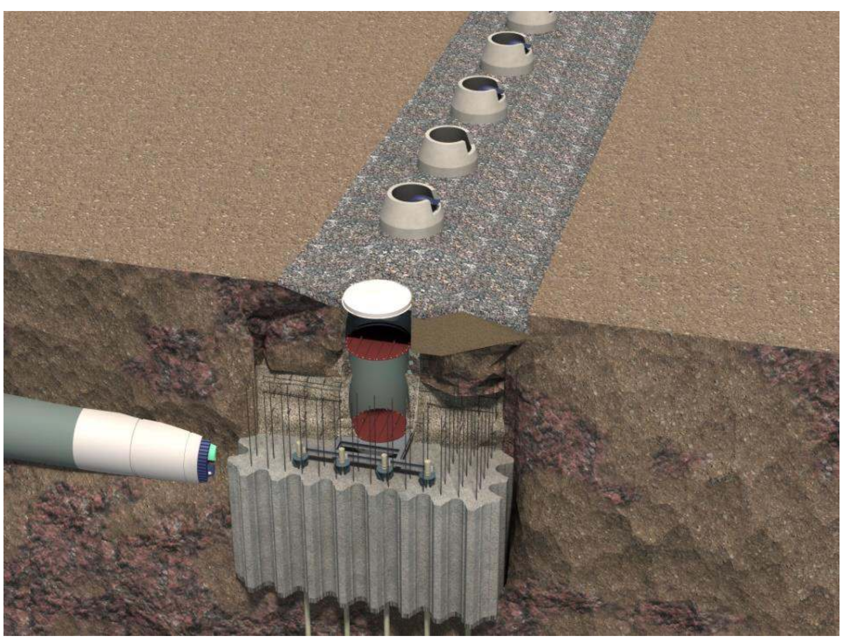
APPENDIX C
GEOMORPHOLOGICAL STUDIES

C.2: Hydraulic Process and Alterations Report

Annacis Island WWTP New Outfall System

Vancouver Fraser Port Authority
Project and Environmental Review Application



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NHC Ref. No. 3000386.60

17 October 2017

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Attention: **John Newby, PE**
Principal

Copy to: John Crippen, PE, Project Manager, CDM
Jeff Chen, PEng, CDM

Via email: NewbyJE@cdmsmith.com
CrippenJN@cdmsmith.com
chenjb@cdmsmith.com

Re: **Annacis Island NOS Outfall - Hydraulic Process and Alterations Analysis**
Effect of the Existing Outfall, New Diffuser, and Revised South Surrey Interceptor
Technical Memorandum

Dear Mr. Newby:

Northwest Hydraulic Consultants Ltd. (NHC) is pleased to submit this technical memorandum to support the development of the Hydraulic Process and Alterations report at the Annacis Island Wastewater Treatment Plant (WWTP). This technical document describes the computational fluid dynamics (CFD) modelling conducted to analyze (a) the effect of the existing outfall, (b) the potential alterations from the new diffuser, and (c) the effect of removing or lowering the south Surrey Interceptor riprap apron.

1 BACKGROUND AND SCOPE OF WORK

1.1 Background

The Port of Vancouver (VFPA) has requested a Hydraulic Process and Alterations Report that addresses potential impacts of the new diffuser system on hydraulics and geomorphology. One immediate neighbor (Southern Railway) has requested similar information to determine what the impacts might be to their maintenance dredging for the Railcar Barge Terminal (Figure 1-1).

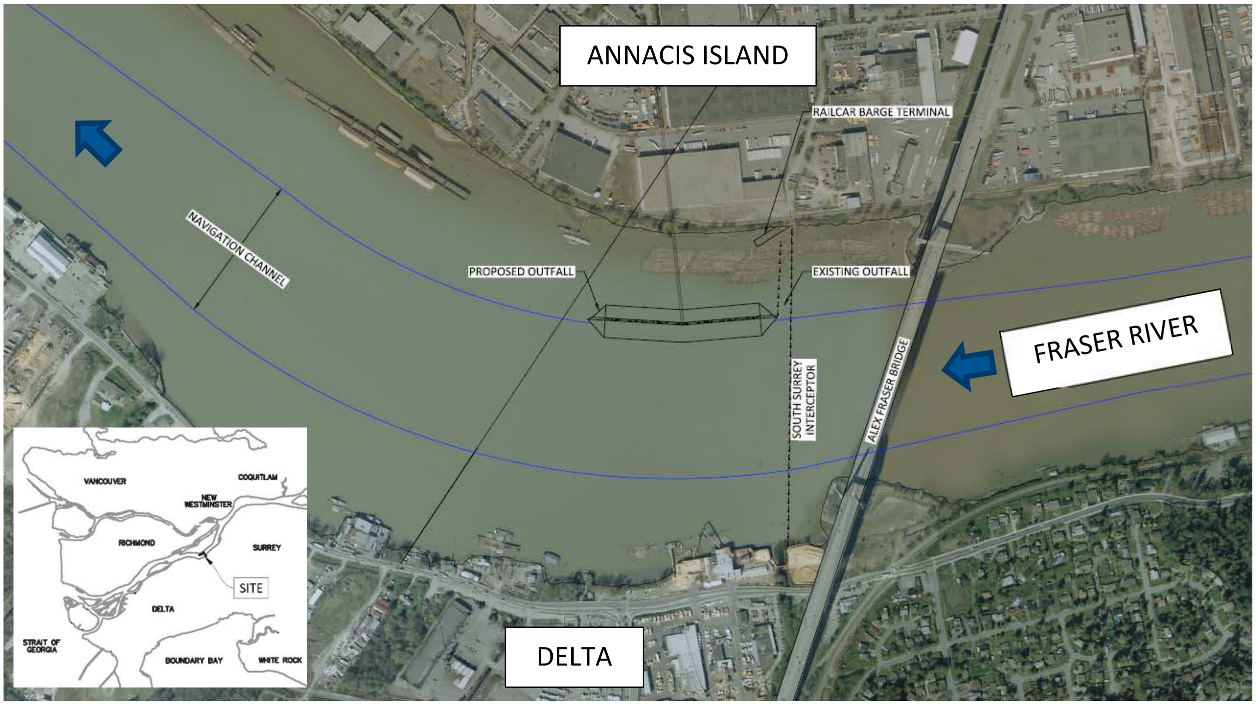


Figure 1-1. Existing and proposed outfall locations, showing also the navigation channel, South Surrey Interceptor and Railcar Barge Terminal.

Specifically, VFPA requested that the Hydraulic Process and Alterations Report cover:

1. Hydraulic Process Summary/overview of the hydraulic processes that are driving the apparent relative stability of the river bed elevation on the north side of the Fraser (+/- 2 m), and the implications (on this relative bed stability) of removing the existing outfall
2. Summary/overview of potential alterations (as a result of the installation of the new diffuser) to river hydraulics, local deposition/erosion, and consequences for immediate neighbours (upstream and downstream).

1.2 Scope of Work

The following scope was proposed by NHC to provide the information requested as part of the Hydraulic Process and Alterations Report.

Task 1: Overview of Sedimentation Processes

Task 2: Baseline Condition - Effect of the Existing Outfall

Task 3: Overview of Potential Alterations from the New Diffuser

Task 4: Effect of Removing South Surrey Interceptor Riprap Apron

2 OVERVIEW OF SEDIMENTATION PROCESSES

2.1 Setting

Background information on the morphology and historical channel changes along this reach are described in NHC (2016[1]). This section provides a brief overview of the key factors that control the pattern of sedimentation near the outfall.

Previous measurements by Water Survey of Canada indicated the total sediment load of the lower Fraser River averages approximately 17.3 million tonnes/year, of which 2.8 million tonnes/year (1.8 million m^3/year) consists of bed material load (mainly medium to fine sand).

Figure 2-1 shows the main channel branches of the lower Fraser River downstream of New Westminster. The new outfall is located at the upstream end of St. Mungo's Bend (near Km 29.2) on the north side of Annievelle Channel. The outfall will be located on the north side of the navigation channel and starts downstream of the existing South Surrey Interceptor (which is located downstream of Alex Fraser Bridge). The Alex Fraser Bridge was constructed in 1984 and has two large ship collision structures which encroach into the channel. Figure 2-2 shows an oblique view of the site showing the channel and bridge from Annacis Island.

Figure 2-1: Lower Fraser River showing river kilometres referenced to Sandheads and approximate flow distribution in channels, referenced to total flow at New Westminster.

[1] NHC (2016). Overview of Fluvial Geomorphology, Annacis Island WWTP Transient Mitigation and Outfall Project. Report submitted to CDM Smith, 11 January 2016.

Figure 2-2: View towards south bank showing Annieville Channel near outfall

Dredging has been carried out in St. Mungo's Bend reach (Km 27 to Km 30) since the 1960s. According to records provided by Port Metro Vancouver, dredging volumes in the reach peaked at over 1 million m^3/year in the 1980s but has typically been less than 200,000 m^3/year since 2000. Navigation dredging has also been carried out upstream of Km 30, particularly below Fraser Surrey Docks.

2.2 Factors Governing Sedimentation Pattern

Figure 2-3 shows the general channel bathymetry through the reach, as surveyed in 2015. The following factors have had a significant effect on the morphology and sedimentation pattern through the reach.

2.2.1 St. Mungo's Bend

St. Mungo's Bend extends for a distance of approximately 1,600 m downstream of the Alex Fraser Bridge between Km 28 to Km 29.6. The channel curvature (Figure 2-3) results in the formation of a prominent shoal (point bar) along the north (inner) bank between Km 27.5 and Km 29, and a deep pool on the south (outer) bank between Km 28 and Km 29. Past dredging in the reach has been concentrated in the region of the shoal, where the outer edge of the point bar encroaches into the navigation channel. This pattern is consistent with experience and observations from many other large sand-bed rivers (Knighton, 1998[2]; Dietrich and Smith, 1983[3], Dietrich and Smith, 1984[4]). Figure 2-4 shows an idealized representation of a bend. .The main processes driving this sedimentation pattern are summarized below:

[2] Knighton, D. 1998. Fluvial forms and processes: a new perspective. Arnold, Oxford University Press, London, New York.

[3] Dietrich, W. and D. Smith 1983. Influence of point bar growth on flow through curved channels. Water Resources Research 19(5), p. 1173-1192.

[4] Dietrich, W. and D. Smith, 1984. Bed load transport in a river meander,. Water Resources Research, 20(10), p. 1355-1380.

- Super-elevation of the water surface towards the outer bank.
- Transverse current directed towards the outer bank on the surface and towards the inner bank near the bed.
- Maximum current velocity moves from near the inner bank at the bend entrance to near the outer bank at the bend exit, crossing the channel through the zone of greatest curvature.
- Shoaling-induced outward flow over top of the point bar (Dietrich and Smith, 1983).

2.2.2 Alex Fraser Bridge

Construction of the ship collision structures at the Alex Fraser Bridge constrict the effective waterway opening from 420 m to 340 m. The north ship collision structure deflects the approach flow southwards and has induced a moderate amount of local scour downstream from the structure. The south ship collision structure has a much greater impact on the approach flow and generates a prominent zone of flow separation and back eddying downstream from the structure (Figure 4-1). The structure is founded on relatively erosion-resistant Pleistocene-age sediments (gravel outwash and till) and has not experienced significant local scour. However, very deep scour has been generated up to 400 m downstream, where the river bed consists of erodible alluvial sand deposits. This scour is limited to the south and middle sections of the channel (Figure 2-3).

2.2.3 South Surrey Interceptor Apron Exposure Due to Navigation Channel Deepening

Construction of the riprap apron over the South Surrey Interceptor started in 1986 and extended towards the north side of the channel in 1990. Ongoing deepening of the navigation channel in the late 1980s and 1990s resulted in the apron projecting above the surrounding bed on the south side of the channel. This has resulted in generation of additional local scour downstream. This process is described further in Section 6.1 and is illustrated in Figure 6-1 and Figure 6-2.

