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QCLNG-PIPELINE BURIAL SEDIMENT PLUME MODELLING

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Prepared for:

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Document draft	*Originated by*	*Edit & review*	*Authorized for release by*	*Date*
Draft 1 - Issued for internal review	Dr Sasha Zigic Dr Ryan Dunn Mr Scott Langtry			
Draft 2 - Issued for client review			Dr Sasha Zigic	

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APASA Project Manager: Dr Sasha Zigic

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EXECUTIVE SUMMARY

British Gas (BG) is intending to lay a 380 km underground pipeline from Miles in southern Queensland to a liquefaction plant on Curtis Island on the states central coast. The pipeline is to be laid across land and two identified marine based sections: a) *Creek Section* – consisting of Humpy Creek, Targinie Creek and Targinie Backwater; and b) *Narrows Section* – a channel between Laird Point and Friend Point.

BG commissioned Asia-Pacific ASA to model the suspended sediment plumes and sediment deposition patterns that would result from the pipeline burial, across the Creek and marine based sections (Creek and the Narrows). The burial of the pipeline will involve three key phases:

Phase 1 - Trench using a backhoe dredge (BHD) within the Creek and Narrows sections to a suitable depth to ensure pipeline stability during installation phase;

Phase 2 – Using a jet trencher to sink the pipeline to required depth; and

Phase 3 – Backfilling of sediments using a BHD into the trench removed during phase 1.

The entire operation is to involve the displacement of approximately 167,000 m^3 of sediment.

An advanced sediment fate model (DREDGEMAP) was applied to simulate the transport, sinking, settlement and resuspension of the material by various operations. DREDGEMAP inputs included site-specific sediment composition, production rate of the equipment, mass flux, initial vertical-distribution of sediments in the water column and location for each operation. This approach provided a realistic estimate of the time spent and the volume of material suspended into the water column.

1 INTRODUCTION

British Gas (BG) is intending on laying a 380 km underground pipeline from Miles in southern Queensland to Gladstone and Curtis Island on the states central coast (see Figure 1), to deliver the natural gas from the exploration and gas production operations to a liquefaction plant.

The pipeline is to be laid across land and two identified marine based sections: a) *Creek Section* – consisting of Humpy Creek, Targinie Creek and Targinie Backwater; and b) *Narrows Section* – a channel between Laird Point and Friend Point (see Figure 2). The burial of the pipeline will involve three key phases:

Phase 1 - Trench using a backhoe dredge (BHD) within the Creek and Narrows sections to a suitable depth to ensure pipeline stability during installation phase;

Phase 2 – Using a jet trencher sink pipeline to required depth; and

Phase 3 – Backfilling of sediments using a BHD into the trench removed during phase 1.

The entire operation is to involve the displacement of approximately 167,000 m^3 of sediment. The associated volumes for each phase and marine section are presented in Table 1.

Asia-Pacific ASA (APASA) was commissioned to model the suspended sediment plumes and sediment deposition patterns that could be generated by the various operations.

This report documents the model set-up, methodologies and data input for the dredge plume modelling tasks, and the scenario specific model results in terms of total suspended sediment (TSS) concentrations and cumulative sedimentation rates on the seabed.

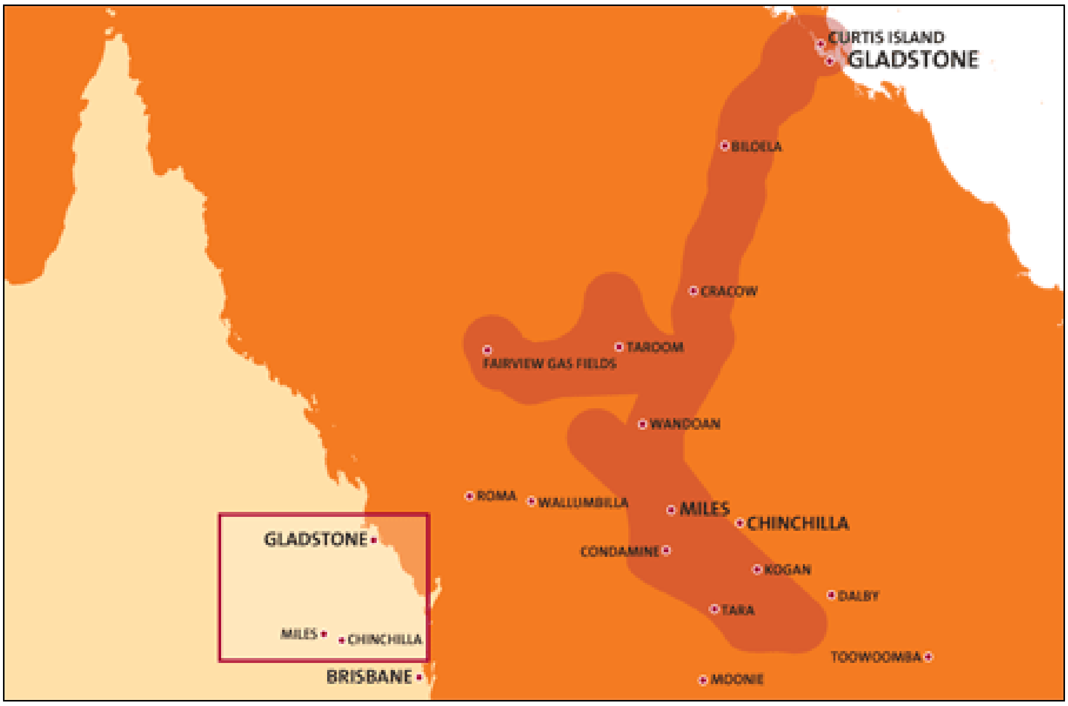


Figure 1: Map of the Queensland Curtis LNG project area, with the 380 km underground natural gas pipeline from Miles in southern Queensland to Gladstone and Curtis Island on central Queensland coast (source: QCLNG 2009)

Table 1: Approximate volume for displaced sediments for each phase and marine based section.

Marine Based Section	***Operation Phase***		***Approximate volume of displaced sediments (m^3)***
Creek Section	1	Pre-lay dredging by BHD	24,070
	2	Post-lay trenching by Jet trencher	8,625
	3	Backfill of sediments by BHD	23,589
Narrows Section	1	Pre-lay dredging by BHD	49,730
	2	Post-lay trenching by Jet trencher	12,150
	3	Backfill of sediments by BHD	48,732
		TOTAL	**166,896**

Figure 2: Large scale view (top) and zoomed in view (bottom) of the proposed QCLNG facility and layout of the natural gas pipeline (denoted in blue) within Port Curtis. (Note: yellow lines represent the marine based sections examined as part of the sediment dispersion modelling assessment).

2 SCOPE OF WORK

The scope of work included:

1. Integrate third party hydrodynamic data for the study area into the purpose designed, three-dimensional sediment model (DREDGEMAP);
2. Assess available sediment cores to ascertain the grain size distribution;
3. Define the initial discharge of sediments, differential sinking and settlement of released sediments (by particle size and rates of cohesion), production rates and mass flux for each operation;
4. Simulate operations for each marine section and amalgamate to present the cumulative effect; and
5. Produce estimates for the total suspended solid (TSS) concentrations and cumulative sedimentation rates due to all overlapping operations, summarised as maps and time-series graphs at selected sites.

3 STUDY DATUMS

Water depths and levels presented in this report are with respect to Lowest Astronomical Tide (LAT) unless otherwise stated and are presented in the units of meters (m).

Positions are satellite derived from the Global Positioning System using WGS 84 datum (World Geodetic System dating from 1984) and latitudes and longitudes are reported in decimal degrees.

All units are typically reported using the International System of Units (SI units).

4 CURRENT DATA

DREDGEMAP uses current data which varies spatially and temporally to calculate the transport, sinking and turbulence-induced rise of the dredged material. For this project a three-month long (February to April 2009) prediction for the current field was provided at hourly time-steps by BMT-WBM from their 2-dimensional hydrodynamic model (TUFLOW), of the existing bathymetric conditions for Port Curtis. The project team selected February to April 2009 as the period to be modelled as it captured the largest tidal ranges for the year. Figure 3 shows the predicted water levels for February to April 2009 within Port Curtis. Figure 4 and Figure 5 shows a snapshot of the flood and ebb tide currents within Port Curtis during a spring (7-8th February 2009) neap (16-17th April 2009) tide period, respectively.

Figure 4 and Figure 5 are shown to highlight the movement of water across marsh flats south of Friend Point, during a sample spring and neap tide, respectively. During high water spring tide events this region becomes intermittently submerged, directly connecting the waters of Humpy and Targinie Creeks to the waters of Port Curtis. This is illustrated in Figure 4 by the occurrence of current vectors located on the low-lying saltmarsh region between the southern regions of Humpy and Targinie Creeks and the landmass south Friend Point. During neap tide events the low-lying region acts as a barrier between the two water bodies.

For more detail regarding the current modelling refer to BMT-WBM (2009).

To account for the influence of turbulence below the resolution of the current data, the horizontal mixing coefficient was set to 0.5 m^2/s for the Narrows Section and 0.1 m^2/s for the Creek Section. The vertical mixing coefficient were set to 0.001 m^2/s throughout the model domain.

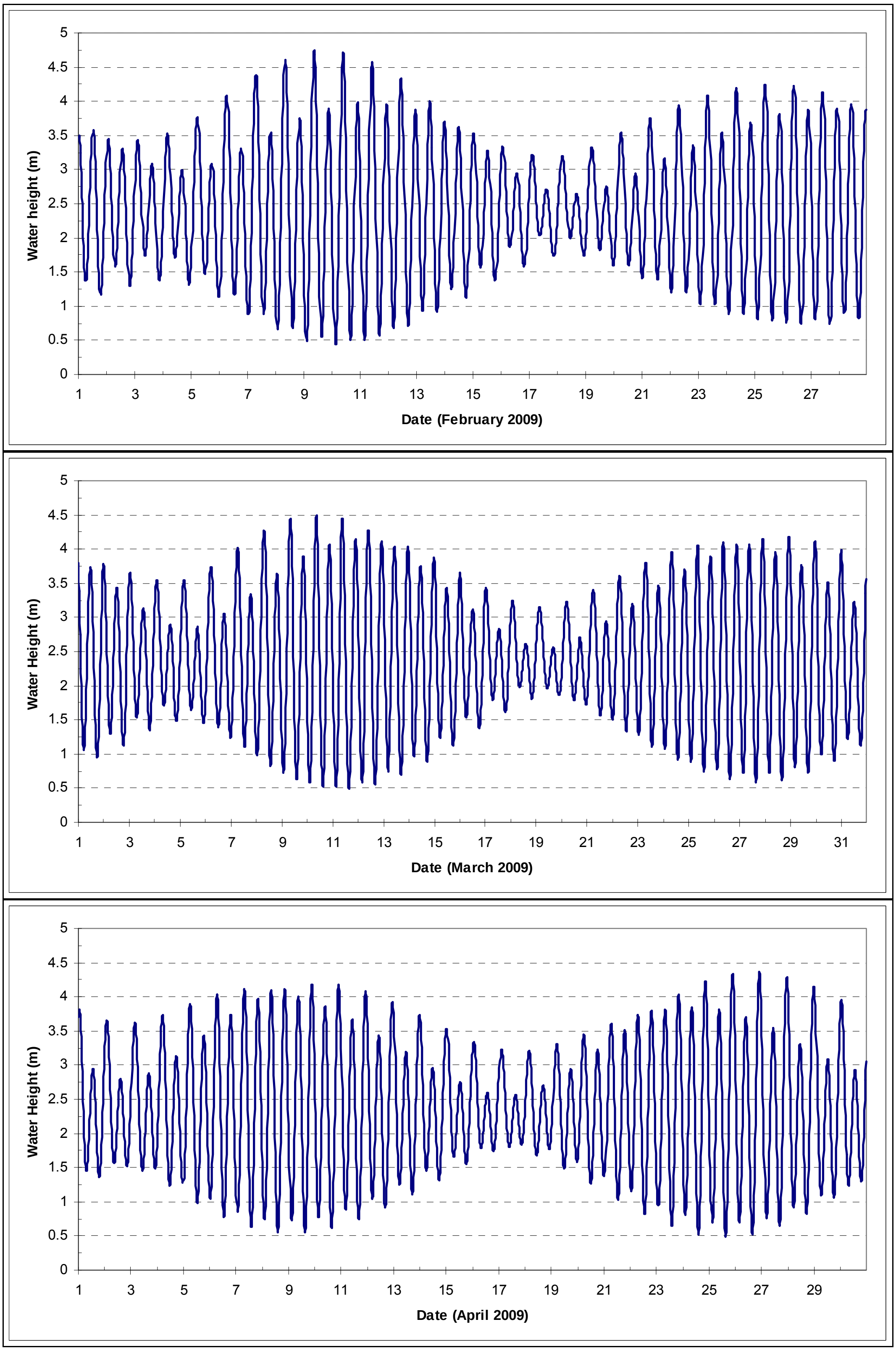


Figure 3: Predicted water levels within Port Curtis during February to April 2009.

