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Turbidity Monitoring of the 'Volvox Asia' at the Spitfire Channel Realignment - 2008

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Turbidity Monitoring of the *'Volvox Asia'* at the Spitfire Channel Realignment - 2008

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Title:	Turbidity monitoring of the '*Volvox Asia'* at the Spitfire Channel Realignment – 2008.
Author:	Brad Hiles, Craig Morgan
Synopsis:	Summary of *in situ* water quality (drogue based) monitoring measurements during two capital dredging 'runs' by the trailing hopper suction vessel *"Volvox Asia"* at the Spitfire channel Realignment Area at Western Banks, northern Moreton Bay.

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1 INTRODUCTION

1.1 Background

The Port of Brisbane Corporation (PBC) commissioned the Van Oord dredger *'Volvox Asia'* to undertake capital dredging operations at Western Banks, northern Moreton Bay. The dredging works form part of a long-term extraction project with the purpose of realigning Spitfire Channel, which will ultimately provide a more direct route for deep draught vessels entering and leaving Port between existing Beacon pair M3 and M4 (Main Channel) and Beacon NW12 (North West Channel).

Sand extracted from the new channel alignment is utilised as reclamation capping within the Future Port Expansion (FPE) areas at the Port of Brisbane. The project will remove an estimated total of 15 million cubic metres of sand material over 15 years with a maximum of 4 million cubic meters removed annually. As a component of these works it is understood that the '*Volvox Asia*' will remove 2.4 million cubic meters of the permitted material during a 3-month period commencing in January 2007.

The *'Volvox Asia'* is a trailing arm suction hopper dredger with a hopper capacity of approximately 8000m^3. The '*Volvox Asia'* provides for the discharge of hopper overflow water at depth (approximately five metres below the water surface), as opposed to discharging the hopper overflow above the water surface. The hopper discharge design is based on the concept that there is a greater opportunity for material settlement with a consequent reduction in the visible turbid plume, when the hopper overflow water is discharged at depth.

PBC commissioned BMT WBM Pty Ltd (BMT WBM) to measure turbidity within the dredging plume whilst '*Volvox Asia'* was dredging the realigned Spitfire Channel on a flooding and an ebbing tide. Turbidity measurement results were used to determine compliance of the dredging works with turbidity criteria outlined within the dredging EMP (Van Oord 2007).

Figure 1-1 The Van Oord dredger *'Volvox Asia'* at the Fisherman Islands pump-out facility, Port of Brisbane - 2nd April 2008

1.2 Study Objectives

The broad aims of this study are to monitor patterns in turbidity generated by dredging, and based on this, determine compliance with dredging permit conditions relating to turbid plume generation. The specific objectives of this study were as follows:

- Undertake measurements of the water turbidity within the initial plume created by dredging and within the plume of turbid water discharged from the dredger's hoppers;
- Undertake measurements of the movement of the turbid plume(s) as indicated by drogue(s) using differential GPS;
- Undertake measurements of the water turbidity within the centroid of the turbid plume(s) at regular intervals for a period of approximately 2 hours following their creation or until the plume(s) were no longer evident;
- Collect corresponding water samples from the turbid plume(s) for laboratory analysis of suspended solids concentrations within the dredge plume; and
- Compare the turbid plume measurements from the operation of the dredger *'Volvox Asia'* with the turbidity criteria listed in the *'Volvox Asia'* Environmental Management Plan for the dredging of the Spitfire Channel realignment.

2 STUDY METHODOLOGY

2.1 Drogue-Based Plume Monitoring

2.1.1 Background

Drogues are devices that are designed to follow the set and drift of tidal currents. These devices were used in the present study to obtain information on: (i) the direction of movement of turbid plumes of water during ebbing and flooding stages of the tide, and (ii) patterns in the degradation[1] of turbid plumes of water over time. The general arrangement of the drogues used during the present study is presented in Figure 2-1.

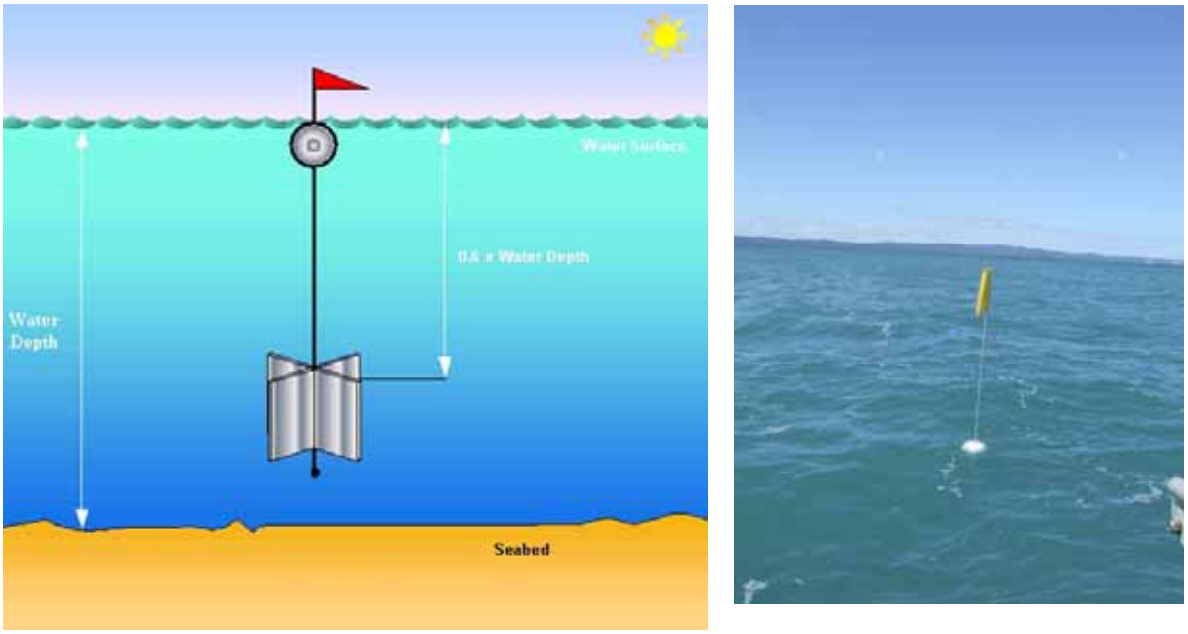


Figure 2-1 General arrangement of drogues used for turbidity plume monitoring

The movement of turbid plumes of water was tracked by recording the position of the surface relocation flag affixed to each drogue at regular intervals. The position of the drogue was recorded using a differential GPS, and water depth and time were also noted at each location. Generally one or two drogues were used to identify plume movements during dredging operations by the '*Volvox Asia'*.

The degradation of turbid plumes of water was also examined at regular intervals through both *in situ* measurements of turbidity and the collection of water samples for laboratory analysis of total suspended solids. Each of the drogues were tracked for a period of time until either the turbid plume was no longer visible or evident from *in-situ* measurements (i.e. within range of background measurements) or until the turn of the tide. In addition, background turbidity measurements were taken within adjoining areas in the Western Banks region, prior to, during and after dredging operations. Background turbidity measurements during and after dredging were collected to account

[1] 'Degradation' refers to the settlement of suspended sediment particles released or disturbed by dredging operations.

for potential changes in background turbidity caused by changes in wind and tide conditions during the periods of measurements.

2.1.2 *In situ* Water Quality Measurements

In-situ water quality profile measurements were collected at regular intervals for each drogue using a YSI Model 6600 water quality instrument connected to a YSI Model 650 MDS multi-parameter display unit with a 30m cable. The YSI instrument's sensors were calibrated prior to use. At each site, the following water quality parameters were measured: turbidity (NTU[2]), water temperature, electrical conductivity, salinity, pH, and dissolved oxygen. This suite of parameters was recorded at five-second (approximately 0.5m) intervals while lowering the instrument from the surface to the seabed at each site. Since the environmental performance/compliance criteria for dredging were mainly based upon turbidity, this represented the key indicator for the present study (refer to Section 2.4). Plots of the measured turbidities are provided in Appendix C.

Where possible, a standard (30 cm diameter) Secchi disc was lowered into the water column, which provided a surrogate measurement of surface water clarity, known as 'Secchi Depth'. Summaries of *in situ* water quality measurements taken during monitoring events 1(ebb tide) and 2 (flood tide) are presented in Tables 2-1 and 2-2, respectively.

