

Vancouver Fraser Port Authority Centerm Expansion Project Addendum to the PER Application

May 2017





Vancouver Fraser Port Authority
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May 18, 2017

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Submitted via email: tim.blair@portvancouver.com

Attention: Tim Blair, Supervisor, Planning & Development

Subject: Addendum to PER #15-012

Please accept the attached addendum to the Centerm Expansion Project Category D Project and Environmental Review (PER) permit application, #15-012.

Since the original submission of the permit application, geotechnical investigations have progressed which resulted in innovative design and construction changes for the project. The attached addendum addresses a design and construction change to the original application.

The project proposes to reuse dredge on-site to reduce the quantity of fill which is sourced from off-site.

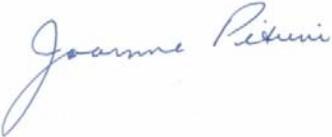
Please review the attached addendum for additional details.

Sincerely,

A handwritten signature in black ink, appearing to read "Liisa Hein".

Liisa Hein
Manager, Infrastructure Delivery

Quality information

Prepared by	Checked by	Approved by
		
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Revision History

Revision	Revision date	Details	Authorized	Name	Position
1	May 11th , 2017	Draft for Review	Yes	Giovanna (Joanne) Petrini	Associate Vice President
2	May 18th , 2017	Draft for Review	Yes	Giovanna (Joanne) Petrini	Associate Vice President

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1. Introduction

1.1 Purpose of Addendum

The purpose of this addendum is to formally inform VFPA's Project Environmental Review (PER) team of the proposed changes in design of the Eastern Expansion Area 1. Specifically, this addendum provides detail on:

- Design and construction of the containment dykes for the Eastern and Western expansion areas.
- Dredging methodology and effects on the marine water quality.
- Infilling and the effects on the marine water quality.

1.2 Project Background

The proposed Centerm Expansion Project (CEP) (the proposed Project) is a series of proposed infrastructure improvements that would increase the number of containers that can be handled at Centerm by approximately two-thirds. To increase the container capacity of Centerm, the proposed infrastructure improvements include an expansion of both the western and eastern extension of the existing Terminal footprint.

Ocean infilling is required to create the land base for the western and eastern expansions. This will require construction of perimeter dykes to contain the infill. Construction of structurally sound foundations for the perimeter dykes will require dredging of fine surficial sediments (Figure 1-1 and Figure 1-2). The total estimated area of dredging to support the western and eastern perimeter dykes is 6.36 ha. In addition, the western expansion will affect how cruise ships manoeuvre and berth at the Canada Place terminal. As a result, a small area southeast of the Canada Place cruise ship terminal near the Sea Bus terminal (Figure 1-1 and Figure 1-2) will need to be dredged to provide sufficient depth for cruise ships to manoeuvre. The area estimated for navigational dredging is 0.33 ha. The total estimated volume of dredging for the CEP in these three areas (western dredge area, eastern dredge area and navigational dredge area) is approximately 397,000 m³ of fine sediments (Table 2-2). The dredging requirements for the proposed Project are further described in Section 3. The dredging methodology and sequence is described in Section 3.1.

Even with efforts to minimize the amount of dredging and to identify options for beneficial reuse or alternative disposal of the dredged sediments, it was determined that ocean disposal would still be the most viable disposal option for a portion of the dredged sediments. In Canada, Disposal at Sea (DAS) is regulated under the Canadian Environmental Protection Act, 1999 (CEPA 1999) and is prohibited without a permit issued by Environment and Climate Change Canada (ECCC). CEP is in the process of completing the studies and reporting required for the DAS permit application.

In fall 2016, CEP undertook sampling and analysis of the sediments in accordance with a Sampling and Analysis Plan (SAP) approved by ECCC to determine whether the physical and chemical properties of the sediments were suitable for consideration for ocean disposal. As a result of that program, it was determined that the top 0.6 m of the marine sediment (approximately 45,000 m³) are not considered suitable for ocean disposal (AECOM, 2017). Those sediments contained levels of some metals and polycyclic aromatic hydrocarbons (PAHs) that do not meet the regulatory benchmarks for DAS. Based on this finding, CEP is proposing a cautionary approach to the dredging program, and will remove and divert the top 1 m of sediments for alternative use (approximately 70,400 m³). Of this 70,400 m³, 64,150 m³ of material will be used as general fill in the Eastern Expansion Area 1, while the remaining 6,250 m³ will be transported off site to a licenced upland disposal facility.



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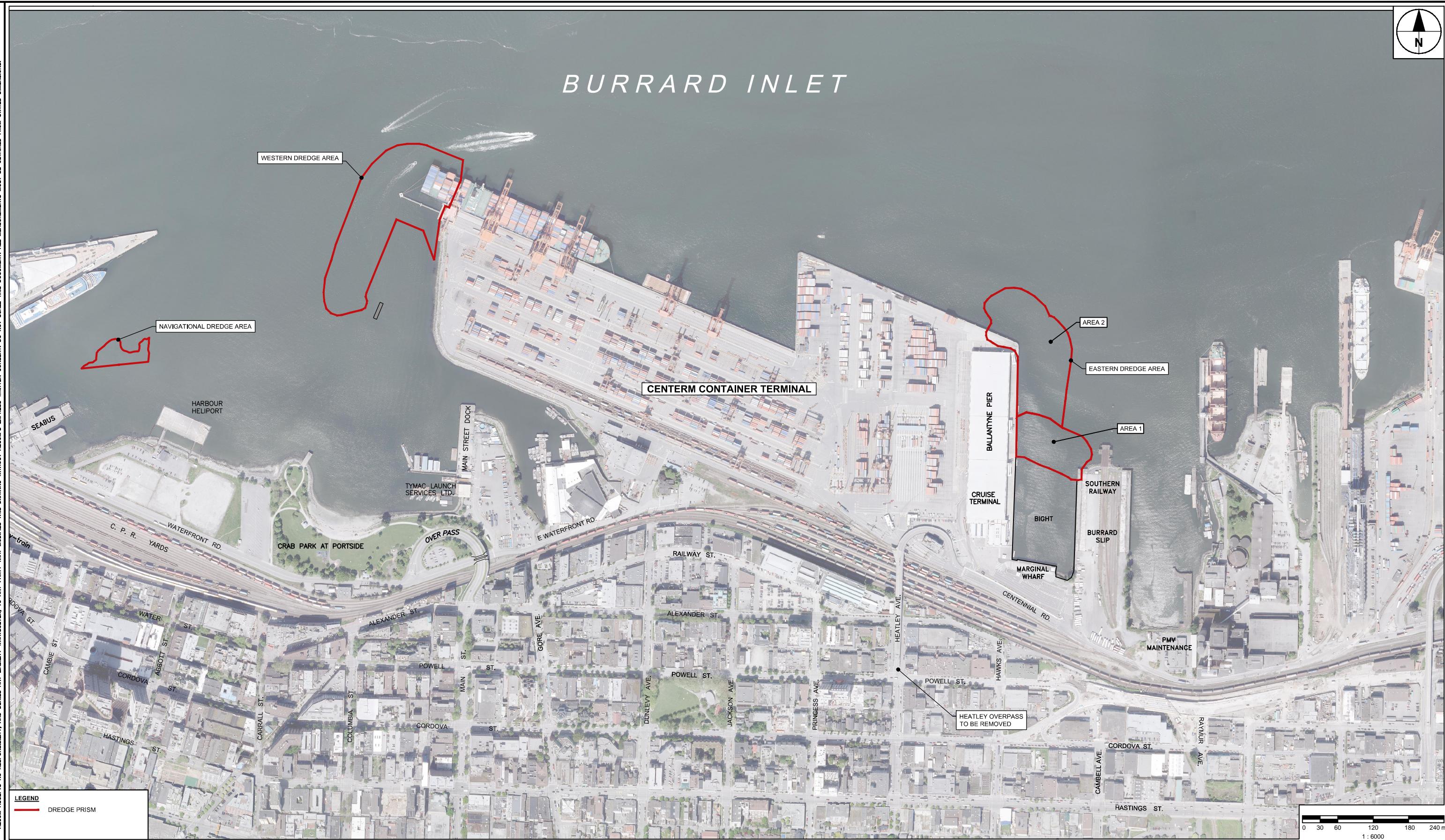
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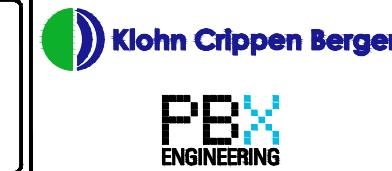
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**CENTERM EXPANSION PROJECT
PROPOSED DREDGE AREAS
ASSOCIATED WITH THE PROJECT**

Figure 1-2

1.3 Original Scope and Rationale for Design Change

The original PER application, filed in November 2016, had suggested that any dredged sediments not sent for ocean disposal would be transported off site to an approved inland facility. Since the original PER submission, an analysis of alternatives for disposal of sediments has been completed. The results of that alternative analysis indicated that the sodium levels in the marine sediments present a difficult challenge for land disposal; there were few sites that could or would accept the material. In addition to limited options for disposal, the costs of disposal and energy requirements both in terms of transportation and dewatering were significant. Based on these findings, CEP began investigating reuse of the top 1 m of sediments as potential fill behind the Eastern Expansion area dyke, identified as Area 1 (Figure 1-2). A geotechnical analysis of the sediments indicated that the dredge material would make suitable fill for this area provided it is capped with a significantly thick layer of imported fill and retained behind an appropriately designed dyke. Upon determination that the dredge material could be used as fill, a subsequent assessment was undertaken to determine whether with appropriate design, the use of dredge sediments could be undertaken without potential for marine pollution. Based on both of these assessments it was determined that the best and most effective use of the material would be to use it as fill in Eastern Expansion Area 1.

The use of the dredge sediments as fill in Eastern Expansion Area 1 represents a design change to the original design of the Eastern Expansion area proposed in the original PER application.

2. Background

2.1 Need for Eastern and Western Expansion Areas, and Dredge Requirement

The goal of the CEP is to increase the throughput capacity of Centerm. To facilitate the increase in throughput capacity the existing footprint of the Terminal requires extension. A smaller rail yard and footprint was initially considered, but did not provide the required capacity to increase container throughput and make the project economically feasible. A smaller surface footprint was therefore not considered further.

Because of the location of CEP in a densely developed area on the shores of Burrard Inlet, and because of the requirement to increase berthing capacity, there is no possibility or rationale to extend the Terminal on land: the expansion of the surface footprint therefore necessarily requires extension into the marine environment. Extending the terminal footprint westward is proposed to accommodate an expansion of the wharf, container yard and intermodal yard. The extension eastward is proposed to accommodate additional container storage, a new terminal gate, parking, and a new administrative building.

Two options were considered for ocean infilling. These included permanent dykes to contain the deposited and compressed fill, or vertical structures, such as sheet piles or caissons. Because vertical structures would be three to four times more expensive, they were not considered cost effective, and were only considered where a vertical face for vessel berthing was required.

Containment dykes are required for both the Western and Eastern Expansion areas. The Eastern Expansion will include a Northeast Dyke (Area 2) and an East Dyke (Area 1) (Figure 2-1)). The Western Expansion area will include a caisson wharf extension, a West Dyke, and a South Dyke (Figure 2-2). The marine areas that will support the dykes currently contain post-glacial marine and fluvial surface sediments overlying glacial till. The marine sediment generally contains fine-grained silts and clays with some sand, and is soft to very soft. The fluvial sediment varies from silty sand to fine sand, and is loose to compact. In comparison, the underlying glacial till contains a mixture of silt, sand and gravel with occasional cobbles and boulders, and is dense to very dense.

To be effective and safe, it is essential that the caisson wharf extension and containment dykes are stable over the long-term. The engineering and geotechnical design criteria required to meet construction and operations stability requirements include seismic design levels and static slope stability analysis (KCB, 2017). Two seismic design levels were used in the design of these marine structures, including:

- For the dykes: A100 Operating Level Event (OLE), which is a seismic event that produces ground motions associated with a 100-year return period. The performance objective for A100 is minor damage with no interruption in operations (KCB, 2017).
- For the caisson wharf extension: A475 Contingency Level Event (CLE), which is a seismic event that produces ground motions associated with a 475-year return period. The performance objective for A475 is repairable damage with some interruption to operations, but no collapse (KCB, 2017).

Slope stability analysis for the CEP required specific factors of safety (FoS) for static slope equilibrium, defined as the ratio of the shear strength to the shear stress. These vary for the CEP from 1.1 to 1.5 (Table 2-1).

Table 2-1 Slope Stability Requirements for the Centerm Expansion Project Containment Dykes

Category	Factor of Safety (FoS) ¹
Post Construction - Undrained	>1.3
Extreme Loading - Undrained	>1.3
Operating Conditions	>1.5
Post-Seismic	>1.1

1. A slope is unstable if the FoS is <1.0.

Left in place, it is the post-glacial sediments that will determine the geotechnical stability of the containment dykes. Stability and seismic analyses of the surface sediments for each containment dyke concluded the following:

- **Eastern Expansion Dyke, located in Area 1** (Figure 2-1): Post-construction and post-seismic FoS <1.0, liquefaction during an A100 seismic event.
- **Northeast Dyke, located in Area 2** (Figure 2-1): Post-construction and post-seismic FoS <1.0, liquefaction during an A100 seismic event.
- **Caisson Wharf Extension**: Post-construction and post-seismic FoS <1.0, liquefaction during an A100 seismic event.
- **West Dyke** (Figure 2-2): Post-construction and post-seismic FoS <1.0, liquefaction during an A100 seismic event.
- **South Dyke** (Figure 2-2)¹: Post-seismic FoS <1.0, liquefaction during an A100 seismic event

The conclusions of the stability and seismic analyses indicated that the overlying post-glacial marine and fluvial sediments were not appropriate foundation materials for support of the containment dykes. Ground improvement options were evaluated and it was determined that only the sediments beneath the South Dyke, which were more granular than other areas, could practically be improved in-situ. Therefore, complete removal of the marine and fluvial sediments to the depth of the underlying dense to very dense glacial till was recommended for all but the South Dyke. The amount of dredge material was minimized to the extent possible to still meet the required design criteria for safety and stability.

2.2 Dredging Requirements

To achieve the stability of the dykes and to provide safe navigation to the cruise ship terminal there are three dredging elements required for the Project, two at the western end and one at the eastern end of the terminal. These elements are:

- Western Expansion area (for dredging at the caisson wharf and west perimeter dyke)
- Eastern Expansion area (for the perimeter dyke to the north (Area 2 and east of the Ballantyne Pier Area 1)
- Navigation dredge area (located west of the terminal, just north of the Sea Bus terminal)

The dredge prism in the Western Expansion area varies in depth from 8 m at the southwest corner of the expanded terminal, to approximately 17 m at the wharf extension. For the caisson wharf foundations, the dredging would comprise a large trench adjacent to the west end of Berth 6, with dredged side slopes of 2 horizontal to 1 vertical (2H:1V) anticipated.

The Eastern Expansion area dredge prism in this location varies in depth between 1 m at the southern end of the Bight (Area 1), and approximately 4 m at the northern end of Ballantyne Pier (Area 2).

¹ The south dyke noted above is considered to be part of the western expansion from a construction and infilling perspective. Additionally, potential effects arising as a resulting of the construction and infilling are considered under the creation of the Western Expansion Area Dyke.

2.2.1 Description of the Size and Depth of Dredge Area

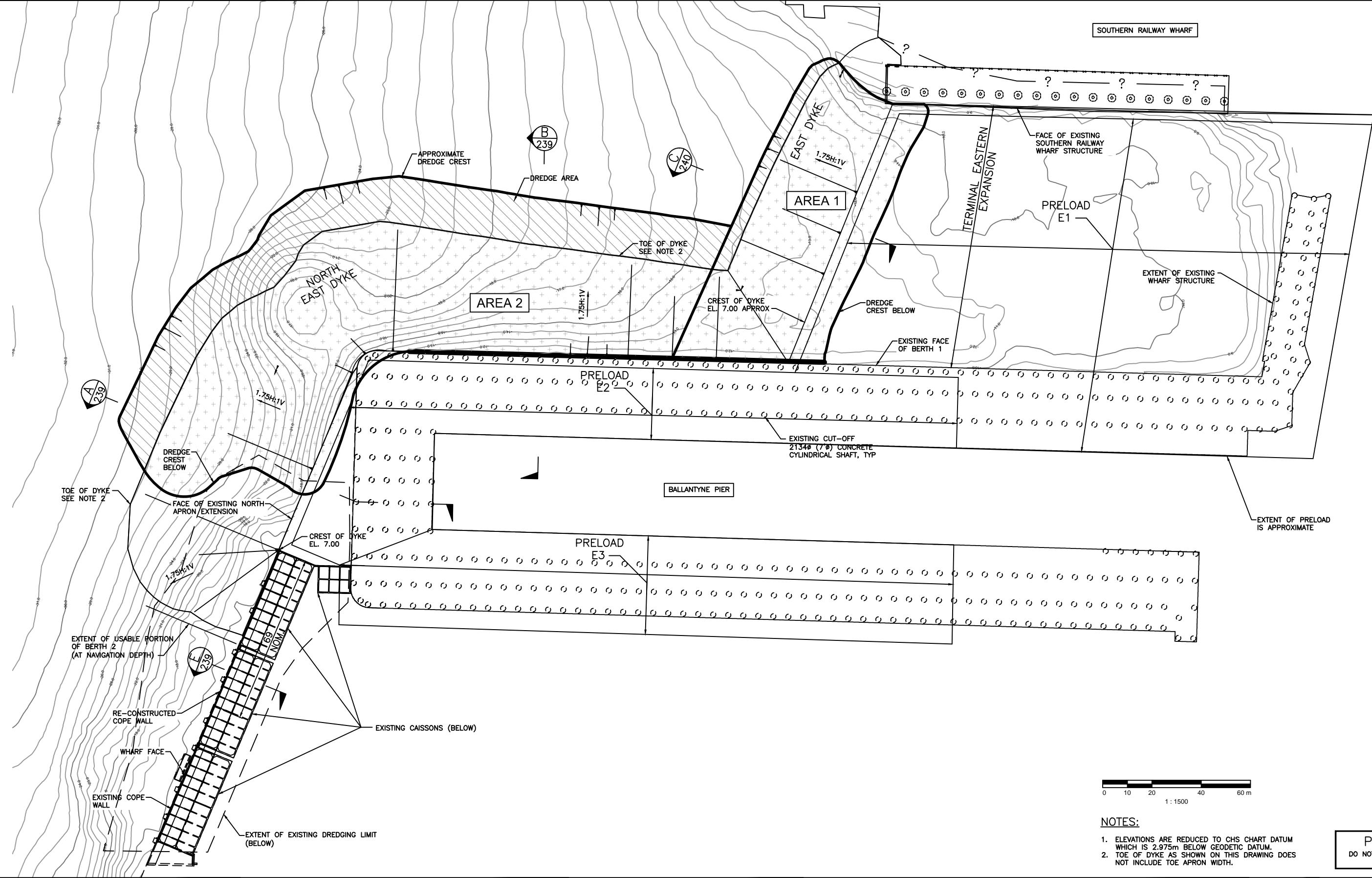
Dredge areas, and volumes generated, from the proposed Project are presented in Table 2-2.

Table 2-2 Dredge Areas and Volumes

	Eastern Expansion	Western Expansion	Navigation Dredge	Total
Dredge Area (m ²) –under permanent footprint	19,300	20,800	0	40,100
Dredge Area (m ²) – outside the permanent footprint (temporary loss)	11,000 ¹	12,500 ¹	3,300 ²	26,800
Dredge Prism Volume (m ³)	155,000	235,000	6,800	396,800
Dredged amount to be used as fill for Eastern Expansion (m ³)	29,400	28,800	5,950	64,150
Materials Not meeting CCME Soil Guidelines ³ for industrial land use (m ³) – requires off-site disposal	900	4,500	850	6,250
Remaining Material for disposal at sea (m ³)	124,700	201,700	0	326,400

1. Dredge area not under Project footprint. The dredge footprint extends beyond the toe of the retaining dykes at the east and west end and will be replaced with clean sand fill (and Figure 2-2).
2. Dredge area not under Project footprint and no replacement material will be placed on top after dredging complete.
3. Canadian Council of Ministers of Environment Canadian Soils Quality Guidelines for the Protection of Environmental and Human Health - these are guidelines that define numerical limits for contaminants in soil to protect human health and the environment and are based on the current and future use of a site. In the case of CEP the current and future land use is industrial.

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CENTER EXPANSION PROJECT
EASTERN EXPANSION
TERMINAL - PLAN
DREDGE AREA

Figure 2-1

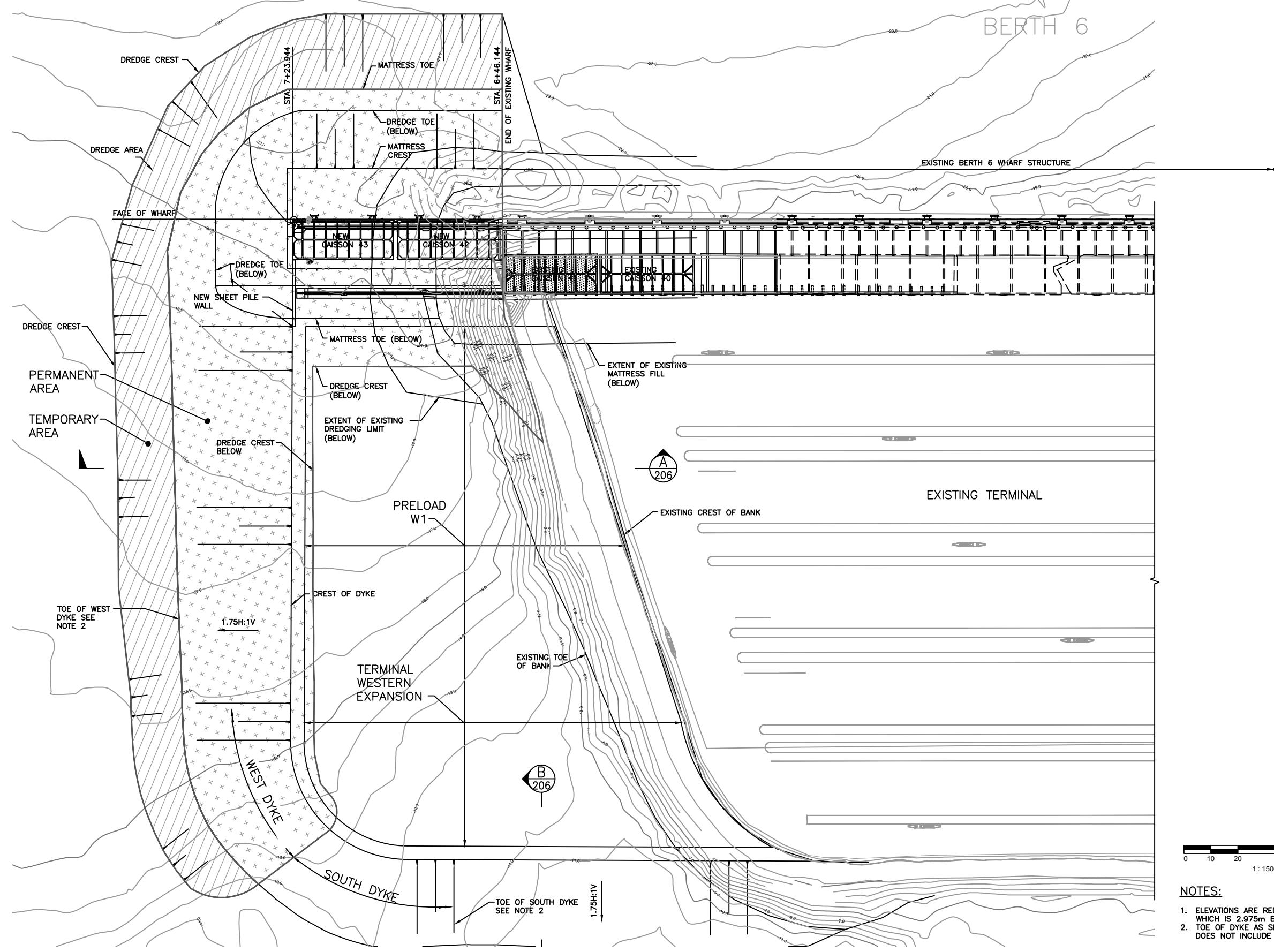
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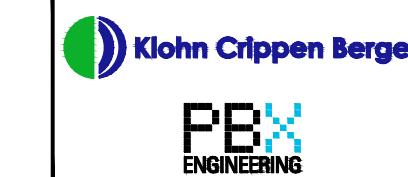
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Figure 2-2

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2.3 Sediment Analysis

Prior to ECCC considering a DAS permit application, the pre-application phase of the regulatory process must be completed. The pre-application process begins with determination of whether the physical and chemical properties of the sediments are suitable for further consideration for ocean disposal. This requires sampling and analysis of the sediments in accordance with a Sampling and Analysis Plan (SAP) approved by ECCC. For the CEP, the SAP was finalized and approved by ECCC in late August 2016 (AECOM, 2016a). The primary objective of the SAP was to characterize the physical and chemical properties of the sediments in the proposed dredge areas (Figure 1-2) and assess them against applicable regulatory benchmarks. Sediment sampling and analysis in conformance with the SAP was conducted in fall 2016.

A Sediment Characterization Report, describing the findings of the sampling and analysis program based on the SAP requirements, was submitted by AECOM on behalf of the CEP to ECCC on 4 January 2017 (AECOM, 2017). The following represents a breakdown of findings in the report by dredge area:

- **Western Expansion Area**
 - Sediments from 0 to 0.6 m were not acceptable for further consideration of DAS due to elevated concentrations of copper.
 - None of the contaminants of interest in deeper sediments exceeded screening benchmarks and therefore deeper sediment (>0.6 m) was acceptable for further consideration for ocean disposal.
- **Eastern Expansion Area**
 - Sediments from 0 to 0.6 m were not acceptable for further consideration for DAS due to elevated concentrations of cadmium, copper, lead, and zinc.
 - None of the contaminants of interest in deeper sediments exceeded screening benchmarks and therefore deeper sediment (>0.6 m) was acceptable for further consideration for ocean disposal.
- **Navigation Turning Basin Area**
 - Surficial sediments from 0 to 0.2 m were not acceptable for further consideration for DAS due to elevated concentration of cadmium, copper, lead, and total PAHs.
 - Sediment below 0.2 m were predominantly coarse gravel and cobbles with limited surficial fine material. This coarse material will be diverted for beneficial reuse.

Based on the results of the Sediment Characterization Report (AECOM, 2017), it was concluded that approximately 326,400 m³ of marine sediment in the proposed dredge areas met the regulatory benchmarks and was suitable for DAS, and approximately 70,400 m³ of marine sediment² did not meet the regulatory benchmarks and was therefore not considered suitable for DAS. Based on these results further investigation for reuse and disposal were considered.

2.4 Assessment of Alternatives to Ocean Disposal

To assess alternatives to ocean disposal of sediments AECOM conducted a survey of companies that specialize in disposal and re-use of sediments and soils to identify and assess feasibility of beneficial use options for all of the dredged sediments including both the top 1m and bottom dredge sediments. The survey focussed on options within a reasonable transportation distance of (50 km) of CEP. Because of the sodium content of the sediments, finding land based options for use proved challenging. Because of the marine origin of the dredged sediments, the sodium concentration of the dredge sediments is greater than BC Contaminated Site Regulation (CSR) commercial land use (CL) standards for use of dredge sediment on land, and represents a challenge to finding options for either beneficial re-use and for conventional disposal in a landfill. The CSR sodium standards were developed to protect land-based plant growth, and therefore any use of the dredge material on land would create a risk of environmental damage. Landfills do not want to accept marine sediments because the sodium levels in the sediments negatively impact their leachate treatment systems. In addition to limited options for disposal, the costs and energy requirements for transportation and processing for land disposal were estimated to be considerably higher than for DAS. The

² 70,400 m³ is the sum of materials requiring off-site disposal (6,250 m³) and sediment suitable for beneficial reuse in Eastern Expansion Area (64,150 m³)

alternative assessment of the dredge material suitable for DAS indicated that the DAS option was the least energy intensive and the environmentally safest option as well as being the most economical; however, because the top dredge sediment was not considered suitable for DAS, an alternative disposal option for this dredge material was required.

2.4.1 Beneficial Reuse of Top Sediment

While the results of the Sediment Characterization Report (AECOM, 2017) showed that only the top 0.6 m of material was not suitable for ocean disposal, CEP is proposing a cautionary approach to the dredging program, and will remove the top 1 m of sediments using an environmental clam shell dredge bucket (8 m^3 volume) and all of that material be diverted for alternative disposal. The environmental bucket will improve the vertical dredge cut accuracy ($\pm 0.15\text{ m}$) when dredging the relatively thin top surface layer, and will reduce release of fines during the excavation process.

Given the challenges identified with land based options it was determined that the best and most effective use of the material would be to use it as fill in Area 1 of the Eastern Expansion area of the CEP. A geotechnical analysis of the sediments indicated that the dredge material would make suitable fill for this area provided it is capped with a thick layer of granular fill.

The total volume of dredged sediment that will be used as general fill for the Eastern Expansion is approximately $64,150\text{ m}^3$ (see Table 2-2). Sediment that does not meet the Canadian Council of Ministers of Environment Canadian Soils Quality Guidelines for industrial land use (CCME Soil Quality IL) (approximately $6,250\text{ m}^3$) will be removed from site and disposed of at an approved on land waste facility. The current plan is to cap the $64,150\text{ m}^3$ of processed sediment with sand fill.

2.5 Alternatives to Dredging

Alternatives to dredging considered for the CEP included flattening the fill slopes to reduce shear stress, and ground improvement and in-situ stabilization of the surface sediments to increase shear strength (KCB, 2017). These considerations are discussed further below.

Flattening Fill Slopes

Flattening the fill slopes would decrease the shear stress imposed on the foundation soils by the fill materials and would therefore increase the FoS. To achieve the FoS design criteria for limit equilibrium stability it was estimated a flattened slope in the order of 10H:1V might be required (KCB, 2017). A slope with this gradient would both extend the dyke far beyond the current project limits and massively increase the footprint into the marine environment. The extension of the dyke would negatively impact vessel navigation and marine operations adjacent to the terminal. Flattening of the fill slopes is therefore not a feasible option within current CEP design constraints.

Ground Improvement

Installed stone columns would support a portion of the fill load, increase the shear strength of the marine and fluvial sediment, and decrease the compressibility of the sediment mass (KCB, 2017). Effective installation of stone columns would require precise placement of columns at a spacing ranging from 1.5 m to 1.9 m. The precision required would be difficult to achieve working from a barge in water depths of up to 25 m. If the required precision was not achieved, then the design criteria would not be met. In addition, flatter dyke slopes would still be required in conjunction with installation of the stone columns. As discussed above, flattened slopes would increase the project footprint and negatively affect marine operations. Installation of stone columns is therefore not a feasible option for all areas except the South Dyke, which is considerably shallower than the other areas. The foundation soils in the South Dyke area are also more granular, which increases the effectiveness of stone column installations and allows for larger column spacing.

Installation of piles as structural elements would reinforce the marine and fluvial sediments and would carry the majority of the vertical loads from the fill material (KCB, 2017). Effective installation would require precise placement of piles at a spacing ranging from 1.0 m to 1.5 m. The required precision, however, would be very difficult and impractical to achieve working from a barge in water depths of up to 25 m. If the required precision was not achieved, then the design criteria would not be met. In addition, the piles would need to penetrate into the glacial till below to

provide any lateral resistance to the soils above. It would be impractical to achieve the required penetration from driven piles into these very dense soils. Finally, there is no precedent for this type of installation in 25 m of water with deposition of 30 m of reclamation fill material. Installation of piles is therefore not a feasible option for the CEP.

In Situ Stabilization

The shear strength of the marine and fluvial sediments can be increased through injection or mixing of cementitious material with the sediment. It would, however, be difficult to control the vertical and horizontal position of the mixing process, and therefore the continuity of the stabilized material. If there were gaps in the matrix established within the sediment, then design criteria would not be met. Use of high pH cement in the marine environment would also be an environmental concern because of the localized increase in pH, which could be toxic to marine organisms. In situ stabilization is therefore not a feasible option for the CEP.

3. Dredging and Dyke Construction

3.1 Introduction

Dredging is a key requirement for the delivery of the proposed Project. Within this section the methodology and sequencing of the dredging program is presented. As stated, the proposed Project requires the creation of three containment dykes to support the extension of the Terminal facility, (one in the Western Expansion Area and two in the Eastern Expansion Area (Figure 2-1 and Figure 2-2 respectively)). While the proposed Project requires three individual dykes, from an engineering and design perspective there are two unique dyke designs; (1) the Western Expansion Area dyke and Northeast Expansion Area 2 dyke, and (2) the Eastern Expansion Area 1 dyke. The requirements for a variation in the design of the dykes stems from the differing engineering requirement, build sequence and permeability of the dykes.

3.2 Dredging Methodology and Sequence

The marine dredging for all areas will be carried out using clam-shell marine derrick equipment supported by transfer barges, rather than cutter-suction dredge equipment with a dredgeate pipeline to the disposal point. This is due to the relative small volumes involved, physical constraints (e.g., proximity of existing wharf structures and terminal perimeter dykes), potential interference with other stakeholders' marine operations (e.g., a dredgeate disposal pipeline on or below the water surface could be a navigation hazard in this high marine traffic area), and the need for careful control of dredged side slopes to avoid unnecessary over-excavation or undermining nearby existing structures.

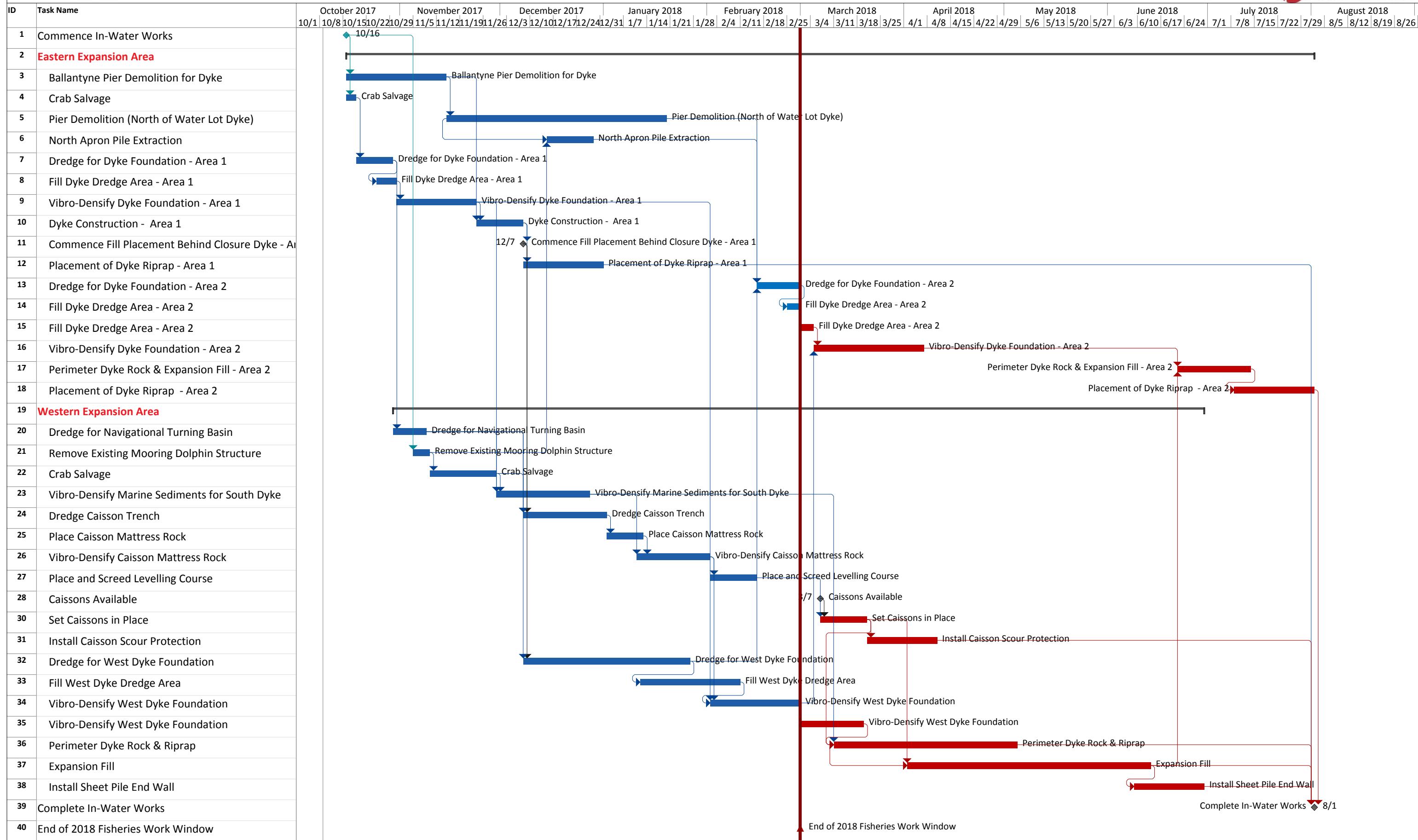
Dredging is anticipated to take approximately 4.5 months to complete with two clam shell dredge operations working 24 hours per day, 7 days per week. However, in reality, effective dredge hours are approximately 12 hours per day with the remainder required for repositioning, barge moves, and downtime for maintenance. This would result in one or two barge loads per day leaving the site for the DAS site.

The following are the main assumptions made in development of the DAS production estimate, the figures represent ideal conditions, that are unlikely to be realized in the field, and do not account for down time as a result of: movement of dredges, maintenance of equipment, confirmatory sampling, and work slowdown or stoppage to prevent exceedances of turbidity in the water column:

- Work Day: 24hr/day, 7days/week.
- Effective dredge hours: approximately 12 hr/day, per dredge with the remainder required for repositioning, barge moves, and downtime for maintenance.
- Dump scow unloading: 1 hr/trip, including positioning, with a maximum of approximately 5 minutes for unloading.
- Environmental bucket: 8m³, with a bucket fill factor of 0.65, based on level cut for dredging to 1 m of sediments. Total volume removed by the environmental bucket: 70,400 m³
- Conventional clamshell bucket: 26 m³, with a bucket fill factor of 0.6, based on a non-uniform (sloped) surface to dredge sediments from depths > 1 m. Total volume removed by conventional clamshell bucket: 326,400 m³
- Barge capacity for ocean disposal: 4,000 m³.
- Towing tug speed under tow: 6 knots.
- Cycle times: 2 min/cycle for dredging of surficial sediment (0 - 1 m) from surface, 2.5 min/cycle for trench dredging of surficial sediment because of greater depth.

Based on these assumptions, it is estimated that for disposal of sediment suitable for DAS at the Point Grey DAS site, a total of approximately 100 discharges will be required. Assuming ideal conditions, this would result in one (4,000 m³) dump scow barge discharging at the DAS site every 0.71 days (every 17.1 hr) for a period of 78 consecutive days. In practice, this is likely to be one discharge per day once other factors affecting production are

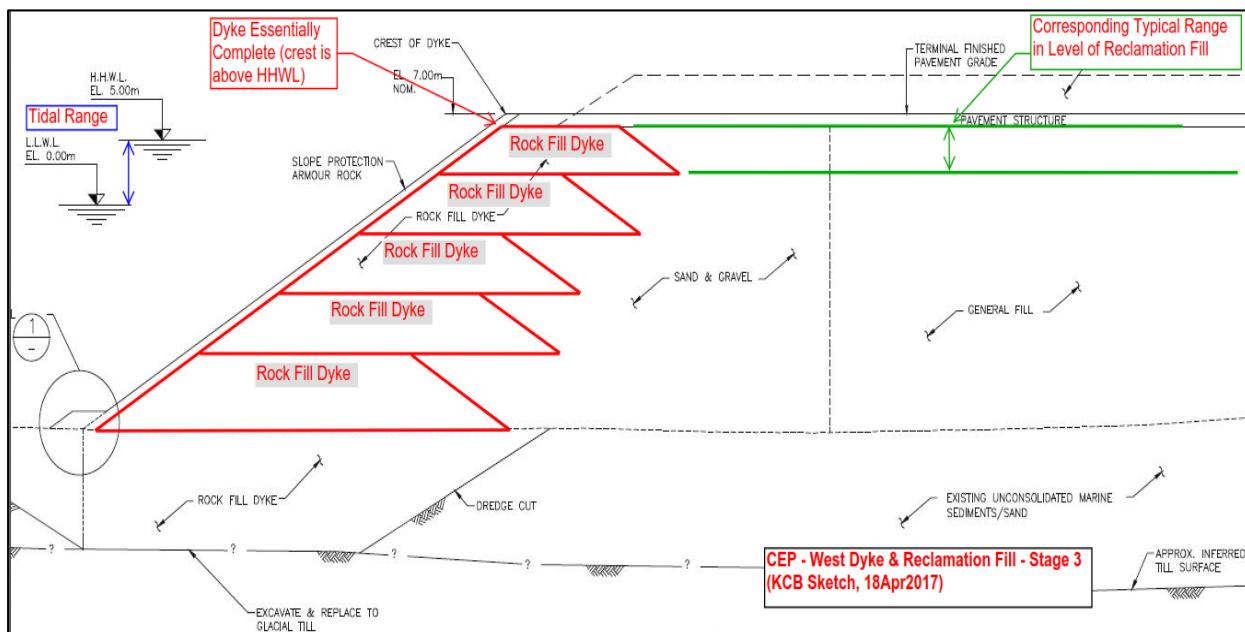
accounted for. The total amount of time required to dredge is estimated to be up to 135 days (approximately 4.5 months). The scheduling and staging of dredging has been planned to enable the dredging work to be completed within the fisheries timing windows. The schedule for the in-water works, including the infilling sequences is provided in Figure 3-1.



3.3 Construction of the Western and Northeast Expansion (Area 2) Dykes

The design and construction of the Northeast Expansion Area 2 and Western Dykes will follow the same design and infilling sequence.

The dykes are expected to be constructed in trapezoidal layers of imported granular materials. Each layer will be approximately 4.5 m thick with a 1.75H:1V sloping face. The rock cores for the dykes are formed from quarried rock, sized up to 600 mm diameter with the majority of the material sized over 125 mm diameter. The material contains reduced fines content with less than 15% of the material comprising of particles of less than 4.75 mm. The material is laid down in layers (approximately 4.5 m thick) and compacted in place to form a solid core. Behind the dykes, there will be a zone of sand and gravel acting as a filter between the dykes and the general fill materials. As stated, the outer slope of the perimeter dyke will be sloped at 1.75H:1V and faced with riprap ranging in size from 195 to 600 mm with a D50 size (median riprap particle size) of 415 mm. Riprap of this size will provide sufficient interlock between the rock pieces and protect the dyke from marine environmental forces while still offering interstitial habitat for marine species. Sketch 1, illustrates the conceptual design.



Sketch 1: Conceptual Design of the Western and Northeastern (Area 2) Expansion Dykes

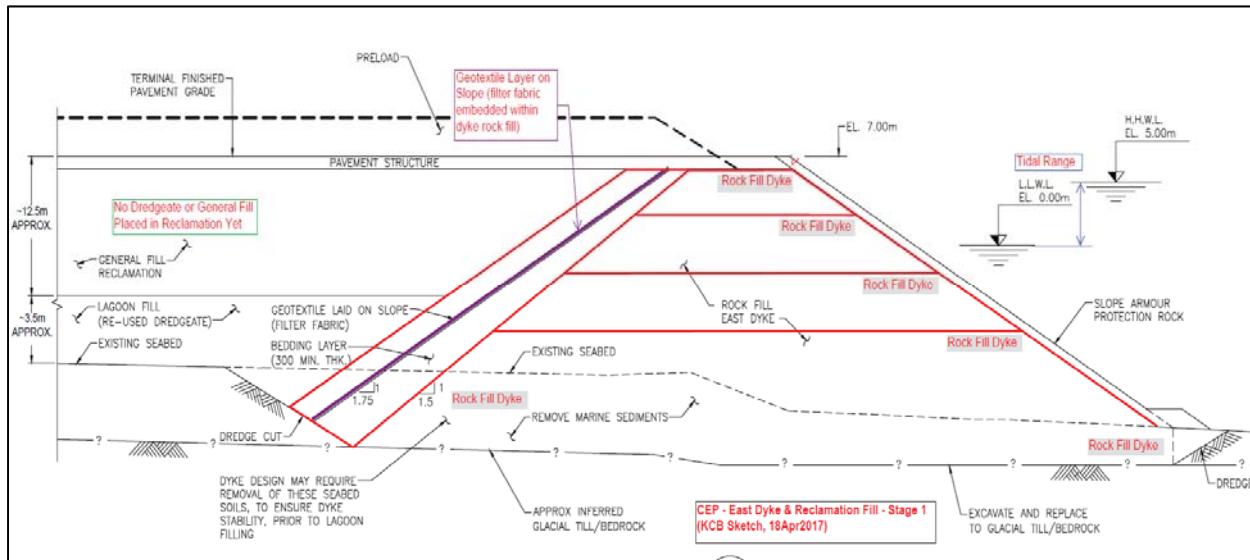
3.4 Construction of the Eastern Expansion Area 1 Dyke

The Area 1 Dyke will be constructed to full height prior to placing dredgeate and other general fill behind the dyke. It is envisaged that the dyke will be constructed of layers of rockfill with a 1.75H:1V sloping face on either side. The rock core for the Area 1 dyke will be formed from quarried rock, sized up to 600 mm diameter with the majority of the material sized over 125 mm diameter. The material contains reduced fines content with less than 15% of the material comprising of particles of less than 4.75 mm. The material is laid down in layers and compacted in place to form a solid core with little-to-no voids.

The Area 1 dyke will adopt a filter layer system combined with geotextile (filter cloth). It is anticipated that the geotextile will carry out the work of filtration while the filter rock layer(s) provide an even placement slope for the geotextile, thus avoiding puncturing. A capping layer is then placed over the geotextile to protect the geotextile and hold it in place during tidal fluctuations. It is anticipated that the capping layer of crushed filter rock can stand at a slope of about 1.75H:1V. The material gradation(s) and filter compatibility requirements of the filter rock layer(s) will be determined by the geotechnical Engineer of Record for the project prior to construction.

Behind the Area 1 dyke, there will be a capping layer of sand and gravel acting as a filter between the dyke, the geotextile and the beneficial reuse fill materials. As stated, the outer slope of the perimeter dyke will be sloped at

1.75H:1V and faced with riprap ranging in size from 195 to 600 mm with a D50 size (median riprap particle size) of 415 mm. Riprap of this size will provide sufficient interlock between the rock pieces and protect the dyke from marine environmental forces while still offering interstitial habitat for marine species. A conceptual design of the dyke is provided in Sketch 2.



Sketch 2: Conceptual Design of the Eastern Area 1 Dyke

3.5 Project Dredging and Infilling Sequence

The proposed dredging and infilling sequence is as follows:

1. Removal of adjacent structures, including concrete wharves, to clear the area for dredging and dyke construction. The adjacent structures have earthen cores that form the centre of the pier. These will have their surfaces prepared to remove any concrete facing and other similar features.
2. Dredge all sediments from the proposed East Expansion Area 1 using an 8 m³ environmental clamshell bucket (the total dredge depths in this area are expected to be in the range of 1 to 4 m based on a geotechnical investigation carried out in December 2016). The environmental bucket will improve the vertical dredge cut accuracy (± 0.15 m) when dredging the relatively thin top surface layer, and will reduce release of fines during the excavation process. The clamshell bucket will hang from a crane barge and will descend to the seabed where it will grab and pick up the sediment material. The bucket will then be slowly raised out of the water at a speed that minimizes loss of sediment. The bucket will then place the excavated material in dump barges (scows) tethered adjacent to the crane barge.
3. Store the dredge material prior to processing and placement in the Eastern Expansion Area 1. Dredgeate will be stored until the Area 1 Dyke is fully constructed to above the High High Water Level (HHWL) to provide containment prior to placement of the dredgeate. Dredgeate handling and transfer procedures will be instituted that include:
 - Surficial sediment that does not meet DAS criteria will be removed from the western, eastern and navigation channel and;
 - Material will be transferred to a containment facility on the barge or on the CEP Site where the water and solids are separated. The decant water is collected in a containment tank.
 - The water is tested to determine whether it meets Canadian Council of Ministers of the Environment (CCME) Water Quality Guidelines for Protection of Aquatic Life (WQGs).
 - Water that meets CCME standards can be discharged to the marine environment.
 - Water that does not meet the standards will require treatment so that it meets CCME WQGs for Protection of Aquatic Life before it is discharged.

4. Construct the East Dyke to the full height to create a containment area to the south across Area 1 to accommodate the stored surficial materials. Complete with rock fill core, filter bedding layers and riprap. Tie the new dyke into the adjacent earthen cores for the existing piers. At this stage, no fill has been placed in the containment area created by the dyke, resulting in a trapped pool of water subject to tidal fluctuations. There is limited tidal exchange (water flow through the dyke core).
5. Complete Navigation Turning Basin area dredging using the environmental bucket.
6. Dredge surficial sediments (0 – 1 m) from the Western Expansion area and from beneath the Northeast Dyke portion of the Eastern Expansion area (Area 2) using the environmental bucket.
7. Process the surficial dredge material from the Western Expansion area, Eastern Expansion area (Area 1 and Area 2) and the Navigation Turning Basin area to improve its suitability as fill. If required, this could be accomplished by:
 - a. Screening to separate the granular material and centrifuge or filter press treatment of the fine grained materials; or
 - b. Adding stabilizers.
8. Place processed surficial dredge material behind the Eastern Expansion Area 1 as general fill for the Eastern Expansion area. Dredgeate that is not suitable for DAS, but meets CCME Canadian Soils Quality Guidelines for the Protection of Environmental and Human Health – Industrial Land Use (CCME IL Soil Guidelines), is placed behind the dyke to a maximum height of 1 m below Low Low Water Level (LLWL). The dredgeate layer is then capped with clean general fill material. The rate of fill placement is such that the water trapped behind the dyke is expected to be displaced through the dyke during construction through tide cycles with the sand gravel barrier in place behind the dyke inhibiting the flow of suspended solids.
9. Sample newly exposed sediment in the Western Expansion area and Eastern Expansion Area 2 in accordance with a SAP approved by ECCC to confirm suitability for DAS.
10. If the confirmatory sampling indicates that the material is suitable for DAS, continue dredging of the Western Expansion area and from Area 2 with an approximately 26 m³ conventional clamshell dredge until a stable foundation of glacial till is reached. Anticipated to range in depth from 1 to 4 m for Eastern Expansion Area 2 and 8 to 17 m for the Western Dykes. During this stage of the work, it is estimated that approximately one 4,000 m³ barge load of material per day would be delivered to the Point Grey DAS site.
11. Infill and complete construction of the Western Expansion area and Area 2 by:
 - Filling the dredge cut with rock fill material and densify using vibro-densification techniques.
 - Placing rock dyke fill in 5 stages in a stepwise approach. During the placement of materials at depth i.e., the first 1-3 layers, it is expected that the majority of materials will be placed using hopper barge dumping complemented with barge mounted mechanical equipment (clam-shell marine derrick) used for placement and shaping of the materials (mainly the dyke core rock and slope armour rock). The barge will be floated into place over the placement location and the hoppers emptied via doors in the hull to deposit material directly into place. The Contractor may elect instead to offload the granular dyke materials directly into the water by front-end loader equipment working on a flat-deck barge. As the dyke elevation increases during construction, the ability to position the hopper barge (or flat-deck barge) over the infill area will reduce as the navigation clearance to the underside of the barge (and the hopper doors) would be reduced. The final two layers of dyke construction will therefore need to use barge-mounted mechanical placement (clam-shell derrick) for the rock core, and pumping of granular materials into place for the terminal expansion sand fill.
 - As the dyke is being a built-up it will be progressively infilled with sand and gravel material placed directly behind the dyke that will act as a semipermeable barrier, followed by general fill. Dewatering will take place naturally through the sand gravel barrier as the dyke is being built during low tides. During periods when the dyke is partially completed, and the dyke is below the HHWL, water will flow naturally over the dyke. Modelling results, described below, have shown that the natural flow of water through the sand gravel barrier will not result in a spike in total suspended solids (TSS) in excess of CCME WQGs for Protection of Aquatic Life.
 - Place slope protection armour rock on the outside of the dyke.

4. Effects Assessment and Mitigation

4.1 Effects and Activities

AECOM has assessed the following in consideration of the potential effects to the marine environment of the alteration to the design of the proposed Project.

1. Dredging
2. Infilling
 - a. Sediment dispersion during dredging
 - b. Sediment dispersion during infilling
 - c. Porewater infilling
3. Beneficial Re-use of Sediments (Eastern Expansion Area 1)

4.2 Background

Fugitive sediment loss to the water column during dredging can affect turbidity. Turbidity is the cloudiness of the water and may be caused by particles suspended in the water, and there is always a certain degree of natural turbidity. Turbidity can be affected by any type of suspended particle, for example algae blooms, zooplankton (pelagic shrimp-like organisms) or the natural scouring and resuspension of sediments caused by tidal currents and wind-driven waves. In the area of CEP, turbidity may vary naturally by a 10-fold factor. During dredging there will be some loss of dredge sediments as the dredge bucket is raised to the surface. Even the most efficient dredge buckets, such as those that will be used for this work, are not 100% efficient in containing all the dredgeate (e.g., a few percent can be lost to the water column during the upward haul). This section updates the initial assessment of dredging effects on water quality that was reported in the PER Application (AECOM 2016b).