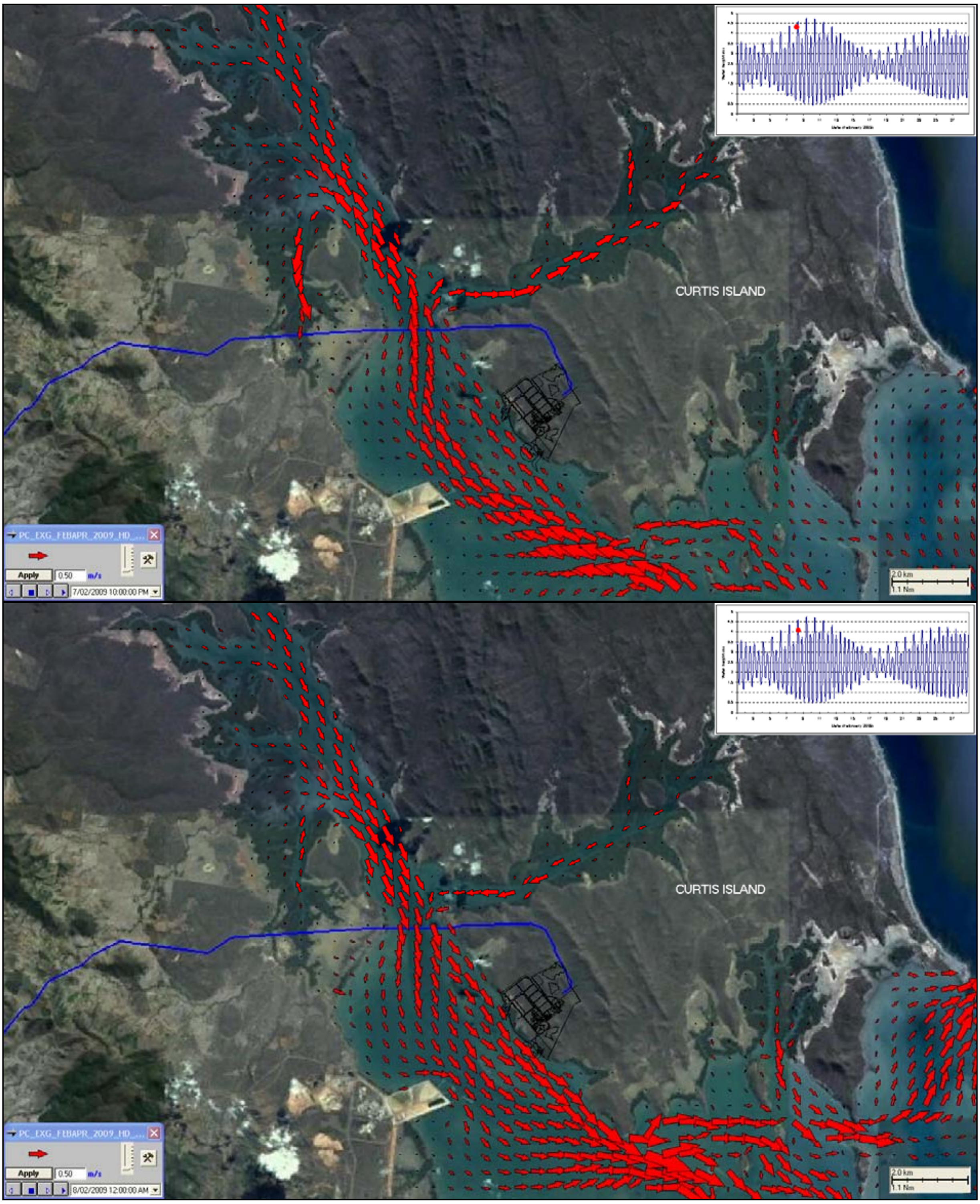


Figure 4: Snapshot of the predicted flood (top) and ebb (bottom) tide currents within Port Curtis, during a spring tide.

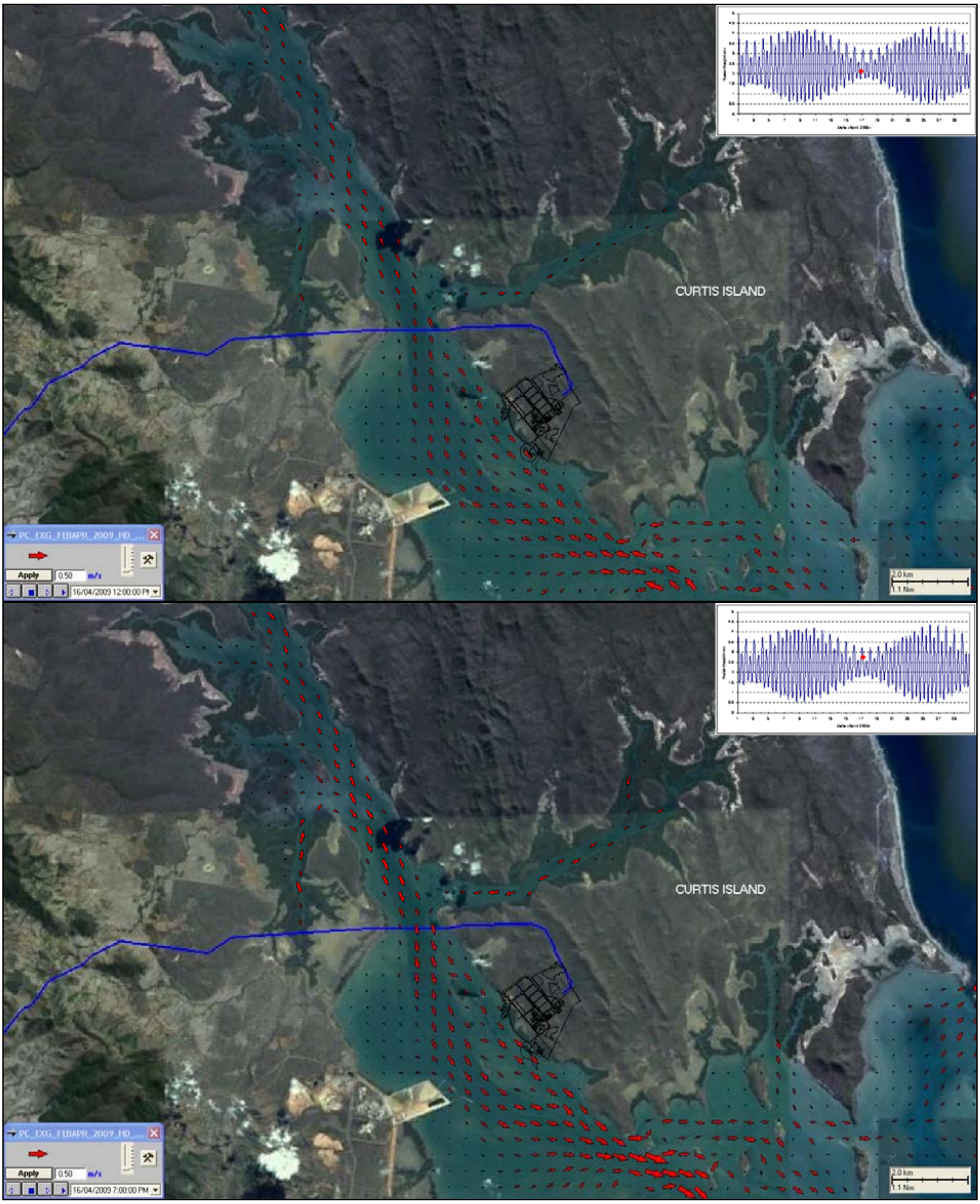


Figure 5: Snapshot of the flood (top) and ebb (bottom) tide predicted currents within Port Curtis during a neap-tide event.

5 PARTICLE SIZE DISTRIBUTION

As particle size distributions (PSDs) were not available at the time of this study for the Narrows Section, sediment cores analysed in close proximity were used as a proxy (see Figure 6). Where as the PSD data for the Creek Section was established from sediment analysis alongside mangrove vegetation near the proposed QCLNG facility. Table 2 shows the sediment grain size distribution to represent sediment classes along the Creek and Narrows Sections.

Within the Creek Section particle sizes less than 35 μm represented the bulk of the material (~73 %), compared to a contribution of 25% along the Narrows Section.

A dry bulk density value of 1700 kg/m^3 used to represents sediments within Port Curtis (APASA, 2009).

Table 2: Particle grain size distribution used to represent the Narrows and Creek Sections.

Size range (μm)	***Grain size distribution for the Creek Section (%)***	***Mean grain size distribution for the Narrows Section (%)***
0-7	56	20
8-35	17	5
36-74	6	4
75-130	2	8
> 130	19	63

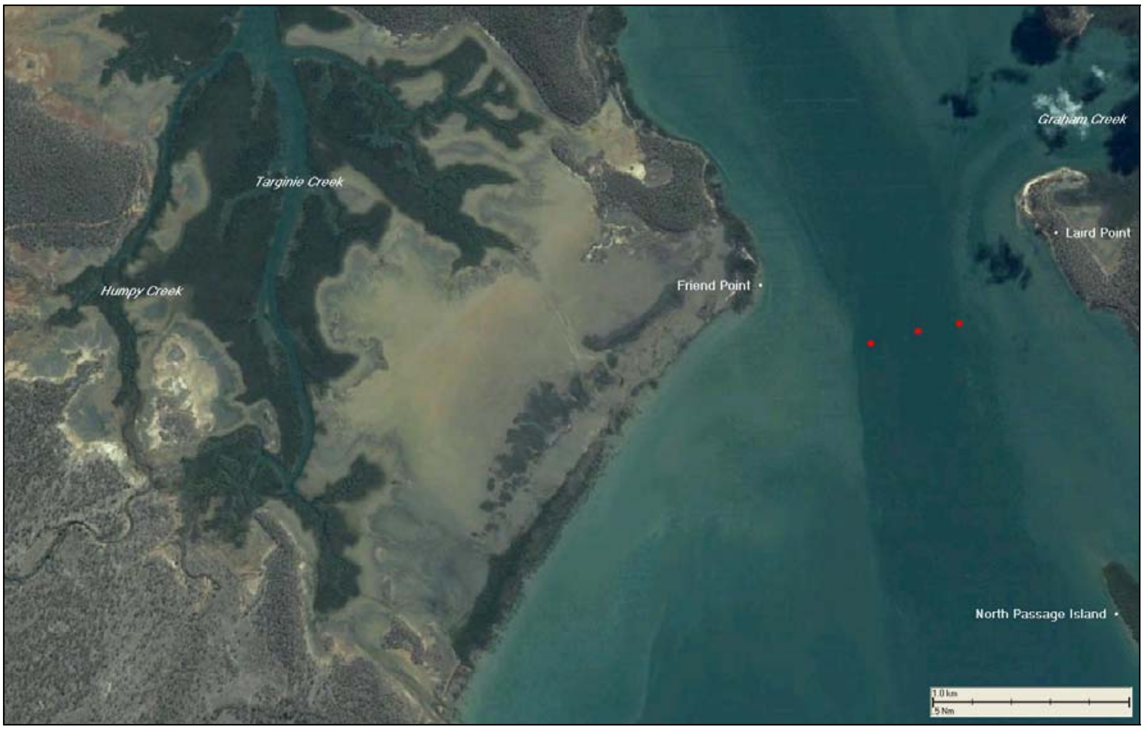


Figure 6: Location of the sediment cores analysed for the sediment modelling.

6 DREDGE MODEL DESCRIPTION

The fate of sediments suspended by dredging operations was simulated using a purpose-designed, three-dimensional, sedimentation process modelling system, DREDGEMAP. The model was developed by Applied Science Associates (ASA) in collaboration with the U.S. Army Corps of Engineers (USACE). This modelling system is a GIS-based application of the model originally developed by USACE, which was developed and refined based on their experience with management of a large number of dredging and disposal operations.

DREDGEMAP computes total suspended sediment (TSS) distributions and sedimentation patterns resulting from dredging operations. The model predicts the transport, dispersion and settling of suspended sediment released to the water column using a random-walk procedure. The focus of the model is on the far-field (i.e. immediately beyond the initial release jet) processes affecting the fate of suspended sediment. The model uses specifications for the suspended sediment source strengths (i.e. mass flux), vertical distributions of sediments and sediment grain-size distributions to represent the effect of different types of mechanical or hydraulic dredges, sediment dumping practices or other sediment disturbing activities such as jetting or ploughing for trunkline burial. Multiple sediment types or fractions can be simulated simultaneously; as can discharges from moving sources.

Settling of mixtures of particles is a complex process due to interaction of the different size classes, some of which tend to be cohesive and thus clump together to form larger particles that have different fall rates than would be expected from their individual sizes. Enhanced settlement rates due to flocculation and scavenging are particularly important for clay and fine-silt sized particles (Teeter 1998, Swanson *et al*., 2004) and these processes have been implemented in DREDGEMAP. The model employs five material classes based on sediment grain sizes. The classes are biased towards the finer materials, as these are typically the most dispersive and are responsible for the greatest turbidity increases in the water column.

Table 3 gives a summary of the size ranges and minimum sinking rates for each of the particle classes employed in DREDGEMAP.

The model represents the total mass of sediments suspended over time by a defined sub-sample of Lagrangian particles, allocating an equal proportion of the mass to each particle (e.g. 1/1000th of the total release if 1000 particles are used). The initial size distribution of the sediments is used to apportion the sample of Lagrangian particles to size classes.

Horizontal transport, sinking and turbulence-induced rise of each particle is modelled independently at each time step. Minimum sinking rates are calculated using Stokes equations, based on the size and density of the particle. However, sinking rates of finer classes (representing clay and silt-sized particles) are increased based on the local concentration of the same and larger particles, to account for clumping and entrainment. Deposition (i.e. the process whereby particles move from being in suspension to being settled on the bed) is calculated as a probability function of the prevailing bottom stress, local sediment concentration and size class. This formulation accounts for inhibition of deposition where shear stress at the bed is excessive. Matter that is deposited may be subsequently resuspended into the lower water column if critical levels of bottom stress are subsequently exceeded. Mixing of resuspended sediment into higher levels of the water column will be a dynamic balance between estimates of the sinking rate and vertical mixing induced by turbulence (as specified by vertical mixing coefficients).

The model employs two different resuspension algorithms. The first applies to material deposited in the last tidal cycle (Lin *et al*., 2003). This accounts for the fact that newly deposited material will not have had time to consolidate and will be resuspended with less effort (lower shear force) than consolidated bottom material. The second algorithm is the established Van Rijn method (Van Rijn, 1989) and applies to all other material that has been deposited prior to the start of the last tidal cycle. This method calculates a constantly varying critical threshold for resuspension, based on the median (d_{50}) local particle-size distribution for settled material. In this way, the model accounts for interactions between different particle sizes. For example, finer sediments will tend to be armoured from resuspension in the presence of coarser material." Swanson *et al*. (2007) has previously summarised the justification and use for this approach. Particles initially released by operations are continuously tracked for the length of the simulation, whether suspended or deposited.

To avoid edge effects, transport is estimated in a grid-less space with the vertical and horizontal position in space recorded for each particle at the end of each time step. At the conclusion of the transport and settlement simulation phase, suspended solid concentrations (as mass per volume) and sedimentation values (as mass per area of seabed and thickness) are calculated for each time-step based on the local density of particles. Because each of the Lagrangian particles represents a larger mass of material, with each particle representing the central loci of a concentration of sediment, a Gaussian distribution is applied to the particle densities to represent the distribution of sediment mass around each of the particles for each sediment class.

To maximize resolution of the plume, contours are calculated for a uniform, user-defined, grid resolution that is independent of the resolution of the current and wave data used to calculate transport, thus supporting finer spatial differentiation of plume concentrations and avoiding underestimation of concentrations caused by spatial averaging over larger volumes/areas. Model outputs consist of water-column concentrations in both horizontal and vertical planes, time-series plots of suspended sediment concentrations, and thickness contours of sediment deposited on the sea floor.