2.1.3 Collection of Water Samples

To explore the relationship between turbidity and total suspended solids (TSS) at the Spitfire Bypass, water samples were collected and analysed for total suspended solids (TSS) from sites that were coincident with turbidity measurements representative of background conditions and within the turbid dredge plume. This approach allowed a broad range of turbidity and TSS conditions to be measured. The water samples were collected from a depth of 2m using a two litre Van Dorn Sampler. Summaries of the turbidity measurements and water samples collected during monitoring events 1 (ebb tide) and 2 (flood tide)[3] are presented in Tables 2-1 and 2-2, respectively.

[2] NTU – Nephelometric Turbidity Unit.
[3] Monitoring event 1 refers to monitoring carried out during an ebbing tide, whilst event 2 occurred during a flooding tide.

Table 2-1 Schedule of information collected during Monitoring Event 1 - Ebb tide, 2nd April 2008

Site	Time (hours)	*In situ* (YSI)	Water Samples (TSS)	Secchi Depth	Comment
BG1	1020	✓	✓	✓	Background sites.
BG2	1036	✓	✓	✓	
BG3	1113	✓	✓	✓	
BG4	1221	✓		✓	
YD1	1046	✓	✓	✓	Drogues placed in dredge plume. Dredging underway by '*Volvox Asia*'
RD1	1057	✓	✓	✓	
YD2	1053			✓	Tracking of drogues within plume.
YD3	1105	✓	✓		
RD2	1121	✓	✓	✓	
YD4	1132	✓	✓	✓	
RD3	1142	✓	✓	✓	
YD5	1153	✓	✓	✓	
RD4	1207	✓	✓	✓	
	1210				'*Volvox Asia*' completes dredging
RD5	1235	✓	✓	✓	Final drogue measurement taken, removed due to shipping activities and end of tide (low water).
YD6	1243	✓	✓	✓	Final drogue measurement taken at low water.

BG = Background, RD = Red Drogue, YD = Yellow Drogue.

Table 2-2 Schedule of information collected during Monitoring Event 2 - Flood Tide, 9th April 2008

Site	Time (hours)	In situ (YSI)	TSS Sample	Secchi Depth	Comment
BG1	0957	✓	✓	✓	Background sites.
BG2	1003	✓	✓	✓	
BG3	1112	✓	✓	✓	
	1000				'*Volvox Asia*' commences dredging.
RD1	1013	✓	✓	✓	Drogue placed in dredge plume.
RD2	1019				Tracking of drogue path
RD3	1023	✓	✓	✓	
RD4	1030				
RD5	1035	✓	✓	✓	
RD6	1045				
RD7	1054				
RD8	1058	✓	✓	✓	
RD9	1107				
RD10	1127				Final drogue position at high water.

BG = Background, RD = Red Drogue

2.2 Statistical Analysis

2.2.1 Box and Whisker Plots

Box and whiskers plots were generated to examine patterns in turbidity within the water column on each monitoring event. Plots were prepared showing the variations in background and plume turbidities (at one or more drogues). Note that due to the location of dredging operations, some background measurements (located up-current of the dredger) could in some instances only be undertaken in shoal environments (where water depths <2m), which differed from the area downstream of the dredger where water depths were often deeper (up to 16m below datum). Box-plots of turbidity were generated using the statistical software package Statview Version 5.0.1.

The key statistics incorporated into box and whiskers plots are shown in Figure 2-6. These include:

- 90^{th} percentile: 90% of the values fall below this mark, while 10% of the values exceed this value
- 75^{th} percentile: 75% of the values fall below this mark, while 25% of the values exceed this value
- 50^{th} percentile: 50% of the values fall below this mark, while 50% of the values exceed this value
- 25^{th} percentile: 25% of the values fall below this mark, while 75% of the values exceed this value
- 10^{th} percentile: 10% of the values fall below this mark, while 90% of the values exceed this value
- Outliers: values that exceed the 90th percentile or are below the 10th percentile
- Median (50^{th} percentile): the value that corresponds to the middle case when all individual scores are arranged in order by score; the value that divides the cases into two halves of equal frequency.

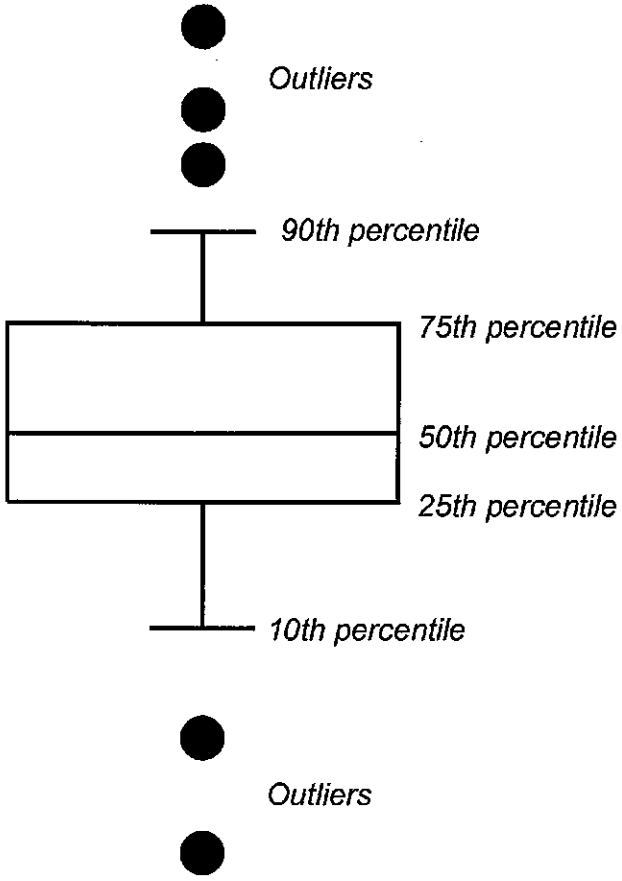


Figure 2-2 Key features of the box and whiskers plots generated in the present study

2.3 Overview – Sequence of Events

2.3.1 Co-ordination of Turbidity Monitoring Activities

Turbidity measurements were scheduled for fine calm weather conditions, thereby minimising potential windage influences on the drogues. BMT WBM personnel were kept informed of dredging progress and day-to-day movements of the '*Volvox Asia'* by liasing with the Van Oord Onshore Operations Manager, Mr. Wilco de Vrider and Brisbane Harbour Control (Maritime Safety QLD).

Brisbane Harbour Control and the master of the '*Volvox Asia'* described the timing and scheduling of dredging operations aboard '*Volvox Asia'* on each monitoring day *via* VHF marine radio.

2.3.2 Monitoring Event 1: 2nd April 2008

The first monitoring event was conducted during an ebbing tide on the 2nd April 2008, from the BMT WBM vessel *'Resolution II'.* The timetable of events at site was as follows:

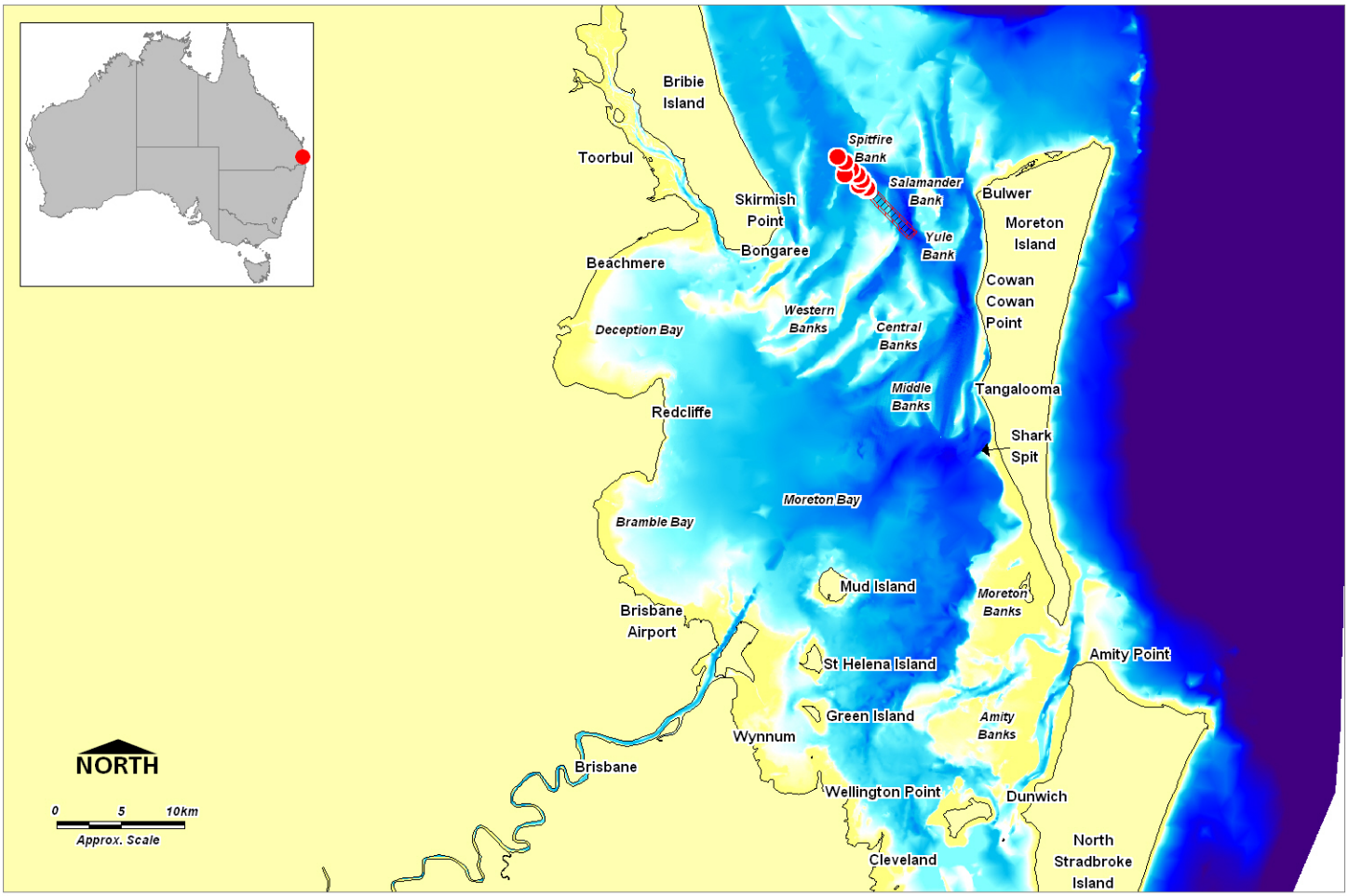
- The dredger, *'Volvox Asia'* had completed one dredging pass along the Spitfire Channel alignment area and was commencing the return dredge cycle at 1030hrs.

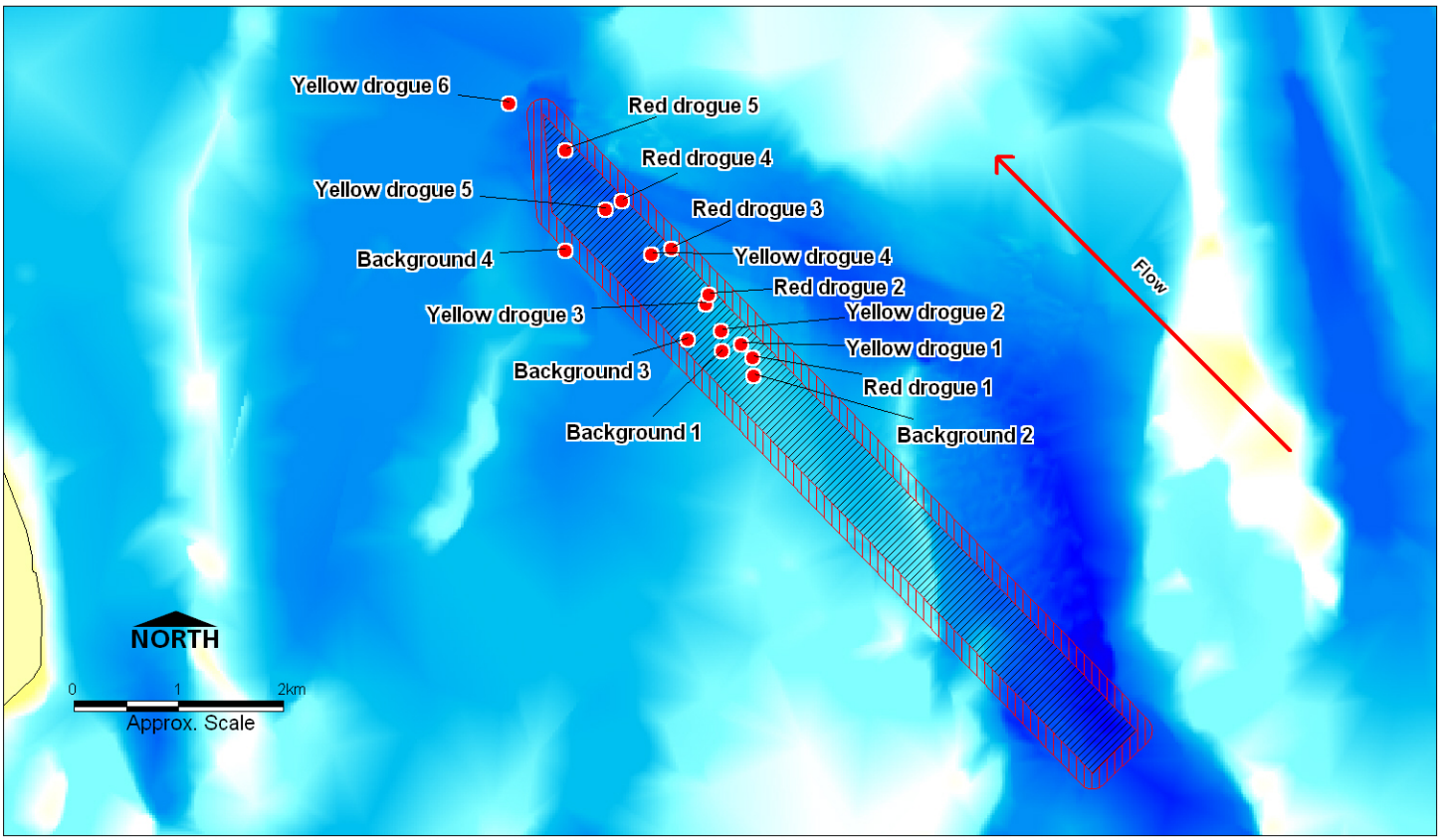
- Two background water quality samples and *in-situ* water quality measurements were collected at 1020hrs and 1036hrs respectively, up-current (south) of the Spitfire Channel realignment footprint.
- Shortly after the commencement of overflow from the dredger's hoppers at 1046hrs and 1057hrs, two drogues (yellow and red) were deployed into the turbid dredge plume to track its movement with the ebbing tide.
- Two additional background measurement of turbidity were taken, including one at site BG3 (and one at BG4, both of which were considered representative of background conditions at Western Banks unaffected by plumes of turbid water generated by dredging.
- Dredging was completed at approximately 1210hrs at which time the '*Volvox Asia'* returned to the Port of Brisbane pump-out facility, exiting the Spitfire Channel realignment area to the south *via* Main Channel.
- Following the cessation of dredging, BMT WBM personnel continued to track the drogues (and turbid plume) until slack tide at low water (approximately 1135hrs), resulting in a monitoring period of approximately two hours.

2.3.3 Monitoring Event II: 9th April 2008

The second monitoring event was conducted during a flooding tide on the 9th April 2008, also from the BMT WBM vessel *'Resolution II'*. The timetable of events at site during the second round of monitoring was as follows:

- Between 0957 and 1112 hours, water quality samples and *in-situ* water quality measurements were collected at three sites immediately up-current (north) of the Spitfire Channel realignment footprint (BG1, 2 and 3).
- The dredging vessel *'Volvox Asia'* arrived at the Spitfire Bypass Channel site at 0950hrs and dredging commenced at 1000hrs.
- Shortly after the commencement of overflow from the dredger's hoppers at 1013hrs, a single drogue was placed into the turbid plume to track its movement with the flooding tide. (Note only a single drogue was deployed on this occasion since the Port of Brisbane dredger *'Brisbane'* was also operating in the Spitfire Channel realignment area at the time, which increased the potential risk of collision of a drogue with one, or other dredger.)
- The '*Volvox Asia'* made two passes of the Spitfire Channel realignment (refer to Appendix B) collecting a full load of dredged material by approximately 1050hrs. The vessel exited the channel realignment area *via* Main Channel shortly thereafter.
- The drogue was removed at 1127 hrs close to slack water (high tide). Turbidity measurements within the dredge plume were conducted for approximately one and a quarter hours on the flooding tide.