Turbidity may be measured either in the form of reduced light transmittance in the water column (expressed as nephelometric units), or as the TSS within the water column (expressed as milligrams of solids/litre of water). The CCME WQGs for the Protection of Aquatic Life are numerical limits intended to provide protection of freshwater and marine life from anthropogenic stressors such as chemical inputs or changes to physical components (e.g., suspended solids). Guideline values are based on the most current, scientifically defensible toxicological data available for the parameter of interest and are meant to protect all forms of aquatic life and all aspects of the aquatic life cycles.

For purposes of understanding effects of dredge scenarios on water quality, the results of modelling were compared against the CCME WQGs for total particulate matter which is a maximum of 25 mg/L above natural background (for events less than 24 hrs), or a *maximum average* 5 mg/L for long term effects (i.e., >24 hrs). The long term standard is the more relevant to the dredge scenario as dredging is expected to last from a few days up to 6 weeks depending on location and number of dredges operating with a total duration of approximately 4.5 months. A complete in-water work schedule is provided in Table 4-1 Summary of In-Water Works, as well as shown graphically on Figure 3-1.

Table 4-1 Summary of In-Water Works

Activity	Duration
Dredging	4.5 months during fall/winter of 2017 and 2018
Demolition Over Water	4 months during fall/winter of 2017 and 2018
Steel Pile Extraction	2 months during fall 2017
Sand Fill Placement	8 months during fall/winter 2017 and into summer 2018
Vibro-Densification	6 months during fall/winter 2017 and into summer 2018
Rock Fill and Riprap Placement	8 months during fall/winter 2017 and into summer 2018
Set Caissons in Place	½ month Spring 2018
Install Caisson Scour Protection	1 month Spring 2018
Sheet Pile Installation	1 month Spring 2018

The predicted TSS values were compared against the standards at a 100 m setback from the dredge area. One hundred meters is considered an appropriate initial dilution zone for marine waters and lakes under the Environmental Management Act Municipal Wastewater Regulation 2016 (B.C. Reg. 41/2016) at which point the water quality standards set out in CCME should apply. However, the Guidance on the Site-Specific Application of Water Quality Guidelines in Canada: Procedures for Deriving Numerical Water Quality Objectives (Canadian Council of Ministers of the Environment, 2003) provides guidance for determining the areal extent of an initial dilution zone, which can allow for a larger initial dilution zone.

4.2.1 Evaluation of Effects

Tetra Tech was retained to conduct hydrodynamic modelling (also referred to as a sediment transport and dispersion modelling) of potential fugitive sediment loss that may arise during the dredging process at the three dredge locations. Initial modelling was completed and reported as Appendix F2 in Volume 3 (Marine Environment) of the CEP Environmental Studies report (AECOM, 2016b). An update to this modelling was recently completed and is provided in Appendix A and B. The hydrodynamic model evaluates fugitive sediment loss on the basis of TSS.

Actual dredging will take place 12 hours per day, with the remainder of time used for repositioning barges and dredge equipment and equipment maintenance. However, due to modelling constraints dredging was modelled as running for 22 hours each day, which is a much more conservative assumption. The model took into account the two types of dredging equipment being proposed, the use of an *environmental* bucket to remove the top 1.0 m of sediments³ and a *conventional* and larger bucket to dredge the deeper, clean sediments as specified in Table 4-2.

Table 4-2 Dredge Bucket type and Volume

Material	Bucket Type	Bucket Volume (m ³)	Bucket Fill Factor	Effective Bucket Volume (m ³)
Surficial sediments that do not meet DAS benchmarks	Environmental bucket	8	0.65	5.2
Clean deeper sediments	Conventional clamshell bucket	26	0.6	15.6

The environmental bucket is smaller than the conventional clamshell bucket allowing for more precise removal of top 1.0 m of sediments. In addition, it has a better seal which helps minimize the release of sediment from the bucket during dredging. Environmental buckets with venting systems can minimize the amount of water removed, by draining excess water through the vents once the bucket reaches the surface.

³ As stated in previous sections, the surficial sediments from 0 to 0.6 m deep exceed sediment quality requirements to allow for disposal at sea; to be conservative, the top 1.0 m of sediment will be removed and re-used as fill for the eastern expansion area (pending approval from VFPA as part of the Project Environmental Review process).

The updated modelling provided two forms of TSS estimates:

- **Water Column Maximum Averaged TSS Concentration:** At hourly intervals, the maximum vertically averaged TSS concentration in the water column is reported on a 25 x 25 m horizontal grid within the study area. *This metric is most comparable to CCME's "maximum average" water quality guideline for total particulate matter, expressed as TSS.*
- **Water Column Maximum TSS Concentration:** At 15 minute intervals, the maximum TSS concentration in the water column (irrespective of its vertical position within the water column) is reported on a 25 x 25 m horizontal grid within the study area. *This metric provides insight into the spatial location of short-lived events with maximum TSS.*

Generally, it was found that dredging programs employing two dredges in the same general area have the potential to generate water column conditions where estimated TSS may exceed the CCME chronic guideline of 5 gm/L at 100 m from the dredge area for a certain percentage of the time (details provided below, presented by dredge area).

It is important to understand that the numerical results presented (i.e., TSS concentration, percentage of time, and location) used to describe exceedances of the TSS standards do not infer a static and continuous condition of the water quality exceedance. Rather, the episodic exceedances vary in concentration magnitude, time, and space, these events are short lived and not continuously in the same place. Locations of the TSS 5 mg/L exceedance at 100 m will vary with the location of the dredge unit and the prevailing tidal cycle.

Key points for each dredge area are as follows:

Navigation Basin Dredge Area

- Under the scenario of one dredge the average concentration of 5 mg/L or less at 100 m is achieved for 94% of the time and a maximum spike of 68 mg/L occurred once.
- With two dredges operating a TSS increase of 5 mg/L or less occurs 89% of the time over 2 days of dredging with an instantaneous maximum spike of 148 mg/L (see Table 4.1 of Tetra Tech 2017, Appendix A); this scenario is purely hypothetical as it would be impractical to have two dredges working this area due to spatial constraints and the impact this would have on Sea Bus operations.

West Basin Dredge Area

- With one barge working the average concentration of 5 mg/L or less at 100 m is achieved 81% of the time and with concentrations of 16 mg/L to 76 mg/L recorded for 5% of the 4.5 weeks the dredging was modelled.
- For the two dredge scenario, the 5 mg/L criteria or less will be achieved for 62% of the time with concentrations of 34 mg/L up to 201 mg/L reported 5% of the 4.5 weeks of dredging that was modelled (see Table 4.3 of Tetra Tech 2017, Appendix A).

East Basin Dredge Area

- With one barge working, the average concentration criterion of 5 mg/L or less at 100 m is achieved 95% of the time and with concentrations of 8 mg/L to 85 mg/L recorded for 5% of the 3 weeks the dredging was modelled.
- For the two dredge scenario, the 5 mg/L criteria or less will be achieved for 85% of the time with maximum concentrations of 15 mg/L up to 156 mg/L reported for 5% of the 3 weeks of dredging that was modelled (see Table 4.3 of Tetra Tech 2017, Appendix A).

4.2.2 Mitigation

The design build contractor (DB Contractor) will be responsible for developing and implementing an environmental management plan that is sufficiently robust to ensure the continued protection of water quality. The DB Contractor must demonstrate that, during the course of their work, they anticipate to be in compliance with the CCME WQGs for Protection of Aquatic Life.

At a minimum, it is expected that the DB Contractor's environmental management plan will include:

- An overview of the applicable water quality guidelines and the requirements contained within those guidelines which must be achieved throughout the construction of the Project;
- Methodology for monitoring compliance, including the use of turbidity as a proxy measurement of TSS for real time monitoring;
- The location of monitoring points and frequency of monitoring during various stages of the Project, taking into account safety and navigational constraints associated with maintaining local marine traffic throughout the construction period;
- The reporting of the results and adaptive management plans should the mitigation measures in place fail to achieve the required water quality criteria;
- The procedure for implementation of stop work orders, if required;
- Monitoring of TSS via the proxy measurement of turbidity as nephelometric turbidity units (NTU) in real time at strategic locations that would be adjusted according to the daily locations of the dredging activity⁴. Monitoring will be conducted for the purpose of establishing whether actions are needed (e.g., temporary cessation or relocation) of dredge units, or other measures (such as silt curtains) to assure compliance with CCME WQGs for Protection of Aquatic Life and policy; and,
- Physical barriers can only be deployed if they do not pose a navigational hazard and would likely only be effective over a shallow depth of water given the relatively high tidal currents in the dredge areas.

4.3 Infilling Effects

4.3.1 Background

Fugitive sediment loss to the water column during *infilling* can also affect turbidity. Infilling may increase turbidity as infill material is released from a hopper barge and descends through the water column to the sea bottom. During descent, some of the fugitive particles in the infill material may disperse and temporarily be suspended in the water column and increase turbidity until they settle to the bottom. Turbidity may also increase due to the perturbation that occurs when the infill contacts the sea bottom. Accordingly, a similar hydrodynamic modelling approach as that described for dredging was undertaken to also assess the effects of infilling.

Tetra Tech was retained to also conduct hydrodynamic modelling of potential fugitive sediment loss and dispersion that may arise during the infilling process (Tetra Tech 2017, Appendix B). Tetra Tech conducted modelling for infilling at both the western and eastern expansion area. However, initial modelling results for infilling activities at the eastern expansion area were for a design scenario in which infilling would occur at both Area 1 and Area 2 during phased dyke construction (i.e., prior to dyke completion and full containment). This design scenario is no longer applicable for infilling at Area 1, since infilling Area 1 will only occur after Area 1 Dyke is completed and fully contains Area 1. In this latter scenario no fugitive particulates will be released to ambient waters of Burrard Inlet because the completed Area 1 Dyke is designed to be impermeable to suspended particulates that may arise during the infilling process. However, the original turbidity modelling still provides a useful and conservative basis (i.e., errs towards overestimating rather than underestimating effects) to understand turbidity effects from infilling of Area 2. Area 2 is immediately adjacent to the outer face of Area 1 Dyke at the tip of Ballantyne pier and subjected to the open waters of Burrard Inlet. The modelling approach for both the eastern and western expansion is described below, and the predicted results for the eastern and western expansion are presented in section 4.3.2. .

Fugitive sediment loss to the water column during infilling can affect water quality turbidity the hydrodynamic model for infilling evaluated fugitive sediment loss (TSS) compared to the CCME WQGs for Protection of Aquatic Life. The two forms of measurements used for predicting TSS for infilling were very similar to those for dredging, but have greater spatial resolution and are as follows:

⁴ Total suspended solids can only be measured in the laboratory to determine the concentration of the particulate material in the water. Given the laboratory requirement for the measurement of TSS and associated process and analysis times, turbidity will be used as a real-time proxy estimate measurement of TSS. TSS and turbidity are not analogous in all situations, and the relationship will be calibrated independently for each sediment type. In addition, the relationship between turbidity and TSS varies temporally due to naturally-occurring variations in local conditions. In order to carry out real time monitoring a relationship must first be developed to correlate the turbidity and totals suspended solids.

- **Water Column Maximum Averaged TSS Concentration:** At hourly intervals, the maximum vertically averaged TSS concentration in the water column is reported on a 10 x 10 m horizontal grid within the study area. *This measurement is most comparable to CCME WQGs “maximum average” for total particulate matter, expressed as TSS.*
- **Water Column Maximum TSS Concentration:** At 15 minute intervals, the maximum TSS concentration in the water column (irrespective of its vertical position within the water column) is reported on a 25 x 25 m horizontal grid within the study area. *This measurement was employed to provide insight to the spatial location of short-lived events with maximum TSS.*

The general conditions modelled for the in-filling followed two scenarios, the first when the developing dyke height was below the low tide level and the second was when the top of the dyke was above the low tide level. Within the “below tide” scenario, the model also considered fugitive sediment loss when the infilled area was either (i) maximum depth below the interim crest of the dyke (“empty berm scenario”), or (ii) when the infilled area was at grade with the interim crest of the dyke (“full berm” scenario). The empty and full berm scenario applied to the three lifts below the low tide level as any sediment plume created by infilling can freely move outside the dyke/work area. When the dyke height exceeds the low tide level, the infill material will be transferred from the barge by mechanical means (i.e., clamshell and crane or pumping). When high tide levels are below the top of the dyke, full infill containment is achieved. The material that will be placed inside the dykes consists of mostly sand and will not travel as far as the finer dredged sediments described above. Therefore dispersion of infill material will be less and is also limited by the fact that suspended material will be contained by a sand filter placed along the backside (inner face) of the dyke.

Tetra Tech’s in-fill report (Tetra Tech 2017, Appendix B) modelled the infilling of each of the four berm lifts over a 14 day period to adequately represent longer infill durations. Results based on the 99th percentile of predicted *maximum average TSS concentrations* for all dyke lifts (i.e., 1 through 4) and both berms scenarios (i.e., berm empty or full) indicate that the vast majority of the TSS levels at 100 m from the infill area will be below 5 mg/L but there is potential for short-lived spikes lasting on the order of an hour or two when maximum levels could marginally exceed 200 mg/L.

The effects of infilling are discussed below for Eastern Expansion Area 2 and the Western Expansion area.

4.3.2 Infilling Effects Eastern Expansion Area 2 and Western Expansion Area

Eastern Expansion Area 2

As noted earlier, the original turbidity model for the combined infilling of Area 1 and Area 2 is as a conservative assessment for the open water infilling of only Area 2. Infilling of Area 2 on its own will be of shorter duration and involve less infill. The turbidity modelling indicated:

- Over the 14 days of simulated infilling, the 99th percentile of predicted *maximum average TSS concentrations* for all dyke lifts (i.e., 1 through 4) and both berms scenarios (i.e., berm empty or full) indicate that the vast majority of the TSS levels at 100 m from the infill area will be below the chronic water quality guideline of 5 mg/L. (Tables 4.8 and 4.9, Tetra Tech 2017, Appendix B).
- Over the 14 days of simulated infilling the average concentration at 100 m from the infill area infrequently exceeded 5 mg/L of TSS, i.e. less than 1.0% of the time (Tables 4.6 and Table 4.7 Tetra Tech 2017, Appendix B).
- The modelling identified instances of maximum TSS levels marginally over 200 mg/L TSS at 100 m (likely lower due conservatism of the model), however these peaks were short lived, (i.e. durations of less than 2 hours) and were spaced several days apart (Tables 4.8 and 4.9 and Figures 4.13, 4.16 and 4.19 Tetra Tech 2017, Appendix B). These spikes were typically associated with large flood tides.
- The analysis also shows that peak TSS events can be significantly reduced by strategically coordinating the timing of hopper barge releases to avoid unfavourable tidal dispersion conditions.

Western Basin Infilling - Effects

Key points for the western infill area are as follows:

- Over the 14 days of simulated infilling, the 99th percentile of predicted *maximum average TSS concentrations* for all dyke lifts (i.e., 1 through 4) and both berms scenarios (i.e., berm empty or full) indicate that the vast majority of the TSS levels at 100 m from the infill area will be below the chronic water quality guideline of 5 mg/L. (Tables 4.4 and 4.5, Tetra Tech 2017, Appendix B).
- Over the 14 days of simulated infilling the average concentration at 100 m from the infill area infrequently exceeded 5 mg/L of TSS, i.e. less than 10% of the time (Tables 4.2 and Table 4.3 Tetra Tech 2017, Appendix B).
- The modelling identified instances of maximum TSS levels marginally over 200 mg/L TSS at 100 m however these peaks were short lived, (i.e. durations of less than 2 hours) and were spaced several days apart (Tables 4.4 and 4.5 and Figures 4.3, 4.6 and 4.09 Tetra Tech 2017, Appendix B). These spikes were typically associated with large flood tides.
- The analysis also shows that peak TSS events can be significantly reduced by strategically coordinating the timing of hopper barge releases to avoid unfavourable tidal dispersion conditions.

4.3.3 Western and Eastern Expansions Area 2 Infilling - Effects Mitigation

Similar to dredging mitigation measures, it will remain the responsibility of the DB Contractor to develop and implement an environmental management plan sufficiently robust to ensure the continued protection of water quality. The contractor must demonstrate that, during the course of their work, they anticipate to be in compliance with the CCME WQGs for TSS.

Mitigation measures will include:

- Monitoring turbidity in real time at strategic locations that would be adjusted according to (i) the daily locations of the infilling activity and (ii) the timing of the prevailing tidal cycle.
- Monitoring will be conducted for the purpose of establishing whether action is needed (e.g., temporary cessation or relocation) of infilling or other measures (such as partial depth silt curtains) to assure compliance with CCME turbidity guidelines and policy.
- Physical barriers can only be deployed if they do not pose a navigational hazard and would likely only be effective over a shallow depth of water given the relatively high tidal currents.

4.3.4 Porewater Release During Infilling - Effects

The potential effects of contaminated porewater being expelled as a result of sediment preloading and compaction during the infilling of the eastern and western expansion was previously modelled and reported in CEP Environmental Studies Volume 3: Marine Quality – Appendix F3 (AECOM 2016b). The previous modelling was based on the assumption that the existing sediments would remain in place and did not account for the dredging of sediments to reach the stable underlying glacial till and therefore the removal of the surficial layer of contaminated sediments as proposed under current design.

A water mixing model (CORMIX) was used to predict how expelled pore water mixes with overlying water. This model helped in determining the distance of the mixing zone that would allow substances dissolved in the pore water to dilute to levels compliant with federal and provincial marine water quality guidelines. In brief, the model predicted mixing and dilution of the pore water substances would occur rapidly and the concentrations would be within federal guidelines within less than 1 m from the pore water release point. Given the conservative assumptions on which the modelling was based, the distance is actually likely to be less than 10 cm, given the large attenuation factors predicted by the model to occur in close proximity to the pore water release point. The results suggested that even with the “no-dredge with preload” there would be no measurable change in water quality within the Marine Water and Sediment Quality Study Area, and no residual effect on overlying water quality is anticipated.

Under the current design, surficial dredged sediments unsuitable for disposal at sea will be temporarily contained on land or in a barge prior to beneficial reuse as fill material in Area 1. Porewater (decant water) released during storage will be collected, tested, and treated if required to ensure it meets CCME WQGs for Protection of Aquatic Life prior to being released into the marine environment. Therefore, under the current design porewater will not affect marine water quality.

4.3.5 Porewater Release During Infilling - Effects Mitigation

The potential effects on marine water quality resulting from porewater release during dyke construction has been virtually eliminated by the decision to dredge sediments under the dykes

Potential effects from porewater that will be released during dredging will be mitigated through use an efficient environmental dredge bucket with minimal loss.

Porewater released during storage of surficial dredgeate prior to deposit in Area 1 will be contained, tested and treated if required to ensure that it meets CCME WQGs for Protection of Aquatic Life prior to being released into the marine environment.

4.4 Beneficial Reuse of Sediments in Eastern Expansion Area 1

Surficial sediment identified at the three dredgeate locations was previously characterized and reported within the AECOM (2016b) report on CEP Environment Studies (Volume 3 – Marine Environment), and also reported in the Disposal at Sea Sediment Characterization report (AECOM, 2017). As previously discussed in Section 2.3, the top 0.6m of sediments are not considered suitable for ocean disposal. While these sediments are not suitable for ocean disposal, they provide a construction benefit if reused as infill to create new land in the Eastern Expansion Area 1 infill. While only the top 0.6m is considered not suitable for ocean disposal, CEP is taking a precautionary approach and removing the top 1 m of sediments and conducting confirmatory sampling to provide further assurance that the remaining sediments are suitable for ocean disposal. This also means that sediments being redirected to Area 1 are a mixture of the top 0.6m of sediments and cleaner underlying sediments. CEP is also proposing a further precaution by identifying any “hot spots” in the top 1 meter of sediments that do not meet CCME Soil Quality Guidelines for Protection of Environmental and Human Health for industrial land use and diverting those sediments for disposal at an approved off site facility.

Avoiding unnecessary disposal of sediments that do not meet DAS criteria in an upland licensed disposal facility is also an environmental benefit, especially given the energy use associated with transportation and processing of sediments.

This beneficial reuse strategy is contingent on the reused dredgeate and its residual constituents being properly contained with the Area 1 land expansion. To this end three questions arise for consideration:

- a. Does the surficial sediment to be repurposed as fill for meet applicable provincial and federal industrial land standards?
- b. Will there be any loss of fugitive sediment to ambient waters of Burrard Inlet during infilling?
- c. Will the residual constituents in the dewatered dredgeate mobilize via groundwater transport and discharge into the ambient waters of Burrard inlet?

4.4.1 Surficial Sediment Quality Relative to Industrial Land Use Soil Quality Guidelines

In the original 2016 CEP Environmental Studies report (AECOM, 2016b), the beneficial reuse of surficial dredgeate at Area 1 infill had not been contemplated. After further characterization of surficial sediments and assessment of alternative options for use, it was determined that the preferred option was to use the surficial sediments as fill for Area 1. Under this beneficial reuse scenario, the surficial dredgeate used as fill material will be repurposed as soil. Accordingly, soil quality standards become relevant in evaluating the dredgeate as acceptable fill material. The soil quality standards used in this evaluation are (i) the federal CCME Soil Quality Guidelines for Industrial Land use (IL), and the BC Contaminated Sites Regulations (BC CSR) Soil Quality Standards for Industrial Land use. The former is relevant given the federal context of the proposed Area 1 infill, and the latter offers additional insight where federal guidelines may be lacking, or in the case if select dredgeate warranted disposal to a provincially licensed repository.

The CEP team retained Keystone Environmental (Keystone) to provide an independent second perspective on surficial sediment quality data previously reported by AECOM (2017) and its feasibility to be used as Eastern Expansion fill. Keystone assessed the sediment quality data with respect to applicable provincial and federal standards industrial land standards. Key findings from Keystone (2017) are restated here as follows:

EVALUATION AGAINST APPLICABLE STANDARDS AND GUIDELINES (From Keystone 2017)

CSR Soil Standards

Within the CSR, there are two types of numerical standards for soil: generic numerical standards (Schedule 4 and Schedule 10) and matrix numerical standards (Schedule 5). Matrix Numerical Standards are provided for certain substances in soil and are determined based on the evaluation of potential site-specific factors including the following:

- Intake of contaminated soil (applicable at all sites)
- Groundwater used for drinking water
- Toxicity to soil invertebrates and plants (applicable at all sites)
- Livestock ingesting soil and fodder
- Major microbial functional impairment
- Groundwater flow to surface water used by aquatic life – freshwater and marine
- Groundwater used for livestock watering
- Groundwater used for irrigation

Once the applicable site-specific soil matrix factors are determined, the lowest standard from those applicable factors is defined as the matrix numerical standard that will apply to the Site.

As the proposed fill areas are each for industrial land use at a filled marine foreshore, only the most stringent of the factors: intake of contaminated soil, toxicity to soil invertebrates and plants, and groundwater flow to surface water used by marine aquatic life would apply.

The “groundwater used for drinking water” matrix standard would not apply as the areas are filled marine foreshore and such areas are exempt from the application of drinking water standards. The remaining matrix standards are for agricultural use which is not present here.

None of the sediment samples collected from the western expansion area contained concentrations of metals, polycyclic aromatic hydrocarbons (PAHs) or polychlorinated biphenyls (PCBs) that exceeded the applicable CSR IL soil standards.

Four sediment samples (DAS-E-01-A0.2, DAS-E-08-A-0.2, DAS-E-09-A-0.2 and DAS-E-10-G) from the eastern expansion area exceed the CSR IL standards for copper. However, the concentration only exceeded the IL matrix standard for protection of soil invertebrates and plants. As these sediments will be at depth (>10 m) and under pavement or buildings there would be no risk to human, terrestrial or aquatic receptors.

One sediment sample from the navigation dredge area (DAS-SB-03-A-0.8) exceeds the CSR IL standard for benzo(a)anthracene. As these sediments will be at depth (>10 m) and under pavement or buildings there would be no risk to human or terrestrial receptors. The benzo(a)anthracene would not be anticipated to reach Burrard Inlet based on BIOSCREEN-AT™ modelling (see porewater section).

CCME Soil Guidelines

CCME industrial use guidelines provide guidelines for coarse and fine soils. However, for the parameters evaluated in this report, there is no difference between the coarse and fine grained soil guidelines.

Two of the sediment samples, DAS-W-06-A-0.2 (91.5 µg/g) and DAS-W-13-A-0.6 (207 µg/g) from the western expansion area contained concentrations of copper that exceeded the CCME industrial guideline (91 µg/g) and one sample (DAS-W-02-A-0.6) had a copper concentration that was equal to but did not exceed the CCME copper guideline. The remaining concentrations of metals, PAHs and PCBs from the western dredge area were less than the guidelines.

Assuming the extent of contamination represented by these two sample areas is half the distance to the next clean sample, this represents an area of approximately 2,250 m² and an in-situ volume (upper 1.0 m of sediments) of approximately 2,250 m³. If the extent of contamination is conservatively estimated to extend to the next clean sample, this represents an area of approximately 4,500 m² and an in-situ volume of 4,500 m³.

Twelve sediment samples from the eastern expansion area exceed the CCME IL soil guideline for copper and one of these (DAS-E-06-A-0.2) also exceeds for arsenic. This represents a volume of approximately 900 m³.

Three sediment samples from the navigation dredge area (DAS-SB-02-G-ALL, DAS-SB-03-G-ALL and DAS-SB-08-A-0.2) exceed the CCME IL soil guideline for copper and one sample (DAS-SB-03-G-ALL) also exceeds for lead. One sample (DAS-SB-03-A-0.3) also exceeds the CCME soil guideline for benzo(a)anthracene and benzo(b+k)fluoranthene. These together represent a volume of approximately 850 m³.

It should be noted that the copper concentrations that exceed the CCME guideline are less than the CSR soil standard for copper (30,000 µg/g at pH>6.5), arsenic (25 µg/g) and lead (40,000 µg/g at pH>6.5) for protection of groundwater flowing to marine surface water supporting aquatic life and therefore, it is considered unlikely that these sediments, used as fill, would leach metals into ground water at a concentration that would exceed the BC WQG or the CCME marine aquatic life guidelines. As these fill sediments will be placed at depth (>10 m) within the east bight lagoon and will be under pavement and/or buildings there would be no risk to human or terrestrial receptors.

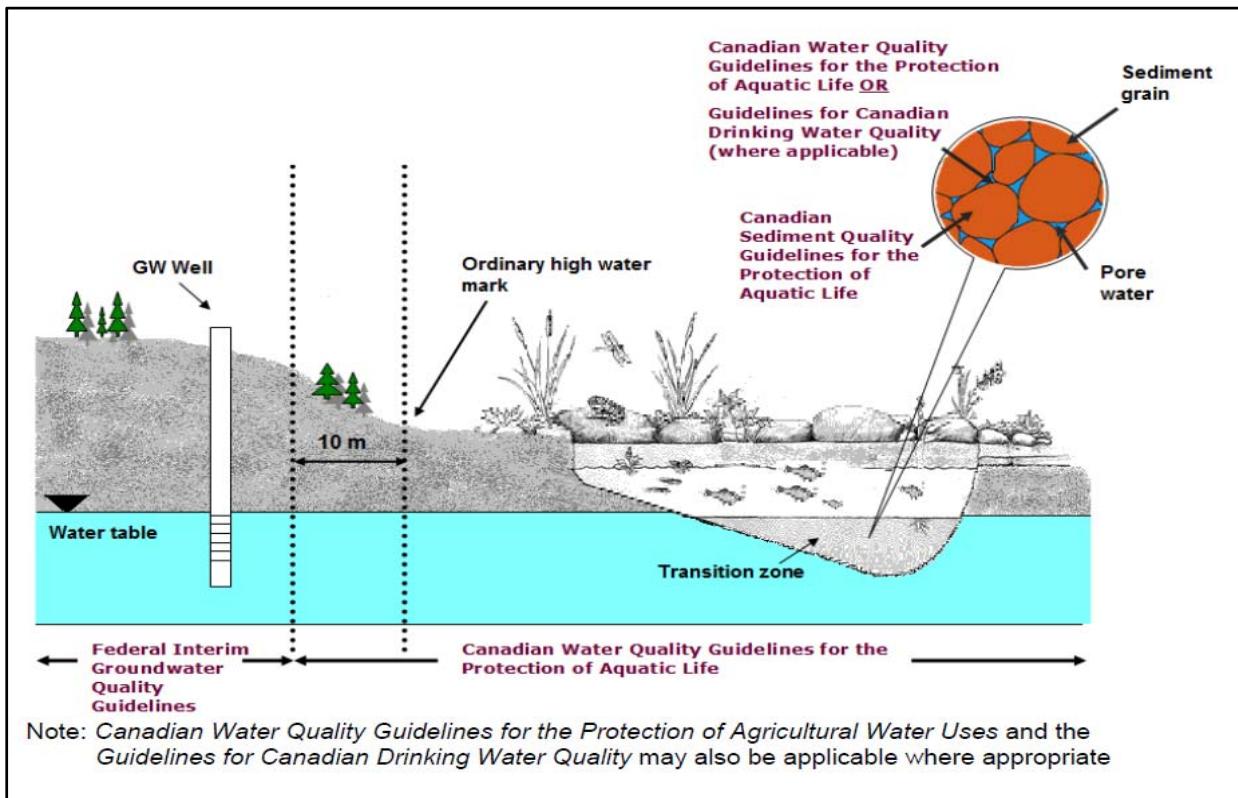
4.4.2 Potential for Discharge of Fugitive Solids to Ambient Waters during Area 1 Infill

Under the proposed design and construction scenario, infilling at Area 1 would only occur after Area 1 Dyke is completed and fully contains Area 1 as a temporary lagoon in preparation for infill. In this design scenario no fugitive particulates within the lagoon will be released to ambient waters of Burrard Inlet because the completed Area 1 Dyke will be higher than the high tide mark, and will be constructed with a filter layer including a geotextile layer along the inner face that will be impermeable to suspended particulates.

4.5 Predicted Groundwater Transport of Residual Constituents in the Far Future

4.5.1 Regulatory Setback for Groundwater Quality Compliance

To examine this groundwater contaminant transport issue, it is necessary to first distinguish between the location of ambient marine environment (the water column) and points of compliance for groundwater relative to the proximity of marine environment. The Federal Contaminated Site Action Plan (FCSAP) policy on Interim Groundwater Quality Guidelines states that groundwater quality within 10 m of the high water mark (freshwater or marine) should meet ambient water quality standards; groundwater greater than 10 m from the high water mark should meet the federal interim groundwater quality guidelines (FCSAP 2010). This concept is illustrated below (from FCSAP 2010):



Drawing from this policy, the evaluation of groundwater contaminant transport of residual constituents that remain in the solid phase of the surficial dredgeate (after placement into Area 1) would need to consider this 10 m setback from the high water mark. Figure 4-1 is a schematic cross section (not to scale) illustrating the application of the FCSAP policy.

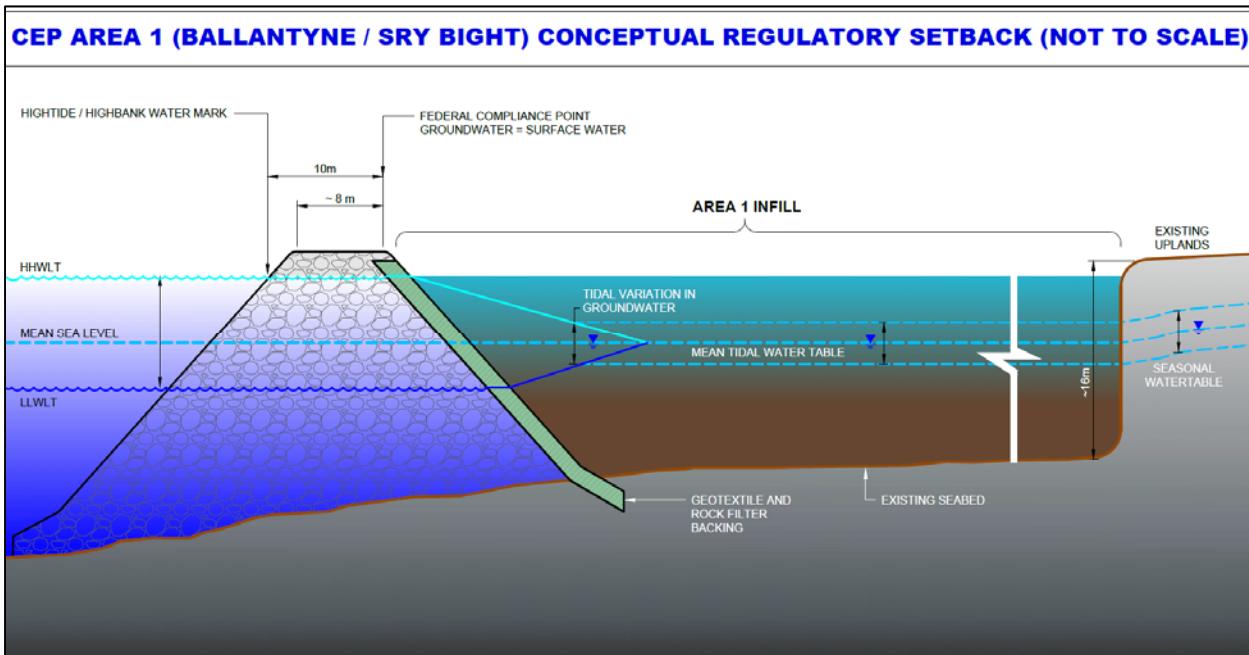


Figure 4-1 CEP Area 1 Conceptual Lagoon showing the Compliance Point

Based on this schematic diagram, it is apparent that the (10 m) setback from the marine high tide water mark is approximately the inner face of the dyke crest (final location will be governed by contractor's final design for dyke construction).

4.5.2 Groundwater Transport Modelling

Modelling was conducted to determine whether there is a significant likelihood that residual constituents in the dewatered dredgeate could mobilize via groundwater transport and discharge into the ambient waters of Burrard Inlet.

A groundwater transport model (BIOSCREEN-AT™) was used to simulate transport of residual PAHs contained in the dredgeate that were earlier reported as porewater (AECOM, 2016b). BIOSCREEN-AT™ is a conservative 1-dimensional analytical transport model. This model was used in this application because it is required under the BC Contaminated Sites Regulation (BC CSR) screening level risk assessment (Protocol 13) to provide a conservative assessment of whether groundwater substances could be transported to sensitive receptors (e.g., aquatic habitat or potable wells) over a protracted timeframe (1,000 years). There are no prescribed models under the Federal contaminated Sites Action Plan or the CCME Soil Quality IL. Among various model parameters, it considers longitudinal dispersion, first order anaerobic degradation, hydraulic conductivity, and hydraulic gradient. This model is suitably conservative such that the BC CSR does not require 2-dimensional or 3-dimensional model to refine the prediction, unless it becomes apparent that the modelled prediction are too conservative and further refinement (less conservatism) is desirable.

Application of this model to the present Area 1 infilling scenario was initially provided to the CEP team by Keystone (2017). They used porewater quality intrinsic to the dredgeate (reported by AECOM, 2016b Environmental Studies Report – Volume 3 Marine Environment) as bases to examine future groundwater transport within the dredgeate once it is placed as Area 1 fill. Keystone established model input parameters largely based on default values described in BC CSR BIOSCREEN-AT™ guidance. During the model setup, Keystone used the analytical laboratory source concentration values for PAHs (benzo(a)pyrene and chrysene) reported in the studies conducted by AECOM, to assess groundwater transport of these constituents. Importantly, Keystone acknowledged that AECOM (2017) had previously flagged these PAH concentrations as exceeding their theoretical solubility limits due to the presence of particulates in the chemical analyses. These reported values could not exist as dissolved concentrations, and while the modelled results provide some context, they are overly conservative in nature. To provide additional insight on predicted future transport of PAHs within Area 1, AECOM recreated the Keystone (2017) BIOSCREEN-AT™ model and adjusted select parameters to reflect more site-specific conditions and more properly reflect concentration values. Specifically, AECOM employed the following assumptions:

- Source concentrations of benzo(a)pyrene and chrysene set to an upper bound porewater concentration (the 95% Upper Confidence Limit of the Mean) reported by AECOM (2017) where solubility limit was substituted for data values exceeding the theoretical solubility limit. This conservatively assumes that after the surficial dredgeate is dewatered at the temporary storage facility and the majority of the intrinsic porewater is removed, the PAHs adsorbed to the solid phase of the dredgeate will re-equilibrate with future groundwater to the solubility limit (i.e., an unlikely plausible worst case assumption).
- Because the model source concentration for PAHs in groundwater was set to their solubility limits, the PAH content in upgradient groundwater has no bearing on the predicted PAH transport because upgradient concentrations cannot further increase PAH concentrations beyond their solubility limit.
- Hydraulic gradient increased from 0.005 to 0.02 (more conservative) to reflect estimated mean interpolated from site-specific cross section of the foreshore uplands.
- Hydraulic conductivity adjusted from 10^{-3} m/s to 10^{-6} m/s to reflect site specific uplands strata and dredgeate infill.

The results from Keystone and AECOM BIOSCREEN-AT™ scenarios are tabulated in Table 4-3 below.

Table 4-3 BIOSCREEN-AT™ Scenarios

Contamination	Input Parameters			Model Results	
	Hydraulic Gradient (-)	Hydraulic Conductivity (m/s)	Concentrations (mg/L)	Max Distance Attenuated to BC CSR AW (m)	Max Distance Attenuated to BCWQG AW (m)
Base Case Measured Max Concentration; Literarure i and K (Keystone 2017)					
Benzo[a]pyrene	0.005	1×10^{-3}	0.0083	3.05	4.57
Chrysene	0.005	1×10^{-3}	0.0072	3.05	6.10
UCL 95 Interstitial Pore Water Concentration.; Measured i and K (AECOM)					
Benzo[a]pyrene	0.02	3.75×10^{-6}	0.002676	0.46	0.46
Chrysene	0.02	3.75×10^{-6}	0.001401	0.46	0.46

The results of these simulations suggest the following:

1. The Keystone simulation reflecting BC CSR default assumptions and the excessive source concentrations predicts the maximum transport groundwater transport distance as 6.1 m, required by chrysene to attenuate to the ambient marine water quality standard.
2. The AECOM simulation employing the aforementioned input values, predicts the maximum transport groundwater transport distance as 0.46 m, required by chrysene to attenuate to the ambient marine water quality standard.

As with any groundwater model there is an element of uncertainty; these two scenarios provide useful context that the far future transport distance for PAHs, even when significantly over estimated, is less than 10 m and likely in the order of 1 m. It is important to note that, these modelled results reflect PAH transport downgradient from the source dredgeate in material that also reflects the same hydraulic conductivity as the dredgeate and uplands (i.e., 3.75×10^{-6} m/s). To a large extent this limiting conductivity will also constrain transport in more conductive materials that compose the Area 1 dyke. As a precautionary design principle and to safeguard for the protection of the marine environment, AECOM recommends placement of the surficial dredged sediment to achieve a setback of 15 m from the compliance point where federal interim groundwater guidance requires groundwater quality to match ambient marine water quality guidelines. The compliance point is located 10m inland from the High High Water Line. This results in the dredgeate placed at least 25 m from the High High Water Line. This point is a vertical plane approximately at the inward most point of the crest for Area 1 Dyke (i.e., the crest of the inner face). Under these conditions, transport modelling indicates PAHs will attenuate and comply with groundwater and ambient marine water standards well before the compliance point and afford protection of the marine environment (Figure 4-2 and Figure 4-3).

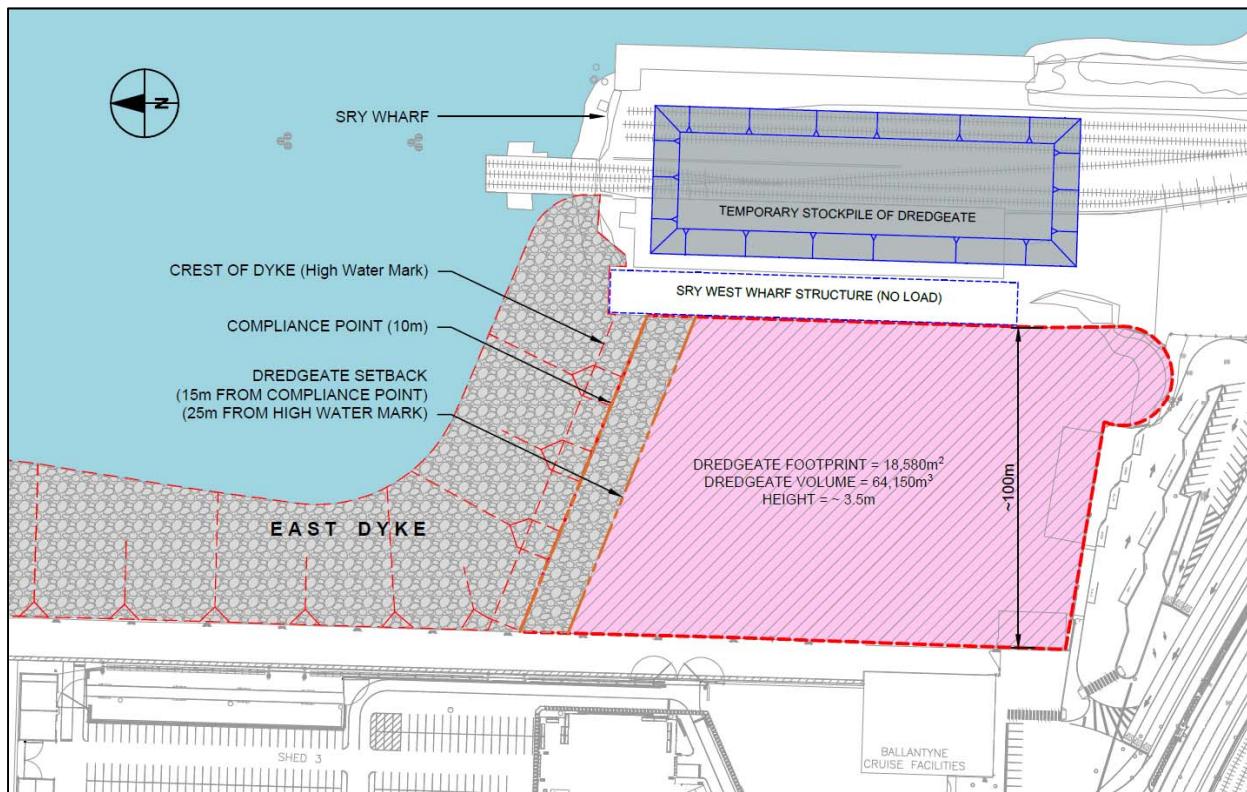


Figure 4-2 CEP Area 1 Conceptual Lagoon Infill (Plan)

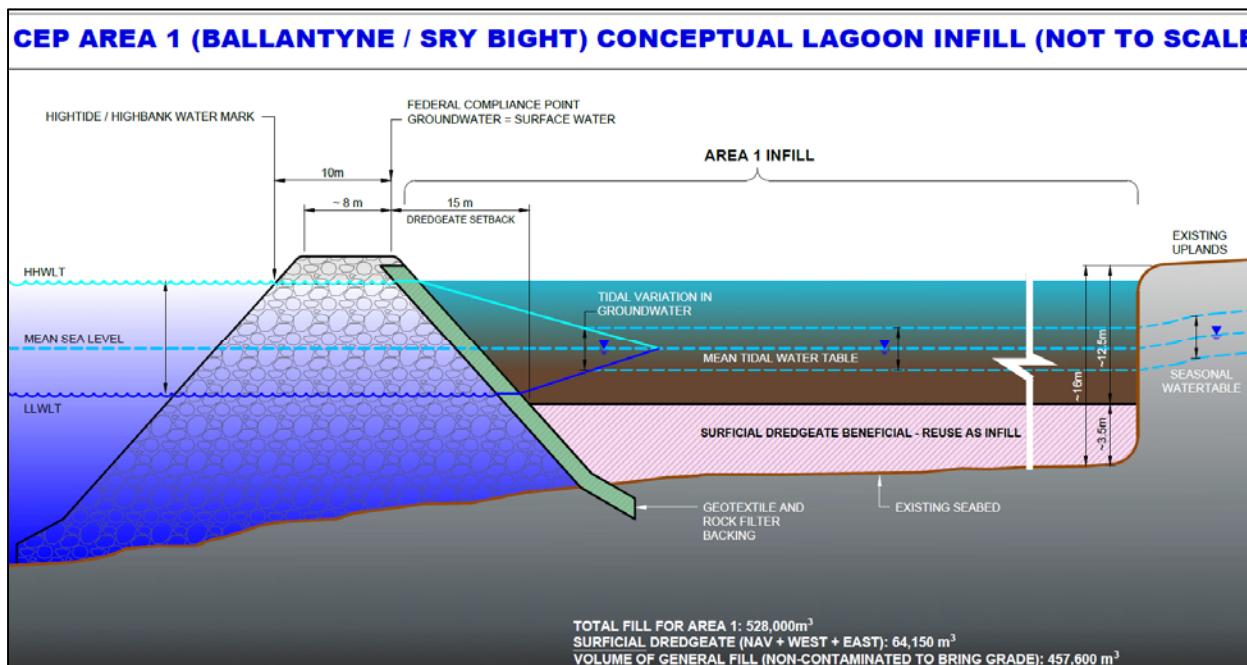


Figure 4-3 CEP Area 1 Conceptual Lagoon Infill (Cross Section)

4.5.3 Mitigation

Surficial sediment beneficial re-use will only occur with the adoption of the following mitigation measures:

- Only sediment which meets CCME IL soil guidelines will be reused
- Adoption of a filter layer system combined with geotextile (filter cloth)
- Material suitable for beneficial reuse will be placed 1 m below Low Low Water Level and at least 25 m (plan distance) from the High High Water Level mark where the marine waters meet the outer face of the perimeter dyke.
- Groundwater monitoring wells will be installed in the east dyke during construction to facilitate a multi-year post-construction groundwater monitoring program. Monitoring of potential marine pollution from Area 1 was an issue raised by First Nations. Monitoring groundwater will provide early detection of any potential effects.

5. Project Scope Change Benefits

The CEP Team feels that this scope change is an improvement to the overall project and the scope change aligns itself with VFPA's Sustainable Gateway Definition: economic prosperity through trade, a healthy environment, and thriving communities. Specifically:

- Economic prosperity through trade: the re-use of approximately 64,150 m³ of surficial sediments as fill material facilitates construction of the eastern expansion area for CEP and reduces construction costs associated with bringing in additional fill from off-site sources. It also avoids the substantial costs associated with transportation and disposal of the surficial sediment estimated to be between 8 and 24 million dollars depending on dewatering requirements and destination.
- A healthy environment: the high sodium content of marine sediments makes it unsuitable for beneficial reuse for most other land use applications or even for landfill disposal. Land based disposal would treat the material as a waste and would require processing of the material prior to re-use. The use of surficial sediments as fill repurposes the material for a beneficial use rather than treating it as waste for disposal. Land based disposal would also result in increased energy use both in terms of potential thermal treatment of the material and fuel used in transportation. The only available options for land based disposal of sediments are not accessible by barge, it is estimated that approximately 6000-6500 truck trips would be required to transport the top 1 m of surficial sediment off site.
- Thriving communities: as noted above, the re-use of the surficial dredgeate on-site eliminates approximately 6000-6500 truck trips from the project site reducing emissions and construction truck traffic on local roads. It also reduces greenhouses gases related to transportation and potential thermal treatment of the material.

6. Revision from the Original Application

The following are comments on the documents which have been revised from the original PER Application.

PER Application Section	Sub-Section of PER Application	Description
Drawings – Volume 3 Marine Structures	Modification to: Drawing No. 32-481-206 Drawing No. 32-481-239 & 32-481-240	Addition of plan and cross section on Eastern and Western Dyke. More information on the design and construction sequence of the dykes, as shown on Figures 2-1, 4-2 and 4-3 in this Addendum.
Chapter 7 Marine Water & Sediment Quality	7.6 Potential Project Effects and Mitigation	Mitigation measures have been further developed and refined as per Section 4.2.2, 4.3.5 and 4.5.3 of this Addendum.
Centerm Expansion Project / South Shore Access Project – Draft Construction Environmental Management Plan - Rev 2	5.7 Marine Works (Working In and Around Water) 5.9 Dredging 5.10 Fill Placement 5.11 Water Quality Monitoring	Mitigation measures presented in the original CEMP have been refined as per Section 4.2.2, 4.3.5 and 4.5.3 of this Addendum and will be incorporated into the Design Build Contractors Construction Environmental Management Plan.

7. Summary and Conclusions

This scope change is in-line with balancing commercial, environmental, and public interests.

- The current design of the eastern and western expansion areas is the most cost effective and least intrusive from a navigational and marine habitat perspective to achieve the required expansion of land base. Dredging and infilling are required to support the expansion of CEP.
- Alternatives to dredging have been explored and dredging has been minimized to the extent possible.
- An alternatives assessment was conducted to identify alternative disposal options for all dredged marine sediments to support the DAS application. The assessment concluded that re-use of the top 1 m of surficial sediments as potential fill is the preferred and most beneficial use of the material from a commercial and environmental perspective. Re-use will avoid truck traffic, reduce energy use, reduce construction costs and repurpose a potential waste to a beneficial use.
- Area 1 has been designed and will be constructed to prevent release of sediment to marine environment and to minimize potential for groundwater migration of contaminants into the marine environment. Design mitigations include:
 - Construction of the dyke to full height above the high water mark before deposit of any material into the dyke.
 - Protective filter materials on the inside dyke face to prevent sediment transport through the dyke.
- Only dredgeate that meets CCME IL Soil Guidelines for soil may be re-used as fill in the eastern expansion area.
- The deposited surficial sediments must be placed at least 1 m below the Low Low Water Level and the placed material is at least 25 m (plan distance) from the High High Water Level where marine water meets the outer face of the perimeter dyke.
- Groundwater modelling shows that the far future transport distance for PAHs, even when significantly over estimated, is less than 10 m and likely on the order 1 m. Groundwater monitoring wells will be installed in the east dyke during construction to facilitate a multi-year post-construction groundwater monitoring program

The project effects resulting from this scope change have been mitigated. No residual effects are anticipated.

8. References

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Appendix A Centerm Expansion Project: Dispersal Modelling of Dredging-Derived Fugitive Sediment. Tetra Tech, 2017.



TETRA TECH

OQM | Organizational Quality Management Program

Centerm Expansion Project: Dispersal Modelling of Dredging-Derived Fugitive Sediment



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LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of AECOM Canada and their agents. Tetra Tech Canada Inc. (Tetra Tech) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than AECOM Canada, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this report is subject to the terms and conditions stated in Tetra Tech Canada Inc.'s Services Agreement. Tetra Tech's General Conditions are provided in Appendix A of this report.

1.0 INTRODUCTION

AECOM Canada (AECOM) retained Tetra Tech Canada Inc. (Tetra Tech) to quantify the release and dispersion of fugitive sediments arising from dredging three sites over the course of the Centerm Expansion Project (CEP). CEP consists of an expansion of the existing Centerm Container Terminal located on the southern shoreline of Vancouver Harbour. The project will consist of two fill expansions to the existing terminal footprint: a westward expansion of approximately 4.2 ha and an eastward expansion of approximately 4 ha. Prior to the construction of perimeter rock dykes and infilling, unstable marine sediments must be removed via dredging. Over the course of CEP additional navigational dredging will take place to the south east of the western expansion to provide a turning basin for ships calling at the East Canada Place cruise ship berth.

This study investigates the behaviour of sediment plumes arising from clamshell dredging operations at the West Basin Dredge Zone, East Basin Dredge Zone and the Navigational Dredge Zone. Dredging will take place using either one clamshell dredge working alone or two clamshell dredges working simultaneously. The entirety of the Navigational Dredge Zone and the surficial sediments of both the East and West Dredge Zones will be dredged with an 8 m³ capacity environmental dredge bucket. Following removal of surficial sediments at the East and West Dredge Zones, dredging will continue with a 26 m³ capacity dredge bucket.

The fate and behaviour of the project-derived fugitive sediments has been simulated using an extensively validated three-dimensional numerical model of Vancouver Harbour for a parameterized dredging schedule based on a conceptual plan for dredging, which may be modified by the contractor during the design stage. The predicted concentrations of fugitive sediments reported here reflect unmitigated conditions, with no consideration of mitigation by avoidance of critical tide conditions, or use of silt containment measures.

2.0 METHODS

2.1 Numerical Model

The primary numerical model employed in this study is a 25-m resolution three-dimension numerical model encompassing Burrard Inlet from west of First Narrows to east of Second Narrows. This model is the highest resolution model in a series of nested numerical models extending from the Pacific Ocean to the upper end of Indian Arm:

- Coarse Resolution: 1-km resolution shelf model extending from the mouth of Juan de Fuca Strait to the southern end of Texada Island and the terminus of Indian Arm. The model is driven by tidal constituents and monthly climatology at its boundaries with hourly wind fields and daily river inflows at 13 significant rivers.
- Mid-Resolution: 125-m resolution Burrard Inlet model extending from the entrance to English Bay to the terminus of Indian Arm. The model is driven by water level, temperature and salinity data from the coarse resolution model, with hourly wind fields and daily river inflows.
- High Resolution: 25-m resolution Burrard Inlet model extending from the mid-point of English Bay (near Jericho Beach) to east of Second Narrows (near Berry Point), driven by water level, temperature and salinity data from the mid-resolution model, with hourly wind fields and daily river inflows.