Table 3: Grain-size classes and minimum sinking rates applied by DREDGEMAP.*

Sediment grain size class	***Size range (μm)***	***Minimum sinking rate (m/s)***
1	0-7	0.0008
2	8-35	0.0023
3	36-74	0.0038
4	75-130	0.0106
5	> 130	0.10

*Note * sinking rates are varied from these minima, based on local concentrations of sediment particles*

7 PIPELINE BURIAL PROGRAM

The pipeline burial program will include:

- Excavation of a trench using a BHD (Phase 1)
- Lowering of the pipeline into the trench
- Burial of pipeline using a jetting trencher within the trench (Phase 2)
- Backfill of the trench (post-lay) using a BHD (Phase 3)

Phase 1: Using a BHD mounted on a pontoon or barge, the sediments will be displaced at an assumed production rate of 95 m^3/hr across the Creek and Narrows Sections. Within the Creek Section dredging will occur along a 1620 m length to a depth of 2 m below the sediment-water interface. The trench will be characterised by a trapezoidal cross section with a bottom width of 2 m and side slopes of 15^o resulting in a trench width at the surface of approximately 18 m. Figure 7 shows selected site photographs from the Creek Section. The same trench dimensions will be dredged at the Narrows Sections within shallow waters (up to 4 m water depth) along the shore approach sections to ensure pipeline stability during the installation phase. Sediments are assumed to be placed adjacent to the trench boundaries.

Phase 2: The 42-inch pipeline will be positioned within the trench and buried to a depth of 2.5 m using a jetting technique. The jetting device includes a series of points, which are inserted into the seabed to fluidise surrounding sediments along the trench. The pipeline will then sink by its own weight under the influence of gravity through the fluidised sediments. To achieve the desired burial depth, three passes were assumed based on information contained within “trenching considerations – pipelines” published by Ocean Engineering Systems (OES, 2009). Figure 8 shows an example of an OES jet trencher of similar dimensions which would typically be used for such operations.

Phase 3: Displaced sediments adjacent to the trench will be returned using a BHD, in a reversal of Phase 1 operations. Figure 9 shows an example of a BHD of similar dimensions which would typically be used for such operations.

Figure 7: Site photographs of the Creek Section (Source: Xodus Group Pty. Ltd., 2009).

Figure 8: Photograph of the “Sumartran Tiger” Bi-directional jet trenching machine (20” – 42” outer diameter pipeline burials) (Source: Xodus Group Pty. Ltd., 2009).

Figure 9: Photograph of a BHD on a barge for dredging of marine sediments (Source: Xodus Group Pty. Ltd., 2009).

It is likely the BHD would operate 24 hours a day, 7 days a week, with the exception of scheduled maintenance activities and unexpected breakdowns. To account for the downtime, an efficiency of 53% for the BHD was factored into the production rates to calculate the overall operation for each phase and location (see Table 4).

Jet trenching normally requires the machinery to be submerged, thus limiting jetting operations to high tide conditions. It is likely that the jet trenching would operate 6 hours a day, 7 days a week, due to tidal activity within the area (i.e. 1.5 h either side of high water), with the exception of scheduled maintenances and unexpected breakdowns. To account for the downtime, an efficiency of 25% for the jetting device was factored into the production rates to calculate the overall jetting duration for each scenario and location.

Both sections will be dredged concurrently with an overall operation period of approximately 85 days (see Table 4).

Table 4: Summary of dredge operations and durations for the Creek and Narrows Section.

Section	***Operation***	***Volume of displaced sediments (m^3)***	***Duration (days)***	***Cumulative Duration (days)***
Creek	Trenching by BHD	24070	10.5	10.5
	Changeover	-	2	12.5
	Burial by jetting	8625	27.5	40
	Changeover	-	1	41
	Backfill by BHD	23589	10.3	**51.3**
Narrows	Trenching by BHD	49727	21.7	21.7
	Changeover	-	2	23.7
	Burial by jetting	12150	38.8	62.5
	Changeover	-	1	63.5
	Backfill by BHD	48732	21.3	**84.8**

8 SPECIFICATIONS AND ASSUMPTIONS FOR SEDIMENT MODELLING

To accurately represent the dredge operations in DREDGEMAP, the preliminary task involved an assessment of the likely sources of sediments for each phase. Two key sources of suspended sediment were identified:

1. Loss of sediment from the BHD bucket from grabbing and lifting sediment through the water column during trenching and backfill phases, and

2. Suspension of seabed material due to jetting operations.

The mass flux, size composition and initial vertical-distribution of sediments in the water column can be expected to vary considerably with each sediment source. Sections 8.1 and 8.2 outline how they were each defined in the model and the assumptions made to supplement the information provided.

8.1 Backhoe Dredging

The BHD will use a large excavator arm fitted with an open bucket and will be mounted upon a barge or pontoon (See Figure 9). The excavator will lift material in the bucket during trenching, spoil repositioning alongside the trench and backfilling. Past observations have shown that material is suspended from the seabed due to the initial grab. Further suspension is generated as sediment overflows from the bucket as the bucket is lifted through the water column. Overflow occurs as the bucket breaks free of the water surface and drains freely. Only sediment < 130 μm are considered “lost” (i.e. suspended into the water column), because the coarser material removed from the bucket while being lifted to the surface would fall immediately to the bottom where it would be re-dredged during subsequent grabs. As such, the distribution of material suspended by the loss with the open bucket was assumed to be evenly spread between the smaller grain sizes (Table 5).

Table 5: Grain size distributions (by percentage) of material lost during the BHD operations.

Sediment grain size class	***Size Range (μm)***	***Grain size distribution (by %) within the Creek Section***	***Grain size distribution (by %) within the Narrows Section***
1	0-7	25	25
2	8-35	25	25
3	36-74	25	25
4	75-130	25	25
5	> 130	0	0

Table 6 shows the assumed vertical distribution of the material during the BHD operations. The distributions are higher at the seabed and water surface, to represent the larger loss rate of material during the initial grab and as the bucket breaks free of the water column.

Loss rates from similar operations are known to vary based on such factors as the size and type of bucket (i.e. open or closed), nature of the bed material, presence of debris, current speed and depth of water, as well as the care of the operator (Hays & Wu 2001, Anchor Environmental 2003). Reported rates compared by Anchor Environmental (2003) varied between 0.1% to 10%, with a mean of 2.1%. In the absence of measurements for the specific situation and equipment, this mean (2.1% of production rate) was assumed for all BHD operations.

Table 6: Initial vertical distribution of sediments in the water column setup by loss from the backhoe dredge.

Elevation above seabed (m)	***% of sediments***
1.5	23
1.2	16
0.9	14
0.6	19
0.3	28

8.2 Jet Trencher

The jetting device includes a series of points, which are inserted into the seabed to fluidise surrounding sediments (see Figure 8). BG pipeline specialists had estimated the jet trencher would travel at a speed of 0.0013 m/s, which also takes into account an efficiency rate of 25 %. The sediment size composition of the material suspended assumed during the jetting operation is presented in Table 7.

Table 7: Grain size distributions (by percentage) of material lost during the jetting operations.

Sediment grain size class	***Size Range (μm)***	***Grain size distribution (by %) within the Creek Section***	***Grain size distribution (by %) within the Narrows Section***
1	0-7	56	20

2	8-35	17	5
3	36-74	6	4
4	75-130	2	8
5	> 130	19	64

Previous jetting studies (ASA, 2003; 2006) assumed that 70% of the sediment was to remain within the limits of the trench during the burial process and 30% would be distributed vertically through the water column to a depth of 1.5 m above the seafloor. Table 8 shows the assumed vertical distribution of material during the jetting operations. A loss rate of 1% was assumed for the jetting operation.

Table 8: Initial vertical distribution of sediments in the water column setup by losses during the jetting operation.

Elevation above seabed (m)	***% of sediments***
1.5	7.5
1.125	7.5
0.75	7.5
0.5	7.5
0.1	70

8.3 Background TSS Concentration

Given that the model only reports the TSS concentrations from material generated by dredging operations, it was necessary to include the background concentrations to the model results to understand the collective effect.

Because the turbidity due to suspended solids within Port Curtis is highly variable, BMT-WBM selected to use satellite-derived data collected between February and April during the years 2007-2009 to determine the likely background concentrations. A number of quality control measures were employed during the analysis, including a comparison between recently composed satellite data (November 2009) with water samples measured by Vision Environment (VE) at the same time as the satellite passed over. Spatial estimates of average background TSS were subsequently provided to APASA for use in the data analysis as a 250 m by 250 m gridded dataset covering Port Curtis.

Because the satellite derived data proved to be highly variable, most likely due to interference with the sensors, APASA carried out some additional manipulation and smoothing:

a) Areas around the edges with values < 5 mg/L were removed as this was assumed to be affected by water level variation (hence a false signal over time);

b) Isolated spikes, which were above 60 mg/L (only 34 points out of 32,000) were removed and set to 60 mg/L on the basis that the estimates were likely to be erroneous;

c) Areas with no background data (mainly within the Narrows) were set to the average TSS value of the entire dataset (~ 20 mg/L);

d) The edited data was interpolated onto a grid the same size as the model results to allow direct addition of background and above background estimates on a common grid, which was set to 40 x 40 m; and

e) Finally, linear smoothing was conducted of the gridded background data to reduce noise in the data assumed to be due to erroneous measurements

Figure 10 shows the interpreted average background TSS concentrations used as part of the modelling assessment. Higher average turbidity levels (25 – 50 mg/L) were generally represented along the main channels.

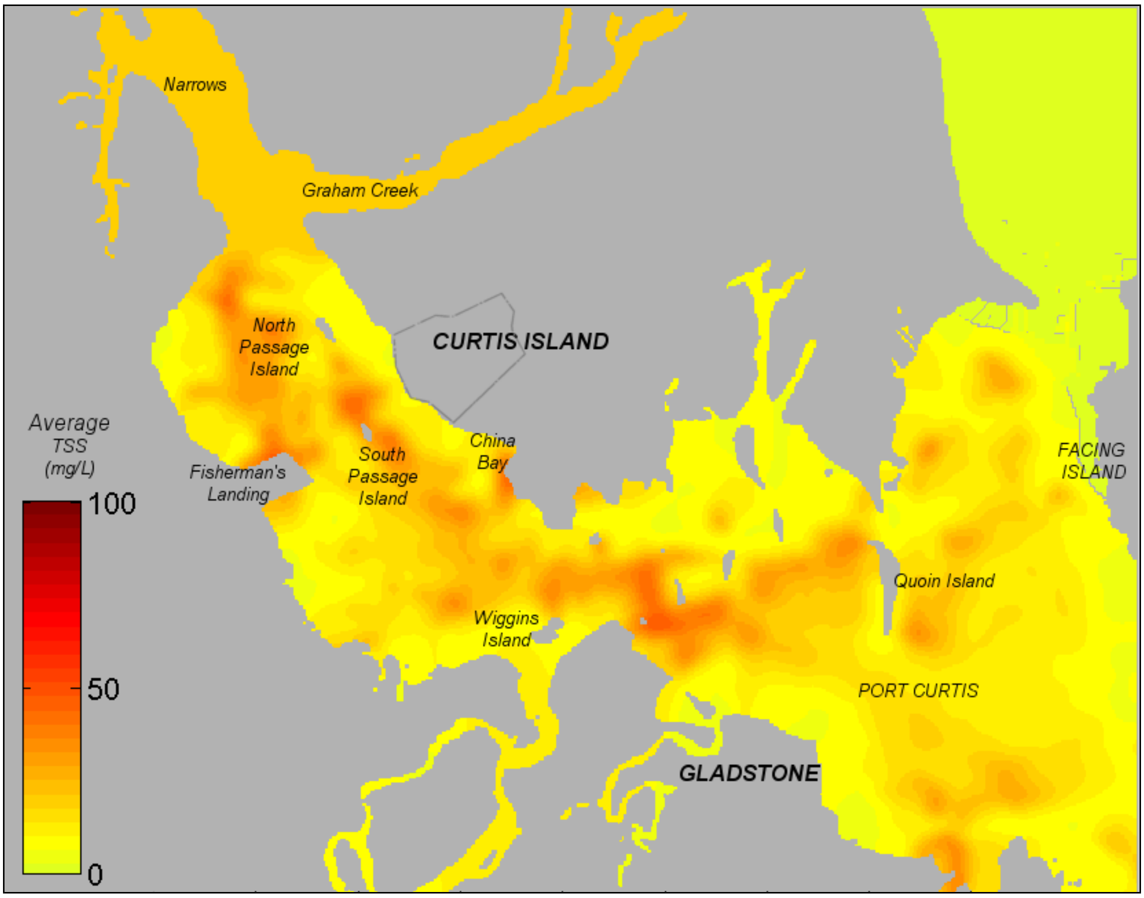


Figure 10: Map showing the average total suspended solids concentrations interpreted from satellite derived data from February to April 2007 – 2009.

8.4 Distribution of Seagrasses

Department of Primary Industries and Fisheries (DPI) is currently remapping the spatial distribution of seagrass meadows and species assemblages within Port Curtis. However, as this information was not available at the time of this study, the DPI survey from November 2002 was used as an indicator of seagrass meadow locations (see Figure 11).

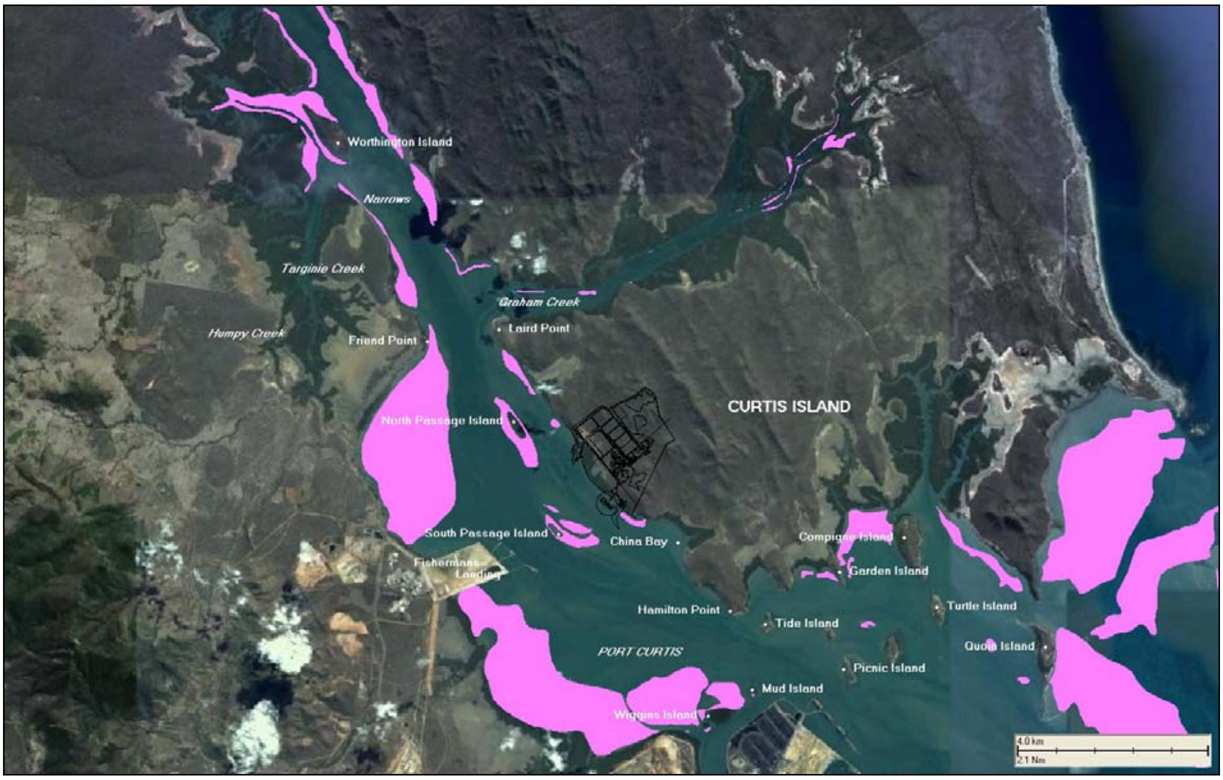


Figure 11: Location of seagrass meadows (pink shading) within the port limits of Port Curtis, during November-December 2002 (source: DPI).