2.2.4 Channel Stability at Existing Outfall

The prominent shoal that has developed in St. Mungo's Bend pre-dates the construction of the Annacis Outfall and Alex Fraser Bridge. This zone of deposition is primarily governed by the curvature of the channel. The existing outfall is situated immediately upstream of the bend entrance in the straight section of the channel. This location is upstream of the point bar region where secondary flow will transport and deposit sediment on the inner (convex) side of the channel. The outfall was located in a stable section of the river, upstream of the region of normal point bar deposition.

The north ship collision structure is set-back from the main flow in the channel and has a relatively minor effect on the general bed topography in comparison to the southern structure (Figure 2-3). The north ship collision structure does produce a local sheltered zone along the shoreline, immediately downstream, which will promote local accretion behind the structure. However, this region is upstream of the existing outfall.

The deep scour hole downstream of the riprap apron is restricted to the south and middle portion of the channel, not the north side. For example, on the south side, the bed level drops at least 6 m within a distance of 75 m from the interceptor.

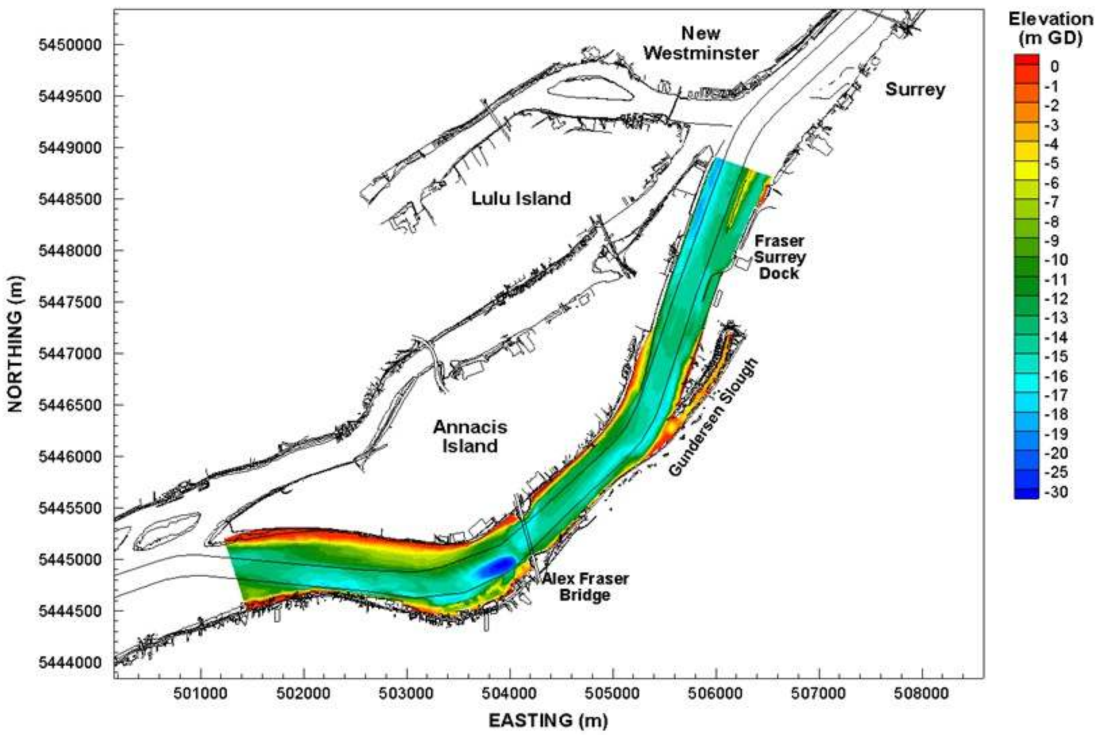


Figure 2-3: Generalized bed topography near site from 2015 bathymetric survey

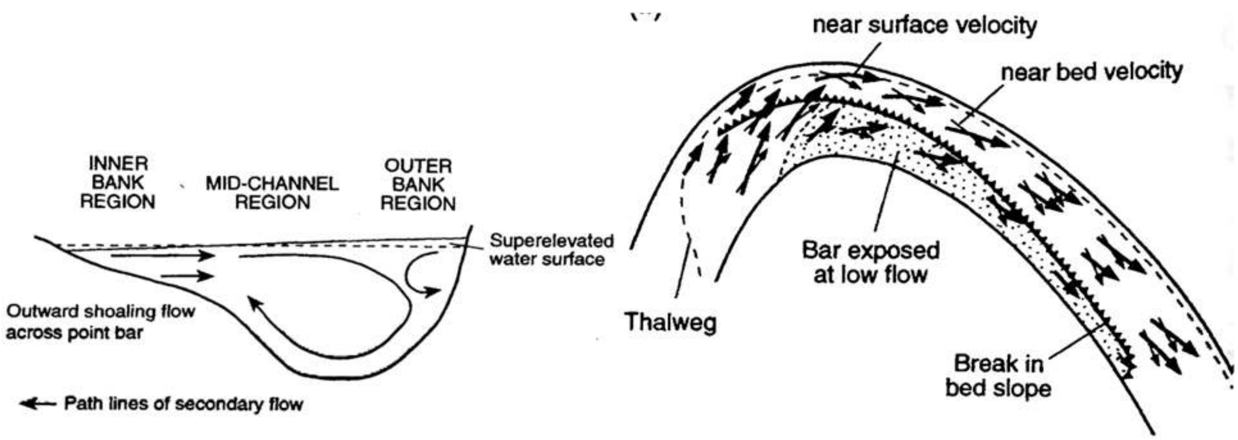


Figure 2-4: Idealized flow and sedimentation pattern in a bend (Knighton, 1998)

Therefore, the relative stability at the existing outfall is governed primarily by its position relative to the bend alignment and the fixed banks which prevent lateral channel shifting. The detailed modelling described in subsequent sections of this report are intended to elaborate on these processes and provide quantitative estimates of the effects described in this overview.

3 NUMERICAL HYDRAULIC MODELING

3.1 CFD Model

Computational fluid dynamics (CFD) modelling was used to provide detail hydraulic information of the study reach shown in Figure 3-1 to analyze (a) the effect of the existing outfall, (b) the potential alterations from the new diffuser, and (c) the effect of removing or lowering the south Surrey Interceptor riprap apron.

CFD is a branch of fluid mechanics that uses numerical analysis and computers to solve and analyze problems that involve fluid flows. CFD modelling provides high resolution and detailed hydraulic information, which is particularly important when structures or complex 3D flow phenomena are present.

The CFD software FLOW-3D, which has advanced capabilities for modelling free-surface flows, was used to model a 6 km long reach of Annieville Channel of the Lower Fraser River (Figure 3-1). The model domain was divided into three main mesh blocks of different resolution (mesh cell size). The inflow and outflow mesh blocks used 10 m cells, while the main central mesh block -where the outfall is located (Figure 3-2)- used finer 2.5 m cells, leading to 11.2 million cells in total. The large size of the modelling domain was designed to ensure that the local flow hydraulics near the outfall and diffusers were not influenced by the inflow and outflow sections.

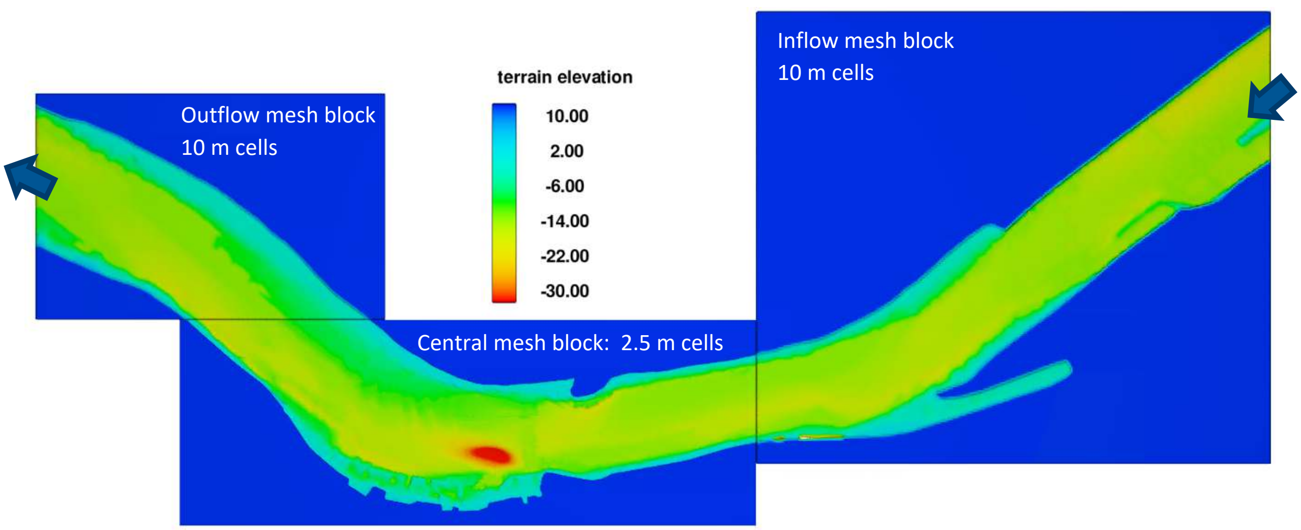


Figure 3-1. CFD model domain of Annieville Channel showing mesh blocks and cell sizes.

The CFD model geometry was based on bathymetric information from 2013 Fugro Pelagos bathymetric survey and 2014 PWGSC (Public Works and Government Services Canada) bathymetric surveys. The geometry of the existing outfall (Figure 3-3) and new proposed diffusers (Figure 3-4; drawing A61C0004.dwg, March 2017) were provided by CDM Smith. The floodplain above the water level was assumed at El. 10 m (Figure 3-1).

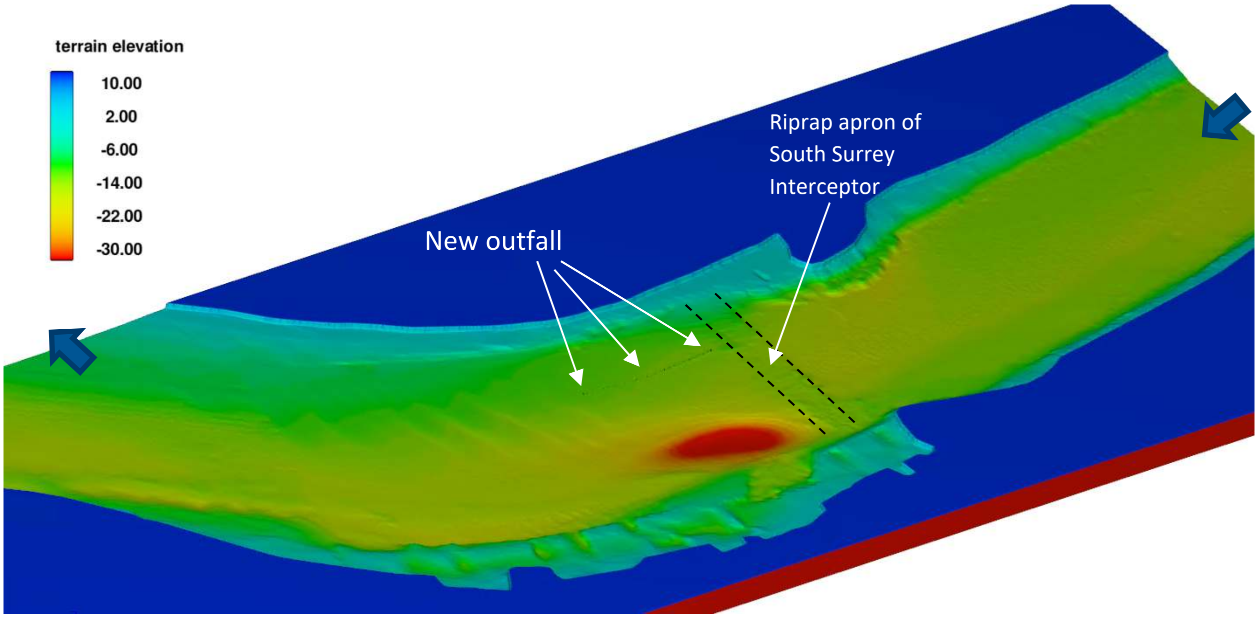


Figure 3-2. Inclined view of central CFD mesh block showing the proposed new diffusers and existing riprap apron of South Surrey Interceptor.