Within the modelling chain, all major rivers in the Salish Sea are included, with Lynne Creek, the Seymour River and the Capilano River feeding directly in the high resolution Burrard Inlet model. Wind fields are interpolated from measured winds at buoys and meteorological stations around coastal British Columbia, with winds for the high resolution Burrard Inlet model based on a dedicated CALMET wind model. Fugitive sediment arising from dredging operations is introduced into the model via a conservatively estimated sediment loss rate specific to clam shell buckets (see Section 3.3). The 25-m resolution model is of sufficient resolution that the near-field (i.e. at a spatial scale smaller than the 25-m grid size) sediment dynamics related to the clam shell dredging operation do not require dedicated simulation to resolve the resulting fugitive sediment dynamics. For each dredging location, the simulation period has been determined based on the dredge prism volume and the estimated production rate of the dredge(s) (see Section 3.3).

The circulation patterns within Vancouver Harbour are tidally dominated, with some baroclinic influence due to seasonal variations in fresh water inflow and heat fluxes at the air/water interface. Streaklines showing the surface currents within western Vancouver Harbour are shown on Figure 1. The most prominent flow features within the harbour are the tidal jets formed at First Narrows and Second Narrows. These jets regularly have peak velocities of over 2.5 m/s, with a maximum velocity nearing 3 m/s possible on occasion. Flood tides result in a strong eastward flowing jet forming at First Narrows that remains coherent well into Vancouver Harbour and establishes a series of eddies and recirculation cells that persist throughout the tidal cycle. The First Narrows jet impinges on the Centerm site resulting in strong eastward flows along the terminal face and generally setting up a clockwise circulation cell between Centerm and Canada Place. On the left panel of Figure 1 two flood-tide circulation cells are shown to the west of Centerm, one clockwise and the other counterclockwise, centered over the Navigation Dredge Zone. Ebb tides result in a strong westward flowing jet forming at Second Narrows (not shown on Figure 1), resulting in complex circulation patterns in the vicinity of Centerm. Ebb tidal currents flowing westward in the middle of Vancouver Harbour result in westward flows along the terminal face and set up a counterclockwise eddy between Centerm and Canada Place (Figure 1). Ebb tides generally result in a counter clockwise eddy forming to the west of the East Basin Dredge Zone. Towards the end of ebb tide (not shown on Figure 1) a counterclockwise eddy can be set up in south western Vancouver Harbour which results in eastward flow in the vicinity of Centerm and, somewhat counterintuitively, in the eastward outflow of water from between Centerm and Canada Place during late stages of ebb tide.

2.2 Fugitive Sediment Plume Tracking

Dredging at the three active dredge sites of the CEP will be undertaken with either one clamshell dredge loading a hopper barge or two clamshell dredges simultaneously loading the same hopper barge. It is assumed that the barge will not overflow supernatant dredge water (AECOM 2016). The three dredge zones are displayed on Figure 2, with the Navigation Dredge Zone in blue, the West Basin Dredge Zone in red and East Basin Dredge Zone in green. Around each Dredge Zone, a dilution zone extending 100 m from the edge of the dredge prism is shown. These dilution zones are used later in this report to determine the dilution of the initial dredgeate source strength at 100 m from the dredging area.

In order to quantify the dispersion of fugitive sediments, the total suspended solids (TSS) content of the fugitive sediment plume is tracked as sediments are released over a simulated dredging program. Two metrics are used to quantify the concentration and extent of the fugitive sediment release:

- **Water Column Maximum TSS Concentration:** At 15 minute intervals, the maximum TSS concentration in the water column (vertical axis) is reported at a 25 m spatial resolution (horizontal axes). This data representation was selected to give a conservative representation of TSS concentration in the water column even though the reported maximum TSS may occur at only one location in the water column.

The goal of reporting the maximum TSS concentration is to characterize any instantaneous, short lived peaks that would not necessarily be captured by the maximum average concentration discussed below

- **Water Column Average TSS Concentration:** At hourly intervals, the maximum vertically averaged TSS concentration in the water column (vertical axis) is reported on a 25 m by 25 m horizontal grid. In this study, an arithmetic mean is uniformly presented.

This metric is most comparable to CCME's "maximum average" guidance on Total Particulate Matter concentration and so is the most relevant measure of TSS in the water column.

As an explanatory example, if the water depth is 40 m, with a near bed (e.g. within 1 m of the seabed) TSS concentration of 100 mg/L with the remainder of the water column having a TSS concentration of 2 mg/L, the maximum TSS concentration would be reported as 100 mg/L, while the water column average (arithmetic mean) TSS would be reported as 4.5 mg/L in accordance with CCME guidance.

These two measures of TSS in the water column are then post-processed to determine:

- **Maximum TSS 100 m from source:** The maximum TSS concentration at a 100 m distance from the active dredge zones, computed from the water column maximum TSS concentration. These 100 m boundaries surrounding each dredge zone are presented on Figure 2.
- **Maximum Average TSS 100 m from source:** The maximum average TSS concentration at a 100 m distance from the active dredge zones, computed from the average water column TSS concentration. These 100 m boundaries surrounding each dredge zone are presented on Figure 2.
- **Probability of Maximum TSS Exceeding 5 mg/L:** The probability of the maximum above-background concentration of TSS exceeding 5 mg/L at any given moment during the dredging operation, defined as the commencement of operations to the moment when the above- background concentration drops below 5 mg/L following cessation of dredging. These probabilities are computed from the water column maximum TSS concentration, which is very conservative compared to CCME guidelines.
- **Probability of Maximum TSS Exceeding 25 mg/L:** The probability of the maximum above-background concentration of TSS exceeding 25 mg/L at any given moment during the dredging operation, defined as the commencement of operations to the moment when the above background concentration drops below 25 mg/L following cessation of dredging. These probabilities are computed from the water column maximum TSS concentration, which is very conservative compared to CCME guidelines.
- **Probability of Maximum TSS Exceeding 10% of Source Strength:** The probability of the maximum above-background concentration of TSS exceeding 10% of the initial source strength, defined as the water column averaged TSS immediately below the dredge vessel.

The shaded probability maps presented in Section 4.0 for the three maximum TSS probability metrics described above do not represent the instantaneous TSS plume footprint or a static plume position. Instead, these probability maps represent the likelihood of a given TSS concentration being exceeded at any one location (a block of water 25 m by 25 m in the horizontal and 1 m thick in the vertical) over the entire dredging operation. This likelihood is derived as a composite of maximum TSS concentrations in space and time over the full dredging period and should not be interpreted as a continuous or prevailing condition.

For example, assume that the probability of the maximum TSS concentration exceeding 5 mg/L is given as 1% at a location in Burrard Inlet. This means that if an observer were to check that specific 25 m by 25 m section of Burrard Inlet at a random time over the dredging operation, there is a 1% probability that they would find a TSS concentration exceeding 5 mg/L at that location in the water column. Over an extended dredge operations (e.g. 16 days), this 1% probability indicates that the TSS at that position (and any others similarly classified by the probability map shading) could exceed 5 mg/L for a total of 3 hours and 50 minutes (i.e. 1% of 16 days).

3.0 SEDIMENT SOURCE TERMS

3.1 Background Suspended Sediment Concentration

The primary source of background suspended sediment concentration in Vancouver Harbour is widely cited as the North Arm of the Fraser River (Davidson 1973, Feely and Lamb 1979, Thomson 1981). A combination of flood currents and the hydraulic head of the river drive a layer of silty fresh water from the North Arm northwards along the edge of Point Grey, then eastward along the southern shore of English Bay. During certain tidal and wind conditions, this near-surface brackish water can be drawn through First Narrows and into Vancouver Harbour; however the intense tidal mixing of the Narrows mixes out much of the initial stratification. There is, however a general lack of information on background suspended sediment concentrations that result from the influx of brackish water into Vancouver Harbour.

The best source of recent information is a report by Tetra Tech in which turbidity on the western side of Canada Place was monitored continuously from December 2004 to July 2007 (Tetra Tech 2007). Turbidity measured in Nephelometric Turbidity Units (NTU) was monitored at depths of 1.0 m and 4.5 m by YSI 6600EDS-M multi parameter sondes. In general, low turbidity values were recorded throughout the year. Average annual turbidity were 1.6 NTU at 1 m depth and 2.0 NTU at 4.5 m depth. Turbidity levels occasionally (approximately once per month) peaked to between 10 NTU and 20 NTU for a period of less than a day, with the maximum recorded turbidity over the monitoring period of approximately 25 NTU. While these spikes have not been attributed to a specific cause, they do show that there is naturally a factor of 10 range in turbidity in Vancouver Harbour. Turbidity values increased slightly during spring and late summer phytoplankton blooms.

3.2 Sediment Characteristics

The in situ sediments from the west and east dredge basins were characterised using data adapted from the Klohn Crippen Berger (KCB 2016a) site investigation report. CPT and borehole samples collected from within the west and east basin footprints yielded eighteen samples at varying depths. To characterize the sediments of the dredge basins into particle size bins that could be applied within the numerical model, the sand, silt and clay fractions of the east and west basins were determined and are presented in Table 3.1. As there is considerable variation in the relative proportions of sand, silt and clay between samples, the sample from each basin with the highest fines content was selected to represent the entire basin, to generate a conservative sediment source term. For the west dredge basin, this is a fines (silt and clay) content of 56.6% and for the east basin this is a fines content of 19.8%. As no data exists for the Navigation Dredge Zone, the values for the West Basin Dredge Zone are applied there.

Table 3.1 Summary of Grain Size Classification

East Basin					
Sediment Class		Maximum	Minimum	Mean	Most Fines ¹
> 2000µm	gravel	83.7%	2.0%	37.2%	2.0%
62µm - 2000µm	sand	88.6%	14.1%	56.4%	78.2%
4µm - 62µm	silt	9.5%	0.7%	4.5%	9.5%
< 4µm	clay	10.3%	0.0%	1.9%	10.3%

West Basin / Navigation					
Sediment Class		Maximum	Minimum	Mean	Most Fines ¹
> 2000µm	gravel	71.5%	0.4%	15.5%	2.4%
62µm - 2000µm	sand	82.8%	27.9%	60.7%	40.9%
4µm - 62µm	silt	42.0%	0.6%	17.8%	35.2%
< 4µm	clay	22.4%	0.0%	6.0%	21.4%

¹ Applied in model

Table 3.2 presents the d_{85} , d_{50} and d_{15} for each of the sand, silt and clay sediment classes determined from the four sediment samples that had a full particle size analysis of fines fraction. As the number of samples is limited and there is little variation in size between them, an averaged value across the four samples was applied at the three dredge basins. In situ sediments have a specific gravity of 2.74 and a solid fraction of 0.485 (KCB 2016b).

For simulating the dispersal of fugitive fine sediment, three sediment classes were defined: sand, silt and clay. The relative proportions of each class were proscribed in the modelling based on the sediment fractions presented in Figure 3.1. The specific grain sizes associated with each sediment class were applied based on the particle size information summarized in Table 3.2.

Table 3.2 Summary of Particle Size Distribution

Clay					
Diameter Percentile	East Basin	West Basin			Mean ¹
	DH15-03	DH15-05, 4.7m	DH15-05, 8.5m	DH15-09	
d_{85} , μm	1.14	1.35	2.66	1.40	1.64
d_{50} , μm	0.67	0.79	1.08	0.82	0.84
d_{15} , μm	0.20	0.24	0.32	0.25	0.25
Silt					
Diameter Percentile	East Basin	West Basin			Mean ¹
	DH15-03	DH15-05, 4.7m	DH15-05, 8.5m	DH15-09	
d_{85} , μm	51.5	47.2	51.9	54.6	51.3
d_{50} , μm	20.9	19.1	25.2	31.4	24.2
d_{15} , μm	6.7	5.5	8.0	7.3	6.9
Sand					
Diameter Percentile	East Basin	West Basin			Mean ¹
	DH15-03	DH15-05, 4.7m	DH15-05, 8.5m	DH15-09	
d_{85} , μm	382	251	288	147	267
d_{50} , μm	194	149	118	109	142
d_{15} , μm	104	94	74	72	86

¹ Applied in model

3.3 Sediment Release

The loss rate of sediments from a clamshell dredge is less well defined than for other dredge types, therefore, the loss rate of dredgeate was calculated based on values cited in literature. The loss rate from clamshell dredging largely depends on the operational conditions of the dredge itself, for example, the descent and ascent rate of the bucket, the style of bucket and the swing rate of the dredge arm. Without more detailed information regarding the characteristics of the clamshell dredge to be employed at the CEP, the loss rate from the clamshell has been conservatively estimated as 2%, based on a range of 1% to 2% found in literature (Collins 1995; Hayes et al. 2007; Bridges et al. 2008). The suspended sediment release cloud is generally considered evenly distributed over the water column, though some studies place the volume distribution of the sediment as 40% near bed 30% mid-depth and 30% surface (Lackey et al. 2012). For simplicity, sediment is assumed to be evenly distributed over the volume of water that the dredge bucket passes through, as presented in Table 3.3 below.

An important consideration in clamshell dredging is that the clamshell bucket will not be completely filled with dredgeate. Each seabed material and bucket style has an associated efficiency, with a certain proportion of the bucket filled with dredgeate and the rest, with seawater. The fill efficiency of common clamshell buckets is estimated as 83% for fines, 80% for loose sand and 77% for compact sand, meaning that, for a given bucket volume, approximately 80% of the bucket contains seabed material (including voids) and approximately 20% is seawater (Hayes et al. 2007). Based on local experience, methods and equipment, the 8 m³ environmental bucket has an anticipated fill factor of 65% and the 26m³ high capacity bucket has an anticipated fill factor of 60% (AECOM 2017).

In-situ seabed materials have an average solids fraction of 0.485. Therefore each clamshell scoop will transport, for the 8 m³ and 26 m³ buckets respectively, 2.52 m³ and 7.57 m³ of solids. The dredge buckets are assumed to lose 2% of their content before delivery to the barge, resulting in the fugitive sediment release of 0.050 m³ and 0.151 m³ of sediment solids per dredge cycle for the 8 m³ and 26 m³ buckets respectively. For each dredge location, the resulting release of each sediment fraction is summarized in Table 3.3.

The fugitive release of sediment during each dredge cycle results in an initial source TSS concentration ranging from 1,989 mg/L to 463 mg/L, as summarized in Table 3.3. The initial dilution volume for the volumetric sediment input is assumed to be equal to the cylindrical volume of water the dredge bucket passes through as it is drawn through the water column. For the 8 m³ dredge bucket, the diameter of this cylinder has been based on the dimensions of a Ransome YC7000 dredge bucket, while the 26 m³ dredge bucket dimensions have been interpreted from a variety of 2 and 4 rope clamshell dredge buckets. An additional 0.5 m radial allowance is assumed for the lateral release of slurry from the bucket. The initial source TSS concentration varies from location to location with the depth of water column through which the dredge bucket is pulled. The essential logic underlying this is that any dredgeate that could be mobilized by travel through the water column (i.e. isn't sheltered by larger grains) will be flushed from the bucket relatively quickly compared to the travel time of the bucket from the seabed to the surface. Therefore, for each dredge cycle, the same volume of dredgeate is released, with the initial concentration consequently depending on the water depth via the dilution volume. While it is likely that the blow-off volume has a relationship with the depth of water the bucket is pulled through, in the absence of appropriate literature or data to support a depth dependant blow-off rate, the conservative assumption of a depth-independent blow off rate has been made.

Dredging operations are expected to proceed 24 hours per day with 2 hours per day allocated to maintenance downtime and 10 hours per day spent re-positioning the dredge, resulting in 12 hours per day of effective working time. Dredges operating with an 8 m³ environmental bucket are estimated to have a 120 second cycle time (i.e. the time between successive bucket grabs), while dredges operating with a 26m³ high capacity bucket have an estimated 150 second cycle time. Based on an assumed schedule and efficiency, one clamshell dredge with one attending hopper barge has a 1,900 m³/day production volume (seabed dredged per day) if an 8m³ dredge bucket is used, compared to a production volume of 4,500m³/day if a 26 m³ dredge bucket is employed. Similarly, two clamshell dredges with one attending hopper barge each have a combined production rate of 3,800 m³/day of seabed with 8m³ dredge buckets, or 9,000 m³/day with 26 m³ dredge buckets. Based on these production rates, the total dredge operation duration is estimated in Table 3.4.

To derive a worst-case sediment TSS concentration, numerical model simulations have been conducted with continuous dredge operation until the completion, such that the total volume of fugitive material is released in as temporally-compressed a manner as possible. The simulations were run until the total volume of fugitive material given in Table 3.4 has been released.

Table 3.3 Summary of Dredge Operation

	Parameter	Navigation	West Basin	East Basin	Unit	Notes
Sediment	Void Ratio	1.0625	1.0625	1.0625	-	KCB Report, 2016
	Porosity	0.515	0.515	0.515	-	$\eta = e/(1+e)$
	Solids Fraction	0.485	0.485	0.485	-	SF = 1 - n
	Specific Gravity	2.74	2.74	2.74	-	KCB Report, 2016
	Sand Fraction	0.434	0.434	0.576	-	KCB Report, 2016
	Silt Fraction	0.352	0.352	0.301	-	KCB Report, 2016
	Clay Fraction	0.214	0.214	0.103	-	KCB Report, 2016
Clam Shell Dredge	Cycle Time	90	90	90	s	Time between bottom grabs
	Bucket Size	8	26	26	m ³	
	Efficiency	0.65	0.60	0.60	-	Factor for partially filled bucket
	Effective Volume	5.20	15.60	15.60	m ³ /cycle	Dredgeate per cycle, total
	Solids Volume	2.52	7.57	7.57	m ³ /cycle	Dredgeate per cycle, solids
	Loss Rate	0.02	0.02	0.02	-	Portion of dredgeate lost per cycle
	Fugitive Solids	0.05	0.151	0.151	m ³ /cycle	Solids volume lost per cycle
	Fugitive Sand	0.022	0.066	0.087	m ³ /cycle	Sand volume lost per cycle
	Fugitive Silt	0.018	0.053	0.046	m ³ /cycle	Silt volume lost per cycle
	Fugitive Clay	0.011	0.032	0.016	m ³ /cycle	Clay volume lost per cycle
Source Strength	Zone Radius	2.3	3.1		m	Based on dredge bucket size
	Depth	Min: 9.0 m Max: 11.5 m	Min: 6.9 m Max: 29.6 m		m	Based on depth in dredge cut
	Volume	Min: 150 m ³ Max: 191m ³	Min: 208 m ³ Max: 894 m ³		m ³	Volume dredge passes through
	TSS Conc.	913 / 717	1,989 / 463	1,989 / 463	mg/L	Max/Min TSS concentration
	Sand Conc.	402 / 316	869 / 202	1,146 / 267	mg/L	Max/Min sand concentration
	Silt Conc.	329 / 258	698 / 162	619 / 144	mg/L	Max/Min silt concentration
	Clay Conc.	201 / 158	422 / 98	224 / 52	mg/L	Max/Min clay concentration

Table 3.4 Summary of Dredge Volume, Release Volume and Dredge Operation Duration

	Dredge Prism	8 m ³ Dredge ¹	26 m ³ Dredge ²	Total Solids	Fugitive Release	Duration 1 Dredge ³	Duration 2 Dredge ³
	m ³	m ³	m ³	m ³	m ³	days	days
Navigation	7,000	7,000	0	3,786	76	4	2
West Basin	235,000	33,300	201,700	113,975	2,280	63	31
East Basin	155,000	15,000	124,700	75,175	1,504	36	16
Total	397,000	55,300	335,400	192,936	3,860	103	49

¹ Surficial sediments² Deep sediments.³ Based on nominal 4,500 m³/day production volume for a 26 m³ dredge bucket, 1,900 m³/day production for a 8 m³ dredge bucket (AECOM 2017).

4.0 RESULTS

4.1 Navigation Dredge Zone

The Navigation Dredge Zone consists of an approximately 7,000 m³ dredge prism to be dredged by an 8 m³ clamshell dredge operating for two (two dredges) or four (one dredge) days including down time and repositioning. Sediments released by an individual clamshell dredge operating in the Navigational Dredge Zone result in a source TSS concentration ranging from approximately 700 mg/L to 900 mg/L depending on the specific location in the dredge cut (Section 3.3). The Navigation Dredge Zone is in a relatively sheltered location, being located in the embayment formed by Centerm and Canada Place. Therefore, the TSS plume originating from the Navigation Dredge Zone, while generally well flushed, has the tendency to build up a background concentration of TSS adjacent to Canada Place over the course of the dredging operation.

Figure 3 presents the fugitive sediment concentration at a 100 m distance from the active dredge zone for 1 and 2 active dredge scenarios. Within 6 hours of the start of dredging the maximum and maximum average TSS concentrations crossing the 100 m boundary from the dredge area exceed 5 mg/L; however, taken along the entire 100 m boundary, 5mg/L represents a 94th and 89th percentile values for one dredge and two dredge scenarios, respectively. The embayment between Canada Place and the SeaBus terminal does not have strong tidal currents and, as a result, TSS concentrations in this area remain elevated above 5 mg/L for 72 hours (one dredge) or 96 hours (two dredges) following the end of dredging operations. During this period, which can be seen on the top and second panels of Figure 3, the isolated pocket of fugitive sediment concentration is attenuated through the processes of bottom deposition and dilution in the receiving environment. Table 4.1 presents the maximum, minimum and percentile concentrations of TSS along the 100 m boundary from the active dredge zone.

Table 4.1 Maximum Average and Maximum Concentration 100 m from Source

Percentile Along 100m Boundary	Maximum Average Concentration ¹		Maximum Concentration ²		Unit
	1 Dredge	2 Dredges	1 Dredge	2 Dredges	
Maximum	45.13	89.23	68.24	148.47	mg/L
99³	15.42	30.18	29.47	58.84	mg/L
95	6.32	13.0	12.56	25.55	mg/L
90	2.58	5.74	7.92	17.31	mg/L
50	0.06	0.18	0.68	1.71	mg/L
10	0.00	0.01	0.07	0.26	mg/L
Minimum	0.00	0.00	0.00	0.00	mg/L

¹ Percentile, maximum and minimum values are calculated from the water column average TSS concentration at 1 hour intervals.

² Percentile, maximum and minimum values are calculated from the water column maximum TSS concentration at 15 minute intervals.

Therefore, the maximum value occurs for less than 15 minutes out of 14 days at a 25 m by 25 m by 1 m parcel of water in Vancouver Harbour.

³ The 99th percentile concentrations is the TSS concentration at which 99% of all other possible TSS concentrations occurring in time and space will be lower than the 99th percentile. Any concentrations greater than the 99th percentile will occur for only 30 minutes out of a 2 day dredging period.

Figure 4 presents the probability that the maximum instantaneous water column concentration of TSS will be greater than 10% of the source concentration. In all cases, there is less than 1% probability of exceeding 10% of the initial source concentration (hence the appearance of an apparent empty figure due to use of white shading for <1% probability). This is partly due to the modest dredge size and partly due to the dredging period being defined from the commencement of dredging to the moment when the above-background concentration drops below 5 mg/L. The 5 mg/L above background cut-off for the dredge period extends the dredging window up to 96 hours beyond

the end of dredging due of the TSS pocket between the SeaBus terminal and Canada Place and, since there is no active dredging while this pocket attenuates, lowers the probability of the high concentration source TSS occurring over the period of elevated above background TSS concentration.

Figure 5 presents the probability that the above-background maximum instantaneous water column concentration of TSS will exceed 5 mg/L over the duration of the dredging operation. From Figure 5, it can be seen that in the vicinity of the Navigation Dredge Zone the probability of exceeding a TSS concentration of 5 mg/L above background is 30% to 40% for both one and two dredge scenarios, with this probability tapering to 1% at 1,050 m from the source.

Figure 6 presents the probability that the maximum instantaneous water column concentration of TSS will exceed 25 mg/L over the duration of the dredging operation. The footprint of very high probability of this occurrence is larger for the 2 dredge scenario (bottom panel) than the 1 dredge scenario (top panel), however in both cases there is an approximately 30% probability of exceeding 25 mg/L in the Navigation Dredge Zone itself and a short distance westward towards Canada Place, with the probability rapidly tapering outside of this area. Outside of a 625 m radius, the probability is below 1%. Table 4.2 summarizes the decay of TSS with distance for all Navigation Dredge Zone scenarios. For example, Table 4.2 illustrates that with a single dredge sediment concentrations will exceed 5 mg/L less than 20% of the time 225 m from the source but with two dredges the distance for source required to exceed 5 mg/L less than 20% of the time is 250 m.

Table 4.2 Distance from Source to Achieve Maximum TSS of 5 mg/L and 25 mg/L

Probability of Exceedance ¹	1 Dredge		2 Dredges		Unit
	5 mg/L	25 mg/L	5 mg/L	25 mg/L	
90%	Within Dredge Zone	Within Dredge Zone	Within Dredge Zone	Within Dredge Zone	m
80%					m
70%					m
60%					m
50%					m
40%					m
30%	125		125	125	m
20%	225	125	250	175	m
10%	300	150	525	250	m
1%	1,000	325	1,050	625	m

¹ The probability that the instantaneous water-column maximum TSS will exceed a given value over the dredging period. For example, a 1% probability of exceeding 5 mg/L indicates that, over a 2 day dredging period, the maximum TSS in the water column may exceed 5 mg/L for a total of 30 minutes.

4.2 West Basin Dredge Zone

The West Basin Dredge Zone consists of an approximately 235,000 m³ dredge prism. Surficial sediments will be dredged using an 8 m³ clamshell dredge, with the vast majority of dredging to be undertaken with a 26 m³ capacity clamshell dredge. The duration of dredging operations at the West Basin is anticipated to be 31 (two dredges) to 63 (one dredge) days including down time and repositioning. Sediments released by an individual clamshell dredge operating at the West Basin Dredge Zone result in a source TSS concentration ranging from approximately 500 mg/L to 2,000 mg/L depending on the specific location within the dredge cut (Section 3.3). Compared to both the Navigation and East Basin Dredge Zones, the West Basin Dredge Zone is relatively deep, exposed and well flushed. This results in two distinct features of the TSS plume at this location: the initial source concentration is

rapidly diluted; and, the strong ambient currents widely disperse the plume. In particular, during a strong ebb tide fugitive project-derived sediment can very infrequently be entrained into the First Narrows tidal jet. Over a 31 day simulation period (i.e. 62 ebb tides), project derived TSS was transported west of Brockton Point one time at a maximum concentration exceeding 5 mg/L and this was only possible with 2 active 26 m³ capacity dredges in operation.

Figure 7 presents the fugitive sediment concentration at a 100 m distance from the active dredge zone for 1 and 2 active dredge scenarios. Owing to strong tidal action at the West Basin Dredge Zone the concentration crossing the 100 m boundary rises almost immediately following the commencement of dredging and drops to baseline levels within one tidal cycle of the end of dredging. Figure 7 and Table 4.3 present the source attenuation at the West basin Dredge Zone. Almost immediately following the start of dredging, the maximum and maximum average TSS concentrations crossing the 100 m boundary from the dredge area exceeds 5 mg/L; however, taken along the entire 100 m boundary, 5 mg/L represents 81st and 62nd percentile values of maximum average TSS for one dredge and two dredge scenarios, respectively.

Table 4.3 Maximum Average and Maximum Concentration 100 m from Source

Percentile Along 100m Boundary	Maximum Average Concentration ¹		Maximum Concentration ²		Unit
	1 Dredge	2 Dredges	1 Dredge	2 Dredges	
Maximum	60.90	139.40	75.65	201.38	mg/L
99 ³	19.72	40.22	27.05	59.47	mg/L
95	11.04	23.36	16.06	34.27	mg/L
90	7.80	16.54	11.48	24.64	mg/L
50	1.70	3.41	2.37	4.73	mg/L
10	0.16	0.34	0.20	0.42	mg/L
Minimum	0.00	0.00	0.00	0.00	mg/L

¹ Percentile, maximum and minimum values are calculated from the water column average TSS concentration at 1 hour intervals.

² Percentile, maximum and minimum values are calculated from the water column maximum TSS concentration at 15 minute intervals.
Therefore, the maximum value occurs for less than 15 minutes out of 31 days at a 25 m by 25 m by 1 m parcel of water in Vancouver Harbour.

³The 99th percentile concentrations is the TSS concentration at which 99% of all other possible TSS concentrations occurring in time and space will be lower than the 99th percentile. Any concentrations greater than the 99th percentile will occur for only 7 hours and 30 minutes out of a 31 day dredging period.

On Figure 8 it can be seen that the probability of the maximum instantaneous water column concentration of TSS being greater than 10% of the source concentration is low and confined to the immediate vicinity of the dredge zone. In all cases, the initial source concentration is rapidly diluted by the tidal action in Burrard Inlet.

The probability that the above-background maximum instantaneous water column concentration of TSS will exceed 5 mg/L over the duration of the dredging operation is presented on Figure 9. In this figure the model indicates that the highest probability of the maximum TSS concentration in the water column exceeding 5 mg/L is generally concentrated in the vicinity of the active dredge zones. Also in Figure 9 (lower panel), the model suggests a 3,075 m one-time excursion (during a single ebb tide over 31 days of dredging) of the TSS plume in which the maximum concentration exceeds 5 mg/L above background. This is an extremely rare and short-lived event arising from particularly unfavorable dredge positioning and ebb tidal conditions: it has a 1% occurrence probability, equivalent to a single ebb tide. It should also be noted that the aim of this study is not to forecast a specific dredging operation but to estimate all possible iterations of TSS plume positions, however unlikely or unfavorable. As measure of more typical TSS plume behaviour, the fugitive TSS plume arising from dredging does not exceed 5 mg/L beyond 125 m (one dredge) or 275 m (two dredges) from the West Basin Dredge Zone more than 50% of the time.

The probability that the instantaneous TSS concentration will exceed 25 mg/L above background during the dredging period is much more modest and occurs over a small area (Figure 10). With one active dredge this area is limited to within 275 m of the dredge zone, and with two active dredges, the probability of exceeding a 25 mg/L above background TSS concentration threshold drops to 1% within 750 m of the source. By comparing Figures 9 and 10, it can be seen that the vast majority of the probability footprint displayed in Figure 9 is no longer present in Figure 10. Outside the 1% probability contour shown in Figure 10, there is no significant probability that the maximum water column concentration of TSS will exceed 25 mg/L at any location in Burrard Inlet. Therefore, while the 5 mg/L threshold might theoretically be exceeded over an occasionally wide area, the maximum water column TSS remains well below 25 mg/L and, likely, only slightly exceeds 5 mg/L.

Table 4.4 summarizes the decay of TSS with distance for all West Basin Dredge Zone scenarios. For example, Table 4.4 illustrates that with a single dredge sediment concentrations will exceed 5 mg/L less than 20% of the time 600 m from the source but with two dredges the distance for source required to exceed 5 mg/L less than 20% of the time is 675 m.

Table 4.4 Distance from Source to Achieve Maximum TSS of 5 mg/L and 25 mg/L

Probability of Exceedance ¹	1 Dredge		2 Dredges		Unit
	5 mg/L	25 mg/L	5 mg/L	25 mg/L	
90%	Within Dredge Zone	Within Dredge Zone	Within Dredge Zone	Within Dredge Zone	m
80%					m
70%					m
60%					m
50%	125		275		m
40%	150		450		m
30%	225		525		m
20%	600		675	275	m
10%	800	125	1,150	375	m
1%	1,425	275	3,075	750	m

¹ The probability that the instantaneous water-column maximum TSS will exceed a given value over the dredging period. For example, a 1% probability of exceeding 5 mg/L indicates that, over a 31 day dredging period, the maximum TSS in the water column may exceed 5 mg/L for a total of 7 hours and 30 minutes.

4.3 East Basin Dredge Zone

The East Basin Dredge Zone consists of an approximately 155,000 m³ dredge prism. Surficial sediments will be dredged using an 8 m³ clamshell dredge, with the vast majority of dredging to be undertaken with a 26 m³ capacity clamshell dredge. The duration of dredging operations at the East Basin is anticipated to be 16 (two dredges) to 36 (one dredge) days including down time and repositioning. Sediments released by an individual clamshell dredge operating at the East Basin Dredge Zone result in a source TSS concentration ranging from approximately 500 mg/L to 2,000 mg/L depending on the specific location within the dredge cut (Section 3.3). Dredging operations at the East Basin Dredge Zone are assumed to begin at the shore, near the Southern Railway Pier, and progress northwards along the eastern face of Ballantyne Pier. At the south end of the embayment formed by the Southern Railway and Ballantyne Piers there is relatively poor flushing and there is potential for the build-up of TSS. Towards the north end of Ballantyne Pier, tidal currents increase in magnitude and result in both better dilution of the fugitive sediment plume and a wider dispersal of the sediments.

Figure 11 presents the fugitive sediment concentration at a 100 m distance from the active dredge zone for 1 and 2 active dredge scenarios. The initial period (first 7 days) of elevated TSS concentration is due to the aforementioned poor flushing capacity of the embayment between Southern Railway and Ballantyne Piers. TSS builds up in the embayment and is occasionally flushed by tidal action. As the dredging operation progresses northwards, mixing improves and the concentration of TSS drops (attenuates) significantly before crossing the 100 m boundary. As discussed in Section 3.2, the source concentration is tied to the water depth in which the dredge is operating, which is why the source concentration drops as the dredge moves northwards into deeper water. This also contributes to the gradual decline in TSS concentration at the 100 m boundary from the dredge area.

Exceedance values at a 100 m boundary from the East Basin Dredge Zone are presented in Table 4.5. Compared to both the Navigation and West Basin Dredge Zones, high-percentile maximum average TSS concentrations observed at the East Basin 100m boundary are elevated due to the buildup of TSS between the Southern Railway and Ballantyne Piers. Comparing the median and low-percentile concentrations, the East Basin Dredge Zone has generally lower maximum average TSS concentrations at the 100 m boundary, due to the high flushing in the northern dredge area. Taken along the entire 100 m boundary at the East Basin Dredge Zone, 5 mg/L represents 95th and 85th percentile values of maximum average TSS concentration for one dredge and two dredge scenarios, respectively.

Table 4.5 Maximum Average and Maximum Concentration 100 m from Source

Percentile Along 100m Boundary	Maximum Average Concentration ¹		Maximum Concentration ²		Unit
	1 Dredge	2 Dredges	1 Dredge	2 Dredges	
Maximum	83.44	148.03	85.31	156.16	mg/L
99 ³	17.18	30.06	19.06	33.53	mg/L
95	5.21	13.36	7.82	15.30	mg/L
90	1.91	8.31	5.06	10.28	mg/L
50	0.12	0.44	0.38	0.80	mg/L
10	0.02	0.13	0.07	0.15	mg/L
Minimum	0.00	0.00	0.00	0.00	mg/L

¹ Percentile, maximum and minimum values are calculated from the water column average TSS concentration at 1 hour intervals.

² Percentile, maximum and minimum values are calculated from the water column maximum TSS concentration at 15 minute intervals.

Therefore, the maximum value occurs for less than 15 minutes out of 16 days at a 25 m by 25 m by 1 m parcel of water in Vancouver Harbour.

³ The 99th percentile concentrations is the TSS concentration at which 99% of all other possible TSS concentrations occurring in time and space will be lower than the 99th percentile. Any concentrations greater than the 99th percentile will occur for only 3 hours and 50 minutes out of a 16 day dredging period.

On Figure 12 it can be seen that the probability of the maximum instantaneous water column concentration of TSS being greater than 10% of the source concentration is very low north of the northern extent of Ballantyne Pier (<10%), but increases towards the southern end of the dredge zone (up to 70%).

The probability that the instantaneous TSS concentration will exceed 5 mg/L over the duration of the dredging operation at the East Basin Dredge Zone (Figure 13) is similar in magnitude but generally smaller in extent compared to the probabilities determined for the West Basin Dredge Zone. The probability of exceeding 5 mg/L in the embayment between Southern Railway and Ballantyne Piers is approximately 70% due to the buildup up TSS during the dredging operation. As the northern extent of the East Basin Dredge Zone is dredged, the fugitive sediment plume is more widely dispersed by tidal action in Burrard Inlet, with a single instance of the TSS concentration exceeding 5 mg/L over background 2,075 m from the source with two operational dredges. This rare and shore-lived event has a 1% probability of occurrence (i.e. approximately 4 hours) and is caused by a concurrence of strong tides and unfavorable dredge positions near the northern edge of the East Basin Dredge

Zone. As measure of more typical TSS plume behaviour, the fugitive TSS plume arising from dredging does not exceed 5 mg/L outside of the East Basin Dredge Zone footprint more than 50% of the time. In all cases, the fugitive TSS plume remains confined to the southern shoreline of Burrard Inlet with the most likely locations for the maximum TSS concentration to exceed 5 mg/L being in the immediate vicinity of Centerm.

The probability of the instantaneous above-background TSS concentration exceeding 25 mg/L over the course of the dredging operation is relatively low (<20%) and is generally confined to a relatively small area in the immediate vicinity of the East Basin Dredge Zone, as shown on Figure 14. Beyond 550 m from the East Basin Dredge Zone there is a less than 1% probability of the instantaneous TSS concentration exceeding 25 mg/L. Similar to at the West Basin Dredge zone, when Figures 13 and 14 are compared, it can be seen that the vast majority of the probability footprint displayed in Figure 13 is no longer present in Figure 14. Outside the 1% probability contour shown in Figure 14, there is no significant probability that the maximum water column concentration of TSS will exceed 25 mg/L at any location in Burrard Inlet. Therefore, while the 5 mg/L threshold might theoretically be exceeded over an occasionally wide area, the maximum water column TSS remains well below 25 mg/L and, likely, only slightly exceeds 5 mg/L.

Table 4.6 summarizes the decay of TSS with distance for all East Basin Dredge Zone scenarios. For example, Table 4.6 illustrates that with a single dredge sediment concentrations will exceed 5 mg/L less than 20% of the time 425 m from the source but with two dredges the distance for source required to exceed 5 mg/L less than 20% of the time is 500 m.

Table 4.6 Distance from Source to Achieve Maximum TSS of 5 mg/L and 25 mg/L

Probability of Exceedance ¹	1 Dredge		2 Dredges		Unit
	5 mg/L	25 mg/L	5 mg/L	25 mg/L	
90%	Within Dredge Zone	Within Dredge Zone	Within Dredge Zone	Within Dredge Zone	m
80%					m
70%					m
60%					m
50%					m
40%		150		350	m
30%		300		475	m
20%		425	150	500	m
10%		675	275	875	m
1%		1,575	375	2,075	m

¹ The probability that the instantaneous water-column maximum TSS will exceed a given value over the dredging period. For example, a 1% probability of exceeding 5 mg/L indicates that, over a 16 day dredging period, the maximum TSS in the water column may exceed 5 mg/L for a total of 3 hours and 50 minutes.

5.0 CONCLUSION

Based on the results of this modelling study:

Navigation Dredge Zone

- **One Dredge:** modeling results of the Navigation Dredge Zone dredging process suggest that the maximum project-derived TSS concentrations above background drop below 5 mg/L 1,000 m from source 99% of the time and drop below 5 mg/L within the dredge zone 50% of the time.
- **One Dredge:** modeling results of the Navigation Dredge Zone dredging process suggest that the maximum project-derived TSS concentrations 5 mg/L above background are attenuated 72 hrs following cessation of dredging.
- **Two Dredges:** modeling results of the Navigation Dredge Zone dredging process suggest that the maximum project-derived TSS concentrations above background drop below 5 mg/L 1,025 m from source 99% of the time and drop below 5 mg/L within the dredge zone 50% of the time.
- **Two Dredges:** modeling results of the Navigation Dredge Zone dredging process suggest that the maximum project-derived TSS concentrations 5 mg/L above background are attenuated 96 hrs following cessation of dredging.

West Basin Dredge Zone

- **One Dredge:** modeling results of the West Basin Dredge Zone dredging process suggest that the maximum project-derived TSS concentrations above background drop below 5 mg/L 1,425 m from source 99% of the time and drop below 5 mg/L 125 m from source 50% of the time.
- **One Dredge:** modeling results of the West Basin Dredge Zone dredging process suggest that the maximum project-derived TSS concentrations 5 mg/L above background are attenuated 12 hrs following cessation of dredging.
- **Two Dredges:** modeling results of the West Basin Dredge Zone dredging process suggest that the maximum project-derived TSS concentrations above background drop below 5mg 3,075 m from source 99% of the time and drop below 5 mg/L 275 m from source 50% of the time.
- **Two Dredges:** modeling results of the West Basin Dredge Zone dredging process suggest that the maximum project-derived TSS concentrations 5 mg/L above background are attenuated 12 hrs following cessation of dredging.

East Basin Dredge Zone

- **One Dredge:** modeling results of the East Basin Dredge Zone dredging process suggest that the maximum project-derived TSS concentrations above background drop below 5mg/L 1,575 m from source 99% of the time and drop below 5 mg/L within the dredge zone 50% of the time.
- **One Dredge:** modeling results of the East Basin Dredge Zone dredging process suggest that the maximum project-derived TSS concentrations 5 mg/L above background are attenuated 12 hrs following cessation of dredging.
- **Two Dredges:** modeling results of the East Basin Dredge Zone dredging process suggest that the maximum project-derived TSS concentrations above background drop below 5 mg/L 2,075 m from source 99% of the time and drop below 5 mg/L 200 m from source 50% of the time.
- **Two Dredges:** modeling results of the East Basin Dredge Zone dredging process suggest that the maximum project-derived TSS concentrations 5 mg/L above background are attenuated 12 hrs following cessation of dredging.

Following from the above analysis, the following locations for turbidity monitoring are recommended during dredging activities:

- **Navigation Dredge Zone:** While dredging is taking place, it is recommended to monitor turbidity in the vicinity of the active dredge(s), in the basin between the Navigation Terminal and Canada Place and along the eastern edge of Canada Place.

- **West Basin Dredge Zone:** It is recommended to monitor turbidity on the down-drift side of the active dredge(s) while dredging is taking place.
- **East Basin Dredge Zone:** While dredging is underway, it is recommended to monitor turbidity in the vicinity of the active dredge(s), in the basin between the Ballantyne and Southern Railway Piers and to periodically check the turbidity levels in the basins between Ballantyne Pier and Vanterm.

6.0 CLOSURE

We trust this report meets your present requirements. If you have any questions or comments, please contact the undersigned.

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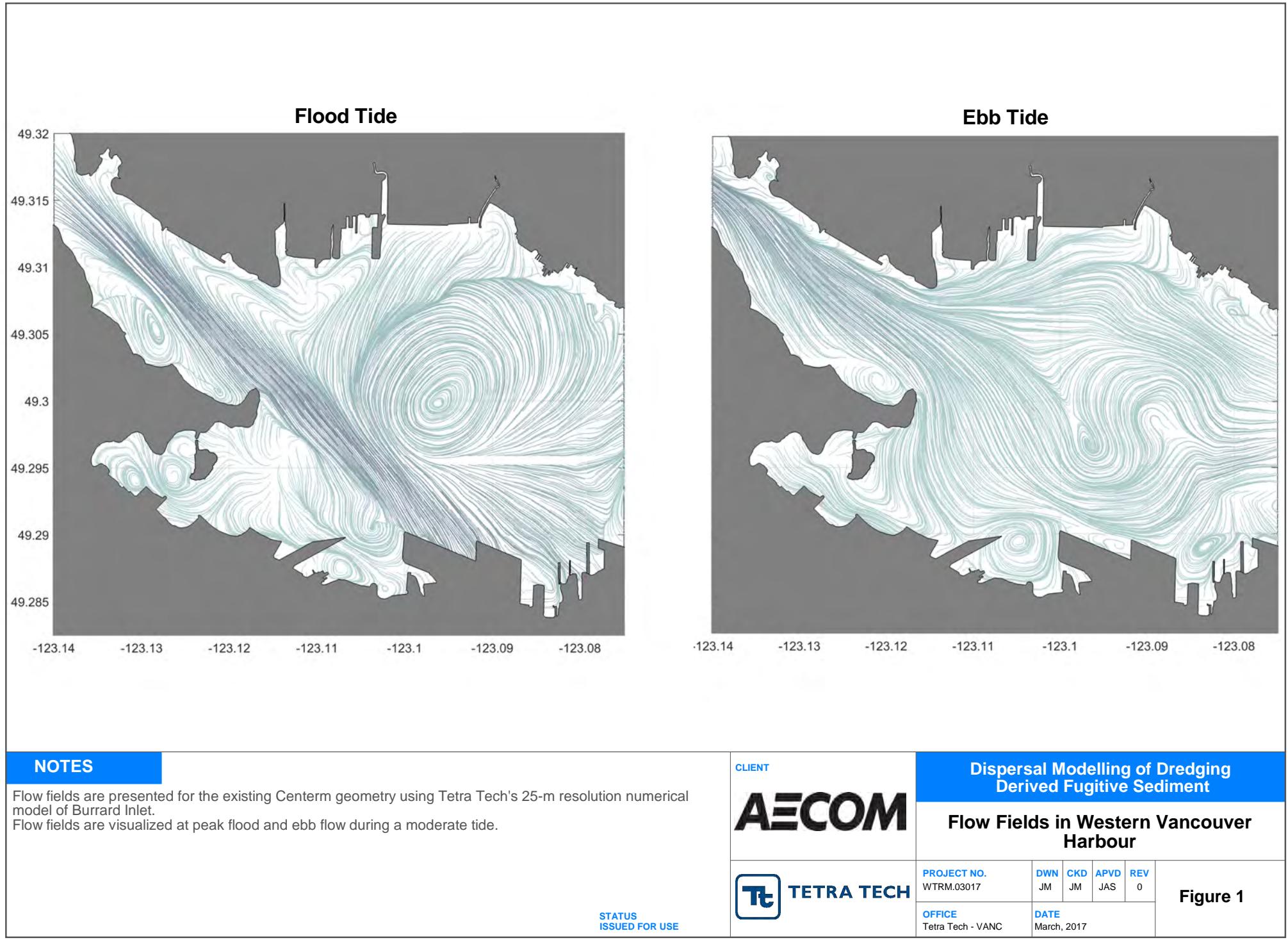
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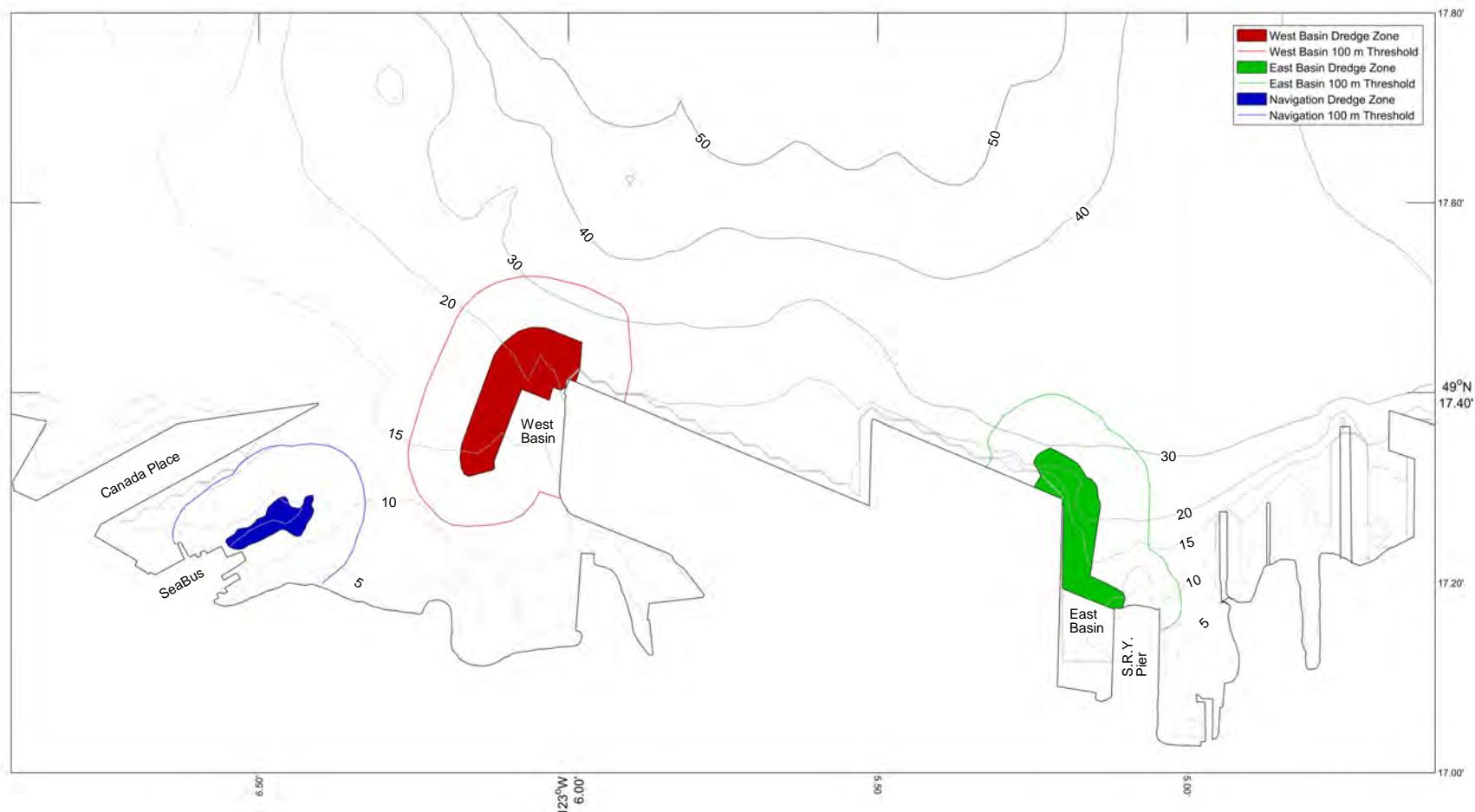
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FIGURES

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NOTES

Dredge prism outlines and 100 m radius boundaries are plotted in the above figure.

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Dispersal Modelling of Dredging
Derived Fugitive Sediment

CEP Dredge Zone Overview

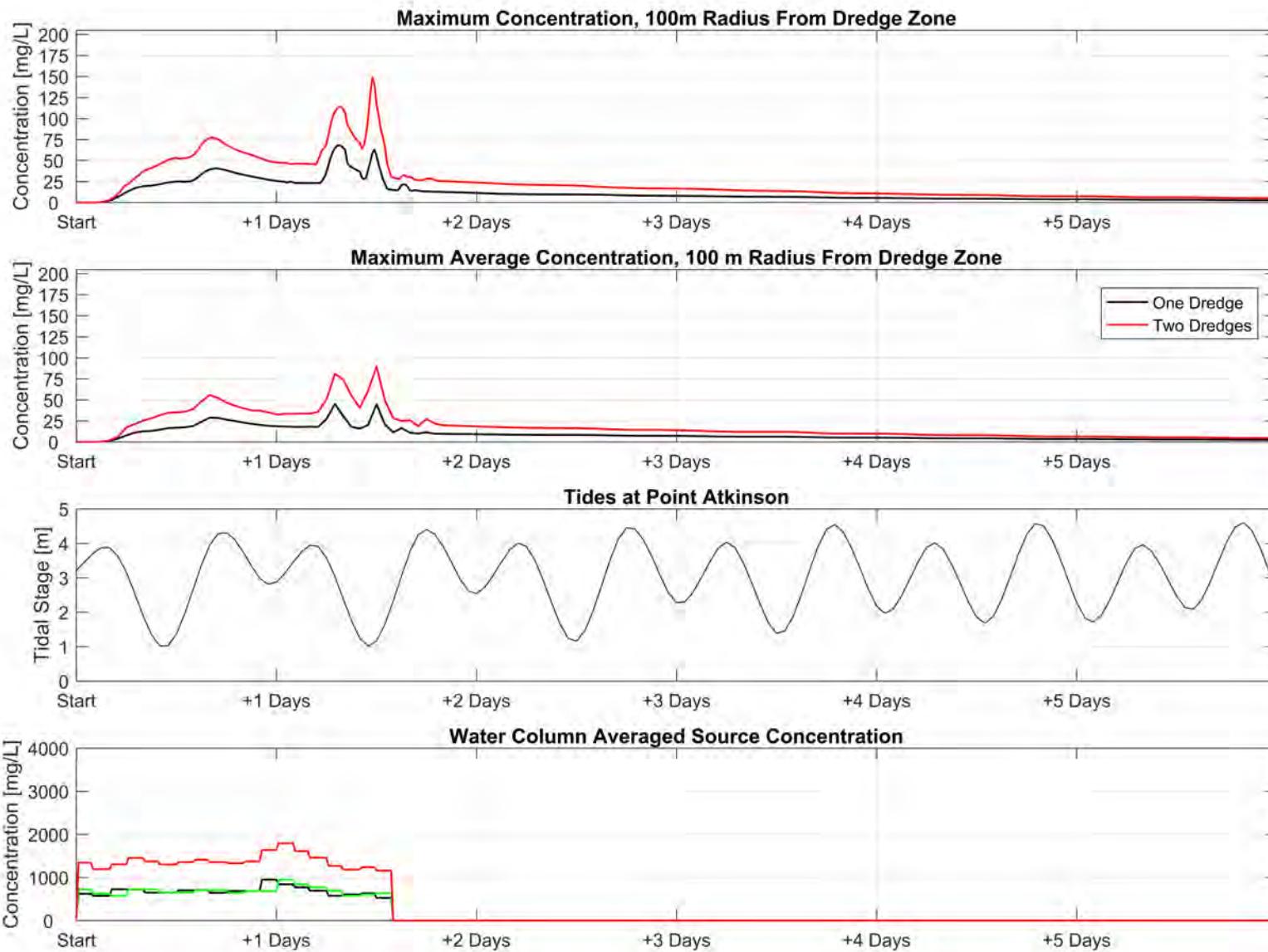


TETRA TECH

STATUS
ISSUED FOR USE

PROJECT NO.	DWN	CKD	APVD	REV
WTRM:03017	JM	JM	JAS	0
OFFICE				
Tetra Tech - VANC				
DATE				
March, 2017				

Figure 2



NOTES

- 1) The concentration axis scale for the Source Concentration plot differs from that of the 100 m Concentration plots.
- 2) Source concentration varies in time due to depth variations between dredge locations and tidal action.
- 3) Maximum concentrations are the maximum of the maximum concentration over the water column (seabed to surface) along the 100 m boundary.
- 4) Maximum average concentrations are the maximum of the average concentration over the water column (seabed to surface) along the 100 m boundary.