8.5 Analysis of Model Results

The model results are presented in a number of forms to highlight the spatial and temporal patterns of effect that were predicted:

- Images of the model predicted maximum TSS and sedimentation patterns due to the individual sediment sources; and
- Time-series graphs of maximum predicted TSS concentrations and bottom sedimentation as a function of time for areas within Port Curtis (Figure 12).

The three phases described in Section 7 were independently modelled for each section (Creek and Narrows). To gain an understanding of the overlapping sediment sources and, in turn, cumulative effects, the individual model outputs were amalgamated to produce:

- Depth averaged median (i.e. the 50th percentile value), 80th and 95th percentile TSS contours were calculated at hourly intervals for each depth layer and location (represented as 0.5 m depth layers within each 25 m x 25 m grid cell within the model domain). The median values indicate a more typical result, while the 80th and 95th percentiles reveal increasingly extreme upper values over time.

- Median and 95th percentile sedimentation rate contours were calculated from hourly predicted changes in sediment thickness at each location (represented by 25 m x 25 m grid cell within the model domain). These plots provide a summary for each location to identify locations that may be at higher risk from sedimentation.

Figure 12: Location of time-series output sites.

9 MODEL RESULTS

9.1 Creek section

Suspended sediments

The trenching and backfilling simulations for the pipeline burial across the Creek Section, indicated that TSS concentrations > 5 mg/L (above background) would generally be restricted to Humpy and Targinie Creeks. Although, patchy plumes are predicted to emerge from Targinie creek over the final period of spring ebbing tides during the operation.

Figure 13 highlights the change in maximum predicted TSS concentration (above background) generated from losses by the BHD while trenching within the Creek during a flood and ebb tide.

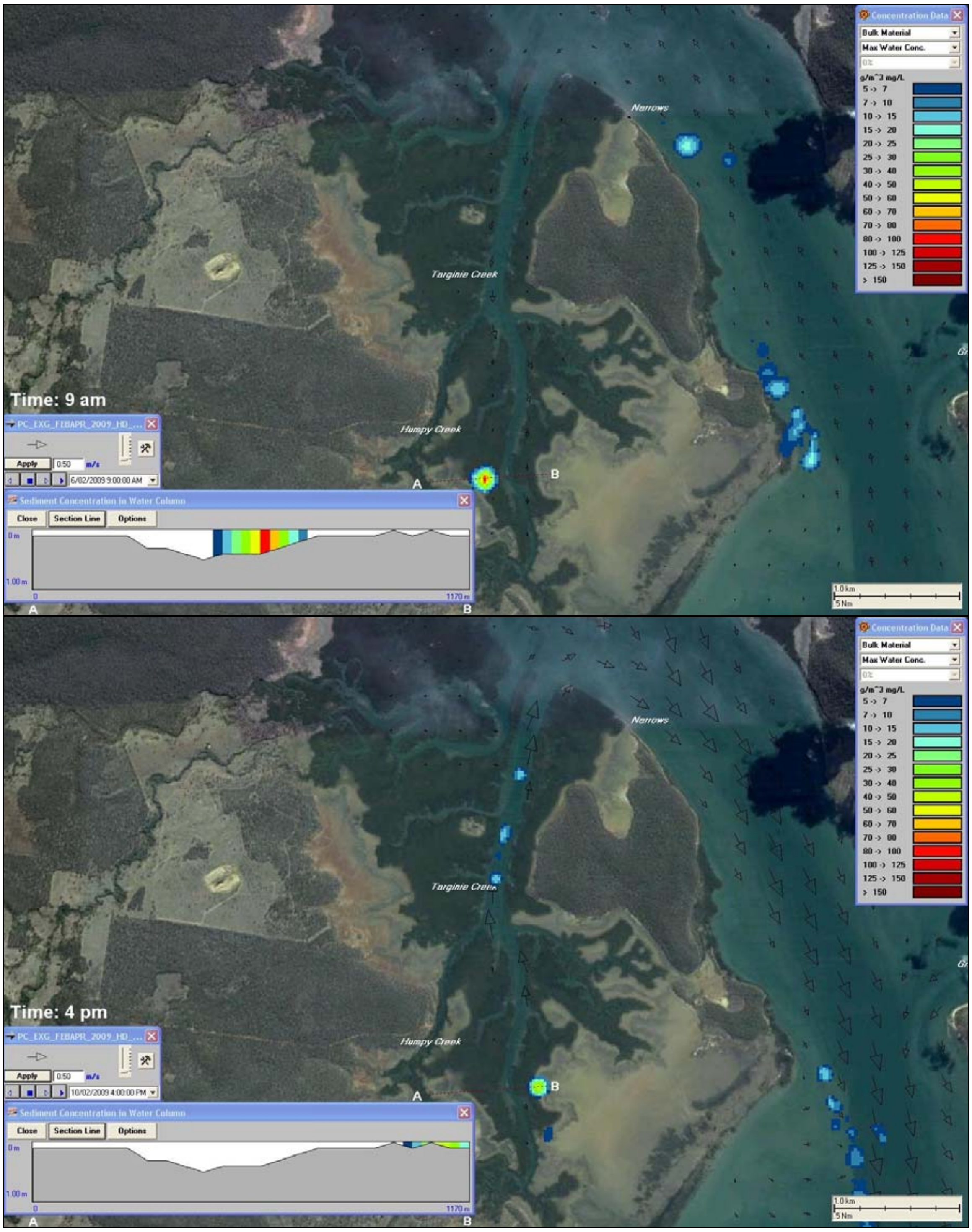
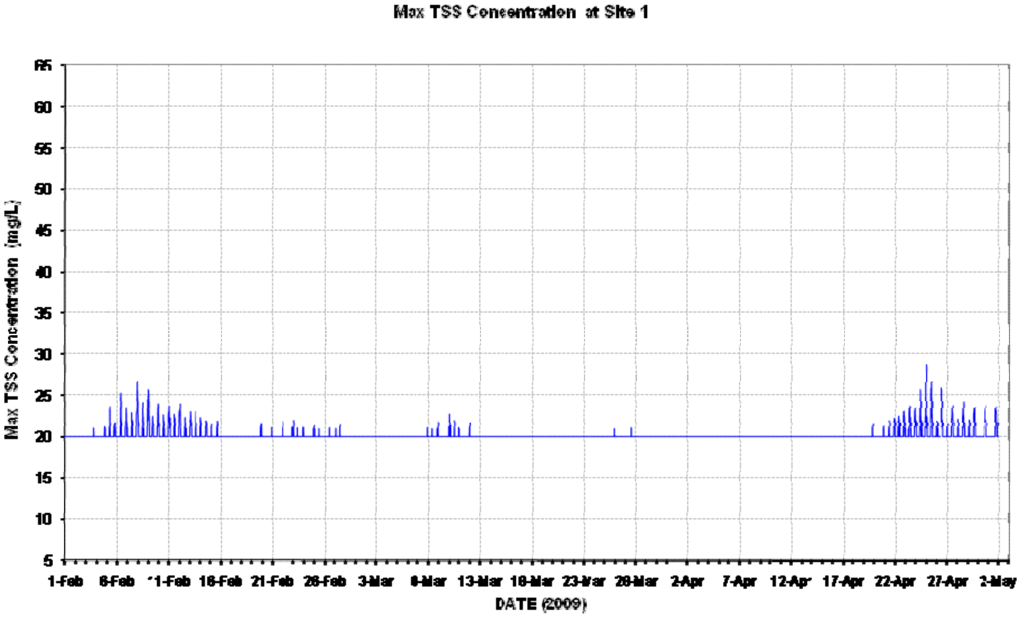


Figure 13: Snapshot of the maximum predicted suspended sediment concentration at any depth layer (above background) generated from losses by the BHD while trenching within the Creek during a sample February 2009, flood (above) and ebb (below) tide.

Concentrations midway along Targinie Creek (Sites 2 & 3) and at the entrance (Site 1) were predicted to peak at 8 -10 mg/L above background for short durations (1-2 hours) during spring ebb tides while concentrations at the upper extent of the creek, near to the operation (site 4), are predicted to potentially exceed 20 mg/L above ambient TSS concentrations (> 40 mg/L combined), with levels sustained above ambient for extended periods (days). However, such extremes are only expected periodically and the median predicted concentrations over time at all sites were at ambient levels in the simulation.

Backfilling operations were completed by the 23 March 2009 in the simulation and TSS concentrations in the creek were predicted to reduce to ambient within one or two tidal cycles of cessation, suggesting that flushing and settlement will reduce TSS suspensions quickly. Plumes that emerge from Targinie Creek during the operations in the creek are expected to disperse to background concentrations before reaching the Narrows and no build up of turbidity is indicated within the waters of Port Curtis from this part of the operation. Note that elevated TSS concentrations indicated for Sites 1 to 3 after the 20th April in Figure 14 and Figure 15 were not related to creek operations but were contributed by later operations in the Narrows.

The model results also indicated that sedimentation resulting from operations in Targinie Creek would be mostly restricted to the creek, with highest rates occurring immediately adjacent to the trenching operation and decreasing rapidly thereafter (Figure 16 & Figure 17). Sediment was predicted to accumulate at the back of the creek (Site 4) at a concentration of 4.7 kg / m^2 by the end of the operation, with highest rates of accumulation during the BHD operations to trench and to backfill. Little additional sedimentation was indicated at this site during the jetting phase. This estimate for the peak sediment load equates to an average thickness of approximately 3 mm, based on the assumed density of the sediment (1700 kg/m^3). Sediment loads at the back of the creek were predicted to stabilise after cessation of new dredging inputs, indicating that tidal currents are generally too weak to resuspend these deposits. Hence, they would tend to remain and consolidate into the existing mud deposits over time.



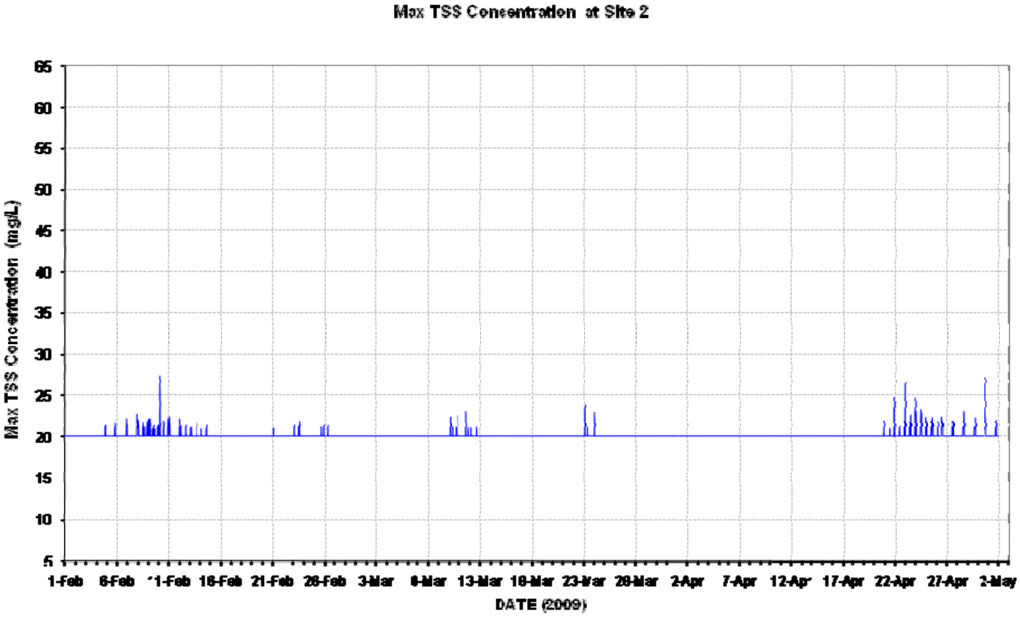


Figure 14: Maximum TSS concentrations predicted at any depth level over time at Site 1 (above) and Site 2 (below) within Targinie Creek (inclusive of average background TSS estimates).

