Appendix F

Residence Time, Turbidity and Dispersion Modelling

AECOM

Appendix F1

Tetra Tech Residence Time Modelling Analysis

TETRA TECH

TECHNICAL MEMO

ISSUED FOR USE

To:	Neil Snowball	**Date:**	June 23, 2016
c:	Jim Stronach		
From:	Justin Rogers, Jordan Matthieu	**File:**	704-WTR.WTRM03017-01
Subject:	Flushing Time Modelling Analysis - Centerm		

1.0 INTRODUCTION

AECOM retained Tetra Tech EBA Inc. (Tetra Tech) to use a three-dimensional hydrodynamic model to quantify differences in circulation shoreward of the proposed Centerm expansion. This study investigates changes, if any, to the circulation regime of the embayment between CRAB/Portside Park and Centerm resulting from the expansion. In order to quantify these changes, we have chosen to compute flushing time of the embayment under a range of tidal conditions and compare this flushing time with and without the expansion in place. Increased flushing times, hence increased exposure to contaminants, could have implications for water quality and affect recreational uses, specifically at CRAB/Portside Park.

2.0 METHODS: FLUSHING TIME MODELLING

Flushing time is the average length of time a parcel of water spends in a particular area and it is useful for understanding the behaviour and availability of nutrients or other water quality constituents.

The flushing time in a simple, well-mixed water body can be predicted by Equation 1.

$$\tau = V/Q \qquad \text{Equation 1}$$

Where τ is the bulk flushing time, V is the water body volume, and Q is the flux through the water body. However, this single number may not represent the complexity or variability of a system, especially complex geometry in a tidal harbour. Tetra Tech used an existing three-dimensional model of Vancouver Harbour (H3D) to examine flushing time in the area south of Centerm with and without the proposed expansion, and compared the results to standard equations. To determine flushing time experimentally, the model was initialized with a uniform dye tracer concentration of one (1.0) within the Centerm embayment, and zero (0.0) elsewhere, for models with and without the expansion in place (Figure 1).

The model was then run for a period of three days, encompassing approximately six tidal cycles, with the zero dye concentration water outside of the Centerm embayment mixing with the dyed water within the embayment via tidal action. The total dye mass within the Centerm area was plotted as a function of time, and then a decay curve with the form of Equation 2 was fit to the dye concentration.

$$C(t) = C_0 * e^{-t/\tau} \qquad \text{Equation 2}$$

Where C is the concentration within the water body, t is time since the start of the simulation, and C_0 is the initial concentration. The result τ is the flushing time, based on realistic hydrodynamic behaviour. The flushing time corresponds to the time it takes for 63% of the dye to be removed by flushing. After two flushing times, 86% of material is removed, and 95% of material is gone after three flushing times.

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Repeat simulations of flushing time were run every three days for a complete spring-neap tide cycle to cover a variety of tidal conditions. A separate simulation was run for winter conditions to test whether reduced water column stratification would change the flushing time results.

3.0 RESULTS: FLUSHING TIME MODELLING

A series of model snapshots 9, 18 and 48 hours after the initial dye condition are shown in Figures 2, 3 and 4 respectively. The contoured variable is the water column sum of dye mass while the vectors represent surface currents. As the model is three dimensional, the dye plume can appear to move in the opposite direction to surface currents, which indicates counterflowing currents deeper in the water column. Throughout the modelled time period, water level changes cause dyed water to flow out of the embayment on falling tides, and new water to flow in on rising tides. In Figure 2, 9 hours after the simulation start, ebb tidal currents flowing westward in the middle of Vancouver Harbour set up a counterclockwise eddy in the southwestern portion of the harbour. This eddy results in eastward flow in the vicinity of Centerm and results, somewhat counterintuitively, in the eastward transport of the outflowing tracer during ebb tide. Since the existing Centerm configuration has a wider opening, the tidal exchange is more effective for the existing case.

In Figure 3, after 18 hours, flood tidal currents set up a clockwise eddy within the Centerm embayment. The expanded Centerm configuration moves this eddy slightly offshore, and appears to reduce flushing effectiveness at the shoreline. In both configurations some residual dye is evident in the western section of the embayment, next to the cruise ship terminal, and in the protected eastern sections of the embayment. After 48 hours (Figure 4) the western and central portions of the embayment are completely flushed in both configurations. A small amount of dye remains in the easternmost section, with slightly higher concentration and slightly greater affected area with the expanded Centerm.

The total mass of dye within the embayment is plotted for five separate tests in the top panel of Figure 5. Thin lines are the modelled mass, and thick lines represent a fitted curve (Equation 2). Looking at the modelled dye mass, the exchange is very effective during high-range tides (a steeply dropping line). During small tidal ranges, the rate of dye export slows. Fitting Equation 2 simplifies these plots to a single number, flushing time in hours. The flushing times determined for summer cases with and without the Centerm Expansion are summarized in Table 1 below.

The modelled flushing times were checked with an exchange volume calculation based on the tidal range during each test. Water level variability was summarized for each dye test, the tidal prism volume calculated as a percentage of the total volume, and any water re-entering the embayment was assumed to contain no dye. The exchange volume method overestimated flushing time but confirmed the general pattern. The exchange volume method is a useful check, but cannot differentiate between the case with and without the Centerm expansion, or account for the increased flushing as the tidal stream from First Narrows directly impinges upon the area.

Table 1: Comparison of Flushing Time Calculations – Summer

Test Start Day	Existing Centerm Geometry	Expanded Centerm Geometry	Tidal Prism Check Method
	[hours]	[hours]	[hours]
7/12	8.6	10.6	13.4
7/15	8.4	10.6	11.0
7/18	8.4	9.6	9.6
7/21	5.8	7.4	12.7
7/24	4.8	7.0	13.2
Mean	7.2	9.0	12.0
Min/Max	4.8/8.6	7.0/10.6	9.6/13.4

Flushing times were longer during tests with lower tidal range. In the summer simulations, the modelled mean flushing time in the existing case is 7.2 hours. With the Centerm expansion in place, the modelled mean flushing time in summer increased to 9.0 hours. The increase in mean flushing time is on the order of two hours, with minimal differences between the two cases after two days, primarily in the eastern portion of the embayment. No differences were observed in any test after three days.

Flushing time results for the winter experiment are shown in Table 2. The modelled flushing times for winter conditions are somewhat longer than in summer. The mean flushing time with existing Centerm geometry is 8.9 hours. With an expanded Centerm, the modelled flushing time increases to 12.4 hours. The tidal prism check continued to overestimate flushing time. The reasons for longer flushing times in winter is undoubtedly the lack of two-layer flow due to a well-mixed water column. The change attributable to the Centerm expansion is a 2.5 hour increase in flushing time during the winter.

Table 2: Comparison of Flushing Time Calculations – Winter

Test Start Day	Existing Centerm Geometry	Expanded Centerm Geometry	Tidal Prism Check Method
	[hours]	[hours]	[hours]
1/24	8.9	13.7	10.6
1/27	7.0	10.3	13.5
1/30	9.4	12.2	17.4
2/02	10.6	13.4	15.7
Mean	8.9	12.4	14.3
Min/Max	7.0 / 10.6	10.3 / 13.7	10.6 / 17.4

4.0 CONCLUSION

Three-dimensional modelling techniques were used to study the flushing behavior in the Centerm embayment with and without an expanded terminal footprint. According to statistical fits to modelled dye dispersion, existing flushing time within the Centerm embayment ranged from approximately 5 to 11 hours depending on season and tide. With an expanded Centerm and narrower connection to Vancouver Harbour, the flushing time within the embayment ranged from 7 to 14 hours.

This study addressed a somewhat artificial situation, in which the entire embayment was marked with a dye, and then the reduction in dye concentration over several tidal cycles was tracked. Other plausible scenarios, such as a spill at a specific point within the embayment were not investigated, because of the lack of realistic scenarios. Similarly, a spill from outside the embayment could enter into the embayment, under certain conditions. This type of event could also be simulated.

However, the modest difference in between the case with and without the expansion in place, suggests that as a preliminary assessment, there is likely no significant, long-lasting impact on water quality in the embayment due to construction of the Centerm Expansion.

5.0 CLOSURE

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

Respectfully submitted,
Tetra Tech EBA Inc.

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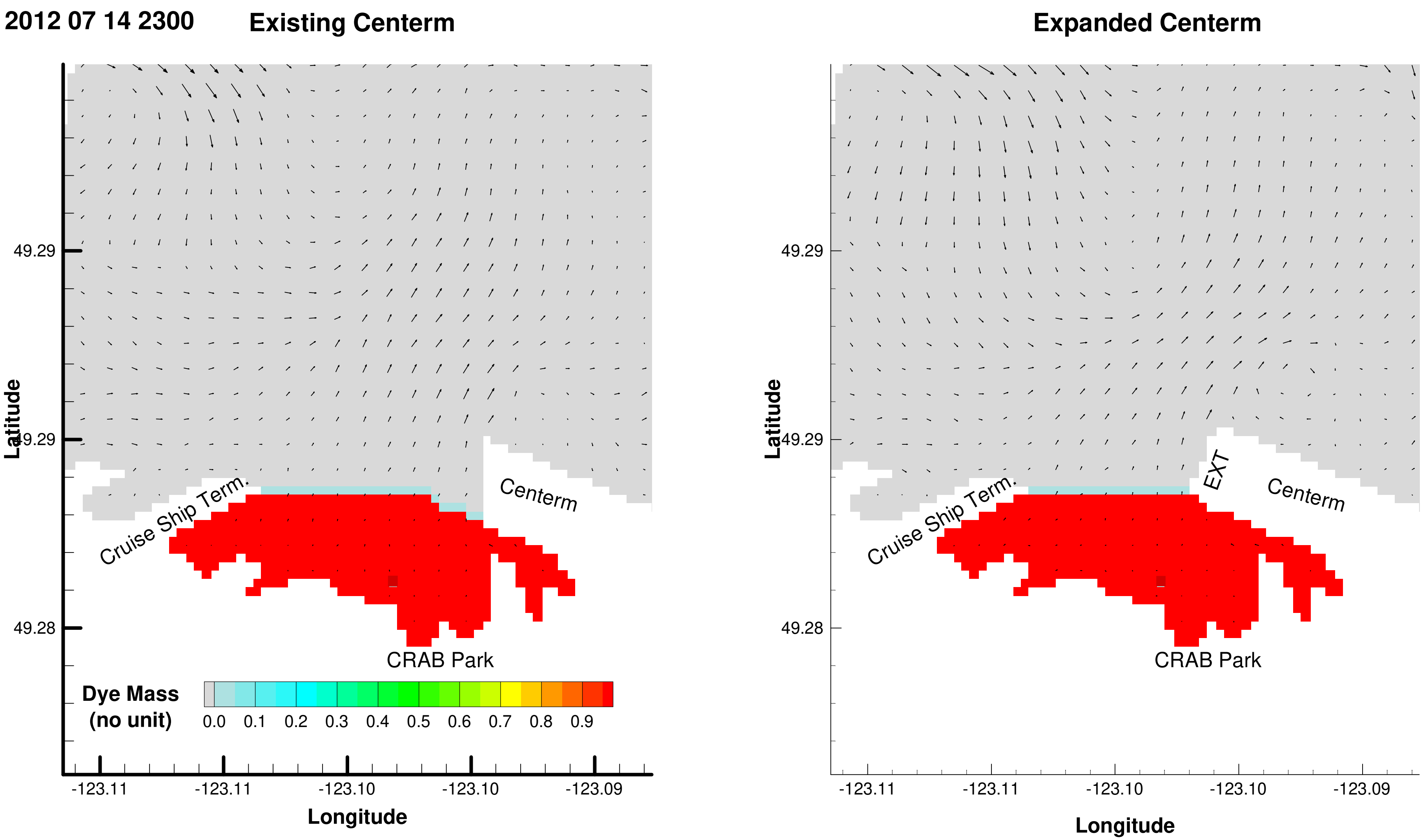
FIGURES



NOTES

Centerm Expansion assumed to be solid structure, i.e. not pile-supported.
Water can flow under the pile-supported seaward portion of the cruise ship terminal.