STATUS
ISSUED FOR USE

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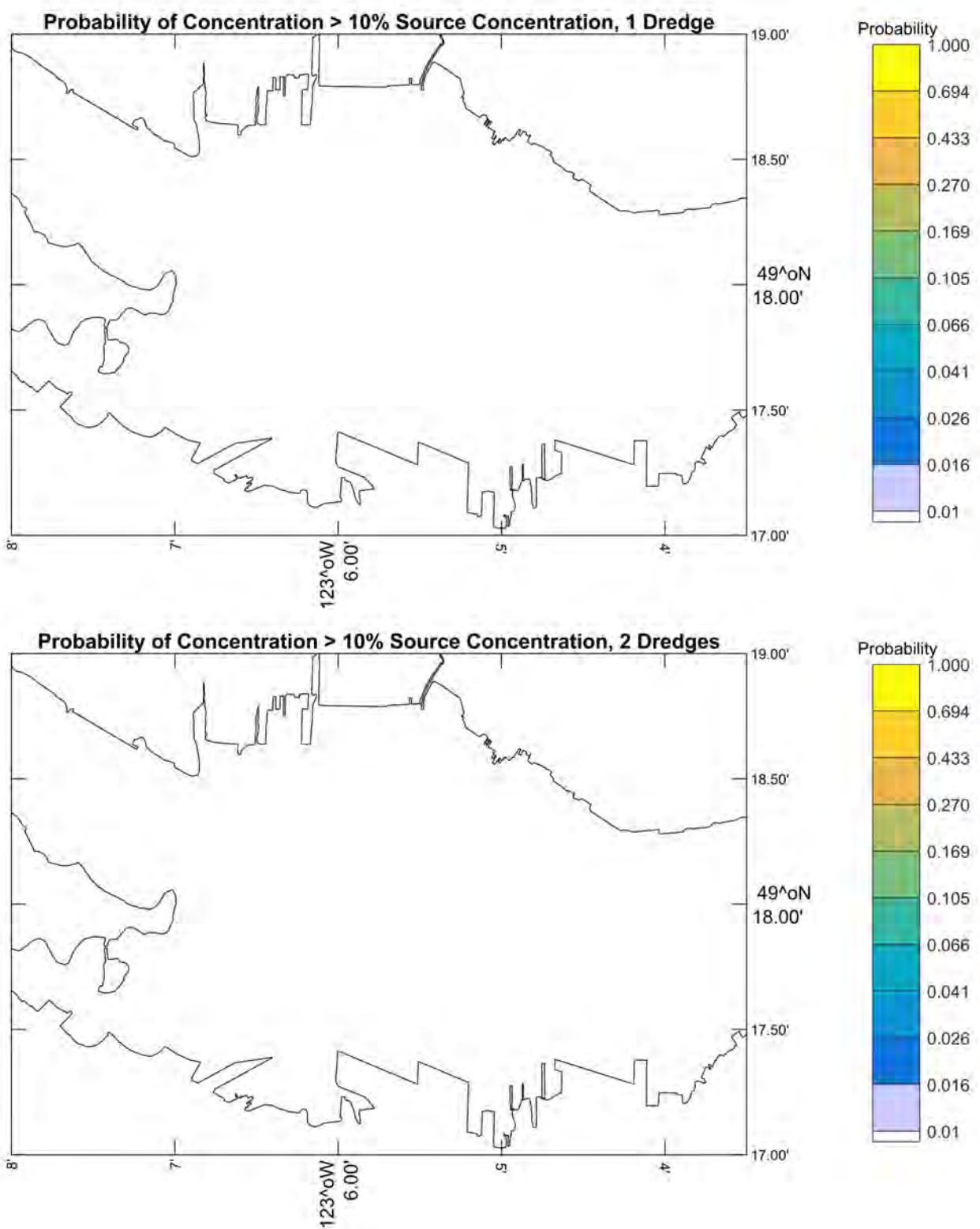
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**Dispersal Modelling of Dredging
Derived Fugitive Sediment**

**Navigation Dredge Zone
TSS Source Attenuation**

PROJECT NO.	DWN	CKD	APVD	REV
WTRM.03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 3



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

STATUS
ISSUED FOR USE

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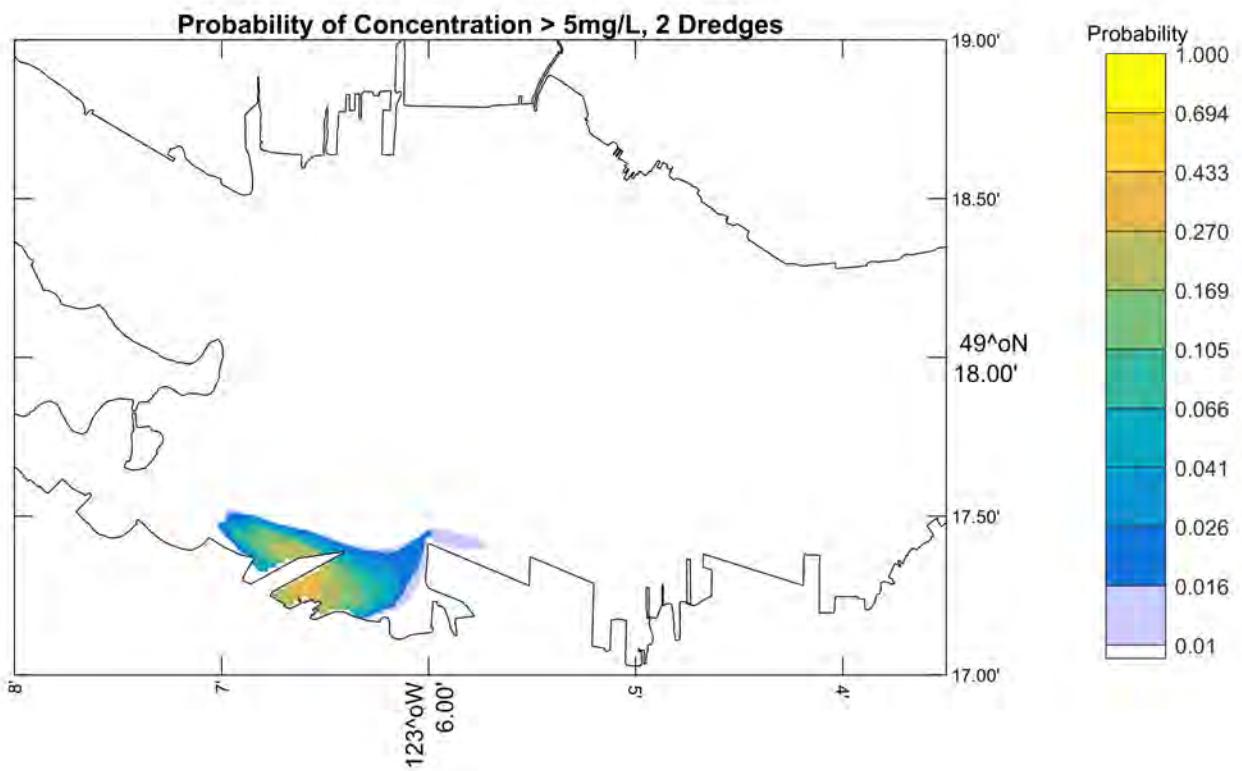
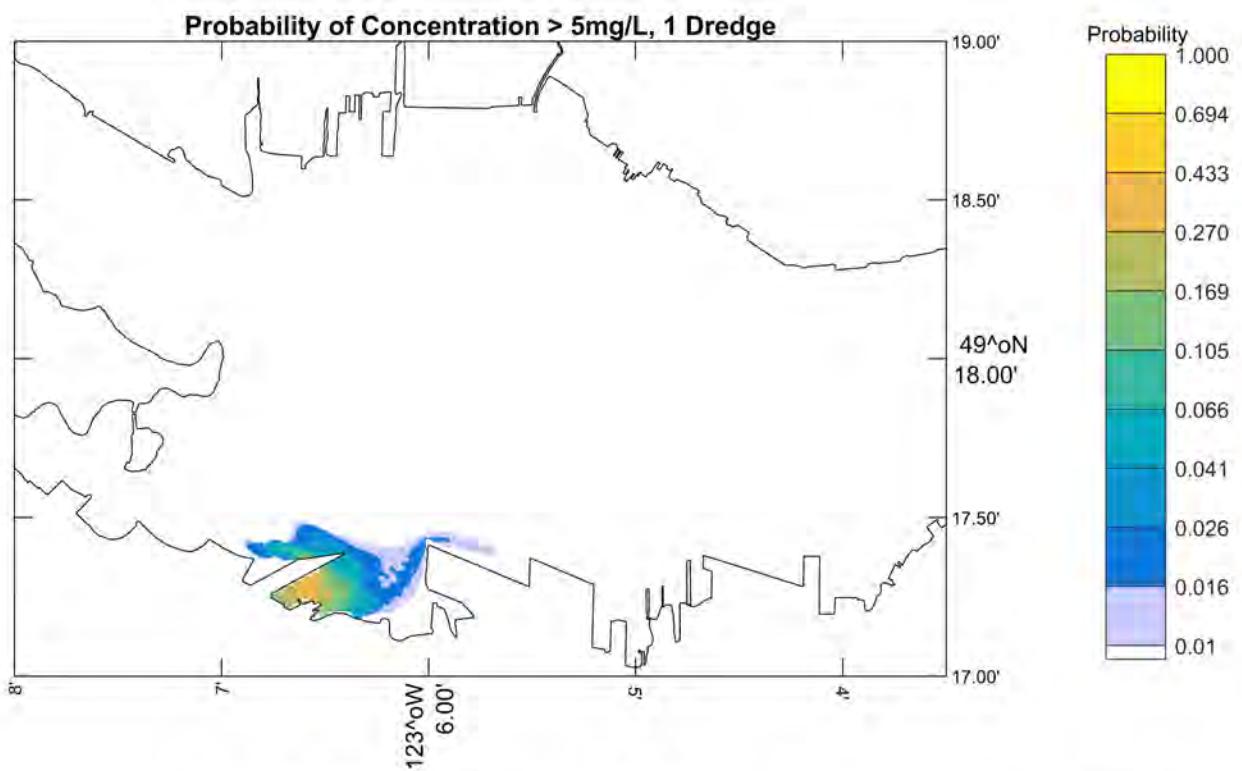
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Dispersal Modelling of Dredging Derived Fugitive Sediment

Navigation Dredge Zone Probability Maximum TSS More Than 10% of Source

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 4



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

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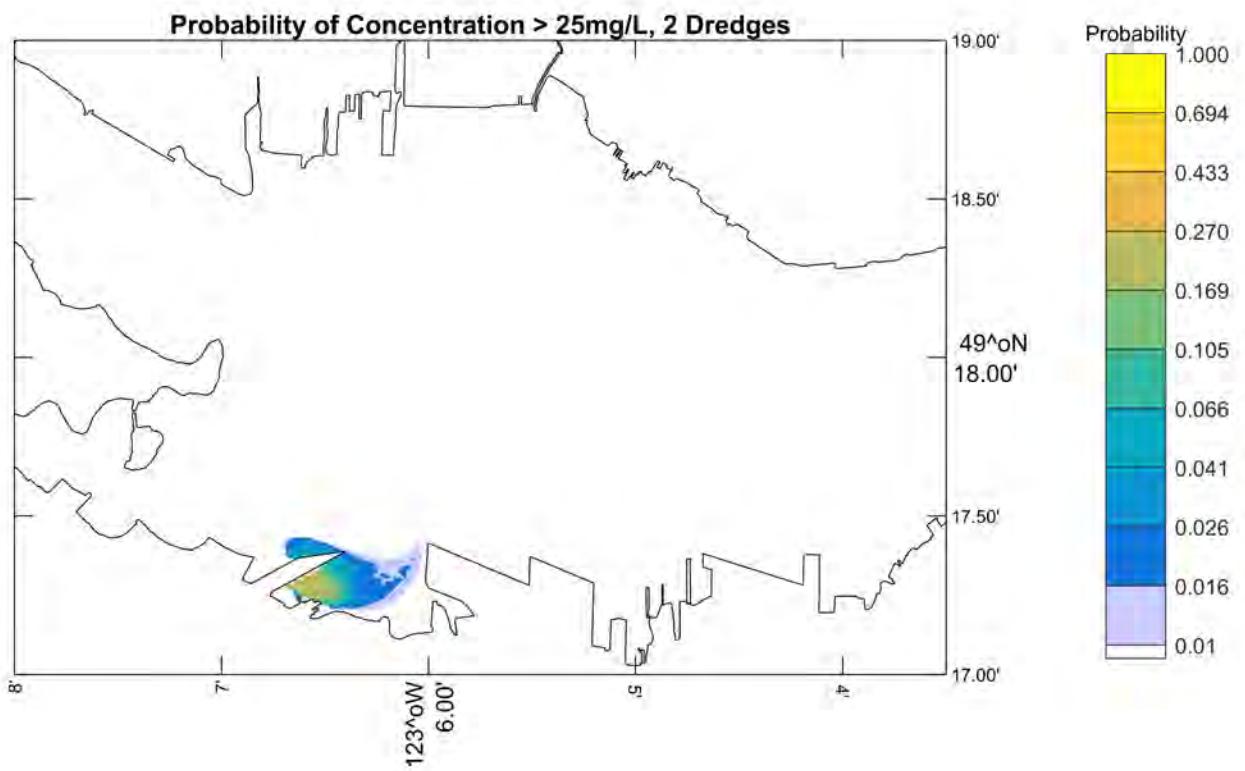
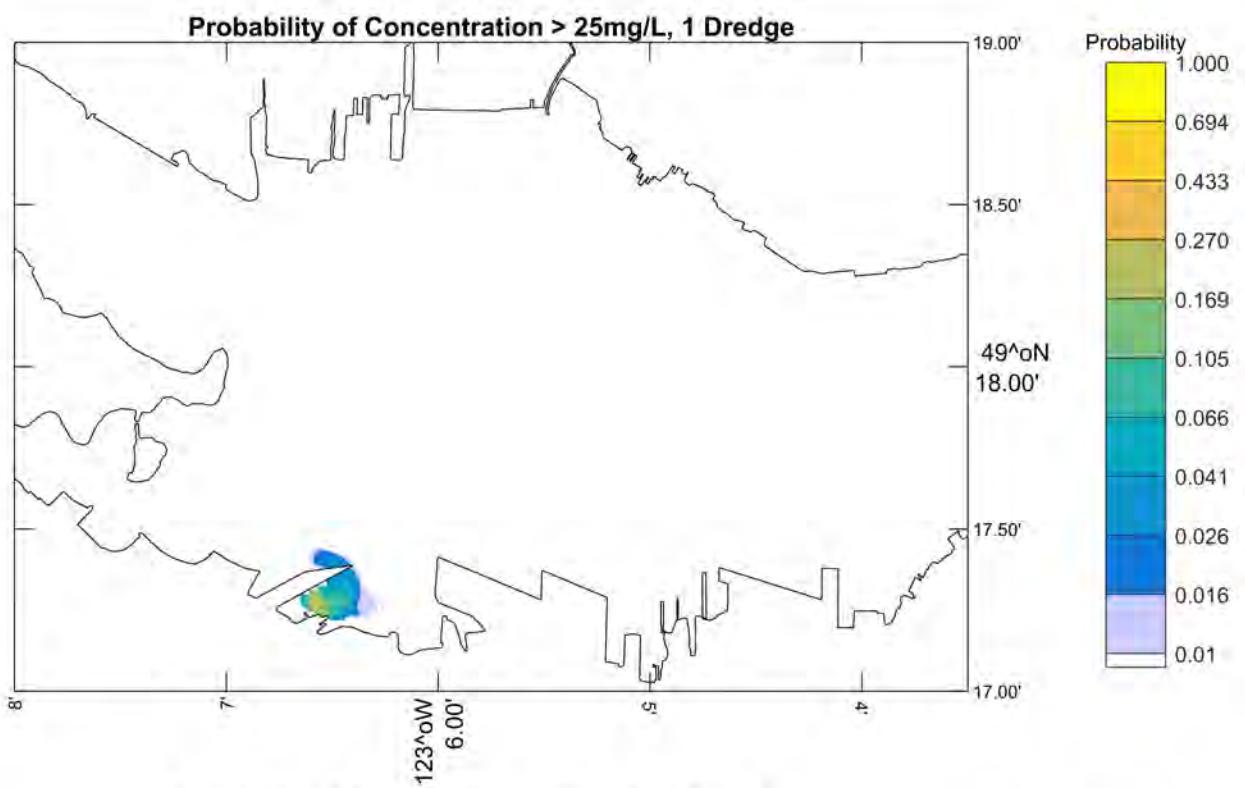
STATUS
ISSUED FOR USE

Dispersal Modelling of Dredging Derived Fugitive Sediment

Navigation Dredge Zone Probability of Maximum TSS Exceeding 5 mg/L

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 5



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

CLIENT

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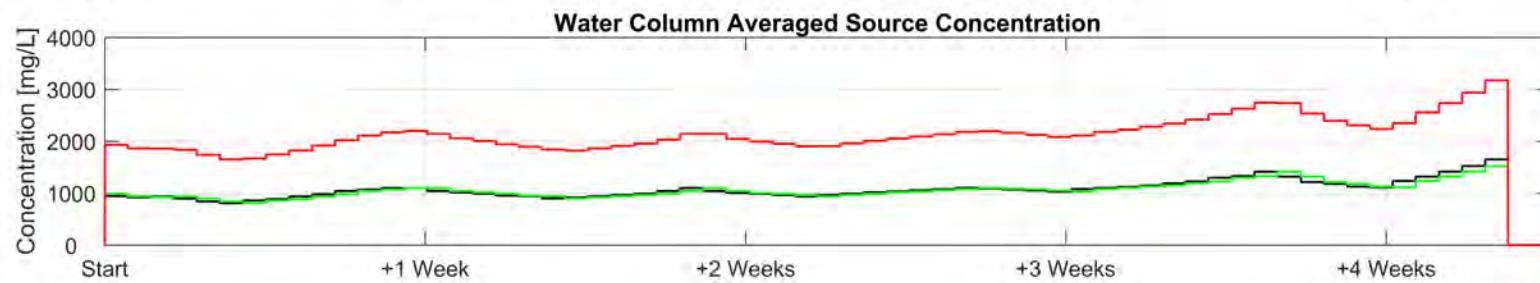
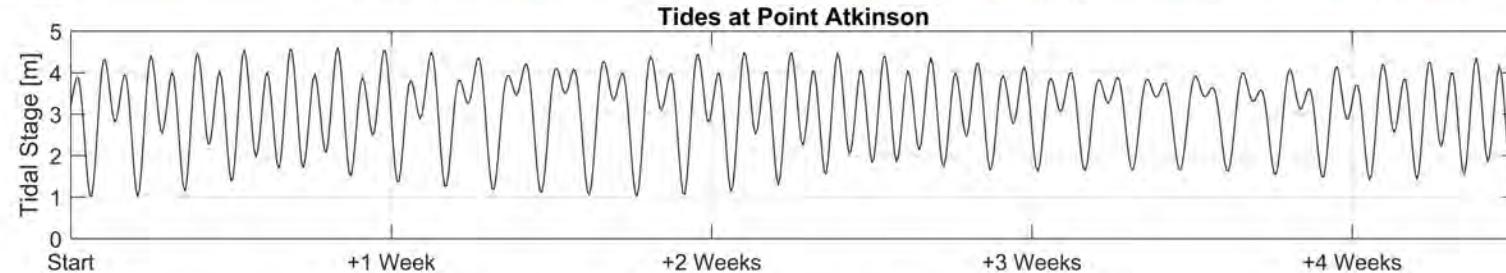
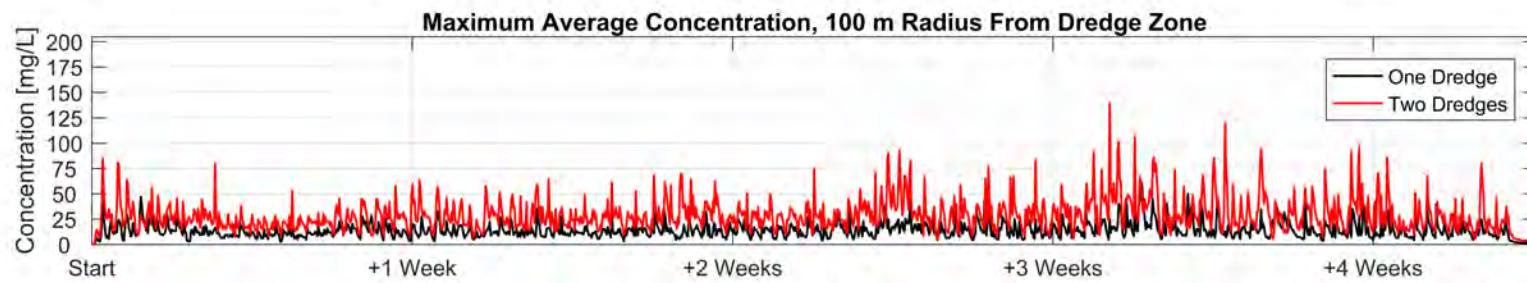
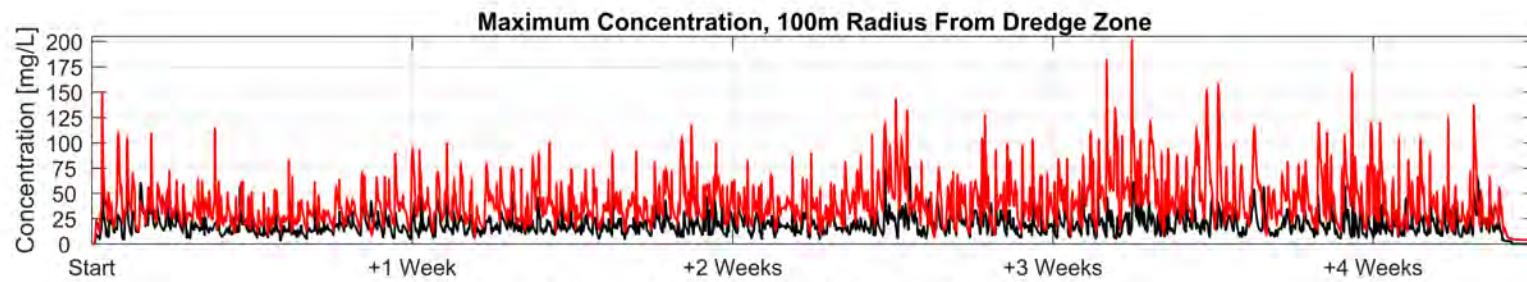
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Dispersal Modelling of Dredging Derived Fugitive Sediment

Navigation Dredge Zone Probability of Maximum TSS Exceeding 25 mg/L

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 6



NOTES

- 1) The concentration axis scale for the Source Concentration plot differs from that of the 100 m Concentration plots.
- 2) Source concentration varies in time due to depth variations between dredge locations and tidal action.
- 3) Maximum concentrations are the maximum of the maximum concentration over the water column (seabed to surface) along the 100 m boundary.
- 4) Maximum average concentrations are the maximum of the average concentration over the water column (seabed to surface) along the 100 m boundary.

STATUS
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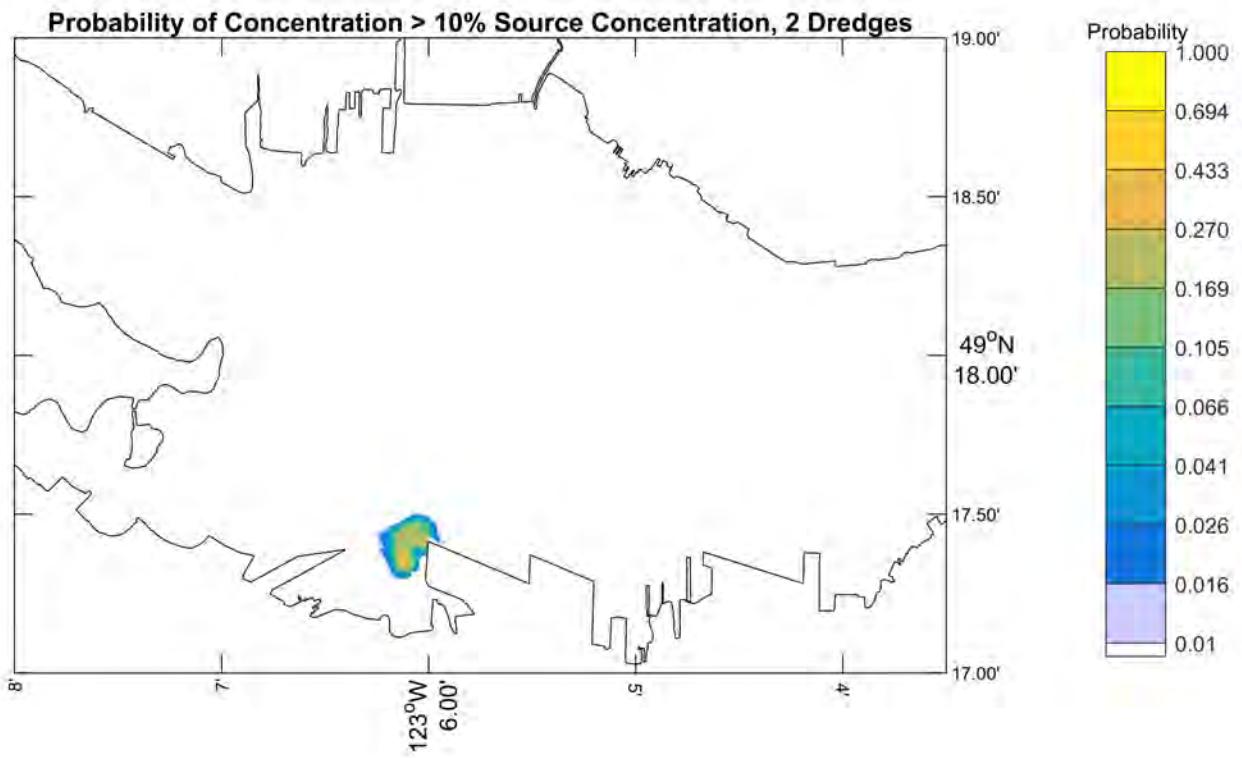
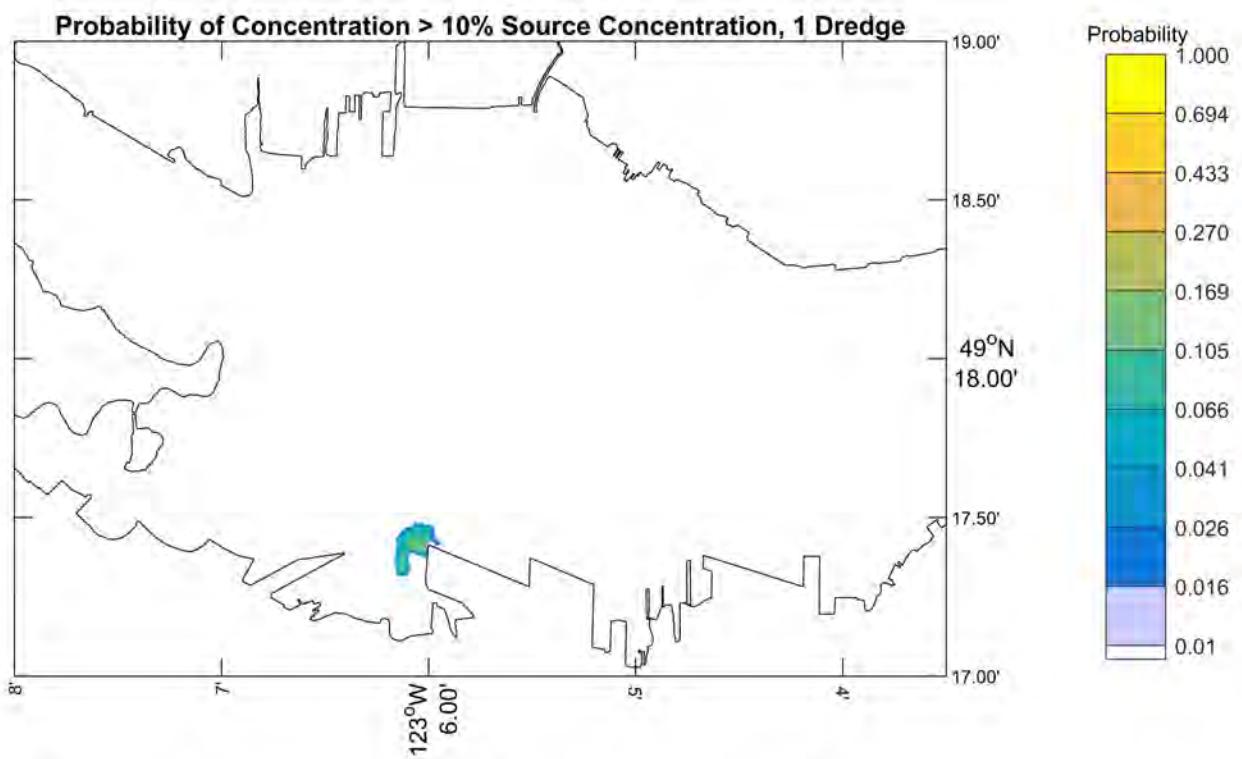
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Dispersal Modelling of Dredging Derived Fugitive Sediment

West Basin Dredge Zone TSS Source Attenuation

PROJECT NO.	DWN	CKD	APVD	REV
WTRM.03017	JM	JM	JAS	0
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Figure 7



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

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**Dispersal Modelling of Dredging
Derived Fugitive Sediment**

**West Basin Dredge Zone
Probability of Maximum TSS
More Than 10% of Source**



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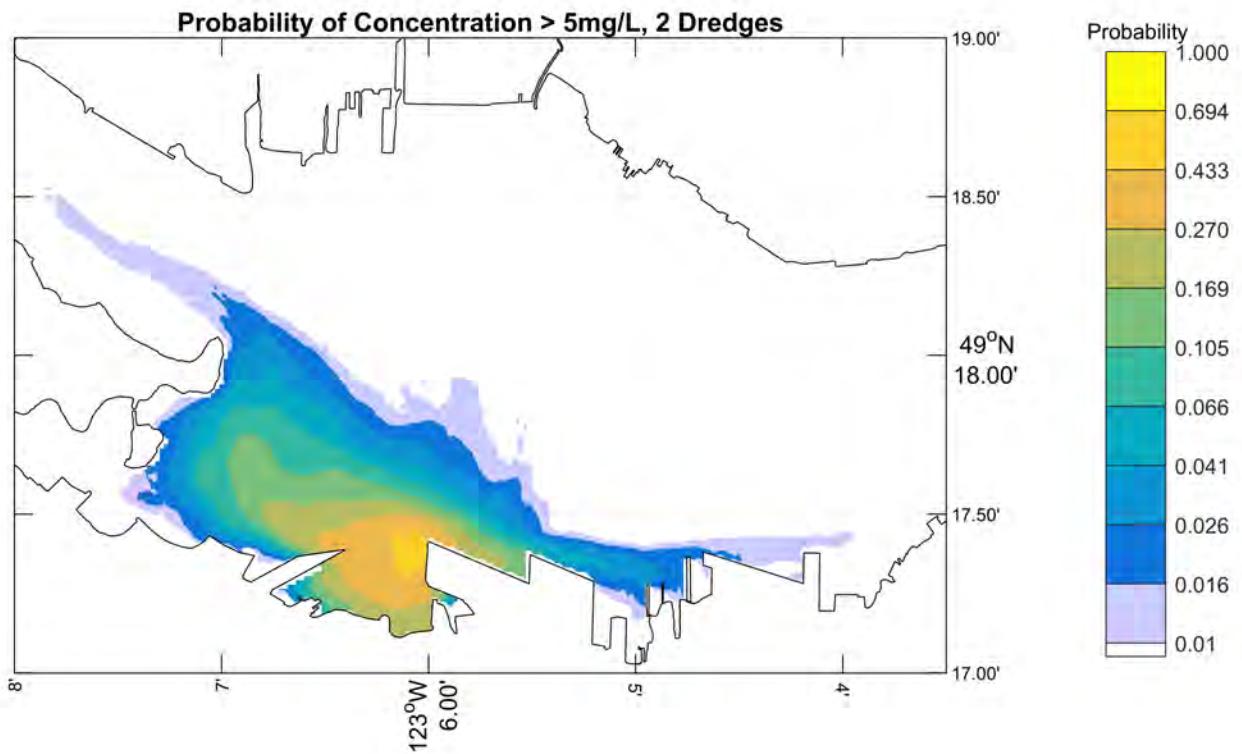
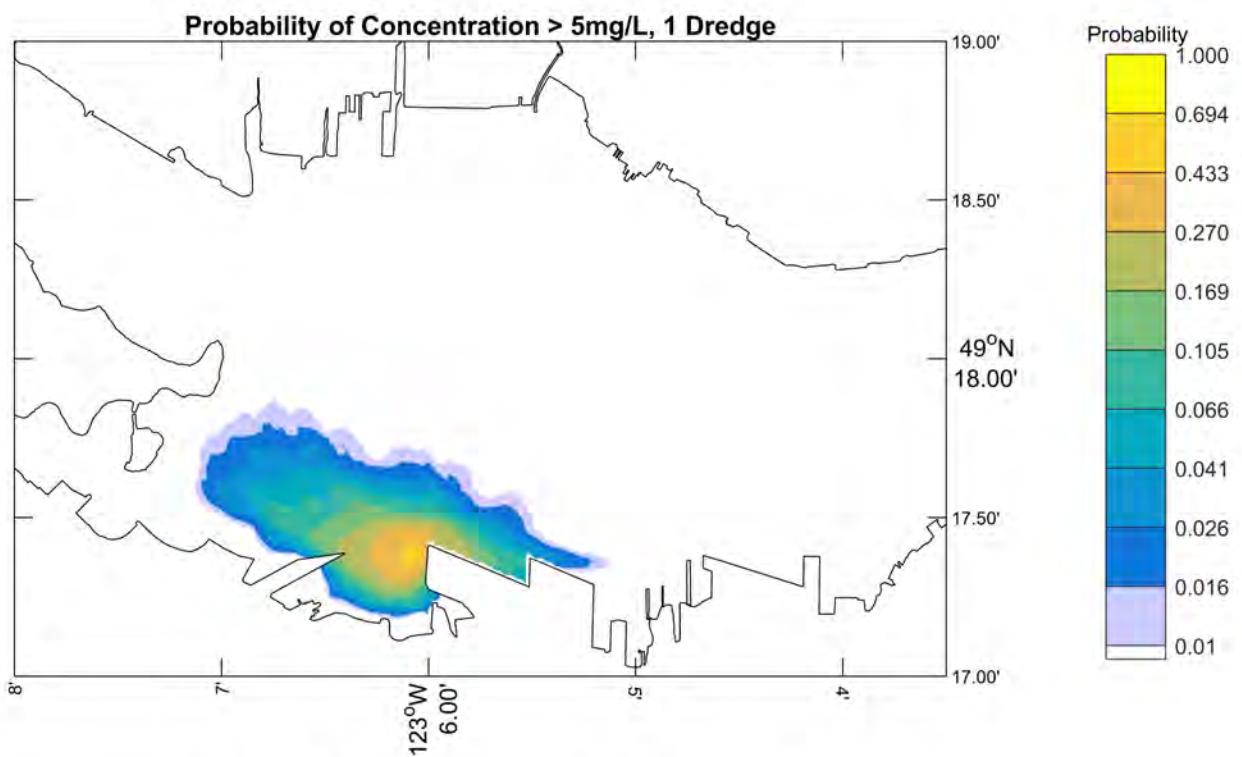
PROJECT NO.
WTRM03017

DWN JM CKD JM APVD JAS REV
0

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DATE March, 2017

Figure 8



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

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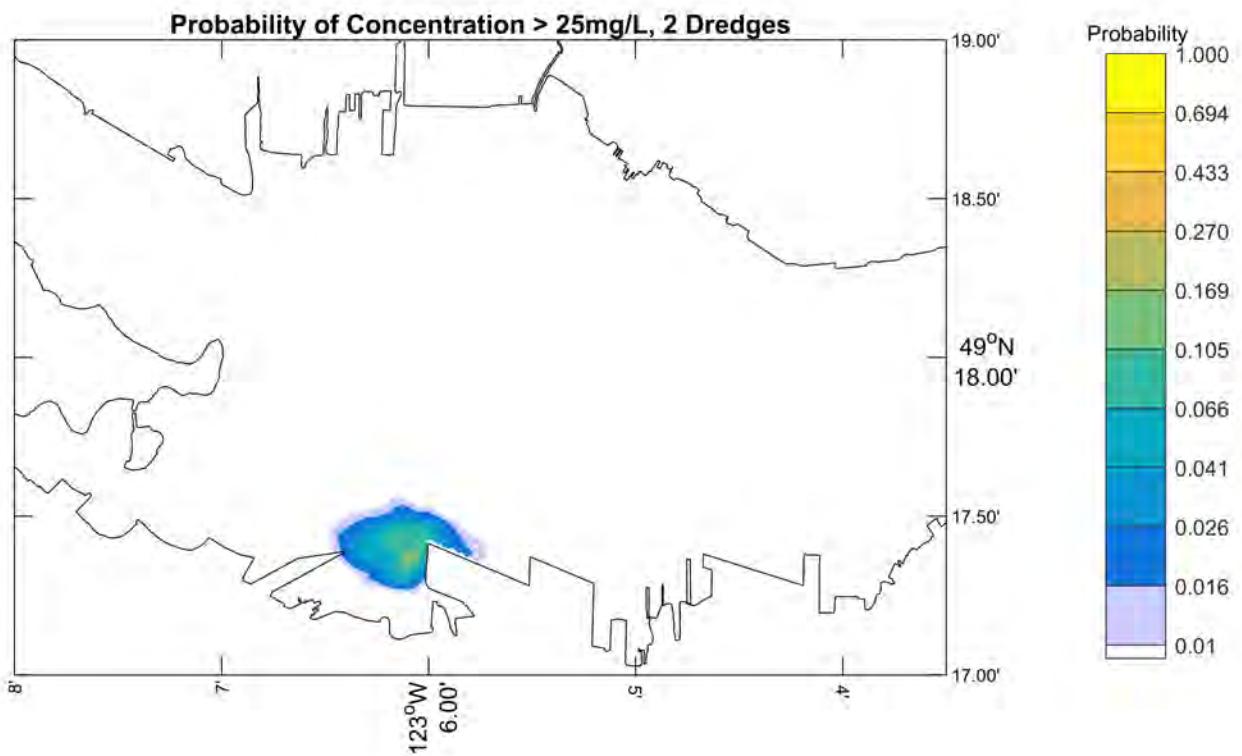
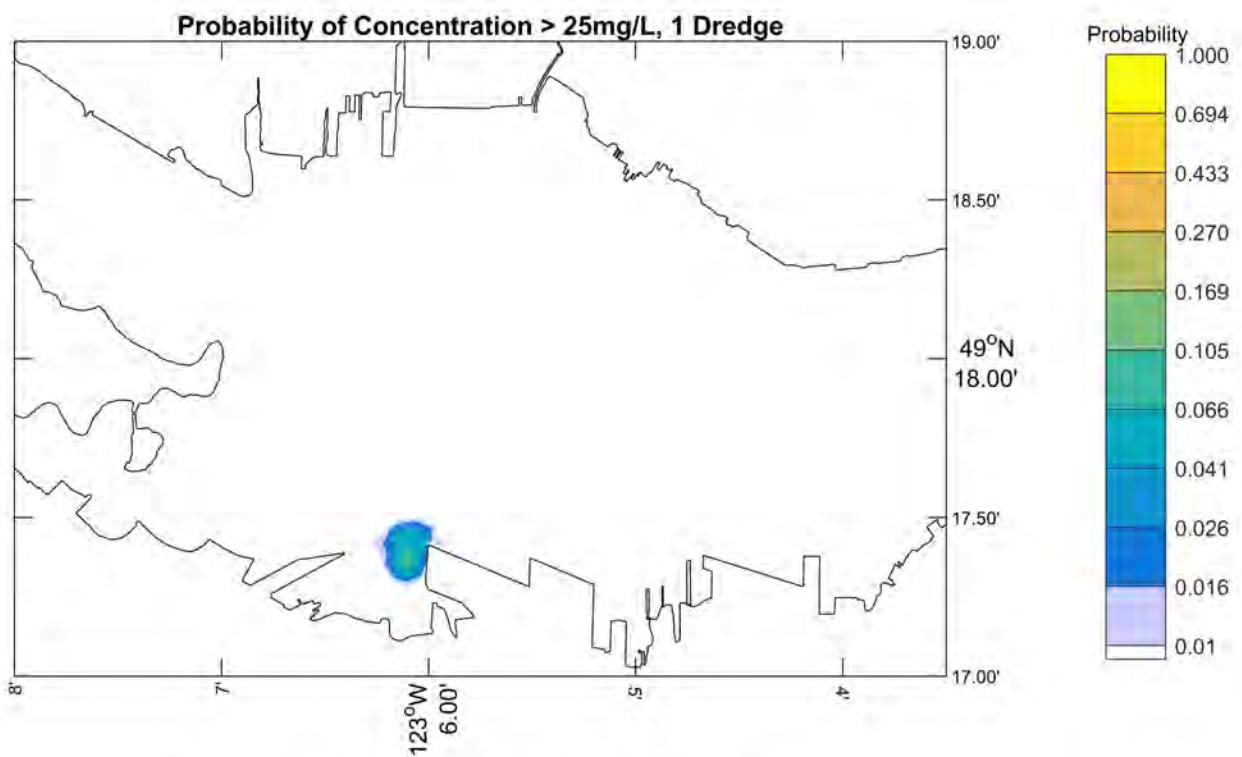
STATUS
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Dispersal Modelling of Dredging Derived Fugitive Sediment

West Basin Dredge Zone Probability of Maximum TSS Exceeding 5 mg/L

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 9



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

STATUS
ISSUED FOR USE

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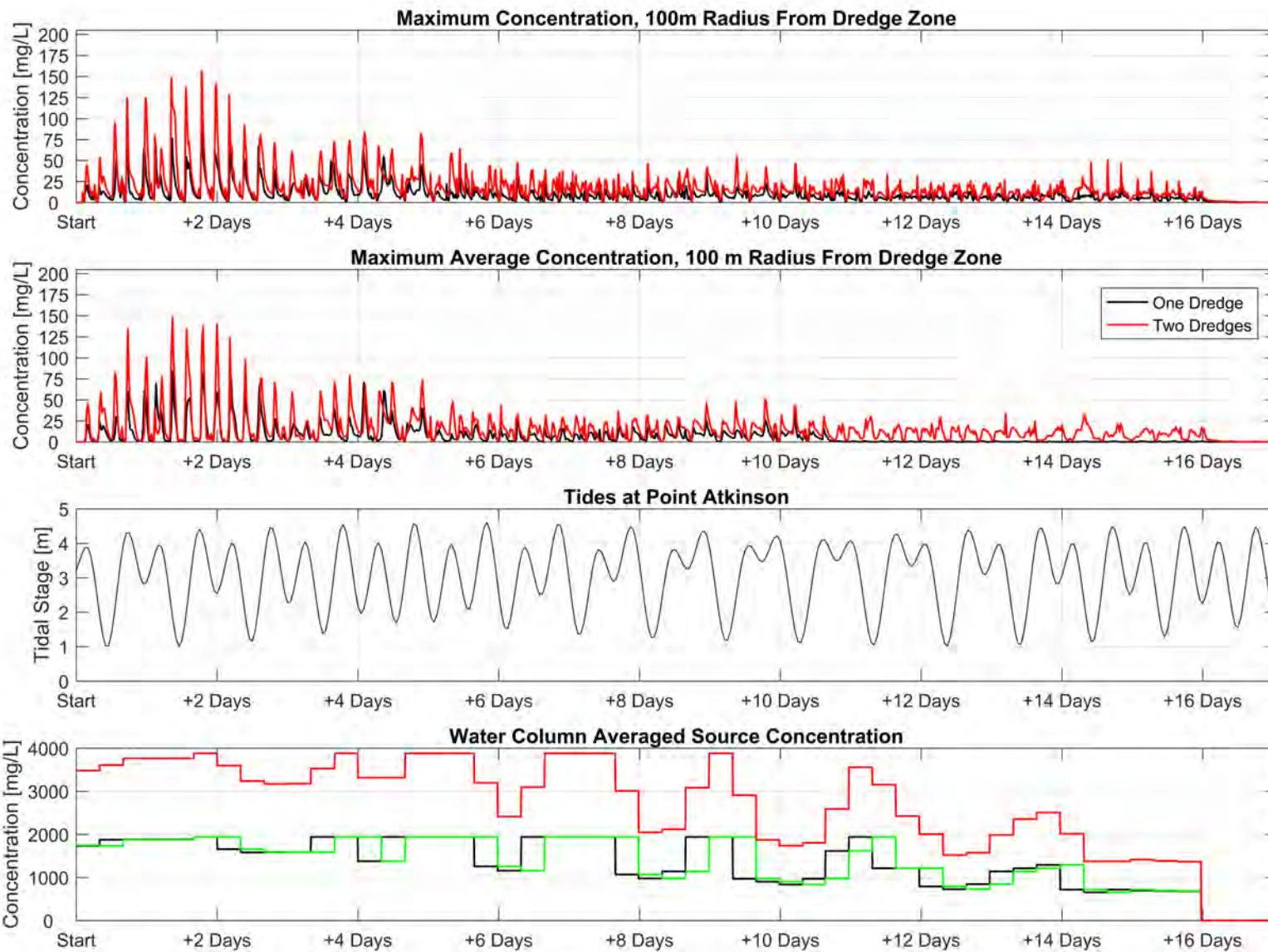
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Dispersal Modelling of Dredging Derived Fugitive Sediment

West Basin Dredge Zone Probability of Maximum TSS Exceeding 25 mg/L

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 10



NOTES

- 1) The concentration axis scale for the Source Concentration plot differs from that of the 100 m Concentration plots.
- 2) Source concentration varies in time due to depth variations between dredge locations and tidal action.
- 3) Maximum concentrations are the maximum of the maximum concentration over the water column (seabed to surface) along the 100 m boundary.
- 4) Maximum average concentrations are the maximum of the average concentration over the water column (seabed to surface) along the 100 m boundary.