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Volvox Asia Dredge Monitoring Locations
Ebb Tide - 2nd April 2008

Figure: 2-3

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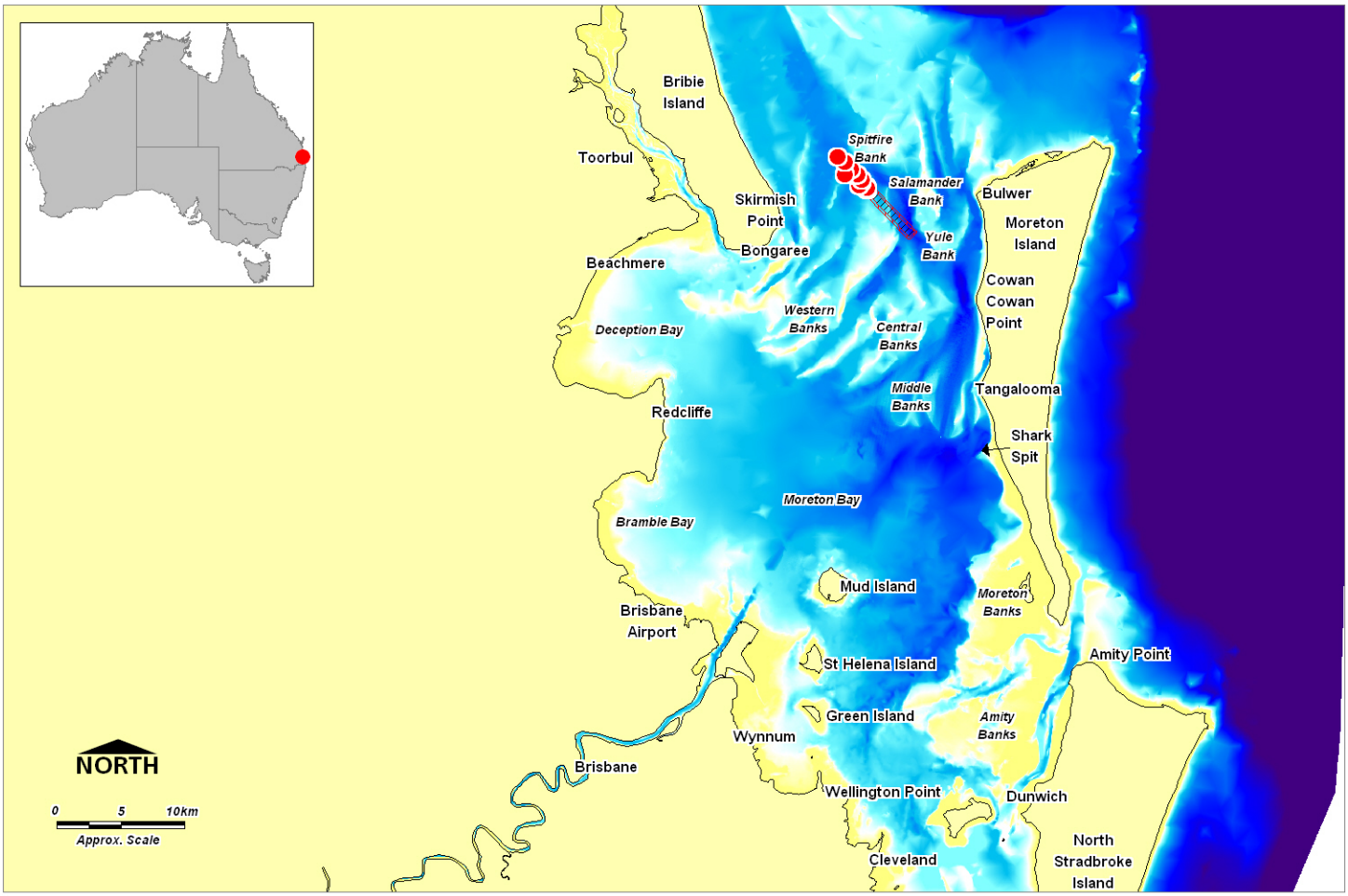

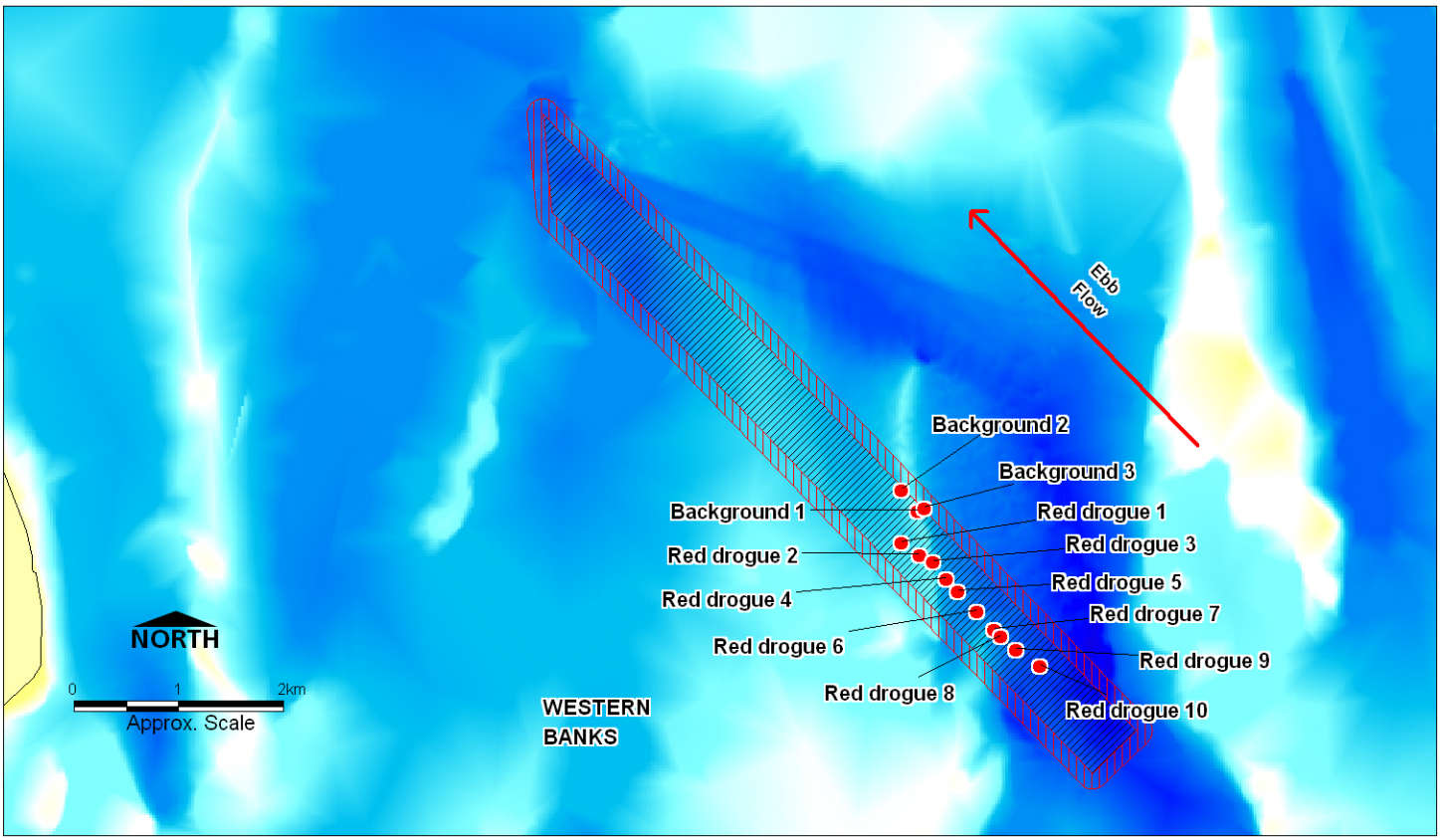

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Volvox Asia Dredge Monitoring Locations
Flood Tide - 9th April 2008

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Impact Zone

Re alignment Area

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2.4 Turbidity Criteria for Dredging at the Spitfire Channel Realignment Area

Turbidity based performance/compliance criteria for the dredging of the Spitfire Realignment Channel have been prepared by the Port of Brisbane Corporation in conjunction with the dredging contractor Van Oord. The criteria are embodied in the *'Volvox Asia'* Environmental Management Plan (EMP) for the Spitfire Channel realignment dredging, see Appendix A for details. The EMP stipulates that dredging plumes should not exceed the acceptable criteria outside the Spitfire extraction area ('impact zone'). The turbidity at the impact zone should not exceed the following turbidity concentration criteria:

- 10 NTU above the background, where the background concentrations are <25 NTU, or
- 25% above the background, where background concentrations are >25 NTU.