3.2 Boundary Conditions and Numerical Settings

The boundary conditions used for CFD modelling are shown in Table 3-1. These varied flow conditions were selected to encompass the full range of possible flow conditions to be expected in the study area. The slack tide is a short period between ebb and flood tide before the direction of the tidal stream reverses, when there is little movement either way in the Fraser River. Although short-lived, the effect of the outfall discharge should be most noticeable under slack tide conditions. The typical winter flow represents a more frequent and probably more representative flow condition. The 2012 flood, which was near the 20-year return period flood, represents the highest flood event experienced in recent years. Although infrequent, sediment transport and hence morphological impacts are significant under such conditions.

Table 3-1. Flow conditions used for CFD modelling

Flow condition	Inflow discharge* (m^3/s)	Outflow water level* (m)
Winter Slack tide	0	0.63
Typical winter flow	7,000	-0.59
2012 flood (peak flow)	13,500	0.46

* Peak values extracted from results of a one-dimensional MIKE11 tidal flow model

The exact values of inflow discharge and outflow water level shown in Table 3-1 are peak values extracted from results of a one-dimensional MIKE11 tidal flow model of the entire Lower Fraser River between Mission and the Strait of Georgia. These conditions represent an instantaneous snapshot in time and were used as steady boundary conditions in the CFD model. Although FLOW-3D is a fully unsteady flow model, because of the high spatial resolution used by the model (e.g. millions of computational cells) it was run under constant inflow and outflow boundary conditions to minimize computational time. Also, because the goal of the model is to compare the effects of having the outfall on or off, steady flow conditions were considered acceptable for such a purpose.

The total riverbed roughness height was assumed to be 0.4 m, based on a previous calibration undertaken for a different location on the Fraser River (NHC, 2007[5]). Turbulence was modelled using the RNG k-epsilon turbulence model.

3.3 Outfall Modelling

Flow discharging from each outfall port was simulated as a point source with a specified discharge and flow direction (3D unit vector). The number of ports open (point sources) and flow from each port for the existing and proposed outfalls are shown in Table 3-2.

Table 3-2. Number of ports and point discharge used in CFD model

Outfall	Total outfall flow (m^3/s)	Number of ports open	Flow at each port (m^3/s)
Existing	10.4	21	0.50
Proposed (Stage V)	18.9	18	1.05

Figure 3-3 shows a longitudinal profile of the existing outfall, which is made of 3 rows of 7 vertical ports aligned parallel to the South Surrey Interceptor (Figure 1-1). The ports discharge directly upwards and perpendicular to the river flow direction.

[5] NHC (2007). "Pattullo Bridge Modeling – River2D modeling". Technical memo prepared by Northwest Hydraulic Consultants Ltd. for Translink.

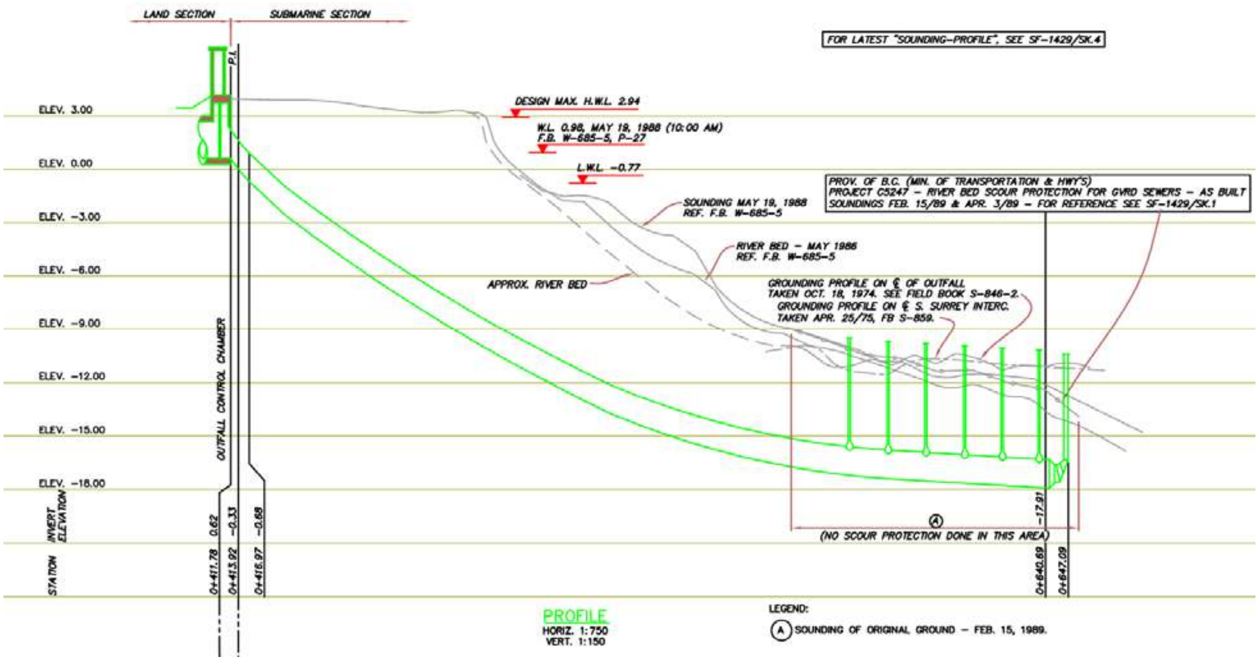


Figure 3-3. Longitudinal profile of existing outfall.

The new proposed outfall is a manifold aligned parallel to the river flow (Figure 3-2) near the north edge of the navigation channel (Figure 1-1). The proposed ports[6] are located at El. -10.85 m and discharge horizontally towards the navigation channel (Figure 3-4), not the water surface as in the existing outfall (Figure 3-3).

Since the existing riprap apron of the South Surrey Interceptor causes local scour immediately downstream, the riverbed elevation is lower on the upstream east end of the new outfall (~El. -13.5 m), exposing the proposed riprap protection on that side (Figure 3-4). On the downstream west side, the bed level rises up to ~El. -12.0 m covering the proposed riprap protection.

[6] As shown in CDM Smith's 60% Design Review Drawing A61C0071, dated August 2017.

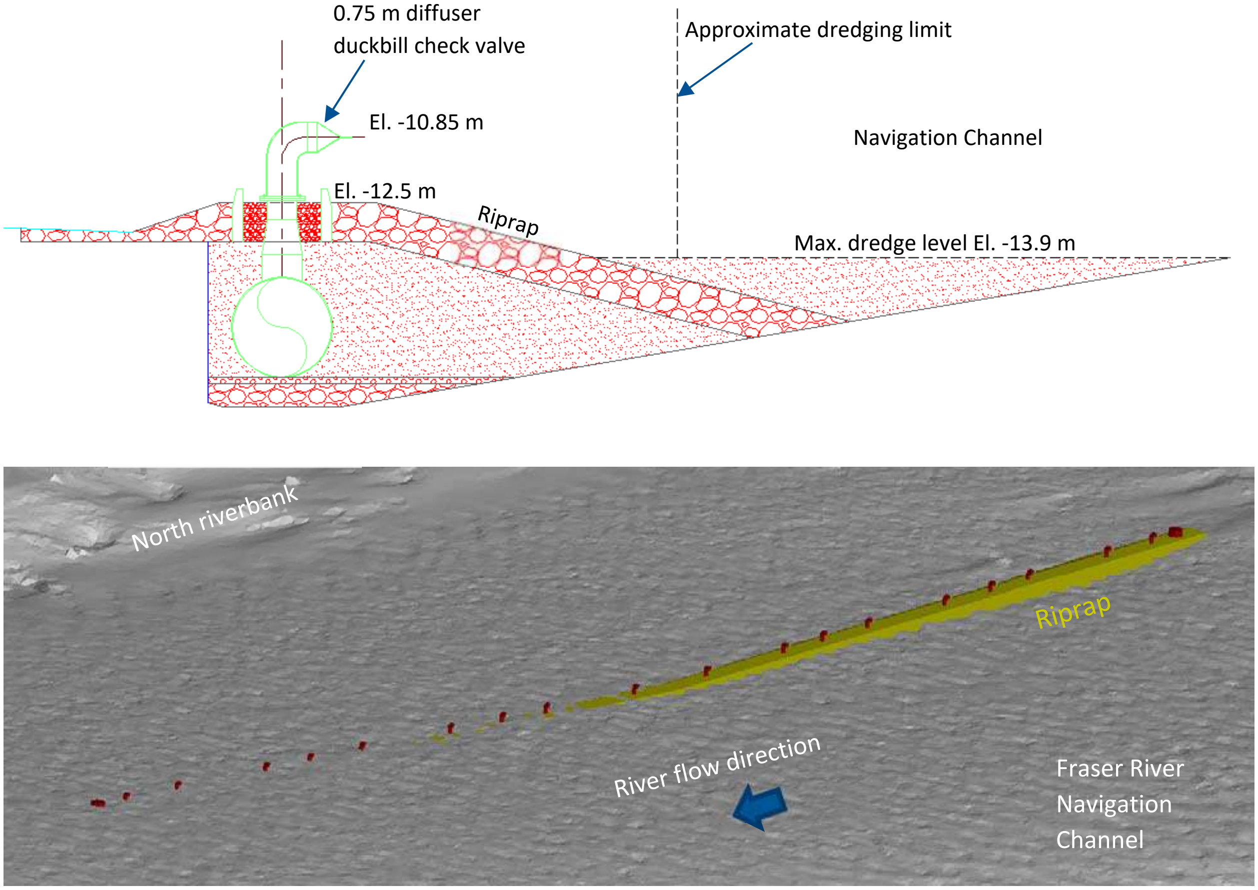


Figure 3-4. Elevation view of proposed diffuser (top) and 3D solid representation of 18 ports in CFD model (bottom).

4 EFFECT OF THE EXISTING OUTFALL

It has been proposed that the discharge from the existing outfall may reduce localized sedimentation rates on the north side of the channel. In order to test this hypothesis, the CFD model was used to simulate the interaction between the outfall discharge and the river flow and compute bed shear stresses with the existing outfall operating (on) and not operating (off); for the flow conditions listed in Table 3-1. Although there was no data available to calibrate or verify the local diffuser hydraulics, it is expected that the CFD should represent the turbulence and entrainment of a diffuser system.

First, the general flow patterns predicted by FLOW-3D were compared with field observations. Figure 4-1 shows a comparison of general flow patterns observed in a 2004 Google Earth satellite image with those predicted by FLOW-3D for the simulation flow of 7,000 m^3/s. The satellite image shows flow separation along the south ship collision structure of the Alex Fraser Bridge, leading to the formation of a large recirculation (eddy) zone immediately downstream. This prominent feature creates uneven flow distribution at the cross section where the outfall is located and is likely due to the upstream flow curvature (Figure 3-1) interacting with the large ship-collision protection at the south bridge abutment. This large eddy and the varied transverse velocity profile were captured by FLOW-3D (Figure 4-1).