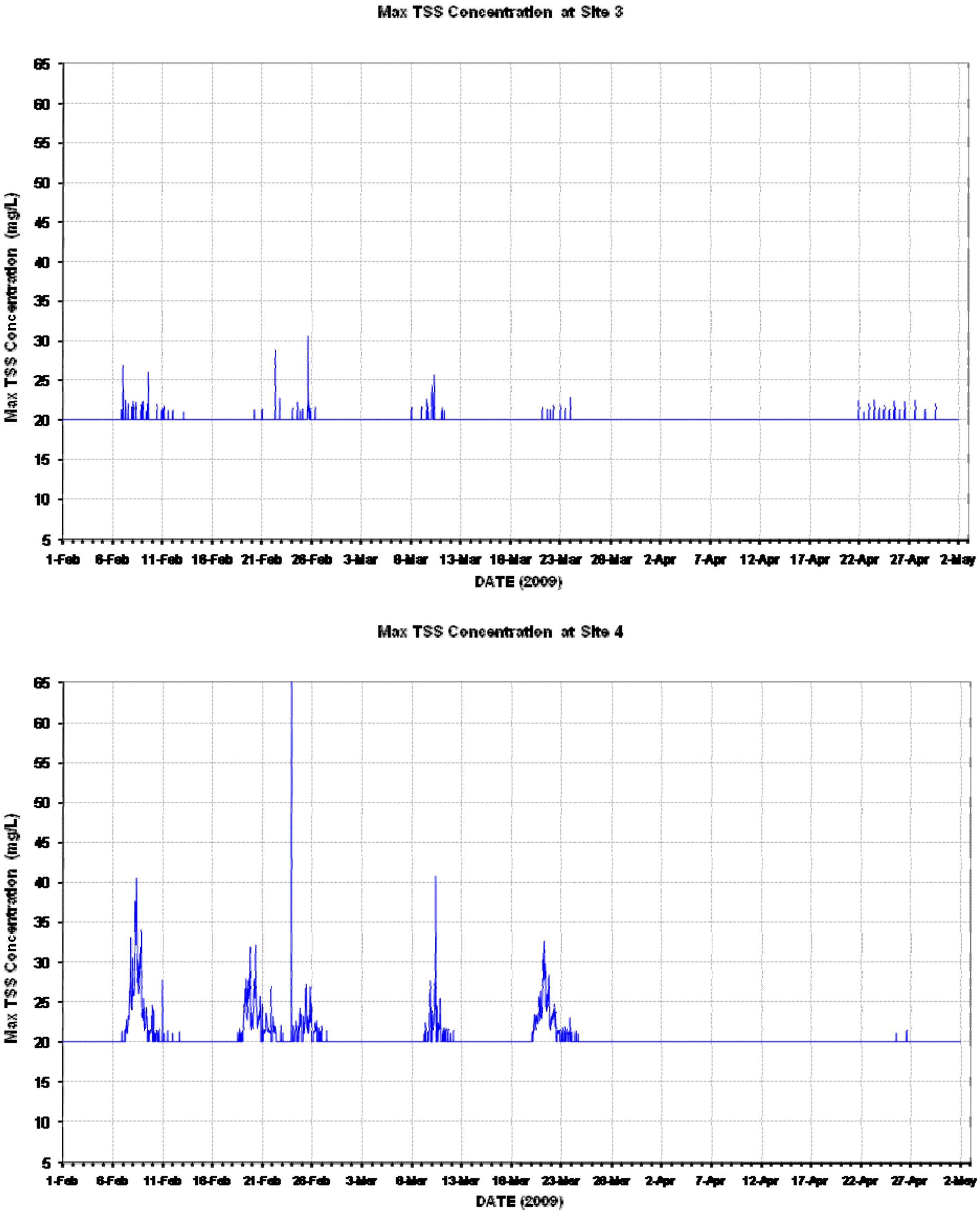


Figure 15: Maximum TSS concentrations predicted at any depth level over time at Site 3 (above) and Site 4 (below) within Targinie Creek (inclusive of average background TSS estimates).

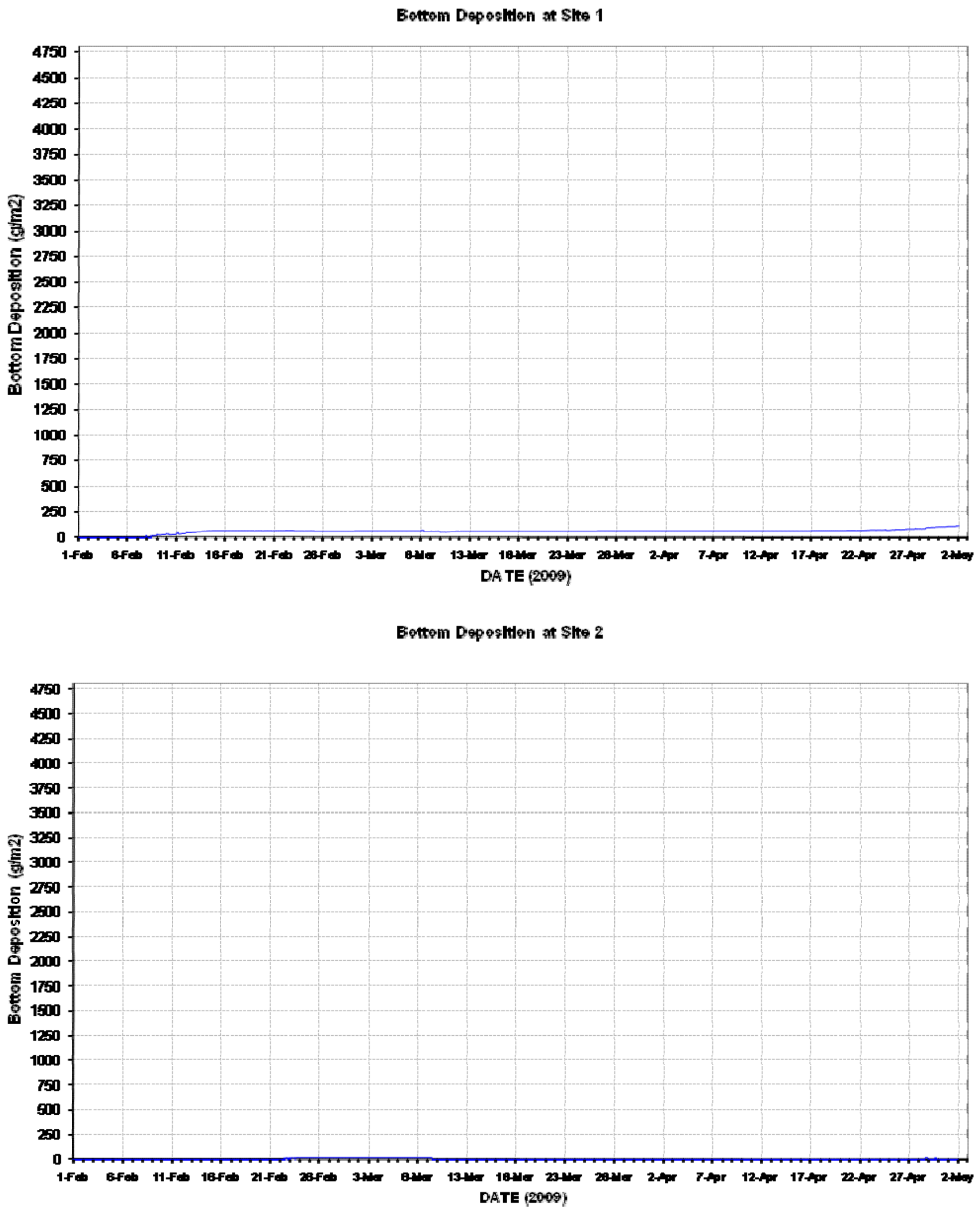
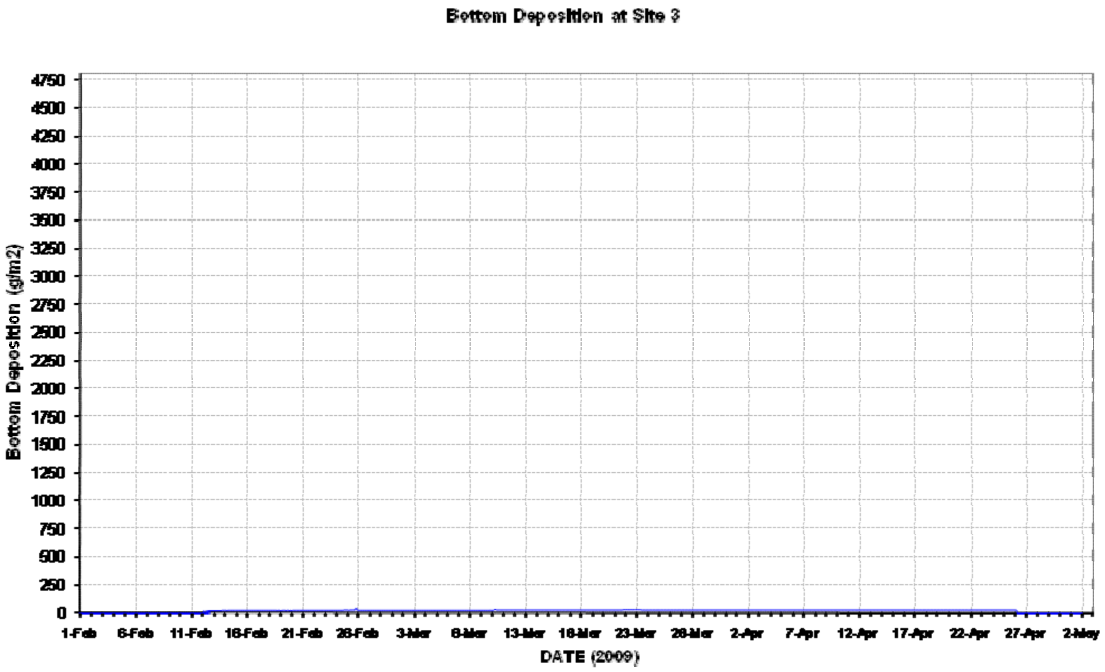


Figure 16: Cumulative sedimentation (g/m^2) predicted for Site 1(above) and Site 2 (below) within Targinie Creek due to dredging operations.



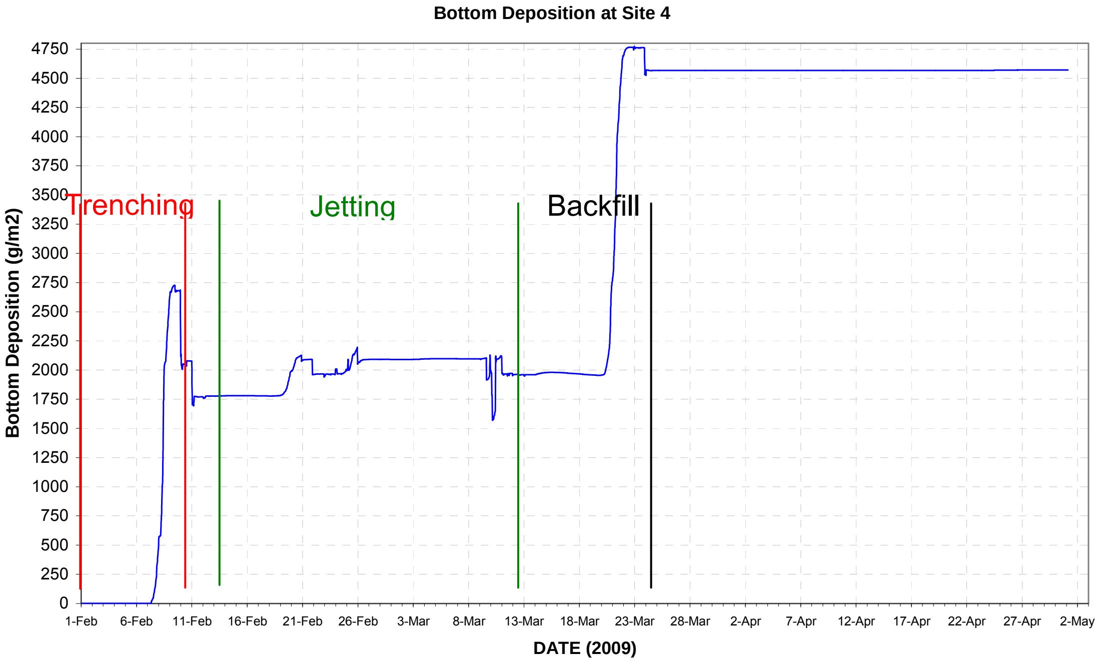


Figure 17: Cumulative sedimentation (g/m2) predicted for Site 3(above) and Site 4 (below) within Targinie Creek due to dredging operations.

9.2 Operations in the Narrows

The BHD operations to trench and backfill across the Narrows were predicted to generate higher TSS concentrations than operations in the creek, due to the higher rate of production (hence rate of sediment discharge), the deeper water (hence increased fall distance for sediment particles) and stronger currents. Sediment plumes generated by BHD operations on the west side of the channel are predicted to migrate as a relatively narrow plume along the west side of the tidal channel through Port Curtis, with the potential for some ingress into Targinie Creek during flooding tides (Figure 18). Sediment plumes generated by BHD operations on the east side of the crossing are also predicted to trend towards the west side of the tidal channel. However, with the likelihood that parts of the sediment plumes will flow directly into the entrance of Graham Creek on the flooding tide and along the eastern shoreline on the ebbing tide (Figure 19).

A distinct inequality of the plume distributions was indicated over the flooding and ebbing tide for BHD operations across the Narrows. Plumes are predicted to have markedly shorter upstream migrations during flooding tides compared to the downstream migrations over ebbing tides. Concentrations were also predicted to build up during the flooding tides and decrease during the ebbing tides. This outcome is related to the bathymetry of the waterway, with flooding tides pushing the suspended sediment plume into shallower water and ebbing tides tending to draw sediments down the slope of the channel. Hence, concentrations of the order of 25 to 80 mg/L are predicted to build up within 1600 m upstream on the flooding tide but concentrations > 5 mg/L TSS above background are not expected to normally extend far beyond the confluence of Targinie Creek. In contrast, plumes > 5 mg/L TSS are predicted to occur, low in the water column, as far as Tide Island on the ebbing tide. Due to the predicted vertical distribution of the sediments, the plume is unlikely to be visible over the extent predicted for ebbing tides, for observers above water level. Backfilling operations with the BHD were predicted to generate similar concentrations and plume distributions to the initial trenching operations with this equipment.

Figure 20 to Figure 22 show predicted maximum predicted TSS concentrations (at any level) as a function of time for defined sites. Consistent with the earlier observation that plumes will tend to migrate along the western side of the channel, the highest and most consistently elevated concentrations were predicted for Sites 5, 8 and 10 (in that order). Concentrations at Site 5 peaked at 53 mg/L above background in the simulation and concentrations > 10 mg/L above background are predicted to occur regularly during the BHD operations, depending upon the tidal state. However, concentrations are predicted to be highly variable rather than chronic. Based on the assumed rates of sediment suspension, jetting operations were predicted to generate significantly lower concentrations of suspended sediments than the BHD operations. This resulted in only localised TSS elevations above background.

