Cape Lambert Port B

MARINE WATER QUALITY BASELINE MONITORING REPORT

- Revision 1
- 28 July 2009

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SKM derived the data in this report primarily from the data collected on behalf of the Client, and supplementary data. The passage of time, manifestation of latent conditions or impacts of future events may require further exploration at the site and subsequent data analysis, and re-evaluation of the findings, observations and conclusions expressed in this report.

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List of Abbreviations

BLR	Bells Reef
BPPH	Benthic Primary Producer Habitat
BTR	Boat Rock
BZI	Bezout Island
BZR	Bezout Rock
Port A	Cape Lambert 85 Mtpa development
CLW	Cape Lambert West
DEC	Department of Environment and Conservation
DIE	Dixon Island East
DLI	Delambre Island
DSDMP	Dredge Spoil Disposal Management Plan
HAT	Hat Rock
MAN	Mangrove Point
MDR	Middle Reef
NTU	Nephelometric Turbidity Unit
PLR	Pelican Rock
PAR	Photosynthetically Active Radiation
PWR STN	Power Station
QAQC	Quality Assurance, Quality Control
SMSB	Samson Beach
SKM	Sinclair Knight Merz

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Executive Summary

Water quality monitoring to collect baseline turbidity, light, sediment and temperature data has been undertaken in preparation for the proposed Cape Lambert Port B development dredging at Cape Lambert in the north-west of Western Australia. The Cape Lambert region is an exposed, open water environment and the water quality observed at these shallow sites can be considered typical of areas where local conditions are largely influenced by the macro-tidal environment and prevailing winds which promote mixing and suspension of sediment.

This report provides a summary of the water quality at the 13 monitoring locations around Cape Lambert for the entire monitoring period from 21 February 2008 to 28 May 2009. Baseline data was also collected for the previous Cape Lambert Port Upgrade 85 Mtpa (Port A) monitoring study from 7 February 2007 to 29 July 2007, this period excludes dredge activity. The Port A baseline data was investigated however due to the differences seen between the Troll loggers and the Port B loggers, which excluded them from meaningful comparisons, they were not included in the report. The data is presented in both tabular and graphical form summarising all the data collected since the monitoring sites were first established.

The Cape Lambert Port B baseline water quality monitoring program aimed to collect and document a comprehensive baseline data set that captured the natural range of water quality conditions for over a period of more than 12 months prior to dredging. Turbidity, temperature, light, particle size distribution (PSD) and sedimentation in the Cape Lambert region were investigated. This baseline data set forms part of the water quality and coral health monitoring program that is part of the Dredging and Spoil Disposal Management Plan (DSDMP). The data will be used to develop site specific water quality thresholds to be used as management triggers.

Spatial variation between monitoring sites and temporal variation over the monitoring period occurred across all of the parameters measured as part of the baseline water quality monitoring program. The turbidity measured indicated spatial similarities amongst nearshore sites and between those situated further offshore, sites protected from prevailing east and west winds, and sites in close geographical locations. Temporal variation was observed between different seasons and over short-lived weather events.

The highest light climates were recorded at the shallower sites, with the offshore sites recording less light total photosynthetically active radiation (PAR) per day. The deeper offshore sites recorded a smaller range and less fluctuation in daily light than the shallower nearshore sites. A strong trend was observed from the baseline turbidity and light data measured during the monitoring period indicating the influence of turbidity on the light climates at the sites. The turbidity at the monitoring sites had a direct impact on the light climate at the monitoring sites. The time of year and hence the angle of the sun, cloud cover, sea state and light scattering caused by material

dissolved and suspended in the water column are all key factors affecting the light climate at the sites.

The current baseline PSD results show that silt and very fine sand is present in the water column however this material represents only a small percentage of the sediments that are deposited and retained on the underlying substrate (reef). This indicates that the oceanographic conditions at the monitoring sites either prevent this fine material from being deposited on the reef or if the material is deposited it is re-suspended relatively quickly. The implication of this may be that sediments transported to the monitoring sites from dredging operations could follow a similar process with minimal net deposition. An increase in net deposition could be monitored by measuring increases in the percentage of fine sediments on the reef.

Generally low sedimentation rates were recorded at sites further offshore, with high sedimentation rates experienced during the winter and summer months. The spatial and temporal variation between adjacent sites indicates sedimentation is affected by local oceanographic conditions. The local physical processes such as large tidal currents and wind/wave patterns are likely to cause continual re-suspension of sediments throughout the area.

The water temperature at nearshore sites recorded a large range and fluctuation in temperatures while the offshore sites had a moderating effect on the water temperatures recorded. The effect of climate had the greatest influence on the water temperatures recorded leading to seasonal and short-term variations. Elevated water temperatures during the baseline monitoring period preceded coral bleaching at some of the monitoring sites and this was followed by survival and recovery.

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1. Introduction

The proposed Cape Lambert Port B development (the Port B development) will involve a dredging and spoil disposal program that requires the removal of up to 16 Mm^3 of benthic material. The dredging and spoil disposal program may potentially influence water quality in close proximity to the Port B development. The aim of this investigation is to collect a baseline water quality data set to be used for comparison against water quality to be monitored during dredging.

Turbidity and temperature loggers were deployed at 13 reef sites in the vicinity of Cape Lambert between February and March 2008 to collect baseline data on water quality prior to the commencement of the Port B development dredging and spoil disposal program. This comprehensive water quality monitoring program constitutes part of an overarching baseline monitoring program described in the Port B Dredging and Spoil Disposal Management Plan (DSDMP; SKM 2008a).

This report represents the complete baseline water quality monitoring program, aimed at documenting the baseline water quality data collected for the proposed Port B development. The data set available for use in this report is comprised of two sets of data: the first, baseline data collected for the Cape Lambert Port B development from 21 February 2008 to 28 May 2009; and the second, baseline data collected as part of the recent Cape Lambert port upgrade (Port A) monitoring study from 7 February 2007 to 29 July 2007. The baseline data excludes periods of dredge activity and influence, the dredge monitoring period went from 30 July 2007 to 08 January 2008.

This report describes turbidity in Nephelometric Turbidity Units (NTU) and water temperature in degrees Celsius (°C) measured during the baseline monitoring period. In addition, the light climate in Photosynthetically Active Radiation (PAR) measured in (µmol/m^2/day), sedimentation rates (mg/cm^2/d) and the particle size distribution (PSD) of sediments at the monitoring sites are examined.

1.1. Aims

The primary aim of the Port B development baseline water quality monitoring program was to collect and record a comprehensive baseline data set that captured the natural range of water quality conditions for over a period of more than 12 months prior to dredging. The data would be used to develop site specific water quality thresholds that would be used as trigger values as part of the DSDMP water quality and coral health monitoring.

