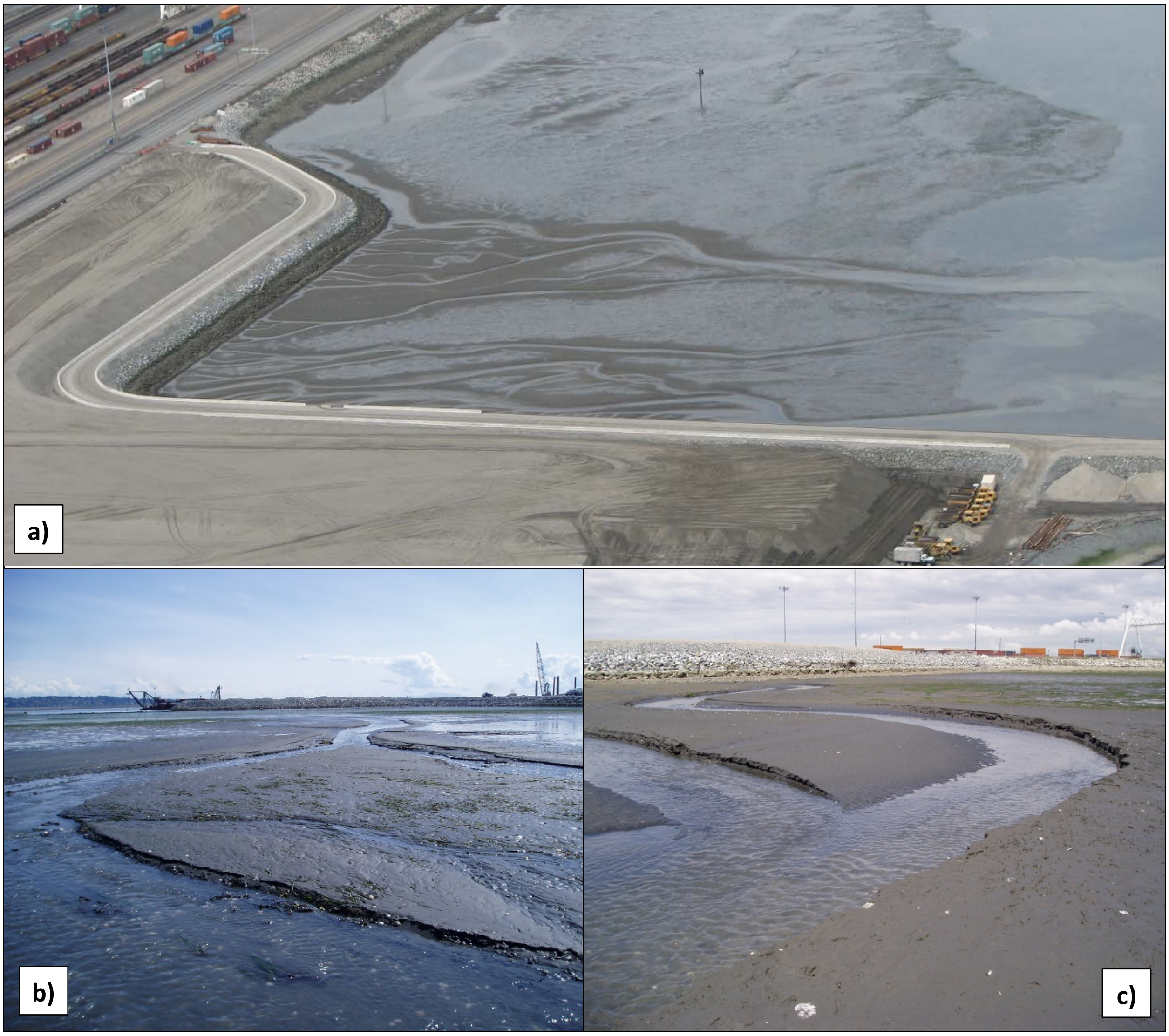

Figure A-6 a) Aerial view of DP3 tidal channels (photo taken 12 March 2008 during project construction); b) and c) show various segments of the channels from the ground (photos taken 18 April and 14 June 2007, respectively).

Appendix IR2020-2.2-D

Northwest Hydraulic Consultants Report: RBT2 – Marine Terminal Breach Hydraulic Assessment

Image source: Stantec

RBT2 Marine Terminal Breach Hydraulic Assessment
Results Report - Final

Prepared by:

Northwest Hydraulic Consultants Ltd.
30 Gostick Place
North Vancouver, BC V7M 3G3
Tel: (604) 980-6011
www.nhcweb.com

NHC Project Contact:
Derek Ray, P.Geo.
Principal

Prepared for:

Vancouver Fraser Port Authority
100 The Pointe, 999 Canada Place Vancouver, BC
Vancouver, BC V6C 3T4

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Report prepared by:

E. C. WANG
29366

APR 6, 2021

Edwin Wang, P.Eng.
Senior Hydrotechnical Engineer
Coastal Numerical Modelling

Dan Maldoff, EIT
Hydrotechnical Engineer

Report reviewed by:

D. A. RAY
[illegible]

April 6, 2021

Barry Chilibeck, P.Eng.
Senior Hydrotechnical Engineer - Principal
Hydrotechnical and Fisheries Engineering

Derek Ray, P.Geo.
Senior Coastal Geomorphologist - Principal
Coastal Geomorphology

(for coastal geomorphology)

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1 INTRODUCTION

The Roberts Bank Terminal 2 Project (RBT2 or Project) is a proposed new container terminal located in Delta, B.C. The Project consists of three main components: 1) a new multi-berth marine container terminal; 2) a widened causeway and 3) an expanded tug basin.

The Vancouver Fraser Port Authority (VFPA) received an Information Request (IR) from the Government of Canada to provide any additional terminal and causeway design options (e.g., breaches) that could avoid or reduce habitat loss and potential disruption of juvenile salmon migration (IR2020-2.2). Northwest Hydraulic Consultants Ltd. (NHC) has been tasked with undertaking a hydraulic analysis of potential breach concepts, located at the marine terminal or along the causeway, that would reduce the potential disruption of migrating juvenile salmon. The only technically feasible location for a marine terminal breach, from an engineering design and constructability standpoint, is at the east end of the terminal (Appendix IR2020-2.2-A; Figure 1.1). This breach location would connect the tidal waters of the Strait of Georgia with the tidal waters of Roberts Bank and maintain the existing juvenile salmon migration corridor around the west side of Westshore Terminal. This report summarizes our findings of the hydraulic analysis for a marine terminal breach, and a separate report summarizes our findings for causeway breach locations (Appendix IR2020-2-2-D).Note that standard practice in coastal engineering is to reference elevations to Chart Datum (CD), which has a variable conversion factor to Geodetic Datum (GD) across the various regions within the model domain. As a result, the model results are referenced to GD, which for the purposes of this assessment, has a conversion adjustment factor of 3.0 m below CD.

Figure 1.1 Artistic rendering of proposed RBT2 Project and approximate location of potential marine terminal breach (from Appendix IR2020-2.2-A)

1.1 Background

The VFPA has previously presented information about a conceptual flow passage channel between the proposed RBT2 Terminal and the existing Westshore Terminal as part of its response to the Review Panel's Information Request (IR) 1-12[1]. A 100 m wide flow passage channel was investigated as part of a project design optimisation study to assess whether scour that is anticipated in the vicinity of the northwest corner of the RBT2 Terminal could be reduced by allowing some of the tidally-induced flow (that would otherwise be required to pass around the terminal) to flow between the terminals. As reported in the IR1-12 response, the option of rounding the northwest corner was found to have the greatest positive effect in terms of decreasing the areal extent of scour and this feature was adopted for the terminal reference concept design presented in the Environmental Impact Statement (EIS). The 100 m wide flow passage was found to have a negligible positive effect and was not adopted. As the sole focus of the assessment was on scour reduction, and since this potential optimization was not adopted, further assessments (such as the determination of feasibility) were not required.

The location of the conceptual flow passage channel is similar to the location of the marine terminal breach. In contrast to the conceptual flow passage channel, the marine terminal breach is being assessed solely for the purposes of mitigating potential disruptions to juvenile salmon migration.

This document focuses on the assessment approach and findings of the hydraulic analysis for the marine terminal breach, also referred to as a breach concept. The intent of NHC's hydraulic analyses is to inform subsequent evaluations (by others, see response to IR2020-2.2) regarding reducing the potential disruption of juvenile salmon migration.

2 MARINE TERMINAL BREACH

As described in the Stantec memo RBT2 Marine Terminal Breach Technical Evaluation (Appendix IR2020-2.2-A), a technically feasible design concept for a breach has been developed by a multi-disciplinary team between the east boundary of the RBT2 marine terminal and the existing Westshore Terminals. Details related to a breach at this general location that are pertinent to the hydraulic assessment of the alignment shown in Figure 1.1 are summarized below.

2.1 Marine Terminal Breach Conceptual Design

With the objective of mitigating potential disruption of juvenile salmon migration by maintaining the existing corridor for juvenile salmon along the west side of Westshore Terminals, a marine terminal breach concept was developed and subsequently assessed technically from an engineering design and construction perspective (Appendix IR2020-2.2-A). The channel concept has an overall width of 15 m at

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[1] For more information refer to VFPA responses to Information Request Package 1 (https://www.ceaa-acee.gc.ca/050/evaluations/document/116534), which includes the specific response to IR1-12 (https://www.ceaa-acee.gc.ca/050/documents/p80054/116546E.pdf)

the surface opening and follows the boundary between the existing Westshore Terminals and the proposed RBT2 marine terminal (Figure 2.1).

For this breach concept, two crossing structure types were considered (Appendix IR2020-2.2-A):

- Two double concrete box culverts installed for a distance of approximately 60 m at the north end of the channel where road and rail crossings are required (structural segment). Each of the four box culverts has an interior box width of 3.2 m and artificial lighting to promote fish migration. The overall effective channel width[2] for this culvert structure is 12.8 m;
- Open deck bridge spans installed across the 60 m structural segment of the breach, which do not alter the channel geometry.

For both structure types, the channel segment paralleling the west side of Westshore Terminals for a distance of approximately 300 m is an open channel, with a bottom width of 2.75 m, increasing to 15 m at the top of the riprap slope (see Figure 2.1).

For the purposes of this hydraulic assessment, which was carried out in parallel with the engineering evaluation of breach locations, NHC has assessed the breach concept with bridge structures, which has a relatively consistent cross-sectional geometry throughout its length. The box culvert configuration was found to be the only structure that is technically feasible from an engineering design and constructability standpoint (Appendix IR2020-2.2-A). The open deck bridge structure is not technically feasible, as there is insufficient elevation to satisfy the freeboard design criteria[3]. Although the engineering evaluation concluded (after the hydraulic analysis was complete) that a bridge structure is not technically feasible (from an engineering design and constructability standpoint), based on the similarities between both crossing structures, the hydraulics of the box culvert structure are expected to be very similar.

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[2] Effective width refers to the portion of the channel that is available to convey flow.

[3] Freeboard is defined as the clearance above the design high water level (including future sea level rise) to the underside of the bridge span.

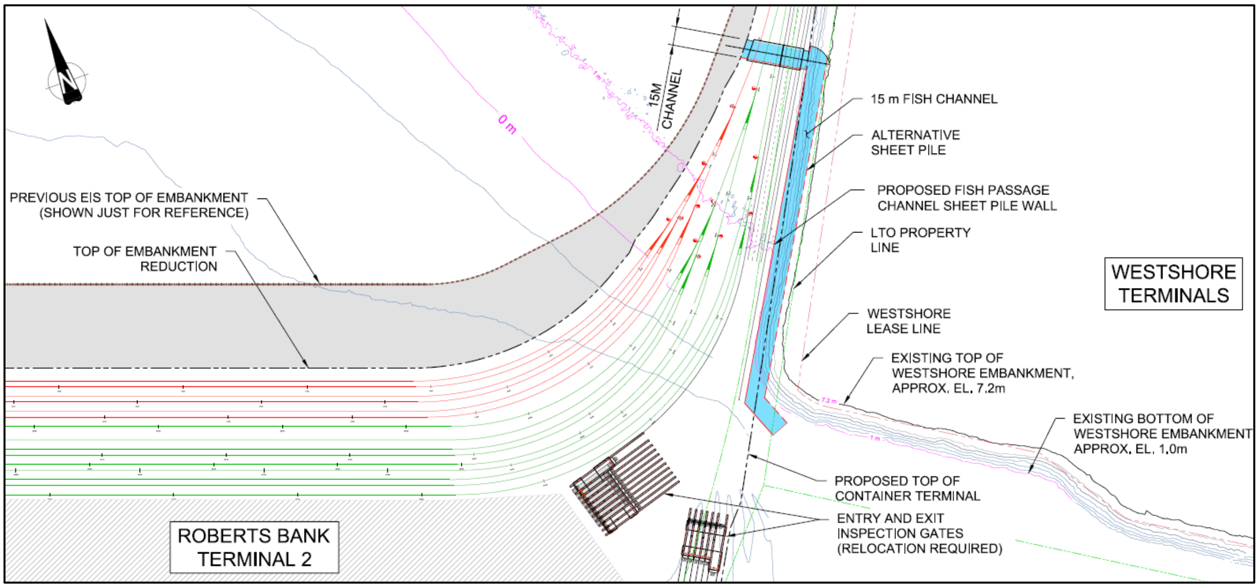

Figure 2.1 Marine Terminal Breach Concept Alignment (from Appendix IR2020-2.2-A).

The overall alignment geometry and channel width for the assessment incorporated design modifications to improve hydraulic performance. These included incorporating a radius of curvature to the channel at inside and outside bends to reduce back eddies and setting a design channel invert (bottom) elevation to match with the adjacent seabed elevation (see Figure 2.2). To match with the existing elevation of the adjacent seabed at the north entrance and to improve hydraulic performance and reduce scour potential, the channel invert elevation was set at 1.3 m CD.

Both sides of the channel were assumed to be sloped along the length of the channel, with riprap lining extending from the bottom of the channel up to the HHWL (higher high water level) elevation on each side. The channel has a bottom width of approximately 2.8 m with side slopes consisting of riprap at 1.75:1 H:V (Figure 2.2).