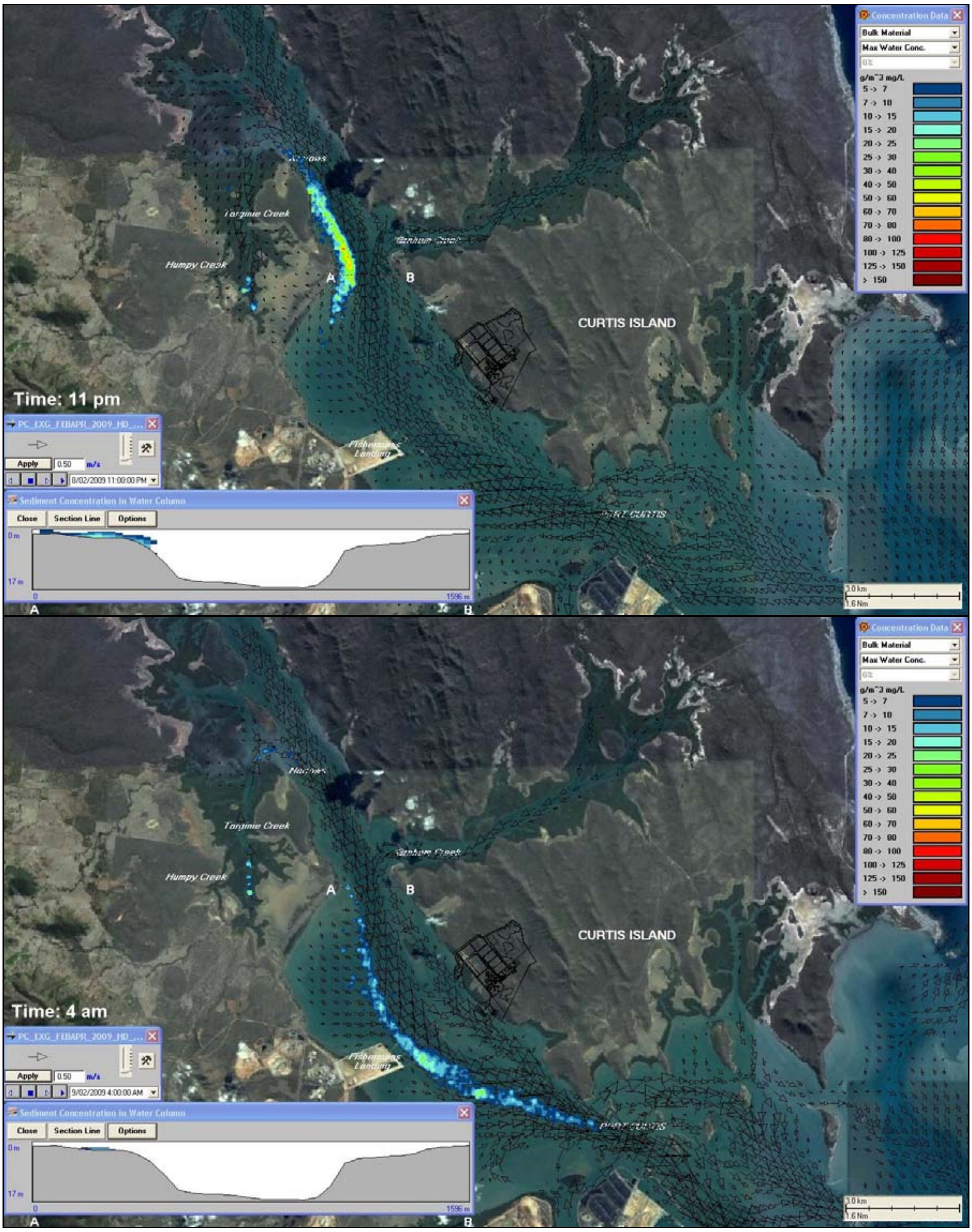


Figure 18: Snapshot of the maximum predicted suspended sediment concentration (above background) at any depth level generated from losses by the BHD when trenching on the west side of the Narrows section during a sample February 2009 flood (top) and ebb (bottom) spring tide.

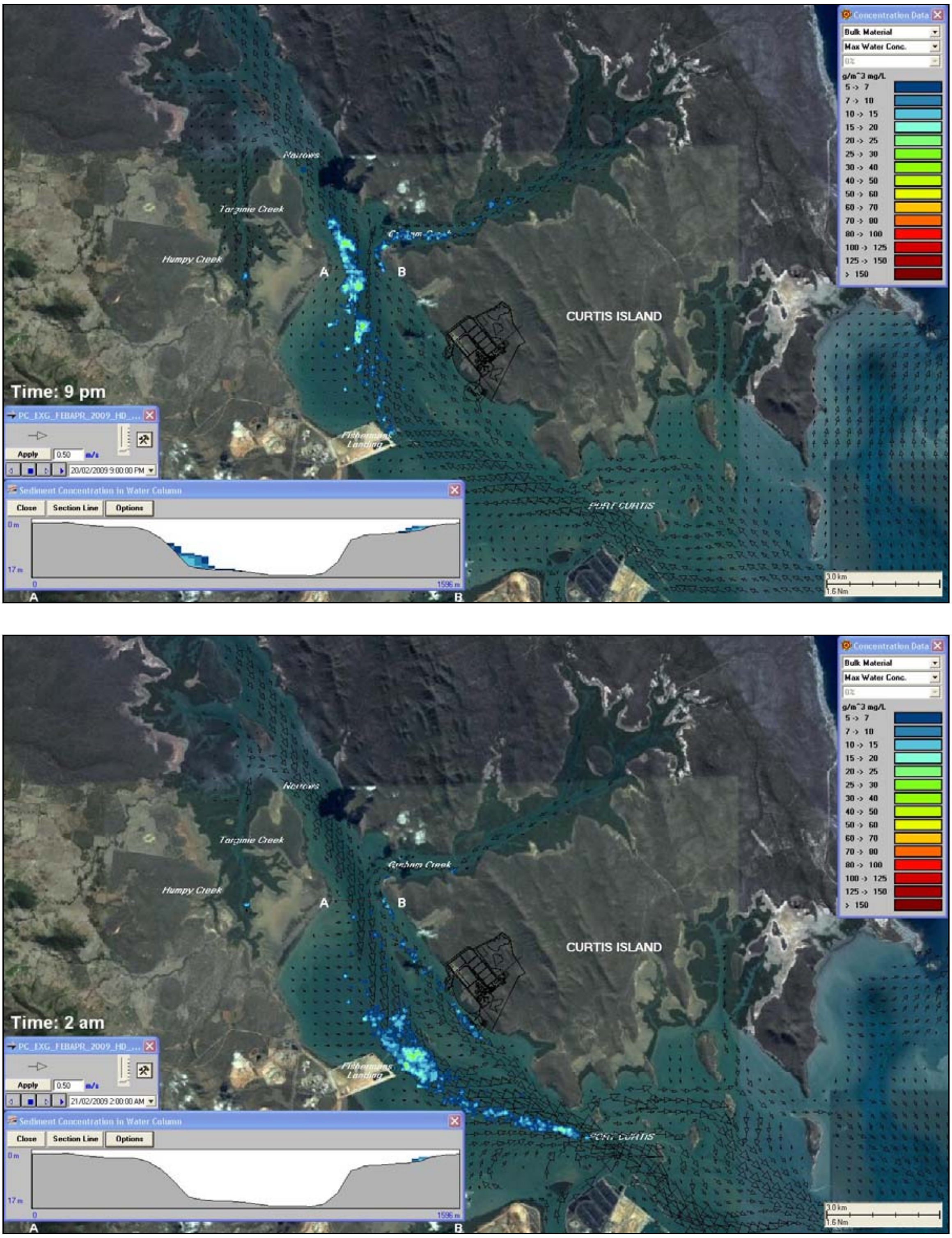
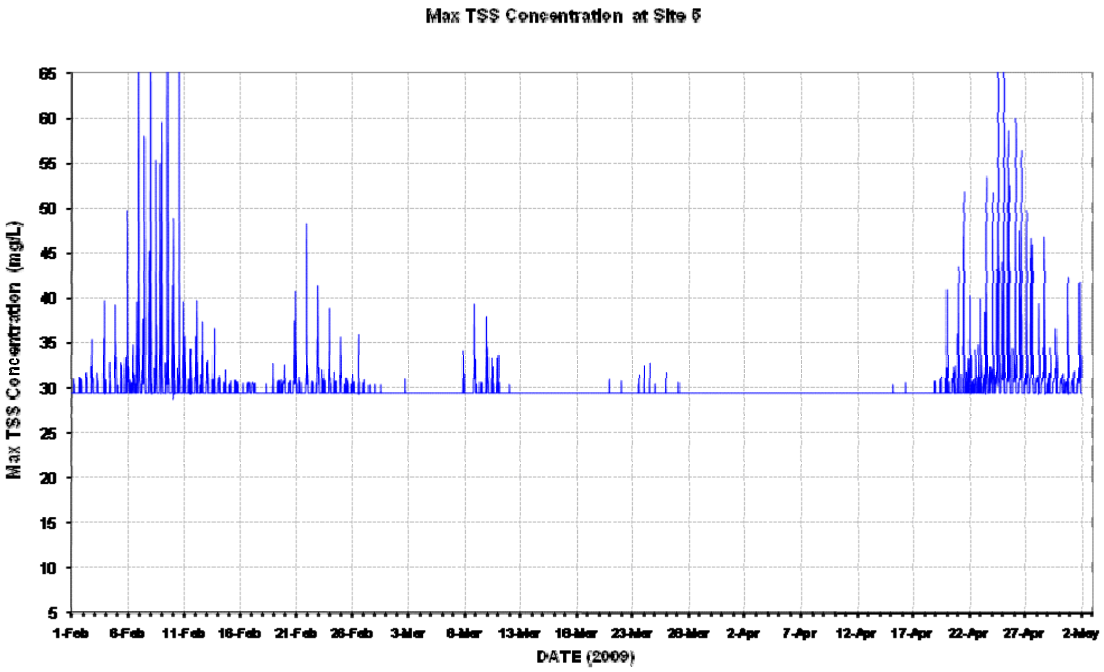


Figure 19: Snapshot of the maximum predicted suspended sediment concentration (above background) at any depth level generated from losses by the BHD when trenching on the east side of the Narrows section during a sample February 2009 flood (top) and ebb (bottom) spring tide.



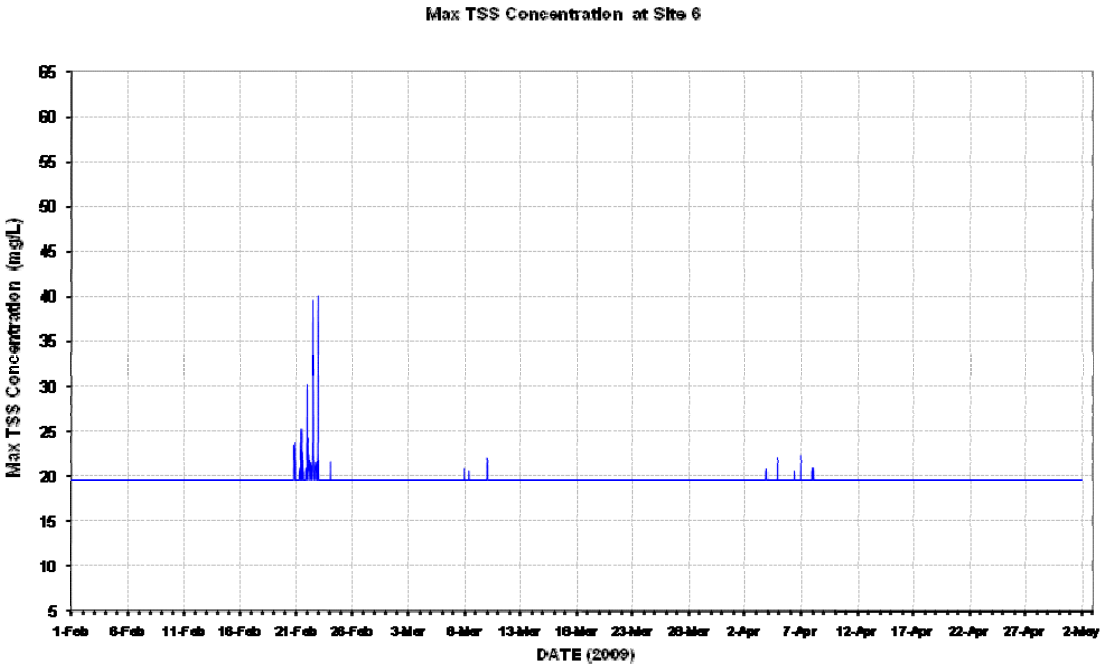


Figure 20: Maximum TSS concentrations predicted at any depth level over time at Site 5 (above) and Site 6 (below) within Port Curtis (inclusive of average background TSS estimates).

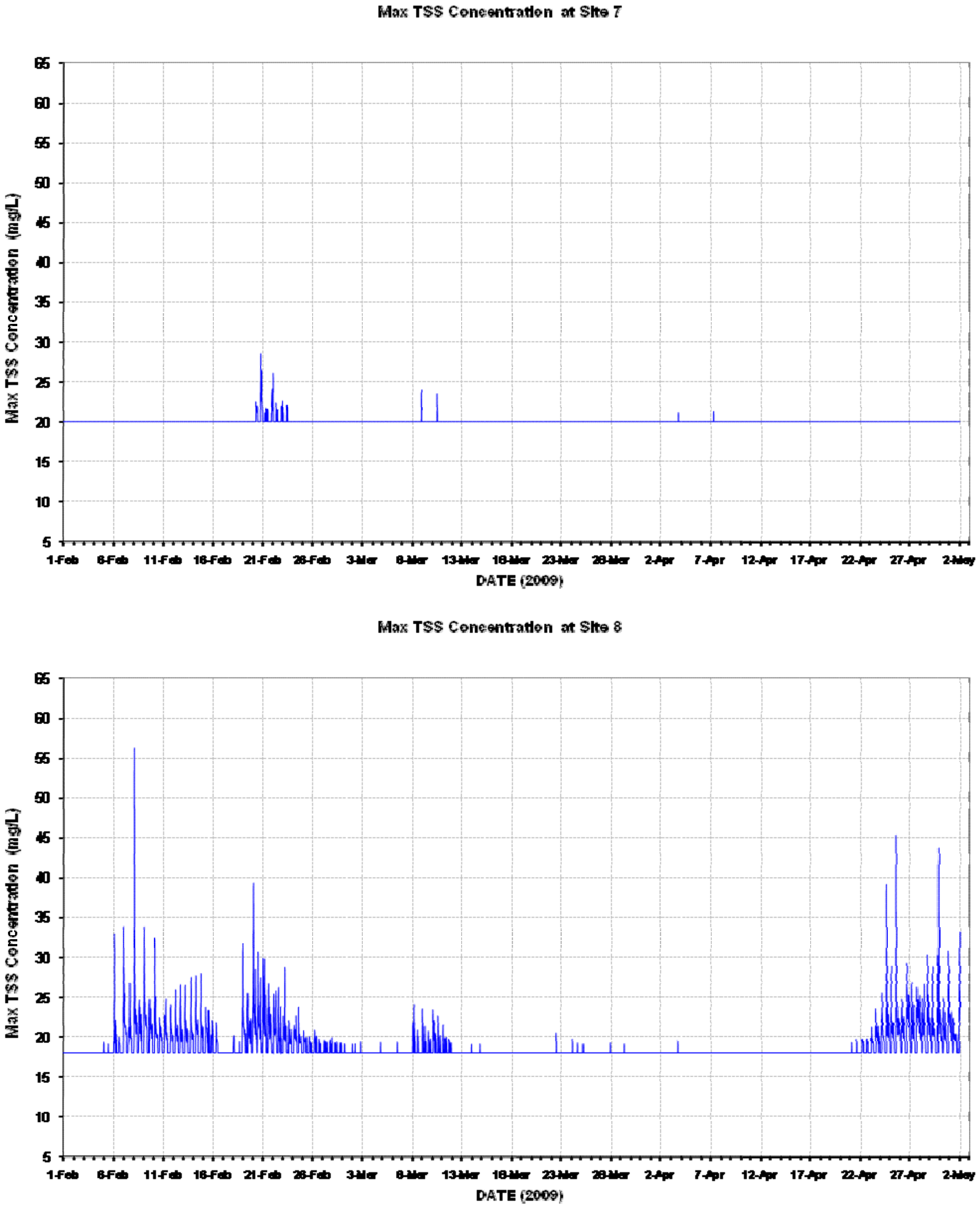


Figure 21: Maximum TSS concentrations predicted at any depth level over time at Site 7 (above) and Site 8 (below) within Port Curtis (inclusive of average background TSS estimates).