1.2. Report Structure

This report is structured as follows:

- Section 1: describes the aims of the baseline monitoring program;
- Section 2: describes the methods and materials used to collect water quality data;
- Section 3: provides the results and interpretation of the monitoring program;
- Section 4: discussion of water quality parameters and the thresholds determined by the data;
- Section 5: provides conclusion;
- Appendix A: provides details and an example of SKMs quality assurance, quality control (QAQC) programme implemented with this programme;
- Appendix B: logger comparison; and
- Appendix C: tropical cyclone events.

2. Methods and Materials

2.1. Introduction

This section provides an overview of the methods and materials used to collect baseline water quality data. In addition, it provides specific details about the sites monitored, as well as data management, analysis and interpretation.

2.2. Sampling Locations

The water quality monitoring sites were selected to encompass a wide area around the Cape Lambert Port with the potential to be affected by a dredge program. The monitoring sites were selected both on the basis of previous modelling (Port A) and upon the application of professional and local knowledge of the area. New sites were established for the purpose of this study, and these along with existing water quality and coral monitoring sites from the Port A monitoring study, provide a set of 13 reef monitoring sites in the vicinity of Cape Lambert. The water quality monitoring sites are listed below in **Table 2-1** and illustrated in **Figure 2-1**.

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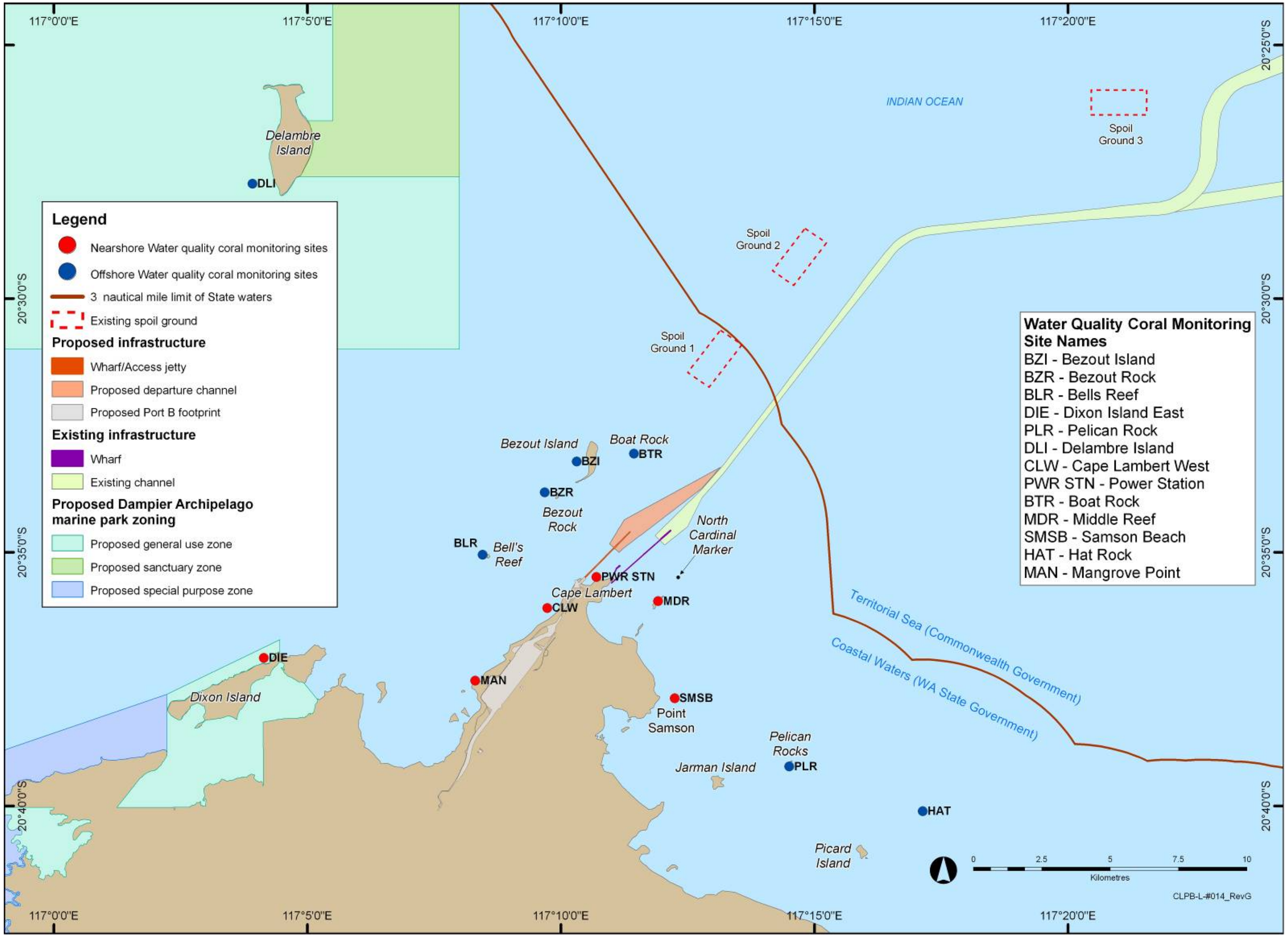
- **Table 2-1 Water quality monitoring sites (GDA94 datum)**

Site Name	Site Code	Latitude	Longitude	Water depth logger was situated (m)	Site Characteristics*	Parameters measured**
Bells Reef	BLR *	20°35.052'S	117°08.456'E	3	Rocky outcrop, nearshore, West	NTU, Temperature, Sedimentation, PSD
Boat Rock	BTR	20°33.750'S	117°10.621'E	9	Rocky outcrop, strong currents, West	NTU, Temperature, Sedimentation, PSD
Bezout Island	BZI *	20°33.213'S	117°10.311'E	3	Fringing island reef, West	NTU, Temperature, Light, Sedimentation, PSD
Bezout Rock	BZR *	20°33.823'S	117°09.682'E	4	Rocky outcrop, nearshore, West	NTU, Temperature, Sedimentation, PSD
Cape Lambert West	CLW *	20°36.090'S	117°09.756'E	4	Nearshore, West	NTU, Temperature, Light, Sedimentation, PSD
Dixon Island East	DIE *	20°37.084'S	117°04.143'E	8	Fringing island reef, West	NTU, Temperature, Sedimentation, PSD
Delambre Island	DLI *	20°27.736'S	117°03.916'E	9	Offshore fringing island reef, West	NTU, Temperature, Light, Sedimentation, PSD
Hat Rock	HAT	20°40.105'S	117°17.136'E	6	Rocky outcrop, East	NTU, Temperature, Light, Sedimentation, PSD
Mangrove Point	MAN	20°37.555'S	117°07.988'E	3	Nearshore, West	NTU, Temperature, Sedimentation, PSD
Middle Reef	MDR	20°35.817'S	117°11.862'E	5	Nearshore rock outcrop, East	NTU, Temperature, Light, Sedimentation, PSD
Pelican Rock	PLR	20°39.249'S	117°14.415'E	6	Rocky outcrop, East	NTU, Temperature, Light, Sedimentation, PSD
Power Station	PWR STN	20°35.440'S	117°10.685'E	6	Nearshore, West	NTU, Temperature, Sedimentation, PSD
Samson Beach	SMSB	20°37.337'S	117°11.890'E	4	Nearshore, East	NTU, Temperature, Sedimentation, PSD

Note: East and West refers to the site location relative to the existing Cape Lambert wharf, while * indicates sites used in the previous Cape Lambert Port Upgrade 85 Mtpa monitoring program. ** Light was the only parameter not measured at each monitoring site.