STATUS
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Flushing Time Modelling Analysis Centerm

Example Dye Distribution Initial Condition

PROJECT NO.	DWN	CKD	APVD	REV
WTRM.03017	JMR	JAS	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	May 2016

Figure 1

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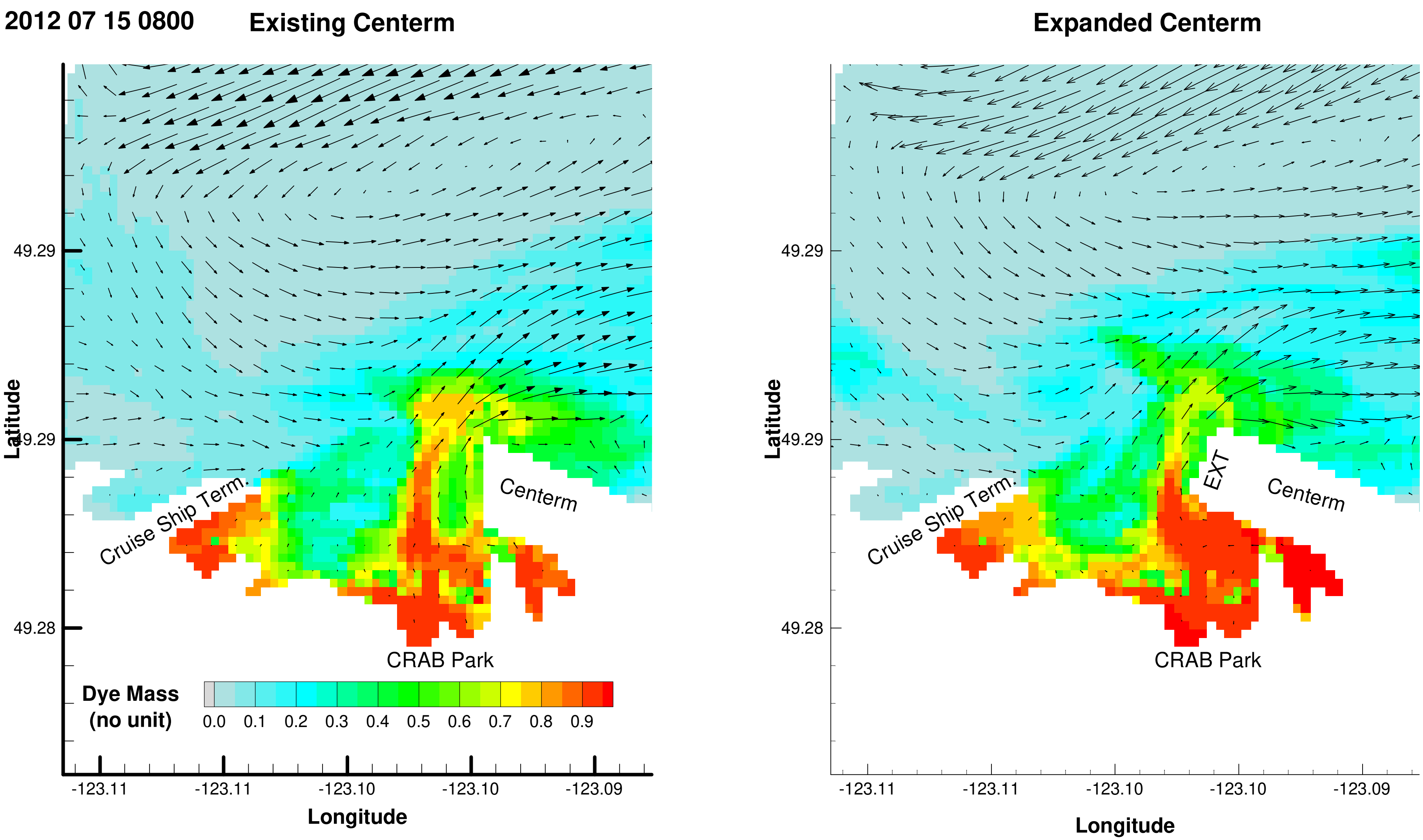
05 May 2016 17:34:25



NOTES

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Water can flow under the pile-supported seaward portion of the cruise ship terminal.

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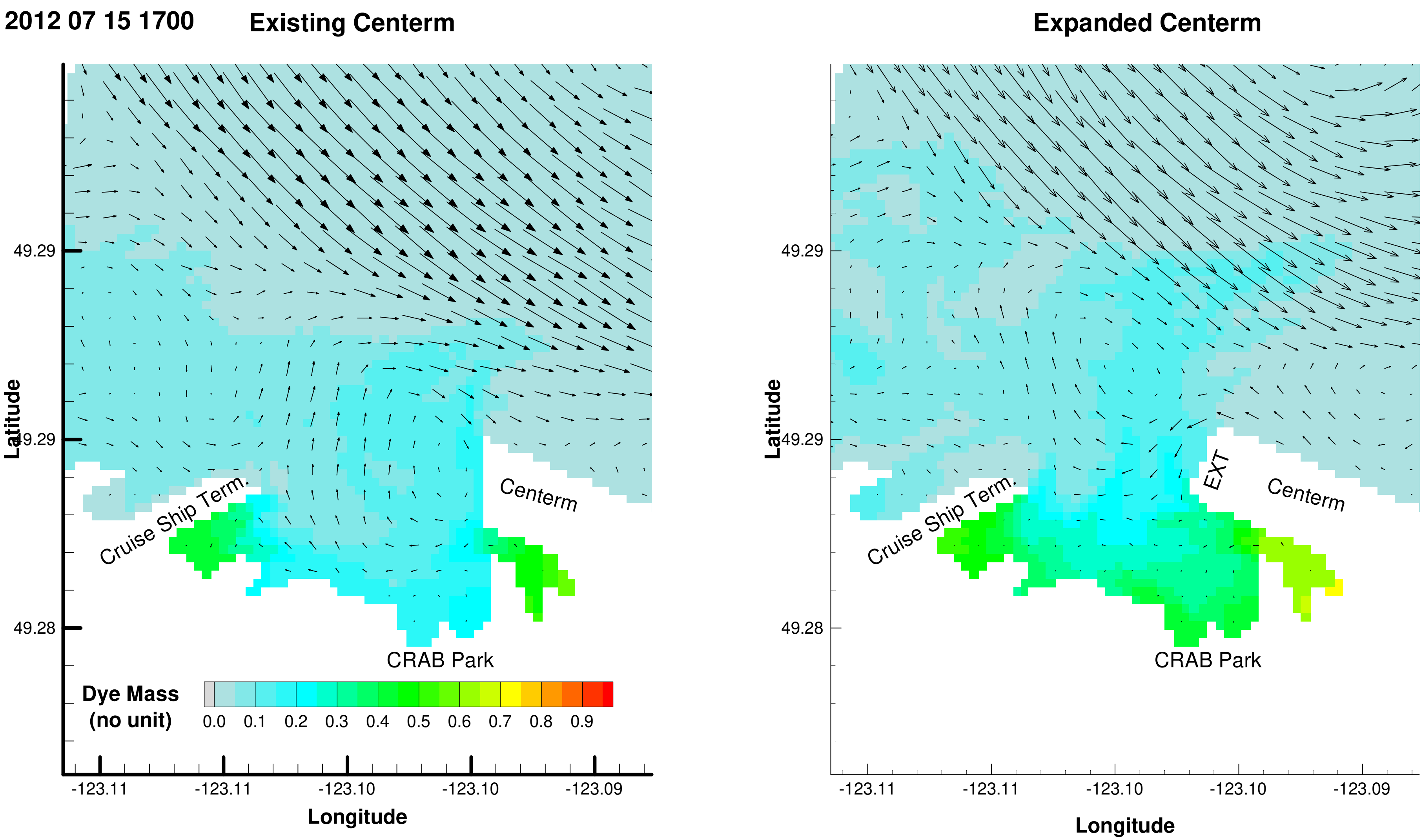
Flushing Time Modelling Analysis Centerm

Example Dye Distribution After 9 Hours

PROJECT NO.	DWN	CKD	APVD	REV
WTRM.03017	JMR	JAS	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	May 2016

Figure 2



NOTES

Centerm Expansion assumed to be solid structure, i.e. not pile-supported.
Water can flow under the pile-supported seaward portion of the cruise ship terminal.

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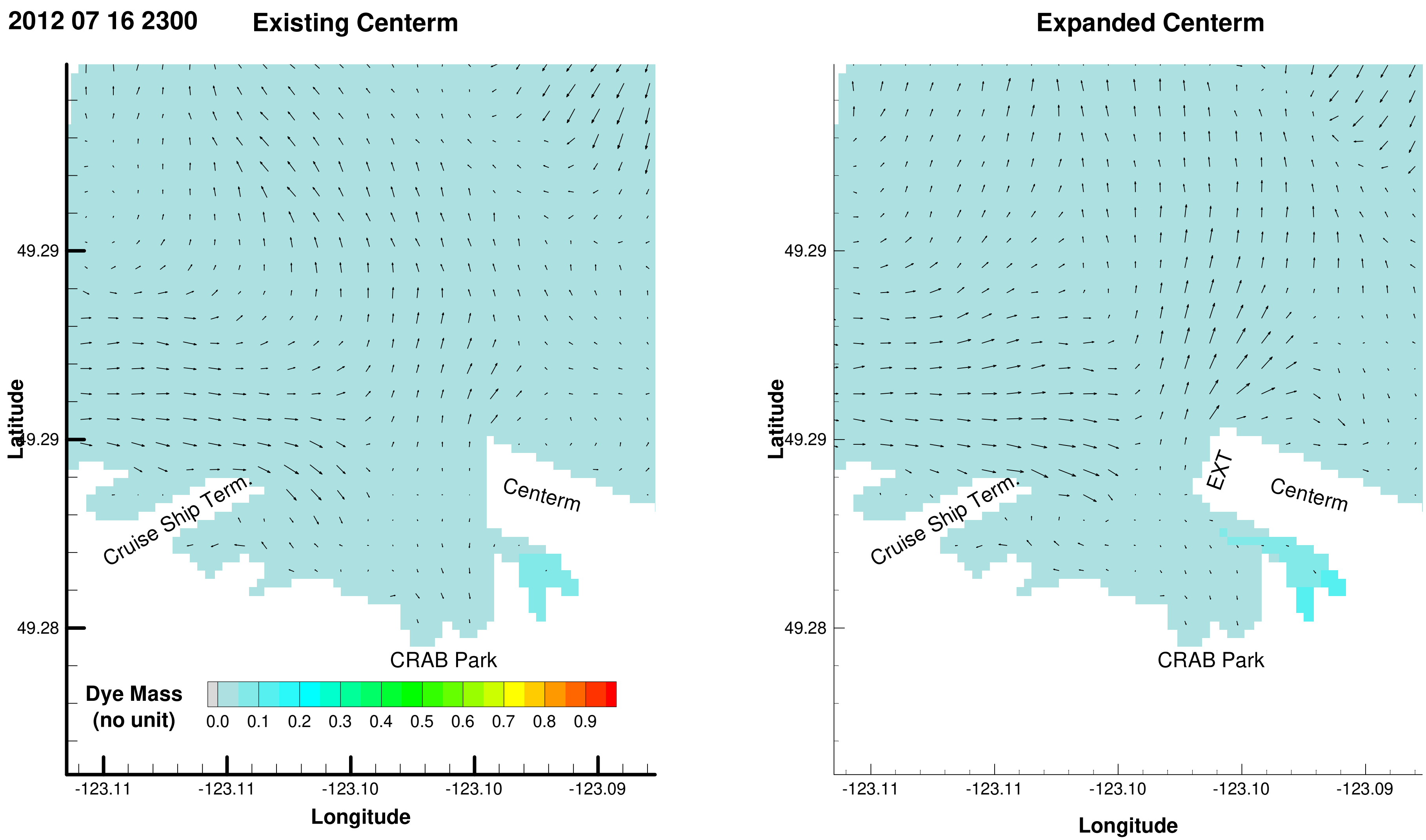
Flushing Time Modelling Analysis Centerm

Example Dye Distribution After 18 Hours

PROJECT NO.	DWN	CKD	APVD	REV
WTRM.03017	JMR	JAS	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	May 2016

Figure 3



NOTES

Centerm Expansion assumed to be solid structure, i.e. not pile-supported.
Water can flow under the pile-supported seaward portion of the cruise ship terminal.

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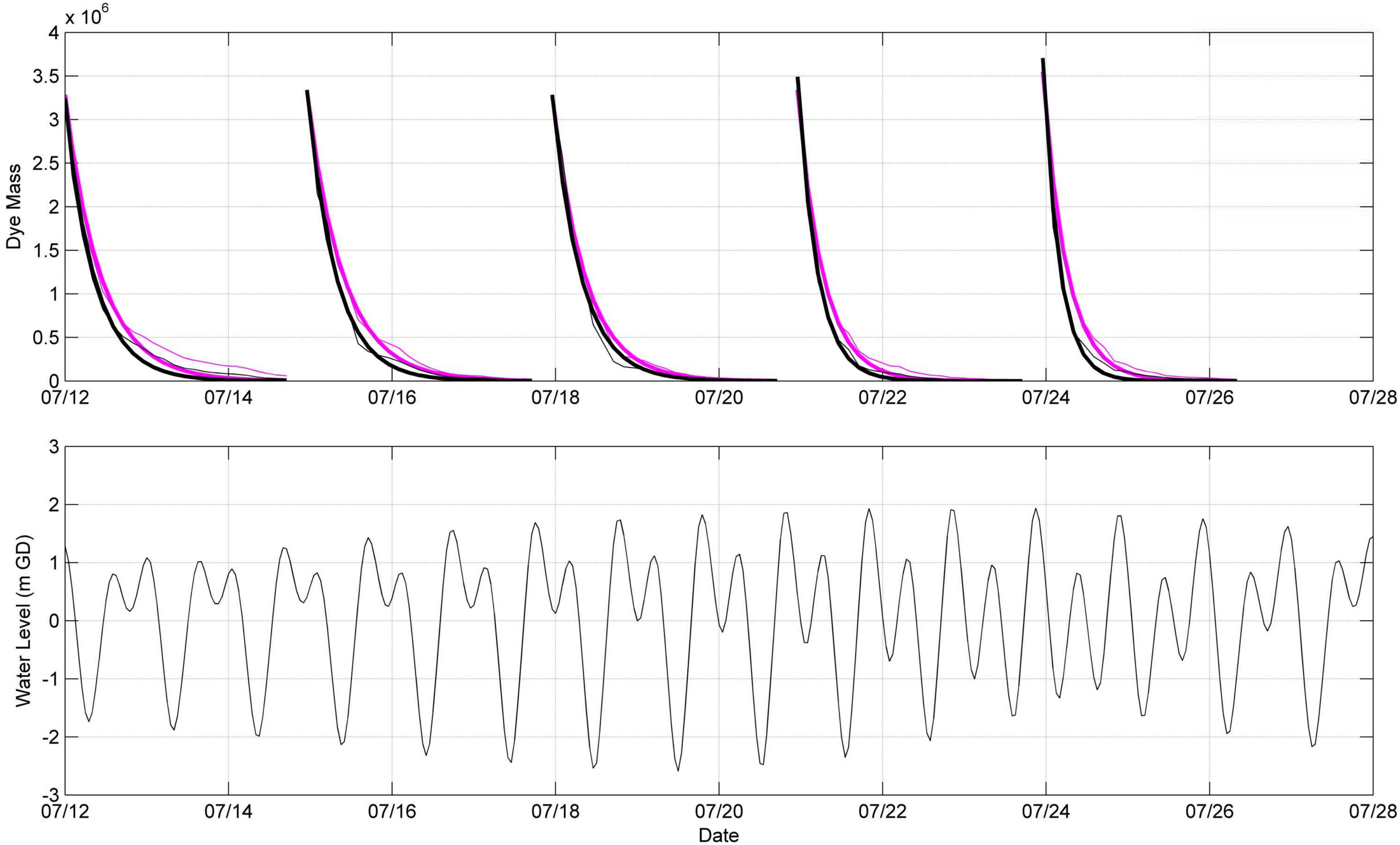
Flushing Time Modelling Analysis Centerm