Figure 4-2 shows in detail the vertical plane with several of the existing outfall ports discharging under slack tide conditions. As the openings of the ports are directed upwards towards the free surface (Figure 3-3), the jets do not interact with the bed and hence produce no noticeable change in the bed shear stresses as shown in Figure 4-3. The same is true for the winter flow (Figure 4-4) and 2012 flood condition (Figure 4-5); as the bed shear stress with the outfall on or off is practically the same. The highest areas of bed shear stress (red colour in plots) occur over the crest of the non-erodible riprap protection of the South Surrey Interceptor and are due to the normal river flow currents.

Based on the negligible bed impact caused by the existing outfall, it can be concluded that the apparent relative stability of the river bed elevation on the north side should be attributed to the factors discussed previously in Section 2.2.4, and hence not related to the presence or operation of the existing outfall.

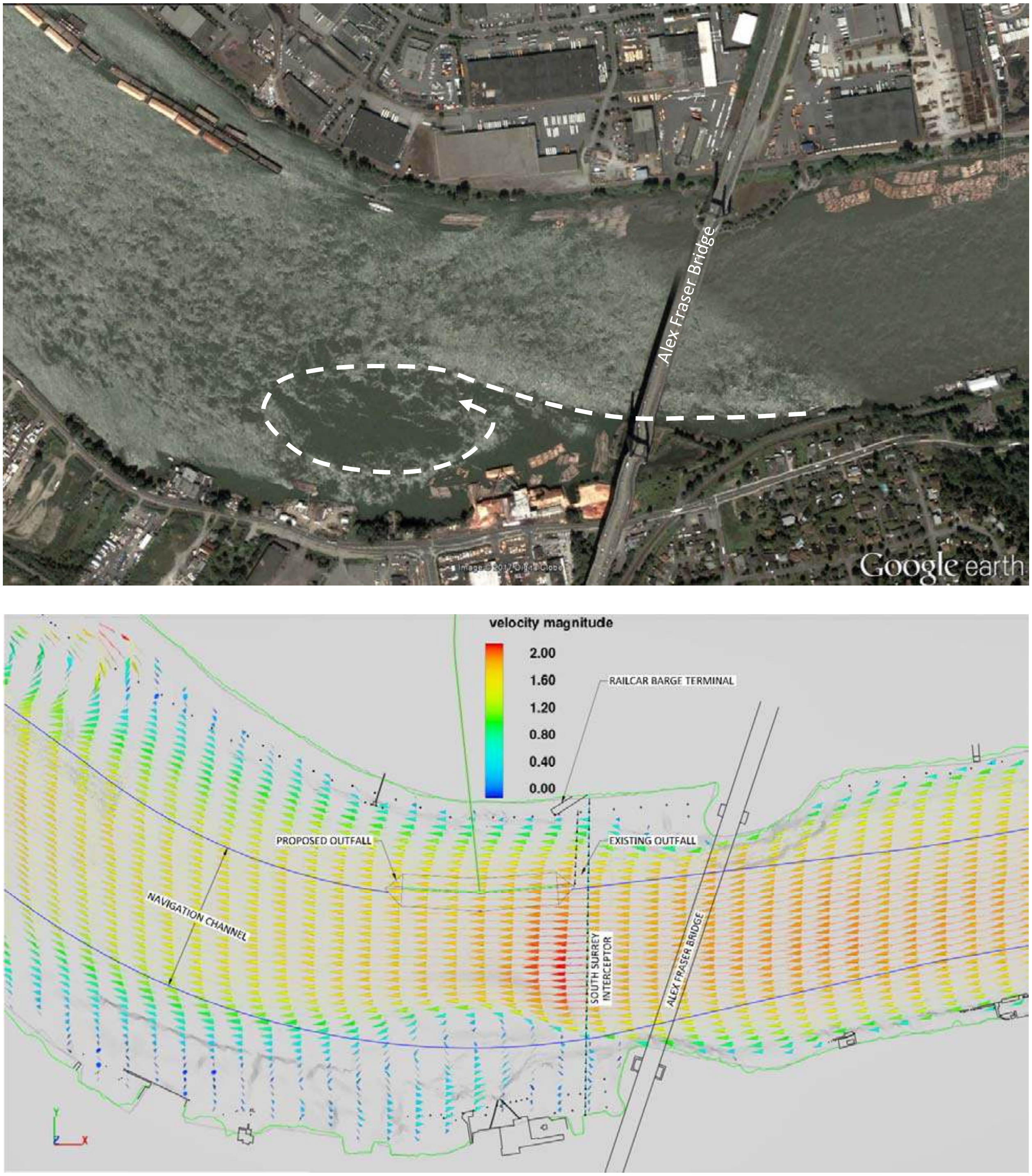


Figure 4-1. Google Earth image showing flow recirculation downstream of south abutment of Alex Fraser Bridge (top), and similar flow pattern predicted by FLOW-3D for 7,000 m^3/s (bottom).

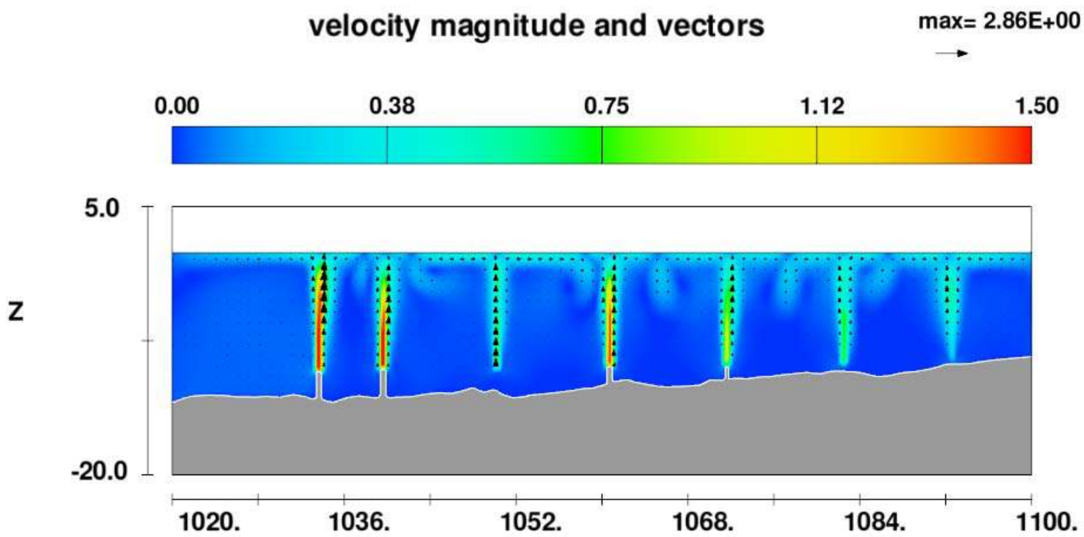


Figure 4-2. Detail of existing outfall ports discharging during slack tide.

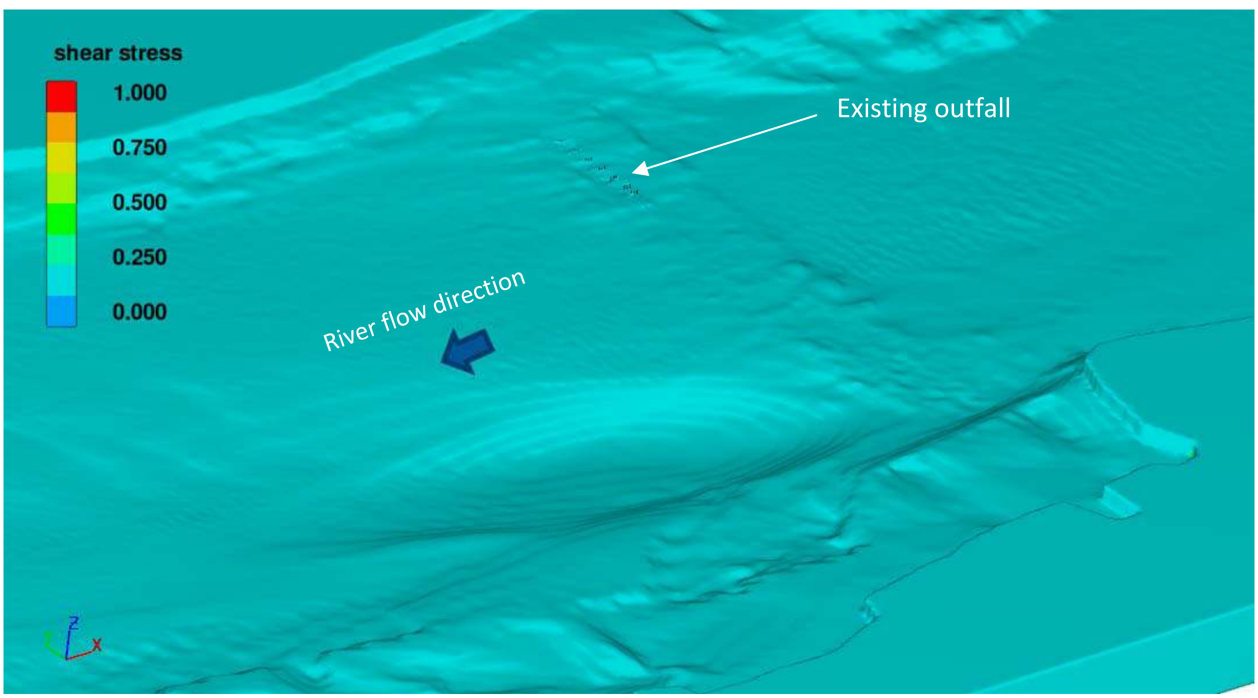


Figure 4-3. Bed shear stress predicted by FLOW-3D for slack tide condition with the existing outfall operating shows no noticeable effect.