- **Figure 2-1 Water quality monitoring locations near Cape Lambert, Western Australia**

2.3. Sampling Rationale and Protocol

The sampling approach is consistent with that used during the Cape Lambert Port A dredging program. The period between water quality sampling trips aligns with the expected 14 days between coral monitoring surveys for the Cape Lambert Port B development dredging program. In addition, sampling routines have been kept to 14 days to limit the impact of biofouling on instrument performance.

The following water quality measurements were collected during the baseline monitoring:

- turbidity (NTU)
- temperature (ºC)
- light (µmol/m^2/day)
- sedimentation rates (mg/cm^2/d)
- particle size distribution

These parameters were selected to encompass a variety of factors which are known to be impacted by dredging activities and are relatively easily monitored, collected and interpreted. These parameters provide a way of monitoring the influence of dredging activities on the local environment.

Sampling was undertaken every fortnight, weather permitting, and the following procedures were used:

- loggers were retrieved by SKM divers on SCUBA
- data from the loggers were downloaded and data saved as text files
- photographs of the loggers were taken *in situ* prior and post retrieval, as well as on the surface to show their condition and degree of biofouling
- a QAQC sheet (**Appendix A**) was completed at the time of data download, this included a visual assessment of the weather conditions during the data collection period
- sediment traps were retrieved at the same time as the loggers and the samples were put into plastic sample jars to be shipped for analysis before the sediment traps were cleaned and re-deployed.

2.4. Instruments

The data obtained during this baseline study were collected using several different types of loggers. This includes both separate (and combined) turbidity and temperature loggers, and light loggers which measure the light climate.

The use of the instruments is summarised below.

2.4.1. Turbidity and Temperature Loggers

Turbidity and temperature data were collected as part of the Port B development water quality monitoring program from 21 February 2008 to 28 May 2009. In addition, baseline data collected during Port A monitoring from 7 February to 29 July 2007 were combined with the data collected for the Port B development. During this period, three types of turbidity loggers were used due to equipment malfunction and other problems experienced during monitoring:

- Troll 9500 (*Professional XP*) Multi Parameter Water Quality Unit (Troll)
- Analite NEP495 (Analite)
- ECO NTU-SB Wetlabs Turbidity Sensors (Wetlabs).

The first two of these loggers integrated a temperature sensor as well as a turbidity sensor; however, the Wetlabs logger required a separate temperature logger, the TidBit temperature logger.

The Troll loggers were used for the entire Port A baseline survey and subsequently replaced by Analite loggers deployed at the beginning of monitoring for the Port B development. This change in turbidity logger was due to technical difficulties (i.e. flooding of the instrument and data retrieval problems) and the amount of poor quality data (due to sensor drifting, fouling of the probe, faulty sensor wiper etc.) experienced during Port A monitoring.

At the start of Port B development monitoring program, Analite and Troll loggers were deployed simultaneously for a period of time to obtain a set of overlapping turbidity results for comparison purposes. Over time, the Analite loggers developed problems with data accuracy, where data was observed to plateau or reach the upper limit of the recording range. In December 2008 the Analite loggers were replaced by the Wetlabs turbidity loggers. Again, both loggers were deployed simultaneously for a period of time to obtain a set of concurrent turbidity data from the loggers for comparison (**Appendix B**).

Turbidity and temperature readings were recorded *in situ* every 30 minutes, 24 hours a day on the hour and half hour, during the baseline monitoring period. All turbidity data obtained during both the Port A and Port B development monitoring programs were reviewed immediately upon download and if necessary (i.e. poor quality, erroneous or missing data, and/or instrument damage) the instrument was returned for servicing and recalibration. A basic description of each type of logger is provided below:

- Troll 9500 (*Professional XP*) Multi-Parameter Water Quality Unit (Troll):

  This multi-parameter logger incorporates several parameters: XP ISE turbidity sensor, Delrin dissolved oxygen optical sensor, In-Situ pH sensor, and In-Situ marine grade (316) stainless temperature sensor; with a “Rugged Reader” control and data logging Pocket PC. These devices were calibrated by the supplier, EnviroEquip (Perth, Western Australia), prior to deployment.

- Analite NEP495 (Analite)

  The Analite turbidity logger is used to measure both turbidity and temperature with an ANALITE NEP495 turbidity probe. The download procedure utilises standard PC software to obtain the data. These loggers were calibrated by the supplier, McVan Instruments, prior to deployment.

- ECO NTU-SB Wetlabs Turbidity Sensors (Wetlabs)

  The Wetlabs turbidity logger uses the ECO NTU-SB backscatter turbidity sensor to solely measure turbidity. These loggers were calibrated by the supplier (Wetlabs) prior to deployment, in a formazin based standard which is directly proportional to the turbidity the logger measures in NTU. These calibration standards are applied to the data from each logger at the time of data download, through the specialised computer program.

- TidBit v2Temperature Loggers (TidBit)

  The TidBit temperature logger is designed to only record temperature. It can be downloaded *in situ* using a data shuttle to optically transfer data directly from the logger to the shuttle, before the shuttle is brought to the surface and downloaded using HOBOware ® Pro Software.

2.4.2. Light Loggers

ALEC light loggers, the COMPACT – LW model ALW-CMP, were used to measure the light climate. Light was not measured at all sites, loggers were deployed at four sites at any given time and six sites in total during the monitoring period (**Table 2-1**). These instruments record the data as photo quantum (counts/second), and this along with a date/time record and the sensor’s calibration coefficients are transferred with the measured data. These loggers were programmed to have a sampling interval which recorded the light climate *in situ* by taking ten photo quantum measurements for one second of time every 30 minutes, 24 hours a day, during the baseline monitoring period of the Port B development. The light data recorded during night time hours has a value of zero and no influence on the resulting light climate.

These photo quantum counts are averaged to obtain a mean reading for every half hour before transforming with the calibration coefficient, shown below, and multiplying by the immersion value (1.33) to obtain a measure of PAR.

$$PAR = (a_0 * counts + a_1) * I$$

Where: a_0 and a_1 are the calibration standards provided by the logger supplier
I is the immersion value as the calibration standards are performed in air rather than seawater.