Example Dye Distribution After 48 Hours

PROJECT NO.	DWN	CKD	APVD	REV
WTRM.03017	JMR	JAS	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	May 2016

Figure 4



NOTES

Dye Mass is a unitless parameter
Thin lines are modelled dye mass
Thick lines are decay curve best fit

Centerm Existing Geometry

Centerm Expansion

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Flushing Time Modelling Analysis Centerm

Flushing Time Curves - Existing and Expanded Centerm, Summer Conditions

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

OFFICE	DATE
Tetra Tech EBA - VANC	May 2016

Figure 5

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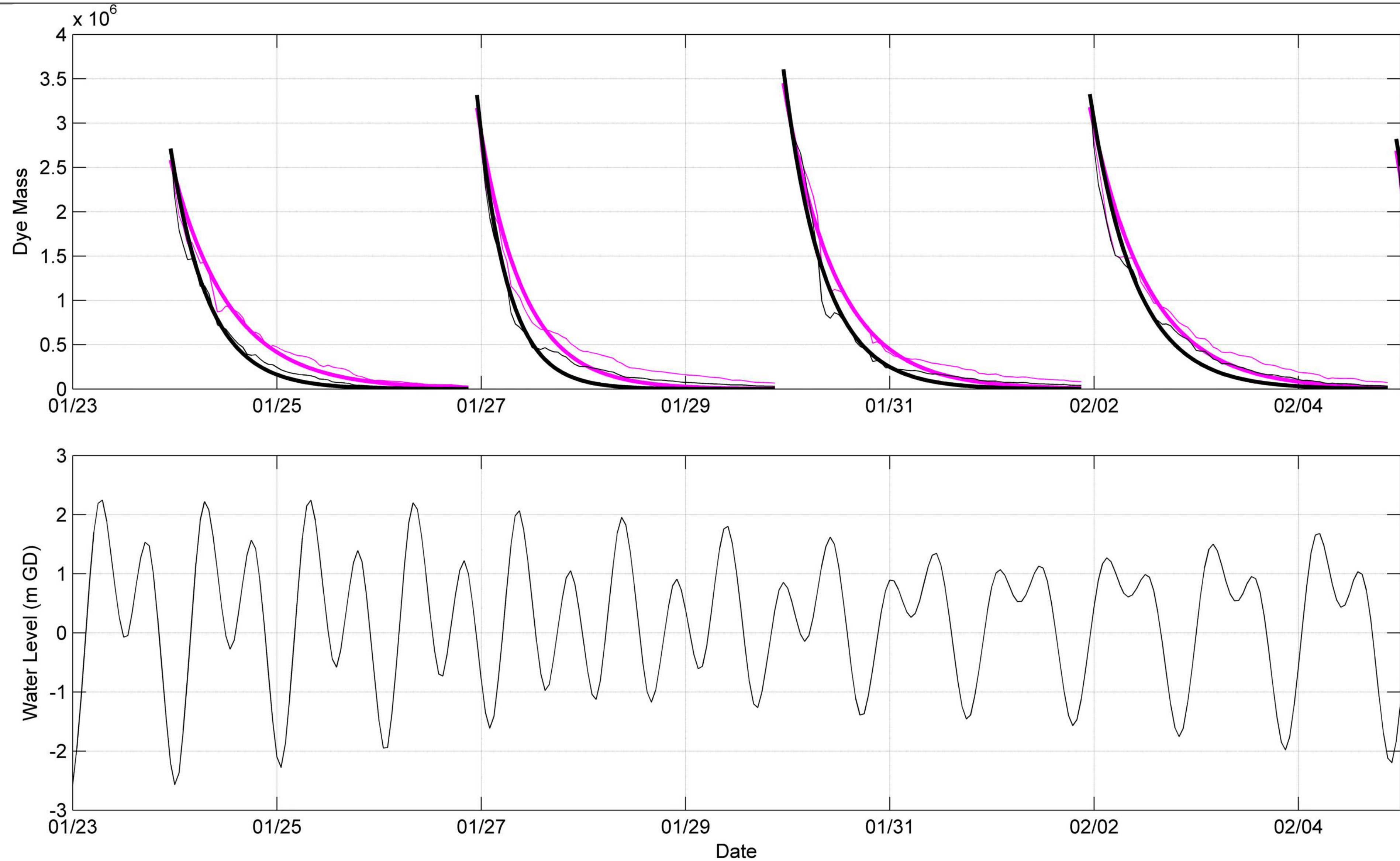

NOTES

Dye Mass is a unitless parameter
Thin lines are modelled dye mass
Thick lines are decay curve best fit

Centerm Existing Geometry

Centerm Expansion

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Flushing Time Modelling Analysis Centerm

Flushing Time Curves - Existing and Expanded Centerm, Winter Conditions

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

OFFICE	DATE
Tetra Tech EBA - VANC	May 2016

Figure 6

APPENDIX A: TETRA TECH EBA'S GENERAL CONDITIONS

GENERAL CONDITIONS

HYDROTECHNICAL

This report incorporates and is subject to these “General Conditions”.

1.0 USE OF REPORTS 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 EBA’s Client (the “Client”) as specifically identified in the Tetra Tech EBA Services Agreement or other Contract entered into with the Client (either of which is termed the “Services Agreement” herein). Tetra Tech EBA 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 EBA.

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Where Tetra Tech EBA 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.

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2.0 ALTERNATIVE REPORT FORMAT

Where Tetra Tech EBA 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 EBA’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 EBA shall be deemed to be the original. Tetra Tech EBA 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 EBA’s Instruments of Professional Service shall not, under any circumstances, be altered by any party except Tetra Tech EBA. Tetra Tech EBA’s Instruments of Professional Service will be used only and exactly as submitted by Tetra Tech EBA.

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

3.0 STANDARD OF CARE

Services performed by Tetra Tech EBA 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 EBA.

4.0 ENVIRONMENTAL AND REGULATORY ISSUES

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

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

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

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.

8.0 JOB SITE SAFETY

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.

AECOM

Appendix F2

Tetra Tech Turbidity Modeling of Project Dredging

TECHNICAL MEMO

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To:	Neil Snowball, Micheal Rankin	**Date:**	October 19, 2016
c:	Jim Stronach		
From:	Jordan Matthieu	**File:**	704-WTR.WTRM03017-01
Subject:	Centerm Expansion Project: Fugitive Sediment Numerical Modelling Study		

1.0 INTRODUCTION

AECOM Canada (AECOM) retained Tetra Tech EBA Inc. (Tetra Tech) to use a three-dimensional hydrodynamic model to quantify release and dispersion of fugitive sediments arising from dredging three sites over the course of the Centerm Expansion Project (CEP). This study investigates the behaviour of sediment plumes arising from clamshell dredging operations, using either one dredge or two dredges simultaneously.

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 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.

Within the modeling 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.

Figure 1 shows the boundary of the 25-m resolution Burrard Inlet model (red box), with 30-minute duration streamlines (white streaks) demonstrating the surface water circulation patterns resulting from a moderate ebb tide.

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The initiation point of each streamline is semi-random, with a higher initiation point density weighted to locations of higher velocity.

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 SeaBus Dredge Zone in red, the West Basin Dredge Zone in green and East Basin Dredge Zone in blue. In the upper left corner of Figure 2 two boxes are presented: the inner box is 100 m on edge and the outer box is 250 m on edge. Boxes of these dimensions are used later in this report to determine the dilution of the initial dredgeate source strength at 100 m and 250 m distances.

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. At 15 minute intervals, the concentration and position of the sand, silt and clay comprising the TSS plume is reported. This data is then post processed to determine:

- The TSS concentration at a 100 m distance from the clam shell dredge(s). In the upper left corner of Figure 2, the inner white box demonstrates the 100 m boundary from an example dredge point in the center.
- The TSS concentration at a 250 m distance from the clam shell dredge(s). In the upper left corner of Figure 2, the outer white box demonstrates the 250 m boundary from an example dredge point in the center.
- The probability of achieving a less than 90% attenuation of the initial fugitive sediment release concentration over any given 15 minute window of the dredge operation.
- The probability of the above-background concentration of TSS exceeding 5 mg/L for the shorter of the dredge period or 30 days.
- The probability of the above background concentration of TSS exceeding 25 mg/L for a period exceeding 24 hours.

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 pf 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. Turbidity values increased slightly during spring and late summer phytoplankton blooms.

3.2 SEDIMENT CHARACTERISTICS

The in situ sediments from 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 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 SeaBus Dredge Zone, the values for the West Basin Dredge Zone are applied there.

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).

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 / SeaBus					
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 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). As seabed sediments within each dredge basin contain a significant proportion of fine material, the fill efficiency rate for fine grain seabed material, 83%, has been applied.

Assumed properties of the clamshell dredge and associated production rates of the dredge operations are presented in Table 3.3. The dredging operation was assumed to use 24-hour work days, seven days per week with 10% down time and a 90 second cycle time (i.e. the time between successive bucket grabs). A clamshell bucket size of 5 m^3 has been assumed, with a complete fill comprised of 83% seabed and 17% water. With a 0.485 solids fraction of native material, the expected volume of solids per dredge cycle is 2.01 m^3. The clamshell scoop is assumed to lose 2% of its contents before delivery to the barge. Therefore, the fugitive sediment release per dredge cycle is 0.04 m^3. At the SeaBus Dredge Basin and West Dredge Basin, the release of each sediment class is 0.017 m^3 of sand, 0.014 m^3 of silt and 0.009 m^3 of clay per dredge cycle. At the East Dredge Basin, the release of each sediment class is 0.023 m^3 of sand, 0.012 m^3 of silt and 0.004 m^3 of clay per dredge cycle.

The release of 0.04 m^3 of sediment per dredge cycle results in an initial source TSS concentration ranging from 1,260 mg/L to 295 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. The diameter of this cylinder has been based on the dimensions of Robotech CSB600 and Ransome YC4000 dredge buckets, with an additional 0.5 m allowance for the lateral release of slurry from the bucket. The initial source TSS concentration varies from location to location because the available literature for clamshell dredges provides an estimate of dredgeate blow off (e.g. 2%) based on the properties of the seabed and dredge bucket, but not on the length 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 (0.04 m^3) was 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 and data, a constant blow off rate has been maintained.

The total volume of dredging and fugitive sediment release at the three dredge basins is presented in Table 3.4. In addition to the calculated dredge prisms, a 5% over dredge contingency has been applied to account for any uncertainty in the prism estimation. Utilizing one clamshell dredge loading a single hopper barge, a 2,000 m^3/day production volume is achievable which, with a 2% loss rate, totals 2,040 m3/day of seabed dredged per day. Similarly, two dredges loading a two hopper barges are estimated to dredge 4,080 m^3/day of seabed. Based on these production rates, the total dredge operation duration is estimated in Table 4. It should be noted that a dredge operating to the specifications laid out in Table 3, operating 24 hours per day with 10% downtime can dredge 3,586 m^3/day of seabed (3,551 m^3/day delivered to a barge), so the limiting factor on the dredge operation is the capacity and estimated cycle time of barges servicing the dredges. The resettlement of dredgeate blow off within the dredge prism is expected to be minimal due to tidal action in Vancouver Harbour.

Table 3.3 Summary of Dredge Operation

	Parameter	SeaBus	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	-	η = 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	5	5	5	m^3	
	Efficiency	0.83	0.83	0.83	-	Factor for partially filled bucket
	Total Volume	4.15	4.15	4.15	m^3/cycle	Dredgeate per cycle, total
	Solids Volume	2.01	2.01	2.01	m^3/cycle	Dredgeate per cycle, solids
	Loss Rate	0.02	0.02	0.02	-	Portion of dredgeate lost per cycle
	Fugitive Solids	0.040	0.040	0.040	m^3/cycle	Solids volume lost per cycle
	Fugitive Sand	0.017	0.017	0.023	m^3/cycle	Sand volume lost per cycle
	Fugitive Silt	0.014	0.014	0.012	m^3/cycle	Silt volume lost per cycle
	Fugitive Clay	0.009	0.009	0.004	m^3/cycle	Clay volume lost per cycle
Source Strength	Zone Radius	2.0			m	Based on dredge bucket size
	Depth	Min: 6.9 m Max: 29.6 m			m	Based on depth in dredge cut
	Volume	Min: 87 m^3 Max: 372 m^3			m^3	Volume dredge passes through
	TSS Conc.	1,260 / 295	1,260 / 295	1,260 / 295	mg/L	Max/Min TSS concentration
	Sand Conc.	535 / 125	535 / 125	724 / 169	mg/L	Max/Min sand concentration
	Silt Conc.	441 /103	441 / 103	378 / 88	mg/L	Max/Min silt concentration
	Clay Conc.	283 / 66	283 / 66	126 / 29	mg/L	Max/Min clay concentration

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

	Dredge Prism	Over Dredge[1]	Total Volume	Total Solids	Fugitive Release	Duration 1 Dredge[2]	Duration 2 Dredge[3]
	m^3	%	m^3	m^3	m^3	days	days
SeaBus	7,000	5%	7,350	3,786	76	4	2
West Basin	235,000	5%	246,750	127,114	2,542	121	60
East Basin	155,000	5%	162,750	83,841	1,677	80	40
Total	**397,000**	**-**	**416,850**	**214,741**	**4,295**	**204**	**102**

[1] Contingency over-dredge volume.
[2] Assumed 2,000 m^3/day production volume, with 2% loss rate for total of 2,040 m^3/day of seabed dredged.
[3] Assumed 4,000 m^3/day production volume, with 2% loss rate for total of 4,080 m^3/day of seabed dredged.