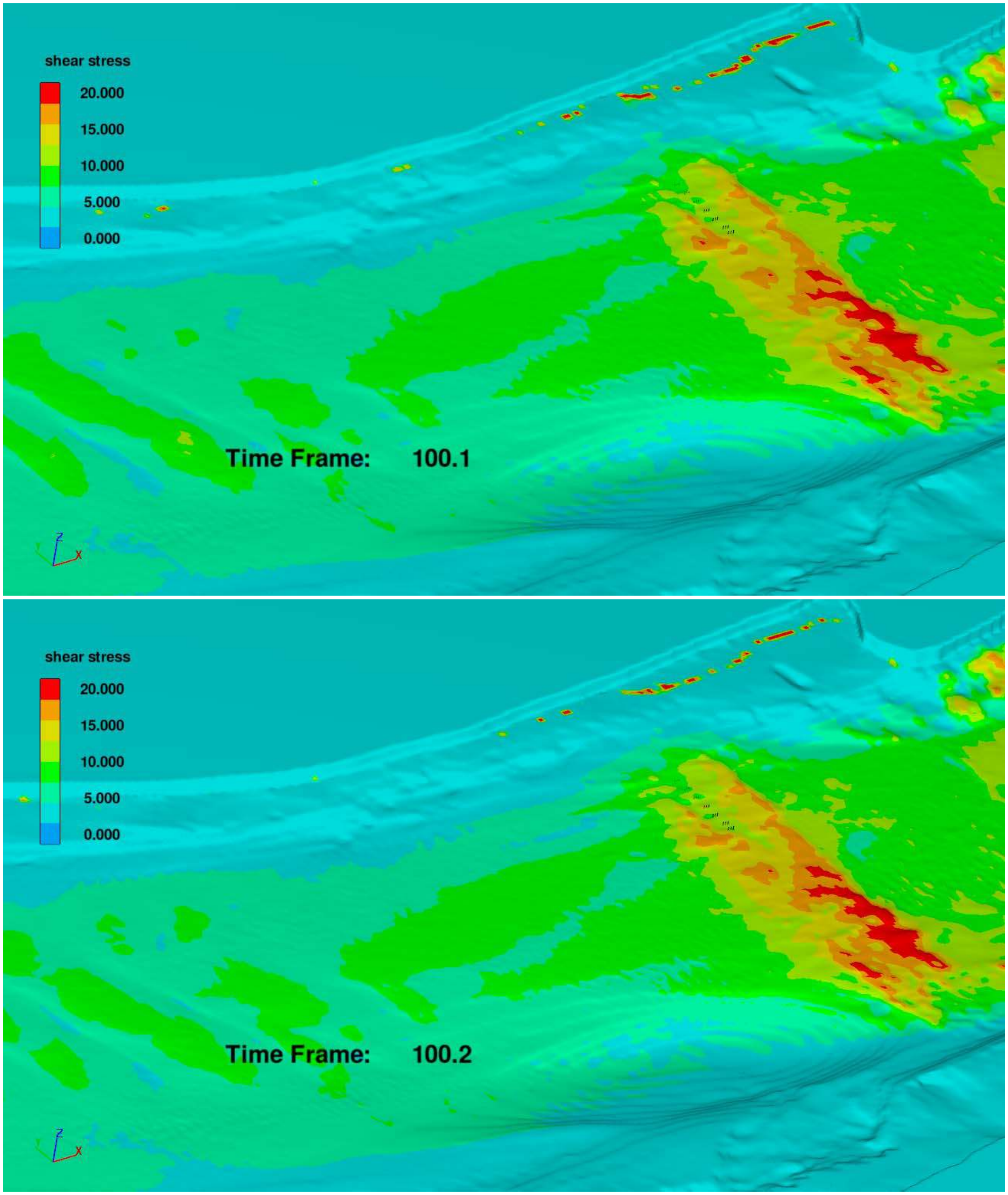
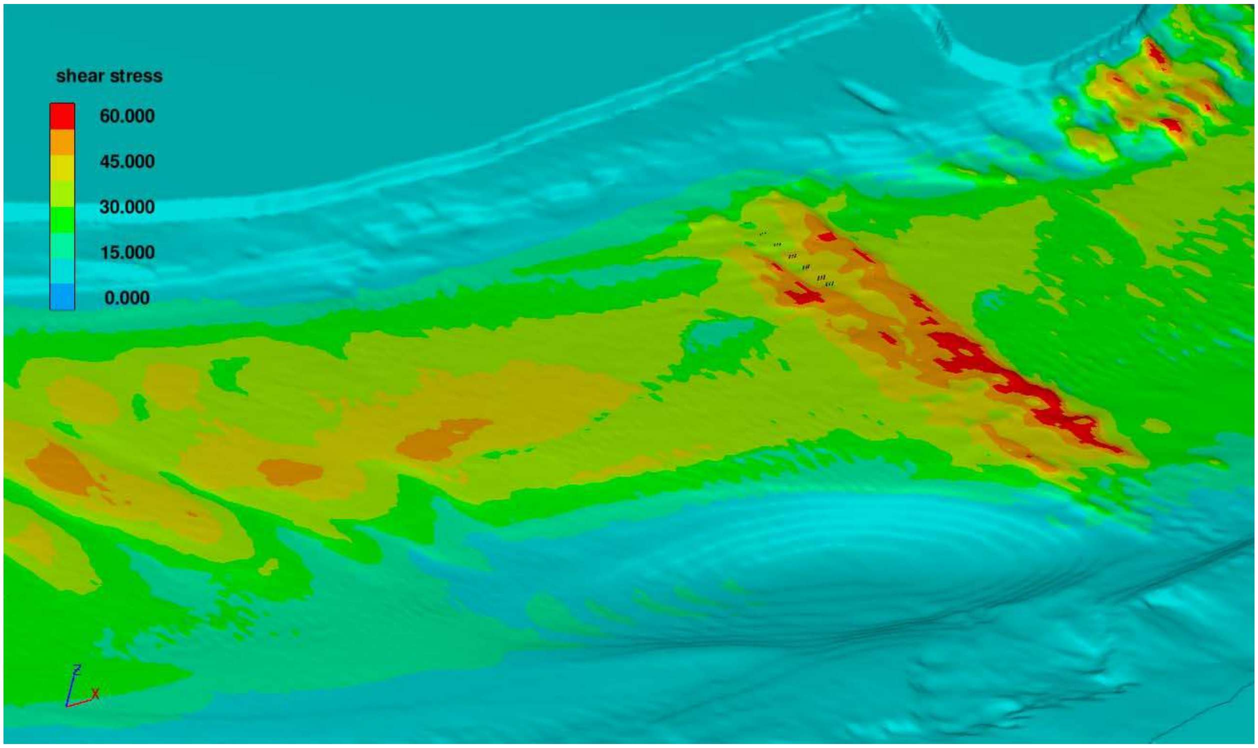


Figure 4-4. Comparison of bed shear stress predicted by FLOW-3D for 7,000 m^3/s with the existing outfall off (top) and on (bottom), showing no significant difference between them.



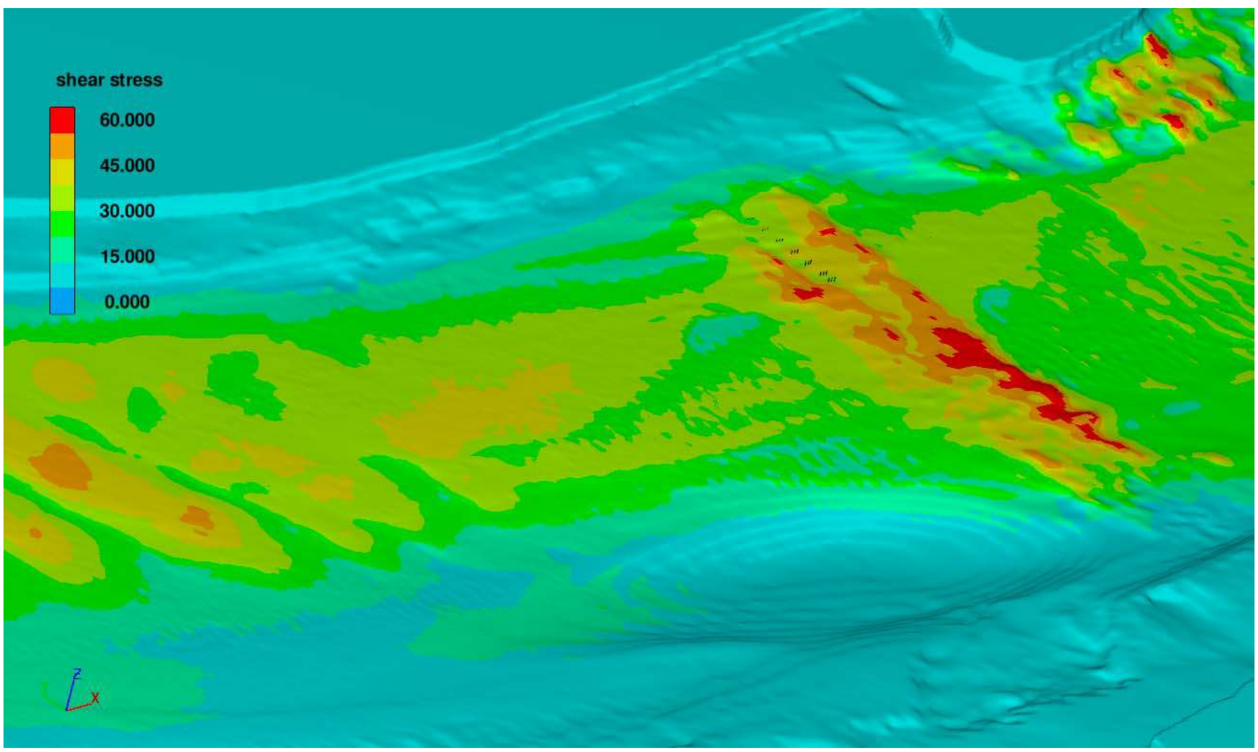


Figure 4-5. Comparison of bed shear stress predicted by FLOW-3D for 13,500 m^3/s with the existing outfall off (top) and on (bottom), showing no significant difference between them.

5 POTENTIAL ALTERATIONS FROM THE NEW DIFFUSER

Figure 5-1 shows the bed shear stress predicted by FLOW-3D when the new proposed outfall operates during a slack tide. Because the new ports are located a few meters above the bed and discharge horizontally (Figure 3-4), they cause a small increase in the bed shear stress (up to 3 Pa) south of each port. Since the critical shear stress needed to move the 0.3 mm sand resting on the riverbed is approximately 0.2 Pa, the jets can entrain and erode sediment. However, the duration of the slack tide is so short that is unlikely that any bed feature generated during this time will be permanent.

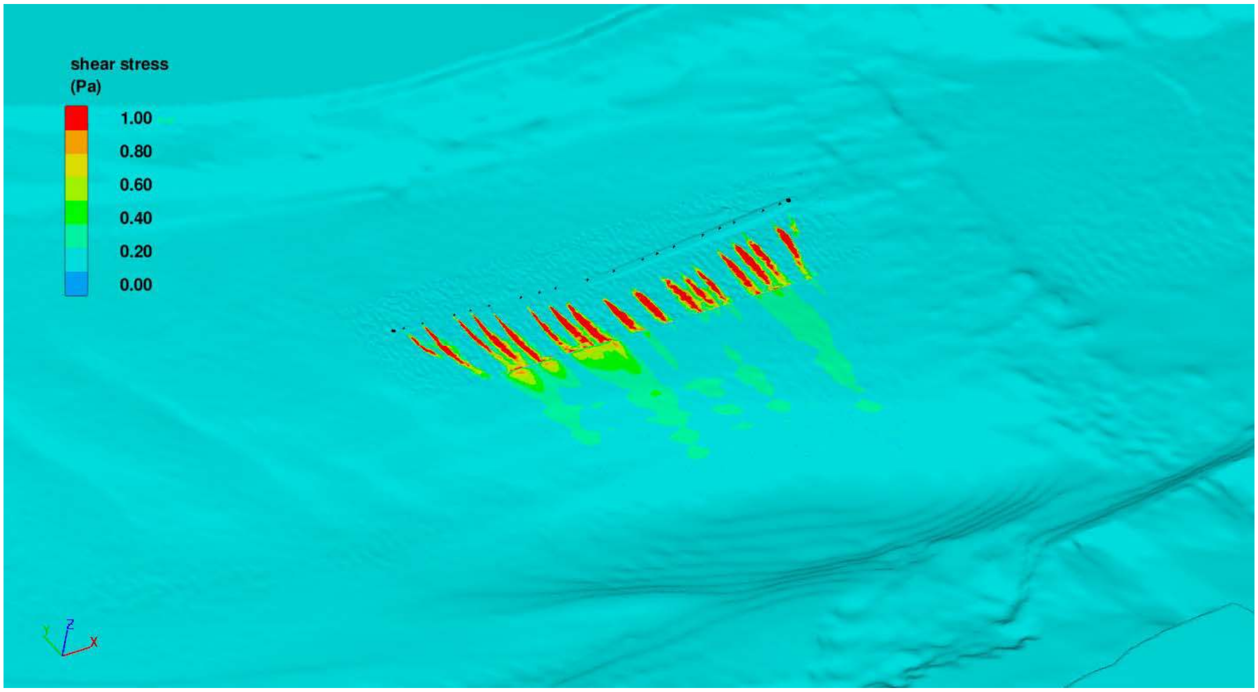


Figure 5-1. Bed shear stress predicted by FLOW-3D for slack tide with the new proposed outfall operating.