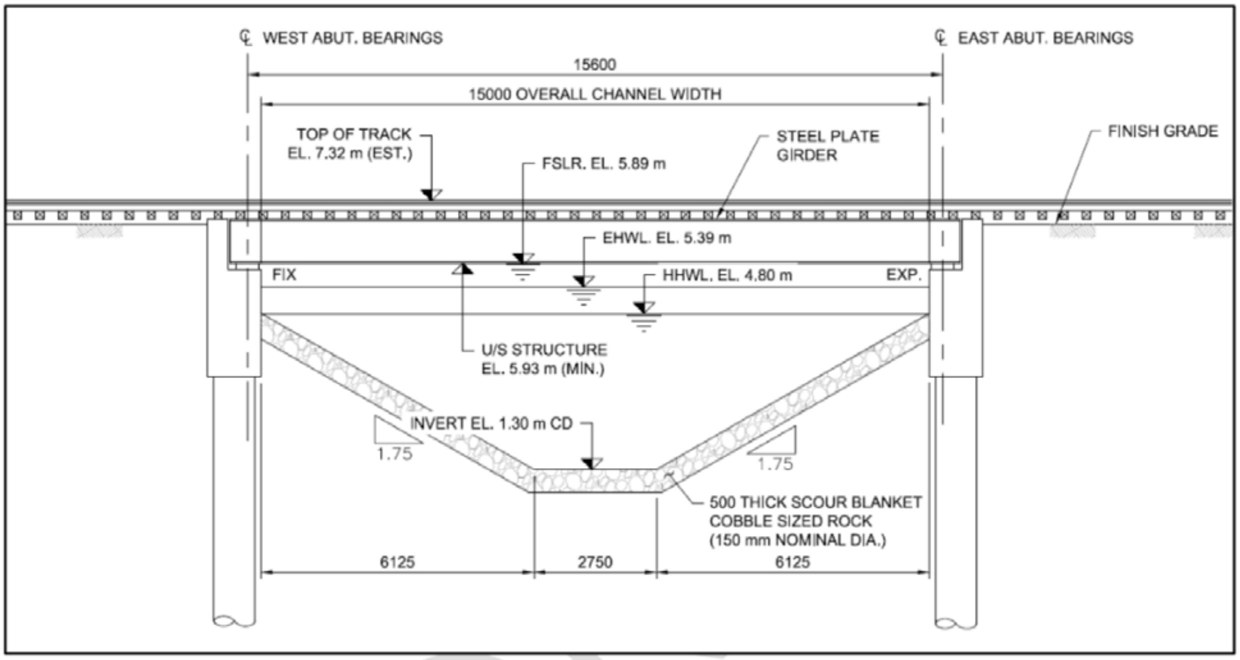

Figure 2.2 Marine Terminal Breach with bridge structure section at rail crossing (from Appendix IR2020-2.2-A).

3 HYDRAULIC ASSESSMENT

A hydraulic assessment was conducted for the purposes of providing information to support a broader analysis of the breach by other environmental specialists. Parameters important to facilitating juvenile salmon migration that were assessed include:

- percentage time wetted;
- flow velocity; and
- flow rate (volume over time).

Flow through the channel is driven by tide height differences on either side of the terminal, while the amount of time that the channel will be wetted is essentially a function of tide height and channel bottom elevation. Therefore, the assessment was conducted using a combination of numerical modelling and empirical analysis.

The numerical modelling was conducted using the TELEMAC SYSTEM to evaluate changes in hydraulics associated with the marine terminal breach concept. TELEMAC is a suite of finite element computer programs developed by the Laboratoire National d'Hydraulique et Environnement (LNHE), a department of Electricité de France's Research and Development Division.

3.1 Model Implementation

For the purposes of this hydraulic assessment, a few minor modifications were made to the Roberts Bank TELEMAC model that was previously used to assess project interactions with coastal geomorphology processes, as reported in the RBT2 EIS[4]. Minor modifications to the model and simplifying assumptions incorporated in this hydraulic assessment are summarised as follows:

- Updated Telemac version v8p0r0 is used instead of Telemac version r3356;
- Mesh refinement near the breach to provide greater resolution near the alignment;
- A 2D depth-averaged model is used instead of a 3D model; and
- Wind forcing is not considered.

The 2D model is appropriate for the level of this hydraulic analysis. It is computationally more efficient than the 3D model, permitting faster model run-times and therefore more model run tests, but a key limitation of a 2D model is that it does not provide insight into the vertical flow (z-axis) direction. Thus, it may not accurately predict the tidal hydraulics in a highly stratified environment, such as over the adjacent tidal flats or where deep, complex circulations occur. Nevertheless, for the purpose of evaluating the hydraulic characteristics of the breach (in which highly stratified waters are not expected), the 2D model environment provides an appropriate approximation of the tidal hydraulics during juvenile salmon migration. Wind forcing is not considered because it is not expected to affect the dominant hydraulic conditions in the channel.

The TELEMAC model mesh used for the study extends from Ballenas Island to Port Renfrew and south into Puget Sound (Figure 3. 1). The model also includes the Fraser River up to km 36, upstream of New Westminster and downstream of the Skytrain Bridge. The model mesh contains approximately 36,000 nodes and 66,000 elements. The element lengths vary from approximately 500 m in the Strait of Georgia to about 2 m in the vicinity of the breach concept. The model geometry for the breach concept, along with mesh refinement, is shown in Figure 3.2.

The model bathymetry was derived using the following distinct datasets:

1. In the vicinity of the Roberts Bank terminals and surrounding areas, 2011 bathymetric surveys and LiDAR;
2. In the Fraser River, 2004 Public Works and Government Service Canada (PWGSC) bathymetric surveys and 2005 Fraser Basin Council LiDAR; and
3. In Puget Sound, the Strait of Georgia and Juan de Fuca Strait, the coarse dataset comprised of Canadian Hydrographic Service (CHS) bathymetry data.

Tides (on the ocean boundary) are simulated with amplitudes and phases of dominant tidal constituents along the open boundaries obtained from the TPXO model (Egbert and Erofeeva, 2002). Inflows (on the

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[4] For more information refer to EIS Section 9.5 and supporting appendices, available at CIAR Document #181 (https://www.ceaa-acee.gc.ca/050/documents/p80054/101376E.pdf for Section 9.5 and https://www.ceaa-acee.gc.ca/050/documents/p80054/101370E.pdf for Appendix 9.5-A)

upstream boundary) to the Fraser River were obtained from the hydraulic model of the lower Fraser River that uses the MIKE11 one-dimensional hydrodynamic model software developed by the Danish Hydraulic Institute. NHC developed the lower Fraser River MIKE11 model for the Fraser Basin Council in 2006 (NHC, 2006) and updated it for BC Ministry of Environment two years later (NHC, 2008).

The 2D model simulation utilized December 2012 conditions for both ocean water levels and Fraser River flow. This period offers good representation of typical hydraulic conditions for assessing the breach concept that would be used in the spring-summer period during juvenile salmon migration. This representative period excludes storm surge and future sea level rise. The December 2012 period was selected because of the availability of data that was used to calibrate and validate a Strait of Georgia and Roberts Bank hydrodynamic-morphodynamic model that NHC previously developed as part of the EIS assessment on coastal geomorphology processes.

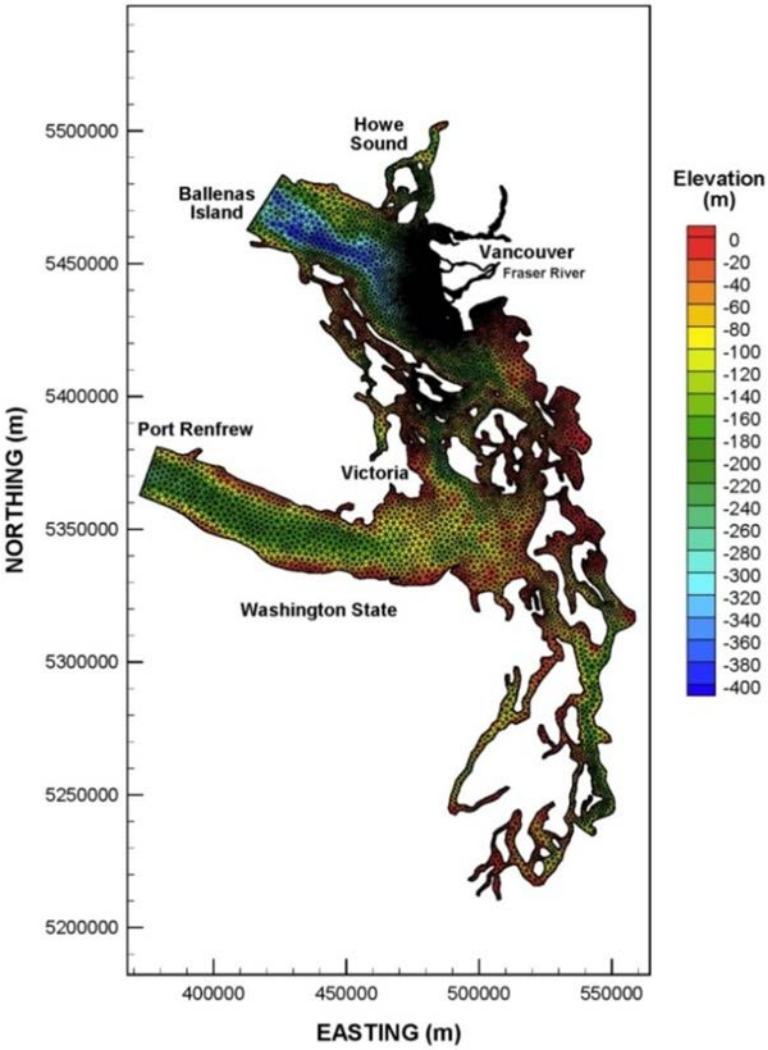

Figure 3.1 TELEMAC model domain used for the hydraulic assessment.

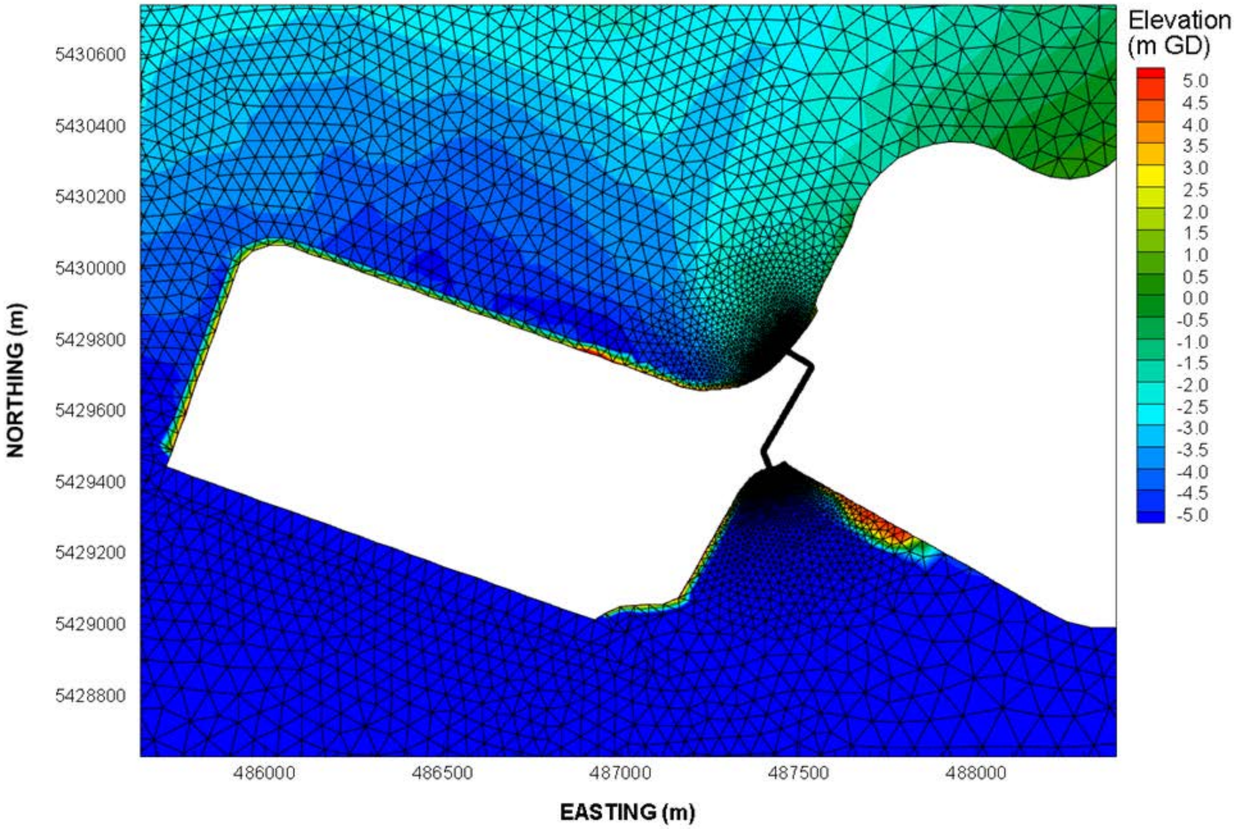

Figure 3.2 TELEMAC model geometry and model mesh resolution for hydraulic assessment near the proposed RBT2 marine terminal and breach concept.

3.2 Tidal Analysis

Table 3.1 summarizes the percentage exceedance of specific tide level (in half meter increments) based on predicted 2020 Point Atkinson water levels. As shown in Figure 2.2, the channel invert elevation was set at 1.3 m CD (-1.7 m GD), which corresponds approximately to lower low water mean tide (LLWMT) elevation. Using a minimum depth criterion of 50 cm, the breach would be adequately wetted (to -1.2 m GD) about 86% of the time. The depth criterion of 50 cm was selected as a water depth that juvenile salmonid movement could be expected to move freely and unimpeded, based on habitat use data on juvenile chinook from the Fraser River estuary (Mesa, 1985) and the Columbia River estuary (Hering et al., 2010).

Table 3.1 Tide level percentage exceedance based on 2020 Point Atkinson tide levels.

Tide Level (m) GD	Tide Level (m) CD	% Exceedence
1.5	4.5	1.9%
1.0	4.0	15.8%
0.5	3.5	36.5%
0.0	3.0	57.4%
-0.5	2.5	70.8%
-1.0	2.0	80.9%
-1.5	1.5	89.3%
-2.0	1.0	95.7%

3.3 Hydraulic Analysis

The local change from the breach concept on hydraulics at Roberts Bank was assessed by examining the hydrodynamic model simulation for the December 2012 Fraser River flow and Strait of Georgia tidal conditions[5]. The Fraser River flow at Hope and Point Atkinson tidal conditions, which includes representative typical spring and neap tide cycles, over the simulation period are shown in Figure 3.3.

Two analyses were conducted:

1. Flow rate and speed in the channel plotted as a time-series over the representative simulation period; and
2. Maximum velocity and bed shear stress predicted over the representative simulation period and displayed spatially on a map.

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[5] For additional information that describes how tides and Fraser River flows are representative, please refer to Sections 4.1 and 4.2 of EIS Appendix 9.5-A (CIAR Document #181) and VFPA’s responses to IR3-41 and IR12-09 (CIAR Document #934).