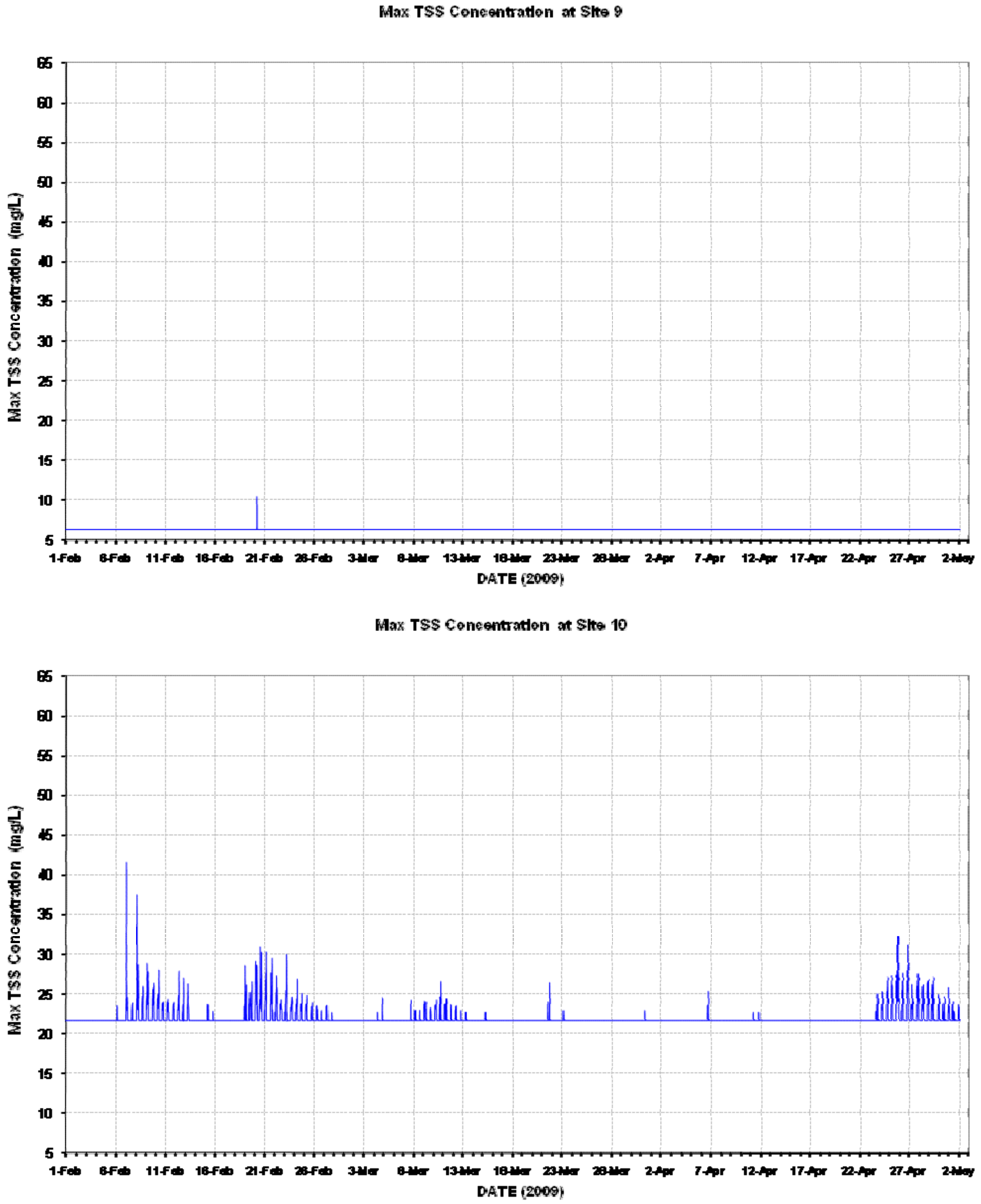
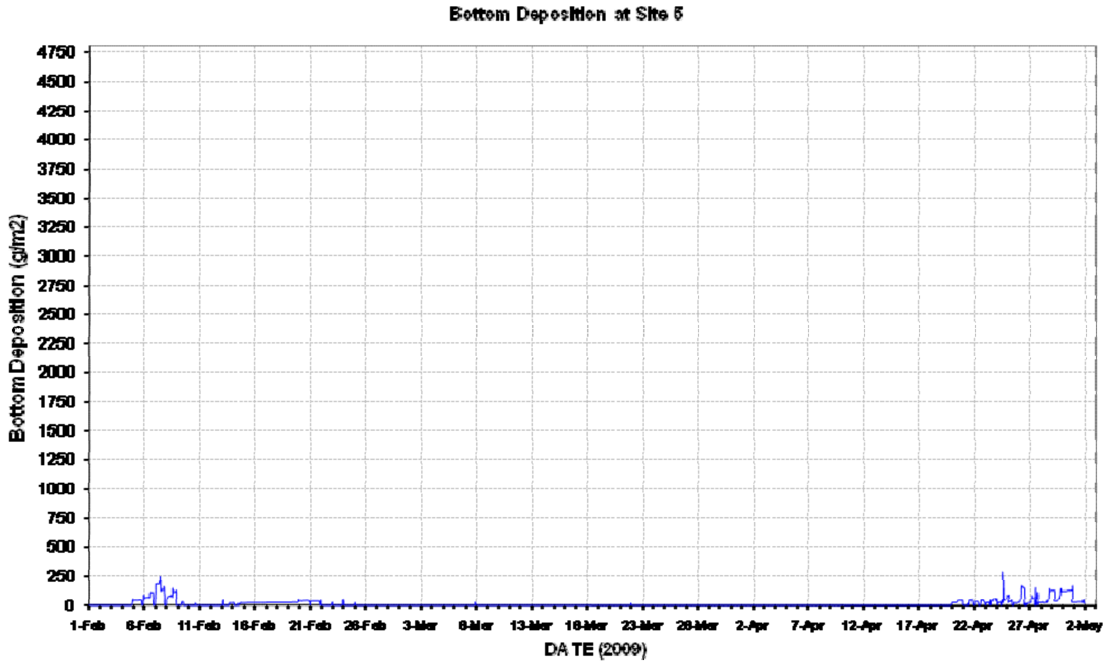


Figure 22: Maximum TSS concentrations predicted at any depth level over time at Site 9 (above) and Site 10 (below) within Port Curtis (inclusive of average background TSS estimates).

Predictions for the cumulative sedimentation due to dredging across the Narrows indicated that sediments will tend to be dispersed widely along the tidal channel but accumulate if they are transported over the mud banks lining the channel. Consequently, very minor sedimentation was predicted for sites along the navigation channel (Figure 23 to Figure 25). The mudbanks on the downstream side of the Narrows are indicated to be more likely sites of settlement, with most sediment building up on the larger bank on the western side of the channel because the plume will tend to be pushed to this side. This is the natural process that has resulted in the build up of mud banks in these areas. However, the dredging will be contributing additional material to the natural suspension loads, hence higher sedimentation rates.



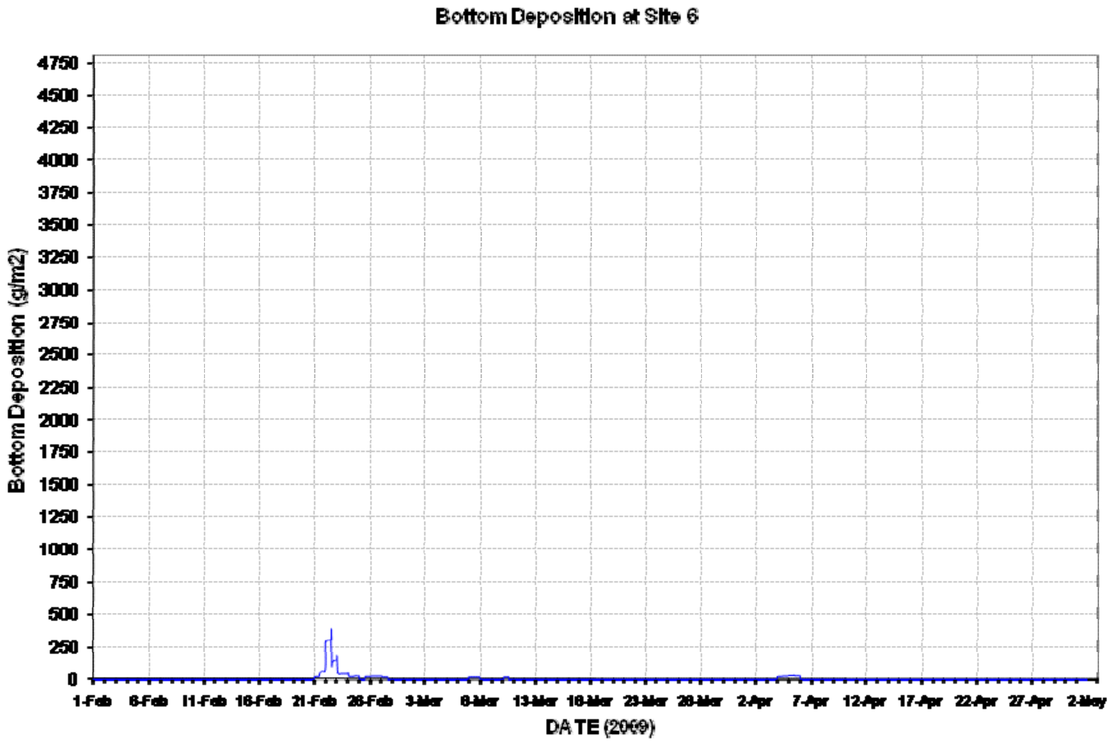


Figure 23: Cumulative sedimentation (g/m2) predicted for Site 5 (above) and Site 6 (below) due to dredging operations across the Narrows.

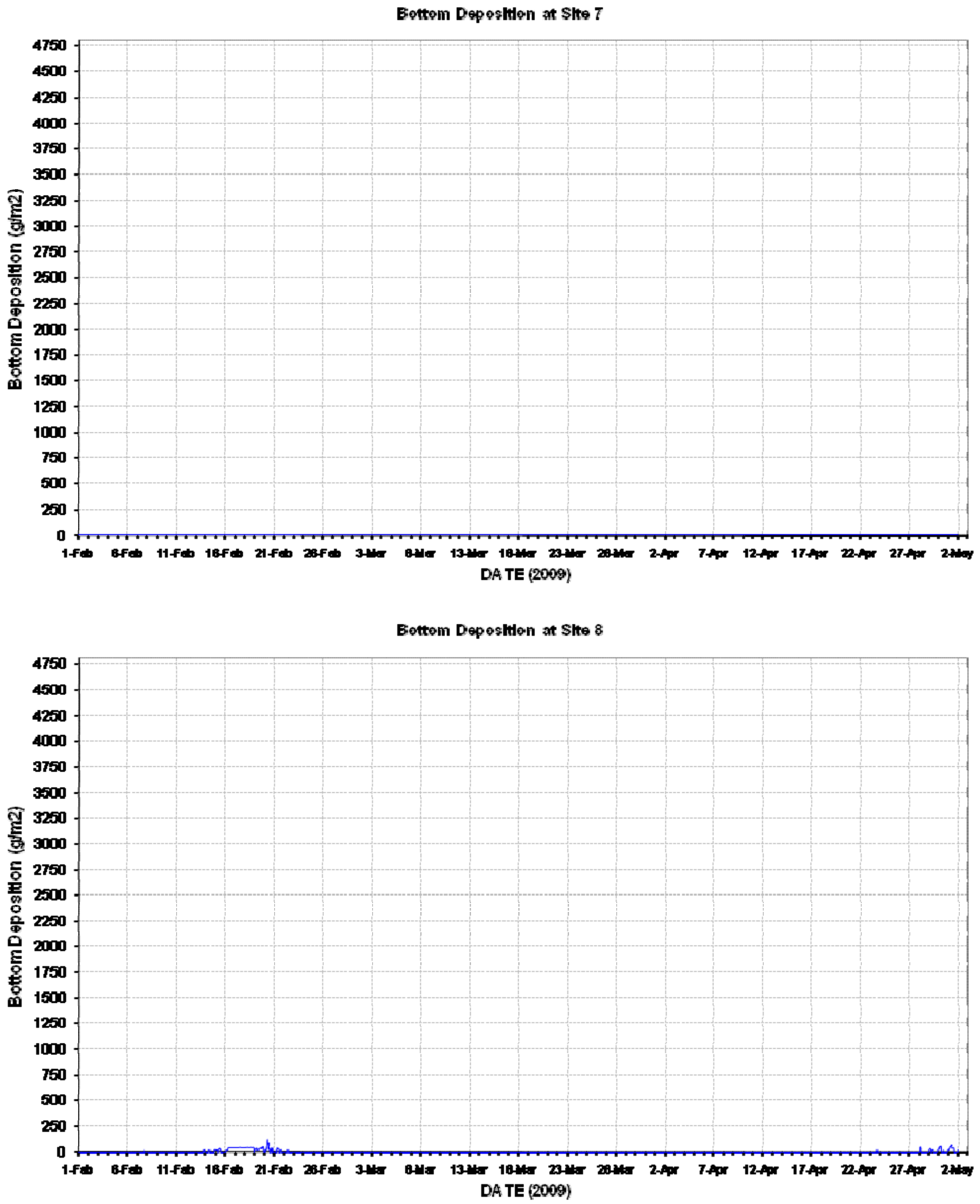
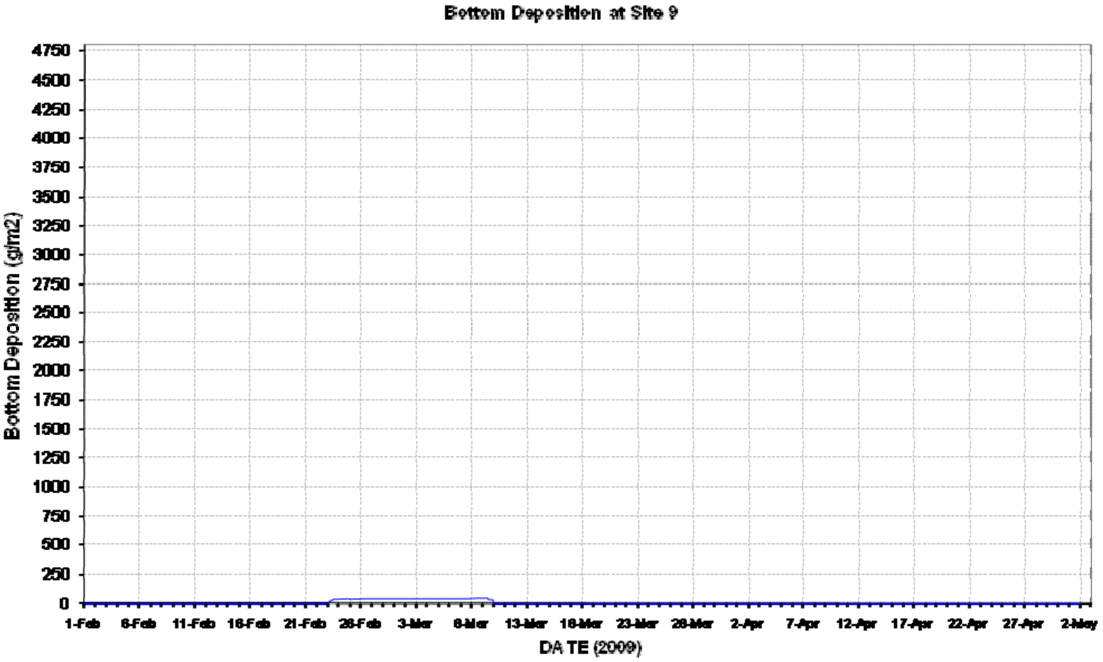


Figure 24: Cumulative sedimentation (g/m2) predicted for Site 7 (above) and Site 8 (below) due to dredging operations across the Narrows.