The bed shear stresses predicted by FLOW-3D are shown in Figure 5-2 for 7,000 m^3/s and in Figure 5-3 for 13,500 m^3/s. In all cases with flow moving downstream (ebb tide), bed shear stress is low on the upstream half of the outfall where the proposed riprap protection emerges as a mound above the surrounding riverbed (see Figure 3-4); which occurs regardless of the ports discharging or not and hence can be attributed to the partial obstruction caused by the riprap mound. Most notably, once the diffusers start operating, they cause a noticeable reduction in bed shear stress over a distance between 120 m (13,500 m^3/s) and 180 m (7,000 m^3/s) downstream of the diffusers. Higher river flows show a tendency to reduce the effects of the diffusers on bed shear stress.

In order to further investigate the effects of the diffusers on flow hydraulics, the mesh around the diffusers was refined to 0.25 m (over 50 million cells) and near-field vector velocity plots generated for 13,500 m^3/s; as shown in Figure 5-4 for a longitudinal profile on a vertical plane and Figure 5-5 for a horizontal view at the elevation of the ports.

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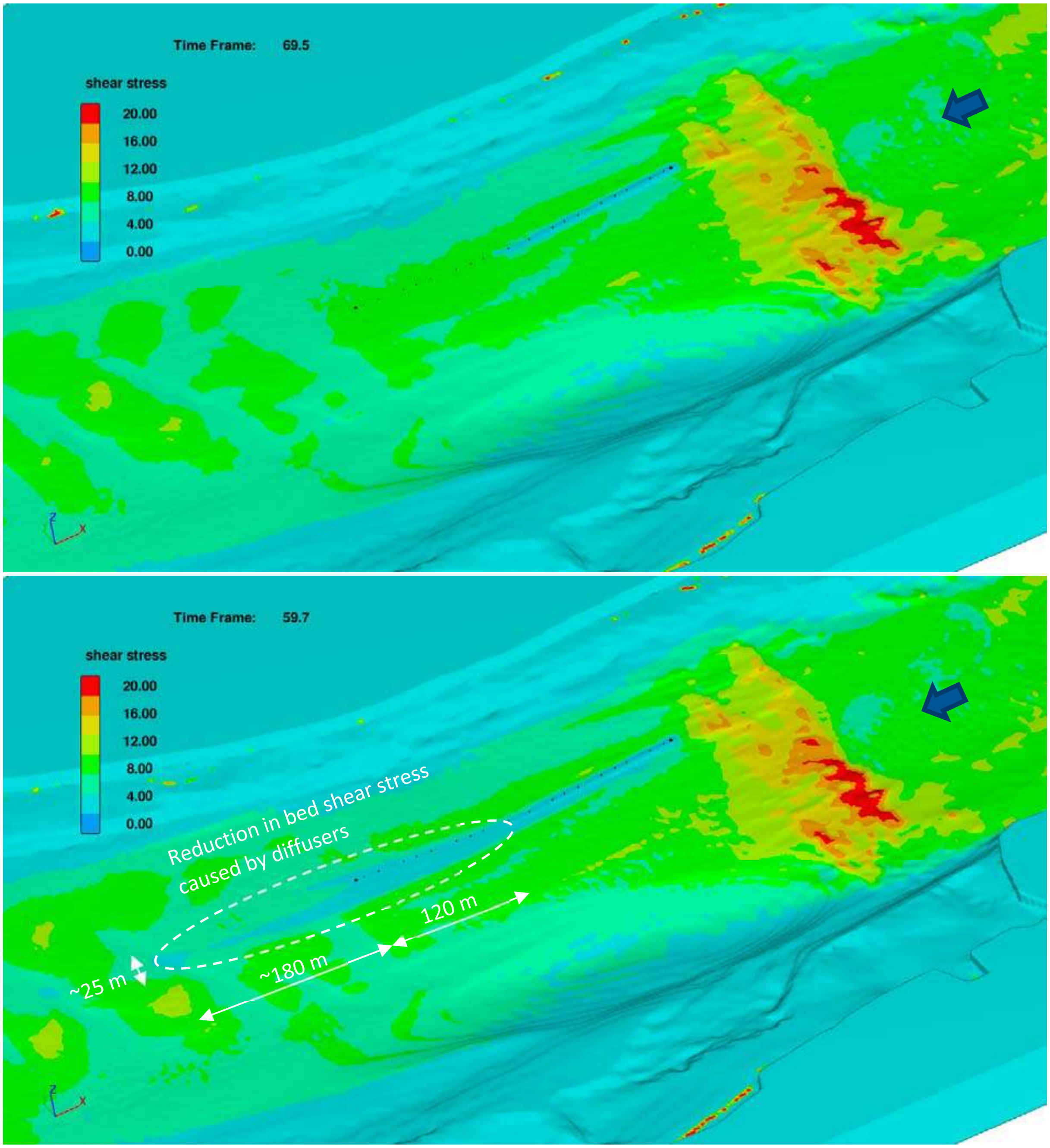

Figure 5-2. Comparison of bed shear stress predicted by FLOW-3D for 7,000 m^3/s with the new proposed outfall off (top) and on (bottom) showing downstream reduction in bed shear stresses caused by the diffusers discharging.

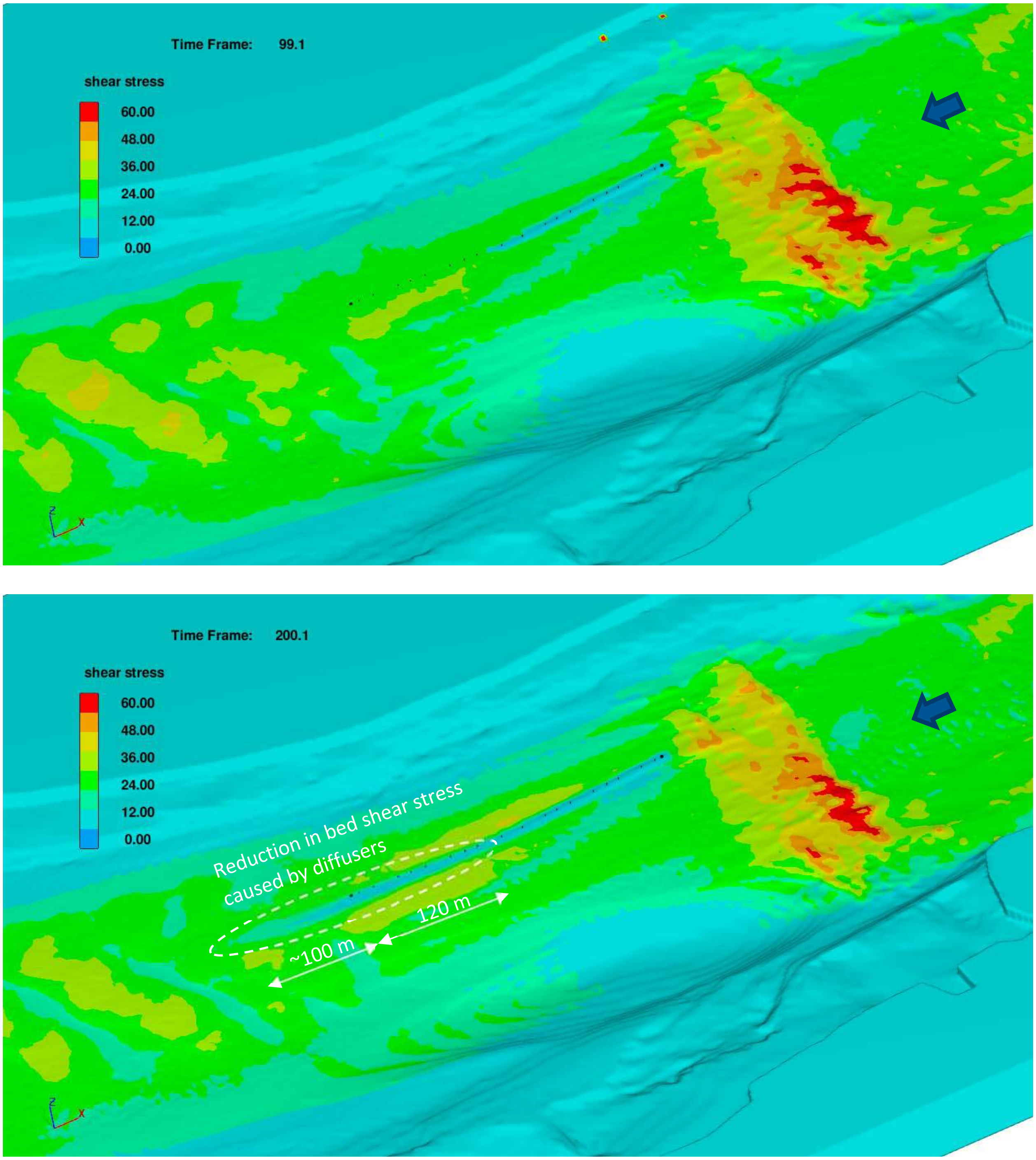

Figure 5-3. Comparison of bed shear stress predicted by FLOW-3D for 13,500 m^3/s with the new proposed outfall off (top) and on (bottom) showing downstream reduction in bed shear stresses caused by the diffusers discharging.

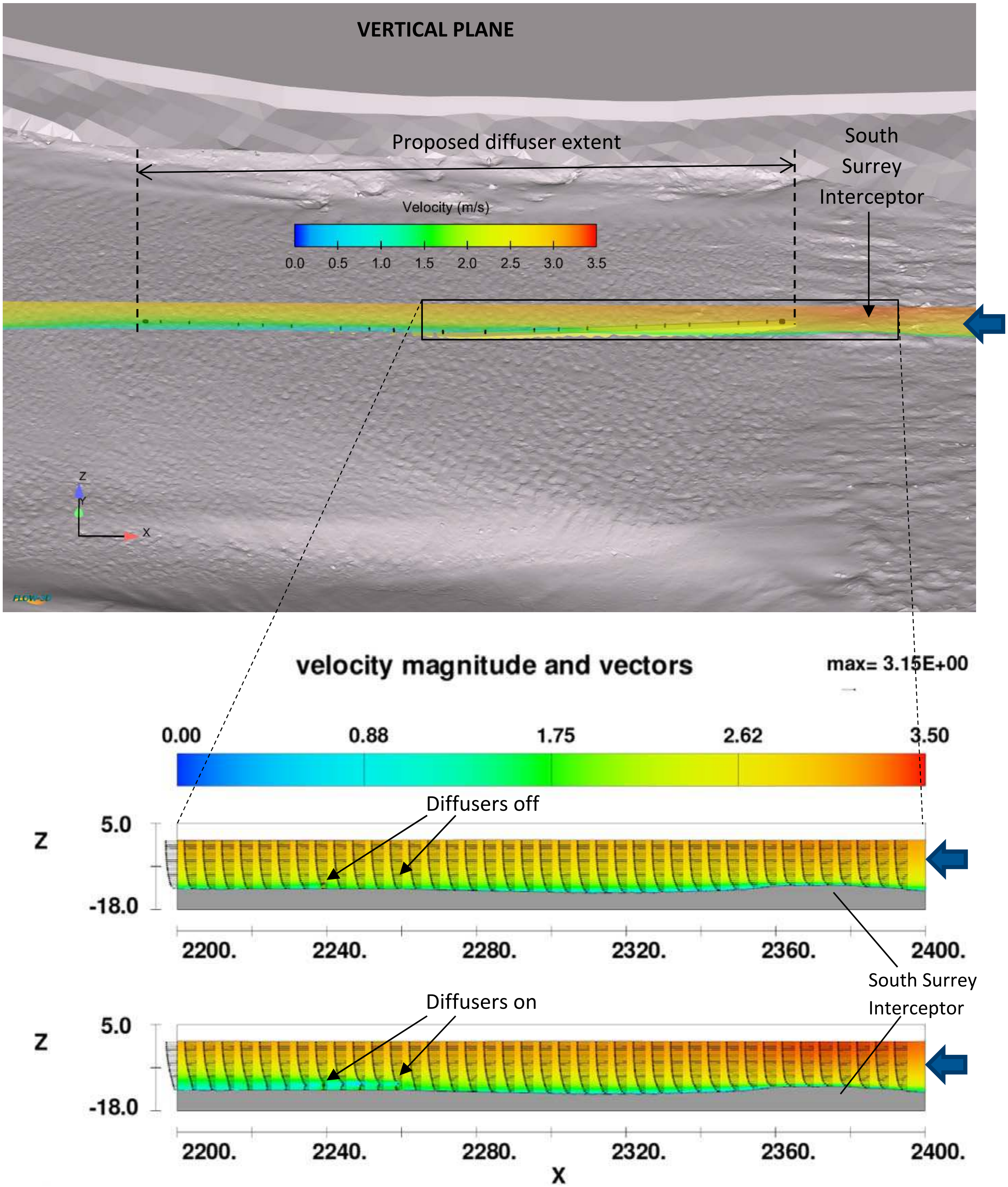

Figure 5-4. Comparison of vertical velocity profiles along the outfall predicted by FLOW-3D for 13,500 m^3/s with diffusers of new proposed outfall either off or on.