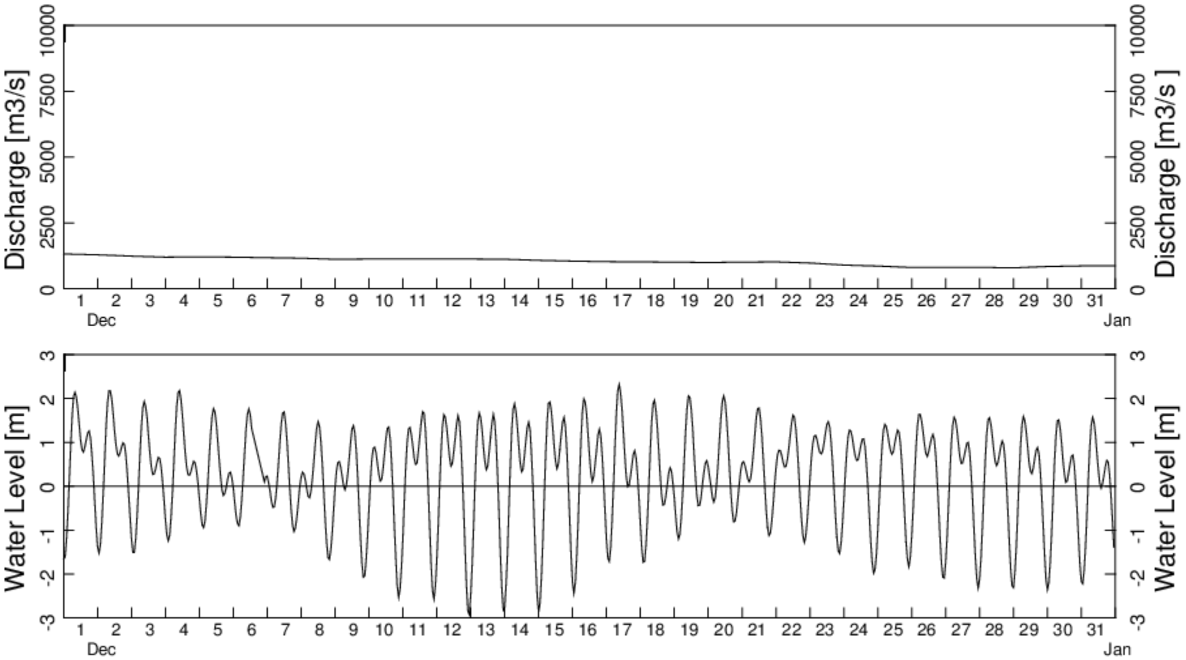

Figure 3.3 Hydraulic conditions for the representative Fraser River period. Tide height (water level in meters) referenced to Geodetic Datum.

3.3.1 Flow Analysis

Key hydraulic criteria for the breach concept (in addition to water depth) include flow rate and velocity (speed) over time. The flow rate into and out of Roberts Bank through the channel concept also provides an indicator of potential changes resulting from the breach on predicted salinity patterns in Roberts Bank.

Figure 3.4 shows the time series of selected key hydraulic parameters for the simulation period. The top panel shows the water level at the north (black line) and south (red line) ends of the breach concept[6]. The middle panel shows the flow rate across the breach concept. Positive values indicate flow north onto Roberts Bank from the Strait of Georgia during rising (flood) tide conditions and negative values indicate flow south or seaward into the Strait of Georgia during dropping (ebb) tide conditions. The bottom panel shows the water velocity or speed at the midway point of the breach. The figure shows:

- The water level differences between the two ends of the breach concept are generally less than 0.2 m. Maximum water level differences of up to 1 m occur during large falling tides (as shown for the Dec 11th to 16th period) when the water level falls below the design channel bottom elevation of -1.7 m GD and so there is no flow in the channel. During such conditions, the channel would be dry;

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[6] On Figure 3-4, when the north and south water levels are the same (overlap), the line color is represented as darker red.

- The maximum inflow and outflow rates through the breach concept are 6.3 m^3/s and -5.6 m^3/s, respectively. This channel flow rate is small compared to modelled tidal flow rates into and out of Roberts Banks. For example, tidal currents result in a flow exchange rate of up to 700 m^3/s within the zone adjacent to the northwest corner of the terminal[7]. The overall volume of water exchanged through the channel concept is quite small in comparison and is not expected to materially influence the salinity distribution in Roberts Bank; and
- The water velocity in the channel is generally less than 0.2 m/s. Speeds greater than 0.4 m/s occurred during the large tidal swing periods during the middle and at the end of the simulation period. Maximum speed over the course of the simulation period is 0.52 m/s.

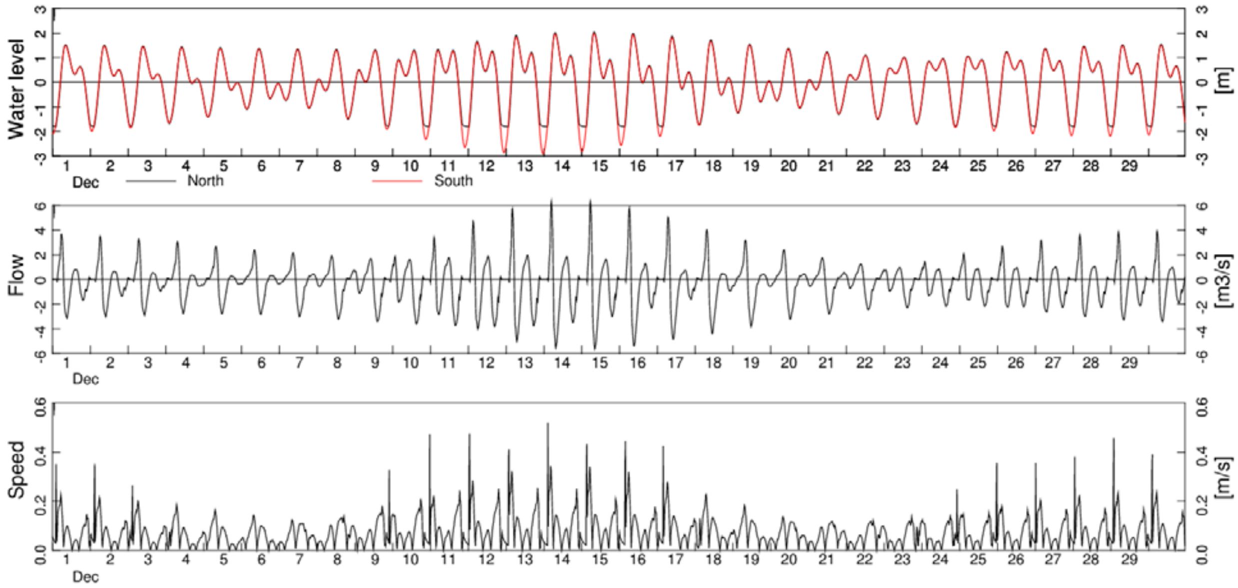

Figure 3.4 Time series of selected hydraulic parameters for the representative simulation period.

3.3.2 Flow Velocity and Bed Shear Stress Distribution

Flow velocity and bed shear stress were used independently to predict sediment mobility resulting from the conceptual breach and need for mitigation of potential scour (e.g., an armour apron) of the seabed at the north and south ends of the channel. Two analytical methods using critical shear stress (Shields) and critical velocity (TAC, 2004; Yang, C.T., 1973) were used to determine thresholds of incipient motion for seabed material with a median grain size (D_{50}) of 175 μm (refer to EIS Appendix 9.5-A for more information)[8].

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[7] For reference, the tidal flow exchange into and out of the inter-causeway area that passes between the Roberts Bank terminals and the BC Ferries terminal to the south was previously assessed to be between 1,600 m^3/s and 2,000 m^3/s, based on both field measurements and numerical modelling (NHC, 2005).

[8] Available at CIAR Document #181 (https://www.ceaa-acee.gc.ca/050/documents/p80054/101370E.pdf for Appendix 9.5-A).

Figure 3.5 and Figure 3.6 show the maximum depth-averaged velocities and 95th percentile bed shear stress over the course of the simulation period, respectively. Figure 3.7, Figure 3.8, Figure 3.9, and Figure 3.10 show results near the north and south entrances of the conceptual breach. The 95th percentile value for shear stress was calculated for this analysis, as maximum (100th percentile) shear stress values would include temporarily occurring computational artefacts that are unlikely to represent hydraulic conditions that typically persist in the natural environment.

The results presented in Figure 3.5 to Figure 3.10 show:

- The maximum velocity at the north entrance of the breach concept is about 0.2 m/s while the maximum velocity at the south entrance is about 0.7 m/s;
- The 95th percentile calculated shear stresses within the channel increases north to south from 0.2 to 2.0 Pa.

Flow velocities in the near-field environment adjacent to the ends of the breach are predominantly a result of tidal exchange currents that are interacting with the terminal land mass within the model domain. These figures indicate absolute values related to the breach hydraulics and should not be used to interpret potential differences to the near-field conditions that are expected to occur as a result of optimization of the terminal land mass footprint[4]. Such analysis would be undertaken at a later stage of design development.

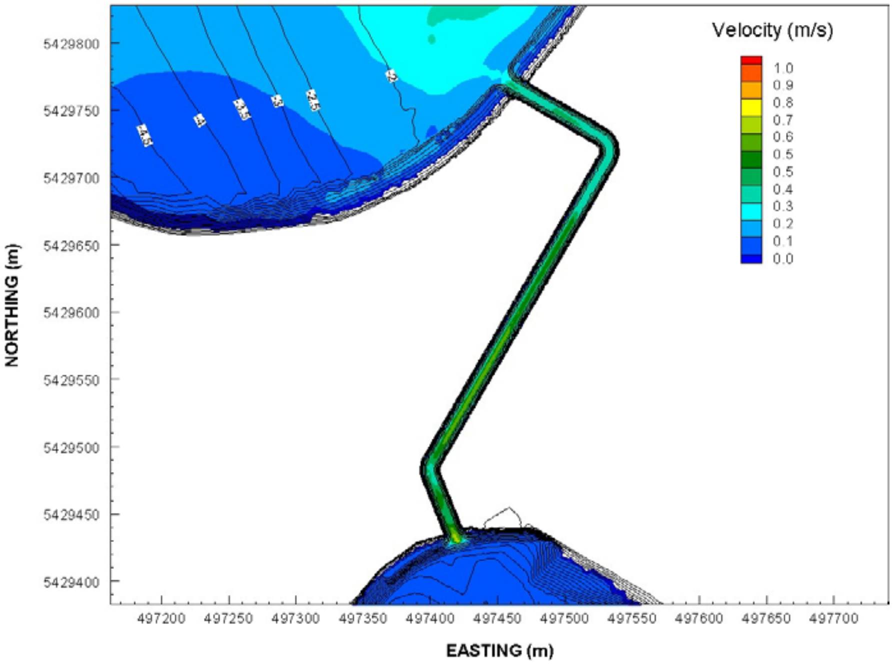

Figure 3.5 Maximum velocity distribution over the representative simulation period.[9]

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[9] Note that for this and subsequent figures, the marine terminal footprint is the same as that represented in the EIS. Predicted hydraulic conditions within the channel are not expected to change with optimization (reduction) of the terminal footprint, a mitigation measure that is under consideration as part of the Government of Canada information request (IR2020-2.1).

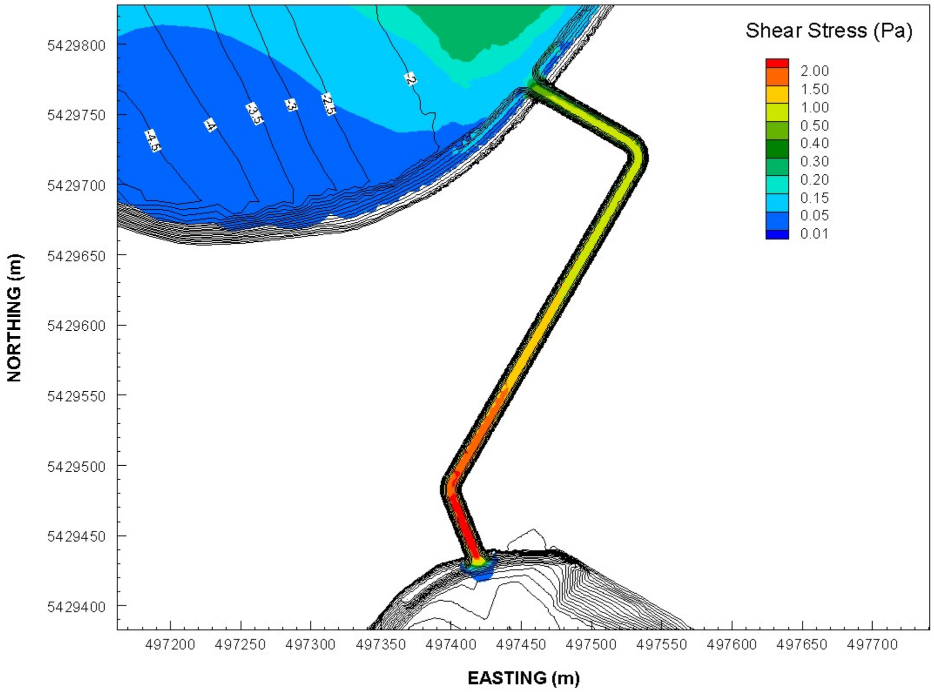

Figure 3.6 95th percentile Shear Stress distribution over the representative simulation period. [10]

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[10] Note that for this and subsequent figures, areas with no colour shading in the marine environment inside the model domain (white land areas not within the model domain) indicate that maximum shear stress is less than 0.01 Pa.

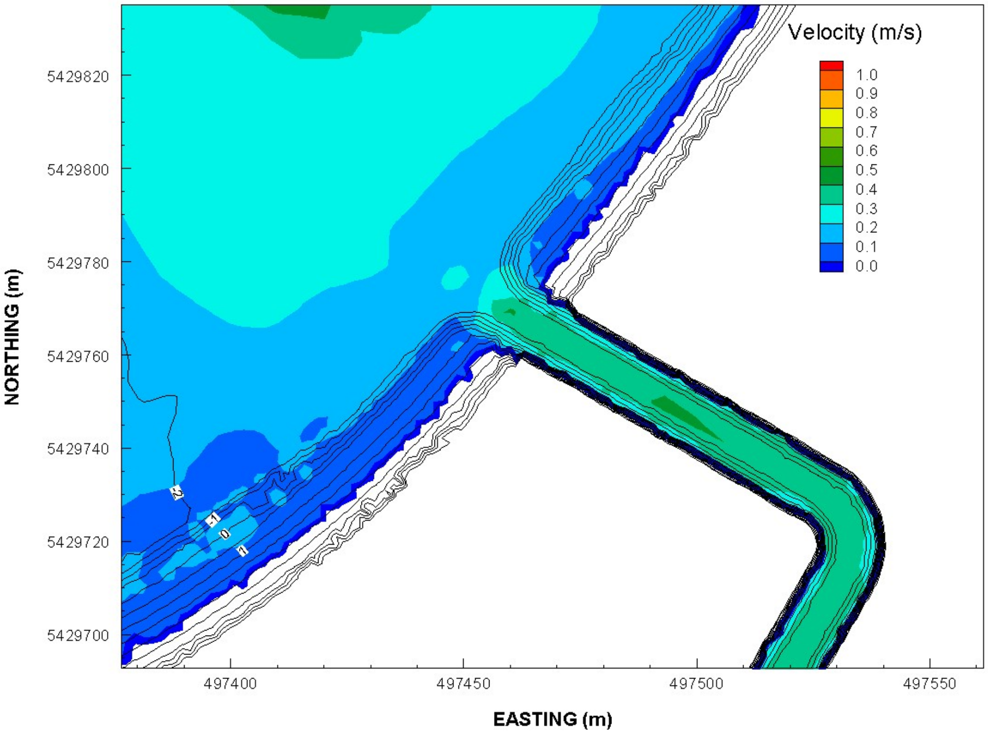

Figure 3.7 Maximum velocity distribution over the representative simulation period, north entrance.