4.0 RESULTS

4.1 SEABUS DREDGE ZONE

Sediments released by a single dredge operating at the SeaBus Dredge Zone result in a source TSS concentration of approximately 1000 mg/L. Figure 3 presents the attenuation of this source concentration at two distances from the dredge and for 1 and 2 dredge scenarios. Within 3 hours of the start of dredging the maximum TSS at a distance of 100 m from the dredge exceeds 25 mg/L. The mean concentration at a 100 m distance from the dredge rarely exceeds 50 mg/L. At a distance of 250 m from the dredge source, the maximum concentration only exceeds 25 mg/L after several hours, once the concentration of TSS in the water column has been built up by many successive dredge cycles. Following the end of dredging operations TSS concentration drops to approximately the baseline level after 48 hours. The maximum concentration of TSS 250 m from the dredge source (middle panel, Figure 3) remains slightly elevated due an isolated attenuating pocket of TSS between Canada Place and the SeaBus terminal. Table 4.2 presents the maximum, minimum and percentile concentrations of TSS simulated at distances of 100 m and 250 m from the dredge.

Table 4.1 Concentration 100 m and 250 m from Dredge Source

Percentile	1 Dredge		2 Dredges		Unit
	100 m	250 m	100 m	250 m	
Maximum	89.05	42.88	160.41	102.75	mg/L
90	21.17	6.76	42.96	16.83	mg/L
75	6.12	2.55	17.49	8.29	mg/L
50	2.06	0.93	6.64	2.44	mg/L
25	1.02	0.26	2.7	0.84	mg/L
10	0.48	0.08	1.64	0.2	mg/L
Minimum	0	0	0	0	mg/L

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, dilution in the vicinity of the SeaBus Dredge Zone is sufficient that there is a low probability of exceeding 10% of the initial source concentration. Figure 5 presents the probability that the above-background maximum instantaneous water column concentration of TSS will exceed 5 mg/L for the duration of the dredging operation (approximately 2 days). The Canadian Council of Ministers of the Environment (CCME) guidelines state that the above background TSS concentration should not exceed 5mg/L for dredging operations with a duration between 24 hours and 30 days. From Figure 5, it can be seen that in the vicinity of the SeaBus Dredge Zone the probability of exceeding a TSS concentration of 5 mg/L above background is 90% to 100% for both one and two dredge scenarios, with this probability rapidly tapering outside of an 800 m radius. The difference in shape between the probability map of the 1 dredge case (top panel) and 2 dredge case (bottom panel) is due to the behaviour of the TSS plume during individual tides, with the plume resulting from each scenario taking a slightly different trajectory due to a slightly different position of the dredge source.

Figure 6 presents the probability that the maximum instantaneous water column concentration of TSS will exceed 25 mg/L for a period of 24 hours or more. 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 100% probability of exceeding 25 mg/L for more than 24 hours in the SeaBus Dredge Zone itself and a short distance westward towards Canada Place, with the probability rapidly tapering outside of this area. Outside of a 500 m radius, the probability is negligible.

4.2 WEST BASIN DREDGE ZONE

Compared to both the SeaBus and East Basin Dredge Zones, the West Basin Dredge Zone is relatively deep, exposed and well flushed. This results in much better dilution of suspended sediments, which are more rapidly mixed and carried from the dredge zone. As a result, the concentration crossing the 100 m and 250 m radii rises almost immediately following the commencement of dredging and drops to baseline levels almost immediately following the end of dredging. Figure 7 and Table 4.2 present the source attenuation at the West basin Dredge Zone.

Table 4.2 Concentration 100 m and 250 m from Dredge Source

Percentile	1 Dredge		2 Dredges		Unit
	100 m	250 m	100 m	250 m	
Maximum	61.9	31.91	127.15	63.97	mg/L
90	10.22	3.93	21.31	8.44	mg/L
75	5.32	1.96	11.68	4.17	mg/L
50	2.11	0.84	4.72	1.84	mg/L
25	0.83	0.19	1.84	0.39	mg/L
10	0.25	0.08	0.53	0.17	mg/L
Minimum	0	0	0	0	mg/L

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 very low. In all cases, initial source concentration is rapidly diluted by the tidal action in Burrard Inlet. This tidal action similarly serves to ensure that, as shown on Figures 9, the probability that the TSS concentration in the water column will exceed 5 mg/L above background for a period exceeding 30 days is relatively low, and confined to a relatively small area. Similarly, the probability that the TSS concentration will exceed 25 mg/L above background for a period exceeding 24 hours is extremely low and confined to a very small area. These low sediment concentration exceedances arise because tidal currents do not allow any significant background concentration to build up in the West Basin Dredge Zone, excluding in the immediate vicinity of the dredge which itself moves one to several times per day excluding a significant TSS buildup in any one location.

4.3 EAST BASIN DREDGE ZONE

Dredging operations at the East Basin Dredge Zone is assumed to begin at the shore, near the B.N.R Pier, at progress northwards from there. At the south, near shore, end of the East Basin Dredge Zone there is relatively poor flushing, which is demonstrated on Figure 11 by the initial period of high concentration (until August 30th) at a 100 m radius. The 250 m radius extends out into less protected waters, which is why it does not display as high a concentration. As the dredging operation progresses northwards, flushing improves and the concentration 100 m from the dredge drops significantly, with the concentration at 250 m reducing slightly. As discussed in Section 3.2, the source concentration is tied to the water depth, which is why it drops as the dredge moves northwards into deeper water. This also contributes to the drop in concentration 100 m from the dredge.

Exceedance values at 100 m and 250 m from the dredge are presented in Table 4.3. Compared to both the SeaBus and West Basin Dredge Zones, high-percentile TSS concentrations observed at the East Basin 100 m from the dredge are elevated. This is because of the confined southern boundary of the dredge area. Comparing the low-percentile concentrations, the East Basin Dredge Zone is very comparable to the West Basin Dredge Zone, due to the high flushing northern dredge area.

Table 4.3 Concentration 100 m and 250 m from Dredge Source

Percentile	1 Dredge		2 Dredges		Unit
	100 m	250 m	100 m	250 m	
Maximum	102.84	35.49	229.82	57.39	mg/L
90	16.88	3.22	35.77	6.24	mg/L
75	7.63	1.48	15.88	2.98	mg/L
50	2.00	0.36	4.39	0.73	mg/L
25	0.26	0.06	0.56	0.15	mg/L
10	0.08	0.04	0.16	0.09	mg/L
Minimum	0	0	0	0	mg/L

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% to 20%), but increases towards the southern end of the dredge zone (up to 60%). The probability that the TSS concentration will exceed 5 mg/L above background for more than 30 days or 25 mg/L for more than 24 hours is relatively low and confined to a relatively small area for dredging operations in the East Basin, as shown on Figures 13 and 14. In all cases, the region where the probability of above background TSS concentration exceeding 5 mg/L for more than 30 days or 25 mg/L for more than 24 hours is elevated (maximum 50% and 10% probabilities, respectively) is confined to the basin between the Ballantyne and B.N.R Piers.

5.0 CONCLUSION

Based on the results of this modelling study:

SeaBus Dredge Zone

- Strong initial dilution of the TSS source ensures that it is very unlikely that the concentration of TSS in the water column will exceed 10% of the source strength.
- Due to a lack of flushing by tidal currents, it is likely that the TSS concentration in the vicinity of the SeaBus Dredge Zone will exceed 25 mg/L for more than 24 hours.
- It is likely that the TSS concentration in the SeaBus Dredge Zone will drop below 25 mg/L within 6 hours after the stop of dredging, and will return to near-baseline values within two days.
- It is possible that residual TSS may linger in between Canada Place and the SeaBus Terminal for a period of several days following the end of dredging.
- It is recommended, if technically feasible, to isolate the active working area of the SeaBus Dredge Zone with a silt curtain.

West Basin Dredge Zone

- Strong initial dilution of the TSS source ensures that it is very unlikely that the concentration of TSS in the water column will exceed 10% of the source strength.
- Due to tidal action, the region where the TSS concentration over background resulting from dredging will exceed 5 mg/L for a period exceeding 30 days is relatively small, and the peak probability region, with a probability of 40%, is confined to an approximately 100 m diameter circle. The probability of TSS concentration exceeding 25 mg/L for a period exceeding 24 hours is very small, and confined to a circular area of approximately 50 m diameter.

East Basin Dredge Zone

- Strong initial dilution of the TSS source ensures that it is very unlikely that the concentration of TSS in the water column will exceed 10% of the source strength except for a small region off the northwest tip of Ballantyne Pier.
- It is unlikely that the TSS concentration resulting from dredging activities at the East Basin Dredge Zone will exceed 5 mg/L for a period exceeding 30 days except for a small area between Ballantyne Pier and Centerm Terminal, with a peak probability of 40% at the centre of this region.
- The probability of TSS concentration exceeding 25 mg/L for a period exceeding 24 hours is exceeding small, and confined to a circular area of less than 100 m diameter.
- At the southern end of the East Basin Dredge Zone, between the Ballantyne and B.N.R Piers, there is an area of reduced flushing that impedes dilution of the dredgeate. Modelling results show there is a 50% probability that the TSS concentration over background will exceed 5 mg/L for more than 30 days and a 10% probability that the TSS concentration over background will exceed 25 mg/L for more than 24 hours.

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

- **SeaBus 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 SeaBus 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 B.N.R Piers and to periodically check the turbidity levels in the basins between Ballantyne Pier and Vanterm.

6.0 CLOSURE

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

Respectfully submitted,
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FIGURES

NOTES

Notes:
The boundary of the 25-m resolution Burrard Inlet model is shown by the red box
30-minute duration streaklinesare shown in white, demonstrating the surface water circulation patterns resulting from a moderate ebb tide.

STATUS
ISSUED FOR USE

CLIENT

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TETRA TECH EBA

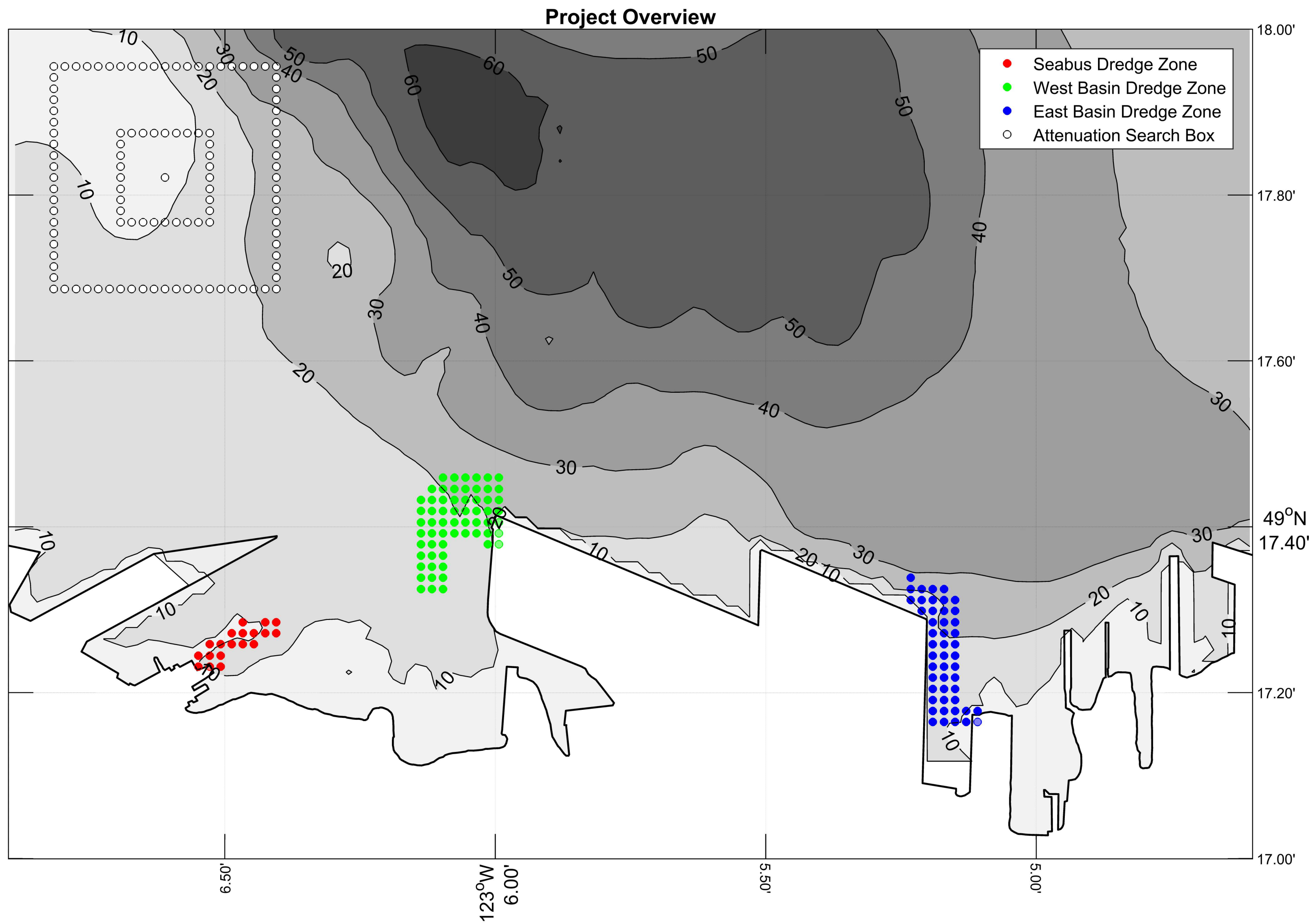
Centerm Expansion Project
Fugitive Sediment Numerical Modelling

Burrard Inlet 25-m Resolution Model Extent and Flow Field Overview

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

OFFICE	DATE
Tetra Tech EBA - VANC	August, 2016

Figure 1



NOTES

In the upper left of this figure, two boxes are presented as white circles at each grid cell centre. The inner box is 100 m on edge and the outer box is 250 m on edge. Boxes of these dimensions are used to determine the dilution of the initial dredgeate source strength at 100 m and 250 m distances.