Note that the background water turbidity concentration measured in the vicinity of the Spitfire Channel realignment were lower than 25 NTU, therefore in this report compliance monitoring has been assessed against the '10 NTU' criterium.

Background turbidity is defined as the average of turbidity measurements taken within three monitoring stations that are representative of the local ambient condition, including factors such as sediment types, exposure, water depth and current directions.

The impact zone is defined as the area between 50 and 150m beyond the boundary of the dredging footprint (refer to Figure 2-4), where turbidities greater than 10 NTU above background are not acceptable. The impact zone is the shaded area shown in Figure 2-3 and Figure 2-4, situated between 50 and 150m from the Spitfire Channel realignment dredged area footprint.

3 RESULTS AND DISCUSSION

3.1 Compliance with Turbidity Criterion

3.1.1 Monitoring Event 1: Ebb Tide - 2nd April 2008

Given the time varying nature of the depth of water, the turbidity measurements are illustrated in Figure 3-1 at a standardised depth of 2m during the ebbing tide. Background turbidity measurements taken before the commencement of dredging ranged between 1 and 2.5 NTU. Background turbidity measurements following the conclusion of dredging and close to low water ranged between 1.7 and 3.2 NTU. As discussed, the turbidity compliance criterion states that turbidity must be within 10 NTU of the range of background turbidity values, beyond 150 metres of the Spitfire Channel Realignment dredge footprint. Therefore for the purposes of comparison, a turbidity compliance criterion of 11 to 12.5 NTU beyond the impact zone was adopted, which is based upon the lowest of background turbidity values. The use of the lowest background value serviced the most conservative scenario.

The turbid plume of water generated by the *'Volvox Asia'* during monitoring event 1 did not exceed this turbidity criterion, either within or beyond the impact zone.

Key patterns in the turbidity measurements at a depth of 2m for each drogue were as follows:

- Red drogue: Within the dredging plume at a short distance from the dredger (site RD1) the measured turbidity was 5 NTU. The turbidity declined to 4 NTU at site RD3, then further decreased to 3.6 NTU at site RD5.
- Yellow drogue: Turbidity was 6.1 NTU at site YD1 (immediately astern of the dredger) which reduced to approximately 4 NTU at site YD2. At site YD4 and beyond (sites YD5 and YD6), the measured turbidity was within the range of background conditions.
- The measured turbidity remained somewhat higher in that part of the dredge plume identified by the red drogue (compared with the yellow drogue). It was unclear why this was so but may have been associated with the initial plume extent, since the initial and subsequent plume extents were noticeably larger at the red drogue.

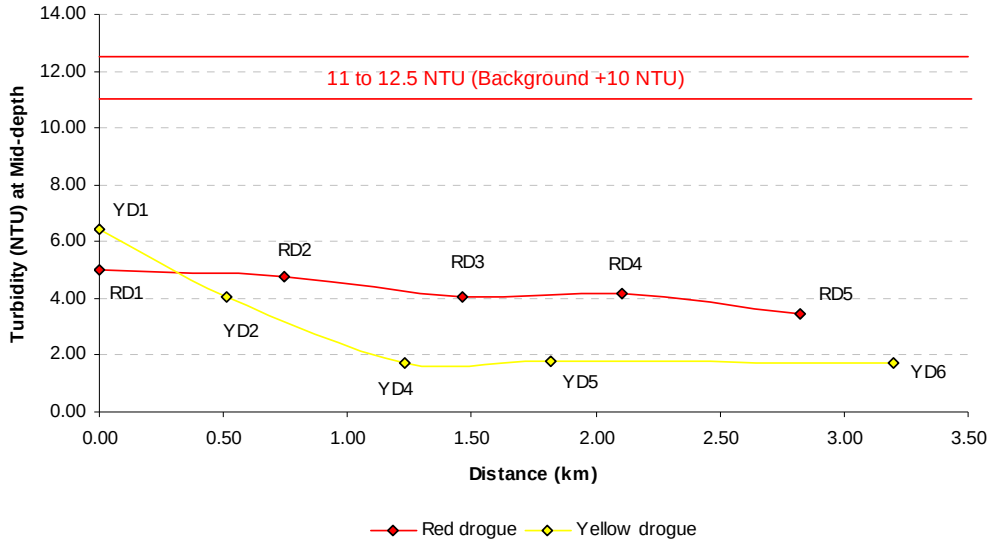


Figure 3-1 Dredge plume turbidity (NTU) at a depth of 2m with distance from the drogue release point. Measurements relate to the red and yellow drogue runs, Monitoring Event *1*.

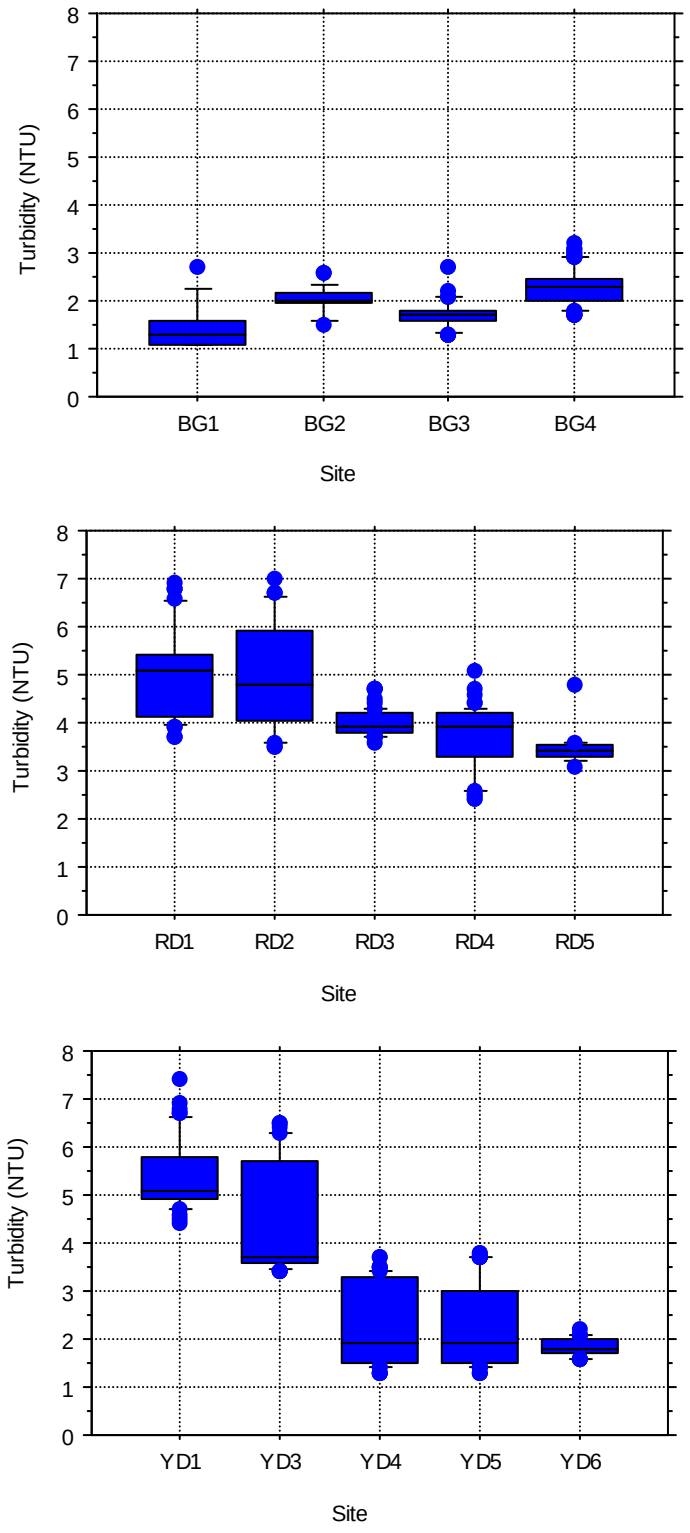


Figure 3-2 Box and whisker plots of *in situ* turbidity measurements (through the water column) taken at discrete points up-current of dredging (BG) and within the turbid dredge plume (RD and YD) generated by 'Volvox Asia' on 2 April 2008 at Western Banks, northern Moreton Bay

Box and whisker plots (Figure 3-2) show variations in turbidity among sites and variation in turbidity within sites (i.e. among depths). The key patterns illustrated in Figure 3-2 can be summarised as follows:

- Median background turbidity ranged between approximately 1.2 - 2.5 NTU;
- Turbidity tended to be somewhat variable within sites initially, but became more homogenous as the plume degraded. For example, the inter-quartile turbidity range was comparatively large (2NTU) immediately after passage of the dredger, but became progressively less variable with time and distance from dredger.