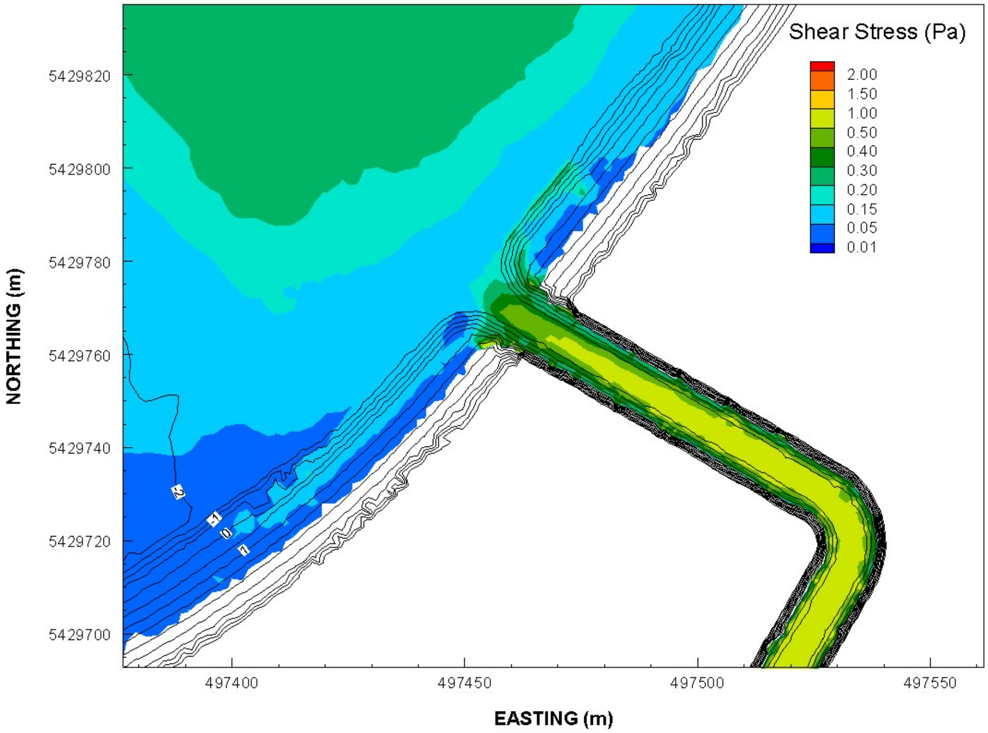

Figure 3.8 95th percentile Shear Stress distribution over the representative simulation period, north entrance.

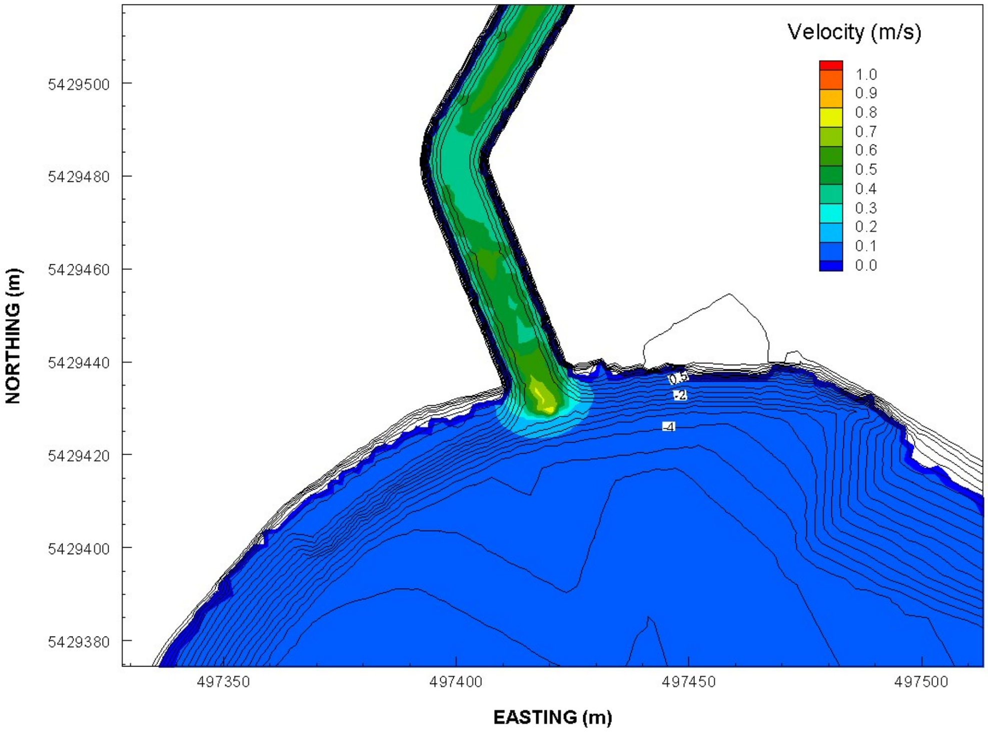

Figure 3.9 Maximum velocity distribution over the representative simulation period, south entrance.

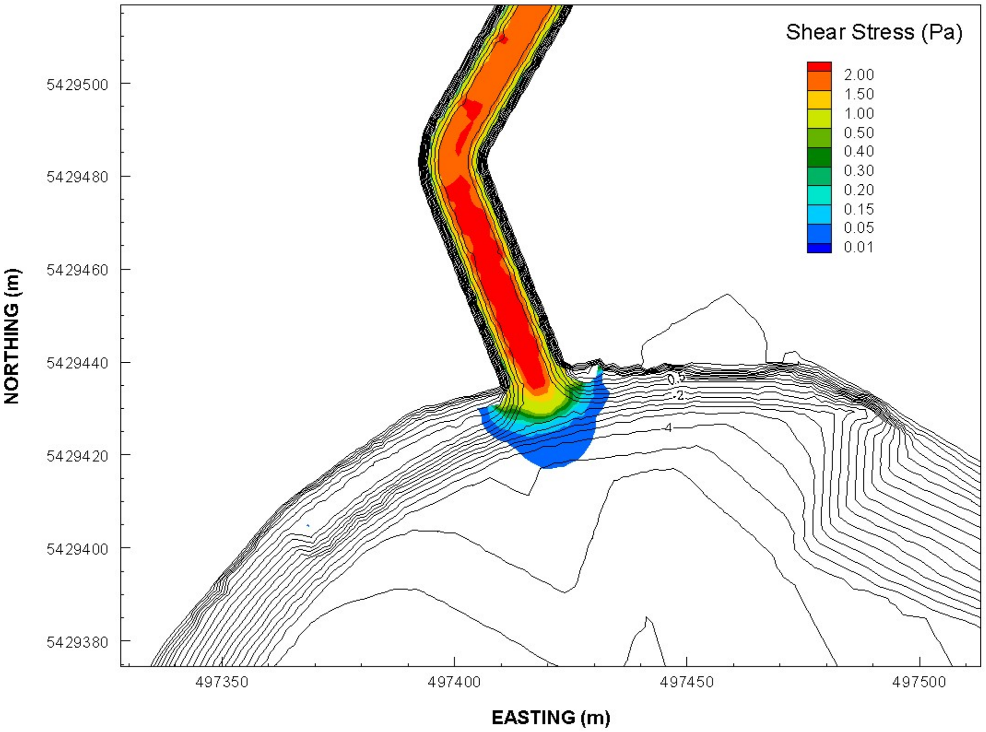

Figure 3.10 95th percentile Shear Stress distribution over the representative simulation period at south entrance.

These analyses indicate:

- Tidal flat sediments are likely to become mobile at velocities exceeding approximately 0.1 m/s, or shear stresses exceeding approximately 0.15 Pa;
- Sediment up to approximately 2 mm (200 μm) in diameter and smaller is likely to be mobile within the channel at various times.

Both critical velocity and critical shear stress were used independently to map the need for scour mitigation at each entrance. Areas where these values are exceeded[11] are expected to require a constructed apron to prevent erosion to mitigate the development of some deformed bed surface and additional changes to the tidal flat. There was good agreement between both methods, though the velocity-based analysis resulted in a slightly larger estimate of armouring extent at both north and south entrances, potentially due to performing the analysis with maximum velocity versus 95th percentile shear stress.

Both methods give rise to a similar conclusion – the need for bed armouring at the breach entrances remains generally confined to locations within 10 m of the toe of riprap slopes at the north entrance, and within the extents of the toe of riprap slope at the south entrance (Figure 3.11, extent of bed armouring indicated by red line). The area required to be armoured at the south entrance is smaller due to flows discharging into deep water and less interaction with the seabed, whereas discharges from the north entrance are expected to result in shallow flow running directly over the adjacent tidal flats. Based on the magnitude of shear stress and velocities shown, the apron could consist of a gravel/cobble transition, tying into the bed armour used within the channel.

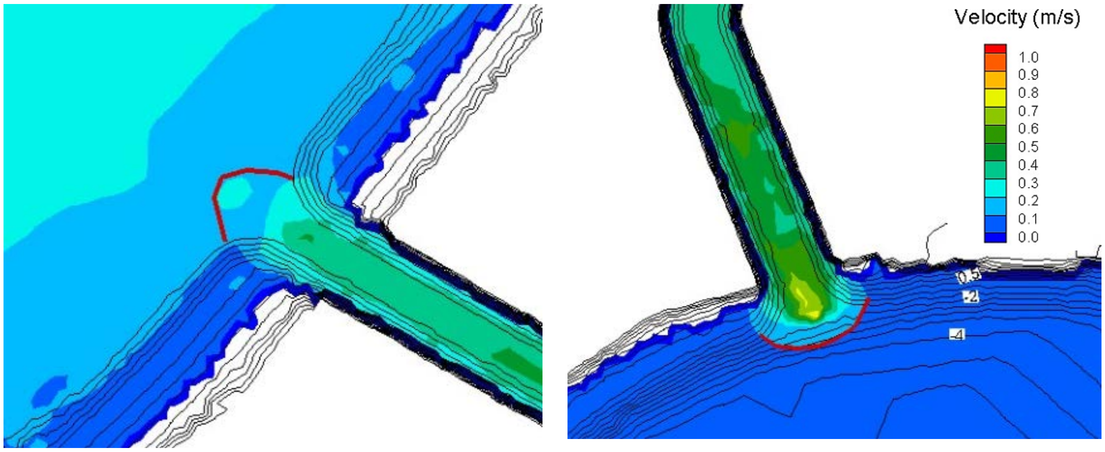

Figure 3.11 Potential scour mitigation extents at north (on left) and south (on right) entrances (from channel entrance to red line), based on calculations of critical velocity.

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[11] Exceeding the critical value (velocity of shear stress) indicates that the specific sediment grain size (in this case 2 mm) would become mobile.

4 CONCLUSION

NHC has assessed a breach concept at the east end of the RBT2 marine terminal that would maintain existing fish migration patterns along the west side of Westshore Terminals to mitigate potential disruption to juvenile salmon migration. The breach design concept was modelled using tidal forcing and the hydraulics within and adjacent to the channel. Our findings are:

- At an invert elevation of 1.3 m CD, the breach concept will remain wetted above the assumed minimum depth (50 cm) approximately 86 percent of the time;
- The maximum discharge (flow) through the channel is 6.3 m^3/s. This flow rate is very small compared to the very large volumes of water that exchange over the tidal flats via direct connection with the Strait of Georgia;
- Simulated velocities in the channel would transport sands and fine gravel near the bed; the need for erosion protection measures on the adjacent seabed to mitigate scour due to breach discharges near the north entrance and south entrance is limited to within 10 m from the breach entrances.

5 REFERENCES

Egbert, G. D., and Erofeeva, S. Y. (2002). Efficient Inverse Modeling of Barotropic Ocean Tides. *Journal of Atmospheric and Oceanic Technology*, 19(2), 183–204. doi:10.1175/1520-0426(2002)019<0183:EIMOBO>2.0.CO;2.

Hering, D. K., Bottom, D. L., Prentice, E. F., Jones, K. K., and Fleming, I. A. (2010). Tidal movements and residency of subyearling Chinook salmon (Oncorhynchus tshawytscha) in an Oregon salt marsh channel. *Canadian Journal of Fisheries and Aquatic Sciences*, 67, 524–533.

Mesa, K. A. (1985). *The influence of temperature, salinity, and dissolved oxygen on juvenile salmon distributions in a nearshore estuarine environment*. Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, University of British Columbia (Department of Zoology), Vancouver, B.C.

NHC (2005). *Questions on Coastal Geomorphology*. Memo prepared by Northwest Hydraulic Consultants Ltd. for Vancouver Port Authority. 8 pp.

NHC (2006). *Lower Fraser River Hydraulic Model Final Report*. Prepared by Northwest Hydraulic Consultants and Triton Consultants for Fraser Basin Council.

NHC (2008). *Fraser River Hydraulic Model Update* (Final Report). Report prepared by Northwest Hydraulic Consultants for the BC Ministry of Environment. 31 pp.

TAC (2004). *Guide to Bridge Hydraulics*. Second Edition. C.R. Neill (Ed.). Thomas Telford.

Yang, C.T. (1973). Incipient motion and sediment transport. *Journal of Hydraulics Division, ASCE*, 99(HY10), 1679–1704.

Appendix IR2020-2.2-E

Hemmera Memo: RBT2 – Quantification of Productivity Losses from Potential Project-related Disruption to Juvenile Salmon Migration

Hemmera Envirochem Inc.
18th Floor, 4730 Kingsway
Burnaby, BC V5H 0C6
T: 604.669.0424
F: 604.669.0430
hemmera.com

April 6, 2021

File No. 102738-10

Attention: **Charlene Menezes, Environmental Project Management Specialist, Infrastructure Sustainability**

Re: **RBT2 – Quantification of Productivity Losses from Potential Project-related Disruption to Juvenile Salmon Migration**

1.0 INTRODUCTION

The Roberts Bank Terminal 2 Project (RBT2 or project) is a proposed new container terminal located in Delta, B.C. The project consists of three main components: 1) a new multi-berth marine container terminal, 2) a widened causeway, and 3) an expanded tug basin.

In support of responding to an information request (IR) from the minister of Environment and Climate Change Canada dated August 24, 2020[1], Hemmera Envirochem Inc. (Hemmera) was tasked with evaluating how a potential breach at the terminal or causeway could avoid or otherwise mitigate potential project-related disruption to juvenile salmon migration. In the environmental assessment presented in the project's Environmental Impact Statement (EIS; VFPA 2015a), placement of the marine terminal in predominantly subtidal waters was assessed to potentially disrupt migration of juvenile salmon by increasing the shoreline distance that juvenile salmon would have to swim from the intertidal flats north of the Roberts Bank causeway to access rearing habitats in the inter-causeway area. This potential effect was assessed qualitatively, based on empirical and literature information, to result in a minor[2] loss in juvenile salmon productivity pre-mitigation. With offsetting, losses in juvenile salmon productivity from disruption to juvenile salmon migration were assessed to be negligible (VFPA 2015a, 2019).

Since submission of the EIS and completion of the project's review panel hearings, advancement in modelling technology and enhancement of computational and processing capabilities facilitated quantification of the effect associated with a potential project-related disruption to juvenile salmon migration. This memo describes our approach to quantifying the amount of juvenile salmon productivity that may be diverted from the inter-causeway area from a potential project-related disruption to migration. Quantification of this effect increases confidence in classifying this potential project effect as minor pre-mitigation, as was done qualitatively in the EIS. Results presented in this report are considered in the evaluation of the effectiveness of a potential breach design mitigation for the project to facilitate juvenile salmon migration between north and south of the Roberts Bank causeway; this evaluation is presented in IR2020-2.2.