STATUS
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Centerm Expansion Project
Fugitive Sediment Numerical Modelling

Project and Dredge Basin Overview

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

OFFICE	DATE
Tetra Tech EBA - VANC	August, 2016

Figure 2

NOTES

Notes:
1) The concentration axis scale for the Source Concentration plot differs from that of the Concentration Radii plots.
2) Source concentration varies in time due to depth variations between dredge locations and tidal action.
3) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

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Centerm Expansion Project
Fugitive Sediment Numerical Modelling

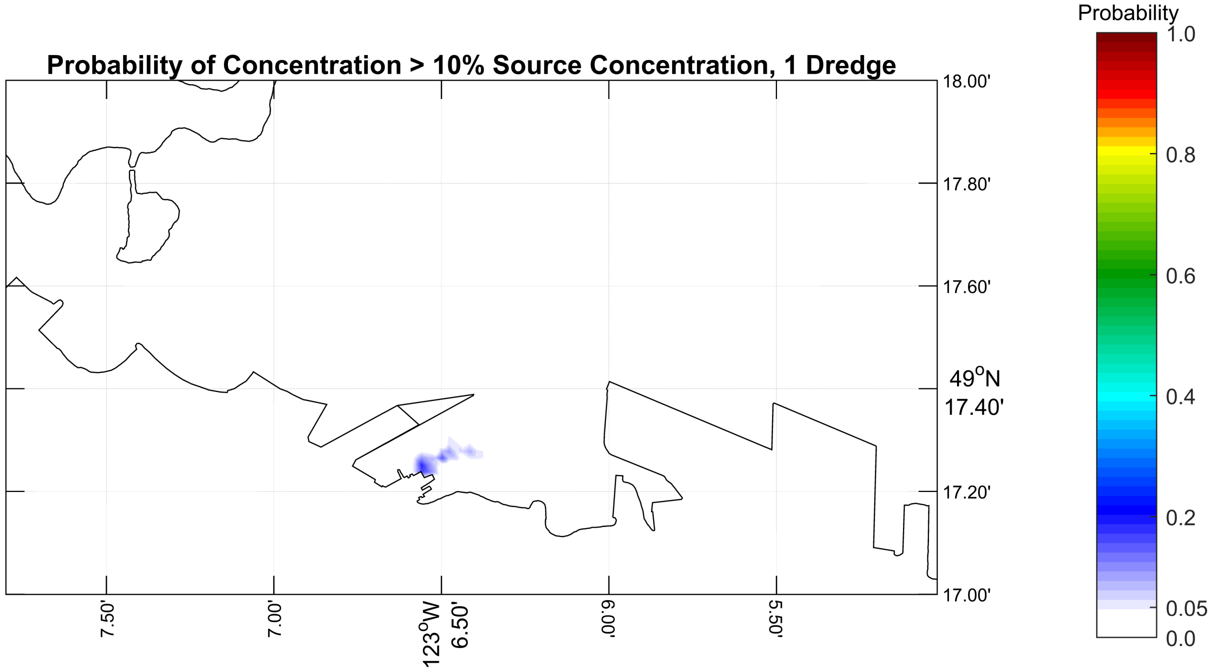
SeaBus Dredge Basin
TSS Source Attenuation

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

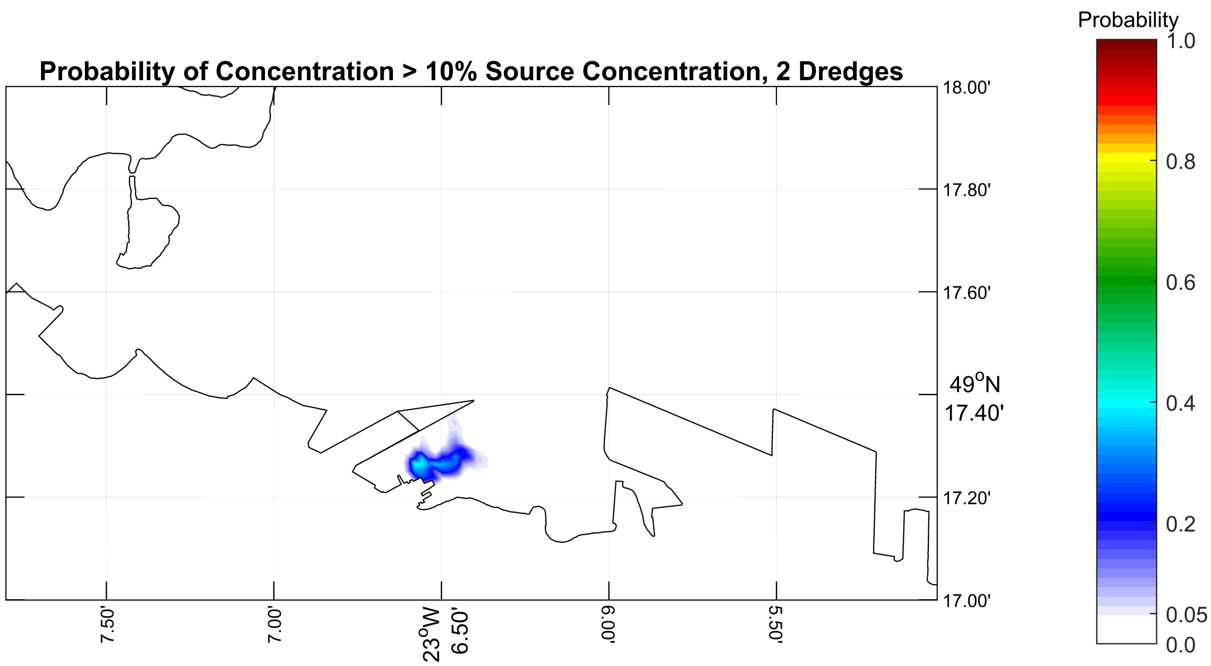
OFFICE	DATE
Tetra Tech EBA - VANC	August, 2016

Figure 3

Probability of Concentration > 10% Source Concentration, 1 Dredge



Probability of Concentration > 10% Source Concentration, 2 Dredges



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

CLIENT
AECOM

TETRA TECH EBA

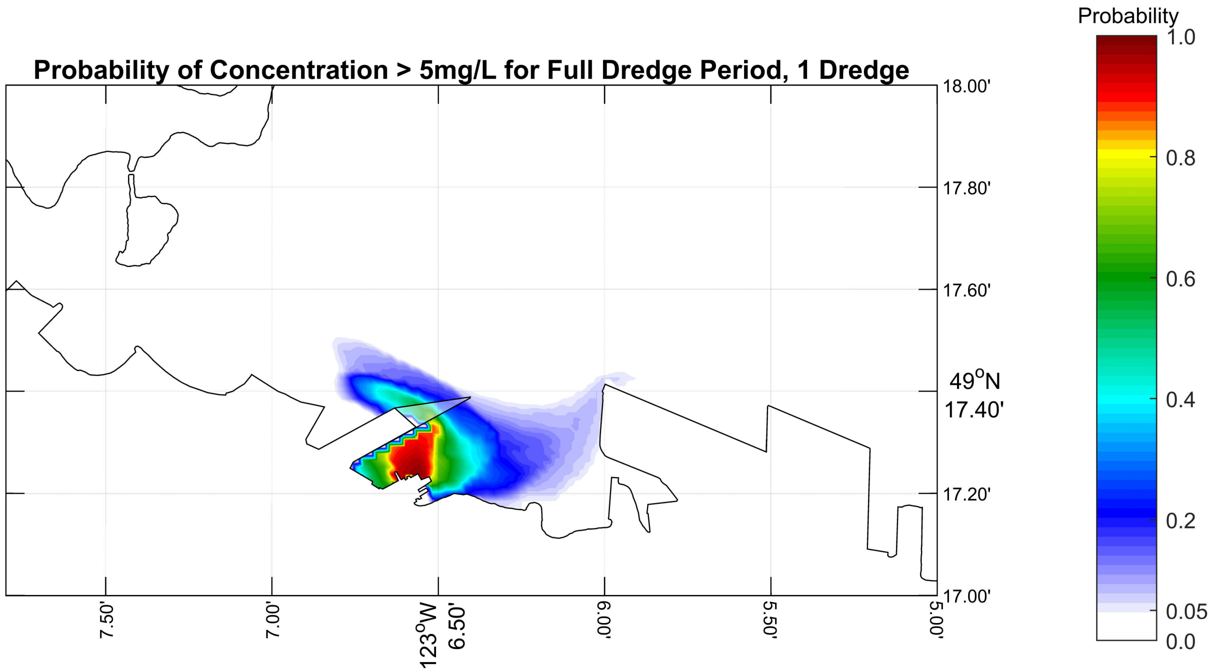
Centerm Expansion Project
Fugitive Sediment Numerical Modelling

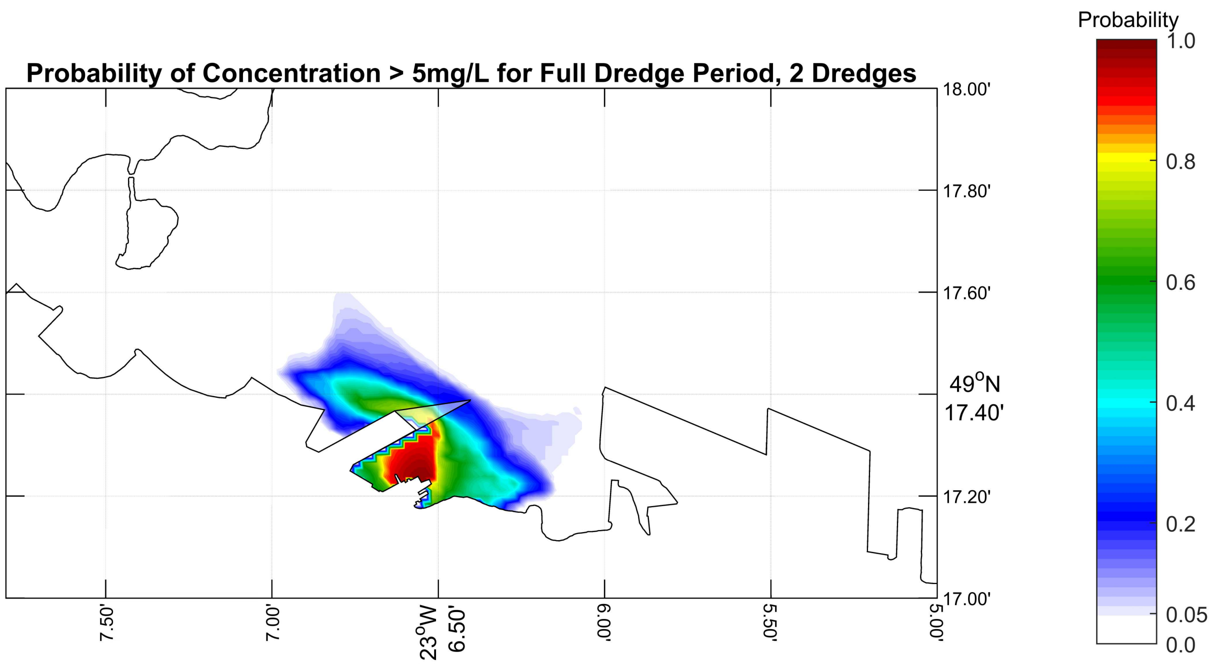
SeaBus Dredge Basin
Probability of Not Achieving
90% Source Attenuation

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	August, 2016

Figure 4





NOTES

1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
2) 5mg/L exceedance probability is presented for the dredge period, rather than 30 days, because the dredge period has a duration shorter than 30 days.
3) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

STATUS
ISSUED FOR USE

CLIENT
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TETRA TECH EBA

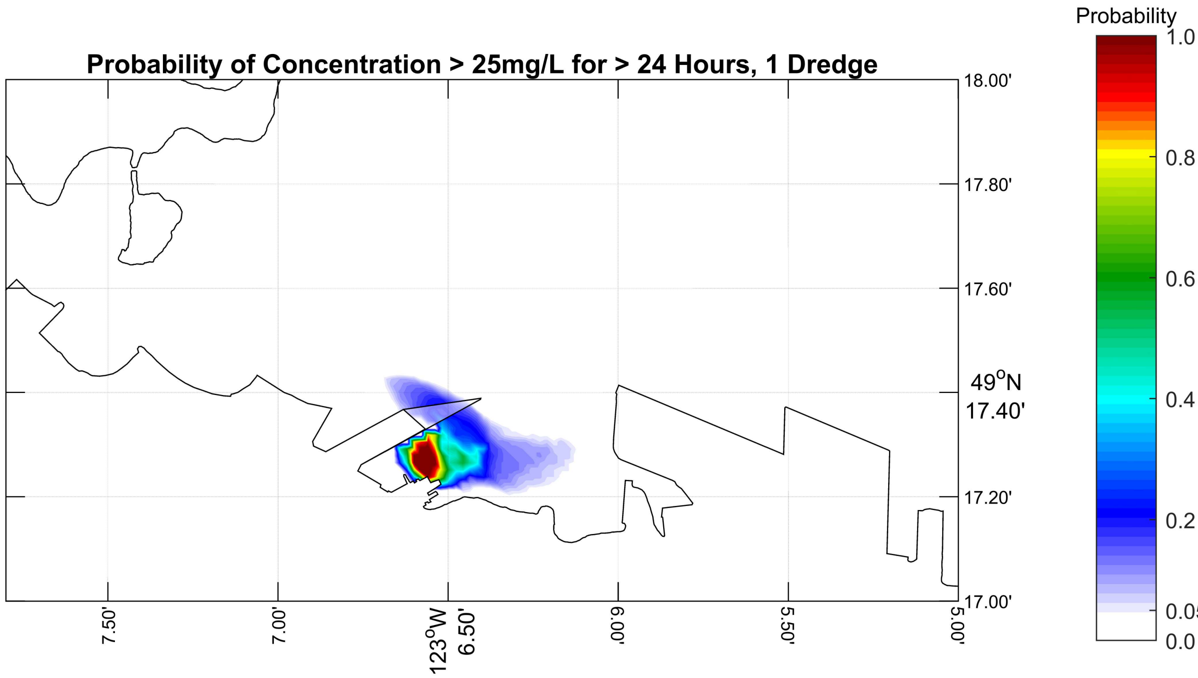
Centerm Expansion Project
Fugitive Sediment Numerical Modelling