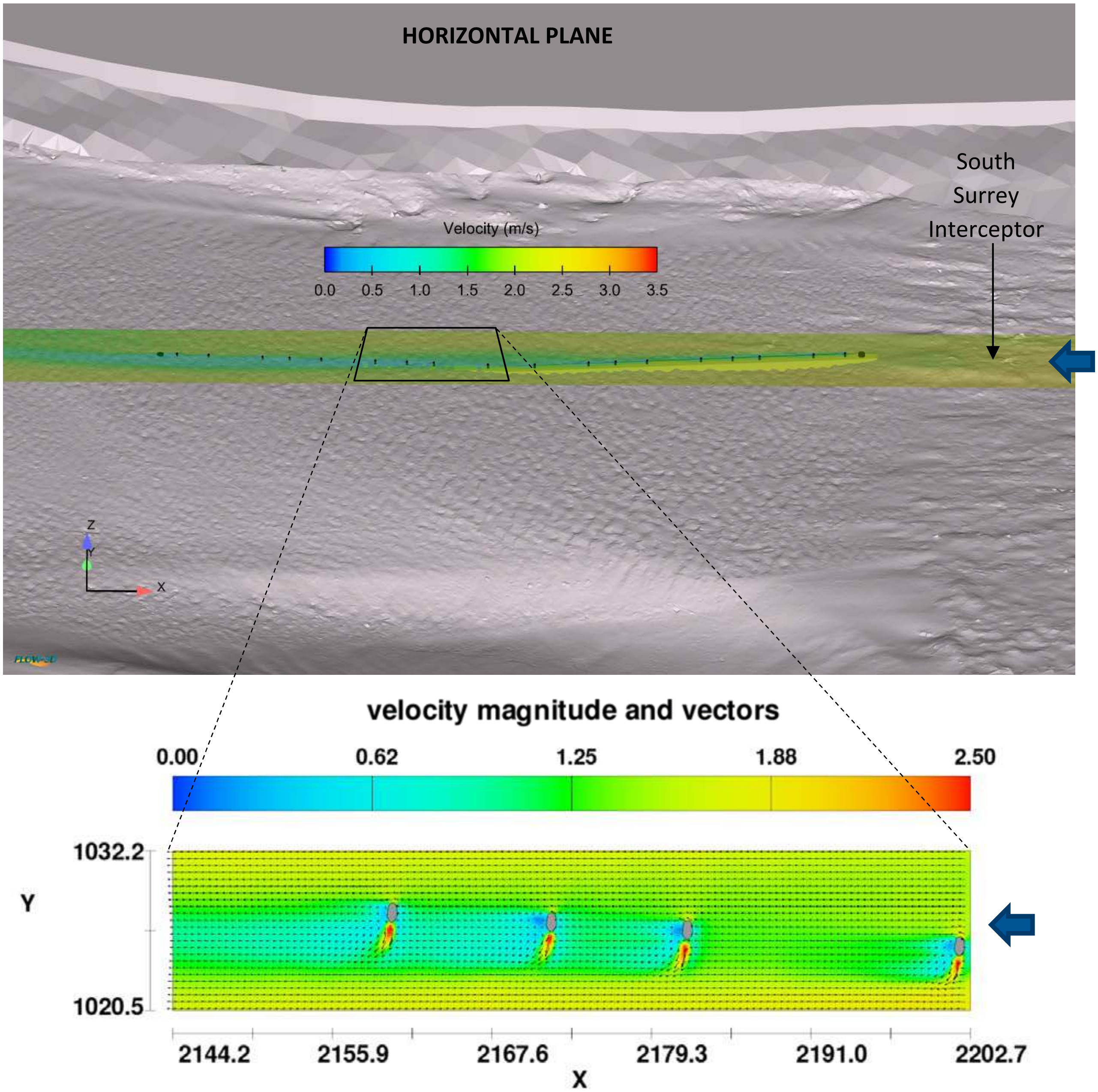

Figure 5-5. Velocity field at horizontal plane (El. -10.75 m) showing local velocity reduction for discharge of 13,500 m^3/s.

In Figure 5-4 the river flow is from right to left, while the diffusers are discharging towards the reader. The vertical velocity profiles with the diffusers off show the typical logarithmic shape with velocity increasing from the bed upwards. When the diffusers are on, they disturb and decrease the local flow velocity near the bed, which is the reason for the reduction in bed shear stress. The effect of the diffusers on the incoming flow is also shown in Figure 5-5, which depicts the vector velocity field at the elevation of the ports. The diffuser jets deflect the incoming flow and generate a low velocity zone immediately downstream of the jets.

Reduction in local flow velocity is typically associated with sedimentation. The velocity reduction predicted for the new proposed Annacis outfall is weak (Figure 5-6), but still noticeable and limited to a distance between 100 m and 180 m downstream and south of the outfall (Figure 5-2 and Figure 5-3). This area of velocity and bed shear reduction occurs south of diffusers and within their riprap protection, so it would not affect the navigation channel. In summary, there is potential for some small local sedimentation downstream of the proposed diffusers; but no impact on the Railcar Barge Terminal located north of the proposed outfall (Figure 1-1) is expected; similarly, no major impact on the navigation channel is expected.

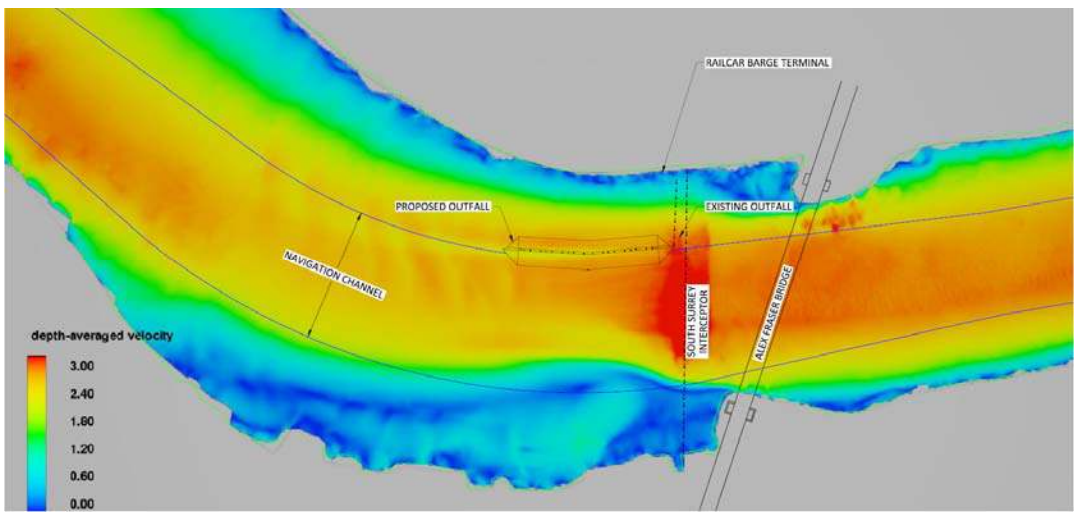

Figure 5-6. Depth-averaged velocity fields predicted at Proposed Annacis outfall.

6 EFFECT OF REMOVING RIPRAP APRON

6.1 Historic Data

The riprap apron over the South Surrey Interceptor (SSI) was installed around the time of the Alex Fraser Bridge's construction in 1984 and was extended northward in 1986. The river bed has undergone significant lowering in this reach due to a combination of factors including general scour from the narrowed bridge opening, local scour from flow impinging against the ship collision abutments, local scour near the SSI's riprap apron and general bed lowering due to dredging. The historic data shows that during the mid-1990's, bed degradation caused the riprap apron over the South Surrey Interceptor (Figure 3-2) to become exposed above the surrounding river bed, so that it acts as a raised sill. As the effective height of the sill has increased over time, the location and maximum depth of scour through the reach has changed significantly (Figure 6-1 and Figure 6-2). Removing or altering the apron and Interceptor would alter this process and could potentially affect river bed levels over a wide area. A future lowering of the apron is approximately equivalent to reducing the sill height and restoring conditions that existed in the 1990's.

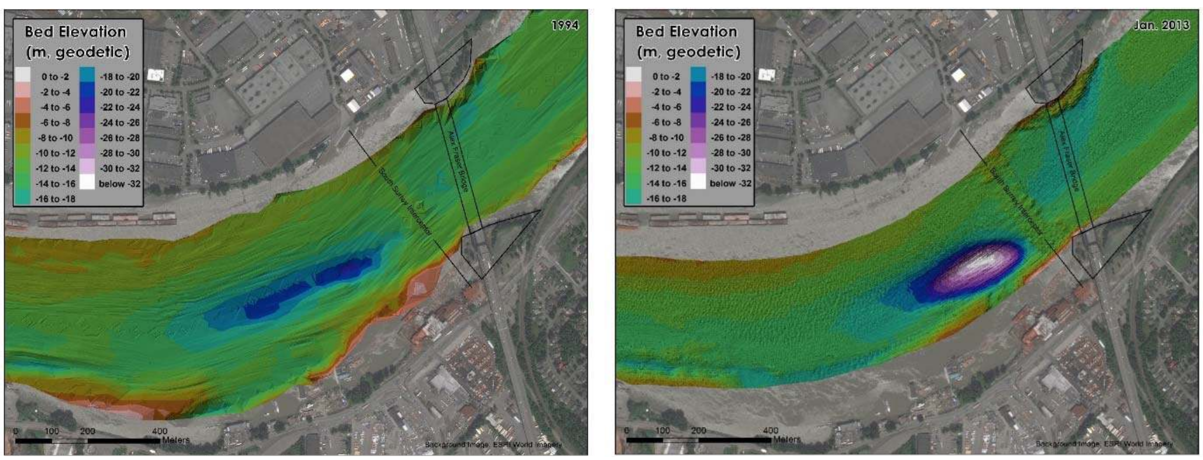

Figure 6-1. Riverbed bathymetry when riprap apron over South Surrey Interceptor was introduced (1994) and current conditions (2013).

Figure 6-1 shows the riverbed bathymetry in 1994, compared to current conditions in 2013. In 1994 there was a large and elongated scour hole with minimum El. -22 m, which was generated after the construction of the ship collision protection abutments of the Alex Fraser Bridge a decade earlier. After 1996the scour hole migrated upstream towards the SSI while becoming shorter, more rounded and deeper, reaching down to El -32 m. Figure 6-2 shows three longitudinal profiles along the right bank, centerline and left bank; plus various cross sections downstream of Alex Fraser Bridge, depicting bed changes observed between 1972 and 2015.