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[1] CIAR Document #2067 From the Minister of Environment and Climate Change to the Vancouver Fraser Port Authority re: Information Request. Available at https://www.ceaa-acee.gc.ca/050/documents/p80054/135827E.pdf.

[2] A minor category assumed changes in productivity ranging between 6% and 30%; see response to IR-7.31.15-07 in VFPA 2015b).

2.0 METHODS

For this memo, and consistent with the project's EIS (VFPA 2015a), we considered that terminal placement has the potential to disrupt movements of juvenile salmon that exit the Fraser River mouth and transition to rearing habitats southeast of the Roberts Bank causeway. In addition, terminal placement would increase shoreline distance that juvenile salmon would have to travel, and potentially the time spent in deeper waters along the terminal length, as they access rearing habitats in the inter-causeway area. We quantified a potential project-related disruption to migration in terms of productivity (expressed in biomass, a measurable metric of productivity in tonnes (t)) of juvenile salmon that may be diverted with the project away from the inter-causeway area.

We quantified potential project-related disruption to migration only for ocean-type[3] juvenile Chinook salmon (*Oncorhynchus tshawytscha*; henceforth referred to as juvenile Chinook salmon) as the potential for a disruption to migration is expected to be greater for juvenile Chinook than for juvenile chum salmon (*O. keta*). Juvenile chum salmon tend to disperse readily to estuarine rearing habitats away from the river mouth (Macdonald 1984, Simenstad et al. 2000, Chalifour et al. 2019) as they physiologically adapt to higher salinities rapidly compared to juvenile Chinook salmon (Simenstad et al. 2000, McCormick 2006, Wong et al. 2019). On the other hand, juvenile Chinook salmon are slower to acclimatize to higher salinities (McCormick 2006, Wong et al. 2019) and tend to preferentially rear in brackish habitats at Roberts Bank with diminishing abundance in more saline waters such as in the inter-causeway area (Levy and Northcote 1981, 1982, Chalifour et al. 2019, 2020). Based on data collected in spring and summer 2020 as part of the RBT2 follow-up program element for juvenile salmon, densities of juvenile Chinook salmon near the river mouth (along the west shoreline of Westham Island and north of the Roberts Bank causeway) were four times higher than in the inter-causeway area. In contrast, for the same period, juvenile chum salmon densities were found to be similar north and south of the Roberts Bank causeway, while catches off Westham Island comprised only three individuals. Data collected during 2020 sampling surveys align with literature findings summarized above.

We developed a simple model to analyze how the project may potentially affect migration of juvenile Chinook salmon. Based on literature (see references herein) and empirical surveys of juvenile salmon at Roberts Bank in support of the project (e.g., Archipelago 2014a,b), we assumed that, after they exit the river mouth, juvenile Chinook salmon would spend weeks in the estuarine environment to gradually adjust to higher salinities (e.g., Chalifour et al. 2019, 2020) and to reduce predation risk by staying in the more turbid water (e.g., Gregory 1993, Gregory and Levings 1998). We also assumed that juvenile Chinook salmon would move with tidal currents, in on the tidal flats during high tide and further out during low tide, but they would not passively drift with currents (e.g., Macdonald 1984, Hering et al. 2010). In addition, we assumed that juvenile Chinook salmon would disperse over time, and that net change in distribution would be due to a combination of tidal currents and dispersal impact (e.g., Sharpe et al. 2019). Lastly, and to keep the analysis simple, we assumed that preferred habitat is only a function of the water level (i.e., depth) influenced by tidal exchange, and not of other behavioural, physiological, or habitat characteristics or predator abundance (e.g., Sharpe et al. 2019, Morrice et al. 2020).

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[3] Behavioural form of Chinook salmon that migrates to sea during the first year of life. Juvenile Chinook salmon that rear at Roberts Bank exhibit predominantly an ocean-type life history (VFPA 2018b, Scott et al. 2019).

We developed a base model (**Section 2.1**) to approximate movements of juvenile Chinook salmon that migrate from the Fraser River to the tidal flats at Roberts Bank where they rear between March and August (e.g., Scott et al. 2019). We then applied this base model to the analysis using two methods, i.e., method #1 (**Section 2.2**) and method #2 (**Section 2.3**). Movements were approximated using the same combination of tidal currents and dispersal to allow juvenile Chinook salmon to move between spatial cells, as well as the same habitat capacity function derived as a function of time-varying, cell-specific water depths. Method #1 differed from method #2 in that it used an individual-based modelling approach (IBM; Walters et al. 2010) with random (diffusive; Walters et al. 2010) movements of individual juvenile Chinook salmon, while method #2 used deterministic distributions of biomass pools that disperse based on abundance, feeding conditions and habitat capacity.

Methods #1 and #2 used different components of the Ecospace module of the Ecopath with Ecosim software (EwE, www.ecopath.org). Implementation of the two modelling methods was made possible following the transfer in 2020 of the Roberts Bank ecosystem model constructed for the project's EIS (Hemmera 2014) to the latest available professional version of the EwE software. This latest available professional version of EwE incorporates new features and increased spatial capabilities for handling temporal-spatial data such as those used here to model movements of juvenile Chinook salmon at Roberts Bank.

The two modelling methods are summarized in **Table 2-1** and are described in more detail below.

Table 2-1 Overview of methods used to quantify potential project-related disruption to migration of juvenile Chinook salmon

#	Method	Type	Models	Drivers
1	Individual-based model	Stochastic	Individual behaviour	Tidal current, water depth
2	Pooled biomass model	Deterministic	Pool behaviour	Tidal current, water depth

Notes:

- Stochastic – method that yields potential outcomes by allowing for random variation of one or more input variables
- Deterministic – method that yields outcomes determined by the parameter values and conditions initially set

2.1 Base model

This section describes the spatial boundaries of the base model used in methods #1 and #2 (**Section 2.1.1**), the model structure and input parameters considered (**Section 2.1.2**), and the approach to approximating movements of juvenile Chinook salmon at Roberts Bank (**Section 2.1.3**).

2.1.1 Modelled area

The area modelled in methods #1 and #2 extends from Canoe Passage to the north to just south of the Canada-United States border (**Figure 2-1** Spatial boundaries were selected to capture the migration of juvenile Chinook salmon as they exit from the lower reaches and mouth of the lower Fraser River and distribute on the tidal flats at Roberts Bank for rearing between March and August (e.g., Scott et al. 2019). The area modelled in methods #1 and #2 included Canoe Passage as the source of juvenile Chinook salmon that migrate to Roberts Bank. The area was mapped using the Ecospace module of EwE (version 6.7.0.17220; V6.7, released on May 19, 2020) and a grid of 56 m x 56 m cells, for a total of 250 columns by 215 rows, resulting in 53,570 grid cells.

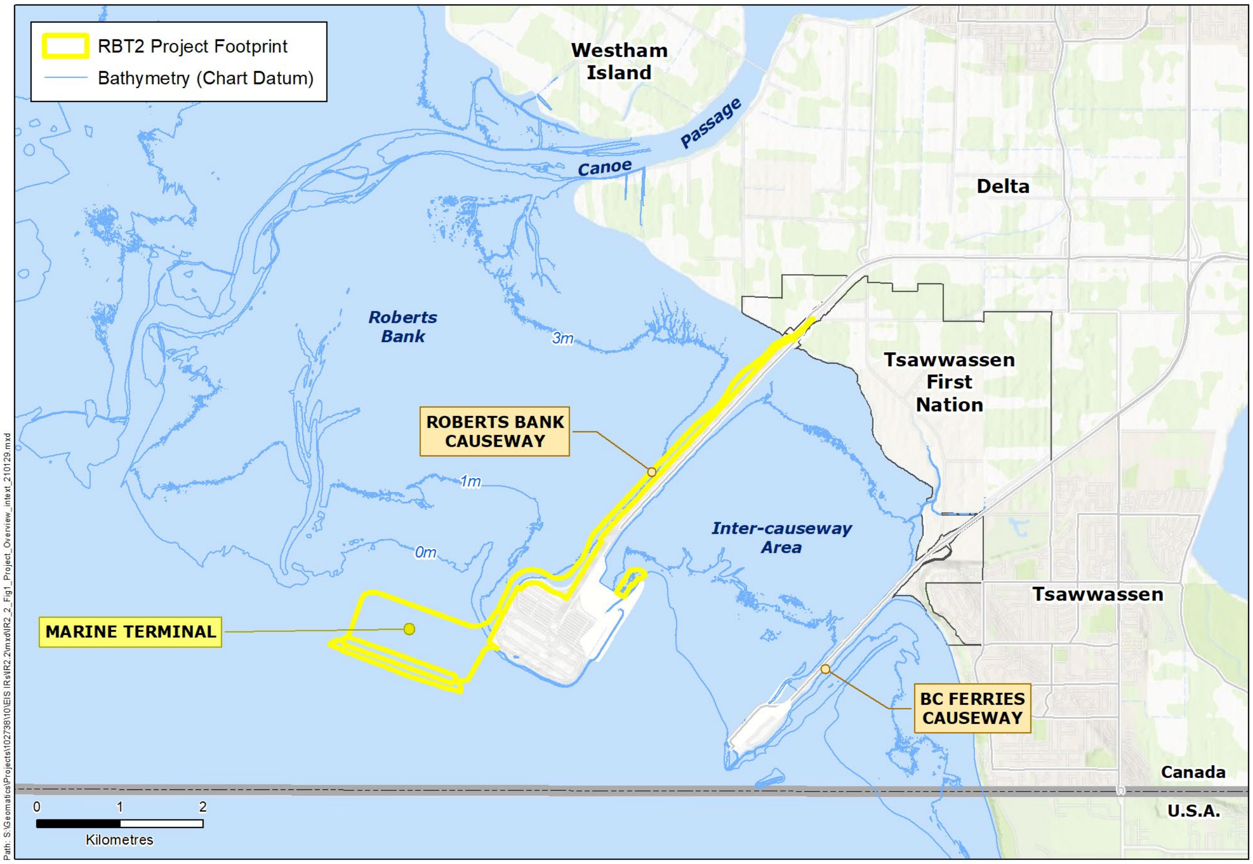

Figure 2-1 Modelled area extending from Canoe Passage to just south of the Canada-United States border considered in the approximation of juvenile Chinook salmon movements rearing at Roberts Bank

2.1.2 Base model structure and input parameters

The base model included a simplified food web of an age-structured population of juvenile Chinook salmon during their relatively short stay at Roberts Bank. The food web was developed in the Ecopath module of EwE and comprised the following functional groups[4]: (i) Chinook freshwater, representing fry[5] that migrate from spawning gravels to the river mouth; (ii) Chinook smolt, representing smolts[6] that transition from brackish to more saline areas at Roberts Bank; (iii) producers, representing prey available to juvenile Chinook salmon; and (iv) detritus, representing decomposing matter in the food web.

The migration of juvenile Chinook salmon to Roberts Bank was modelled in Ecospace using an hourly time step over a one-month period (May 2012) to include a full moon cycle (to adequately represent tides at Roberts Bank) and to cover the period that juvenile Chinook salmon spend in the estuarine habitat as part of their adaptation to higher salinity conditions (e.g., Scott et al. 2019). Older Chinook juveniles that have migrated to the marine waters in the Strait of Georgia were not considered in the model. Chinook freshwater and smolt functional groups were represented in the model as life history stages or stanzas (multi-stanza groups), whereby a cohort of Chinook fry was added to the population for each time step, and the fate of each cohort was followed over the model run time period. Production of Chinook fry was kept constant for

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[4] Species or group of species that share similar life history traits and ecological function and are used to represent pools of biomass in an EwE model.

[5] Juvenile salmon post-larval life stage.

[6] Juvenile salmon life stage ready to transition to higher salinity environments.

each time step by using a ‘hatchery’ function for Chinook salmon, which turns off spawning for the group, and adds instead a constant number of Chinook fry as a cohort for each time step.

Input parameters typically used in EwE to define multi-stanza groups include age, total mortality (equivalent to production/biomass) by life stage, the growth constant K from the von Bertalanffy growth function (VBGF)[7], and biomass and consumption/biomass ratio for one life stage (Heymans et al. 2016). Of these parameters for the multi-stanza groups, only total mortality by life stage matters for the present analysis as the focus of the base model is solely on how the project may affect movements of juvenile Chinook salmon, and not food-web interactions. Total mortality was set to 0.05 per 12-hour period for Chinook freshwater (fry), and to 0.01 per 12-hour period for Chinook smolt (**Table 2-2**). This implies that only 55% (=exp(-0.01*60)) of the smolts entering the system at the first time step would remain in the area after one month. The remaining standard input parameters for the model’s functional groups included biomass, and consumption/biomass ratio and their values are also shown in **Table 2-2**.

Table 2-2 Model input parameters of biomass, total mortality, and consumption/biomass by functional group

Functional group	Biomass (t/km^2)	Consumption/Biomass (per 12 hours)	Total mortality (per 12 hours)
Chinook freshwater	0.0005	0.6	0.05
Chinook smolt	1	0.2	0.01
Producer	1	NA	1
Detritus	100	NA	NA

Notes:
- t/km^2 – tonnes per square kilometre; NA – not applicable

2.1.3 Approximation of juvenile Chinook salmon movements

Movements of juvenile Chinook salmon during their migration to Roberts Bank were set in Ecospace to be directed and influenced by a combination of tidal and dispersal impacts (for both methods #1 and #2) with added random movements for method #1. Consistent with the literature (e.g., Macdonald 1984, Healey 1991, Hering et al. 2010, McMichael et al. 2013, Sharpe et al. 2019), juvenile Chinook salmon were assumed to move in and out of the tidal flats on a flooding and receding tide, respectively, and to disperse alongshore with the prevailing tidal current. For instance, during a study of movements of sub-yearling Chinook salmon in a tidally influenced salt marsh habitat in the Salmon River estuary, Oregon, Hering et al. (2010) demonstrated that in general juvenile Chinook salmon entered and departed the marsh habitat in the direction of tidal currents. Some asymmetry in movement was also documented whereby juvenile Chinook salmon did not drift passively with the current but rather entered the marsh habitat against the current and actively remained until late in the tidal cycle (Hering et al. 2010).

Tidal exchange was represented in Ecospace by water depth (**Figure 2-2**) and depth-averaged current velocity (**Figure 2-3**). Data on water depth and current velocity were extracted for the ‘without project’ and ‘with project’ scenarios, with an hourly time step for the month of May 2012, from the coastal geomorphology TELEMAC-3D model developed for the EIS by Northwest Hydraulic Consultants (NHC 2014). The water surface elevation data (WSE-20120501_to_20120601.dat) was provided from a single location offshore of the proposed terminal (Easting 487335 Northing 5428296).

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[7] The von Bertalanffy growth function is a model to determine in animals growth of the body size (length or weight) as a function of age (von Bertalanffy 1934, reviewed for fish populations e.g., by Pauly 1984, Beverton and Holt 1993).