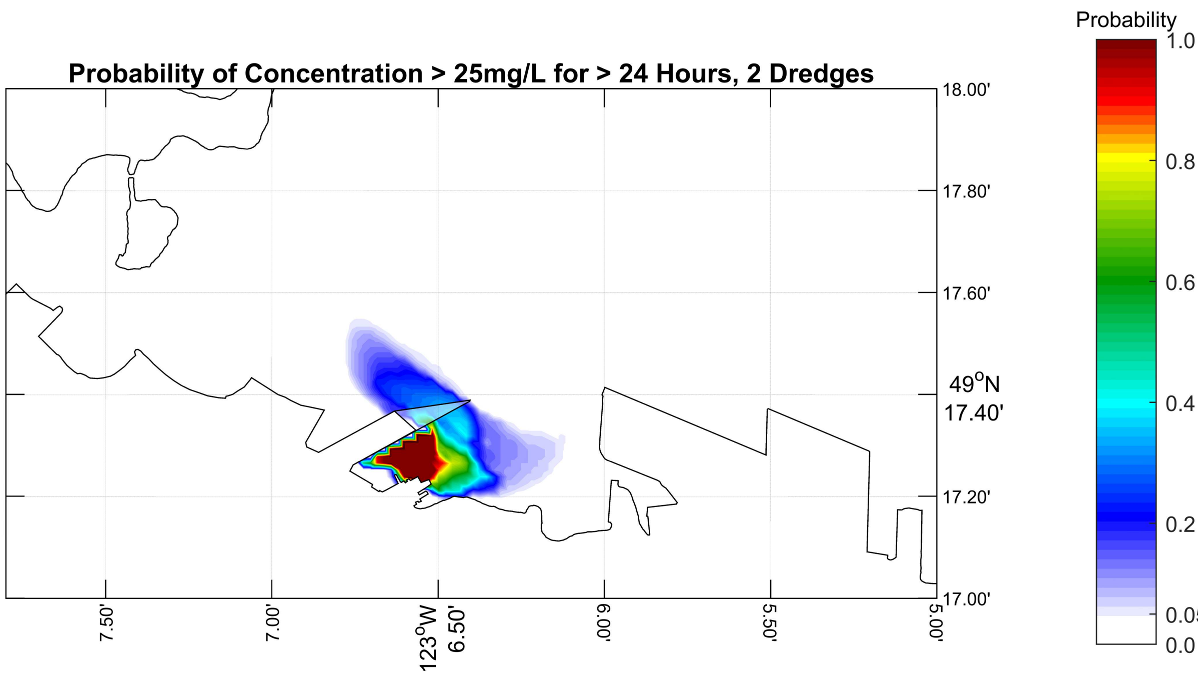
SeaBus Dredge Basin
Probability of TSS > 5 mg/L
for Full Dredge Period

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	August, 2016

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.

STATUS
ISSUED FOR USE

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TETRA TECH EBA

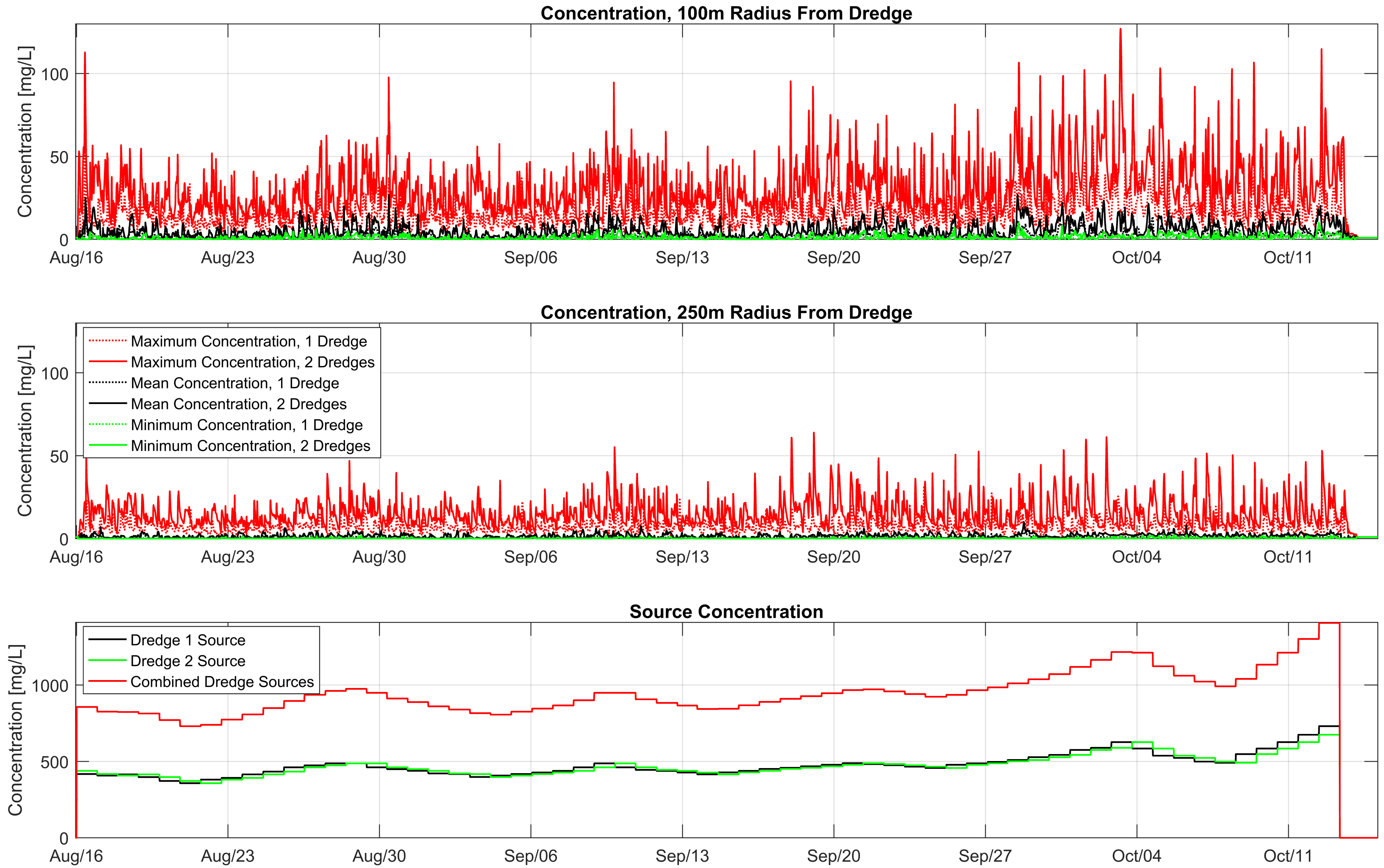
Centerm Expansion Project
Fugitive Sediment Numerical Modelling

SeaBus Dredge Basin
Probability of TSS > 25 mg/L
for 24 Hours

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	August, 2016

Figure 6



NOTES

Notes:
1) The concentration axis scale for the Source Concentration plot differs from that of the Concentration Radii plots.
2) Source concentration varies in time due to depth variations between dredge locations and tidal action.
3) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

STATUS
ISSUED FOR USE

CLIENT
AECOM

TETRA TECH EBA

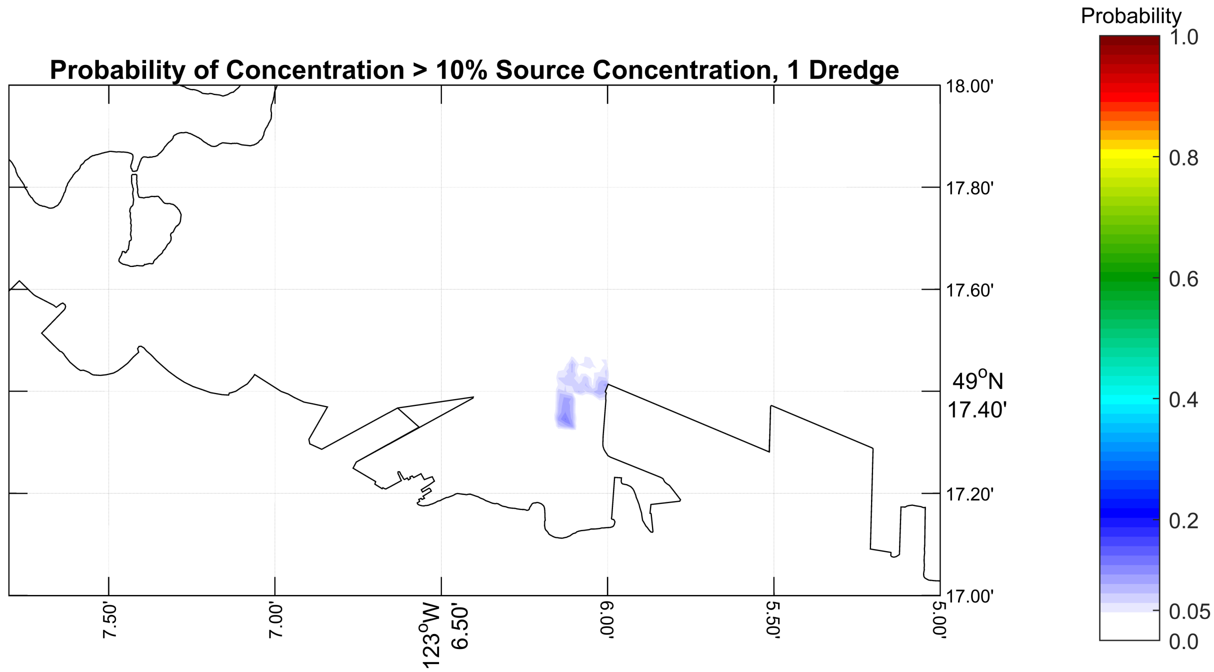
Centerm Expansion Project
Fugitive Sediment Numerical Modelling

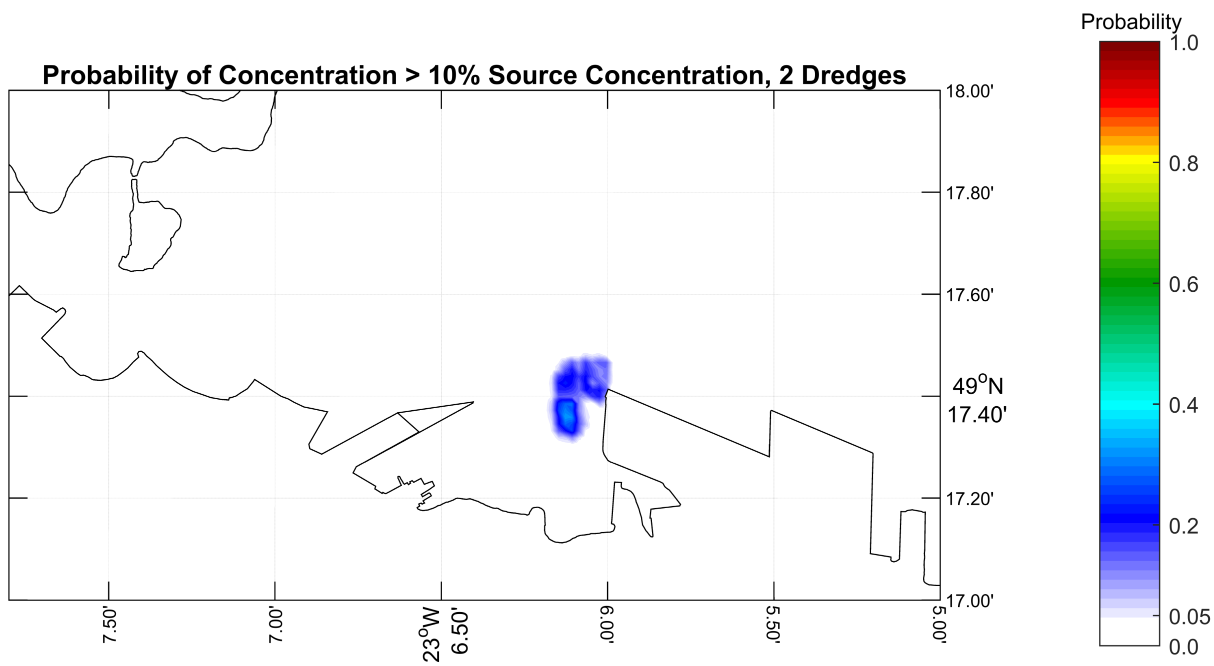
West Dredge Basin
TSS Source Attenuation

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

OFFICE	DATE
Tetra Tech EBA - VANC	August, 2016

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.