This measure of PAR is then converted to daily light by summing all of the half hour PAR (µm/m^2/day) readings for each day then multiplying the value by the integration time (1800). The integration time is the number of seconds during the recording interval (60 * 30 = 1800), as stated above the instruments recorded on each half hour. This gave a measurement of the total PAR per day (µmoles/m^2/day) at the monitoring location.

2.4.3. Particle Size and Sedimentation

Sediment properties were examined throughout the monitoring period by examining both the sedimentation and particle size distribution at each monitoring location.

2.4.3.1. Particle Size Distribution

Particle size distribution was measured at all sites quarterly during the baseline monitoring program. Two methods of collecting sediment for particle size analysis were used: sediment cores were used to measure sediment particle size in surface sediments (0 to 10 cm) depth, and sediment traps which measure the sediment particle size of the suspended sediments which settle out of the water column.

Particle size distribution for each method of collection was determined using laser diffraction and wet sieving techniques, and analysed by CSIRO, Division of Minerals. These methods comply with the international standards (ISO 13320-1).

Sediment samples are manually sieved by wet screening sediments through 2000, 1000 and 500 microns (µm) sieves, while a subsample of the remaining sample was measured by laser diffraction using a Malvern Instruments Mastersizer MS2000 to measure the 0.02 µm to 500 µm size fraction. The representative sub-sample is dispersed in 1000 ppm sodium hexametaphosphate for 10 minutes before being homogenised and dispensed into the sample presentation chamber of the analyser. The optical properties of the particulate matter of the sample were set and the sample analysed using a single optical lens with two laser sources. This method provides two size ranges of data which the analyser software blended together to provide a size distribution from 0.02 µm to 500 µm.

The different size groups are classified into the following categories:

- **Table 2-2 Sediment size classifications**

Classification	Size (µm)
Other	2000 – 10000
Very coarse sand	1000 – 2000
Coarse sand	500 – 1000
Medium sand	100 – 500
Very fine sand	62 – 100
Silt	4 – 62
Clay	0 – 4

2.4.3.2. Sedimentation

Sedimentation was measured by deploying three cylindrical sediment traps (11.5 x 5.0 cm) at each water quality monitoring location. The sediment traps were capped upon collection and the contents transferred to sample bottles ensuring all material was transferred. These samples were analysed by CSIRO, Division of Minerals as indicated below.

The sample was filtered onto pre-weighed GF/C filter paper, which was then ashed in a furnace at 400 degrees Celsius (°C) and re-weighted to determine the total solids weight of the inorganic proportion of the sample (the loss in weight equivalent to the organic material lost during the ashing process was not assessed as part of this study). The weight of inorganic material was then converted into a rate of sedimentation using the area of the sediment trap and the number of days since the sample locations was previously sampled by divers on the previous fortnightly sampling trip.

2.5. Data Management

The data collected over the entire monitoring period were entered into a master spreadsheet for each parameter measured. Turbidity data were then smoothed as appropriate using an equation that takes the average of two adjacent readings when the value in question is greater than two times either of the adjacent values.

All data were then visually assessed for typical and anomalous patterns, such as isolated major peak values, values exceeding the upper limit of the detectable range of the logger or when there was evidence of fouling by marine organisms. If these patterns were identified in the smoothed data, the unreliable data were removed.

2.6. Data Interpretation

Separate graphs are provided for both turbidity and temperature in **Section 3.2** and **Section 3.3**. Each data point in these figures represents a daily median value. The temperature graphs in **Section 3.3** represent a rolling 14 day median calculated from daily consecutive data points (every 14 days of data). In addition, the turbidity and temperature data recoded at each monitoring location is summarised and presented in tabular form.

2.7. Remote Sensing Survey

A supplementary study that captured satellite images of surface water quality conditions in the Cape Lambert area was undertaken. The survey aimed to investigate the potential to use satellite images using MODIS imagery to measure temporal and spatial variation in turbidity around Cape Lambert for the proposed Port B development. The survey documents the use of satellite imagery to assess the turbidity in the study area, while also making comparison to turbidity recorded as part of the Port B water quality monitoring program. This survey is provided in **Appendix D.**

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3. Results and Interpretation

3.1. Introduction

Summaries of the data in tabular and graphical form, and trends of all data collected since the establishment of the baseline water quality monitoring program, are presented within this section.

For the purpose of this report, comparisons are made between nearshore and offshore sites, where nearshore sites are defined as within 2.5 km of the mainland, while offshore sites are any site greater than 2.5 km from the mainland. This separation of site was determined by trends seen in the data; the sites defined as nearshore displayed similar trends and patterns within the data, this pattern was also evident in the sites classified as offshore.

3.2. Turbidity

The turbidity recorded during the baseline water quality monitoring program was spatially variable between monitoring sites (**Table 3-1**) and temporally variable over the monitoring period (**Figure 3-1** to **Figure 3-13**). **Figure 3-1** to **Figure 3-13** displays both the median turbidity and temperature (determined from 1 day periods) recorded at each site during the baseline monitoring period; on each of these graphs, tropical cyclones are indicated by a black line with the cyclone name above it, while the Analite to Wetlabs changeover is indicated in green. Monitoring site MAN recorded the highest median turbidity across the baseline period (2.4 NTU), with the lowest median turbidity recorded at DLI (0.7 NTU) (**Table 3-1**). The turbidity levels at nearshore monitoring sites were consistently higher than the monitoring sites located further offshore (minimum of 2.5km), as shown in **Figure 3-1** to **Figure 3-13**.

The exceptions to this were sites HAT and PLR which had the highest turbidity of the offshore sites. These two sites are located in the vicinity of major drainage creeks in the area and are affected by sediment loads discharged during large rainfall events. The median turbidity increased or remained high at PLR and HAT from the dry season to the wet season (**Table 3-2**), which may be a result of storms and cyclones being more prevalent. An increase in turbidity at the majority of sites from the dry season to the wet season was not recorded, and is a likely result of two different types of loggers being used during the monitoring periods. The Analite turbidity loggers consistently recorded higher turbidity at the same time and location than the Wetlabs loggers (**Appendix B**).

Turbidity peaks and periods of elevated turbidity regularly occurred during increased wind speeds. The nearshore monitoring sites were observed to have a greater influence from periods of increased wind speeds than the offshore sites. Spatial variation was observed between monitoring sites protected from different wind directions. Monitoring sites exposed to the prevailing winds at different times of the year experienced higher turbidity than the protected sites. During the month

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of April and the start of May 2009 easterly winds were the prevailing wind for much of the period and the easterly exposed monitoring locations recorded higher turbidity. Turbidity peaks were recorded at these sites around 7 April, 24 April and 2 May 2009 at which time increased wind speeds from the east occurred.