3.1.2 Monitoring Event 2: Flood Tide - 9th April 2008

The median background turbidity measurements ranged from 1 to 2 NTU during the flood tide monitoring event on the 9th April 2008. The criteria developed for dredging by *'Volvox Asia'* at Western Banks states that turbidity must be within 10 NTU of background turbidity values, beyond 150 metres of the Spitfire Channel Realignment dredge footprint. Therefore the adopted turbidity criterion was no higher than 11 to 12 NTU beyond the impact zone on this date.

The turbid plume of water generated by the *'Volvox Asia'* during monitoring event 2 did not exceed the turbidity criterion, beyond the impact zone. The turbidity measured within the dredge plume did not exceed the adopted turbidity criterion (background plus 10 NTU), or exceed a maximum of 10NTU, either within or beyond the impact zone.

Key patterns in the turbidity measurements at mid water depths for each drogue were as follows:

- Red drogue: The turbidity (at 2m depth) was 6.4 NTU at site RD1, close to the dredger. Whilst the turbidity generally declined at distances and time away from the dredger: (- 3.3 NTU at site RD3), there was a slight increase in turbidity measured at site RD5 (3.7 NTU) before the turbidity reduced to 3.1 NTU at site RD8 (Figure 3-3).

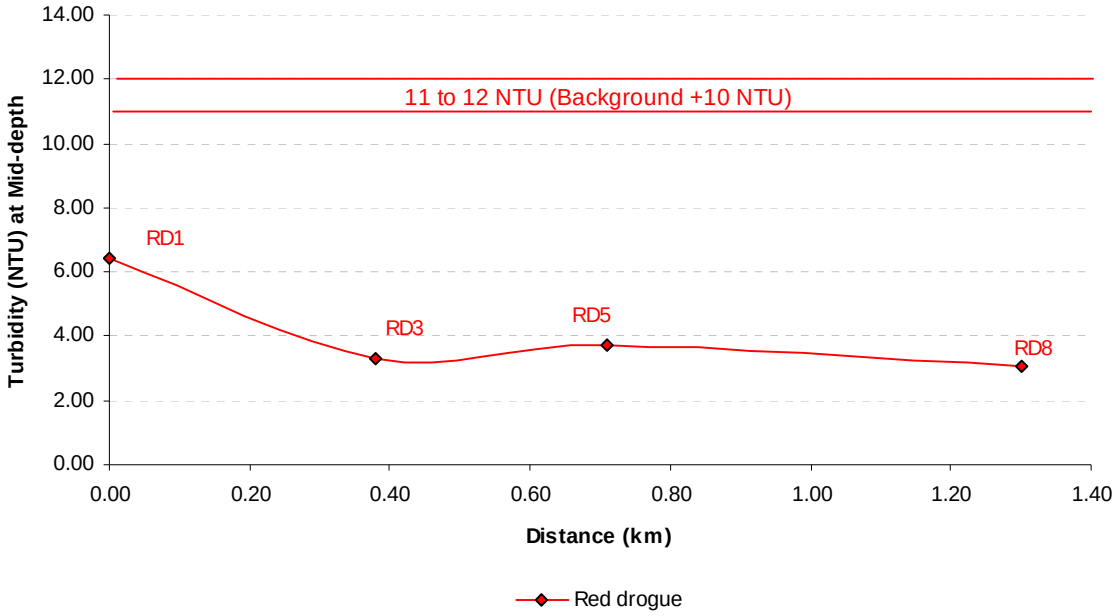


Figure 3-3 Dredge plume turbidity (NTU) at a depth of 2m with distance from the drogue release point. Measurements relate to the red drogue run, monitoring event *2*

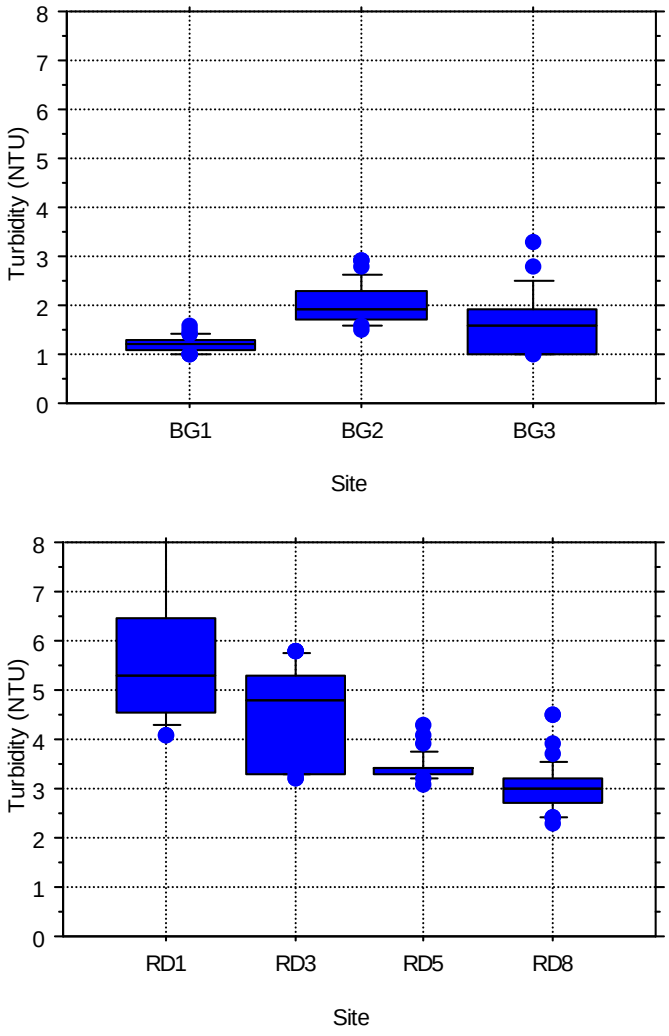


Figure 3-4 Box and whisker plot of *in-situ* turbidity measurements (through the water column) taken at discrete points up-current of dredging (BG) and within the turbid dredge plume (RD) generated by dredger 'Volvox Asia' on 9 April 2008 at Western Banks, northern Moreton Bay

The key patterns illustrated in Figure 3-4 can be summarised as follows:

- Median background turbidity ranged between approximately 1.2 and 2.0 NTU;
- In contrast to the plume turbidity measurements at a depth of 2m (Figure 3-3), the box and whiskers plot illustrates a steady decline in the plume turbidity with time and distance from point of initial plume generation.
- It also shows less variation in the plume turbidity with time and distance.

3.2 Turbidity (NTU) versus Total Suspended Solids

Linear regression analysis was undertaken to determine the nature of the relationship between the measured turbidity (NTU) and the Total Suspended Solids (TSS) concentration (mg/L) as determined by gravimetric analysis of collected water samples. The results for monitoring events 1 and 2 are shown in Figure 3-5 and Figure 3-6 respectively. Appendix B provides a summary of the regression analysis statistics.