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ISSUED FOR USE

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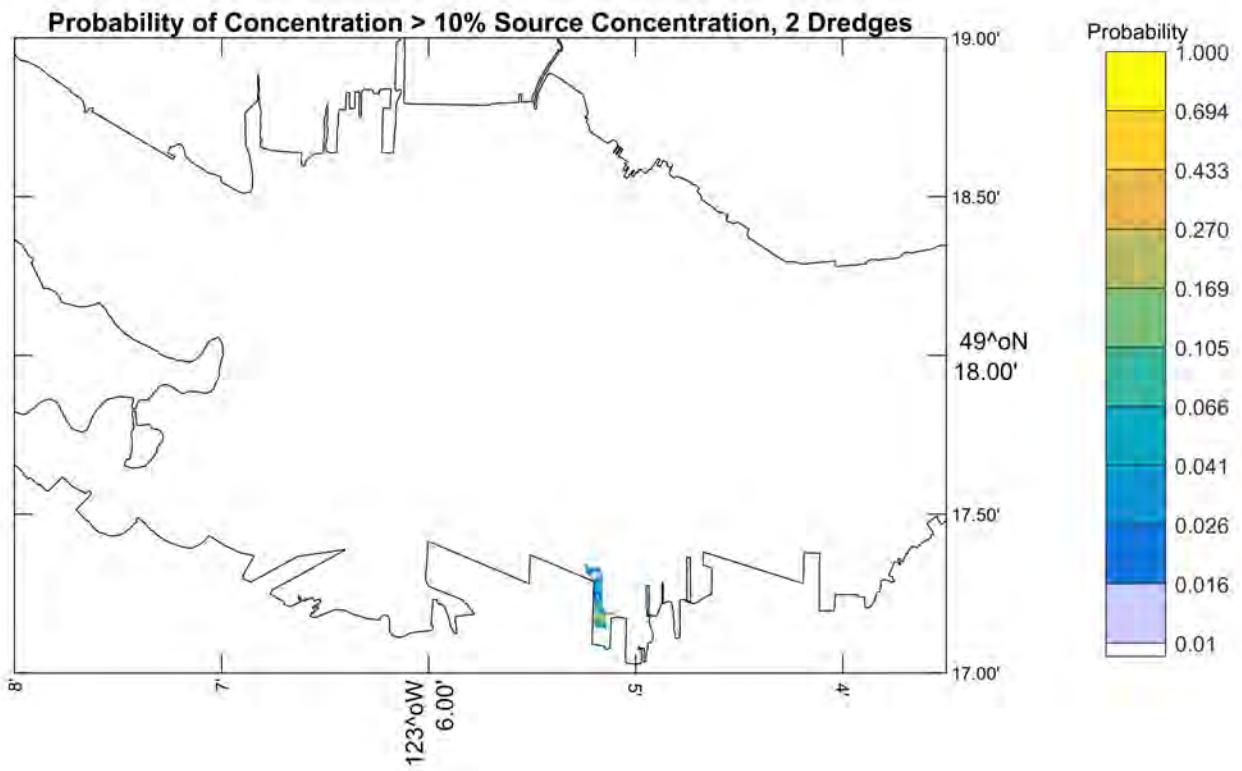
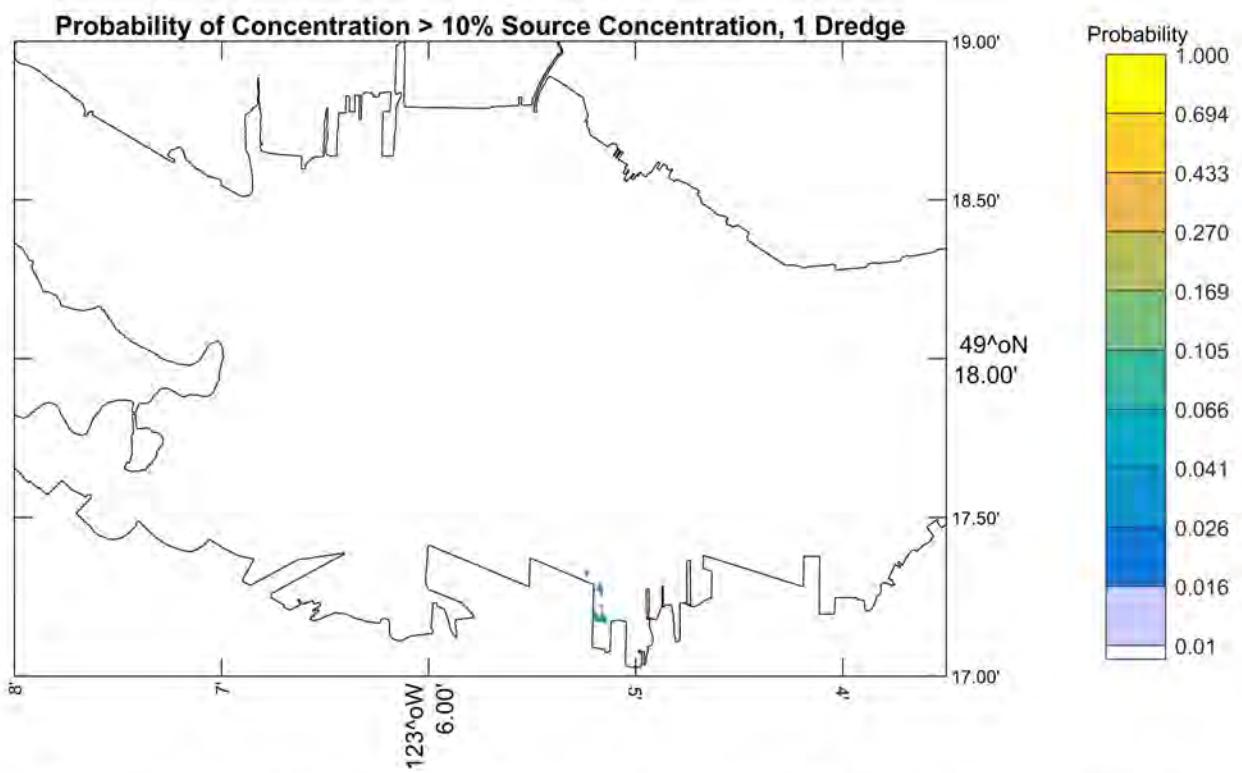
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Dispersal Modelling of Dredging Derived Fugitive Sediment

East Basin Dredge Zone TSS Source Attenuation

PROJECT NO.	DWN	CKD	APVD	REV
WTRM.03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech EBA - VANC	March, 2017			

Figure 11



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

CLIENT

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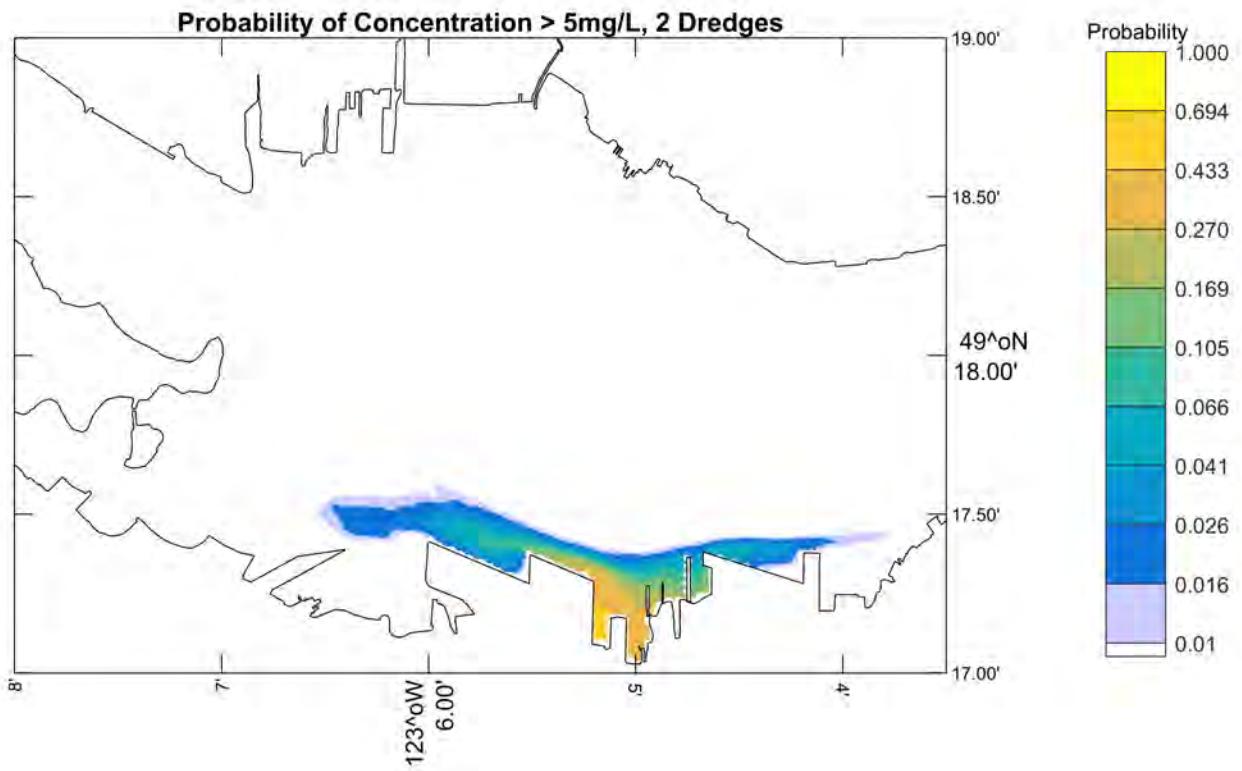
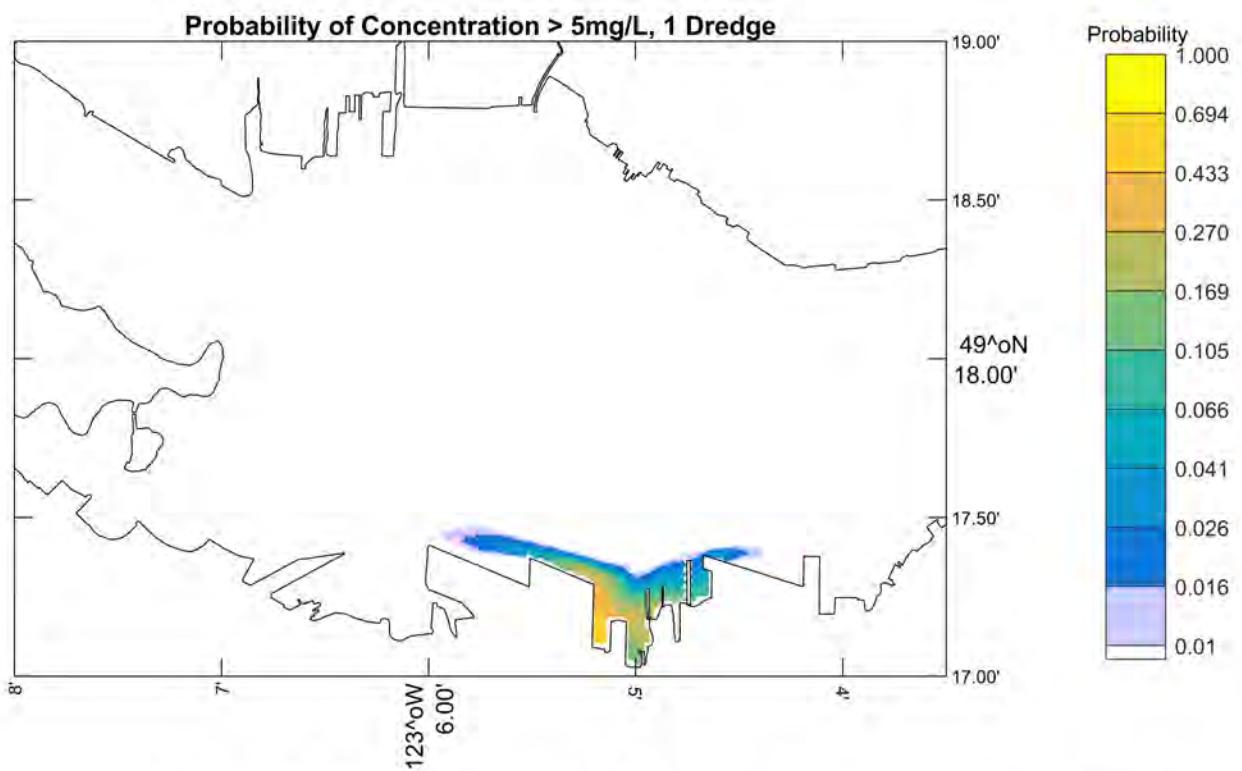
STATUS
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Dispersal Modelling of Dredging Derived Fugitive Sediment

East Basin Dredge Zone Probability of Maximum TSS More Than 10% of Source

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
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Tetra Tech - VANC	March, 2017			

Figure 12



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

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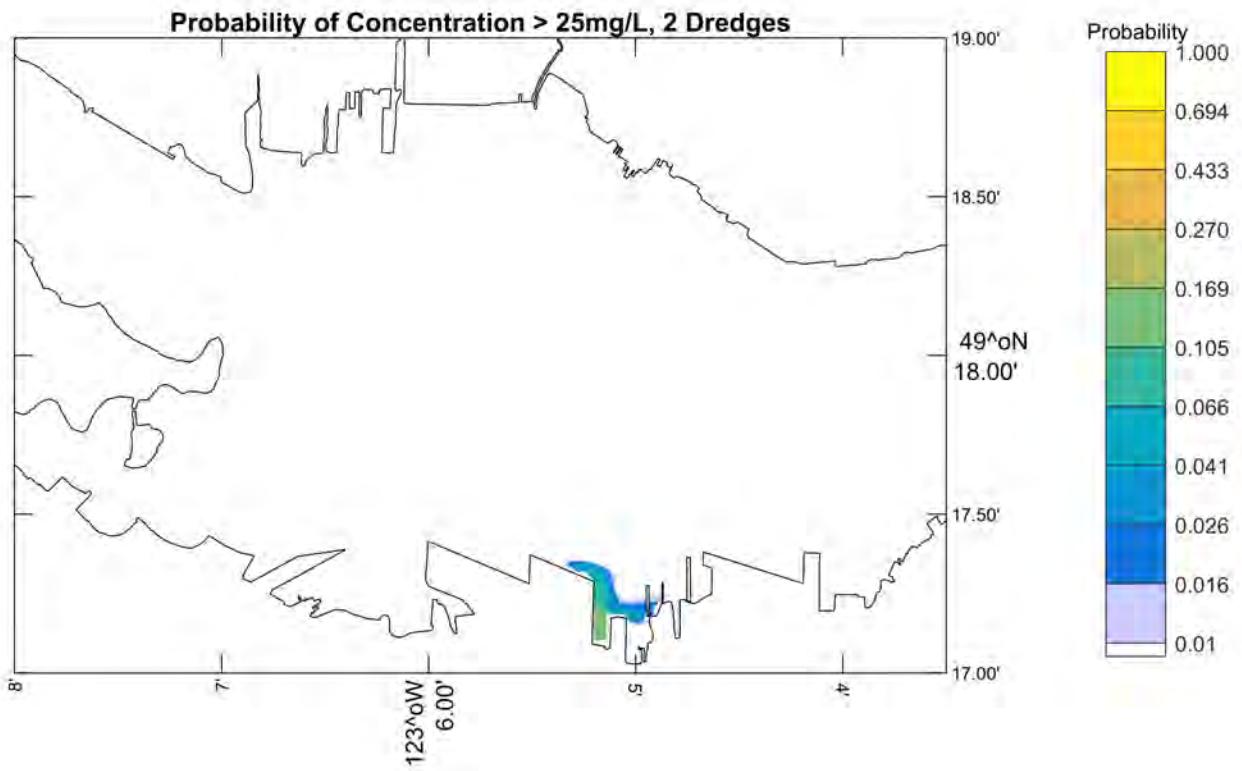
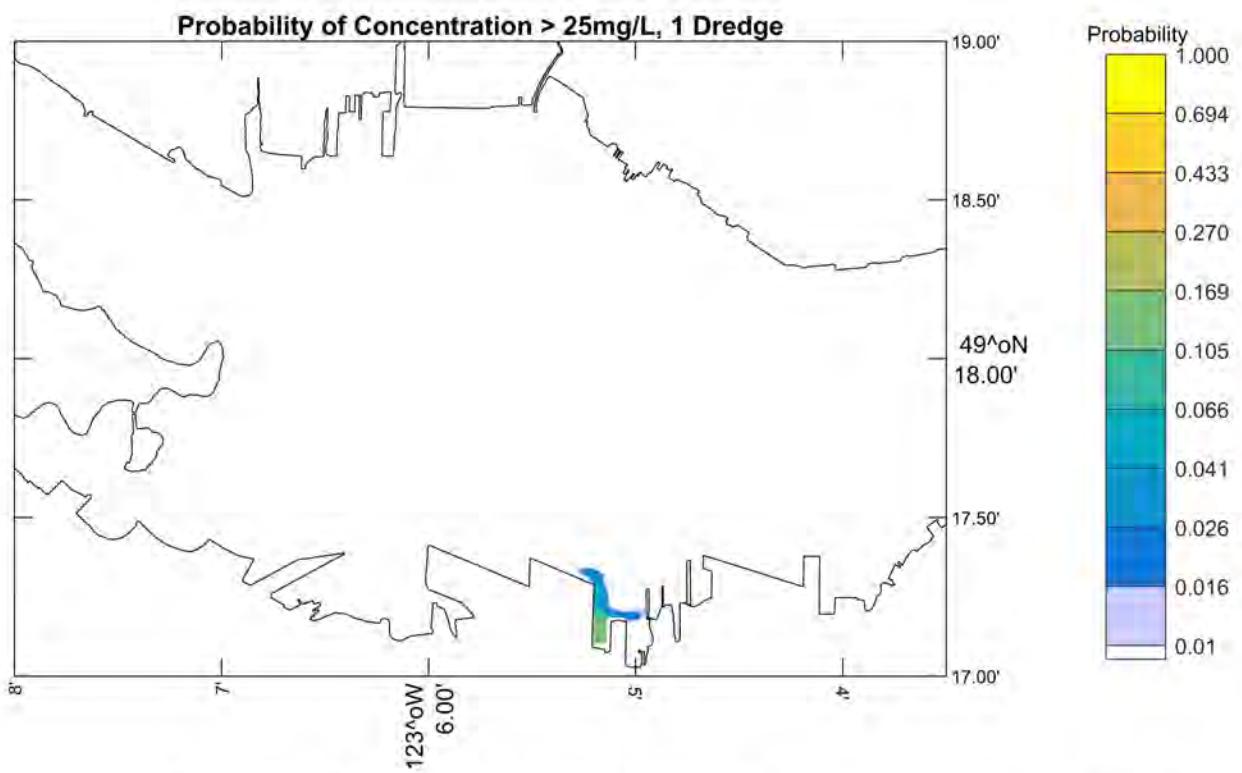
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Dispersal Modelling of Dredging Derived Fugitive Sediment

East Basin Dredge Zone Probability of Maximum TSS Exceeding 5 mg/L

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 13



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

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STATUS
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Dispersal Modelling of Dredging Derived Fugitive Sediment

East Basin Dredge Zone Probability of Maximum TSS Exceeding 25 mg/L

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 14

APPENDIX A

TETRA TECH'S GENERAL CONDITIONS

GENERAL CONDITIONS

HYDROTECHNICAL

This report incorporates and is subject to these "General Conditions".

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5.0 DISCLOSURE OF INFORMATION BY CLIENT

The Client acknowledges that it has fully cooperated with Tetra Tech EBA with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for Tetra Tech EBA to properly provide the services contracted for in the Services Agreement, Tetra Tech EBA has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

6.0 INFORMATION PROVIDED TO TETRA TECH EBA BY OTHERS

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While Tetra Tech EBA endeavours to verify the accuracy of such information, Tetra Tech EBA accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage.

7.0 GENERAL LIMITATIONS OF REPORT

This Report is based solely on the conditions present and the data available to Tetra Tech EBA at the time the Report was prepared.

The Client, and any Authorized Party, acknowledges that the Report is based on limited data and that the conclusions, opinions, and recommendations contained in the Report are the result of the application of professional judgment to such limited data.

The Report is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present at or the development proposed as of the date of the Report requires a supplementary investigation and assessment.

It is incumbent upon the Client and any Authorized Party, to be knowledgeable of the level of risk that has been incorporated into the project design, in consideration of the level of the hydrotechnical information that was reasonably acquired to facilitate completion of the design.

The Client acknowledges that Tetra Tech EBA is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

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Tetra Tech EBA is only responsible for the activities of its employees on the job site and was not and will not be responsible for the supervision of any other persons whatsoever. The presence of Tetra Tech EBA personnel on site shall not be construed in any way to relieve the Client or any other persons on site from their responsibility for job site safety.

Appendix B Centerm Expansion Project - Dispersal Modelling of Infilling-Derived Fugitive Sediment. Tetra Tech, 2017.



TETRA TECH

OQM | Organizational Quality Management Program

Centerm Expansion Project - Dispersal Modelling of Infilling-Derived Fugitive Sediment



PRESENTED TO
AECOM Canada

APRIL 21, 2017
ISSUED FOR USE
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LIMITATIONS OF REPORT

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1.0 INTRODUCTION

AECOM Canada (AECOM) retained Tetra Tech Canada Inc. (Tetra Tech) to quantify release and dispersion of fugitive sediments arising from infilling two sites over the course of the Centerm Expansion Project (CEP). CEP consists of an expansion of the existing Centerm Container Terminal located on the southern shoreline of Vancouver Harbour. The project will consist of two fill expansions to the existing terminal footprint: a westward expansion of approximately 4.2 ha and an eastward expansion of approximately 4 ha.

This study investigates the behaviour of total suspended sediment (TSS) plumes arising from infilling operations at the West Basin Infill and East Basin Infill. This study is based on conceptual plan for infilling and dyke construction, and may be modified by the contractor during the design stage. Each infill zone will be contained behind perimeter rock dykes, raised in a series of trapezoidal 4.5 m lifts until the final fill elevation of +7.0 m CD is reached. Bulk fill material consisting of imported sand-gravel with a small fines fraction will be placed behind the perimeter dykes using a combination of bottom-dumping hopper and flat-deck barges with minor fill, reshaping and some aspects of perimeter dyke construction being undertaken with a clamshell derrick. Mattress, berm rock and lower perimeter dyke lifts will be primarily placed with hopper barges, while upper perimeter dyke lifts will be placed with flat-deck barges offloaded with front-end-loader equipment. When there is sufficient water depth over the perimeter dykes, general infill will be performed by hopper or flat-deck barges floated over the perimeter dyke (AECOM/KCB 2016). Once there is insufficient depth over the infill to safely operate barges, infill will be largely complete using pumped granular materials. Prior to the construction of perimeter rock dykes and infilling, unstable marine sediments will be removed via dredging; the associated fugitive sediment behaviour from dredging was reported in *Centerm Expansion Project: Dispersal Modelling of Dredging-Derived Fugitive Sediment* (Tetra Tech 2017).

The present study uses a high resolution three-dimensional oceanographic model to simulate the dispersion of fugitive sediments arising from infilling the East and West Basins of CEP. Two primary phases of filling will take place: submarine placement of fill using hopper and flat-deck barges; and, surficial infill using pumped slurry fill. Submarine fill placement was simulated for two cases: “empty” perimeter dykes, in which the fill level is several meters below the crest of the dykes forming the outer edge of the infill zones; and, “full” perimeter dykes, in which the fill level is at the crest elevation of these dykes. TSS releases arising from pumped slurry fill material have not been simulated as it has been assumed that supernatant water resulting from the pumped fill material will drain through a sand filter abutting the inner surface of the perimeter dykes, with all sediment being contained by the dykes (i.e. no flow-through of suspended sediment).

Maps, tables and time series are presented to describe the spatial variation in the maximum and average suspended sediment concentration in the water column arising from infilling operations. Data are therefore presented for both a “maximum” approach in which all statistics are presented for the *maximum* suspended sediment concentration in the water column and a “maximum average” approach in which statistics are presented for the *average* suspended sediment concentration in the water column. The “maximum average” metric is referenced in the Canadian Council of Ministers of the Environment (CCME) water quality standard for *Total Particulate Matter* and is therefore the main point of reference for this study. The maximum values are presented to characterize instantaneous and short lived TSS peaks that may not be accounted for by the CCME guidelines.

2.0 METHODOLOGY

2.1 Numerical Model

The fate and behaviour of the project-derived fugitive sediments has been simulated using an extensively validated three-dimensional numerical model of Vancouver Harbour along with a parameterized infilling schedule based on the best available information at the time of writing. The primary numerical model employed in this study is a 10-m resolution three-dimension numerical model focussed on the south-western shore of Vancouver Harbour. This model is the highest resolution model in a series of numerical models extending from the Pacific Ocean to the upper end of Indian Arm:

- Coarse Resolution: 1-km resolution shelf model extending from the mouth of Juan de Fuca Strait to the southern end of Texada Island and the terminus of Indian Arm. The model is driven by tidal constituents and monthly climatology at its boundaries with hourly wind fields and daily river inflows at 13 significant rivers.
- Mid-Resolution: 125-m resolution Burrard Inlet model extending from the entrance to English Bay to the terminus of Indian Arm. The model is driven by water level, temperature and salinity data from the coarse resolution model, with hourly wind fields and daily river inflows.
- High Resolution: 25-m resolution Burrard Inlet model extending from the mid-point of English Bay (near Jericho Beach) to east of Second Narrows (near Cates Park), driven by water level, temperature and salinity data from the mid-resolution model, with hourly wind fields and daily river inflows.
- Project Specific: 10-m resolution model of the Centerm site spanning Canada Place, Deadman Island, Burnaby Shoal and Vanterm. Driven by water level, temperature and salinity data from the high-resolution model.

Within the modelling chain, all major rivers in the Salish Sea are included, with Lynne Creek, the Seymour River and the Capilano River feeding directly in the high resolution Burrard Inlet model. Wind fields are interpolated from measured winds at buoys and meteorological stations around coastal British Columbia, with winds for the high resolution Burrard Inlet model based on a dedicated CALMET wind model.

The layout of the 25-m and 10-m resolution numerical models of Vancouver Harbour are presented on Figure 2.1. This figure presents a map of speeds during a moderate flood tide for the existing Centerm geometry. Water level, velocity, salinity, temperature and sediment information is passed from the 1000-m resolution model to the 125-m resolution model to the 25-m resolution model (across the black boundary in Figure 2.1) and, ultimately, across the red boundary in Figure 2.1 into the 10-m resolution numerical model. In general, the model nesting procedure results in a very high fidelity across model domains, as can be seen in Figure 2.1. Fugitive sediment arising from infilling operations is introduced into the model via a coupled version of the STFATE (Short-Term FATE of dredged sediments) model developed by the U.S. Army Corps of Engineers. This model simulates the near-field (i.e. at a spatial scale smaller than the 10-m grid size) sediment dynamics, before passing its results through to the 10-m resolution hydrodynamic model (see Section 3.4). A simulation period of 14 days has been selected to determine the behaviour of the fugitive sediments over a full spring-neap cycle and because it approximately aligns with the time to complete one full perimeter dyke lift (see Section 3.3).

The circulation patterns within Vancouver Harbour are tidally dominated, with some baroclinic influence due to seasonal variations in fresh water inflow and temperature. Streamlines showing the surface currents within western Vancouver Harbour are shown on Figure 2.2. The most prominent flow features within the harbour are the tidal jets formed at First Narrows and Second Narrows. These jets regularly have peak velocities over 2.5 m/s, with a maximum velocity nearing 3 m/s possible on occasion. Flood tides result in a strong eastward flowing jet forming at First Narrows that remains coherent well into Vancouver Harbour and establishes a series of eddies and recirculation cells that persist throughout the tidal cycle. The First Narrows jet impinges on the Centerm site resulting

in strong eastward flows along the terminal face and generally setting up a clockwise circulation cell between Centerm and Canada Place. On the left panel of Figure 2.2 two flood-tide circulation cells are shown to the west of Centerm, one clockwise and the other counterclockwise, centered over the Navigation Dredge Zone. Ebb tides result in a strong westward flowing jet forming at Second Narrows (not show on Figure 2.2), resulting in complex circulation patterns in the vicinity of Centerm. Ebb tidal currents flowing westward in the middle of Vancouver Harbour result in westward flows along the terminal face and set up a counterclockwise eddy between Centerm and Canada Place (Figure 2.2). Ebb tides generally result in a counterclockwise eddy forming to the west of the East Basin Dredge Zone. Towards the end of ebb tide (not shown on Figure 2.2) a counterclockwise eddy can be set up in south western Vancouver Harbour which results in eastward flow in the vicinity of Centerm and, somewhat counterintuitively, in the eastward outflow of water from between Centerm and Canada Place during late stages of ebb tide.

2.2 Fugitive Sediment Plume Tracking

The eastern and western infill zones are displayed on Figure 2.3 with a 100 m dilution boundary plotted for each infill zone. Dilution zones of these dimensions are used later in this report to determine the dilution of the initial fugitive sediment source strength at 100 m from the infill zone “source”.

In order to quantify the dispersion of fugitive sediments, the TSS content of the fugitive sediment plume is tracked as sediments are released over a simulated infill program. In order to quantify the dispersion of fugitive sediments, the total suspended solids (TSS) content of the fugitive sediment plume is tracked as sediments are released over a simulated infilling program. Two metrics are used to quantify the concentration and extent of the fugitive sediment release:

- **Water Column Maximum TSS Concentration:** At 15 minute intervals, the maximum TSS concentration in the water column (vertical axis) is reported on a 10 m by 10 m horizontal grid. This data representation was selected to give a conservative representation of TSS concentration in the water column even though the reported maximum TSS may occur at only one location in the water column.

The goal of reporting the maximum TSS concentration is to characterize any instantaneous, short lived peaks that would not necessarily be captured by the maximum average concentration discussed below

- **Water Column Average TSS Concentration:** At hourly intervals, the maximum vertically averaged TSS concentration in the water column (vertical axis) is reported on a 10 m by 10 m horizontal grid. In this study, an arithmetic mean is uniformly presented.

This metric is most comparable to CCME’s “maximum average” guidance on Total Particulate Matter concentration and so is the most relevant measure of TSS in the water column.

As an explanatory example, if the water depth is 40 m, with a near bed (e.g. within 1 m of the seabed) TSS concentration of 100 mg/L with the remainder of the water column having a TSS concentration of 2 mg/L, the maximum TSS concentration would be reported as 100 mg/L, while the water column average TSS would be reported as 4.5 mg/L in accordance with CCME guidance.

These two measures of TSS in the water column are then post-processed to determine:

- **Maximum TSS 100 m from source:** The maximum TSS concentration at a 100 m distance from the active dredge zones, computed from the water column maximum TSS concentration. These 100 m boundaries surrounding each dredge zone are presented on Figure 2.3.
- **Maximum Average TSS 100 m from source:** The maximum average TSS concentration at a 100 m distance from the active dredge zones, computed from the average water column TSS concentration. These 100 m boundary surrounding each dredge zone are presented on Figure 2.3.

- **Probability of Maximum TSS Exceeding 5 mg/L:** The probability of the maximum above-background concentration of TSS exceeding 5 mg/L at any given moment during the dredging operation, defined as the commencement of operations to the moment when the above- background concentration drops below 5 mg/L following cessation of dredging. These probabilities are computed from the water column maximum TSS concentration, which is very conservative compared to CCME guidelines.
- **Probability of Maximum TSS Exceeding 25 mg/L:** The probability of the maximum above-background concentration of TSS exceeding 25 mg/L at any given moment during the dredging operation, defined as the commencement of operations to the moment when the above background concentration drops below 25 mg/L following cessation of dredging. These probabilities are computed from the water column maximum TSS concentration, which is very conservative compared to CCME guidelines.
- **Probability of Maximum TSS Exceeding 10% of Source Strength:** The probability of the maximum above- background concentration of TSS exceeding 10% of the initial source strength, defined as the water column averaged TSS immediately below the dredge vessel.

3.0 SEDIMENT SOURCE TERMS

3.1 Background Suspended Sediment Concentration

The primary source of background suspended sediment concentration in Vancouver Harbour is widely cited as the North Arm of the Fraser River (Davidson 1973, Feely and Lamb 1979, Thomson 1981). A combination of flood currents and the hydraulic head of the river drive a layer of silty fresh water from the North Arm northwards along the edge of Point Grey, then eastward along the southern shore of English Bay. During certain tidal and wind conditions, this near-surface brackish water can be drawn through First Narrows and into Vancouver Harbour; however the intense tidal mixing of the Narrows mixes out much of the initial stratification. There is, however a general lack of information on background suspended sediment concentrations that result from the influx of brackish water into Vancouver Harbour.

The best source of recent information is a report by Tetra Tech in which turbidity on the western side of Canada Place was monitored continuously from December 2004 to July 2007 (Tetra Tech 2007). Turbidity measured in Nephelometric Turbidity Units (NTU) was monitored at depths of 1.0 m and 4.5 m by YSI 6600EDS-M multi parameter sondes. In general, low turbidity values were recorded throughout the year. Average annual turbidity were 1.6 NTU at 1 m depth and 2.0 NTU at 4.5 m depth. Turbidity levels occasionally (approximately once per month) peaked to between 10 NTU and 20 NTU for a period of less than a day, with the maximum recorded turbidity over the monitoring period of approximately 25 NTU. While these spikes have not been attributed to a specific cause, they do show that there is naturally a factor of 10 range in turbidity in Vancouver Harbour. Turbidity values increased slightly during spring and late summer phytoplankton blooms.

3.2 Infill Sediment Characteristics

The properties of the infill materials have been characterised using data adapted from data provided by Klohn Crippen Berger and AECOM (AECOM/KCB 2017). A summary of these data is presented in Table 3.1 for each of the four primary sources of infill sediment. Importantly, the General Fill material and Berm Filter material have a similar fines content, while the Mattress Rock and Dyke Core Rock have a negligible content of any sediment smaller than fine gravel. Therefore, the placement of the General Fill and Berm Filter material (which are contiguous) will result in the fugitive release of TSS, while the placement of the Mattress Rock and Dyke Core Rock can be safely assumed to generate a comparatively negligible TSS plume. Consequently, only the placement of General Fill and Berm Filter material is considered in this study.

Table 3.1: Summary of Infill Material Grain Size Classification

		General Fill ¹		Berm Filter ²		Mattress Rock ³		Dyke Core Rock ⁴
Sediment Properties		% Passing		% Passing		% Passing		% Passing
Class	mm	Lower	Upper	Lower	Upper	Lower	Upper	
Boulder	600	100	100	100	100	100	100	100
Small Cobbles	100-150	100	100	100	100	100	100	50
Small Cobbles	75	100	60	100	100	100	60	35
Coarse Gravel	19	100	10	100	75	50	10	19
Medium Gravel	9.5	100	0	100	60	35	0	16
Fine Gravel	4.75	90	0	90	40	20	0	15
Very Coarse Sand	0.425	40	0	15	0	0	0	1
Fine Sand	0.075	5	0	5	0	0	0	0
Medium-Fine Clay	0.001	0	0	0	0	0	0	0

¹ quarry rock and/or river gravels and sands, comprise the vast majority of infill materials² quarry rock to be installed behind caissons³ quarry rock to be installed beneath caissons⁴ quarry rock, comprises bulk of dyke material

Source: AECOM 2017

The particle size distributions presented in Table 3.1 have been parameterized into five particle size classes ranging from a very coarse sand to a very fine silt. As the General Fill material presented in Table 3.1 has the largest fines and sand content, its lower bound has been used to derive the particle size classes used in simulating infill operation.

Table 3.2 presents the median (d_{50}), upper bound and lower bound values proscribed in each sediment class bin. In deriving these bins, the focus was on fine sediments and, therefore, sediment classes were not created for materials greater than a small gravel as this material is neither mobilized by ambient currents nor, in the case of a hopper dump, does it travel more than a few meters from its release location.

Table 3.2: Summary of Particle Size Distribution

Sediment Class	Lower Bound	d_{50}	Upper Bound	% Passing	% Retained
	μm	μm	μm	%	%
Very Coarse Sand	425	1795.70	4750.00	90.00	50.00
Fine Sand	75	201.78	425.00	40.00	35.00
Silt	25.49	43.72	75.00	5.00	3.35
Fine Silt	8.66	14.86	25.49	1.70	1.14
Very Fine Silt / Clay	2.94	5.05	8.66	0	0.52

3.3 Volume and Infill Schedule

To complete the infilling operation, approximately 432,000 m³ of infill material (as distinct from other construction materials) will be required at the West Basin, with 528,000 m³ required at the East Basin. These material volumes exclude the Perimeter Dyke, Caisson Mattress Rock, Dredge Trench Infill and Caisson Fill, as discussed in Section 3.2. The total volume of material is taken as the sum of sand and gravel infill and general fill based on information provided in the AECOM-KCB dredging and infill statement (AECOM 2017). Table 3-3 summarizes the relative volumes of each sediment class and the total infill material volume with a significant fines fraction (excluding the perimeter dykes rock and mattress rock) at each of the East and West Infill.

Table 3.3: Summary of Infill Volume by Sediment Class

Sediment Class	% of Total	West Basin Infill ² Volume	East Basin Infill Volume
		m ³	m ³
Gravel and Cobble ¹	10.00	43,157	52,800
Very Coarse Sand	50.00	216,000	264,000
Fine Sand	35.00	151,200	184,800
Silt	3.35	14,472	18,480
Fine Silt	1.14	4,925	6,019
Very Fine Silt / Clay	0.52	2,246	2,746
Total	100	432,000	528,000

¹ Gravel and cobble not subject to dispersion and therefore not simulated.

² Excluding Perimeter Dyke, Caisson Mattress Rock, Dredge Trench Infill and Caisson Fill

Infilling is assumed to take place using a 1,500 m³ capacity hopper and flat deck barge(s) operating with four deliveries per day (AECOM 2017). Minor infill work using a clam shell derrick have not been simulated in this study as this topic was: 1) extensively covered in previous reports (Tetra Tech 2017); and, 2) initial tests demonstrated that TSS concentration originating from clam shell derrick operations were much lower than either the hopper and flat-deck barge scenarios. The East and West Basin infill operations consist of a maximum of five dyke lifts above the native seabed elevation. Due to the uneven and sloping seabed, the infill following the first dyke life will be smaller than subsequent infills. These subsequent infills will vary slightly in volume (hence infill time) depending on the perimeter dyke elevation. To allow for direct comparison between different lift cases, a 14 day infill period for each lift at both the East and West Basins has been simulated. A 14-day cycle allows for simulation over a complete spring-neap tidal cycle and is approximately the average duration of the four submarine infill operations at each Basin.

3.4 Sediment Release

3.4.1 Hopper Barge

The majority of infill material placement is assumed to be carried out via a hopper dredge. A dredge ship of this design transports dredgeate in several internal bins (hoppers) which empty via doors in the ship's bottom. Upon reaching a dump-site, the bottom doors are opened, typically in a specific sequence to ensure even trim of the ship, releasing the dredgeate in a descending cloud.

Sediments released from a hopper dredge generally escape into the surrounding water body in two main phases which, depending on water depth, can be viewed as either independent or concurrent. Firstly, as material leaves the dredge ship, an initial stripping of fine material occurs as the dredgeate accelerates and segregates. This generates a near-surface cloud of material near the release point. Provided the water depth is great enough (and depending on the specific dredgeate composition), all readily removable fine material is stripped during dredgeate descent towards the seafloor. Some fine material, and possibly the bulk of the fine material, can remain entrained in this descending plume, shielded by the larger sediment fractions. When the plume contacts the seafloor, a second cloud of fine material is released as the plume collapses. In shallow depths, the two phases of plume behaviour occur almost simultaneously, while in deeper waters two distinct clouds of fine materials are generated.

With the complete representation of this conceptual model in mind, the release of fines during the infilling operation was modelled with an updated version of the STFATE (Short-Term FATE of dredged sediments) model developed by the U.S. Army Corps of Engineers. The model is based on work by Johnson and Fong (1994), which in turn is developed from the DIFID (Disposal from Instantaneous Discharge) model by Koh and Chang (1973). The model simulates discrete discharge events from dredging vessels – essentially a single delivery operation – and models the complete life-cycle of the discharged dredgeate. For this study, the underlying equations and framework of STFATE were retained; however, large sections of the code were re-worked to allow the model to operate on the time and spatial scales required to simulate the infilling operations.

The released material is modelled in three distinct phases:

- **Convective Descent:** The material falls under the influence of gravity and the initial momentum imposed by discharge from the dredging vessel. In deep water, the dredgeate plume is parameterised as an ellipsoid (roughly egg-shaped) descending mass, while in depth-limited conditions, a column of descending dredgeate results. Based on the initial momentum of the descending plume and the sediment constituents of the dredgeate, the initial blow-off of suspended sediments is calculated.
- **Dynamic Collapse:** The descending cloud of dredgeate either impacts the seafloor or achieves neutral buoyancy with the surrounding water mass. In the event of seafloor impact, the dredgeate plume forms an approximately Gaussian depositional pattern centred on the release point (subject to horizontal advection during the decent phase). Again, based on the momentum of the descending cloud and sediment properties, the blow-off of suspended sediment on impact is calculated.
- **Advection-Diffusion:** Following dynamic collapse, spreading by ambient currents and diffusion disperse any suspended dredgeate. In this application, this functionality of the model is unused and the cloud of suspended sediment generated by STFATE is superimposed on the 10-m resolution hydrodynamic model of CEP (generally over 10 to 12 horizontal grid cells and across the full depth of vertical grid cells). By coupling the models in this way, each of the models is used in its strongest capacity; the detailed and calibrated dredgeate plume formulae of STFATE are applied at a sub-grid scale (with respect to the 10-m resolution model) until the dredgeate plume is dominated by advection-diffusion, at which point the hydrodynamic model takes over the dispersal of the dredgeate.

Calculations of the TSS plume released during the infilling operation are based on information provided by AECOM (AECOM 2017). Dredge dimensions and operating conditions are provided by, or inferred from, this information, and are summarised in Table 3-4.

Table 3.4: Summary of STFATE Input Parameters

Property	Value	Unit
Ship Properties		
Ship Length	60	m
Ship Beam	12.8	m
Loaded Draft	3.6	m
Unloaded Draft	2.2	m
Dredgeate Release Time	60	s
Capacity	1,500	m ³
Release Volumes		
Gravel/Cobble ¹	150.0	m ³
Very Coarse Sand	750.0	m ³
Fine Sand	525.0	m ³
Silt	50.3	m ³
Fine Silt	17.1	m ³
Very Fine Silt / Clay	7.8	m ³

¹ Gravel and cobble not subject to dispersion and so not transferred to hydrodynamic model

Sample simulation output of hopper barge dumps at water depths ranging from 7.0 m to 20.0 m are presented on Figure 3.1. In general, the fugitive release of sediments can be summarized as follows:

- The vast majority of fugitive TSS release occurs near the seabed as the descending cloud of dredgeate contacts the bottom. Typically, 16% to 35% of the total fugitive TSS is generated within a meter of the seabed, with 62% to 100% of the fugitive TSS generated within 3 m of the seabed.
- In shallower water (e.g. less than 10 m), fugitive TSS is generated relatively uniformly in the lower half of the water column, while in deeper water (e.g. 20 m), TSS is concentrated near the seabed.
- The initial release of finer fugitive sediment spans several meters of the water column as these sediments (very fine silt, fine silt, silt) tend to get striped from the dredgeate plume during descent.
- The initial release of coarser fugitive sediment tends to be concentrated near the bed as these sediments (fine sand, very coarse sand) tend to be released by the impact of the dredgeate plume on the seabed.
- Very coarse sand is only released as a fugitive sediment in water depths greater than 14 m and less than 20 m as this sediment requires a minimum amount of energy to be released when the dredgeate plume impacts the seabed. At depths shallower than 14 m, the dredgeate plume has not accelerated sufficiently to release the very coarse sand. At depths greater than 20 m, the dredgeate plume decelerates due to water entrainment and, similarly, is not descending fast enough to release the very coarse sand on impact.

3.4.2 Flat-Deck Barge

Adequate literature describing the fugitive sediment release process for offloading a flat-deck barge could not be found. Therefore, it was assumed that the release patterns and rates associated with hopper barge dumping were approximately representative. The offloading of a flat-deck barge was parameterized in the following way:

- It was assumed that the inverse of the release patterns for a hopper barge operating in shallow water (i.e. with low plume acceleration or water entrainment) are applicable. Therefore, the largest fugitive TSS release was assumed to be in the top 3 m of the water column, with the 16% of the fugitive TSS released in the top 1 m, the remaining 62% released in the top 3 m and the remaining 38% evenly distributed between 3 m below the surface and the bed.
- It was assumed that one hour was needed to fully offload the flat-deck barge with the offloading occurring relatively continuously. Therefore, rather than a 60 s release time as was assumed for the hopper barge dump, the release was spread uniformly over 3,600 s.

4.0 FUGITIVE TSS RELEASE

Table 4.1 provides a high level overview of the general construction sequence, summarizes the as-simulated construction cases and gives the associated report section number. The placement of Mattress Rock and Dyke Core Rock was not simulated as neither of these materials have a significant fines fraction and there was a worst-case analogue (i.e. a similar activity taking place with a material having a higher fines content) being simulated. In all cases, the infilling of the perimeter dykes with only General Fill and Berm Filter material has been simulated. It has been assumed that materials placed below perimeter dyke lift 3 will be placed using a bottom dump hopper barge, with the infill of perimeter dyke lift 4 being placed with a flat deck barge due to depth limitations associated with the opening of the hopper doors. Infill of perimeter dyke lift 5 is above mean water and, therefore is assumed to be filled using hydraulically pumped materials and, hence, not subject to fugitive TSS release. It has been assumed that supernatant water resulting from the hydraulically placed fill material will drain through a sand filter lining the inside of the perimeter dykes, with all sediment being contained behind the dykes (i.e. no flow-through of suspended sediment).

Table 4.1: Summary of As-Simulated Construction Activity

Construction Activity	Material	Placement Method	Worst-Case Analogue	Report Section
Dredge Cut Back Fill	Mattress Rock	Hopper	Berm Infill 1	
Dyke Lift 1	Dyke Core Rock	Hopper	Berm Infill 1	
Infill 1	General Fill and Berm Filter	Hopper	Directly Simulated	West: Section 4.1 East: Section 4.3
Dyke Lift 2	Dyke Core Rock	Hopper	Berm Infill 2	
Infill 2	General Fill and Berm Filter	Hopper	Directly Simulated	West: Section 4.1 East: Section 4.3
Dyke Lift 3	Dyke Core Rock	Hopper	Berm Infill 3	
Infill 3	General Fill and Berm Filter	Hopper	Directly Simulated	West: Section 4.1 East: Section 4.3
Dyke Lift 4 ¹	Dyke Core Rock	Flat-Deck/ Mechanical	Berm Infill 4	
Infill 4 ¹	General Fill and Berm Filter	Flat-Deck	Directly Simulated	West: Section 4.1 East: Section 4.3
Dyke Lifts 5 ¹	Dyke Core Rock	Mechanical	Not applicable	
Infill 5 ¹	General Fill and Berm Filter	Hydraulic	Not applicable	

¹ Partially or fully above water

4.1 West Basin Perimeter Dyke Lifts 1 to 4: Hopper and Flat-Deck Operations

The West Basin Infill consists of approximately 681,600 m³ of total material (i.e. including dykes, mattress, etc.) of which 432,000 m³ is general fill and berm filter material that contains an approximately 5% fines content and is, hence, simulated in this study. The modelling presented in this section is based on conceptual plan for infilling and dyke construction, and may be modified by the contractor during the design stage. Infill will proceed in a series of five 4.5 m trapezoidal perimeter dyke lifts, with infill contained behind the rising dykes. Infill of the perimeter dykes will proceed with hopper and flat-deck barge placement of fill material, with the barges floated over the perimeter dykes while there is sufficient clearance. For perimeter dyke lifts 1, 2 and 3 there will be clearance to allow direct placement of the fill material. Following perimeter dyke lift 4, the dyke crest will penetrate the water surface at low tide and, therefore, the entire basin footprint will regularly dry as the infilling operation progresses from empty to full. A simulation of the infill of perimeter dyke lift 4 using a flat deck barge for an empty berm condition is included in this section but not a full berm as filling mechanism for this condition was not established at the time of writing. The following dyke crest elevations at the West Basin Infill have been assumed:

- Perimeter Dyke Lift 1: crest elevation -11.0 m CD, toe elevation variable
- Perimeter Dyke Lift 2: crest elevation -6.5 m CD, toe elevation -11.0 m CD
- Perimeter Dyke Lift 3: crest elevation -2.0 m CD, toe elevation -6.5 m CD
- Perimeter Dyke Lift 4: crest elevation +2.5 m CD, toe elevation +2.5 m CD
- Perimeter Dyke Lift 5: crest elevation: +7.0 m CD, toe elevation +2.5 m CD

The West Basin is in a relatively exposed location, being located in the path of the flood tide jet originating in First Narrows. During ebb tides, complex flow patterns along the face of Centerm result from the ebb tide jet from Second Narrows entering central Vancouver Harbour. The proposed construction sequence of the West Basin Infill, however, provides effective sheltering and serves to mitigate the worst effects of fugitive TSS loss:

- **Caisson Installation:** by installing the caissons fronting the western infill of CEP, a relatively sheltered infill zone is created, limiting flushing of the infill zone and, hence, the potential for far-field TSS plume dispersal.
- **Perimeter Dyke Lift Sequence:** the highest concentration of TSS released by hopper barge filling is within a few meters of the seabed. This sediment laden water is denser than then surrounding seawater and tends to remains near the bed. As the Perimeter Dykes are typically several meters above the infill level, they provide a barrier to the dispersal of TSS, effectively damming the TSS as a lens of dense near bed water.

This relationship between caisson sheltering and the dyke containment of TSS laden water results in relatively modest TSS losses to Vancouver Harbour as the perimeter dykes typically contain the TSS plume while the sheltered environments behind the caissons enables far more settling that would otherwise be possible.

The concentration of fugitive TSS arising from infilling at the West Basin is governed the plume's interaction with ambient currents which are, in turn, mediated by the perimeter dyke elevation and fill level behind the dykes. As the TSS plume is transported by the currents away from its source location, the concentration of the plume is reduced by mixing with the ambient waters of Burrard Inlet. The faster the plume is transported away from its source location, higher concentration it will tend to be as there has been less time for settling and dispersion, however, faster currents tend to mix the plume more efficiently with the surround water, lowering its concentration. Therefore, at any given location the concentration of the plume reflects a balance between mixing and transport caused by the ambient currents. During periods of lower ambient currents within the perimeter dykes, which are more prevalent at the West Basin at low dyke elevations and low fill levels, the TSS plume tends to be 'transport governed' meaning that

the plume is transported away from its source as a relatively higher concentration. At higher dyke elevations and at high fill levels, currents within the perimeter dykes tend to be higher, leading to a 'dilution governed' plume that is diluted to a relatively low concentration as it is being transported away from its source.

Figures 4.1, 4.4, 4.7 and 4.10 present the fugitive TSS plumes resulting from infilling operations following Perimeter Dyke Lifts 1, 2, 3 and 4, respectively. These figures present the fugitive TSS pattern resulting from an empty Perimeter Dyke (i.e. dyke crest 4.5 m above fill level) immediately following the dyke lift. Figures 4.2, 4.5, and 4.8 present the fugitive TSS plumes resulting from infilling operations immediately prior to perimeter dyke Lifts 2, 3 and 4, respectively. These figures present the fugitive TSS pattern resulting from a full Perimeter Dyke (i.e. dyke crest at fill level) immediately prior to the next dyke lift.

On these figures, the top panel presents the probability of the water column maximum TSS exceeding 5 mg/L during the infill operation. For example, a 5% probability indicates that for a 14 day infill cycle, the maximum above-background concentration of TSS will exceed 5 mg/L for approximately 17 hours over the entire infill period or, alternatively, 1 hour and 12 minutes per day. The middle panel of these figures shows this same information for an exceedance threshold of 25 mg/L, while the bottom panel shows the probability that the maximum above background TSS concentration will be greater than 10% of the initial source strength. Based on these figures, the following generalizations can be made:

- With the exception of Dyke Lift 3, "empty" perimeter dyke cases have a larger maximum TSS plume above 5 mg/L and 25 mg/L as compared to the "Full" perimeter dyke cases. This is because the TSS plume generated during the full perimeter dyke condition is diluted comparatively faster below 5/25 mg/L than during the empty case when the TSS plumes are sheltered from the strongest currents and, hence, mixing by the dykes.
- The full condition of Dyke Lift 3 has a larger TSS plume footprint than the empty condition because a combination of the sheltering that is provided by the caissons (which is independent of dyke elevation) and the near-surface position of the TSS plume due to its shallow initial release depth. Because the plume is initially confined to the near-surface waters by the shallow depth of the full Dyke Lift 3, when it exits the shadow of the caissons it is exposed to relatively high velocity surface currents which transport the plume comparatively farther than the slightly deeper empty Dyke Lift 3 case.
- As the dykes are built progressively higher (Perimeter Dyke 1 is the lowest, Perimeter Dyke 4 is the highest) the footprint of the TSS plume above 5 mg/L and 25 mg/L becomes smaller. This is because the more modest currents present at deeper depths (e.g. Perimeter Dyke 1) transport the TSS plume away from its source with much less dilution than the stronger near-surface currents that are present as the dykes rise through the water column (e.g. Perimeter Dyke 3). Therefore, as the dykes are built upwards, dilution increases and, hence, the faster the maximum TSS concentration drops below 5/25 mg/L.
- For the 25 mg/L plots for Perimeter Dykes 2 and 3, there is a blocky edge that is apparent. This edge traces the outline of the hopper barge dump location, hence the blockiness.
- For all cases except dyke lift 4, the probability of exceeding 10% of the source concentration at any given instant is always << 1% as the initial TSS concentration associated with the infilling operation is very high and attenuates rapidly. During infilling following dyke Lift 4 the maximum TSS concentration often exceeds 10% of the source concentration, mainly because infilling the perimeter dyke elevation following lift 4 penetrates the water's surface at low tide, occasionally trapping TSS in a perched pool of water behind the dykes.

Tables 4.2 and 4.3 present a summary of the data underlying the above figures for full and empty perimeter dyke cases, respectively. From these tables it is apparent that the probability of exceeding either 5 mg/L or 25 mg/L outside of the perimeter dyke footprint is relatively small, never exceeding 10% beyond 100 m from the dykes and rarely exceeding 1% beyond 150 m from the dykes.

Table 4.2: Distance from Infill Boundary to Achieve Maximum TSS of 5 mg/L and 25 mg/L, Empty Perimeter Dyke

Probability of Exceedance ¹	Infill 1		Infill 2		Infill 3		Infill 4		Unit
	5 mg/L	25 mg/L	5 mg/L	25 mg/L	5 mg/L	25 mg/L	5 mg/L	25 mg/L	
90%	Contained within Perimeter Dykes	Within Per. Dykes	Contained within Perimeter Dykes	m					
80%									m
70%									m
60%									m
50%									m
40%									m
30%									m
20%									m
10%		60		50		25	50		m
1%	190	40	150	50	70	30	m		

¹ The probability that the instantaneous water-column maximum TSS will exceed a given value over the infill period. For example, a 1% probability of exceeding 5 mg/L indicates that, over a 14 day infill period, the maximum TSS in the water column may exceed 5 mg/L for a total of 3 hours and 20 minutes.

Table 4.3: Distance from Infill Boundary to Achieve Maximum TSS of 5 mg/L and 25 mg/L, Full Perimeter Dyke

Probability of Exceedance ¹	Infill 1		Infill 2		Infill 3		Infill 4		Unit
	5 mg/L	25 mg/L							
90%	Contained within Perimeter Dykes	m							
80%									m
70%									m
60%									m
50%									m
40%									m
30%									m
20%		50		60		25			m
10%	60	70	100	30	m				
1%	90								

¹ The probability that the instantaneous water-column maximum TSS will exceed a given value over the infill period. For example, a 1% probability of exceeding 5 mg/L indicates that, over a 14 day infill period, the maximum TSS in the water column may exceed 5 mg/L for a total of 3 hours and 20 minutes.

Figures 4.3, 4.6, 4.9, 4.11 present time-series of the fugitive TSS concentration crossing a 100 m threshold from the crest of the perimeter dykes for Perimeter Dyke Lifts 1, 2, 3 and 4, respectively. The top panel of these figures presents the maximum fugitive TSS concentration exiting a 100 m perimeter around the infill zone, the second from the top panel presents the maximum average fugitive TSS concentration crossing this boundary (this is most directly applicable to CCME guidelines), the second from the bottom panel presents the tidal level at Point Atkinson and the bottom panel presents the source TSS concentration. Note the difference in the vertical axis scale between the top and the second from the top panel graphs.

From these plots it is apparent that for the vast majority of the infilling operation the maximum concentration of fugitive TSS exiting a 100 m threshold from the perimeter dykes is below 5 mg/L, with episodic spikes with a duration typically less than 4 hours with a typical concentration between 50 mg/L and 100 mg/L. The maximum average TSS concentration rarely exceeds 5 mg/L, and only does so during episodic spikes to a typical concentration between 5 mg/L and 10 mg/L with a similar duration of less than 4 hours. Tables 4.4 and 4.5 summarize the data presented in these figures for empty and full perimeter dyke cases, respectively. Taken over all perimeter dyke elevations, the CCME standard for TSS (5 mg/L) may be exceeded 1% of the time beyond 100 m from the dyke crest. When the 5 mg/L is exceeded, however, maximum TSS concentrations as high as 231 mg/L are possible, with a maximum average concentrations as high as 11 mg/L 100 m from the edge of the dyke crest.

Table 4.4: Maximum Average and Maximum Concentration 100 m Infill Boundary, Empty Berm

Percentile	Infill 1		Infill 2		Infill 3		Infill 4		Unit
	Maximum Average ¹	Maximum ²							
Maximum	8.7	81.6	10.8	110.3	6.9	230.6	3.2	13.8	mg/L
99 ³	1.8	6.9	1.2	4.3	1.7	2.2	1.5	2.6	mg/L
95	0.7	1.6	0.5	1.1	0.8	0.5	1.0	0.7	mg/L
90	0.4	0.7	0.3	0.5	0.5	0.3	0.7	0.3	mg/L
50	0.1	0.1	0.1	0	0.1	0	0.2	0	mg/L
10	0	0	0	0	0	0	0	0	mg/L
Minimum	0	0	0	0	0	0	0	0	mg/L

¹ Percentile, maximum and minimum values are calculated from the water column average TSS concentration at 1 hour intervals.

² Percentile, maximum and minimum values are calculated from the water column maximum TSS concentration at 15 minute intervals.

Therefore, the Maximum value occurs for less than 15 minutes out of 14 days at a 10 m by 10 m by 1 m parcel of water in Vancouver Harbour.