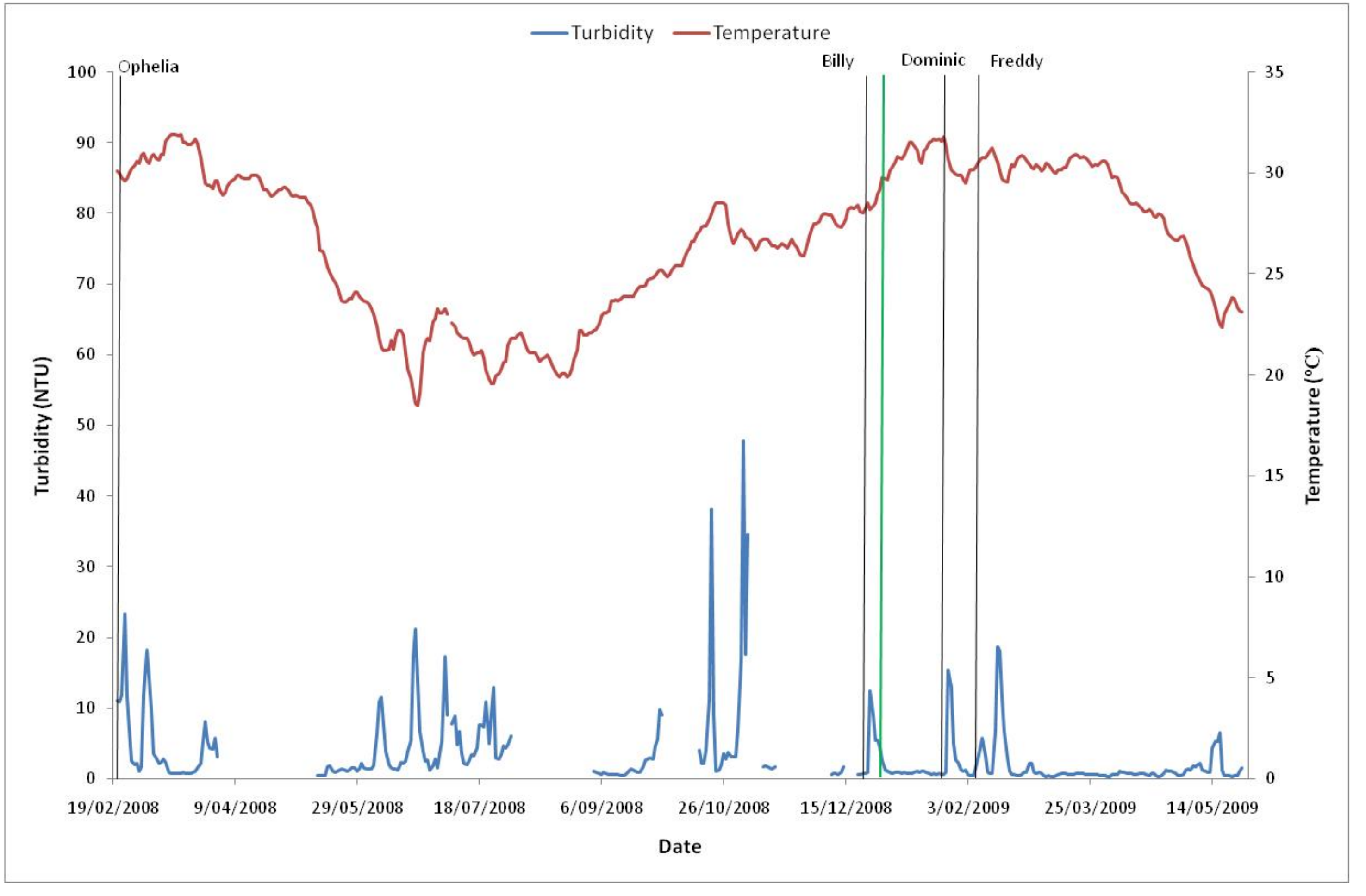
Peaks in turbidity coincided with the large tidal range associated with spring tides in the region and lower turbidity during neap cycles throughout the monitoring period; however, weak to no correlation between tidal fluctuations and the turbidity recorded were observed over certain monitoring periods. This is likely to occur when other factors, including increased wind speeds and passing cyclone and storm events, have a greater influence on the turbidity. The effect of the spring tides on elevated turbidity was again more pronounced at the nearshore monitoring sites.

- **Table 3-1 Summary statistics for turbidity data from each monitoring location during the baseline monitoring period**

Site	Period of sampling	Turbidity (NTU)				Site protected from East/West winds	Nearshore/ offshore
		Median	20th %ile	80th %ile	n		
BLR	21/02/08 – 26/05/09	1.3	0.6	4.5	15966	East	offshore
BTR	11/03/08 – 11/05/09	1.2	0.7	2.9	16955	neither	offshore
BZI	21/02/08 – 25/05/09	0.9	0.5	2.5	21125	East	offshore
BZR	12/03/08 – 26/05/09	0.9	0.5	2.6	13614	East	offshore
CLW	14/04/08 – 14/05/09	1.7	0.8	5.2	12861	East	nearshore
DIE	14/04/08 – 26/05/09	1.3	0.8	2.9	15317	East	nearshore
DLI	14/04/08 – 28/05/09	0.7	0.4	1.9	15733	East	offshore
HAT	13/03/08 – 25/05/09	2.0	1.0	6.5	13835	West	offshore
MAN	11/03/08 – 27/05/09	2.4	1.2	6.9	13326	East	nearshore
MDR	11/03/08 – 25/05/09	1.6	0.9	4.7	15584	West	nearshore
PLR	01/05/08 – 25/05/09	1.6	1.0	4.0	13582	West	offshore
PWR STN	11/03/08 – 26/05/09	1.5	0.8	5.8	13953	East	nearshore
SMSB	13/03/08 – 25/05/09	1.5	0.8	4.7	17702	West	nearshore