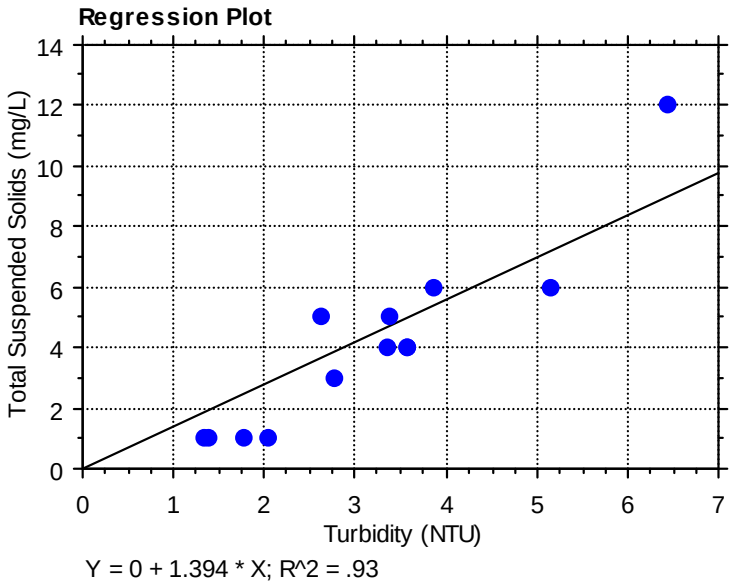


Figure 3-5 Pearson Product Moment Correlation for Turbidity (NTU) and Total Suspended Solids (TSS mg/L) - Ebb tide, 2nd April 2008 at Western Banks, northern Moreton Bay

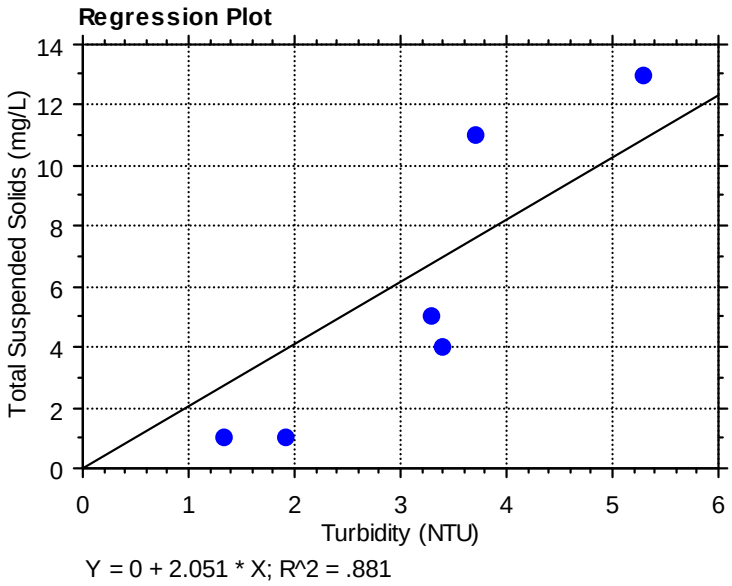


Figure 3-6 Pearson Product Moment Correlation for Turbidity (NTU) and Total Suspended Solids (TSS mg/L) – Flood tide, 9th April 2008 at Western Banks, northern Moreton Bay

In each instance the regression analyses indicated that over 88% of the variation in turbidity was associated with changes in TSS, and these relationships were statistically significant ($p<0.01$). This value is similar to that previously reported in the northern Moreton Bay region (78%) (BMT WBM 2006). The derived relationship for 2008 suggests that TSS concentrations (mg/L) in the dredge plume were approximately 1.4 times the measured turbidity (NTU). In comparison, TSS in 2006 was approximately 1.6 times than the recorded turbidity concentrations. The similarity between these values suggest that turbidity measures could provide valuable estimates TSS concentrations in future monitoring surveys.

3.3 Other Notable Observations

It is notable that given the current depth of the channel realignment area, the ebb and flood tide currents now appear to set in the direction of the newly formed channel (that is, in a north-westerly or south-easterly flow direction respectively). Flow measurements conducted previously (before the dredging project began) in the vicinity of the channel realignment area (WBM, 1998), suggest that the ebb and flood tidal flows were generally directed to the north and south respectively in the vicinity of Western Banks. It is likely that this change in current direction is a localised phenomena occurring in the vicinity of the dredged channel in response to the improved conveyance offered by the channel, compared with the previously shallow and restrictive path for water flows to and from Main Channel.

4 CONCLUSIONS

Key findings of this study are as follows:

- Background water turbidity values measured up-current of dredging were low during both ebb and flood tide monitoring events, typically ranging between 1 and 3 NTU (refer to Figure 3-2 and Figure 3-4). The corresponding background surface water clarities measured by Secchi disc were approximately 3.0-3.5m during the monitoring event 1 on the ebb tide and approximately 4.0-4.3m during monitoring event 2 on the flood tide. The Total Suspended Solids (TSS) concentrations for all background water samples determined by QLD Health Forensic and Scientific Services Laboratory were 1mg/L.
- Given the low background water turbidities up-current of the Spitfire realignment area (water turbidities less than 25NTU), the applicable turbidity compliance criterion for the dredging works undertaken by 'Volvox Asia' was no exceedance of the background turbidity plus 10NTU, beyond the defined impact zone.
- The tracks of the turbid water plumes generated by the 'Volvox Asia' (as indicated by the drogue movements) were mainly contained within the dredged footprint of the Spitfire Channel realignment area on each monitoring event (both ebb and flood tides) (refer to Figure 2-3 and Figure 2-4). Notwithstanding the above, dredging by '*Volvox Asia'* did not result in exceedance of the water turbidity compliance criterion (background plus 10NTU) within the designated dredging footprint or the impact zone during either monitoring event (ebb or flood tide).
- Most importantly, dredging of sand at the Spitfire Channel realignment area by '*Volvox Asia'* did not result in exceedance of the water turbidity compliance criterion (background plus 10NTU) beyond the designated impact zone during either monitoring event (ebb or flood tide).
- Plume turbidities reduced with time and distance from the dredging area such that measured turbidities within the plume were close to (though still above) the background range of measured turbidities after 1.25 to 2 hours and plume travel distances between 3.0km (ebb tide) and 1.5km (flood tide).
- There was a statistically significant correlation between the measured plume turbidity and the total suspended solids (TSS) concentrations within the turbid dredge plume. The TSS concentrations (mg/L) were approximately 1.4 to 2 times the measured turbidity (NTU), depending upon the state of the tide. Given that a larger number of water samples were collected and analysed from the ebb tide monitoring event number 1 (n = 13, on the ebb tide) this relationship is likely to be more reliable. The derived relationship suggests that TSS concentrations (mg/L) in the dredge plume are approximately 1.4 times the measured turbidity (NTU) for the sandy sediments in the Spitfire Channel realignment area.
- It is notable that given the current depth of the channel realignment area, the ebb and flood tide currents now appear to set in the direction of the newly formed channel (that is, in a north-westerly or south-easterly flow direction respectively). It is likely that this change in current direction is a localised phenomena occurring in the vicinity of the dredged channel in response to the improved conveyance offered by the channel.

APPENDIX A: PBC TURBIDITY CRITERIA FOR SPITFIRE CHANNEL REALIGNMENT

Element	Turbidity Management
Objective/Target	To ensure turbid plumes generated by the operation of the Volvox Asia are minimised.
Actions	• Ensure dredging and material relocation is undertaken within the approved areas only, by reference to electronic navigation aids and visual marks as required. • Within the practicalities of the vessel, minimise the generation of plumes by control of the discharge system. • Observe all site-specific requirements, which may influence dredging times such as tides and winds.
Performance Indicators ***Criteria for Spitfire Extraction Area***	***Daily Monitoring*** All dredging operations within the approved extraction area ***Project Monitoring*** No plumes of turbid waters exceeding acceptable criteria to be generated outside the approved extraction area. ***Criteria for areas within Port Limits*** Turbidity at the impact site is not to exceed: • 10 NTU above background where background levels are <25NTU; or • 25% above background where background levels are >25NTU The **impact site** is defined as any point between 50m and 150m outside the extraction area (see Drawing 112247 Appendix A) directly impacted by the operation of the *Volvox Asia.* A number of locations may be monitored within the impact site to ensure a representative sample is taken. Impacted sites will generally be determined by releasing drogues within the plume of the operating *Volvox Asia* and tracking until they intersect the boundary of the extraction site. **Background** is defined as an average of measurements of turbidity representative of local ambient conditions, recognising factors such as sediment type, exposure, water depth and current direction at the impact site. To be representative of the impact site without the influence of the dredging activities, a minimum of three background sites will be assessed within 400m directly up-current of the Volvox Asia. The appropriately qualified and experienced individual undertaking the monitoring will determine measurement locations within this 400m zone. These sites will be varied based on experience, but will generally be located in areas representative of the

Element	Turbidity Management
	depth range within the zone (i.e. deepest, mid depth and shallow site will be selected). **Measurements** are to be taken approximately top, mid and bottom depth within the water column. Spot measurements are an average of a minimum of 20 measurements taken over at least a 1 min period.
Monitoring	Daily – Review of vessel dredging and placement tracks against approved area boundaries. Annual – Plume assessment by appropriately qualified and experienced professionals.
Reporting	Reporting of exceptions to Vessel Master .
Corrective Action	Vessel Master to investigate reason for exception and take appropriate action.
Term	During all operations.
Responsibility	Management and operation of on-board systems is by the Vessel Master.