³ The 99th percentile concentrations is the TSS concentration at which 99% of all other possible TSS concentrations occurring in time and space will be lower than the 99th percentile. Any concentrations greater than the 99th percentile will occur for only 3 hours and 20 minutes out of a 14 day infill period.

Table 4.5: Maximum Average and Maximum Concentration 100 m Infill Boundary, Full Berm

Percentile	Infill 1		Infill 2		Infill 3		Infill 4		Unit
	Maximum Average ¹	Maximum ²							
Maximum	6.0	166.0	5.3	209.9	3.4	20.1			mg/L
99 ³	1.6	3.1	1.6	2.9	0.8	3.5			mg/L
95	0.8	0.8	0.8	0.9	0.3	0.7			mg/L
90	0.6	0.4	0.6	0.4	0.2	0.3			mg/L
50	0.1	0	0.1	0	0	0			mg/L
10	0	0	0	0	0	0			mg/L
Minimum	0	0	0	0	0	0			mg/L

¹ Percentile, maximum and minimum values are calculated from the water column average TSS concentration at 1 hour intervals.

² Percentile, maximum and minimum values are calculated from the water column maximum TSS concentration at 15 minute intervals. Therefore, the Maximum value occurs for less than 15 minutes out of 14 days at a 10 m by 10 m by 1 m parcel of water in Vancouver Harbour.

³ The 99th percentile concentrations is the TSS concentration at which 99% of all other possible TSS concentrations occurring in time and space will be lower than the 99th percentile. Any concentrations greater than the 99th percentile will occur for only 3 hours and 20 minutes out of a 14 day infill period.

4.2 East Basin Perimeter Dyke Lifts 1 to 4: Hopper and Flat-Deck Operations

The East Basin Infill consists of approximately 900,000 m³ of total material (i.e. including dykes, mattress, etc.) of which 528,000 m³ is general fill material that contains an approximately 5% fines content and is, hence, simulated in this study. The modelling presented in this section is based on conceptual plan for infilling and dyke construction, and may be modified by the contractor during the design stage. Infill will proceed in a series of five 4.5 m trapezoidal perimeter dyke lifts, with infill contained behind the rising dykes. Infill of the perimeter dykes will proceed with hopper and flat-deck barge placement of fill material, with the barges floated over the perimeter dykes while there is sufficient clearance. For perimeter dyke lifts 1, 2 and 3 there will almost certainly be clearance to allow direct placement of the fill material. Following perimeter dyke lift 4, the dyke crest will penetrate the water surface at low tide and, therefore, the entire basin footprint will regularly dry as the infilling operation progresses from empty to full. A simulation of the infill of perimeter dyke lift 4 using a flat deck barge for an empty berm condition is included in this section but not a full berm as filling mechanism for this condition was not established at the time of writing. The following dyke crest elevations at the East Basin Infill have been assumed:

- Perimeter Dyke Lift 1: crest elevation -11.5 m CD, toe elevation variable
- Perimeter Dyke Lift 2: crest elevation -6.0 m CD, toe elevation -11.5 m CD
- Perimeter Dyke Lift 3: crest elevation -2.5 m CD, toe elevation -6.0 m CD
- Perimeter Dyke Lift 4: crest elevation +2.0 m CD, toe elevation -2.5 m CD
- Perimeter Dyke Lift 5: crest elevation: +6.5 m CD, toe elevation +2.0 m CD

The East Basin Infill is in a relatively sheltered location, being located in an embayment between Ballantyne Pier and Southern Railway Pier. The location of the East Basin within Vancouver Harbour and the surrounding currents generally act to suppress the dispersion of fugitive TSS releases from the infill operation:

- **Tidal Currents:** the East Basin Infill is generally subject to mild currents with flood tides producing a weak clockwise circulation offshore of the infill location and ebb tides producing a counter-clockwise gyre between Ballantyne Pier and Vanterm. As a result of these generally constrained circulation patterns, TSS released during the East Basin Infilling operation does not tend to disperse far beyond the northern edge of Centerm.
- **Basin Confinement:** The East Basin Infill is constrained by the shoreline on three sides, limiting tidal agitation to simple exchange flows as the water level of Vancouver Harbour rises and falls, rather than the strong tidal currents generated by First and Second Narrows. Therefore the dispersion potential of sediments from the East Basin Infill is relatively low.

The concentration of fugitive TSS arising from infilling at the East Basin is governed by the tidal exchange in the confined basin between the Ballantyne and Southern Railway Piers and the plume's interaction with ambient currents once outside of this embayment. At low perimeter dyke elevations where the dykes present little obstacle to TSS transport, the TSS plume is transported by ambient currents away from its source location and the concentration of the plume is reduced by mixing with the waters of Burrard Inlet. As the perimeter dykes are built upwards through the water column, at mid-depth elevations they present a barrier to plume transport and act to confine TSS in the East Basin footprint. As the perimeter dykes approach the surface, the tidal velocities over the dyke crest become stronger because the same tidal prism (i.e. tidal exchange volume) is flowing through a smaller cross-sectional area. These more vigorous tidal currents lead to a larger TSS plume footprint as the dykes approach the surface.

Figures 4.12, 4.15, 4.18 and 4.21 present the maximum fugitive TSS plumes resulting from infilling operations following Perimeter Dyke Lifts 1, 2, 3 and 4, respectively. This condition is representative of an empty Perimeter Dyke (i.e. dyke crest 4.5 m above fill level) immediately following the dyke lift. Figures 4.13, 4.16, and 4.19 present the fugitive TSS plumes resulting from infilling operations immediately prior to Perimeter Dyke Lifts 2, 3 and 4, respectively. This condition is representative of a full Perimeter Dyke (i.e. dyke crest at fill level) immediately prior to the next dyke lift.

On these figures, the top panel presents the probability of the water column maximum TSS exceeding 5 mg/L during the infill operation. For example, a 5% probability indicates that for a 14 day infill cycle, the maximum above-background concentration of TSS will exceed 5 mg/L for approximately 17 hours over 14 days or, alternatively, 1 hour and 12 minutes per day. The middle panel of these figures shows this same information for an exceedance threshold of 25 mg/L, while the bottom panel shows the probability that the maximum above background TSS concentration will be greater than 10% of the initial source strength. Based on these figures, the following comparisons between the TSS behaviour at rising dyke elevations can be made:

- **Perimeter Dyke Lift 1:** The perimeter dyke crest is essentially at grade along much of the infill footprint between Ballantyne and Southern Railway Piers and, as a result, presents little impediment to the dispersal of TSS. Hence, there is no clear trend between the “empty” and “full” cases as there is always an escape path for the TSS, regardless of the fill level behind the berm.
- **Perimeter Dyke Lift 2:** The perimeter dyke crest is up to 4.5m above the surrounding grade and, therefore, presents an impediment to TSS dispersal. This is why the TSS plume resulting from the infill of perimeter dyke lift 2 is significantly smaller than for lift 1.
- **Perimeter Dyke Lift 3:** Since the perimeter dyke crest is now approaching the surface, TSS dispersal is enhanced by flow acceleration over the dyke crest and the generally higher near surface velocities in Vancouver Harbour. Therefore, the TSS plume resulting from the infill of perimeter dyke lift 3 is larger than that of both lift 1 and lift 2. Consistent with the results of the West Basin Infill, as the dyke crest approaches the surface there is a more marked difference in the shape of the TSS plume based on whether the dyke is “empty” or “full”.
- **Perimeter Dyke Lift 4:** The trend of increasing TSS plume footprint with increasing dyke elevation identified at Perimeter Dyke Lift 3 continues, with the increased tidal flow velocity over the dyke crests leading to enhanced plume transport.

Tables 4.6 and 4.7 present a summary of the data underlying the above figures for full and empty perimeter dyke cases, respectively. From these tables it is apparent that the probability of the maximum TSS exceeding either 5 mg/L or 25 mg/L outside of the perimeter dyke footprint is relatively small, never exceeding 30% beyond 20 m from the dykes and rarely exceeding 1% beyond 380 m from the dykes. From these tables, it is apparent that Dyke Lift 2 has much lower maximum TSS levels compared to all other dyke lifts. This is because, at this mid-depth elevation, the dykes present an effective barrier to plume transport while, at the same time, do not rise high enough in the water column to significantly accelerate tidal exchange flows over the dykes and, hence, draw the TSS plume into Burrard Inlet.

Table 4.6: Distance from Infill Boundary to Achieve Maximum TSS of 5 mg/L and 25 mg/L, Empty Perimeter Dyke

Probability of Exceedance	Infill 1		Infill 2		Infill 3		Infill 4		Unit
	5 mg/L	25 mg/L							
90%	Contained within Perimeter Dykes	m							
80%									m
70%									m
60%									m
50%									m
40%									m
30%									m
20%									m
10%	40	20	10				40	20	m
1%	170	60	40				290	40	
							380	130	

¹ The probability that the instantaneous water-column maximum TSS will exceed a given value over the infill period. For example, a 1% probability of exceeding 5 mg/L indicates that, over a 14 day infill period, the maximum TSS in the water column may exceed 5 mg/L for a total of 3 hours and 20 minutes.

Table 4.7: Distance from Infill Boundary to Achieve Maximum TSS of 5 mg/L and 25 mg/L, Full Perimeter Dyke

Probability of Exceedance	Infill 1		Infill 2		Infill 3		Infill 4		Unit
	5 mg/L	25 mg/L							
90%	Contained within Perimeter Dykes	m							
80%									m
70%									m
60%									m
50%									m
40%									m
30%									m
20%									m
10%	50	20	10				50	m	
1%	100	60	50				330	40	

¹ The probability that the instantaneous water-column maximum TSS will exceed a given value over the infill period. For example, a 1% probability of exceeding 5 mg/L indicates that, over a 14 day infill period, the maximum TSS in the water column may exceed 5 mg/L for a total of 3 hours and 20 minutes.

Figures 4.14, 4.17, 4.20, 4.22 present the fugitive TSS concentration crossing a 100 m threshold from the crest of the perimeter dykes for perimeter dyke lifts 1, 2, 3 and 4, respectively. The top panel of these figures presents the maximum fugitive TSS concentration exiting a 100 m perimeter around the infill zone, the second from the top panel presents the maximum average fugitive TSS concentration crossing this boundary (this is most directly applicable to CCME guidelines), the second from the bottom panel presents the tidal level at Point Atkinson and the bottom panel presents the source TSS concentration..

From these plots it is apparent that for the vast majority of the infilling operation the maximum concentration of fugitive TSS exiting a 100 m threshold from the perimeter dykes is below 5mg/L, with episodic spikes with a duration typically less than 4 hours with a typical concentration less than 100 mg/L. The maximum average TSS concentration above background rarely exceeds 5 mg/L, and only does so during episodic spikes to a concentration typically less than 10 mg/L and never more than 20 mg/L, with a duration less than 4 hours. Tables 4.8 and 4.9 summarize the data presented in these figures for empty and full perimeter dyke cases, respectively. Taken over all perimeter dyke elevations, the above background fugitive TSS concentration of 5 mg/L will be exceeded 2% of the time beyond 100 m from the dyke crest. When the 5 mg/L is exceeded, however, maximum TSS concentrations as high as 207 mg/L and maximum average concentrations as high as 20 mg/L are possible 100 m from the dyke crest.

Table 4.8: Maximum Average and Maximum Concentration 100 m Infill Boundary, Empty Berm

Percentile	Infill 1		Infill 2		Infill 3		Infill 4		Unit
	Maximum Average ¹	Maximum ²							
Maximum	19.8	207.1	8.7	9.4	9.3	45.5	14.8	137.6	mg/L
99 ³	4.2	6.3	2.0	1.9	2.5	8.0	3.7	13.2	mg/L
95	2.1	1.8	1.0	0.7	1.2	2.3	2.0	4.0	mg/L
90	1.4	0.9	0.7	0.3	0.8	0.9	1.4	2.0	mg/L
50	0.3	0	0.1	0	0.1	0.1	0.3	0.1	mg/L
10	0	0	0	0	0	0	0	0	mg/L
Minimum	0	0	0	0	0	0	0	0	mg/L

¹ Percentile, maximum and minimum values are calculated from the water column average TSS concentration at 1 hour intervals.

² Percentile, maximum and minimum values are calculated from the water column maximum TSS concentration at 15 minute intervals.

Therefore, the Maximum value occurs for less than 15 minutes out of 14 days at a 10 m by 10 m by 1 m parcel of water in Vancouver Harbour.

³ The 99th percentile concentrations is the TSS concentration at which 99% of all other possible TSS concentrations occurring in time and space will be lower than the 99th percentile. Any concentrations greater than the 99th percentile will occur for only 3 hours and 20 minutes out of a 14 day infill period.

Table 4.9: Maximum Average and Maximum Concentration 100 m Infill Boundary, Full Berm

Percentile	Infill 1		Infill 2		Infill 3		Infill 4		Unit
	Maximum Average ¹	Maximum ²							
Maximum	10.1	84.0	7.4	13.7	7.6	97.8			mg/L
99 ³	3.8	4.9	2.2	2.5	2.6	8.8			mg/L
95	1.8	1.4	1.1	0.8	1.1	1.9			mg/L
90	1.1	0.7	0.7	0.4	0.7	0.9			mg/L
50	0.2	0	0.1	0	0.1	0.1			mg/L
10	0	0	0	0	0	0			mg/L
Minimum	0	0	0	0	0	0			mg/L

¹ Percentile, maximum and minimum values are calculated from the water column average TSS concentration at 1 hour intervals.

² Percentile, maximum and minimum values are calculated from the water column maximum TSS concentration at 15 minute intervals.

Therefore, the Maximum value occurs for less than 15 minutes out of 14 days at a 10 m by 10 m by 1 m parcel of water in Vancouver Harbour.

³ The 99th percentile concentrations is the TSS concentration at which 99% of all other possible TSS concentrations occurring in time and space will be lower than the 99th percentile. Any concentrations greater than the 99th percentile will occur for only 3 hours and 20 minutes out of a 14 day infill period.

4.3 Fugitive TSS Peaks

The concentration of TSS resulting from individual hopper barge deliveries to the east and west basins is tied to the tidal phase and hopper dump location: certain locations within the infill basins are more prone to fugitive TSS release under specific tidal conditions. For each perimeter dyke elevation, TSS peaks have been investigated to determine the mechanisms that may generate the largest TSS peaks and recommendations been developed to potentially reduce the largest simulated peaks.

An example of the influence of tidal conditions that drives this spatial and temporal variation in TSS peak formation can be found by comparing Figures 4.23 and 4.24. The top panel of these figures shows the hopper barge position at the time of the dump resulting in a TSS peak (red) and a subsequent dump (green) that does not. The second panel shows the maximum of the water column maximum TSS concentration along the 100 m boundary from the perimeter dykes. The red line shows the TSS resulting from dumps occurring behind full perimeter dykes and the black line shows the TSS resulting from dumps occurring behind empty perimeter dykes. The “red” hopper dump plotted in the top panel occurs at time -1:15 and the “green” hopper dump occurs at time +4:45. The third panel shows the equivalent maximum of the water column average TSS concentration along the 100 m boundary. The fourth panel shows the concurrent tidal level at Point Atkinson and the fifth panel shows the water column averaged source concentration with the red point indicating the hopper dump resulting in the TSS spike (matching the red barge position) and the green point indicating a subsequent hopper dump (batching the green barge position).

Figure 4.23 presents the TSS peak resulting from a hopper barge dump occurring near the perimeter dyke edge during a flood time, while Figure 4.24 presents a very similar hopper dump occurring during an ebb tide. By comparing these figures, it is apparent that the same hopper dump operation can result in radically different fugitive TSS concentrations, depending on whether it occurs during flood or ebb tide. The subsequent summary and recommendations presented in Sections 4.3.1 and 4.3.2 are based on this observation and similar observations of peak TSS events at the both basins for all perimeter dyke elevations.

4.3.1 West Basin TSS Peaks

Filling of the eastern edge of the west basin rarely results in high concentration fugitive TSS releases, while filling of the north-east corner almost never results in significant fugitive TSS releases beyond the perimeter dykes. The most release-prone area of the west basin is the north-west corner. Below is a summary of the timing and potential mitigation measures for each perimeter dyke lift of the west basin.

- **Perimeter Dyke Lift 1:** the largest TSS peaks are associated with flood tide and are relatively insensitive to the position of the barge within the infill footprint.

To minimize fugitive TSS release, infilling during flood tides should be avoided and barge deliveries should be timed to coincide with ebb tide and slack water.

- **Perimeter Dyke Lift 2:** the largest TSS peaks do not show a clear pattern between flood tide and high slack water, but in general flood tide and barge positions near the north-west infill corner result in larger TSS peaks.

To minimize fugitive TSS release, infilling near the perimeter dyke edge and in the north-west corner of the basin should be avoided during flood tides.

- **Perimeter Dyke Lift 3:** the largest TSS peaks are associated with peak flood and ebb velocities and vessel positions near the edge of the perimeter dyke. Whether the tide is flooding or ebbing is less significant than the tidal current velocity and vessel position within the perimeter dykes.

To minimize fugitive TSS release, infilling near the perimeter dyke edges should occur during slack water or during the minor tide of the day.

- **Perimeter Dyke Lift 4:** the largest TSS peaks are associated with high tide and barge positions near the edge of the perimeter dyke.

To minimize fugitive TSS release, infilling operations should be conducted when the perimeter dyke crest is dry and, otherwise, towards the east and north-east sections of the basin while the perimeter dyke crests are submerged.

4.3.2 East Basin TSS Peaks

Infilling of the southern end of the east basin rarely results in high concentration fugitive TSS releases, with fugitive releases occurring from this area at high berm elevations and during ebb tides. Infilling the northern side of the east basin, near the perimeter dyke edge, is prone to producing fugitive TSS releases, particularly at high berm elevations during ebb tide. Below is a summary of the timing and potential mitigation measures for each perimeter dyke lift of the east basin.

- **Perimeter Dyke Lift 1:** the largest TSS peaks are associated with flood tide infilling occurring near the edge of the perimeter dykes.

To minimize fugitive TSS release infilling during slack and ebb tides is preferred.

- **Perimeter Dyke Lift 2:** the largest TSS peaks are associated with flood tide infilling occurring near the edge of the perimeter dykes.

To minimize fugitive TSS release infilling during slack and flood tides is preferred.

- **Perimeter Dyke Lift 3:** The largest TSS peaks are strongly associated with infilling during ebb tide near the edge of the perimeter dykes.

To minimize fugitive TSS release infilling during slack and flood tides is preferred.

- **Perimeter Dyke Lift 4:** The largest TSS peaks are associated with high tide, with a slight bias towards the high water turn to ebb.

To minimize fugitive TSS release infilling during slack and flood tides is preferred.

5.0 CONCLUSION

Based on the results of this modelling study, it is apparent that the concentration and dispersal distance of the TSS plume arising from the infill operation can vary significantly depending on the elevation of the perimeter dyke crest and the specific type of equipment being used. The fugitive TSS concentrations arising from the East and West Basin Infills are approximately equal when all configurations are considered; however, the interaction between the local hydrodynamics, dyke crest elevation and TSS dispersal is complex and, while trends are present, the resulting TSS concentration is highly site specific. Section 5.1 presents site specific results for the West Basin Infill Zone and Section 5.2 presents results for the East Basin Infill Zone, followed by general recommendations for TSS monitoring locations.

5.1 West Basin Infill Zone

At the West Basin, the TSS plume footprint tends to shrink as the perimeter dykes are constructed higher in the water column. This is because at high dyke elevations the relatively fast currents near the surface tend to dilute the TSS plume as it is transported away from the West Basin. Comparatively, the relatively weak near bed currents present at low dyke elevations tend to transport the TSS plume with much lower mixing and dilution resulting in a larger plume footprint. Below, a specific summary for each dyke elevation is given:

- **Perimeter Dyke Lift 1:** modelling results of the West Basin Infill Zone infilling process suggest that project-derived maximum TSS concentration above background drops below 5 mg/L 190 m from source 99% of the time and is contained within the perimeter dyke footprint 70% to 80% of the time. The CCME standard for TSS (5 mg/L) may be exceeded 1% of the time beyond 100 m from the dyke crest at a peak maximum average concentration of 8.7 mg/L. To minimize fugitive TSS release, infilling during flood tides should be avoided and barge deliveries should be timed to coincide with ebb tide and slack water.
- **Perimeter Dyke Lift 2:** modelling results of the West Basin Infill Zone infilling process suggest that project-derived maximum TSS concentration above background drops below 5 mg/L 150 m from source 99% of the time and is contained within the perimeter dyke footprint 80% to 90% of the time. The CCME standard for TSS (5 mg/L) may be exceeded 1% of the time beyond 100 m from the dyke crest at a peak maximum average concentration of 10.8 mg/L. To minimize fugitive TSS release, infilling near the perimeter dyke edge and in the north-west corner of the basin should be avoided during flood tides.
- **Perimeter Dyke Lift 3:** modelling results of the West Basin Infill Zone infilling process suggest that project-derived maximum TSS concentration above background drops below 5 mg/L 100 m from source 99% of the time and is contained within the perimeter dyke footprint 80% to 90% of the time. The CCME standard for TSS (5 mg/L) may be exceeded 1% of the time beyond 100 m from the dyke crest at a peak maximum average concentration of 6.9 mg/L. To minimize fugitive TSS release, infilling near the perimeter dyke edges should occur during slack water or during the minor tide of the day.
- **Perimeter Dyke Lift 4:** modelling results of the West Basin Infill Zone infilling process suggest that project-derived maximum TSS concentration above background drops below 5 mg/L 70 m from source 99% of the time and is contained within the perimeter dyke footprint 70% to 80% of the time. The CCME standard for TSS (5 mg/L) is likely not to be exceeded beyond 100 m from the dyke crest; peak maximum average concentration is 3.2 mg/L. To minimize fugitive TSS release, infilling operations should be conducted when the perimeter dyke crest is dry and, otherwise, towards the east and north-east sections of the basin while the perimeter dyke crests are submerged.

5.2 East Basin Infill Zone

At the East Basin, as the perimeter dykes rise higher in the water column the TSS plume footprint grows in size due to the more vigorous tidal exchange over the perimeter dykes and the lower initial dilution volume as the basin shallows. The East Basin Infill has a generally larger TSS plume footprint compared to the West Basin because the weaker current velocities at the East Basin lead to lower mixing (hence dilution) with ambient waters. In all cases, TSS released at or near high water tends to disperse farther than releases at low water due to the outflow of sediment laden water over the perimeter dykes. Below, a specific summary for each dyke elevation is given:

- **Perimeter Dyke Lift 1:** modelling results of the East Basin Infill Zone infilling process suggest that project-derived maximum TSS concentration above background drops below 5 mg/L 170 m from source 99% of the time and is contained within the perimeter dyke footprint 80% to 90% of the time. The CCME standard for TSS (5 mg/L) may be exceeded 1% of the time beyond 100 m from the dyke crest at a peak maximum average concentration of 19.8 mg/L. To minimize fugitive TSS release infilling during slack and ebb tides is preferred.
- **Perimeter Dyke Lift 2:** modelling results of the East Basin Infill Zone infilling process suggest that project-derived maximum TSS concentration above background drops below 5 mg/L 60 m from source 99% of the time and is contained within the perimeter dyke footprint 80% to 90% of the time. The CCME standard for TSS (5 mg/L) may be exceeded 1% of the time beyond 100 m from the dyke crest at a peak maximum average concentration of 8.7 mg/L. To minimize fugitive TSS release infilling during slack and flood tides is preferred.
- **Perimeter Dyke Lift 3:** modelling results of the East Basin Infill Zone infilling process suggest that project-derived maximum TSS concentration above background drops below 5 mg/L 330 m from source 99% of the time and is contained within the perimeter dyke footprint 80% to 90% of the time. The CCME standard for TSS (5 mg/L) may be exceeded 1% of the time beyond 100 m from the dyke crest at a peak maximum average concentration of 9.3 mg/L. To minimize fugitive TSS release infilling during slack and flood tides is preferred.
- **Perimeter Dyke Lift 4:** modelling results of the East Basin Infill Zone infilling process suggest that project-derived maximum TSS concentration above background drops below 5 mg/L 380 m from source 99% of the time and is contained within the perimeter dyke footprint 60% to 70% of the time. The CCME standard for TSS (5 mg/L) may be exceeded 1% of the time beyond 100 m from the dyke crest at a peak maximum average concentration of 14.8 mg/L. To minimize fugitive TSS release infilling during slack and flood tides is preferred.

Following from the above analysis, the following locations for turbidity monitoring are recommended during dredging activities:

- **General Comments:** the highest TSS concentration tends to be concentrated near the bed, therefore, to capture high-turbidity events arising from construction a bottom-mounted monitoring station is recommended.
- **West Basin Infill Zone:** It is recommended to monitor turbidity on the west side of the caissons where they meet the perimeter dyke and on the southeast side of the infill where the perimeter dykes meet the existing Centerm fill. These two locations are the most consistent places where fugitive TSS exits the perimeter dyke footprint. The northeastern end of Canada Place and the northern tip of Main Street Dock would be effective far-field monitoring locations.
- **East Basin Infill Zone:** It is recommended to monitor turbidity at several locations along the perimeter dyke crest, particularly between Ballantyne and Southern Railway Piers. The eastern face of Centerm and the dock structures immediately north-east of Southern Railway Pier would be effective far-field monitoring locations.

6.0 CLOSURE

We trust this report meets your present requirements. If you have any questions or comments, please contact the undersigned.

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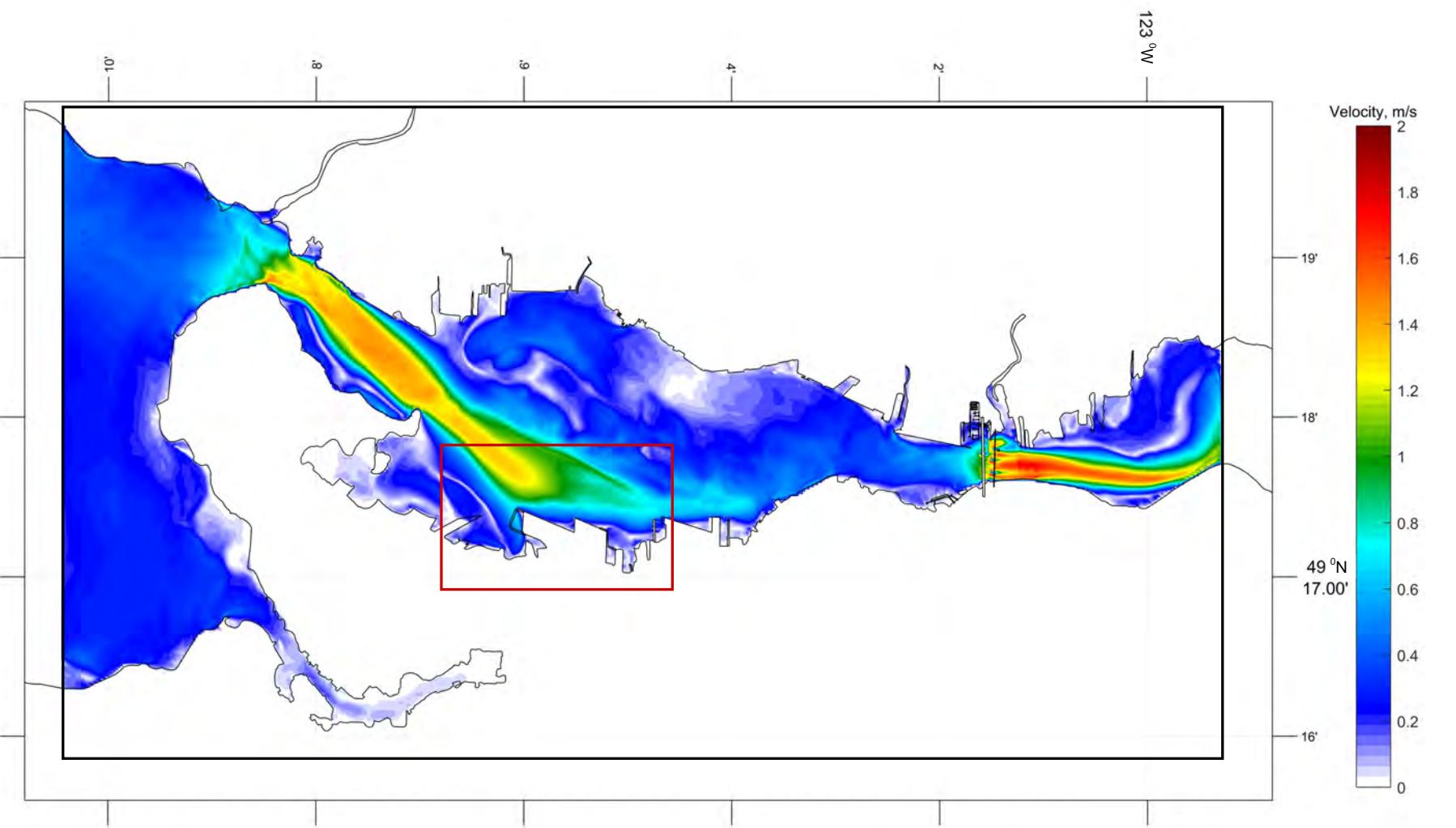
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- Figure 2.3 CEP Infill Overview
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NOTES

- 1) Flow fields are presented for the existing Centerm geometry using Tetra Tech's 25-m and 10-m resolution models of Burrard Inlet.
- 2) Flow fields are visualized at during a moderate flood tide

- 25-m model boundary, nested into larger scale 125-m and 1000-m oceanographic models
- 10-m model boundary, nested into 25-m resolution model

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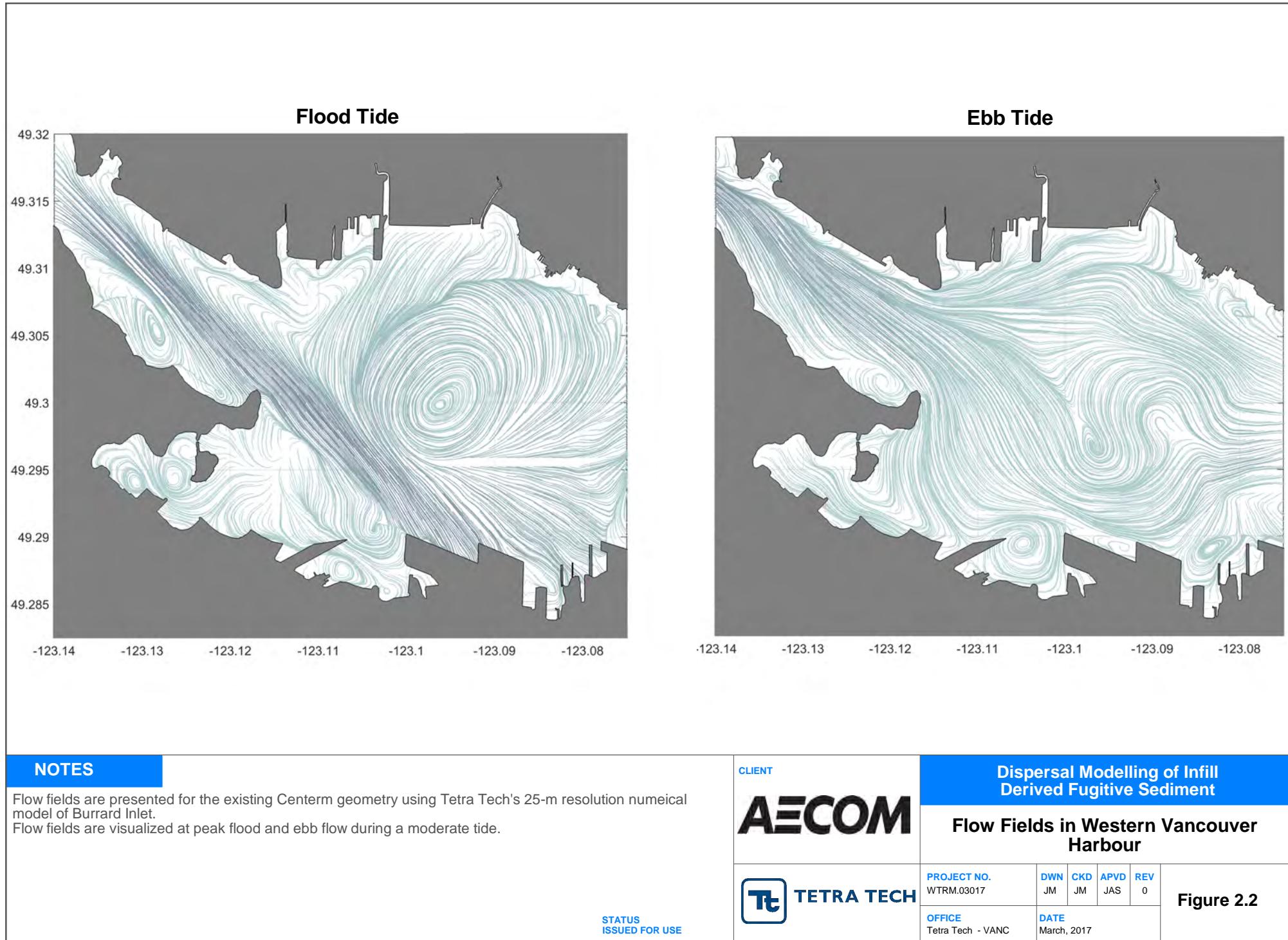
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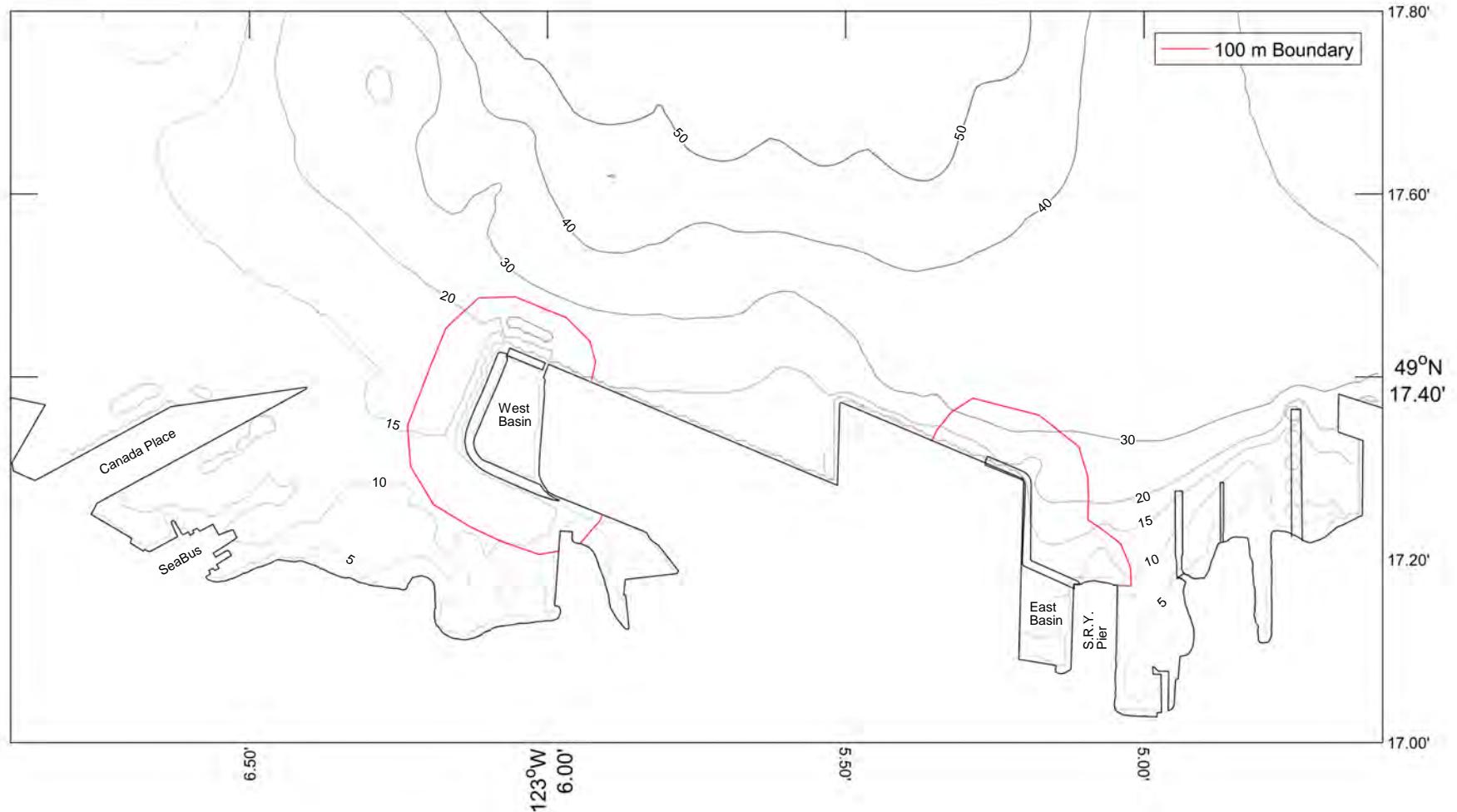
Dispersal Modelling of Infill Derived Fugitive Sediment

25-m and 10-m Resolution Models of Vancouver Harbour

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OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 2.1





NOTES

- 1) West Basin is presented with perimeter dyke lift 3 in place and the northern caissons installed
- 2) East Basin is presented with perimeter dyke lift 3 in place and the current Ballantyne Pier outline

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Dispersal Modelling of Infill
Derived Fugitive Sediment

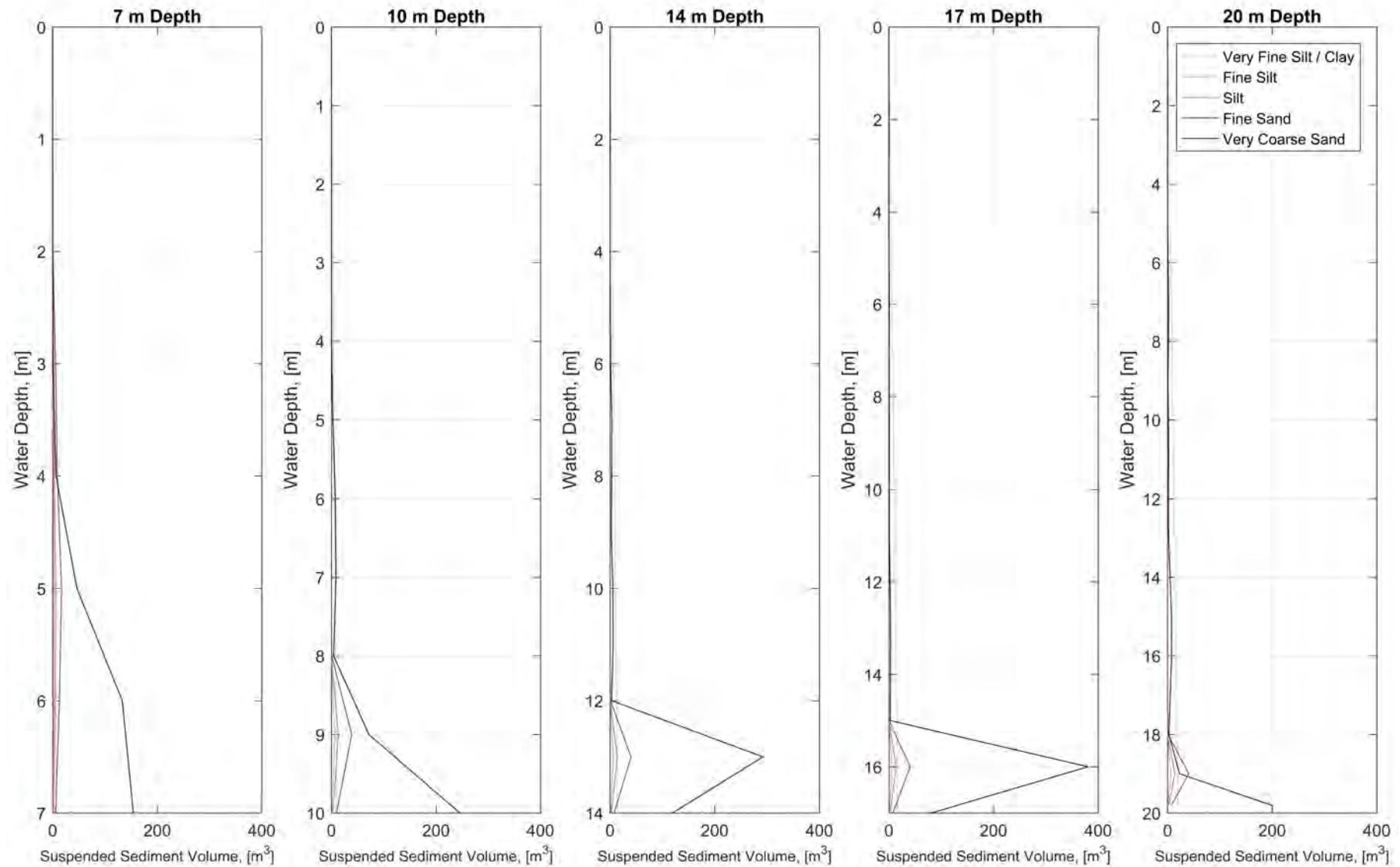
CEP Infill Overview

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Figure 2.3



NOTES

- 1) Suspended sediment concentration as simulated by STFATE, visualized 5 seconds after the dredgeage plume contacts the seabed
- 2) Suspended sediment is presented as the total volume of sediment at a given depth level.
- 3) Note that the vertical scale between panels is not constant

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Dispersal Modelling of Infill Derived Fugitive Sediment

Hopper Barge Dump Suspended Sediment Concentration

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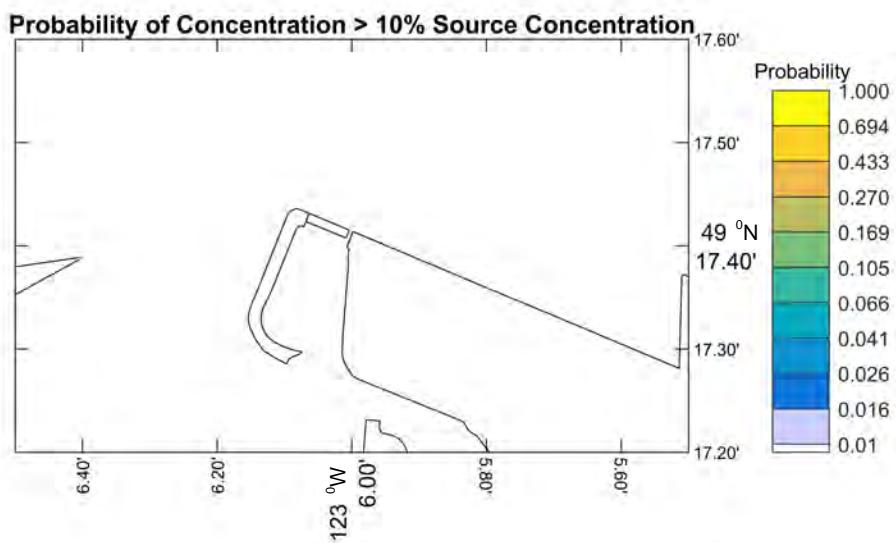
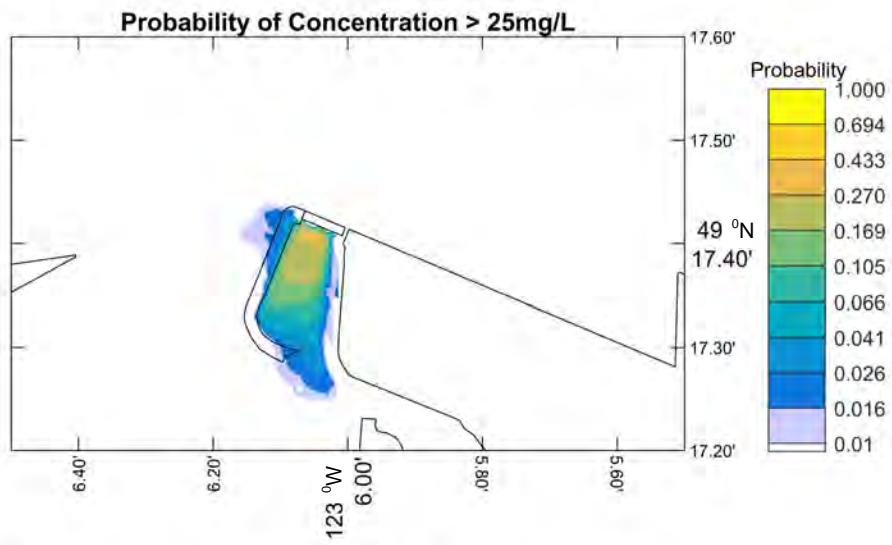
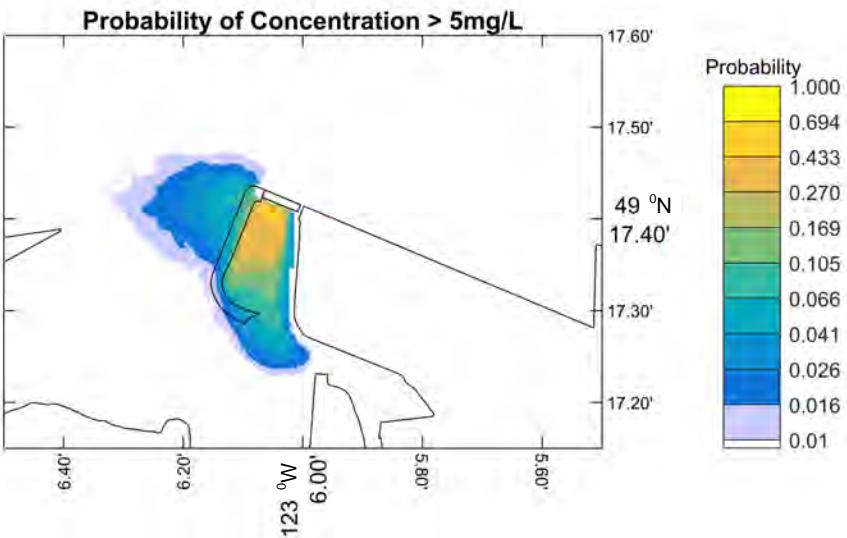
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Figure 3.1



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

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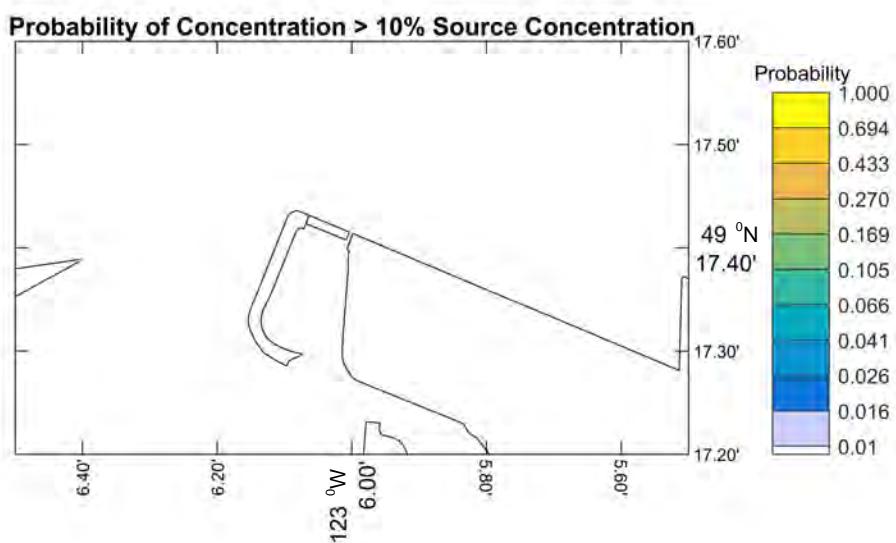
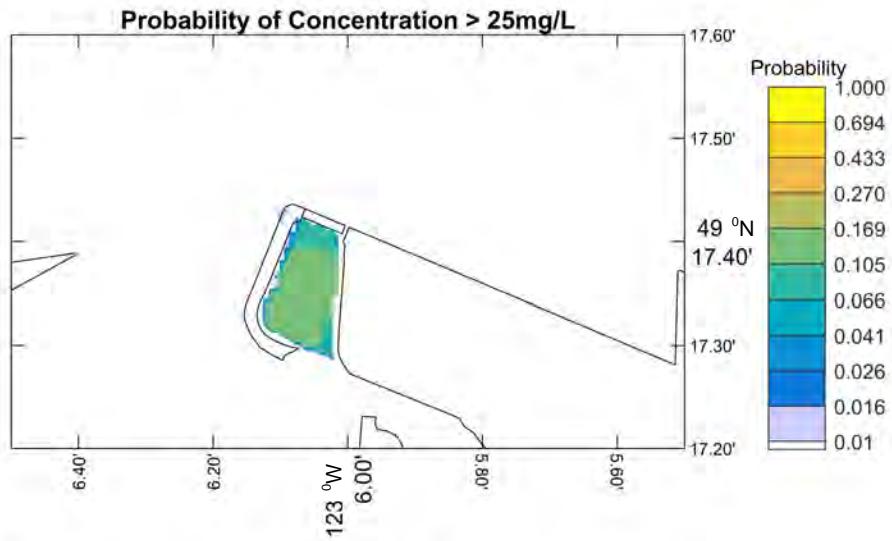
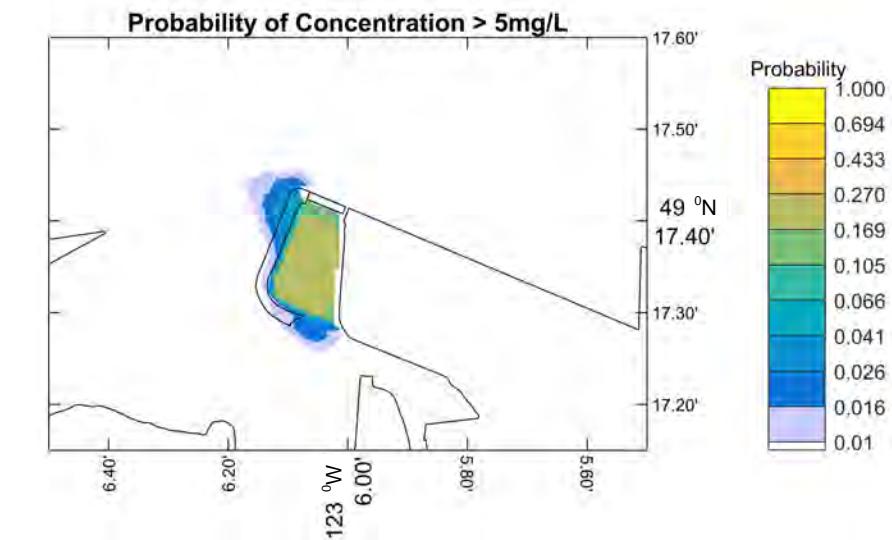
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Dispersal Modelling of Infill Derived Fugitive Sediment

West Basin Infill Zone, Lift 1 Empty Maximum TSS Exceedance Probabilities

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech EBA - VANC	March, 2017			

Figure 4.1



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

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Dispersal Modelling of Infill Derived Fugitive Sediment

West Basin Infill Zone, Lift 1 Full Maximum TSS Exceedance Probabilities



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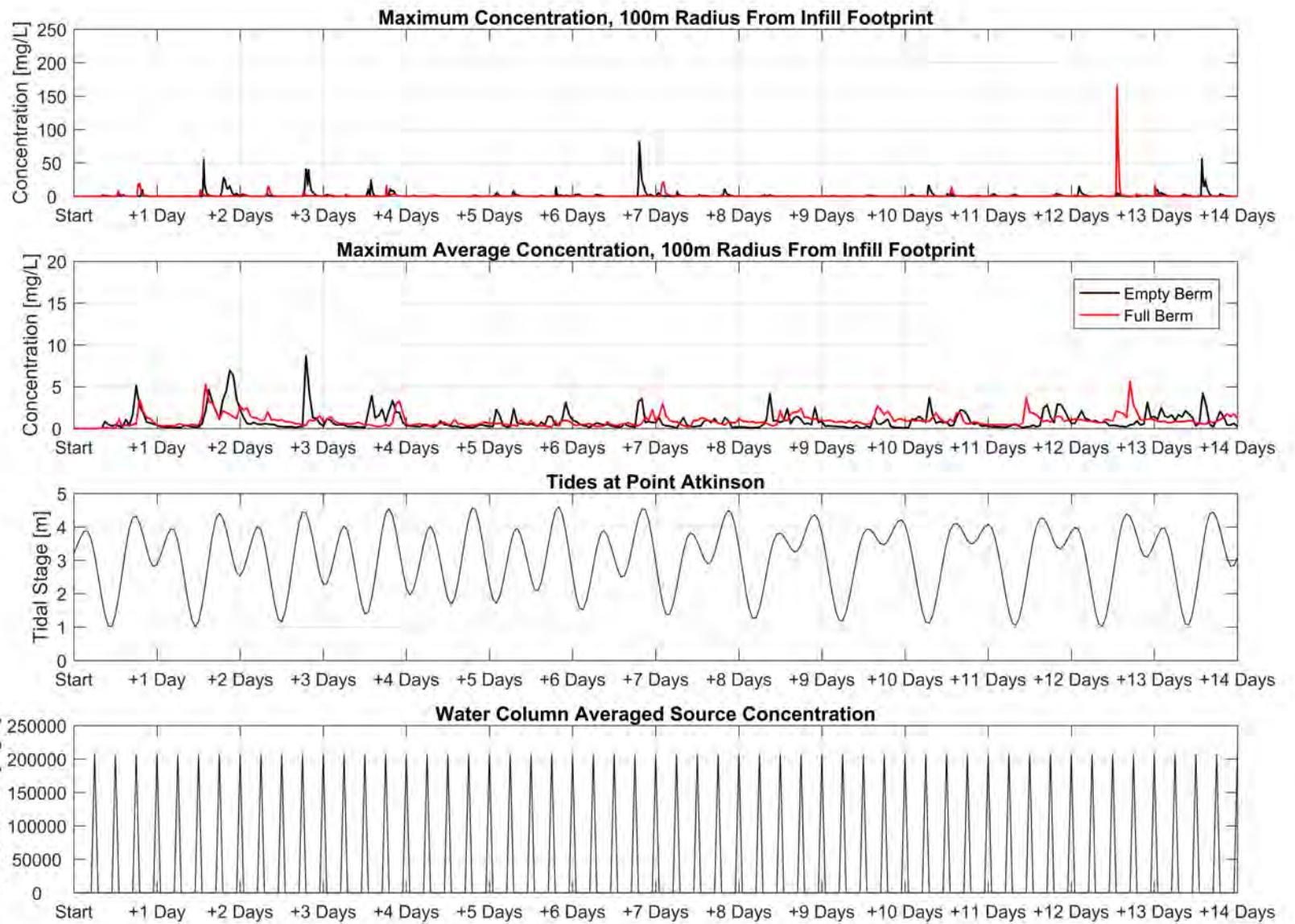
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Figure 4.2



NOTES

- 1) The concentration axis scale differs between plots.
- 2) Maximum concentration is the maximum of the maximum TSS over the water column (seabed to surface) along a boundary 100 m from the edge of the infill footprint.
- 3) Maximum Average concentration is the maximum of the average TSS over the water column (seabed to surface) along a boundary 100 m from the edge of the infill footprint.