STATUS
ISSUED FOR USE

CLIENT
AECOM

TETRA TECH EBA

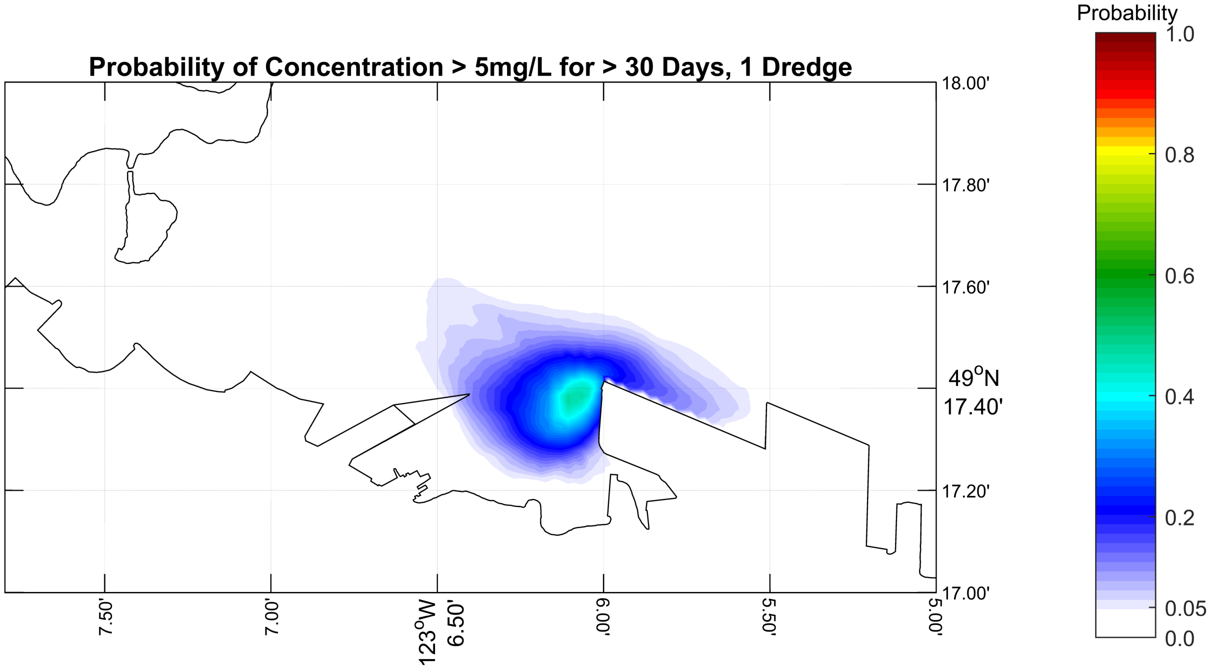
Centerm Expansion Project
Fugitive Sediment Numerical Modelling

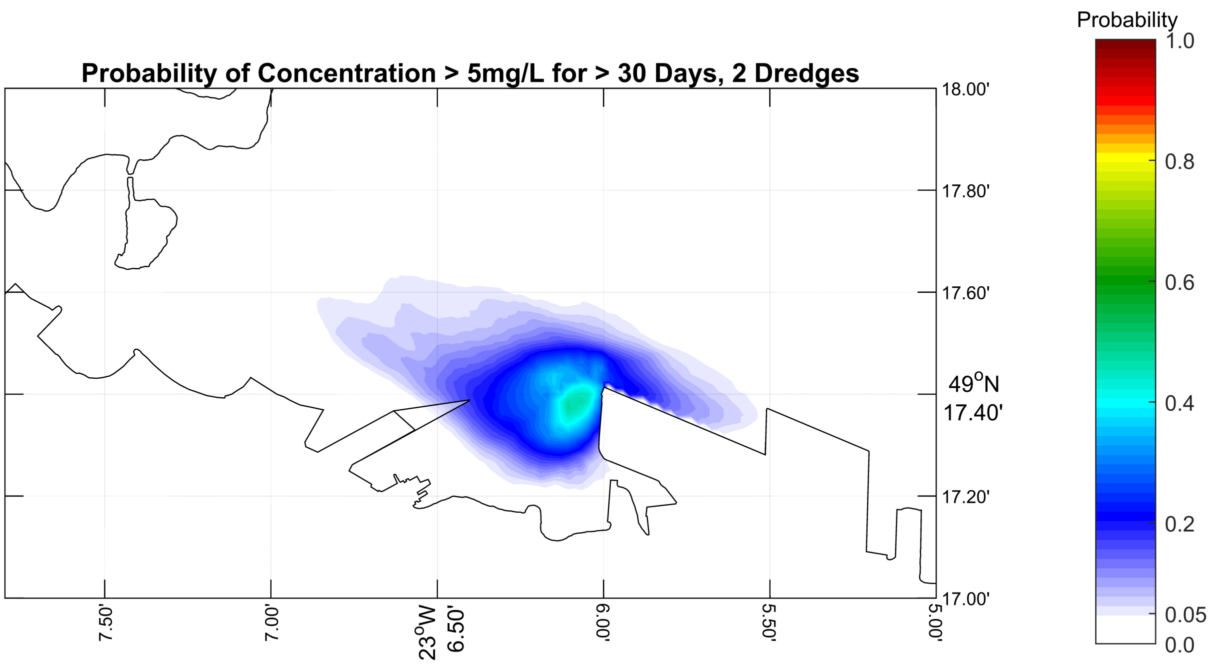
West Dredge Basin
Probability of Not Achieving 90% Source Attenuation

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	August, 2016

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.

STATUS
ISSUED FOR USE

CLIENT
AECOM

TETRA TECH EBA

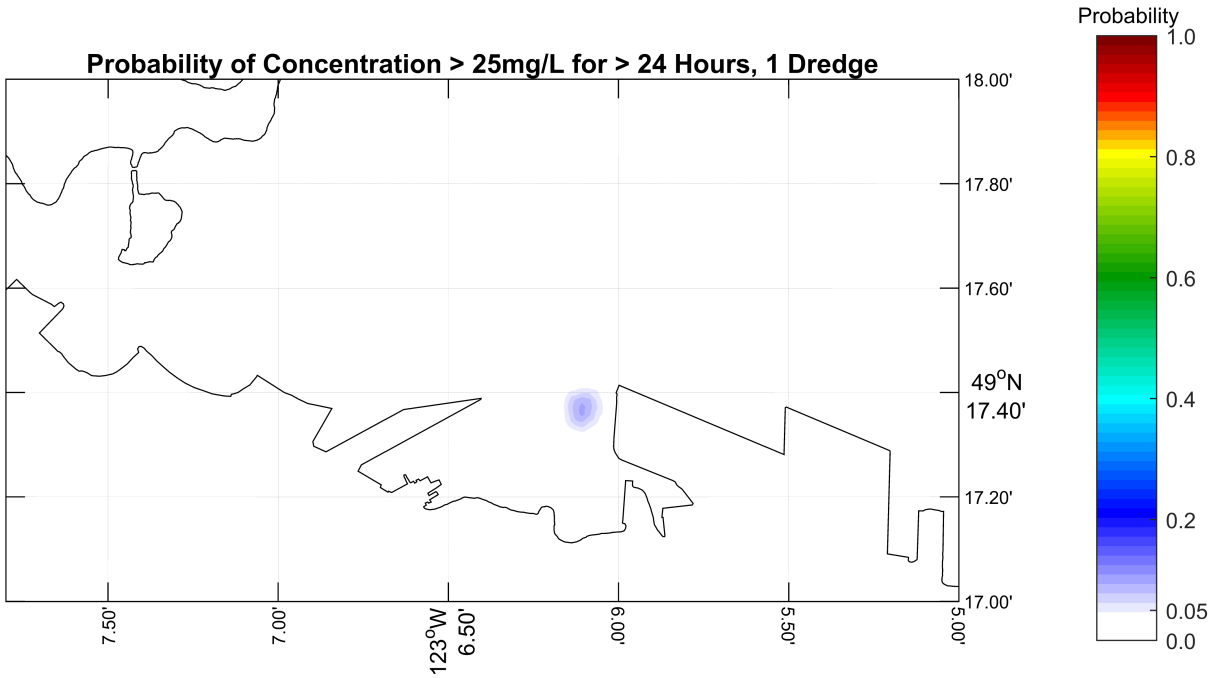
Centerm Expansion Project
Fugitive Sediment Numerical Modelling

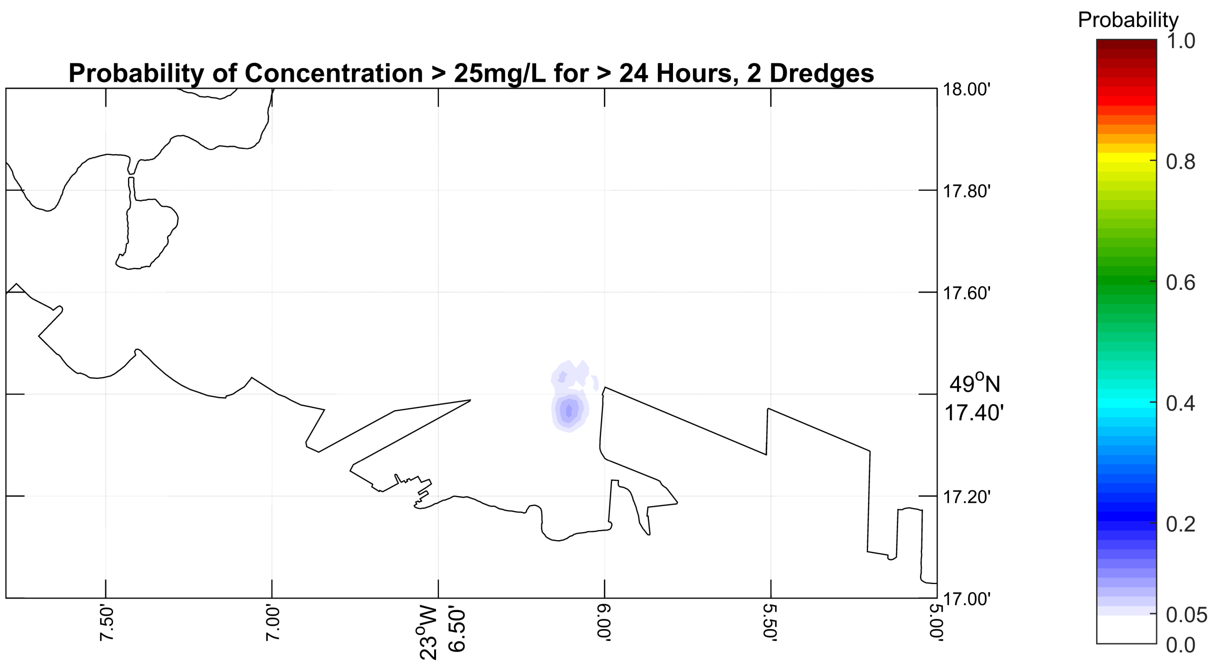
West Dredge Basin
Probability of TSS > 5 mg/L for 30 Days

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	August, 2016

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

CLIENT
AECOM

TETRA TECH EBA

Centerm Expansion Project
Fugitive Sediment Numerical Modelling

West Dredge Basin
Probability of TSS > 25 mg/L
for 24 Hours

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	August, 2016

Figure 10

NOTES

Notes:
1) The concentration axis scale for the Source Concentration plot differs from that of the Concentration Radii plots.
2) Source concentration varies in time due to depth variations between dredge locations and tidal action.
3) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

STATUS
ISSUED FOR USE

CLIENT
AECOM

TETRA TECH EBA

Centerm Expansion Project
Fugitive Sediment Numerical Modelling

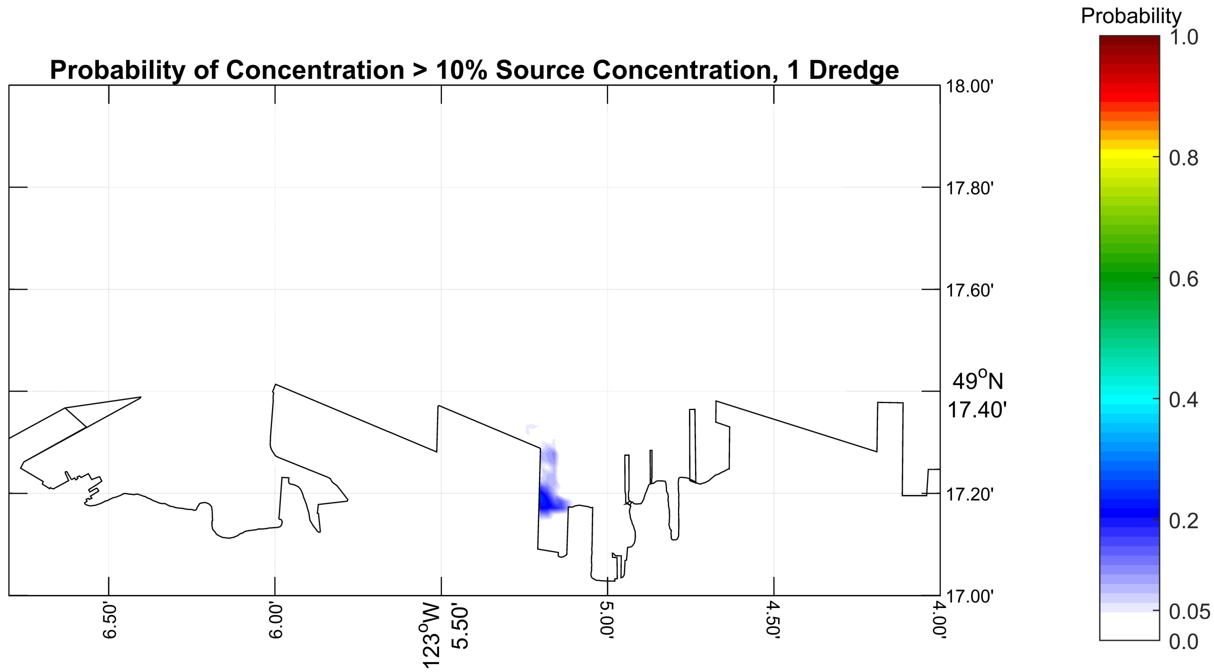
East Dredge Basin
TSS Source Attenuation

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

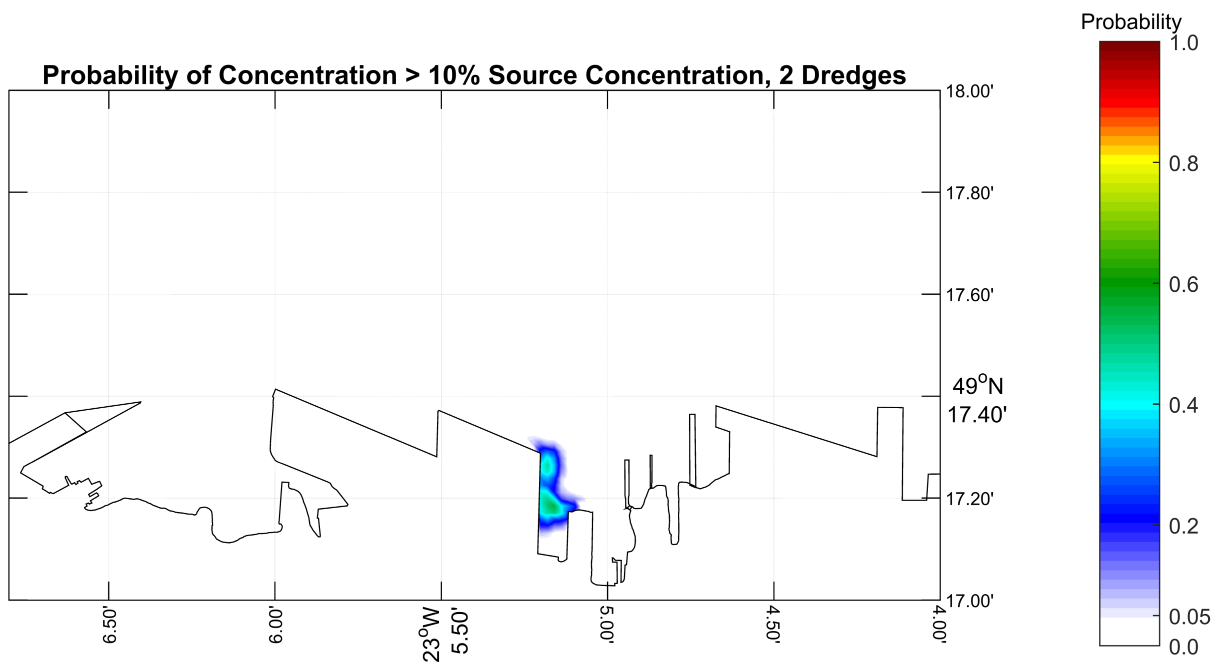
OFFICE	DATE
Tetra Tech EBA - VANC	August, 2016