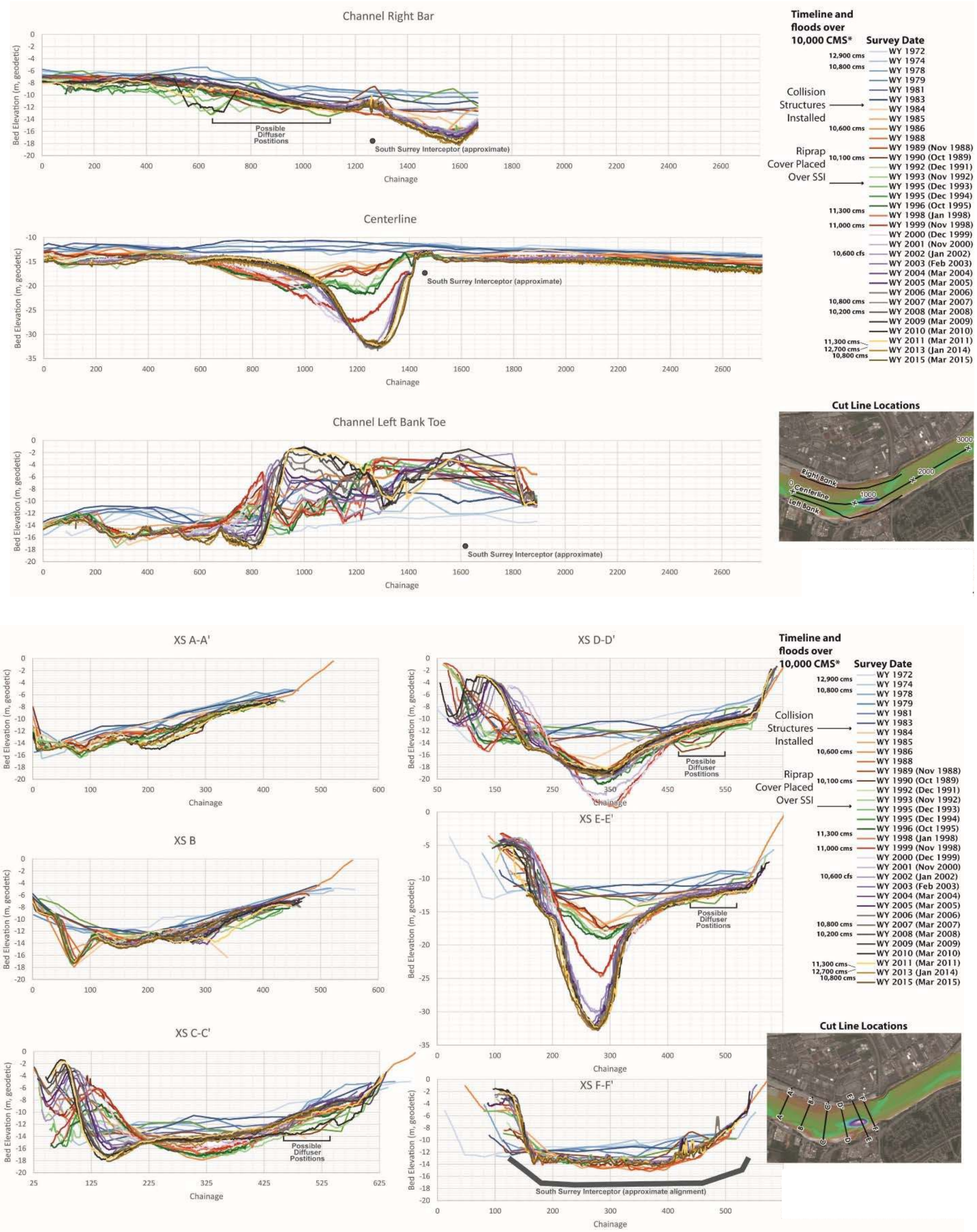

Figure 6-2. Longitudinal profiles and cross sections showing bed level changes between 1972 and 2013.

6.2 CFD Modelling

CFD modelling with the existing SSI apron has shown bed shear stresses over the riprap are very high, reaching peak values above 60 Pa for a discharge of 13,500 m^3/s (Figure 5-3). This is because the riprap apron is located above the bed protruding into the river flow. If the riprap apron were removed, such that the protrusion disappears, then bed shear should decrease substantially, as demonstrated by CFD modelling (Figure 6-3).

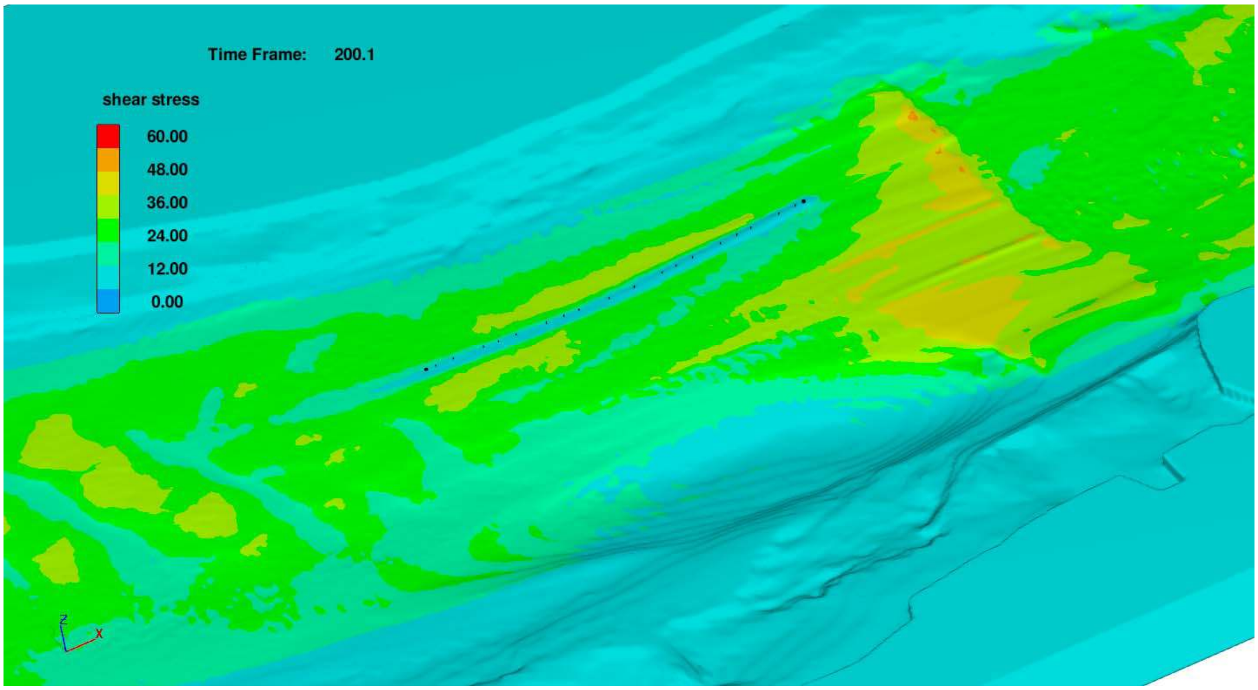

Figure 6-3. Bed shear stress predicted by FLOW-3D for 13,500 m^3/s with the new proposed outfall operating and the riprap apron of the South Surrey Interceptor removed.

Figure 6-3 shows the bed shear stress with the proposed diffuser operating under a river flow of 13,500 m^3/s and the riprap apron removed. Bed levels between the upstream and downstream edges of the apron were linearly interpolated. As expected, local shear stress in the location of the removed apron decreased considerably (compare to Figure 5-3); but the area of low bed shear stress downstream of the new diffuser remained. Based on the historic data (Figure 6-2) and CFD modelling (Figure 6-3); the possible response to the removal of the SSI riprap apron could be:

- The deep scour hole near the south side of channel partially fills in and migrates downstream (conditions similar to 1994 in Figure 6-1);
- Local sedimentation develops downstream of the diffuser due to reduction of bed shear stress (Figure 6-3).

Note that role of the sill in generating scour is being investigated in more detail study under a separate project for Metro. This work is ongoing and is expected to be complete by the end of 2017.

7 CONCLUSIONS

The existing Annacis Outfall, which is aligned perpendicular to the river flow direction and discharges directly upwards to the water surface, produces negligible effects on the riverbed and general Fraser river morphology. The apparent relative stability of the river bed elevation on the north side of the Fraser at this location should be attributed to other factors not related to the presence or operation of the existing outfall.

The new proposed outfall, which is aligned parallel to the river flow direction and discharges laterally towards the Fraser navigation channel, produces a slight decrease in local flow velocity and bed shear stress along the south side of the outfall and for 120 to 180 m distance downstream, without influencing the Railcar Barge Terminal located north. The area of shear stress reduction south the diffusers is narrow and occurs mostly within their proposed riprap protection, reaching maximum width of 25 m south of the westernmost diffuser port. The low-velocity field although weak, may result in some small local deposition around the ports and for some distance downstream; but no major impact to the overall river morphology, the navigation channel or Railcar Barge Terminal should be expected.

8 PROTECTIVE COVERS OVER THE DIFFUSERS

Following the completion of the CFD analysis the diffuser design was modified to include concrete caps over each diffuser to protect the outfall from drag lines and debris. Figure 8-1, provided by CDM, illustrates the covers. The length of the diffuser was also extended 8 m.

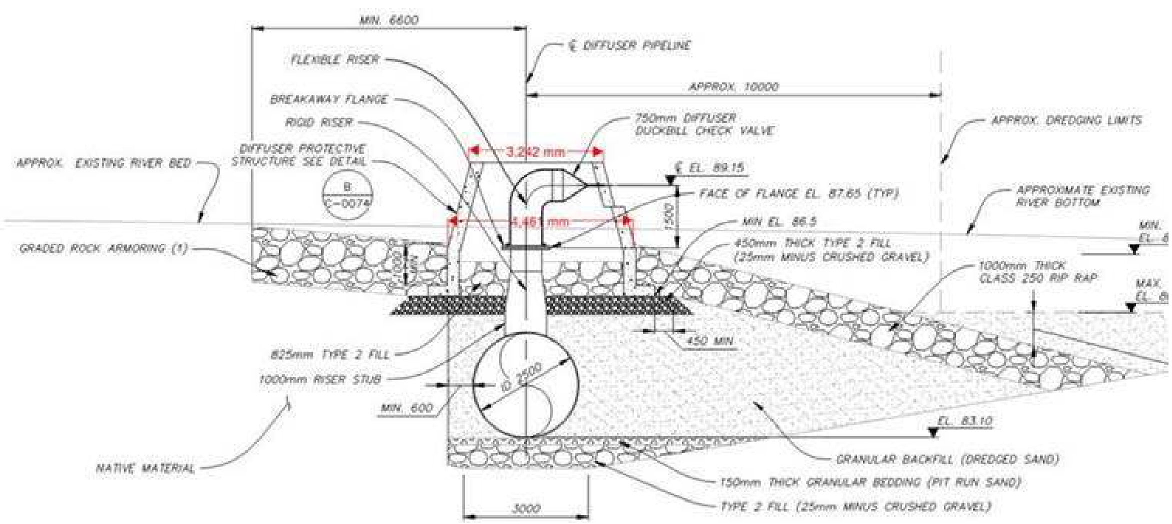

Figure 8-1. Diffuser Design with Concrete Cap

NHC suggests that these protective covers should not significantly impact the magnitude of bed shear stress relative to the design without the covers. The footprint of the impacted area might be slightly wider but should not change the findings. NHC also suggests that the additional 8 m should have no measureable impact on the performance

9 CLOSING

We appreciate the opportunity to submit this report and working with you on this interesting project. Please, do not hesitate to contact any of the undersigned at (604)980-6011 if you have any questions or require additional information.

Sincerely,

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