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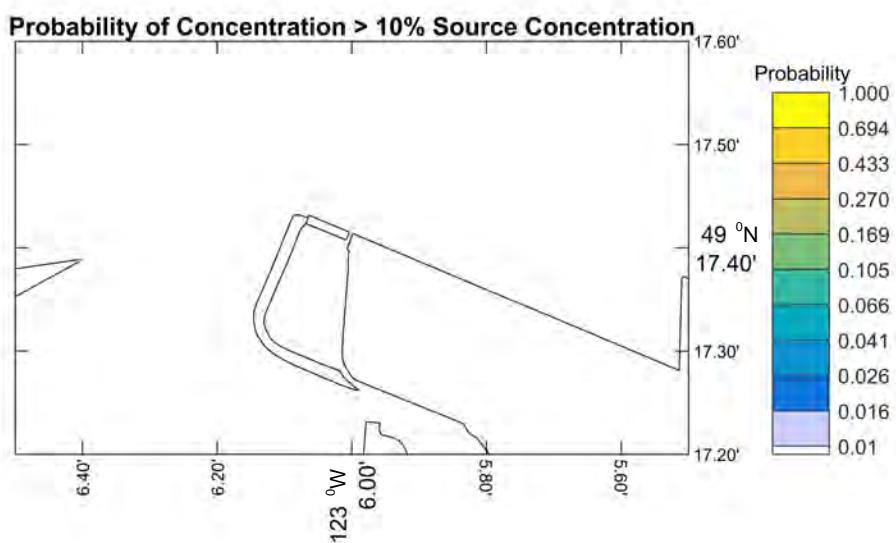
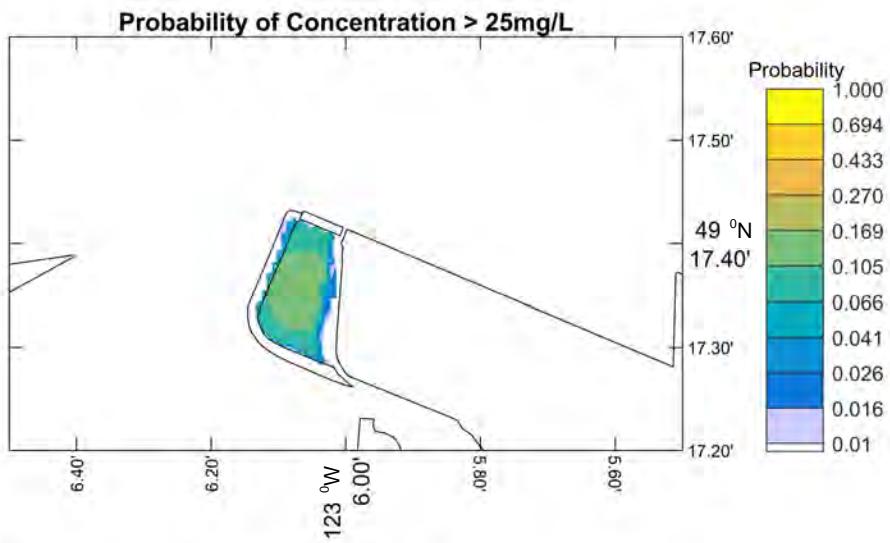
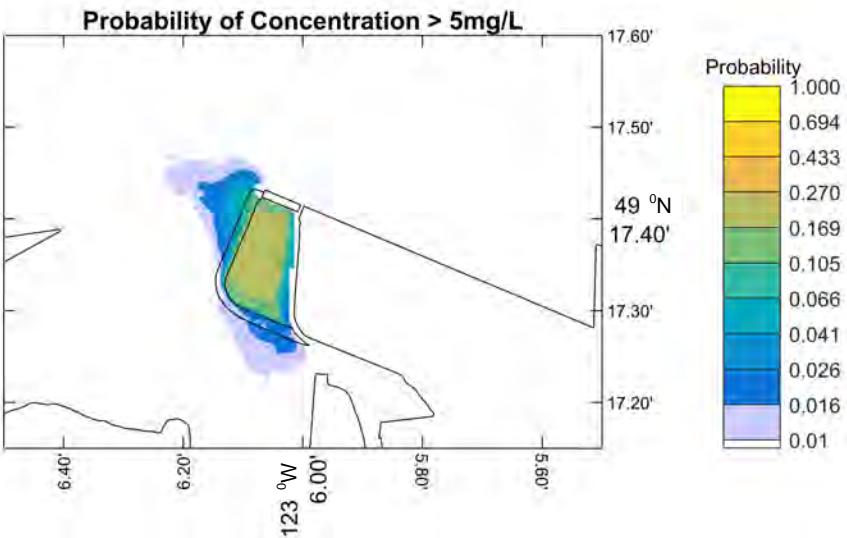
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Dispersal Modelling of Infill Derived Fugitive Sediment

**West Basin Infill Zone, Lift 1
TSS Source Attenuation at 100 m**

PROJECT NO. WTRM:03017	DWN JM	CKD JM	APVD JAS	REV 0
OFFICE Tetra Tech - VANC	DATE March, 2017			

Figure 4.3



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

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Dispersal Modelling of Infill Derived Fugitive Sediment

West Basin Infill Zone, Lift 2 Empty Maximum TSS Exceedance Probabilities



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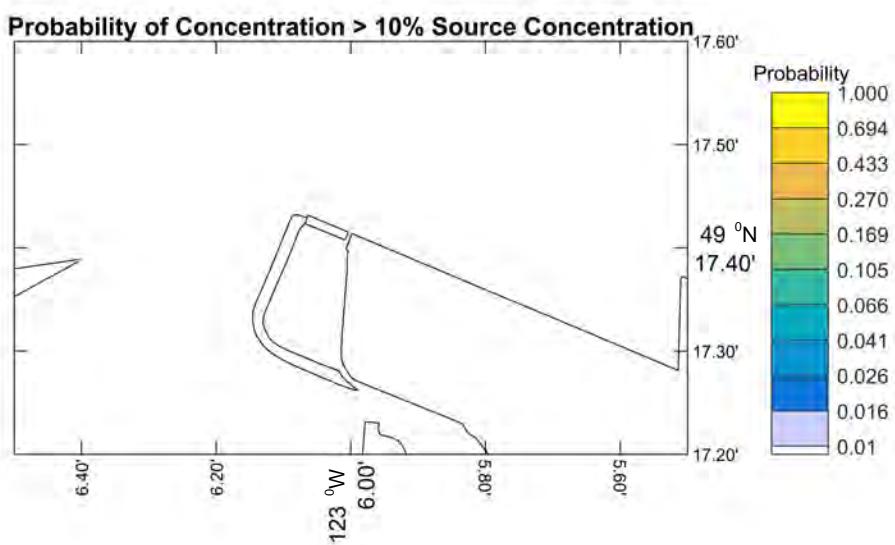
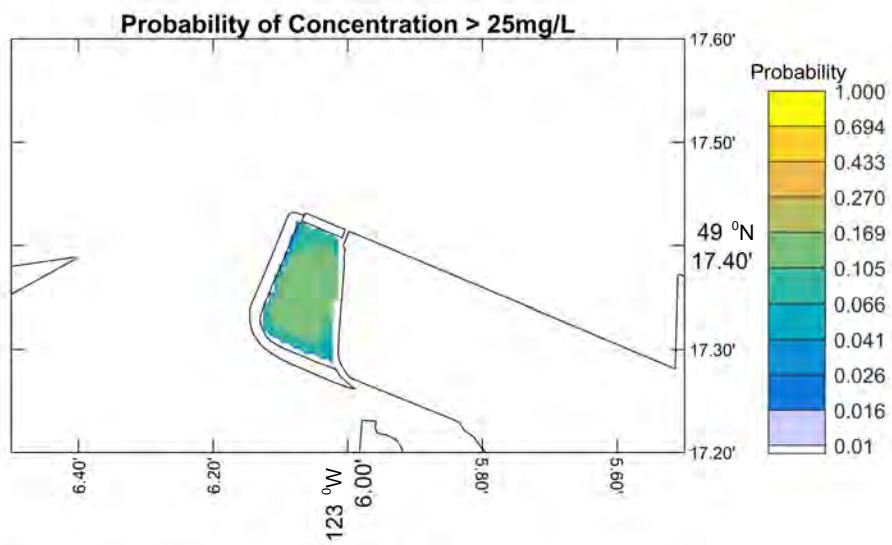
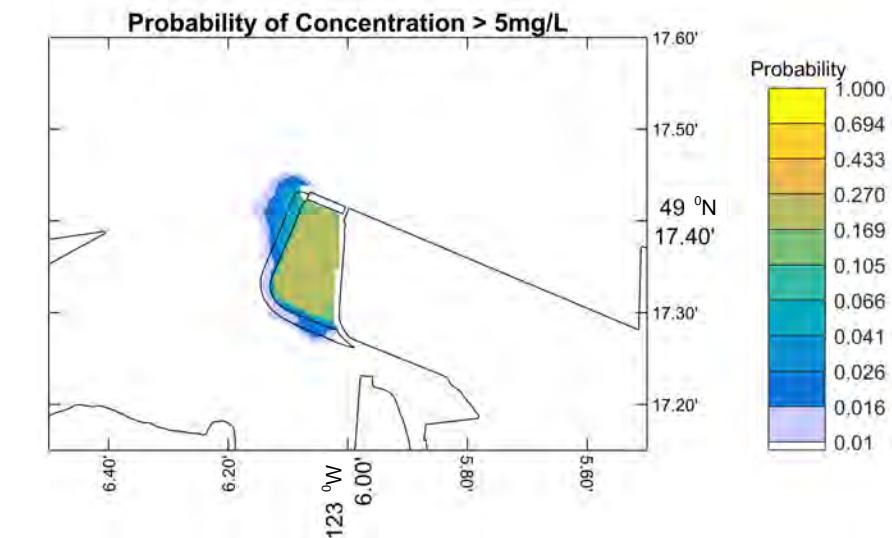
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Figure 4.4



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

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Dispersal Modelling of Infill Derived Fugitive Sediment

West Basin Infill Zone, Lift 2 Full Maximum TSS Exceedance Probabilities



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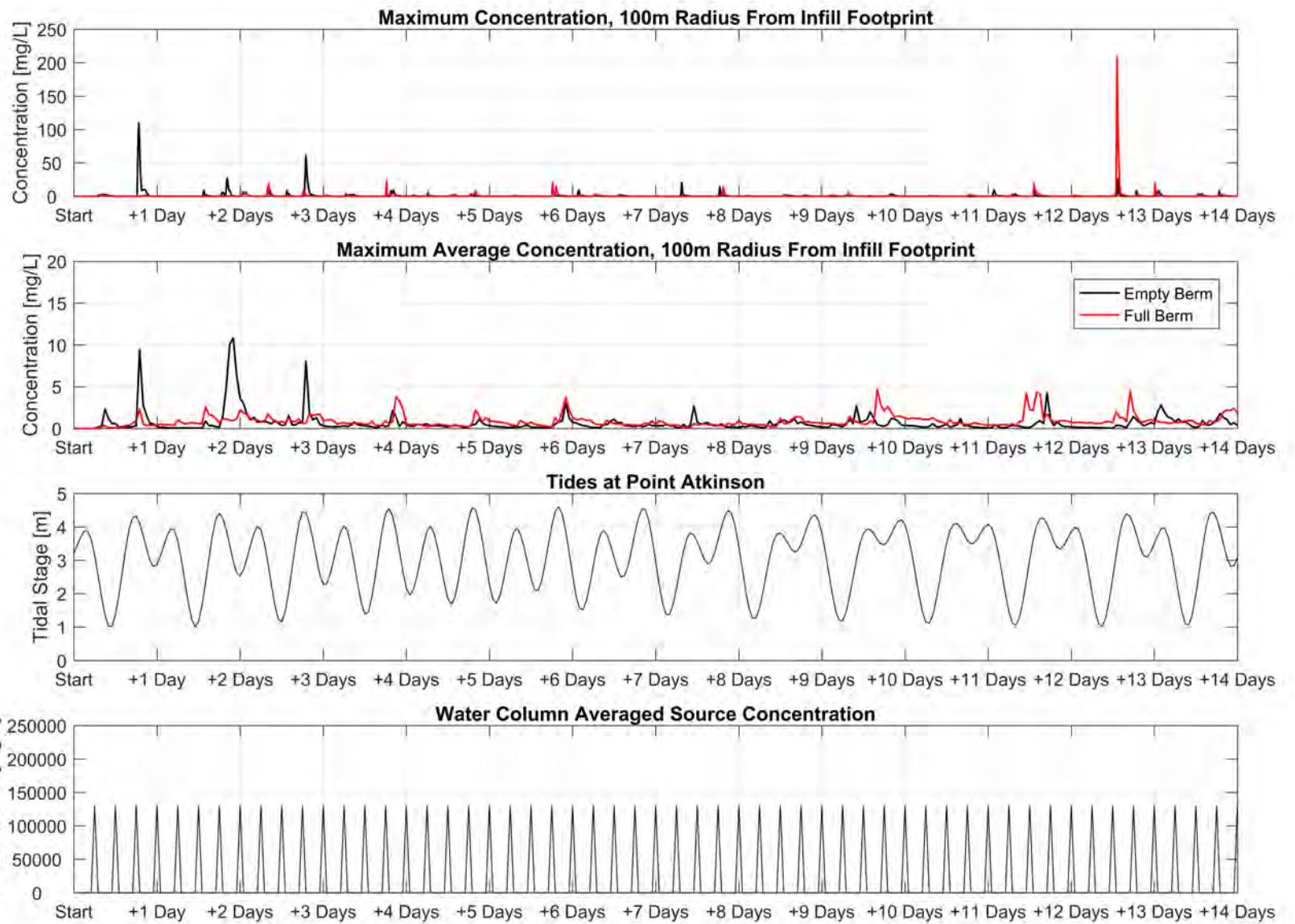
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Figure 4.5



NOTES

- 1) The concentration axis scale differs between plots.
- 2) Maximum concentration is the maximum of the maximum TSS over the water column (seabed to surface) along a boundary 100 m from the edge of the infill footprint.
- 3) Maximum Average concentration is the maximum of the average TSS over the water column (seabed to surface) along a boundary 100 m from the edge of the infill footprint.

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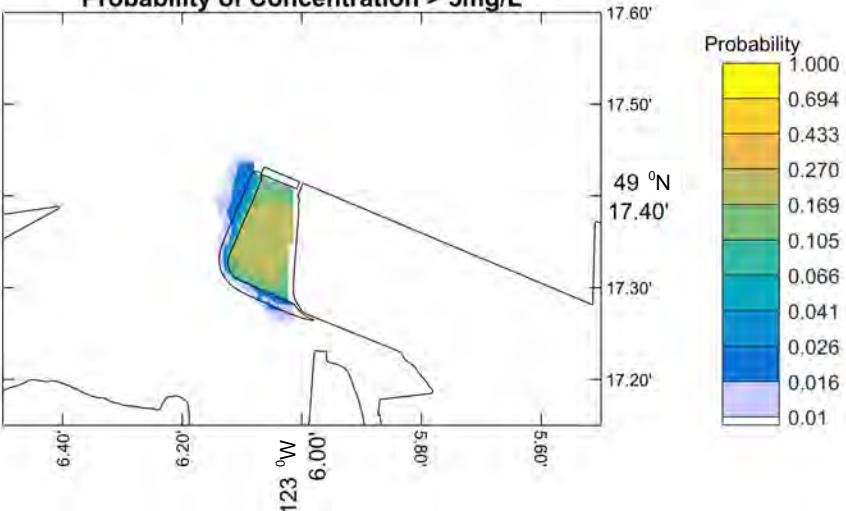
Dispersal Modelling of Infill Derived Fugitive Sediment

**West Basin Infill Zone, Lift 2
TSS Source Attenuation at 100 m**

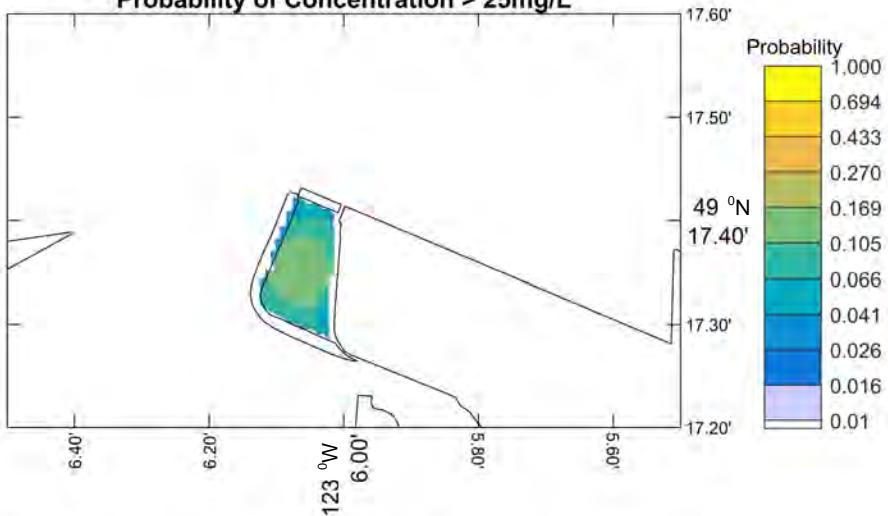
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Figure 4.6

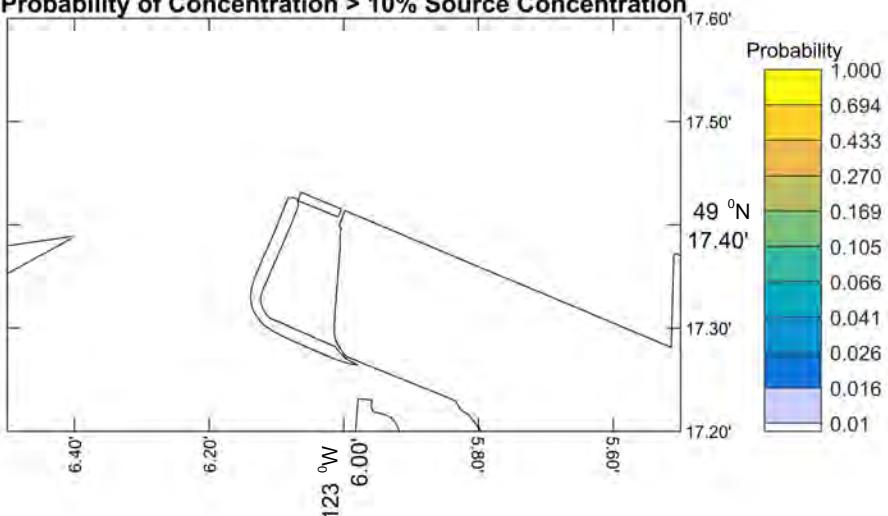
Probability of Concentration > 5mg/L



Probability of Concentration > 25mg/L



Probability of Concentration > 10% Source Concentration



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

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Dispersal Modelling of Infill Derived Fugitive Sediment

West Basin Infill Zone, Lift 3 Empty Maximum TSS Exceedance Probabilities



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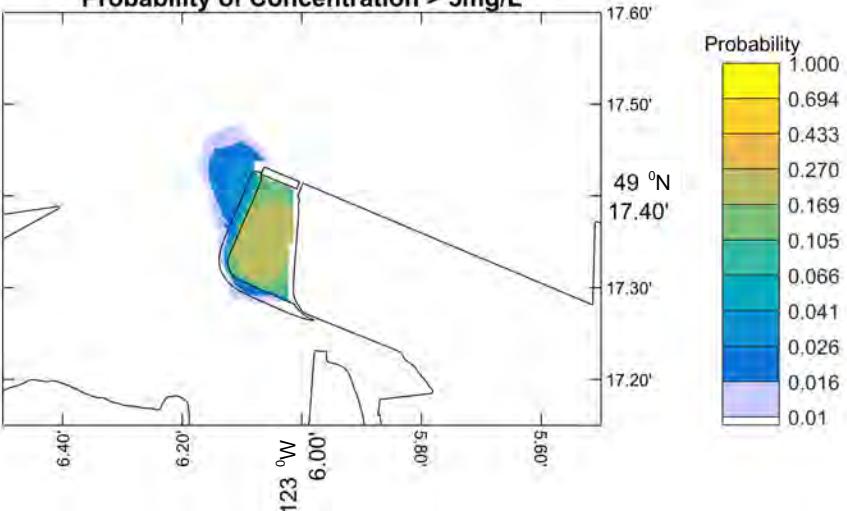
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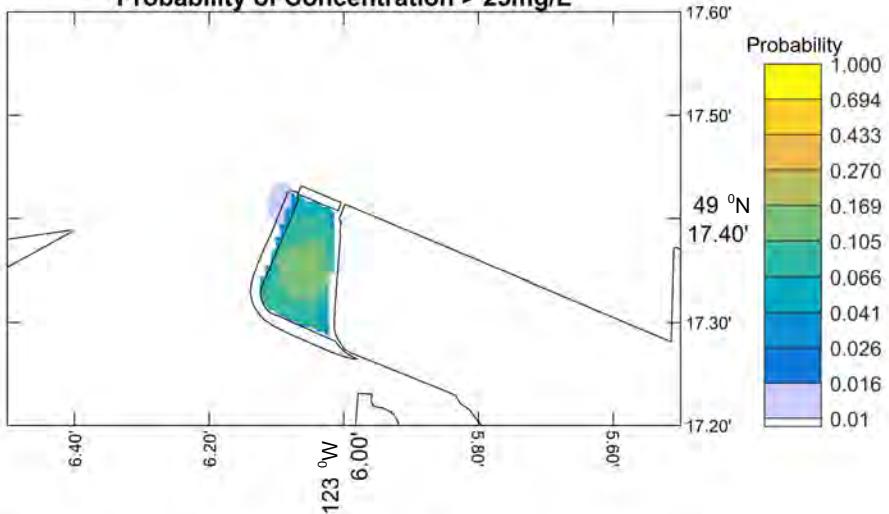
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Figure 4.7

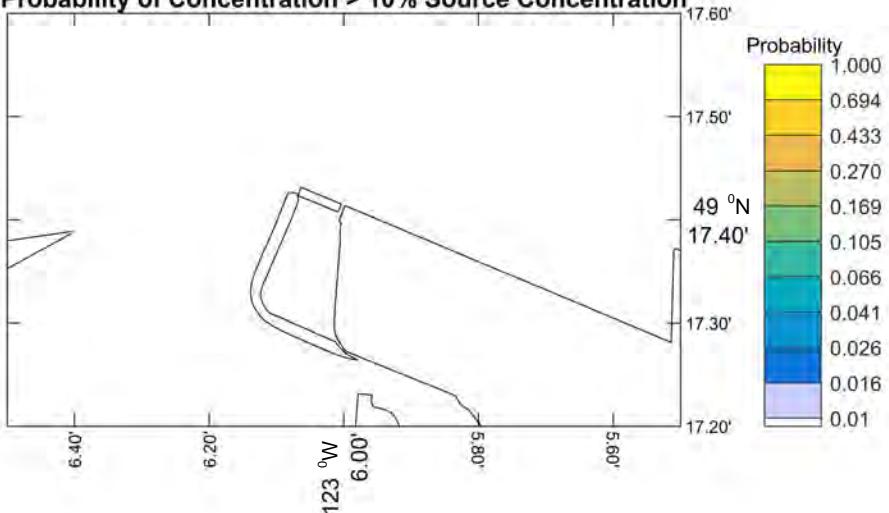
Probability of Concentration > 5mg/L



Probability of Concentration > 25mg/L



Probability of Concentration > 10% Source Concentration



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

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Dispersal Modelling of Infill Derived Fugitive Sediment

West Basin Infill Zone, Lift 3 Full Maximum TSS Exceedance Probabilities



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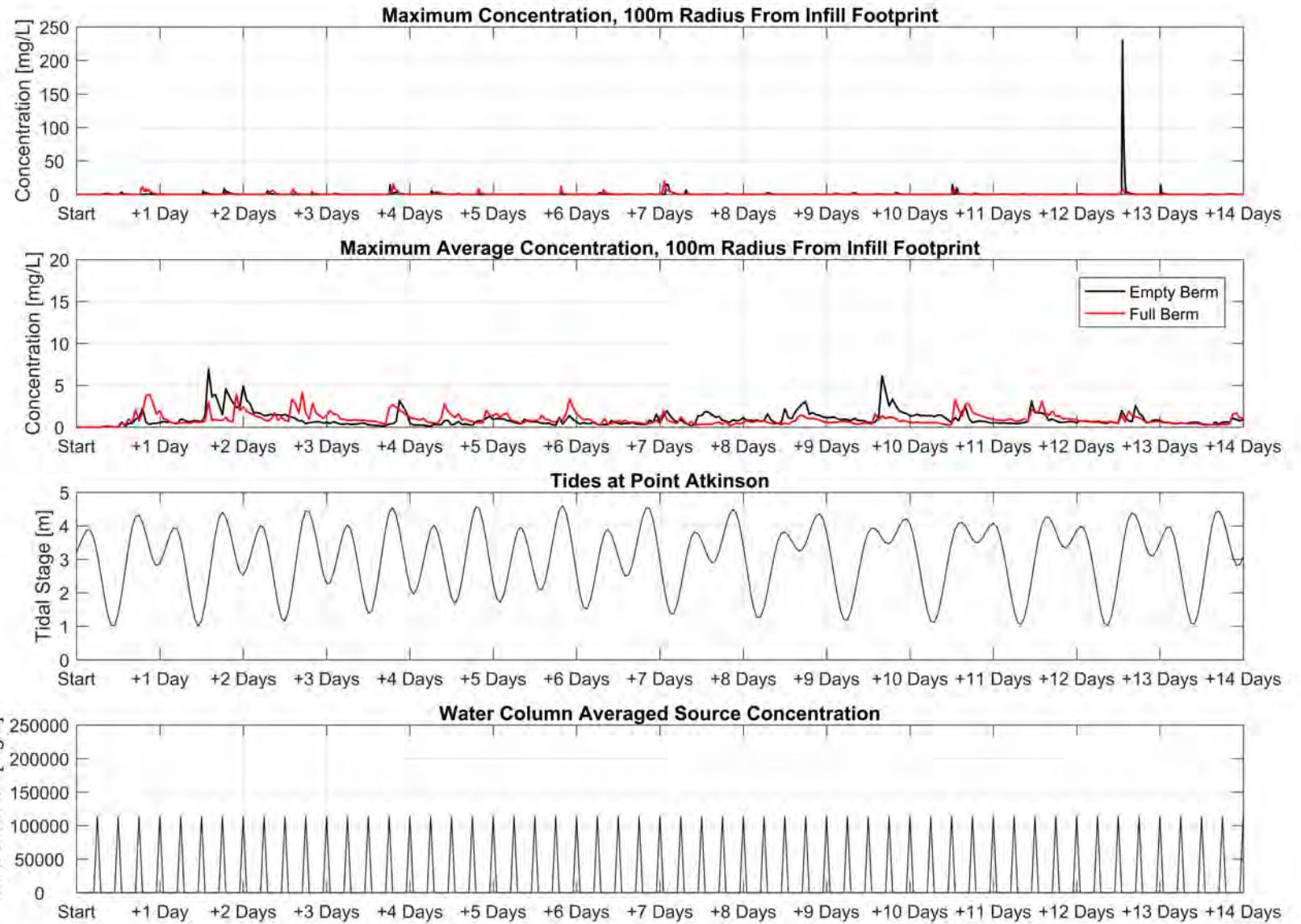
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Figure 4.8



NOTES

- 1) The concentration axis scale differs between plots.
- 2) Maximum concentration is the maximum of the maximum TSS over the water column (seabed to surface) along a boundary 100 m from the edge of the infill footprint.
- 3) Maximum Average concentration is the maximum of the average TSS over the water column (seabed to surface) along a boundary 100 m from the edge of the infill footprint.

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**Dispersal Modelling of Infill
Derived Fugitive Sediment**

**West Basin Infill Zone, Lift 3
TSS Source Attenuation at 100 m**

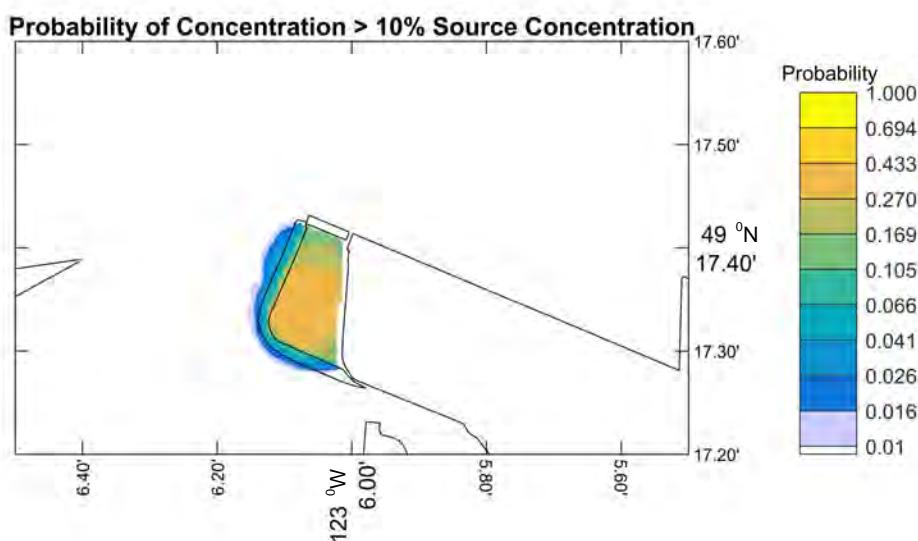
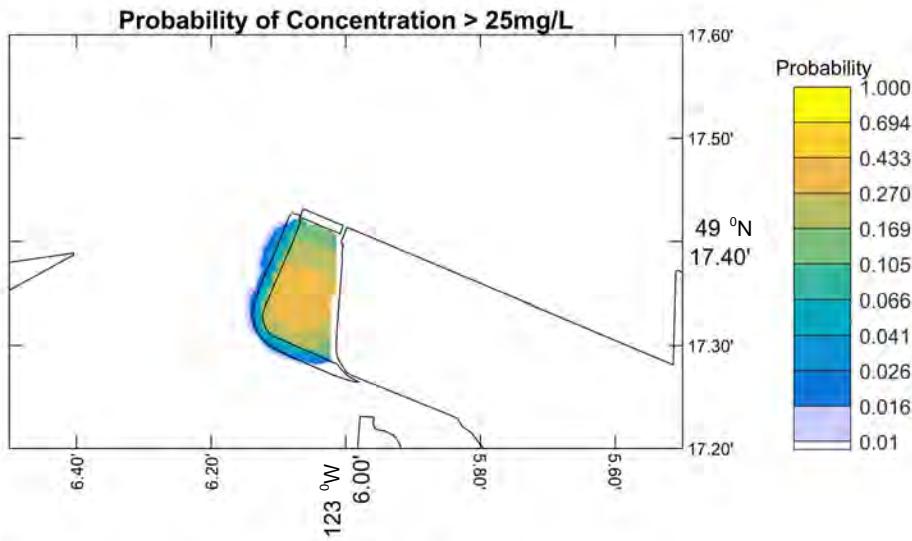
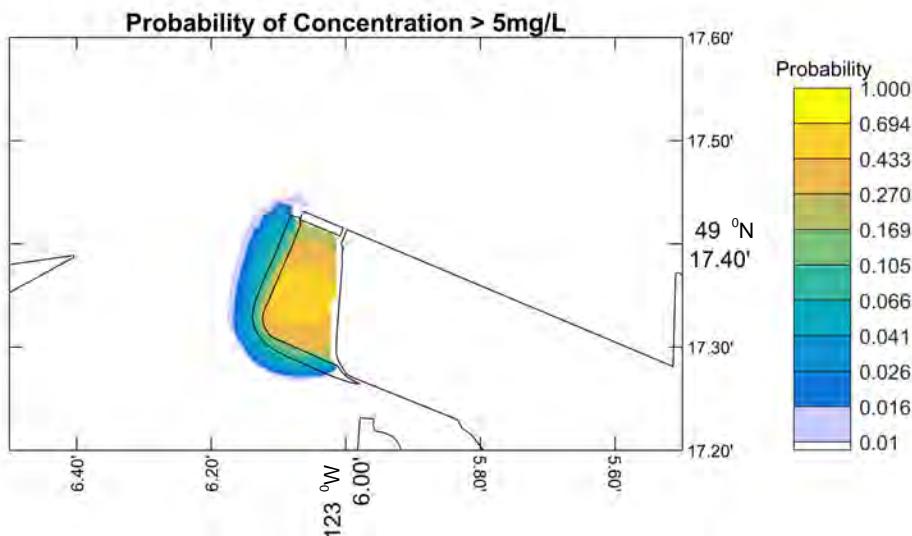


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Figure 4.09



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

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Dispersal Modelling of Infill Derived Fugitive Sediment

West Basin Infill Zone, Lift 4 Empty Maximum TSS Exceedance Probabilities



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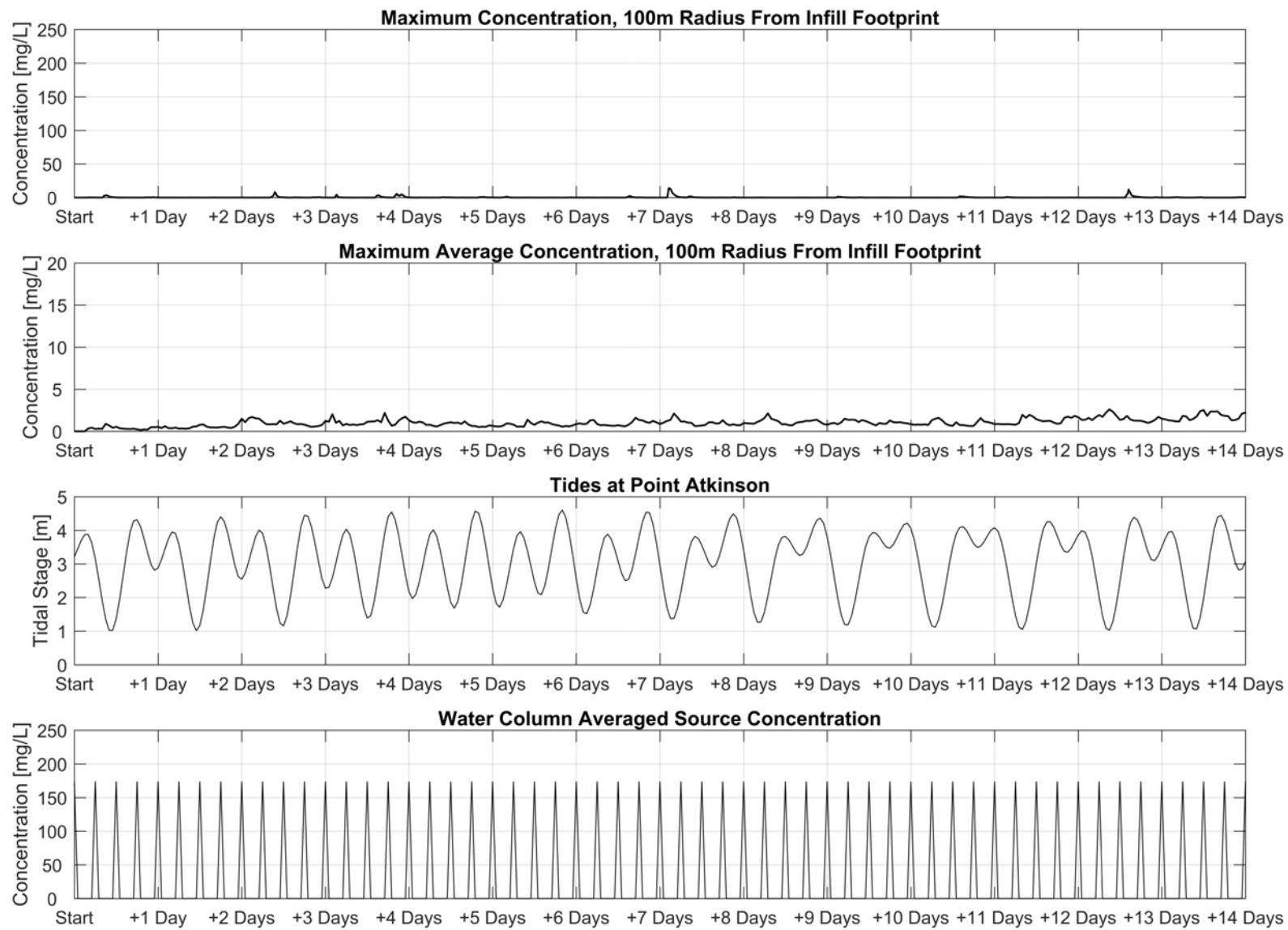
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Figure 4.10



NOTES

- 1) The concentration axis scale differs between plots.
- 2) Maximum concentration is the maximum of the maximum TSS over the water column (seabed to surface) along a boundary 100 m from the edge of the infill footprint.
- 3) Maximum Average concentration is the maximum of the average TSS over the water column (seabed to surface) along a boundary 100 m from the edge of the infill footprint.

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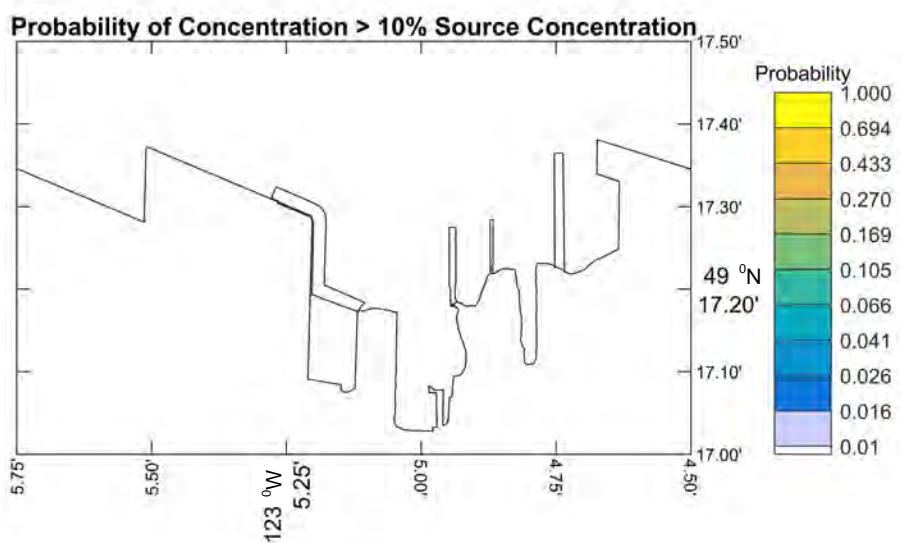
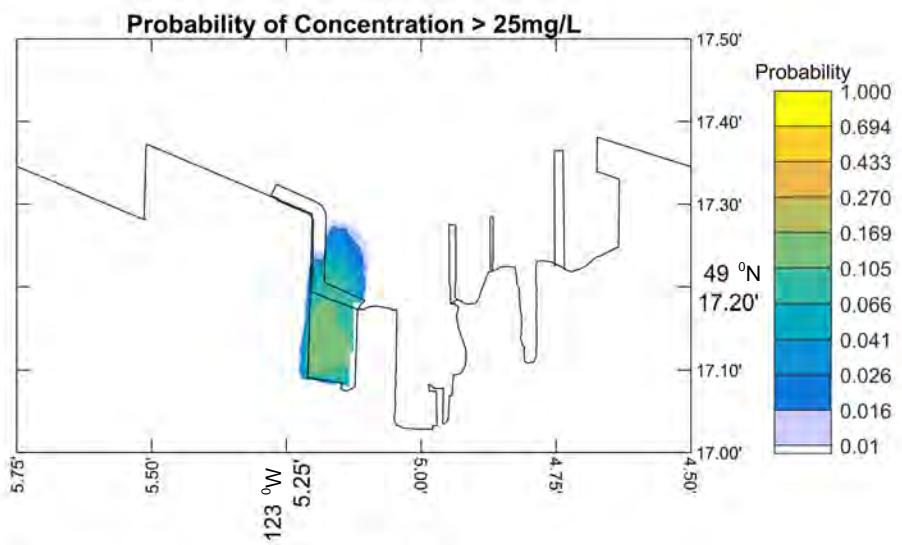
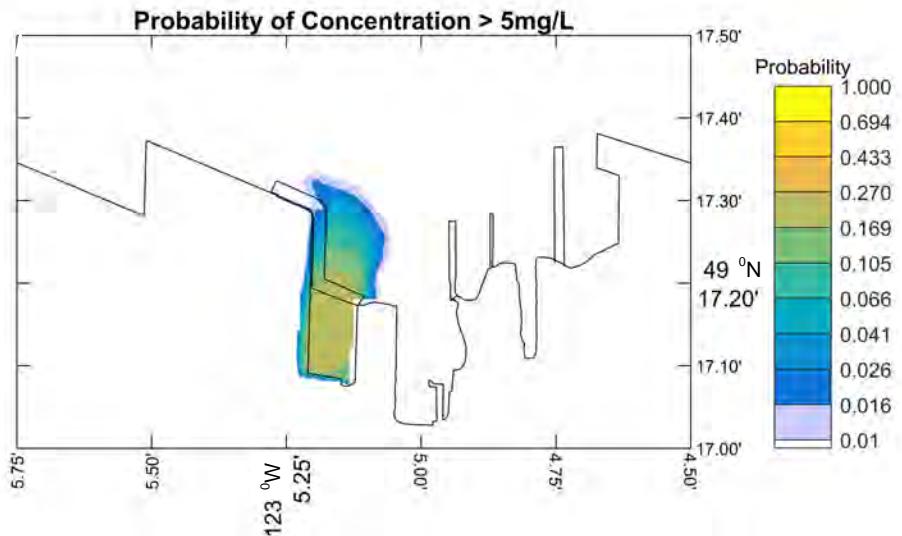
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Dispersal Modelling of Infill Derived Fugitive Sediment

West Basin Infill Zone, Lift 4 TSS Source Attenuation at 100 m

PROJECT NO. WTRM:03017	DWN JM	CKD JM	APVD JAS	REV 0
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Figure 4.11



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

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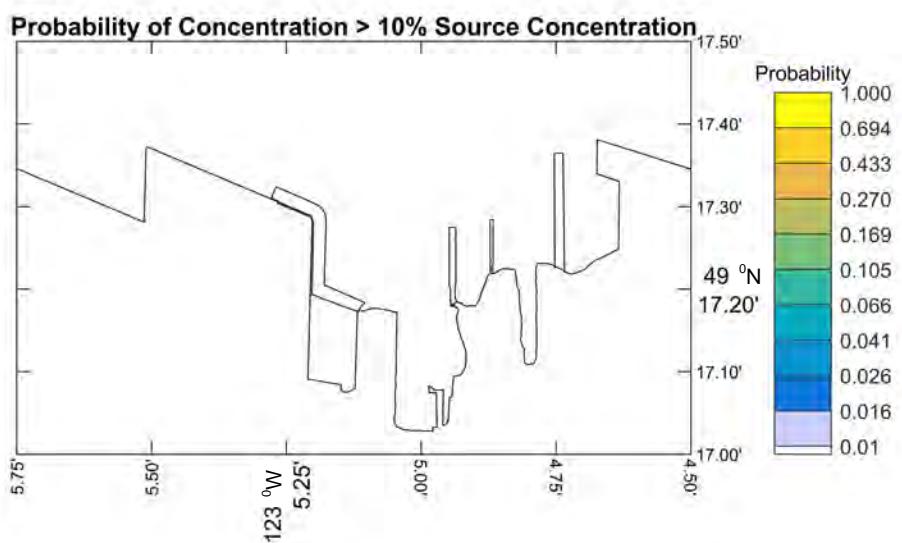
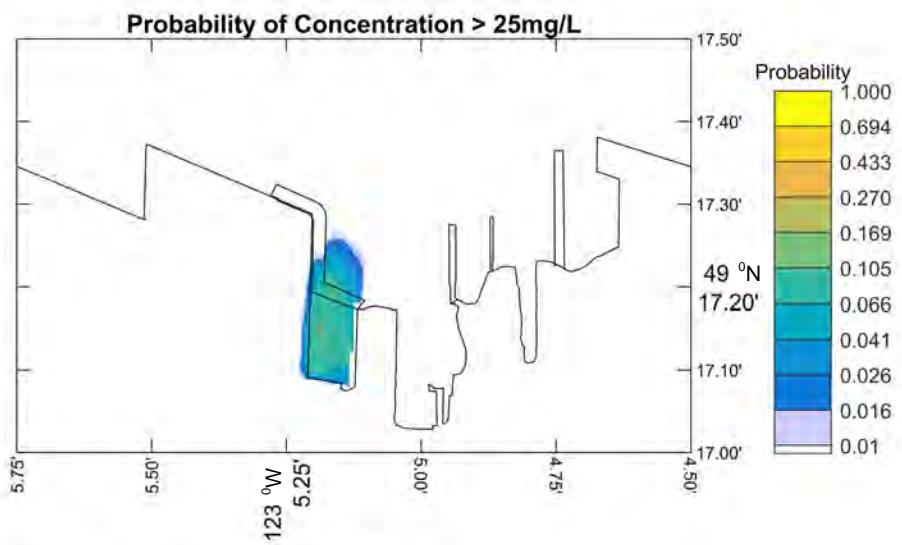
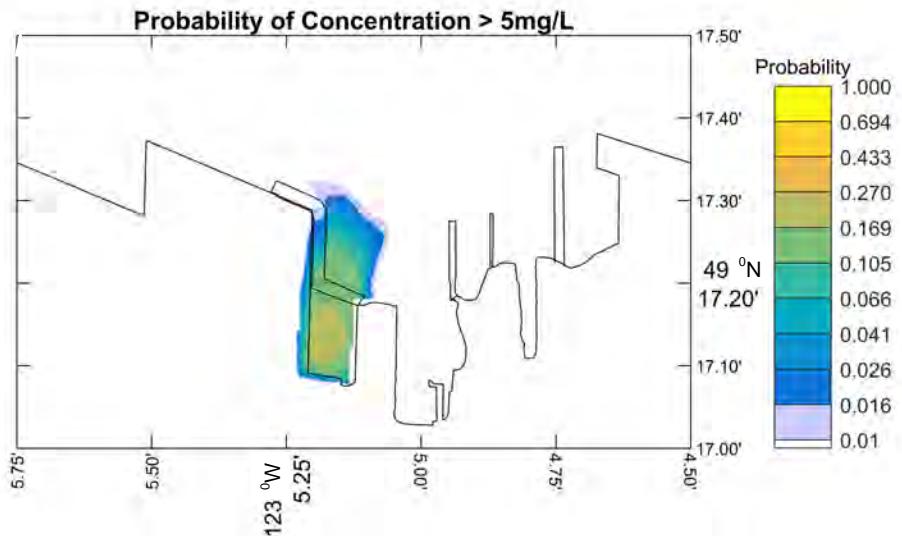
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Dispersal Modelling of Infill Derived Fugitive Sediment

East Basin Infill Zone, Lift 1 Empty Maximum TSS Exceedance Probabilities

PROJECT NO.	DWN	CKD	APVD	REV
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OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 4.12



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

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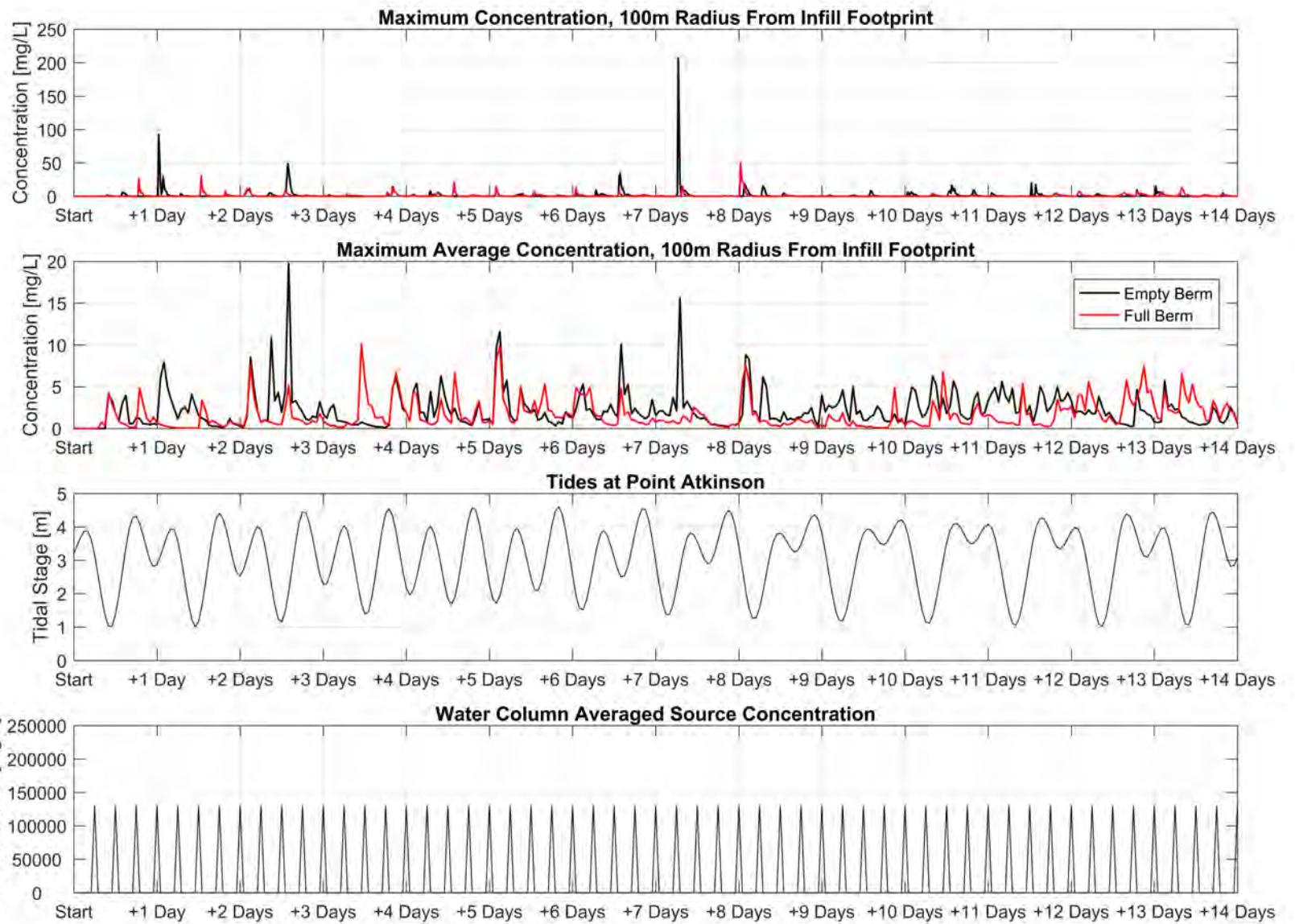
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Dispersal Modelling of Infill Derived Fugitive Sediment

East Basin Infill Zone, Lift 1 Full Maximum TSS Exceedance Probabilities

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 4.13



NOTES

- 1) The concentration axis scale differs between plots.
- 2) Maximum concentration is the maximum of the maximum TSS over the water column (seabed to surface) along a boundary 100 m from the edge of the infill footprint.
- 3) Maximum Average concentration is the maximum of the average TSS over the water column (seabed to surface) along a boundary 100 m from the edge of the infill footprint.