APPENDIX B: REGRESSION ANALYSIS STATISTICS

Monitoring Event I: 2nd April 2008

Regression Summary
Total Suspended Solids (mg/L) vs. Turbidity (NTU)

Count	13
Num. Missing	0
R	.964
R Squared	.930
Adjusted R Squared	.924
RMS Residual	1.384

ANOVA Table
Total Suspended Solids (mg/L) vs. Turbidity (NTU)

	DF	Sum of Squares	Mean Square	F-Value	P-Value
Regression	1	304.024	304.024	158.784	<.0001
Residual	12	22.976	1.915		
Total	13	327.000			

Regression Coefficients
Total Suspended Solids (mg/L) vs. Turbidity (NTU)

	Coefficient	Std. Error	Std. Coeff.	t-Value	P-Value
Turbidity (NTU)	1.394	.111	.672	12.601	<.0001

Monitoring Event II: 9th April 2008

Regression Summary
Total Suspended Solids (mg/L) vs. Turbidity (NTU)

Count	6
Num. Missing	0
R	.938
R Squared	.881
Adjusted R Squared	.857
RMS Residual	2.821

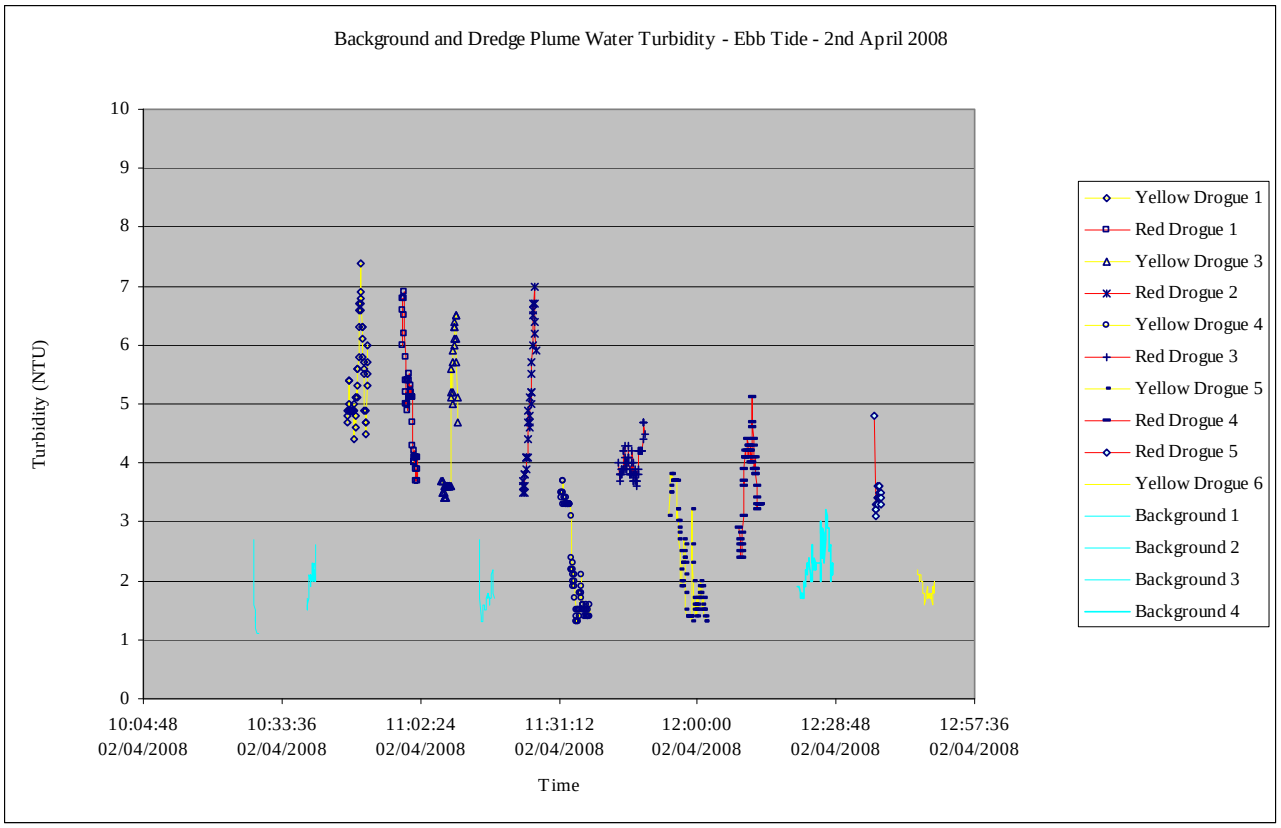
ANOVA Table
Total Suspended Solids (mg/L) vs. Turbidity (NTU)

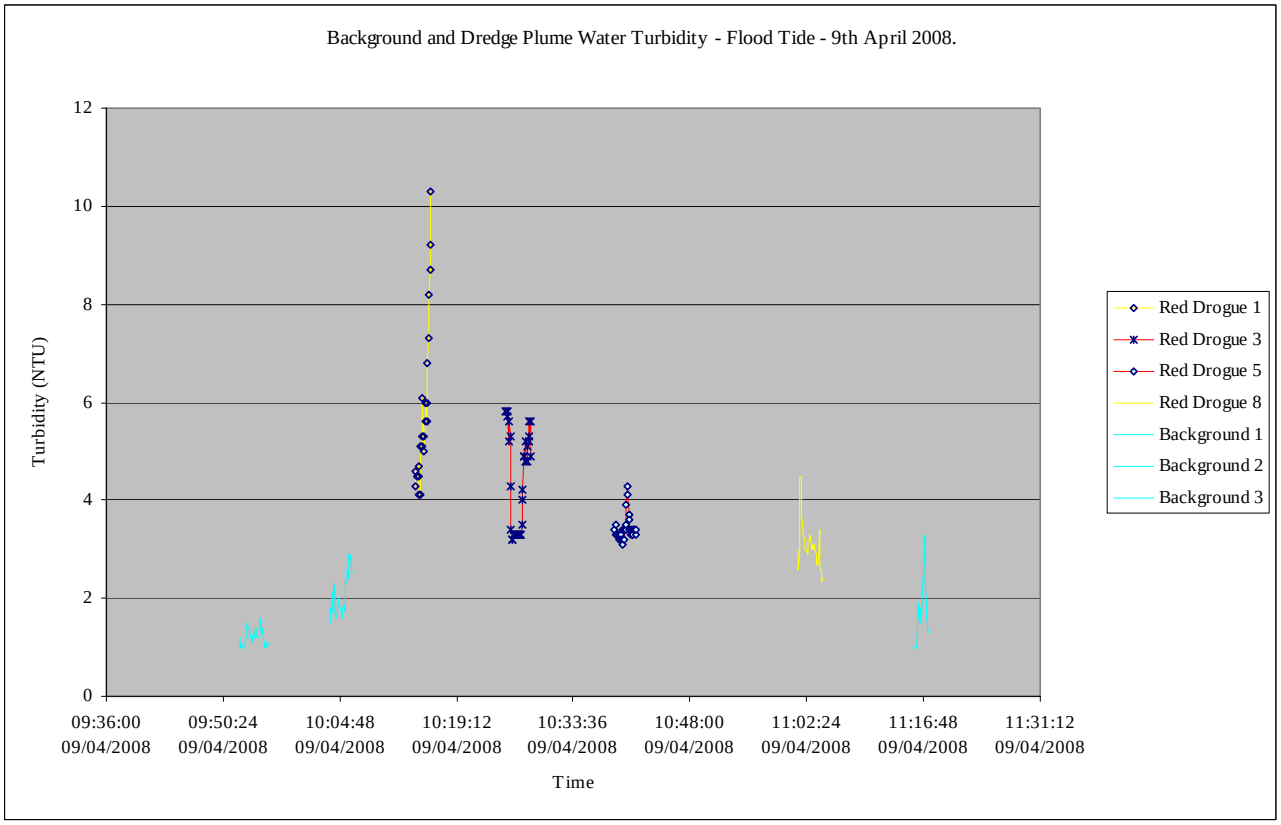
	DF	Sum of Squares	Mean Square	F-Value	P-Value
Regression	1	293.212	293.212	36.847	.0018
Residual	5	39.788	7.958		
Total	6	333.000			

Regression Coefficients
Total Suspended Solids (mg/L) vs. Turbidity (NTU)

	Coefficient	Std. Error	Std. Coeff.	t-Value	P-Value
Turbidity (NTU)	2.051	.338	.564	6.070	.0018

APPENDIX C: RAW TURBIDITY PROFILING RESULTS





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