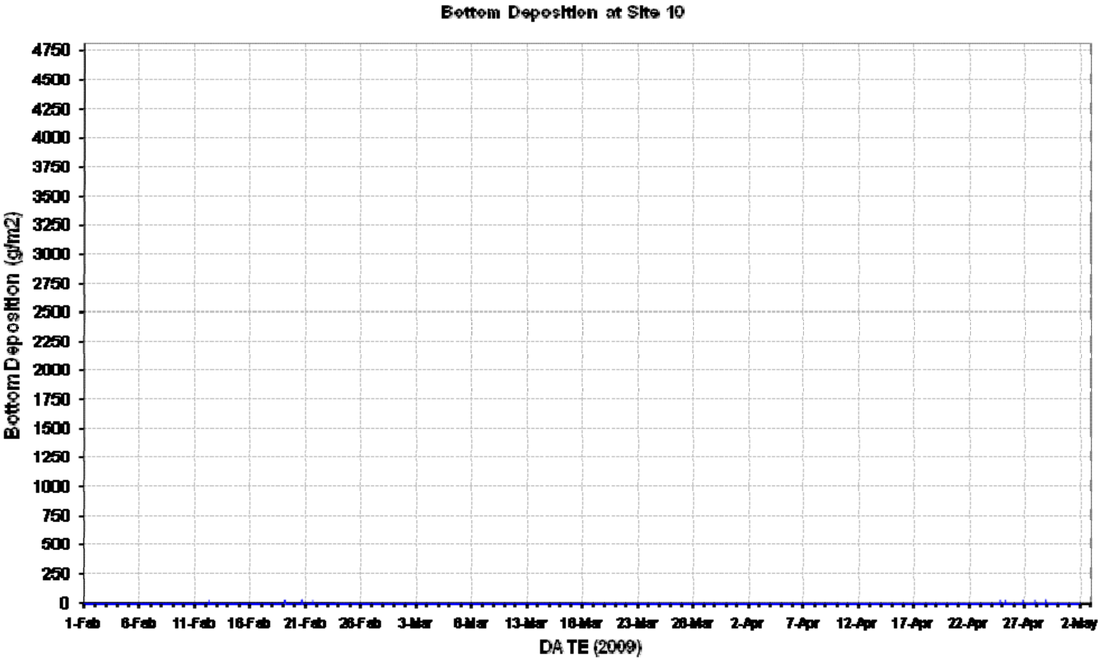


Figure 25: Cumulative sedimentation (g/m2) predicted for Site 9 (above) and Site 10 (below) due to dredging operations across the Narrows.

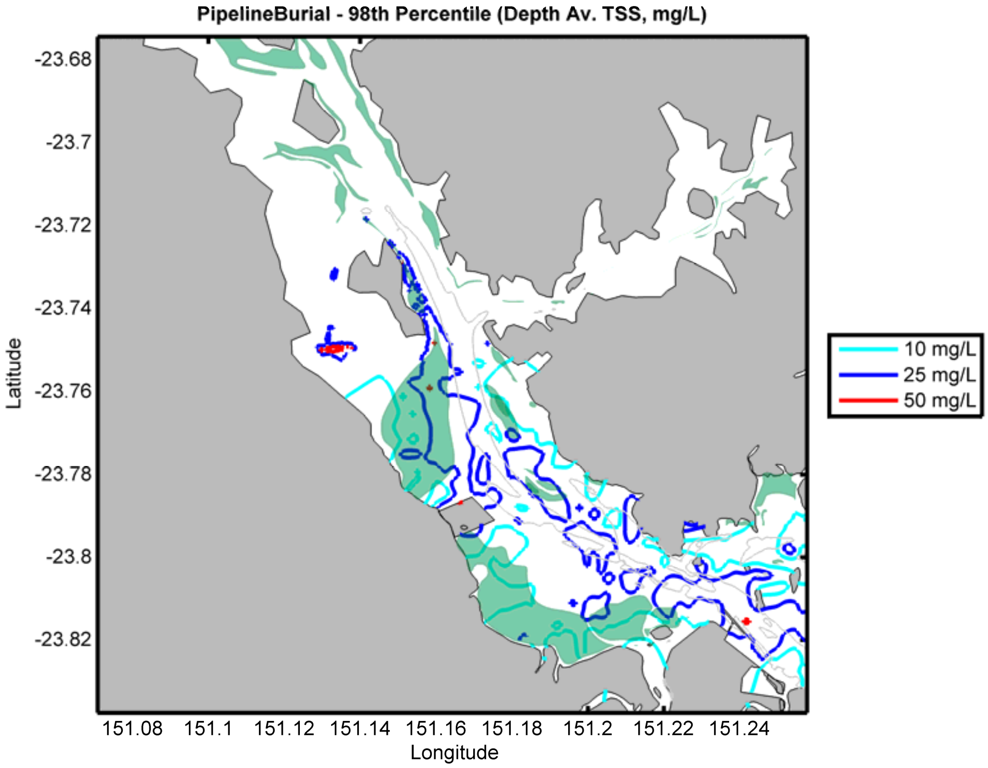
9.3 Cumulative effects of all operations on TSS and sedimentation

As noted previously, some overlap is expected for the sediment plumes generated by the operations in Targinie Creek and the Narrows. The following sections consider the cumulative effect of the combined operations.

Due to the relatively short duration of individual operations, with time gaps between where there will be no discharges, the median increases in depth-averaged TSS concentrations were not higher than background estimates when calculated over the full duration of the operation. The distribution of more extreme concentrations, as indicated by the 95th percentile of the depth-averaged TSS concentrations is presented in Figure 26 for both the background condition and with the addition of dredging estimates. These calculations indicate that TSS concentrations markedly higher (by 5-10 mg/L) than background would be generated at the upstream end of Targinie Creek and immediately up and downstream of the Narrows operations but these concentrations would not be chronic over the duration of the operation. As previously noted, the higher concentrations would be generated during the sub-operations using the BHD.

Estimates for the cumulative sedimentation (Figure 27) indicate that fine sediments would be spread widely but thinly throughout the creek and estuary, with a downstream bias. Note that the scale of this figure is set to highlight small levels of accumulation and that the highest sedimentation rates that are indicated equate to an average thickness of a few millimetres, while the lowest concentrations shown equate to an average thickness of 6 µm. With the rate of sedimentation appears to be at least

Due to the lower current speeds in the creek, highest accumulations were predicted immediately around the operation crossing this section, with the finer sediments distributing along the creek and accumulating to higher levels in deeper pockets along the channel. In contrast, the stronger currents through the Narrows are predicted to transport sediment released from this section upstream and downstream with the tide and finer sediments were predicted to settle as far downstream as the estuary mouth. Upstream settlement is predicted to extend up to 6 km beyond the Narrows and midway along Graham Creek. Highest sedimentation was indicated for locations to the sides of the channels where current speeds are weaker, corresponding to locations where mud banks currently exist, for this same reason. It is also noted that localised accumulation, albeit at relatively low levels, is predicted for the south end of Curtis Island and on Tide Island.



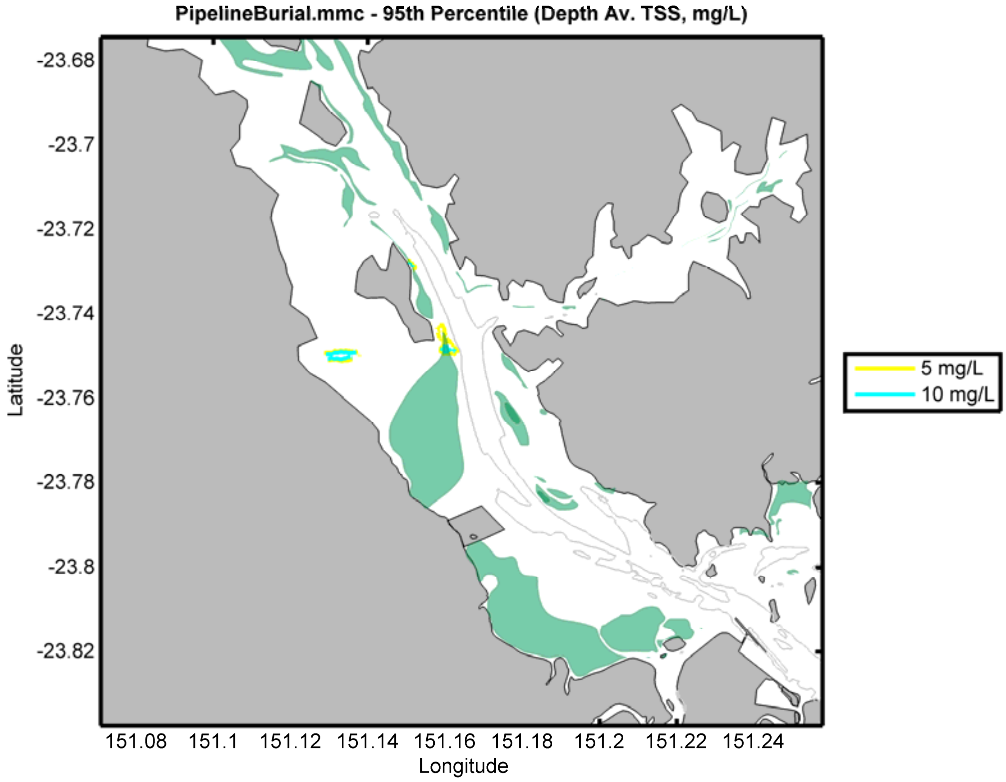


Figure 26: Estimates for the 95th percentile concentrations over time calculated for depth-averaged TSS. Results are shown with (above) and without (below) background estimates.

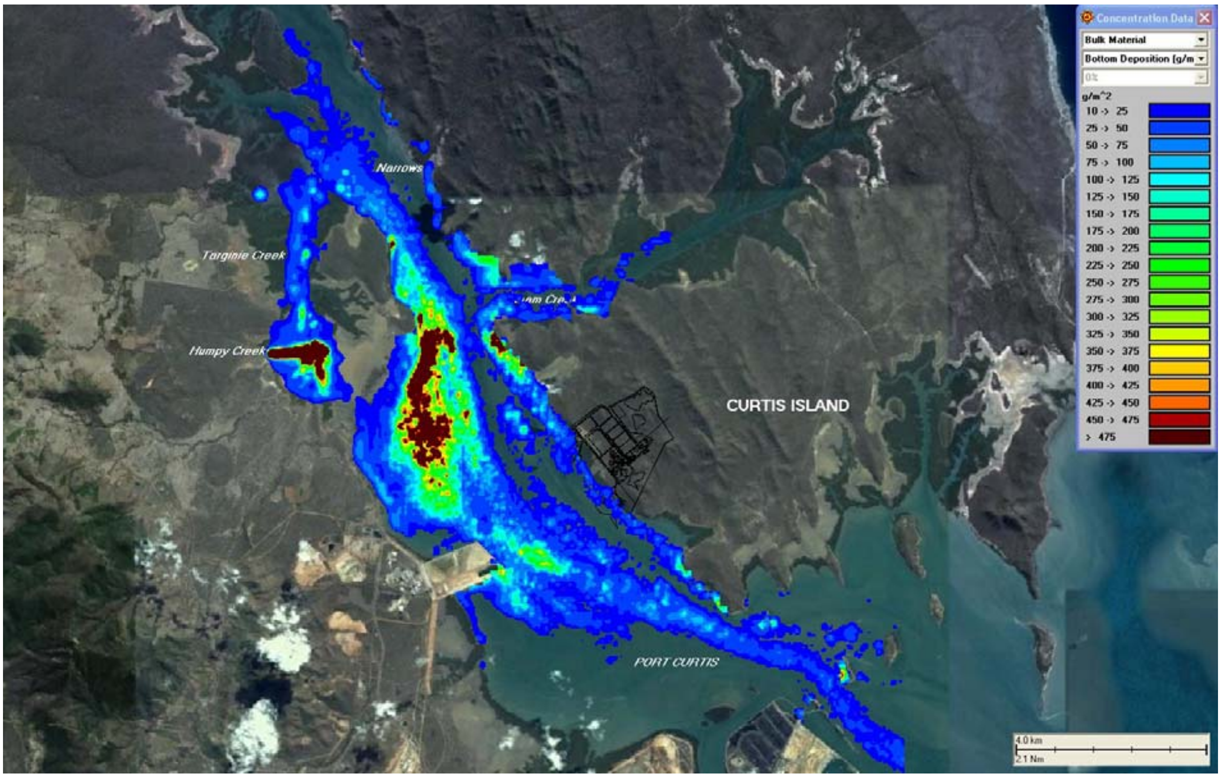


Figure 27: Estimates for the cumulative sedimentation (above background) due to the combined operations.

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