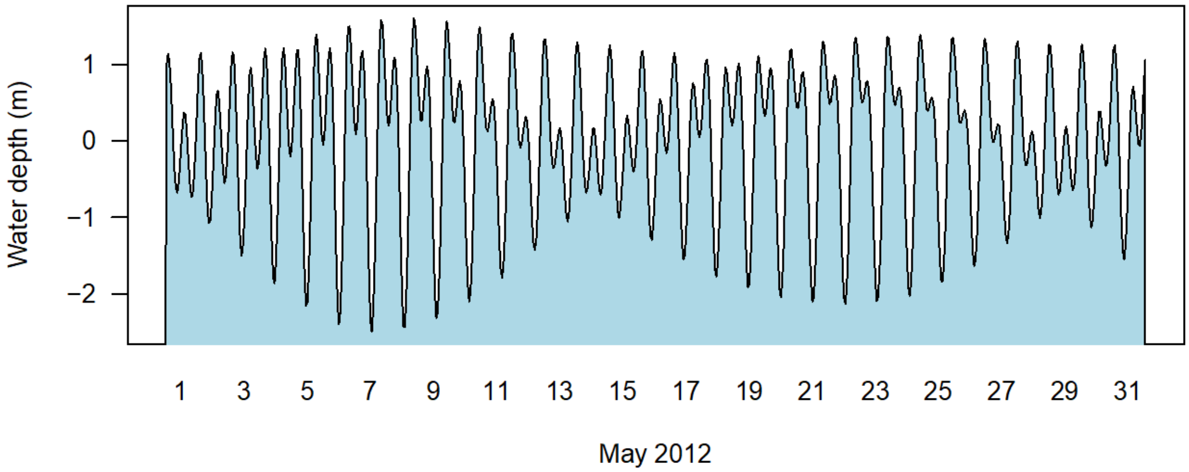

Figure 2-2 **Water depth (in metres; m) influenced by tide with an hourly time step for the month of May 2012 extracted from the coastal geomorphology TELEMAC-3D model developed for the project by Northwest Hydraulic Consultants (NHC 2014)**

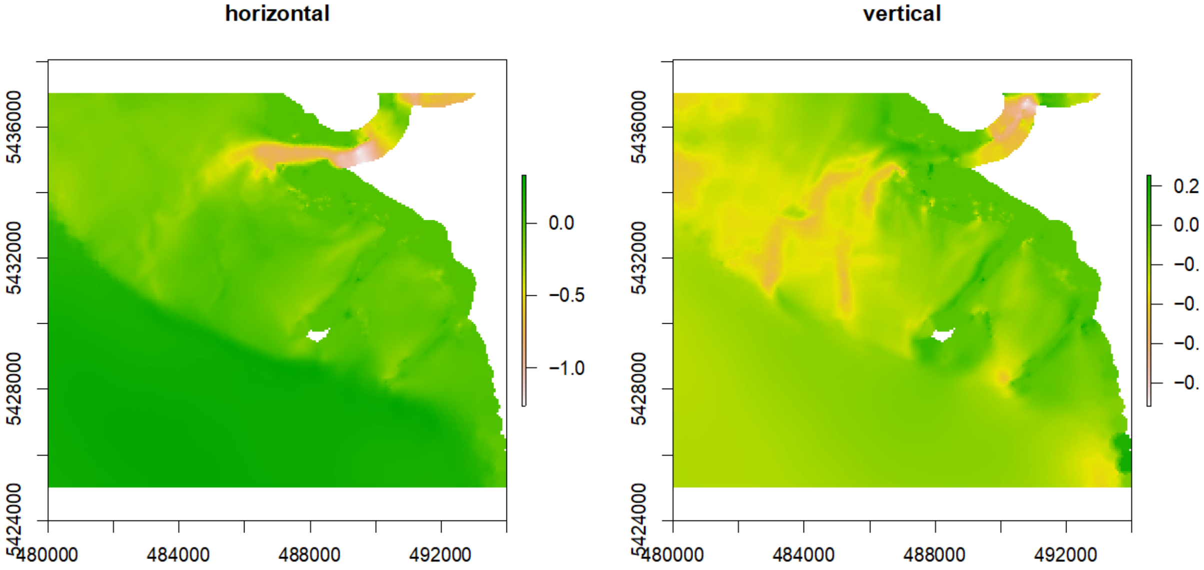

Figure 2-3 **Current velocity fields (in metres per second) for a period with strong ebb currents at Roberts Bank (see Figure 2-1 for spatial boundaries of modelled area); negative values indicate south (left side plot) and west (right side plot) direction of currents**

Transformation of the coastal geomorphic data on water depth and depth-averaged current velocity was required for compatibility and use in Ecospace. Coastal geomorphology data were extracted in the NAD 1983 UTM Zone 10N projection and were issued as XYZ (X-coordinate, Y-coordinate, and Z value) text files. The XYZ data were transformed using ArcGIS (version 10.5) by generating a continuous surface for each environmental variable in triangulated irregular network (TIN; a network of connected triangles) format. Each continuous surface was then converted to a discrete grid with a 56 m x 56 m cell size. Ecospace was executed in the NAD 1983 UTM Zone 10N projection. Ecospace was accordingly configured to run in "Assume square cells" modus (Menu > Ecospace > Edit Basemap UI) to stop Ecospace from trying to correct horizontal movement due to WGS84 projection cell tapering. The transformed grids of water depth and depth-averaged current velocity were integrated into the model using the spatial-temporal data framework of Ecospace (Steenbeek et al. 2013, 2016).

In Ecospace, movement of juvenile Chinook salmon between cells was modelled based on habitat suitability defined by the habitat capacity function (Christensen et al. 2014) combined with dispersal (for both methods #1 and #2) and random movement for method #1. The habitat capacity function for juvenile Chinook salmon was based on water depth only; we approximated Chinook smolt movements by incorporating into the model two depth preference curves shown in **Figure 2-4**. In both depth preference curves, we assumed that Chinook smolts would not occur in cells when the water level drops to less than 0.4 m (Hering et al. 2010) due to increased predation risk and risk of being stranded during a receding tide.

- Shown in **Figure 2-4(a)**, preferred water depth was between 2 and 5 m (habitat suitability set at 1). In waters deeper than 5 m, habitat suitability declined linearly with increasing depth to 0.3 at 100 m depth. Similarly, in waters shallower than 2 m, habitat suitability declined linearly to 0.2 at 0.4 m depth. Habitat suitability was 0 at depths shallower than 0.4 m and deeper than 100 m.
- Shown in **Figure 2-4(b)**, preferred water depth was between 1 and 2 m (habitat suitability set at 1). In waters deeper than 2 m, habitat suitability declined linearly with increasing depth to 0.9, 0.5, 0.35, and 0.2 at depths of 3 m, 5 m, 10 m, and 20 m, respectively. Habitat suitability of 0.2 was set for waters up to 100 m depth and then declined linearly to 0 at 200 m depth. In waters shallower than 1 m, habitat suitability declined linearly to 0.8 at 0.5 m depth and to 0.2 at 0.4 m depth. Habitat suitability was 0 at depths shallower than 0.4 m.

The depth preference curve shown in **Figure 2-4(a)** depicts preference of juvenile Chinook salmon for a range of depths that extend from the intertidal zone to the subtidal zone along the delta foreslope; these areas are occupied by juvenile Chinook salmon when the tidal flats drain during a receding tide. The depth preference curve shown in **Figure 2-4(b)** depicts preference of juvenile Chinook salmon for shallower depths characteristic of the upper intertidal zone at Roberts Bank that is accessible to juvenile Chinook salmon when it is inundated during a flooding tide. Two different depth preference curves were used in the base model to investigate the model's sensitivity to water depth, the single parameter selected to define habitat capacity for juvenile Chinook salmon, and yield a range of model ouputs.

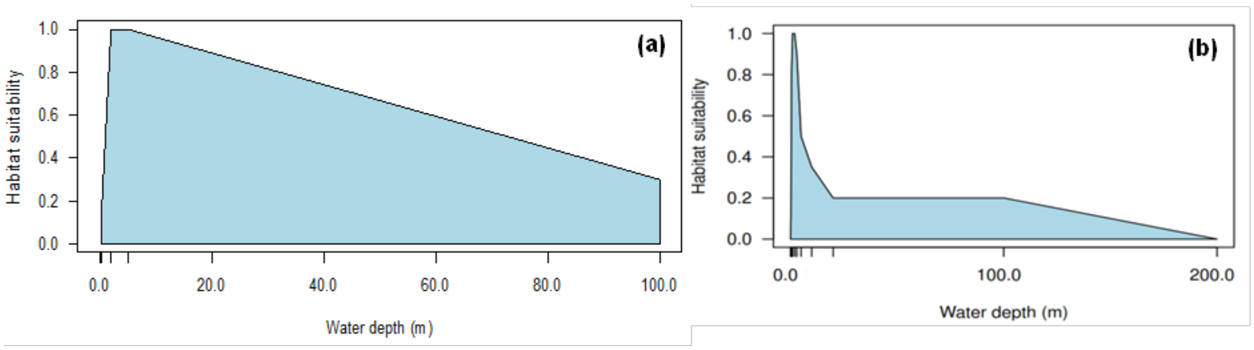

Figure 2-4 **Habitat capacity function for juvenile Chinook salmon based on water depth (in metres; m)**

Based on the bathymetry of the modelled area and combined with the tide water level (**Figure 2-2**), a cell-specific habitat capacity layer was calculated for each hour of the modelled month (May 2012). 'Without project' and 'with project' habitat capacity for depth preference shown in **Figure 2-4(a)** during high (flood) and low (ebb) tides is shown in **Figure 2-5**. Similarly, for depth preference shown in **Figure 2-4(b)**, 'without project' and 'with project' habitat capacity is shown in **Figure 2-6**.

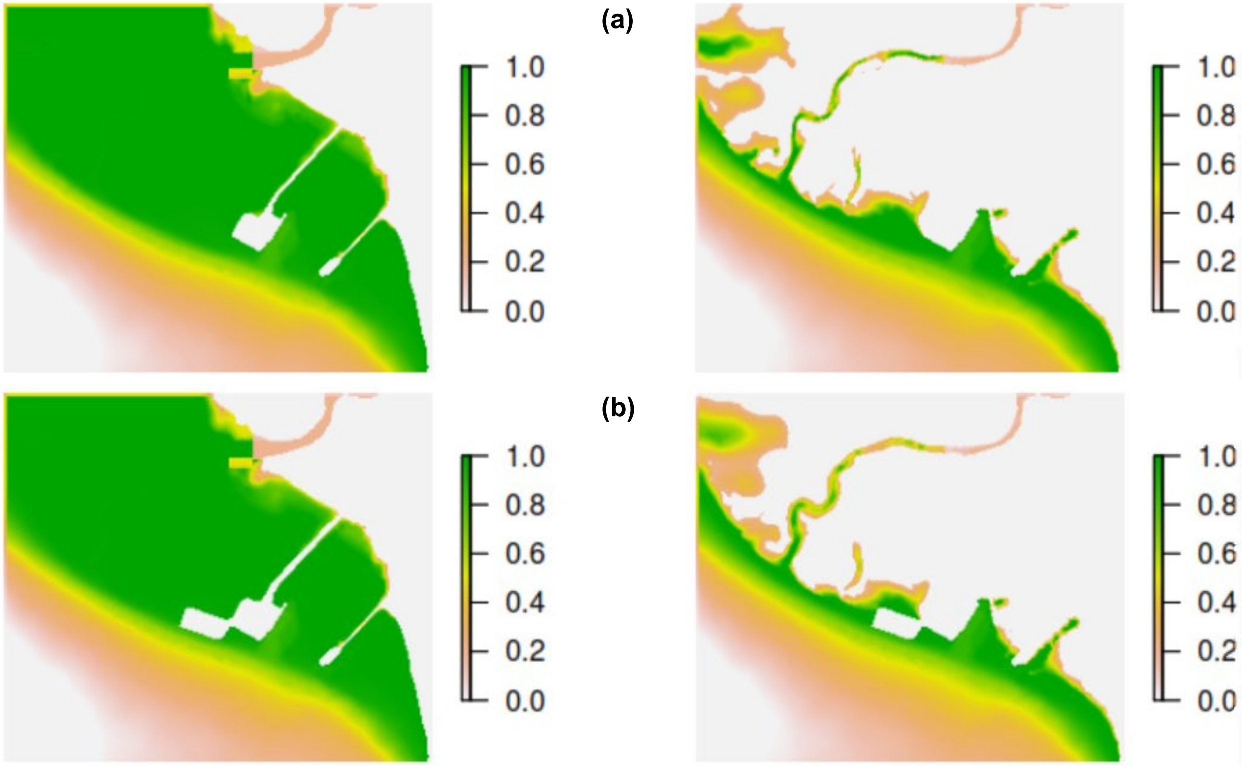

Figure 2-5 **Estimated 'without project' and 'with project' habitat capacity of Chinook smolts for high tide (left plot) and for low tide (right plot) using depth preference curve shown in Figure 2-4(a). Darker (green) colour indicates more preferred habitat areas and lighter (light brown) colour less preferred habitat areas. Land, shallow water (shallower than 0.4 m) and deep water (deeper than 100 m) areas are avoided (value of 0; white)**

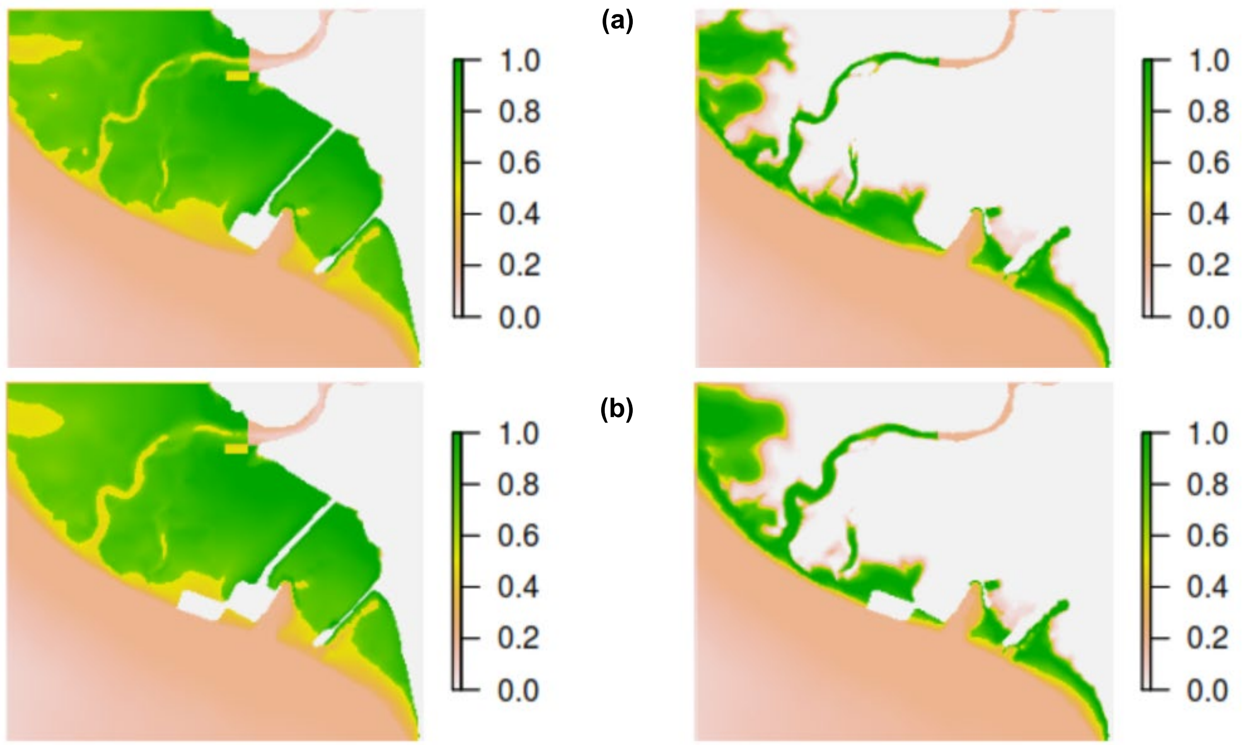

Figure 2-6 **Estimated 'without project' and 'with project' habitat capacity of Chinook smolts for high tide (left plot) and for low tide (right plot) using depth preference curve shown in Figure 2-4(b). Darker (green) colour indicates more preferred habitat areas and lighter (light brown) colour less preferred habitat areas. Land, shallow water (shallower than 0.4 m) and deep water (deeper than 200 m) areas are avoided (value of 0; white)**

2.2 Method #1: Individual-based model

In method #1, the model described in **Section 2.1** was run using the IBM approach incorporated in Ecospace (Walters et al. 2010). In the IBM approach, each of the Chinook freshwater and smolt life stages was divided into packets (i.e., groups/schools of juvenile Chinook individuals). For each time step, recruitment occurred with a constant number of packets of Chinook fry added and randomly placed within their preferred habitat area, i.e., at Canoe Passage (**Figure 2-7**). Each of these packets was then followed over the one-month time period of the model run as it moved within the modelled area based on cell-specific habitat capacity combined with tidal currents and random factors influencing their dispersal.