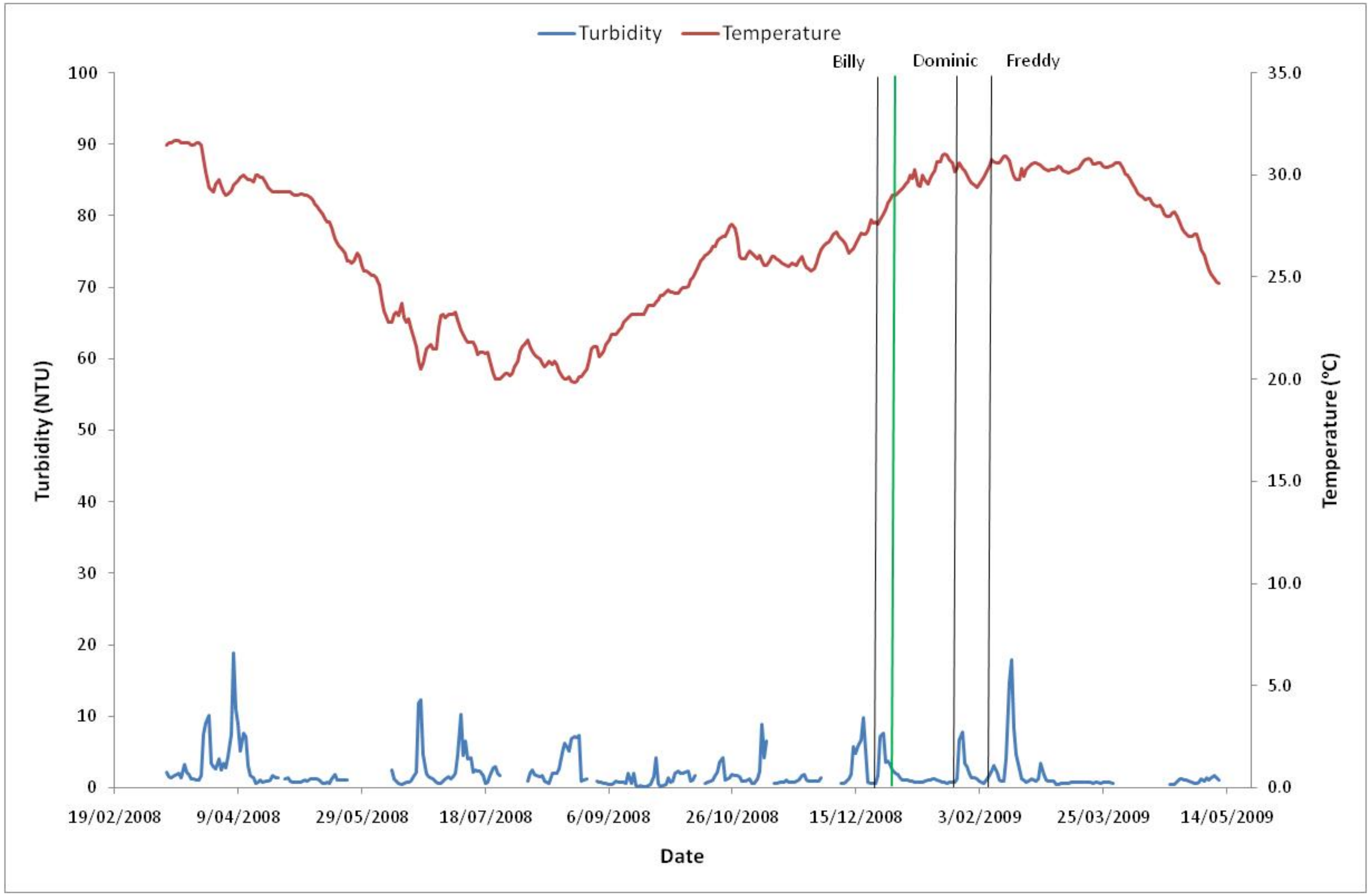
- **Table 3-2 Summary statistics for turbidity data from each monitoring location during the wet season and the dry season.**

Site	Turbidity (NTU) Dry Season 01/06/08 to 31/08/08				Turbidity (NTU) Wet Season 01/12/08 to 28/02/09			
	Median	20th %ile	80th %ile	n	Median	20th %ile	80th %ile	n
BLR	3.8	1.8	1.8	2794	1.0	0.6	3.5	3626
BTR	1.8	0.9	0.9	3304	1.2	0.7	3.6	3954
BZI	0.9	0.5	0.5	4057	0.8	0.5	2.6	4184
BZR	1.1	0.4	0.4	2676	0.9	0.6	3.0	3377
CLW	2.6	1.0	1.0	3680	1.8	1.0	4.8	3356
DIE	1.6	0.8	0.8	3274	1.5	0.9	7.3	4304
DLI	1.0	0.5	0.5	4409	0.6	0.4	1.7	4097
HAT	2.6	1.1	1.1	3918	1.9	0.9	9.4	4171
MAN	3.5	1.8	1.8	2767	2.9	1.6	9.7	3731
MDR	1.7	0.9	0.9	2999	1.8	1.0	7.1	4308
PLR	1.9	0.8	0.8	2691	2.1	1.2	7.8	3863
PWR STN	3.3	0.9	0.9	3447	1.8	1.1	9.6	3385
SMSB	2.8	0.6	0.6	3245	1.6	1.0	3.4	2845