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**Dispersal Modelling of Infill
Derived Fugitive Sediment**

**East Basin Infill Zone, Lift 1
TSS Source Attenuation at 100 m**



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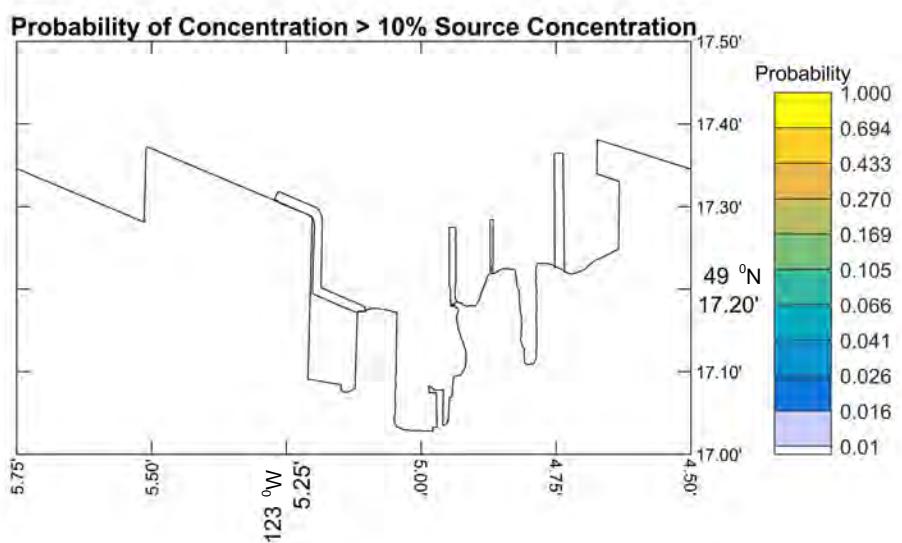
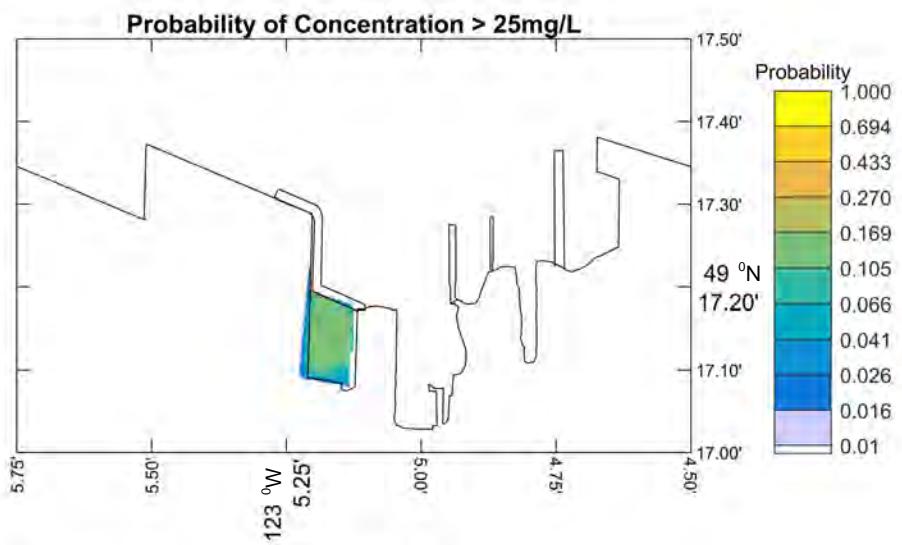
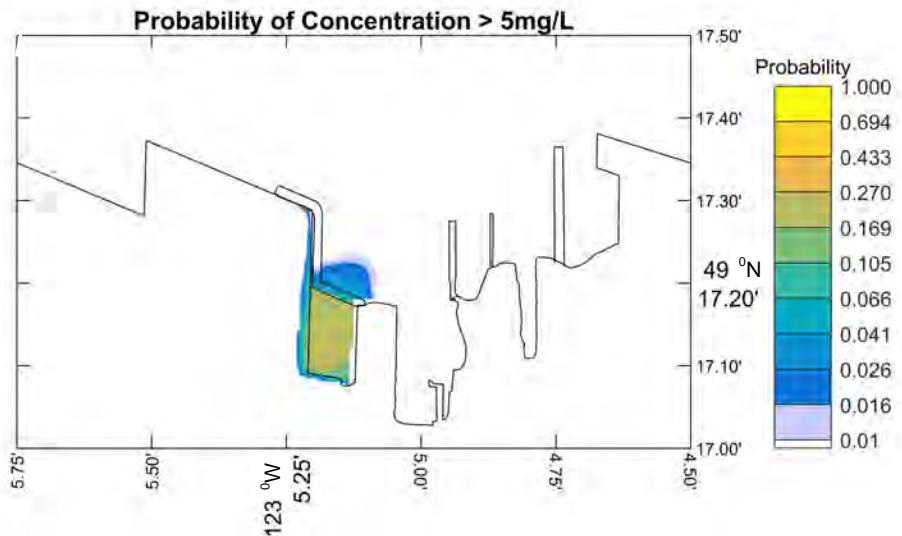
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Figure 4.14



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

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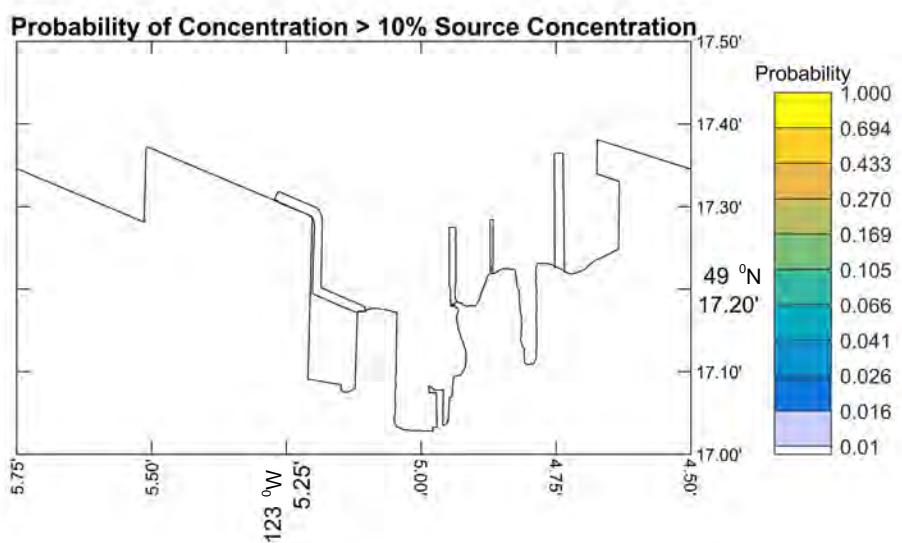
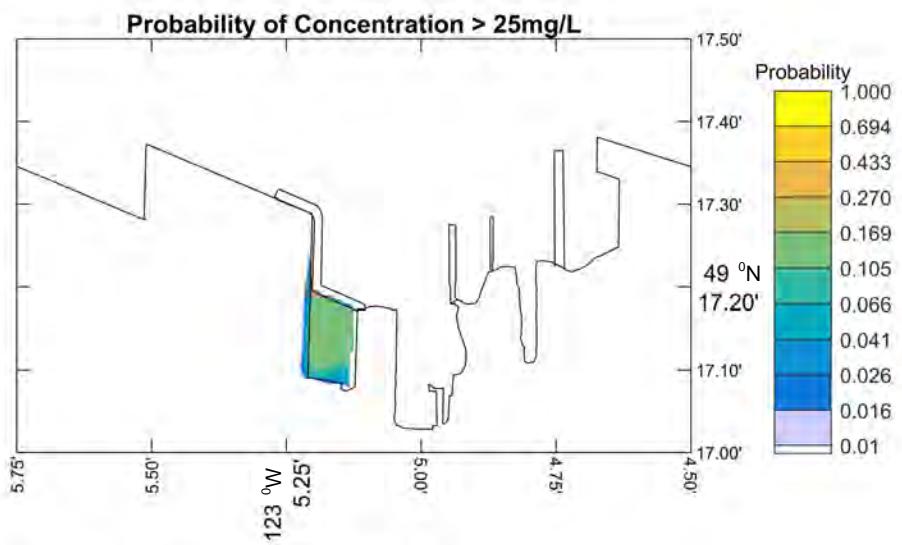
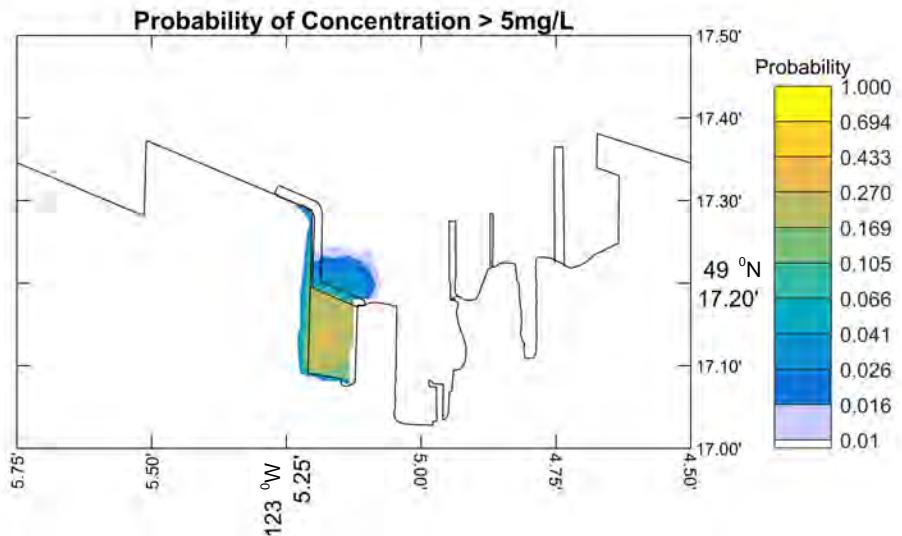
STATUS
ISSUED FOR USE

Dispersal Modelling of Infill Derived Fugitive Sediment

East Basin Infill Zone, Lift 2 Empty Maximum TSS Exceedance Probabilities

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 4.15



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

CLIENT

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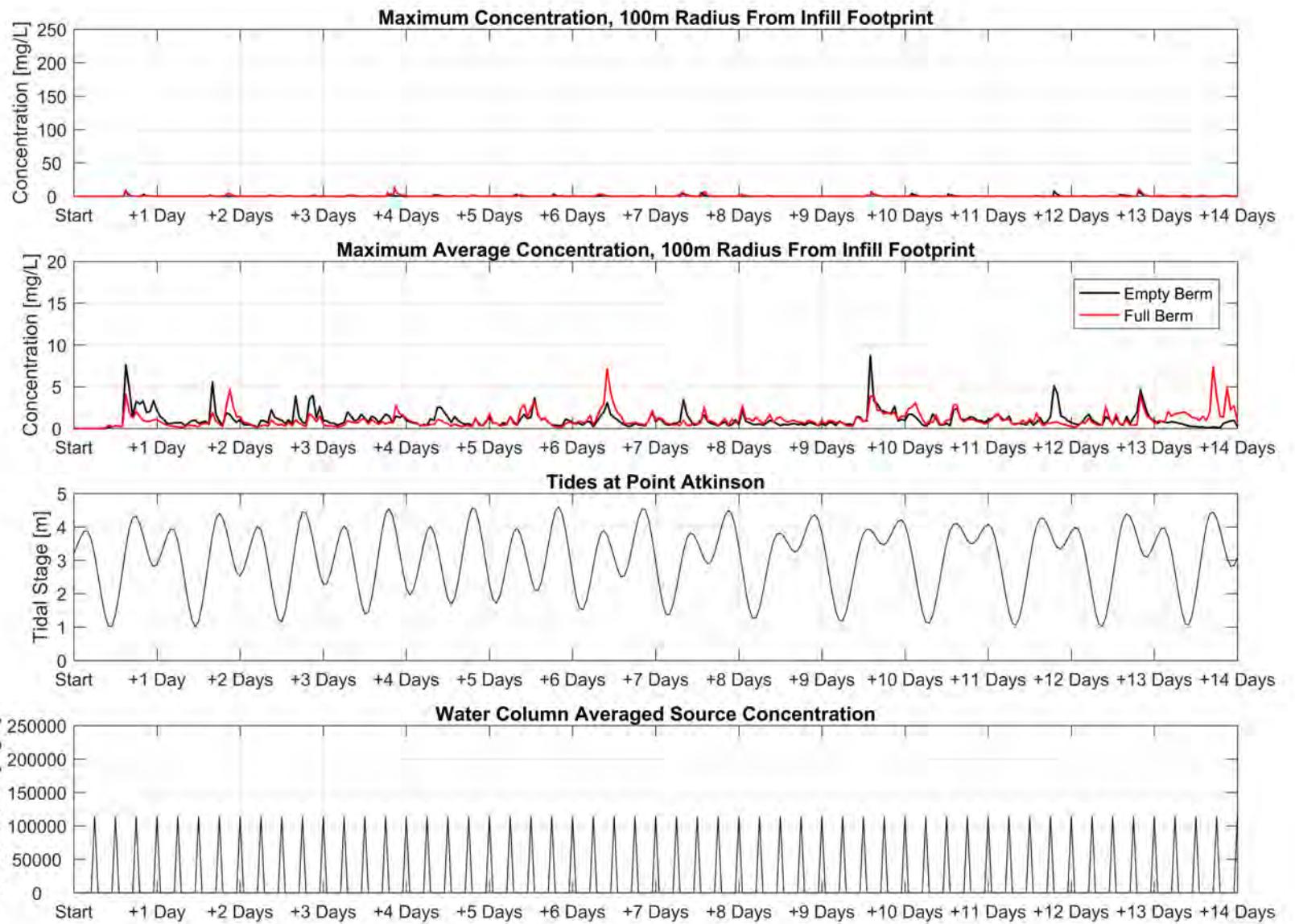
STATUS
ISSUED FOR USE

Dispersal Modelling of Infill Derived Fugitive Sediment

East Basin Infill Zone, Lift 2 Full Maximum TSS Exceedance Probabilities

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 4.16



NOTES

- 1) The concentration axis scale differs between plots.
- 2) Maximum concentration is the maximum of the maximum TSS over the water column (seabed to surface) along a boundary 100 m from the edge of the infill footprint.
- 3) Maximum Average concentration is the maximum of the average TSS over the water column (seabed to surface) along a boundary 100 m from the edge of the infill footprint.

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AECOM

**Dispersal Modelling of Infill
Derived Fugitive Sediment**

**East Basin Infill Zone, Lift 2
TSS Source Attenuation at 100 m**

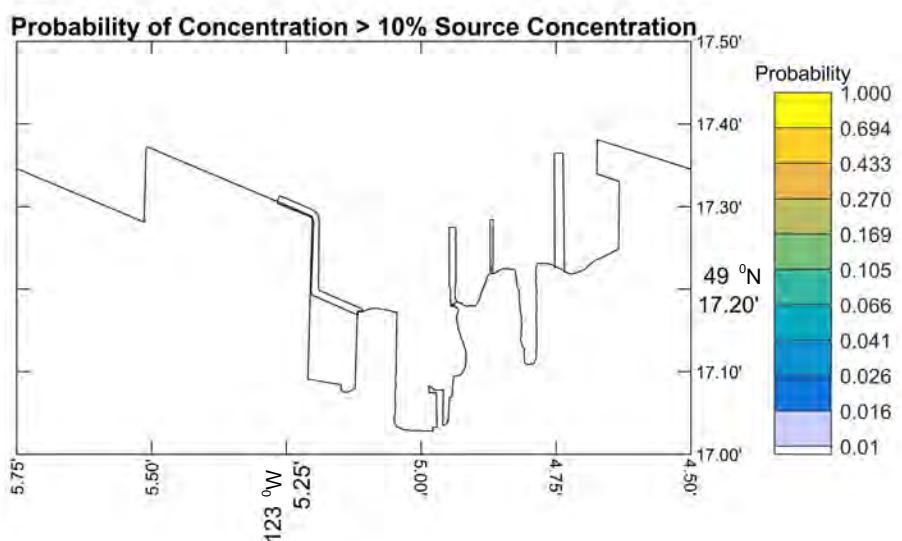
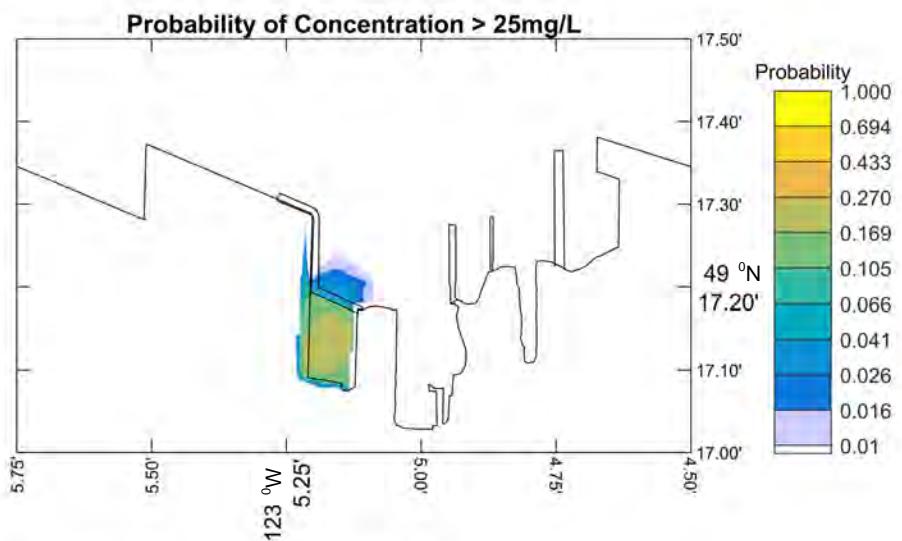
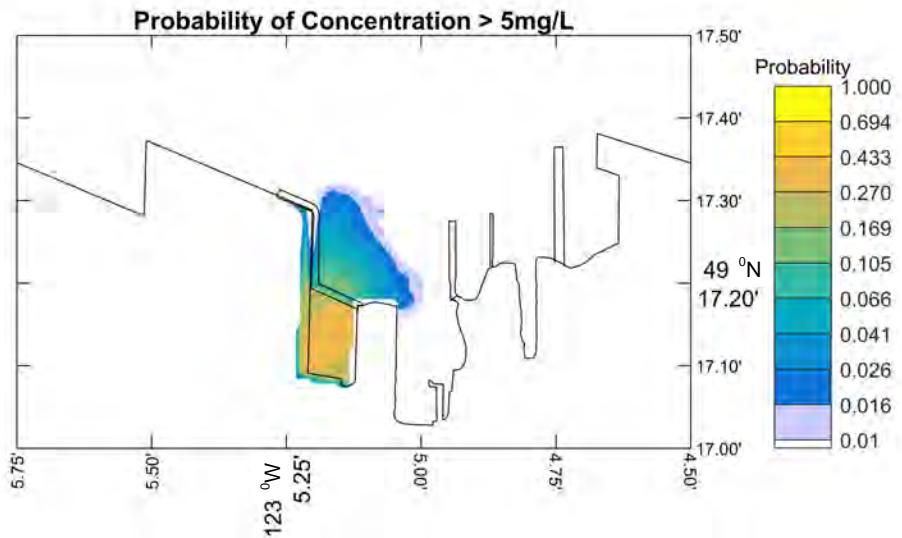


TETRA TECH

STATUS
ISSUED FOR USE

PROJECT NO. WTRM:03017	DWN JM	CKD JM	APVD JAS	REV 0
OFFICE Tetra Tech - VANC	DATE March, 2017			

Figure 4.17



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

CLIENT

AECOM



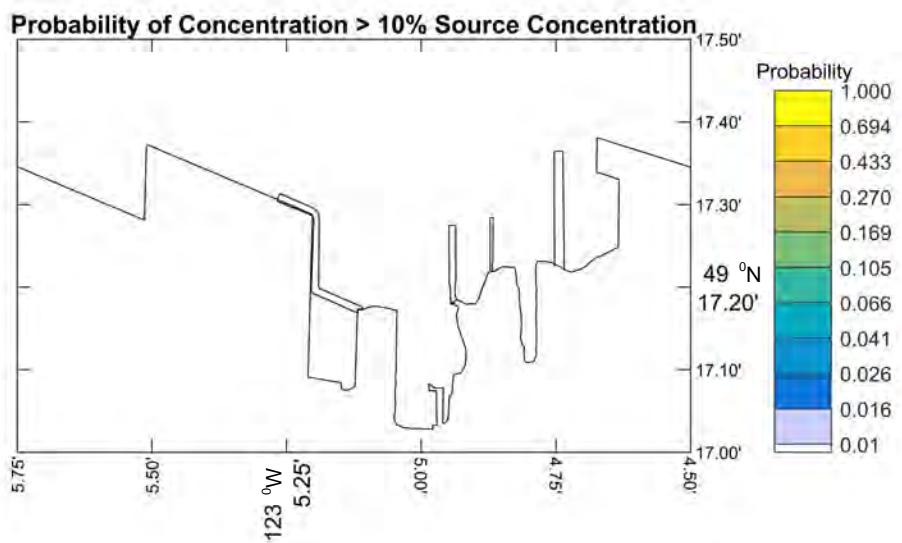
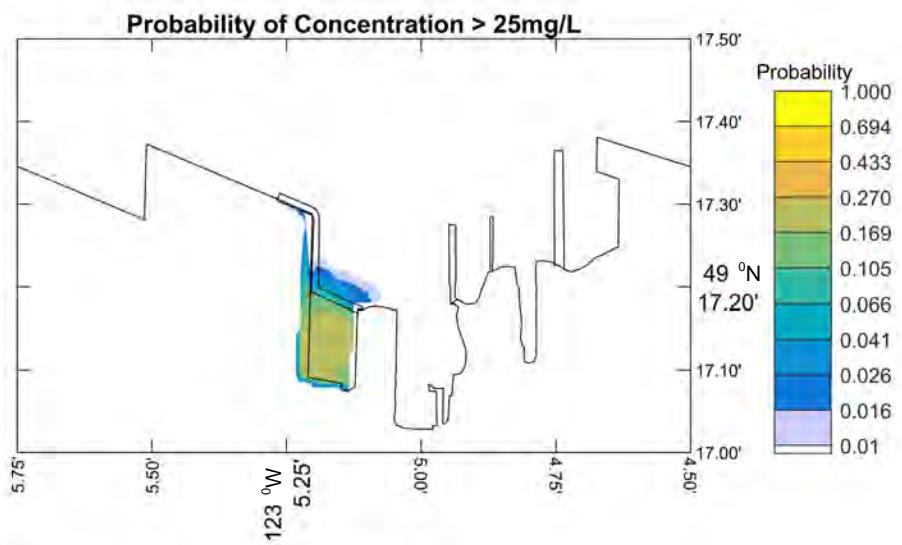
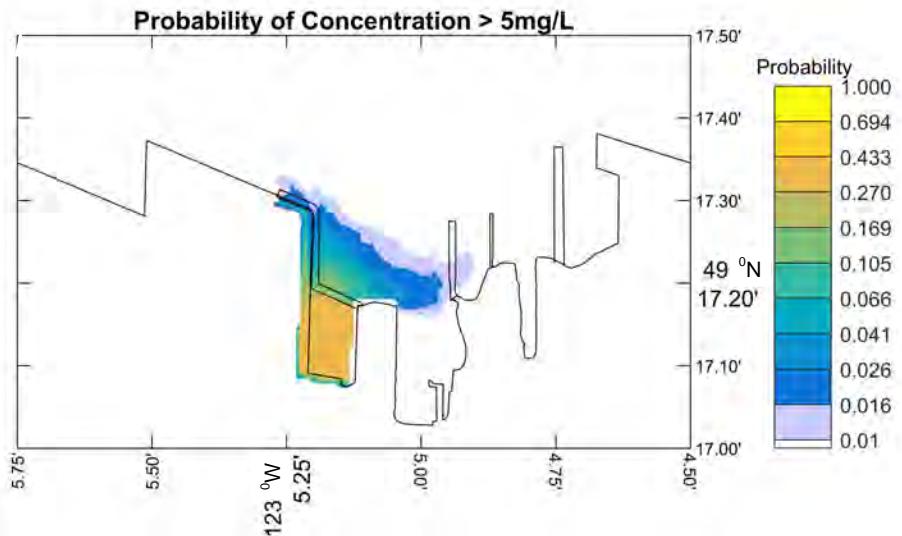
STATUS
ISSUED FOR USE

Dispersal Modelling of Infill Derived Fugitive Sediment

East Basin Infill Zone, Lift 3 Empty Maximum TSS Exceedance Probabilities

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 4.18



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

CLIENT

AECOM

Dispersal Modelling of Infill Derived Fugitive Sediment

East Basin Infill Zone, Lift 3 Full Maximum TSS Exceedance Probabilities

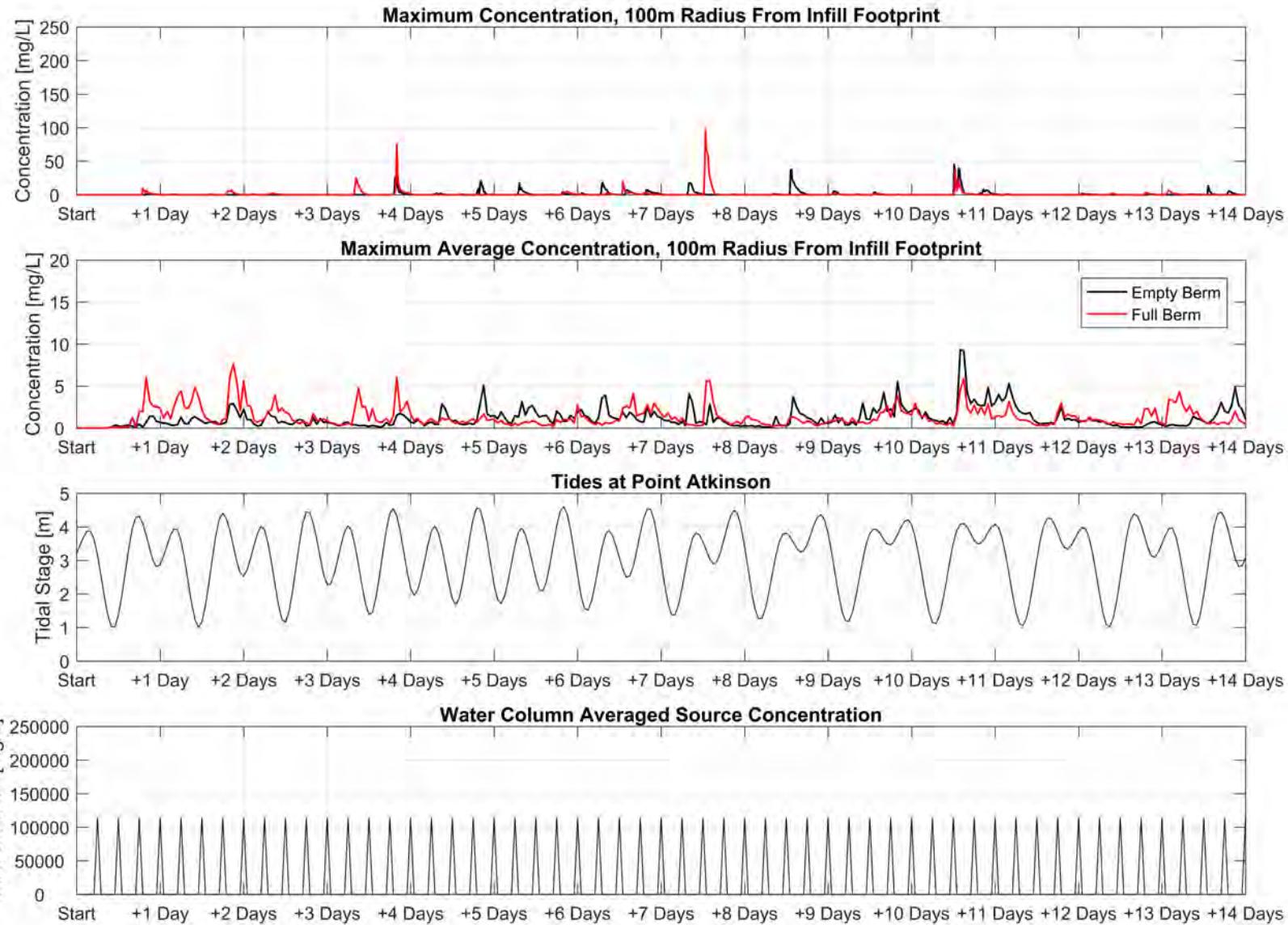


TETRA TECH

STATUS
ISSUED FOR USE

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 4.19



NOTES

- 1) The concentration axis scale differs between plots.
- 2) Maximum concentration is the maximum of the maximum TSS over the water column (seabed to surface) along a boundary 100 m from the edge of the infill footprint.
- 3) Maximum Average concentration is the maximum of the average TSS over the water column (seabed to surface) along a boundary 100 m from the edge of the infill footprint.

CLIENT

AECOM

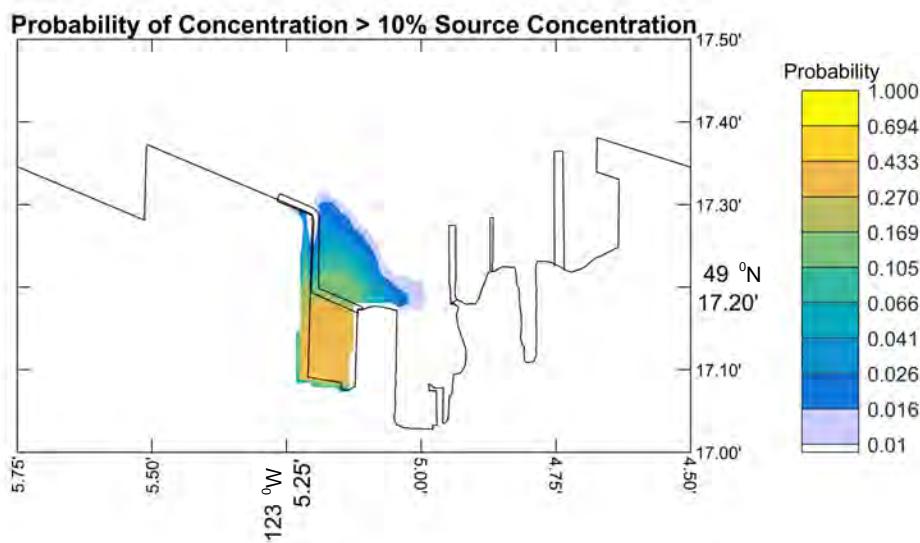
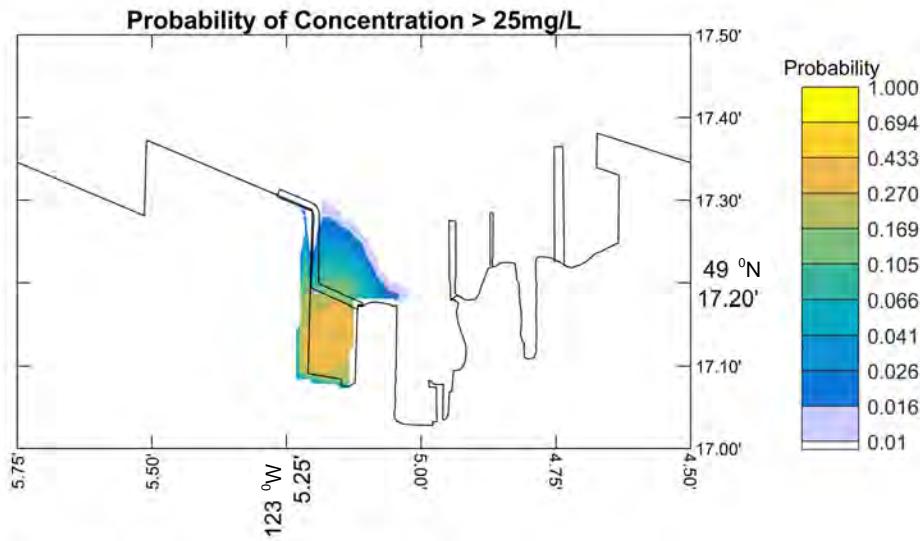
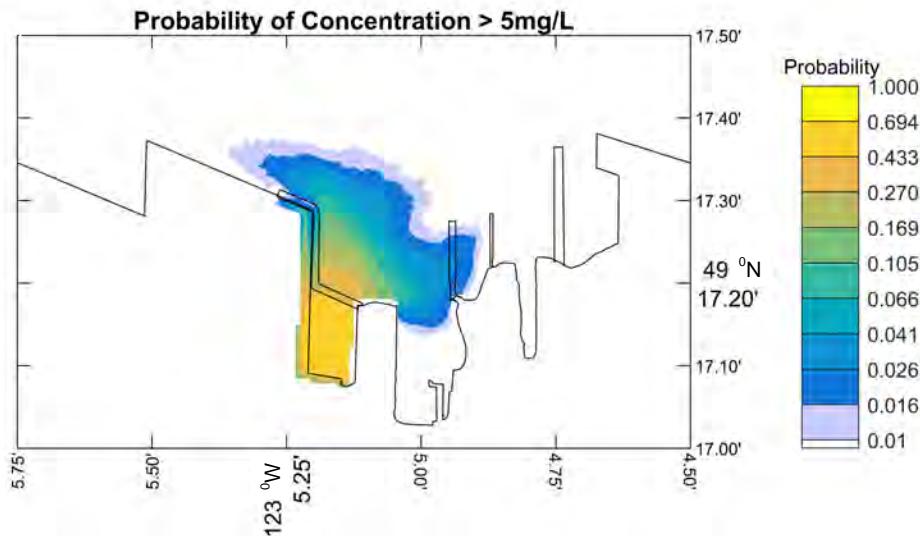
TETRA TECH

Dispersal Modelling of Infill Derived Fugitive Sediment

**East Basin Infill Zone, Lift 3
TSS Source Attenuation at 100 m**

PROJECT NO.	DWN	CKD	APVD	REV
WTRM:03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 4.20



NOTES

- 1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
- 2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

CLIENT

AECOM



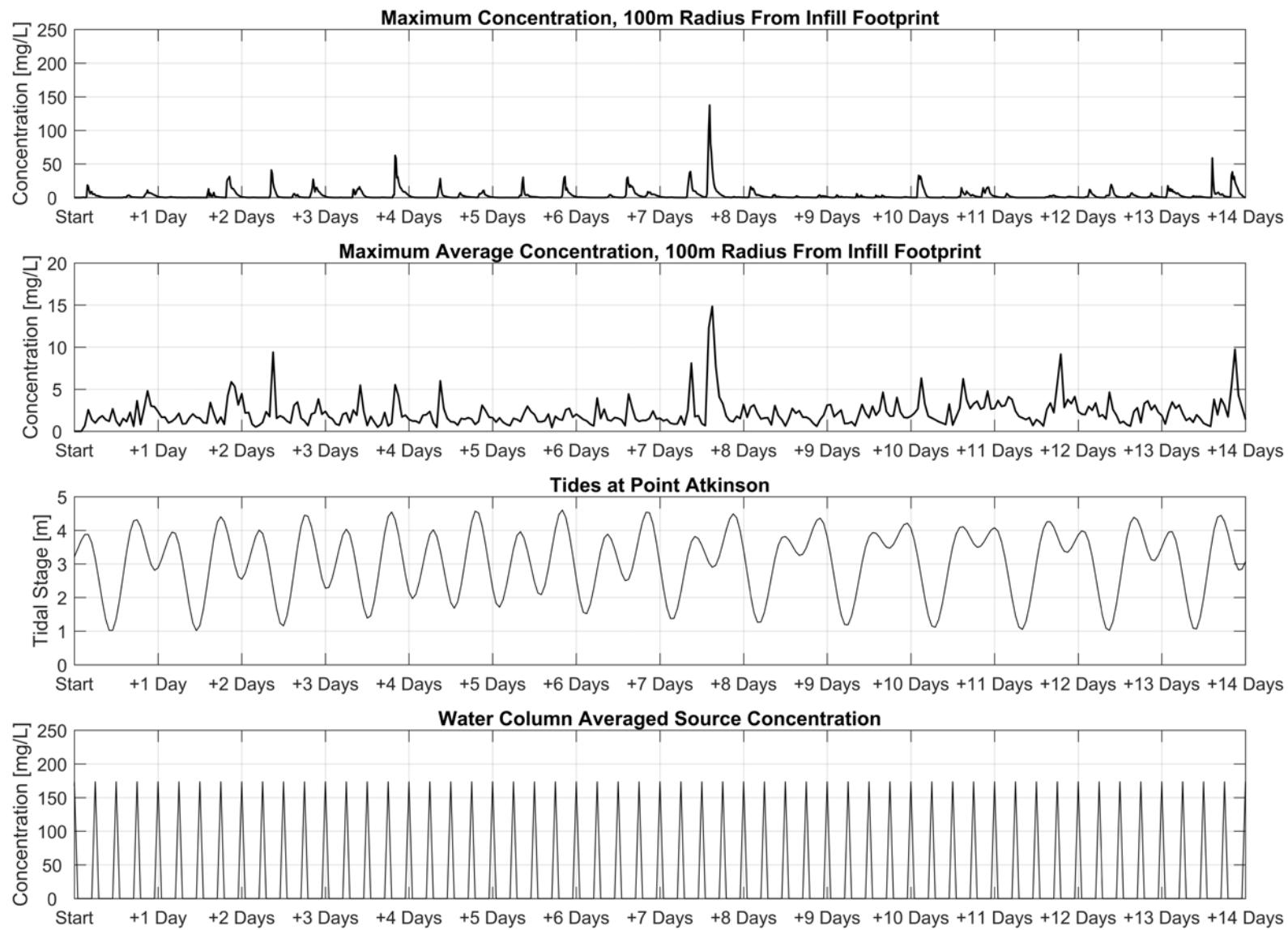
STATUS
ISSUED FOR USE

Dispersal Modelling of Infill Derived Fugitive Sediment

East Basin Infill Zone, Lift 4 Maximum TSS Exceedance Probabilities

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 4.21



NOTES

- 1) The concentration axis scale differs between plots.
- 2) Maximum concentration is the maximum of the maximum TSS over the water column (seabed to surface) along a boundary 100 m from the edge of the infill footprint.
- 3) Maximum Average concentration is the maximum of the average TSS over the water column (seabed to surface) along a boundary 100 m from the edge of the infill footprint.

CLIENT

AECOM

TETRA TECH

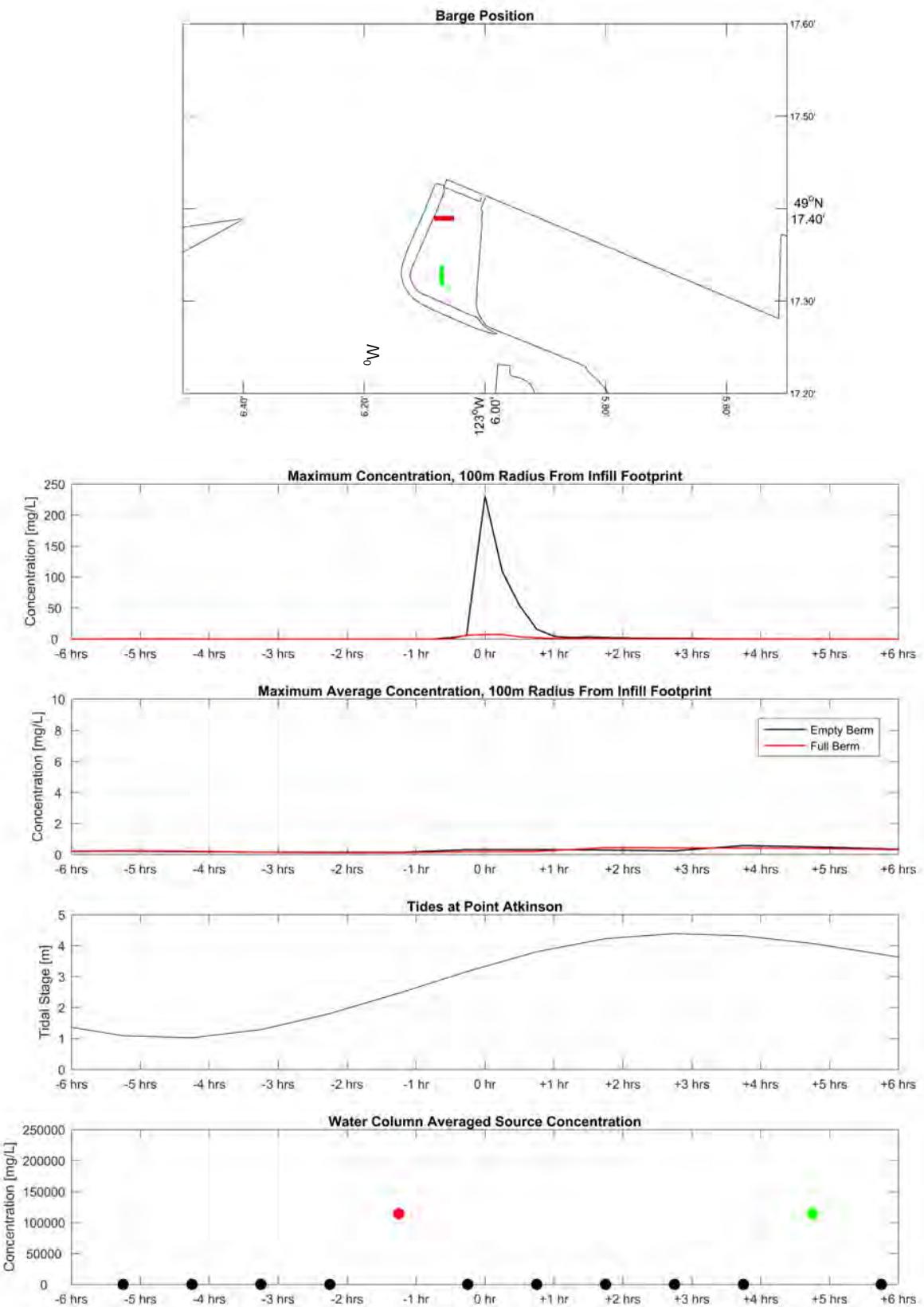
Dispersal Modelling of Infill Derived Fugitive Sediment

East Basin Infill Zone, Lift 4 TSS Source Attenuation at 100 m

STATUS
ISSUED FOR USE

PROJECT NO. WTRM:03017	DWN JM	CKD JM	APVD JAS	REV 0
OFFICE Tetra Tech - VANC	DATE March, 2017			

Figure 4.22



NOTES

1) Barge position is indicated in the upper panel by either a red or green box, corresponding to a red or green point in the bottom panel indicated the hopper dump time.

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AECOM

Dispersal Modelling of Infill Derived Fugitive Sediment

West Basin Infill Zone, Lift 3 Empty
TSS Concentration Peak, Flood Tide

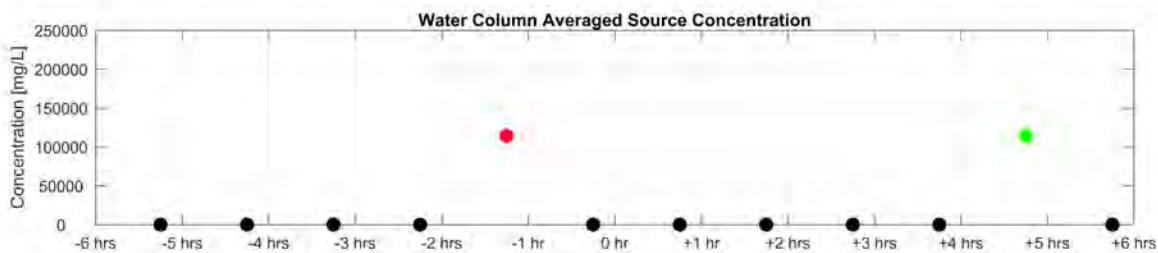
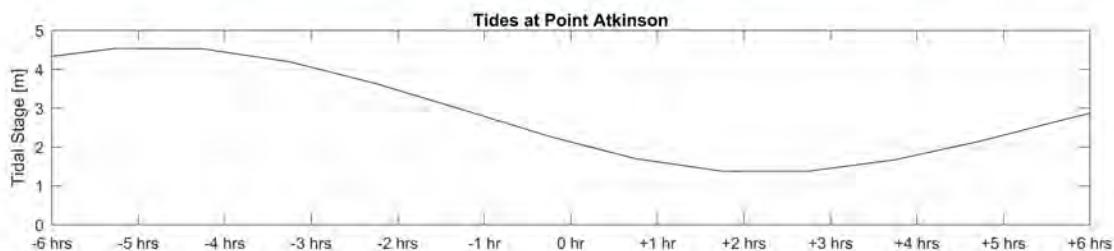
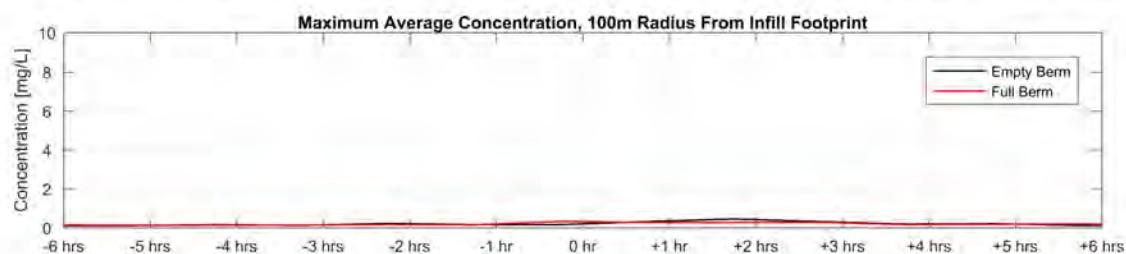
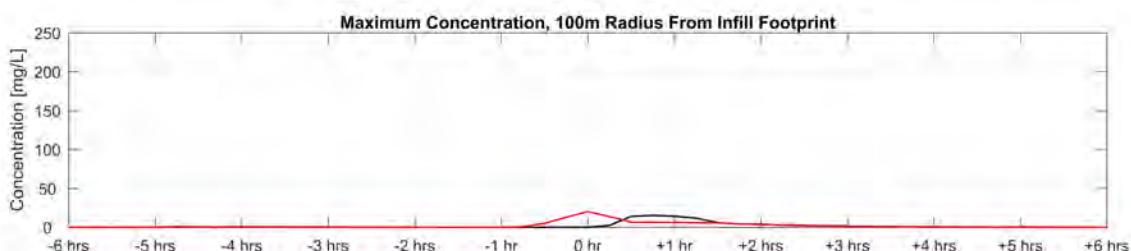
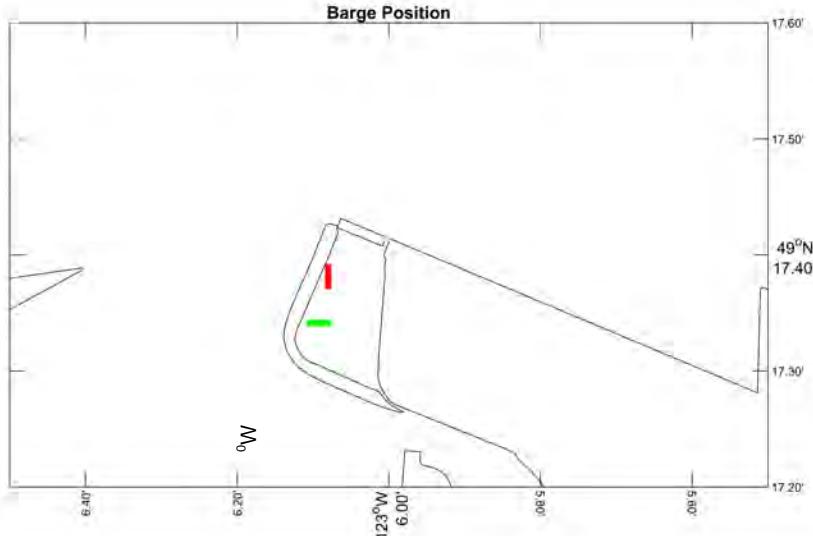


TETRA TECH

STATUS
ISSUED FOR USE

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 4.23



NOTES

1) Barge position is indicated in the upper panel by either a red or green box, corresponding to a red or green point in the bottom panel indicated the hopper dump time.

CLIENT

AECOM

Dispersal Modelling of Infill Derived Fugitive Sediment

West Basin Infill Zone, Lift 3 Empty TSS Concentration Peak, Ebb Tide



TETRA TECH

STATUS
ISSUED FOR USE

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0
OFFICE	DATE			
Tetra Tech - VANC	March, 2017			

Figure 4.24

APPENDIX A

TETRA TECH'S GENERAL CONDITIONS

GENERAL CONDITIONS

HYDROTECHNICAL

This report incorporates and is subject to these "General Conditions".

1.1 USE OF REPORT AND OWNERSHIP

This report pertains to a specific site, a specific development, and a specific scope of work. The report may include plans, drawings, profiles and other supporting documents that collectively constitute the report (the "Report").

The Report is intended for the sole use of TETRA TECH's Client (the "Client") as specifically identified in the TETRA TECH Services Agreement or other Contract entered into with the Client (either of which is termed the "Services Agreement" herein). TETRA TECH does not accept any responsibility for the accuracy of any of the data, analyses, recommendations or other contents of the Report when it is used or relied upon by any party other than the Client, unless authorized in writing by TETRA TECH.

Any unauthorized use of the Report is at the sole risk of the user. TETRA TECH accepts no responsibility whatsoever for any loss or damage where such loss or damage is alleged to be or, is in fact, caused by the unauthorized use of the Report.

Where TETRA TECH has expressly authorized the use of the Report by a third party (an "Authorized Party"), consideration for such authorization is the Authorized Party's acceptance of these General Conditions as well as any limitations on liability contained in the Services Agreement with the Client (all of which is collectively termed the "Limitations on Liability"). The Authorized Party should carefully review both these General Conditions and the Services Agreement prior to making any use of the Report. Any use made of the Report by an Authorized Party constitutes the Authorized Party's express acceptance of, and agreement to, the Limitations on Liability.

The Report and any other form or type of data or documents generated by TETRA TECH during the performance of the work are TETRA TECH's professional work product and shall remain the copyright property of TETRA TECH.

The Report is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of TETRA TECH. Additional copies of the Report, if required, may be obtained upon request.

1.2 ALTERNATIVE REPORT FORMAT

Where TETRA TECH submits both electronic file and hard copy versions of the Report or any drawings or other project-related documents and deliverables (collectively termed TETRA TECH's "Instruments of Professional Service"), only the signed and/or sealed versions shall be considered final. The original signed and/or sealed version archived by TETRA TECH shall be deemed to be the original. TETRA TECH will archive the original signed and/or sealed version for a maximum period of 10 years.

Both electronic file and hard copy versions of TETRA TECH's Instruments of Professional Service shall not, under any circumstances, be altered by any party except TETRA TECH.

TETRA TECH's Instruments of Professional Service will be used only and exactly as submitted by TETRA TECH.

Electronic files submitted by TETRA TECH have been prepared and submitted using specific software and hardware systems. TETRA TECH makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.

1.3 STANDARD OF CARE

Services performed by TETRA TECH for the Report have been conducted in accordance with the Services Agreement, in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Professional judgment has been applied in developing the conclusions and/or recommendations provided in this Report. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of the Report.

If any error or omission is detected by the Client or an Authorized Party, the error or omission must be immediately brought to the attention of TETRA TECH.

1.4 ENVIRONMENTAL AND REGULATORY ISSUES

Unless expressly agreed to in the Services Agreement, TETRA TECH was not retained to investigate, address or consider, and has not investigated, addressed or considered any environmental or regulatory issues associated with the project.

1.5 DISCLOSURE OF INFORMATION BY CLIENT

The Client acknowledges that it has fully cooperated with TETRA TECH with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for TETRA TECH to properly provide the services contracted for in the Services Agreement, TETRA TECH has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

1.6 INFORMATION PROVIDED TO TETRA TECH BY OTHERS

During the performance of the work and the preparation of this Report, TETRA TECH may have relied on information provided by persons other than the Client.

While TETRA TECH endeavours to verify the accuracy of such information, TETRA TECH accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage.

General Conditions

HYDROTECHNICAL

1.7 GENERAL LIMITATIONS OF REPORT

This Report is based solely on the conditions present and the data available to TETRA TECH at the time the Report was prepared.

The Client, and any Authorized Party, acknowledges that the Report is based on limited data and that the conclusions, opinions, and recommendations contained in the Report are the result of the application of professional judgment to such limited data.

The Report is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present at or the development proposed as of the date of the Report requires a supplementary investigation and assessment.

It is incumbent upon the Client and any Authorized Party, to be knowledgeable of the level of risk that has been incorporated into the project design, in consideration of the level of the hydrotechnical information that was reasonably acquired to facilitate completion of the design.

The Client acknowledges that TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.8 JOB SITE SAFETY

TETRA TECH is only responsible for the activities of its employees on the job site and was not and will not be responsible for the supervision of any other persons whatsoever. The presence of TETRA TECH personnel on site shall not be construed in any way to relieve the Client or any other persons on site from their responsibility for job site safety.