The IBM model was run without and with the proposed project to determine the amount of juvenile Chinook productivity that may be diverted away from the inter-causeway area with the project. The seaward extent of the inter-causeway area was defined in methods #1 and #2 as a line from the outmost point of the BC Ferries causeway to the southernmost tip of the existing Roberts Bank terminals. Project-related change in the number of juvenile Chinook salmon accessing the inter-causeway area was expressed using two metrics:

1. The ratio of Chinook smolt abundance present in the inter-causeway area with the project relative to without the project. This metric represents the percentage of juvenile Chinook salmon present in the inter-causeway area predicted to be diverted from the inter-causeway area with the project. Conversion to productivity (in t per year) for the inter-causeway area specifically was not possible as juvenile Chinook salmon productivity with the project is forecasted by the Roberts Bank

ecosystem model for the entire modelled area and not for a portion, in this case the inter-causeway area.

2. The difference between the ‘with project’ and ‘without project’ proportion of the Chinook smolt abundance in the inter-causeway area relative to the total Chinook smolt abundance of the entire modelled area. The ‘with project’ and ‘without project’ proportions of Chinook smolt abundance were multiplied by the Chinook smolt biomass forecasted for the entire modelled area ‘with project’ and ‘without project’ using the Roberts Bank ecosystem model constructed for the EIS and updated in 2020. The difference in biomass (with – without; in t per year) was then calculated to get an estimate of the juvenile Chinook salmon productivity that may be diverted from the inter-causeway area with the project.

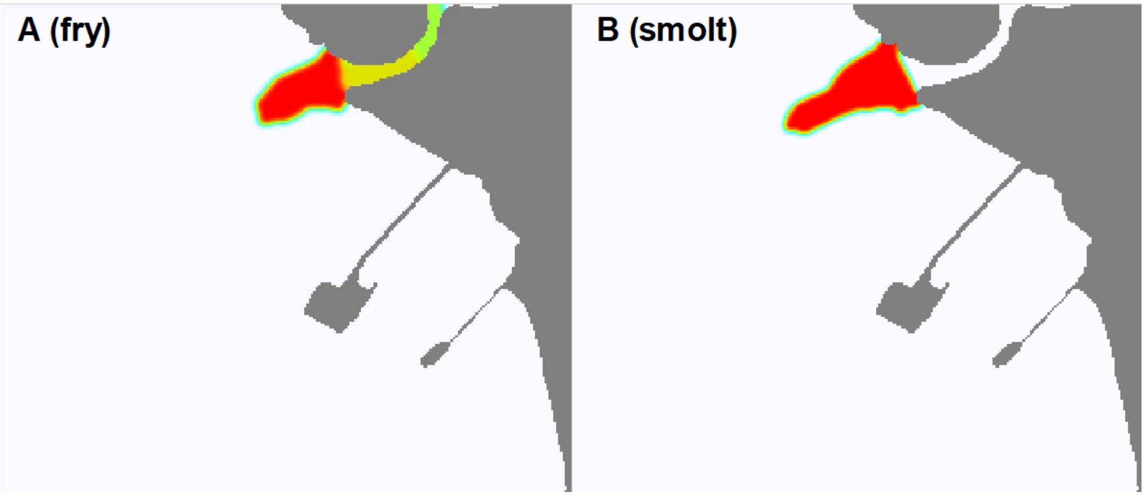

Figure 2-7 **(A) Habitat capacity for Chinook freshwater (fry). Recruitment occurs to the darker coloured (red) area by Canoe Passage only. This layer is used for all time steps of the model run. (B) Habitat capacity for Chinook smolt, used only for model initialization to distribute the smolts. A new habitat capacity layer is then read into the model at the first time step and during the ones that follow, influencing the gradual dispersal of Chinook smolts from Canoe Passage onto the tidal flats.**

2.3 Method #2: Pooled biomass model

For method #2, the model described in **Section 2.1** was run the same way as described in **Section 2.2** and using pooled biomasses (as opposed to individual packets) of Chinook fry and smolt life stages. In summary, method #2 modelled abundance by Chinook life stage as a function of time (hourly) and cell-specific habitat capacity. Habitat capacity was determined by tidal currents and dispersal (as described in **Section 2.2**), and pooled Chinook biomasses moved homogeneously in space from Canoe Passage to Roberts Bank. Method #2 did not incorporate random factors influencing movement of individuals (as did the IBM approach of method #1; **Section 2.2**). The same two metrics described in **Section 2.2** were also calculated using method #2.

3.0 RESULTS

We developed two methods to estimate the amount of juvenile Chinook salmon productivity that may be diverted from the inter-causeway area due to a potential project-related disruption to migration. These two methods (#1 and #2) deployed a base model that approximated movements of juvenile Chinook salmon exiting the river mouth and dispersing on the tidal flats at Roberts Bank. Methods #1 and #2 differed from each other in that method #1 considered random variation in movement of individual Chinook smolt packets alongside environmental parameters, such as water depth and current velocity, that influence movements of juvenile Chinook salmon when rearing at Roberts Bank. On the other hand, method #2 used pools of Chinook smolt biomass in a deterministic manner.

Based on methods #1 and #2, the project has the potential to divert away from the inter-causeway area approximately 7% to 14% of juvenile salmon abundance that would have accessed the inter-causeway area without the project (**Table 3-1**). In terms of productivity, it was estimated that the project has the potential to divert away from and reduce use of the inter-causeway area by approximately 0.002 t/year to 0.004 t/year of juvenile salmon (**Table 3-1**) or approximately 35 to 70 juvenile salmon per day[8]. However, this disruption and apparent effect is unlikely to result in a loss of Chinook salmon productivity because those individuals diverted from the inter-causeway area will either remain north of the causeway, where they will benefit from the increased productivity in new offset habitats (described in IR2020-1.1) and increases with the project in native eelgrass and intertidal marsh forecasted by the ecosystem model (described in IR2020-1.2), and/or they will migrate and successfully rear in offshore and other nearshore habitats in the estuary. Juvenile salmon diverted offshore will occupy the same offshore habitats and experience the same offshore predation risk as do all juvenile Chinook salmon when they migrate offshore currently.

Table 3-1 Quantification of potential project-related disruption to migration of Chinook salmon smolts using two modelling methods

Method	Habitat capacity function (Figure 2-4)	Percent (%) diversion of Chinook smolt abundance in inter-causeway area	Proportion (relative to study area) of Chinook smolt abundance diverted from the inter-causeway area			Potential diversion of juvenile Chinook salmon productivity (t/year)
			Without project	With project	Difference (with–without)	
#1	(a)	14	0.043	0.037	-0.006	-0.004
	(b)	12	0.039	0.034	-0.005	-0.003
#2	(a)	14	0.032	0.027	-0.005	-0.003
	(b)	7	0.027	0.023	-0.003	-0.002

Dispersal of Chinook smolts approximated using methods #1 and #2 relies on a combination of tidal currents and smolt dispersal rates. Given the lack of empirical or literature information, dispersal rates of Chinook smolts were defined in Ecospace based on professional judgement and our empirical understanding of Chinook smolt movements at Roberts Bank. Juvenile Chinook salmon employ multiple strategies as they migrate through the estuary and rely on multiple cues simultaneously when making decision movements. Chinook smolt dispersal is in reality driven by additional factors, including active, unquantifiable behaviour of Chinook individuals based on environmental factors, such as salinity, turbidity, and water temperature, influenced by freshwater flows from the Fraser River and tidal exchanges (e.g., Sharpe et al. 2019, Morrice et al. 2020). Other factors also include behavioural and physiological influences, including growth of juvenile salmon which increases their ability to swim longer distances, as

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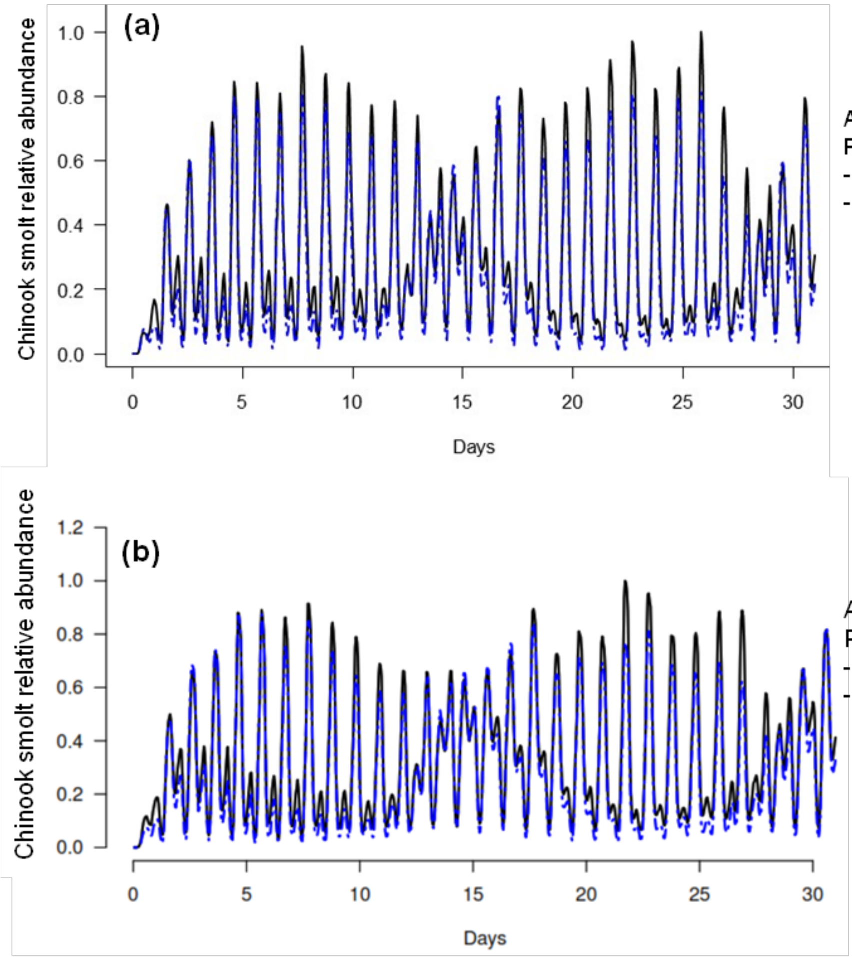
[8] Calculation is based on an average body weight of juvenile Chinook salmon of 1.85 grams, measured during field surveys undertaken for the project in spring and summer 2020, and a 30-day period to account for a full-moon cycle that influences the tides at Roberts Bank and thus movements of rearing juvenile Chinook salmon.

well as the individuals' motivation to access available quality habitats, seek food or refuge (e.g., Sharpe et al. 2019, Morrice et al. 2020). To keep the analysis simple, these additional environmental and behavioural factors were not incorporated in the base model. We considered the results of the model runs for methods #1 and #2 and and the assumptions that: (1) Chinook smolts should distribute away from Canoe Passage to Roberts Bank, and (2) Chinook smolts should not be flushed out of Roberts Bank with the currents. Based on these considerations and despite the above-listed limitations of the model in its current configuration, we determined that the model runs for both methods were effective in approximating movement patterns of juvenile Chinook salmon at Roberts Bank.

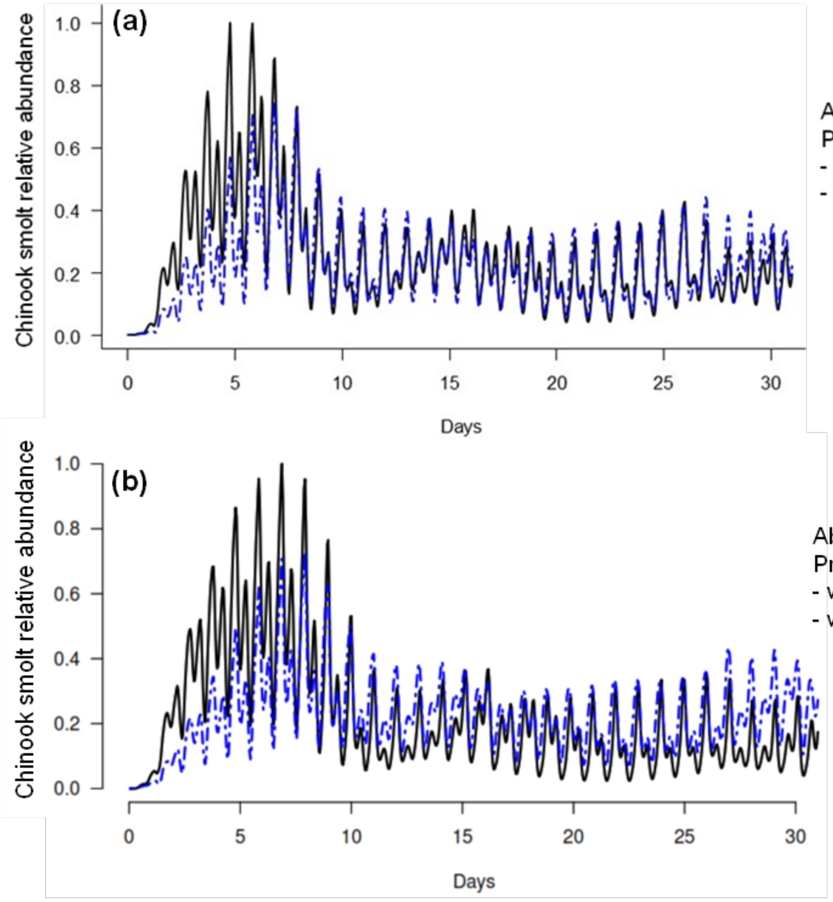
The proportion of Chinook smolt abundance in the inter-causeway area without and with the project for the modelled period is shown for method #1 in **Figure 3-1** and for method #2 in **Figure 3-2**. Compared to method #1, the results of the pooled biomass model (method #2) reveal less movement of Chinook smolts, driven predominantly by depth changes throughout the tidal cycle. On the other hand, movement of Chinook smolts is greater using the IBM model (method #1), driven predominantly by random dispersal. This is evident in **Figure 3-2** during the second half of the modelled period (past day 15) where the variation of Chinook smolt abundance in the inter causeway area (influenced by movement) is much less than in the IBM model (**Figure 3-1**).