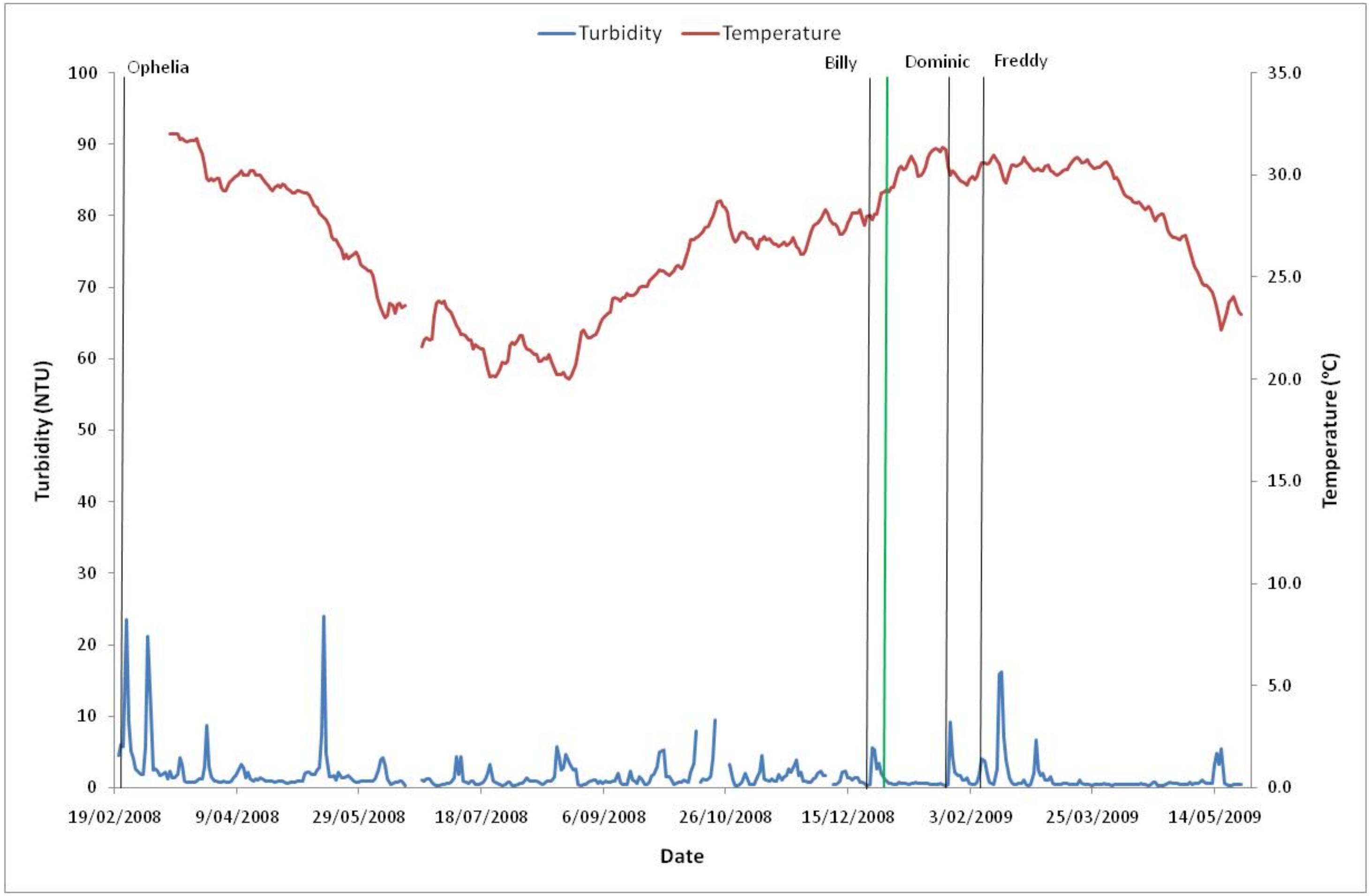


- **Figure 3-1 Median turbidity and temperature (determined from 1 day periods) recorded at BLR for the baseline monitoring period**

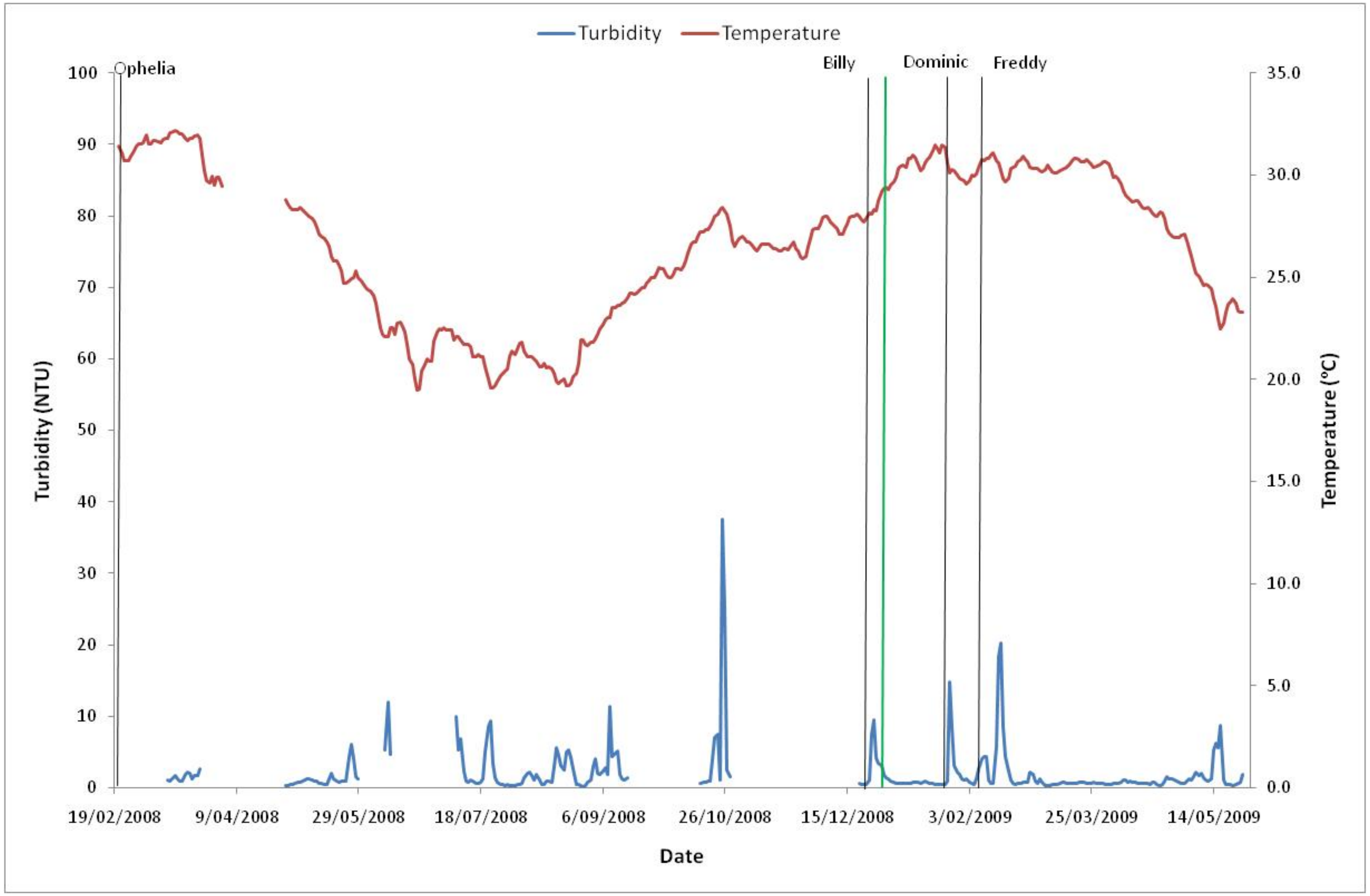
Note: Tropical cyclones are indicated by a black line with the cyclone name above it, while the Analite to Wetlabs changeover is indicated in green (Figure 3-1 to 3-13)