Figure 11

Probability of Concentration > 10% Source Concentration, 1 Dredge



Probability of Concentration > 10% Source Concentration, 2 Dredges



NOTES

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2) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

STATUS
ISSUED FOR USE

CLIENT
AECOM

TETRA TECH EBA

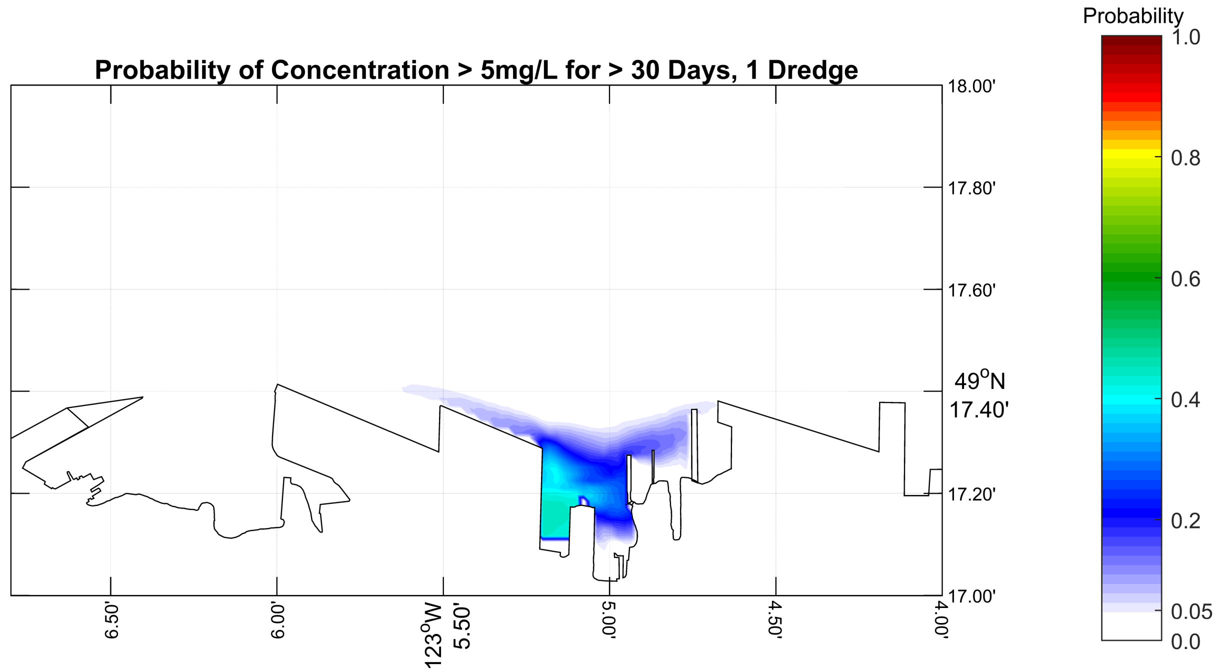
Centerm Expansion Project
Fugitive Sediment Numerical Modelling

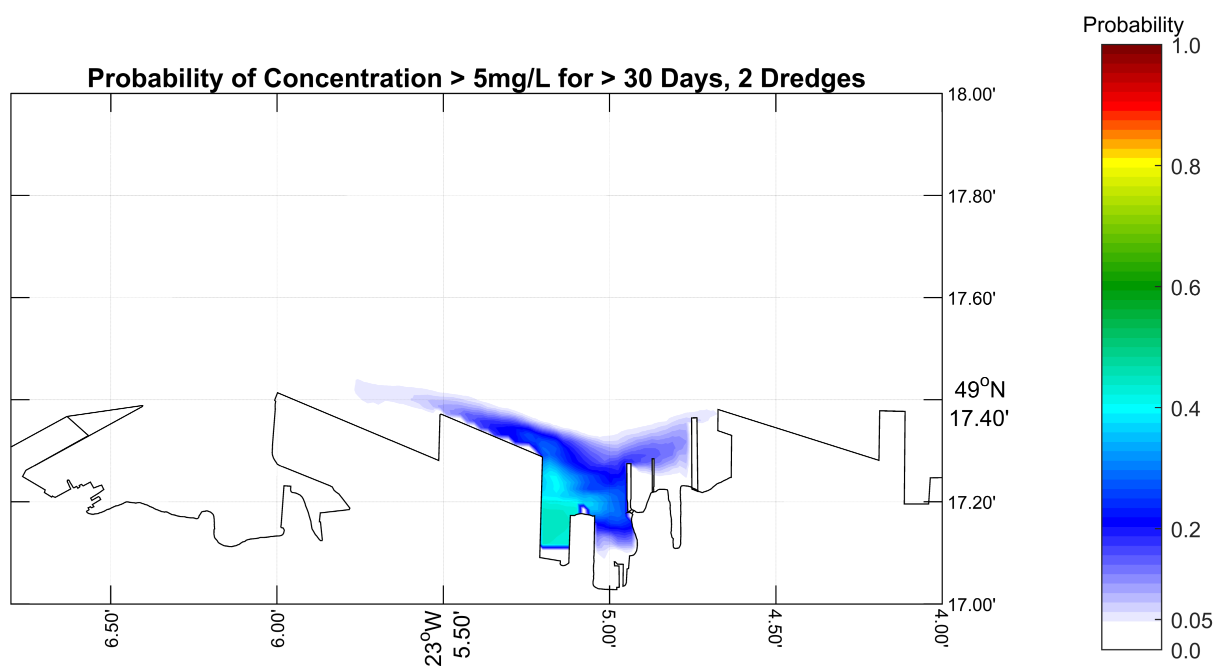
East Dredge Basin
Probability of Not Achieving
90% Source Attenuation

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	August, 2016

Figure 12





NOTES

1) Probability is calculated over the full dredge period and is determined from 15 minute model data.
2) Note the minor discrepancy at the shoreline between Ballantyne and B.N.R Piers. This does not influence the model results.
3) All concentrations are the maximum concentration over the water column (seabed to surface) at a given location.

STATUS
ISSUED FOR USE

CLIENT
AECOM

TETRA TECH EBA

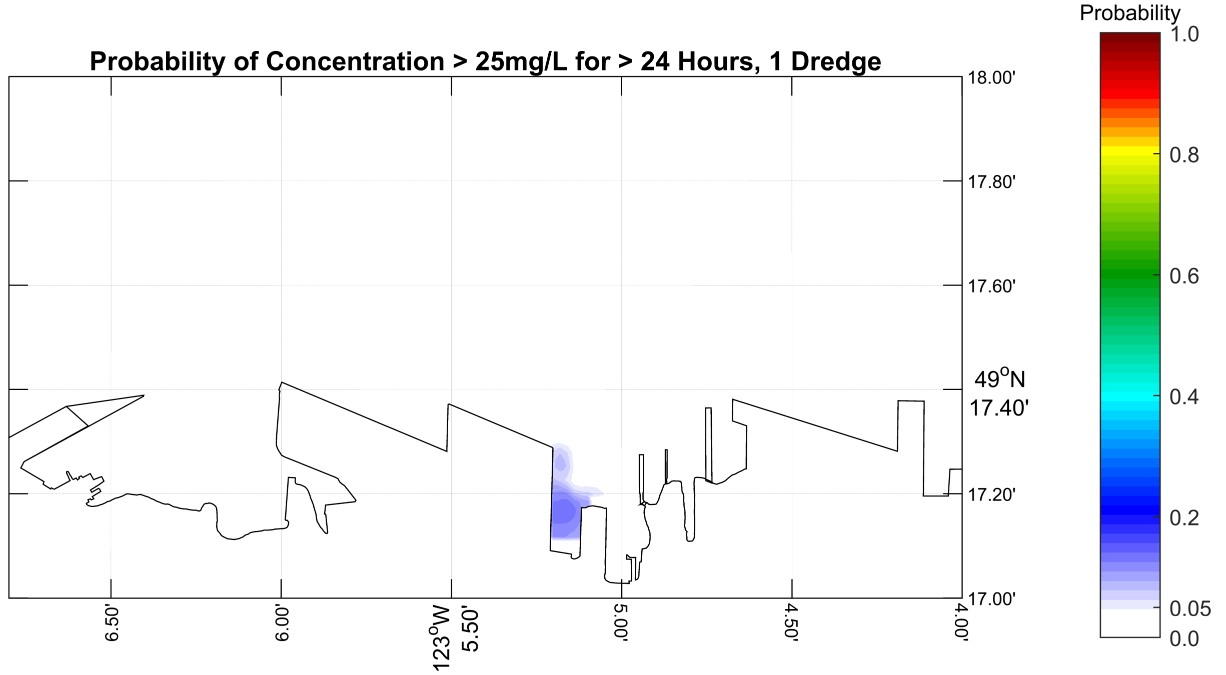
Centerm Expansion Project
Fugitive Sediment Numerical Modelling

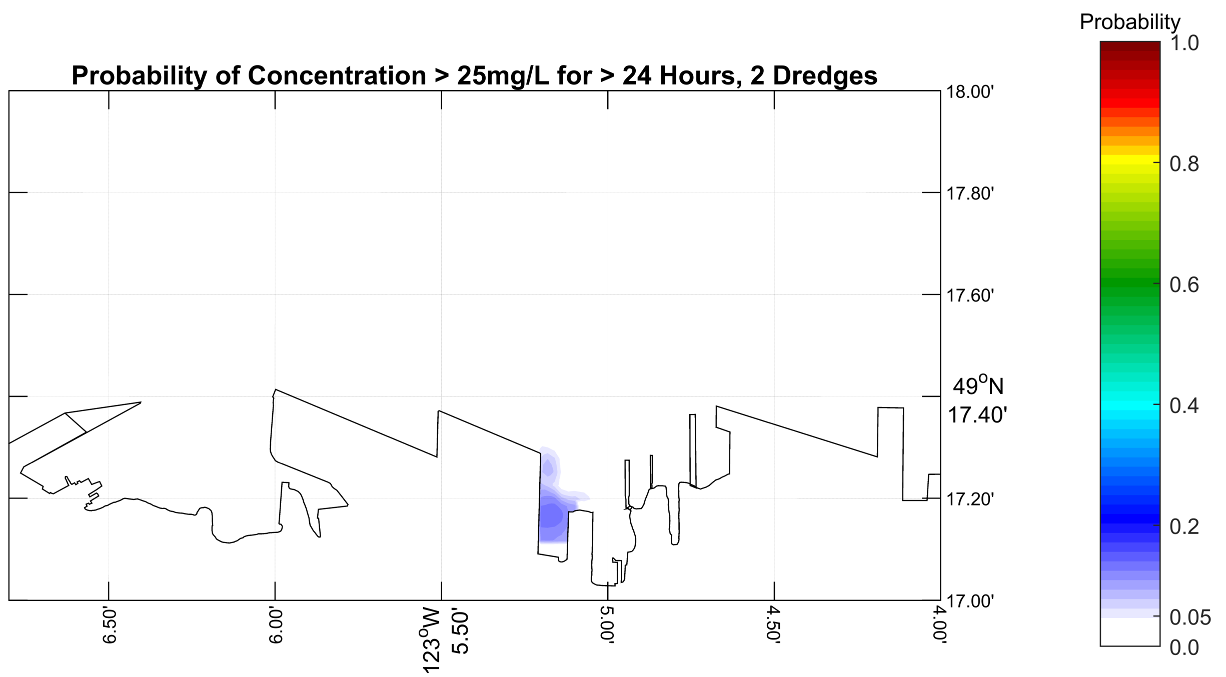
East Dredge Basin
Probability of TSS > 5 mg/L for 30 Days

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	August, 2016

Figure 13





NOTES

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TETRA TECH EBA

Centerm Expansion Project
Fugitive Sediment Numerical Modelling

EastDredge Basin
Probability of TSS > 25 mg/L
for 24 Hours

PROJECT NO.	DWN	CKD	APVD	REV
WTRM03017	JM	JM	JAS	0

OFFICE	DATE
Tetra Tech EBA - VANC	August, 2016

Figure 14

APPENDIX A: TETRA TECH EBA'S GENERAL CONDITIONS

GENERAL CONDITIONS

HYDROTECHNICAL

This report incorporates and is subject to these “General Conditions”.

1.0 USE OF REPORTS 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 EBA’s Client (the “Client”) as specifically identified in the Tetra Tech EBA Services Agreement or other Contract entered into with the Client (either of which is termed the “Services Agreement” herein). Tetra Tech EBA 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 EBA.

Any unauthorized use of the Report is at the sole risk of the user. Tetra Tech EBA 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 EBA 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 EBA during the performance of the work are Tetra Tech EBA’s professional work product and shall remain the copyright property of Tetra Tech EBA.

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

2.0 ALTERNATIVE REPORT FORMAT

Where Tetra Tech EBA 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 EBA’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 EBA shall be deemed to be the original. Tetra Tech EBA 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 EBA’s Instruments of Professional Service shall not, under any circumstances, be altered by any party except Tetra Tech EBA. Tetra Tech EBA’s Instruments of Professional Service will be used only and exactly as submitted by Tetra Tech EBA.

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

3.0 STANDARD OF CARE

Services performed by Tetra Tech EBA 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 EBA.

4.0 ENVIRONMENTAL AND REGULATORY ISSUES

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

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

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

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.

8.0 JOB SITE SAFETY

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.