Abundance with/without: 0.86
Proportion of Chinook smolts:
- with project: 0.037
- without project: 0.043

Abundance with/without: 0.88
Proportion of Chinook smolts:
- with project: 0.034
- without project: 0.039

Figure 3-1 **Chinook smolt abundance in the inter-causeway area without (black solid line) and with (blue dashed line) the project estimated over a one-month period using method #1 and depth preference curve shown in (a) Figure 2-4(a), and (b) Figure 2-4(b)**



Abundance with/without: 0.86
Proportion of Chinook smolts:
- with project: 0.027
- without project: 0.032

Abundance with/without: 0.93
Proportion of Chinook smolts:
- with project: 0.023
- without project: 0.027

Figure 3-2 **Chinook smolt abundance in the inter-causeway area without (black solid line) and with (blue dashed line) the project estimated over a one month period using method #2 and depth preference curve shown in (a) Figure 2-4(a), and (b) Figure 2-4(b)**

4.0 SUMMARY

We developed two methods (#1 and #2) to quantify potential project-related disruption to juvenile Chinook salmon migration. These two methods deployed the same base model that approximated movements of juvenile Chinook salmon exiting the river mouth and dispersing on the tidal flats at Roberts Bank. Habitat capacity for juvenile Chinook salmon was defined using two different depth preference curves, defining movements of juvenile Chinook salmon within a range of depths encountered at Roberts Bank during a tidal cycle. The methods differed from each other in that method #1 modelled random movements of individual Chinook smolt packets whereas method #2 used pools of Chinook smolt biomass in a deterministic manner.

In summary, potential project-related disruption to migration may divert away from the inter-causeway area approximately 7% to 14% of juvenile Chinook smolt abundance. In terms of productivity, the project has the potential to divert away from and reduce use of the inter-causeway area by approximately 0.002 t/year to 0.004 t/year of juvenile salmon or approximately 35 to 70 juvenile salmon per day. This disruption and apparent effect is unlikely to result in a loss of Chinook salmon productivity because those individuals diverted from the inter-causeway area will either remain north of the causeway, where they will benefit from the increased productivity in new offset habitats and increases with the project in native eelgrass and intertidal marsh forecasted by the ecosystem model, and/or they will migrate and successfully rear in offshore and other nearshore habitats in the estuary. Juvenile salmon diverted offshore will occupy the same offshore habitats and experience the same offshore predation risk as do all juvenile Chinook salmon when they migrate offshore currently. This finding confirms the qualitative assessment prediction presented in the project's EIS that, pre-mitigation, the project has the potential to result in a minor effect on juvenile salmon productivity from a potential disruption to migration.

5.0 CLOSURE

We have appreciated the opportunity of working with you on this project and trust that this report is satisfactory to your requirements. Please feel free to contact the undersigned by phone at 604.669.0424 regarding any questions or further information that you may require.

Report prepared by:
Hemmera Envirochem Inc.

Vasiliki Karpouzi, M.Sc., R.P.Bio.
Marine Fisheries Biologist, Technical Lead

Report prepared by:
UBC & ESSA Technologies Ltd.

Villy Christensen

Villy Christensen, PhD
Professor, Ecopath with Ecosim Developer

Report reviewed by:
Ecofish Research Ltd.

Adam Lewis, M.Sc. R.P.Bio.
President, Senior Scientist

6.0 DISCLAIMER

The Work described herein was performed in accordance with Contract No. 16-0087(02) between Hemmera, a wholly owned subsidiary of Ausenco Engineering Canada Inc. (Ausenco), and the Vancouver Fraser Port Authority (Client), dated July 4, 2019 (Contract). This memo has been prepared by Hemmera, based on fieldwork conducted by Hemmera, for sole benefit and use by the Vancouver Fraser Port Authority. In performing this Work, Hemmera has relied in good faith on information provided by others, and has assumed that the information provided by those individuals is both complete and accurate. This Work was performed to current industry standard practice for similar environmental work, within the relevant jurisdiction and same locale. The findings presented herein should be considered within the context of the scope of work and project terms of reference; further, the findings are time sensitive and are considered valid only at the time the Memo was produced. The conclusions and recommendations contained in this Memo are based upon the applicable guidelines, regulations, and legislation existing at the time the Memo was produced; any changes in the regulatory regime may alter the conclusions and/or recommendations.

7.0 REFERENCES

Archipelago. 2014a. Technical Data Report, Roberts Bank Terminal 2 Project, Marine Fish, Juvenile Salmon Surveys. Prepared for Hemmera Envirochem Inc., Prepared by Archipelago Marine Research Ltd., Victoria, B.C. CIAR Document #388. Available at https://www.ceaa-acee.gc.ca/050/documents/p80054/107615E.pdf. Accessed March 2021.

Archipelago. 2014b. Technical Data Report, Roberts Bank Terminal 2 Project, Marine Fish, Eelgrass Fish Community Survey. Prepared for Hemmera Envirochem Inc., Prepared by Archipelago Marine Research Ltd., Victoria, B.C. CIAR Document #388. Available at https://www.ceaa-acee.gc.ca/050/documents/p80054/107611E.pdf. Accessed March 2021.

Beverton, R. J. H., and S. J. Holt. 1993. On the Dynamics of Exploited Fish Populations. Springer, Netherlands.

Chalifour, L., D. C. Scott, M. MacDuffee, J. C. Iacarella, T. G. Martin, and J. K. Baum. 2019. Habitat Use by Juvenile Salmon, Other Migratory Fish, and Resident Fish Species Underscores the Importance of Estuarine Habitat Mosaics. Marine Ecology Progress Series 625:145–162.

Chalifour, L., D. C. Scott, M. MacDuffee, S. Stark, J. F. Dower, T. D. Beacham, T. G. Martin, and J. K. Baum. 2020. Chinook Salmon Exhibit Long-term Rearing and Early Marine Growth in the Fraser River, B.C., a Large Urban Estuary. Canadian Journal of Fisheries and Aquatic Sciences. https://doi.org/10.1139/cjfas-2020-0247.

Christensen, V., M. Coll, J. Steenbeek, J. Buszowski, D. Chagaris, and C. J. Walters. 2014. Representing Variable Habitat Quality in a Spatial Food Web Model: Ecosystems 17(8):1397–1412.

DFO. 2016. Technical Review of Roberts Bank Terminal 2 Environmental Assessment: Section 10.3 – Assessing Ecosystem Productivity. Canadian Science Advisory Secretariat Science Response 2016/050. Fisheries and Oceans Canada, Pacific Region. Available at https://waves-vagues.dfo-mpo.gc.ca/Library/40622642.pdf. Accessed October 2020.

Gregory, R. S. 1993. The Effect of Turbidity on the Predator Avoidance Behaviour of Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 50:241–246.

Gregory, R. S. and C. D. Levings. 1998. Turbidity Reduces Predation on Migrating Juvenile Pacific Salmon. Transactions of the American Fisheries Society 127:275–285.

Healey, M. C. 1991. Life History of Chinook Salmon (*Oncorhynchus tshawytscha*). Pages 311–394. In C. Groot, and L. Margolis, Editors, Pacific Salmon Life Histories. UBC Press.

Hemmera. 2014. Roberts Bank Ecosystem Model Parameter Estimates. Prepared for Port Metro Vancouver, Prepared by Hemmera Envirochem Inc. Environmental Impact Statement, Volume 3: Biophysical Effects Assessments, Appendix 10-B. CIAR Document #181. Available at https://www.ceaa-acee.gc.ca/050/documents/p80054/101363E.pdf. Accessed January 2021.

Hering, D. K., D. L. Bottom, E. F. Prentice, K. K. Jones, and I. A. Fleming. 2010. Tidal Movements and Residency of Subyearling Chinook Salmon (*Oncorhynchus tshawytscha*) in an Oregon Salt Marsh Channel. Canadian Journal of Fisheries and Aquatic Sciences 67:524–533.

Heymans, J. J., M. Coll, J. S. Link, S. Mackinson, J. Steenbeek, C. Walters, and V. Christensen. 2016. Best Practice in Ecopath with Ecosim Food web Models for Ecosystem-based Management. Ecological Modelling 331:173–184.

Levy, D. A., and T. G. Northcote. 1981. The Distribution and Abundance of Juvenile Salmon in Marsh Habitats of the Fraser River Estuary. Technical Report, Westwater Research Centre, Vancouver, B.C.

Levy, D. A., and T. G. Northcote. 1982. Juvenile Salmon Residency in a Marsh Area of the Fraser River Estuary. Canadian Journal of Fisheries and Aquatic Sciences 39(2):270–276.

Macdonald, A. L. 1984. Seasonal Use of Nearshore Intertidal Habitats by Juvenile Pacific Salmon on the Delta Front of the Fraser River Estuary, British Columbia. M.Sc. Thesis. Department of Biology, University of Victoria, Victoria, B.C.

McCormick, S. D. 2006. Ontogeny and Evolution of Salinity Tolerance in Anadromous Salmonids: Hormones and Heterochrony. Estuaries 17(1A):26–33.

McMichael, G. A., A. C. Hanson, R. A. Harnish, and D. M. Trott. 2013. Juvenile Salmonid Migratory Behavior at the Mouth of the Columbia River and Within the Plume. Animal Biotelemetry 1:14 pp.

Morrice, K. J., A. M. Baptista, and B. J. Burke. 2020. Environmental and Behavioral Controls on Juvenile Chinook Salmon Migration Pathways in the Columbia River Estuary. Ecological Modelling 427:109003.

NHC. 2014. Roberts Bank Terminal 2 Technical Report: Coastal Geomorphology Study. Prepared for Port Metro Vancouver, Prepared by Northwest Hydraulic Consultants, North Vancouver, B.C. CIAR Document #181. Available at https://www.ceaa-acee.gc.ca/050/documents/p80054/101370E.pdf. Accessed January 2021.

Pauly, D. 1984. Fish Population Dynamics in Tropical Waters: A Manual for Use with Programmable Calculators. ICLARM Studies and Reviews 8:325.

Scott, D. C., L. Chalifour, M. MacDuffee, J. K. Baum, and S. G. Hinch. 2019. Variation in Out-migration Timing and Estuary Reliance of “Ocean-type” Chinook Salmon in the Fraser River Estuary, B.C. North Pacific Anadromous Fish Commission Technical Report 15. Available at https://npafc.org/wp-content/uploads/technical-reports/Tech-Report-15-DOI/Technical-Report-15.pdf. Accessed January 2021.

Sharpe, C., C. Carr-Harris, M. Arbeider, S. M. Wilson, and J. W. Moore. 2019. Estuary Habitat Associations for Juvenile Pacific Salmon and Pelagic Fish: Implications for Coastal Planning Processes. Aquatic Conservation: Marine and Freshwater Ecosystems 29:1636–1656.

Simenstad, C. A., W. G. Hood, R. M. Thom, D. A. Levy, and D. L. Bottom. 2000. Landscape Structure and Scale Constraints on Restoring Estuarine Wetlands for Pacific Coast Juvenile Fishes. Pages 597–630 in M. P. Weinstein, and D. A. Kreeger, Editors. Concepts and Controversies in Tidal Marsh Ecology. Springer, Dordrecht.

Steenbeek, J., J. Buszowski, V. Christensen, E. Akoglu, K. Aydin, N. Ellis, D. Felinto, J. Guitton, S. Lucey, K. Kearney, S. Mackinson, M. Pan, M. Platts, and C. Walters. 2016. Ecopath with Ecosim as a Model-building Toolbox: Source Code Capabilities, Extensions, and Variations. Ecological Modelling 319:178–189.

Steenbeek, J., M. Coll, L. Gurney, F. Mélin, N. Hoepffner, J. Buszowski, and V. Christensen. 2013. Bridging the Gap Between Ecosystem Modeling Tools and Geographic Information Systems: Driving a Food Web Model with External Spatial-Temporal Data. Ecological Modelling 263:139–151.

VFPA. 2015a. Roberts Bank Terminal 2 Project – Environmental Impact Statement, Volume 3: Biophysical Effects Assessment, Section 13.0: Marine Fish Effects Assessment. CIAR Document #181. Available at https://www.ceaa-acee.gc.ca/050/documents/p80054/101365E.pdf. Accessed January 2021.

VFPA. 2015b. From Port Metro Vancouver to the Canadian Environmental Assessment Agency re: Completeness Review - Responses to Additional Information Requirements (See reference document # 271) for the Environmental Impact Statement. CIAR Document #314. Available at https://www.ceaa-acee.gc.ca/050/documents/p80054/103668E.pdf. Accessed March 2021.

VFPA. 2018a. From the Vancouver Fraser Port Authority to the Review Panel re: Responses to Information Requests IR5-02, IR5-11, IR5-13, IR5-17, IR5-18, IR5-22, IR5-25, IR5-26, IR5-27, IR5-43, and IR5-44 (See Reference Document # 975). CIAR Document #1153. Available at https://www.ceaa-acee.gc.ca/050/documents/p80054/121794E.pdf. Accessed January 2021.

VFPA. 2018b. From the Vancouver Fraser Port Authority to the Review Panel re: Responses to Information Requests IR5-19, IR5-39 and IR5-40 (See Reference Document #975). CIAR Document #1138. Available at https://www.ceaa-acee.gc.ca/050/documents/p80054/121442E.pdf. Accessed January 2021.

VFPA. 2019. From the Vancouver Fraser Port Authority to the Review Panel re: Closing Remarks. CIAR Document #2045. Available at https://www.ceaa-acee.gc.ca/050/documents/p80054/132546E.pdf. Accessed March 2021.

Von Bertalanffy, L. 1934. Untersuchungen über die Gesetzlichkeiten des Wachstums. I. Teil: Allgemeine Grundlagen der Theorie; Mathematische und physiologische Gesetzlichkeiten des Wachstums bei Wassertieren. Wilhelm Roux' Archiv für Entwicklungsmechanik der Organismen 131:613–653.

Walters, C., V. Christensen, W. Walters, and K. Rose. 2010. Representation of Multistanza Life Histories in Ecospace Models for Spatial Organization of Ecosystem Trophic Interaction Patterns. Bulletin of Marine Science 86(2):439–459.

Wong, M. K.-S., S. Nobata, and S. Hyodo. 2019. Enhanced Osmoregulatory Ability Marks the Smoltification Period in Developing Chum Salmon (*Oncorhynchus keta*). Comparative Biochemistry and Physiology Part A 238:110565.