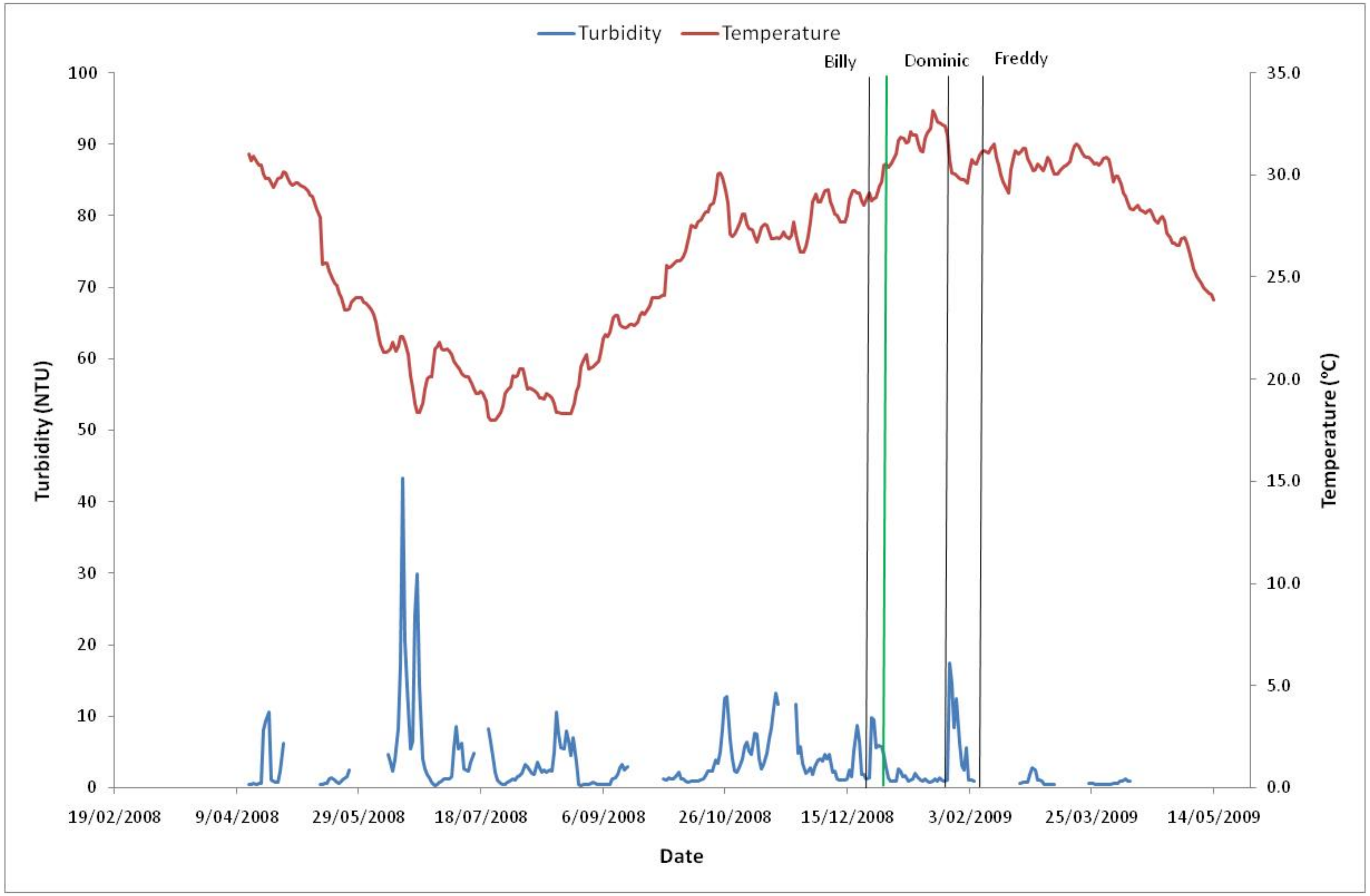
- **Figure 3-2 Median turbidity and temperature (determined from 1 day periods) recorded at BTR for the baseline monitoring period**



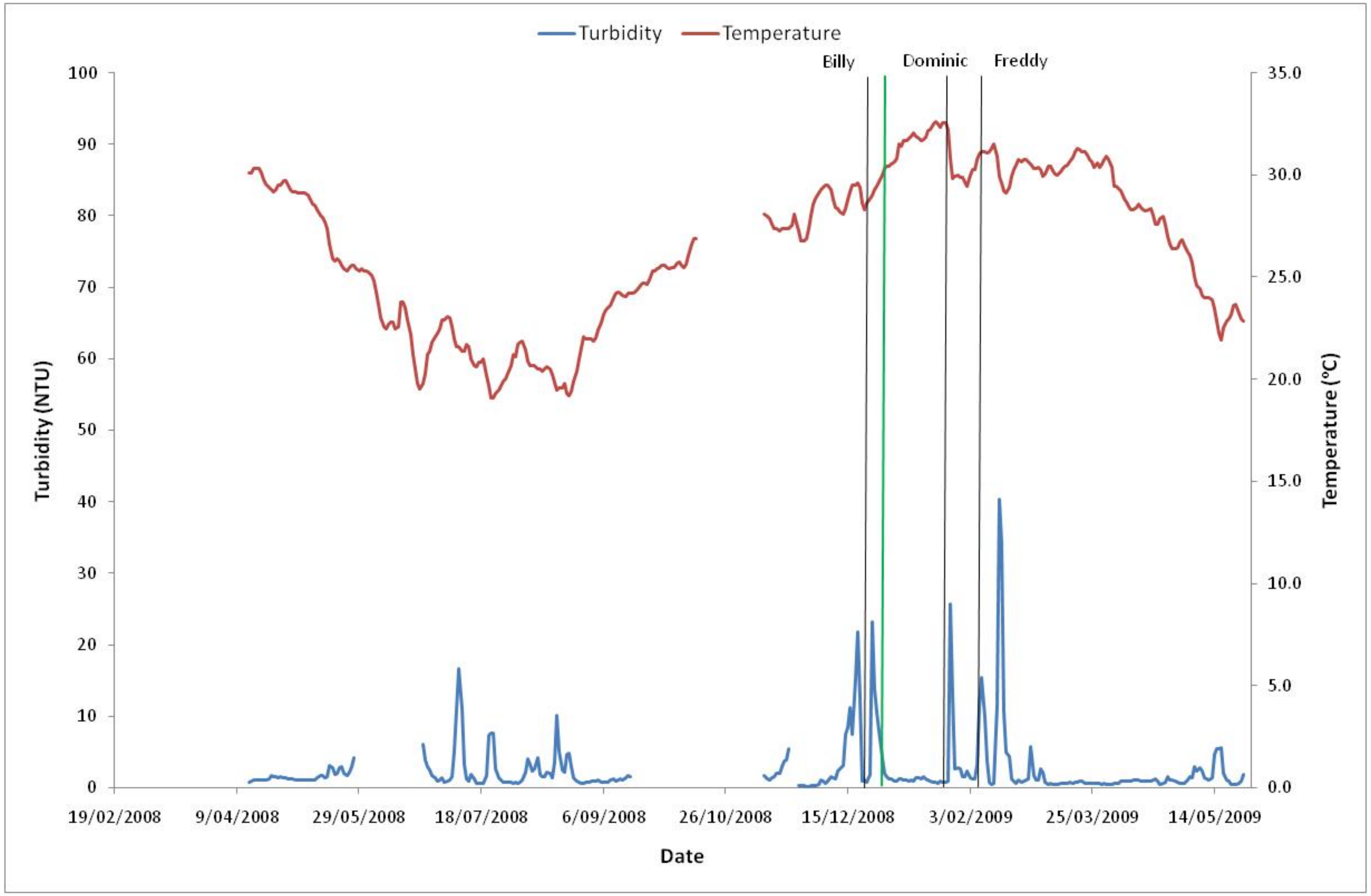
- **Figure 3-3 Median turbidity and temperature (determined from 1 day periods) recorded at BZI for the baseline monitoring period**



- **Figure 3-4 Median turbidity and temperature (determined from 1 day periods) recorded at BZR for the baseline monitoring period**



- **Figure 3-5 Median turbidity and temperature (determined from 1 day periods) recorded at CLW for the baseline monitoring period**



- **Figure 3-6 Median turbidity and temperature (determined from 1 day periods) recorded at DIE for the baseline monitoring period**

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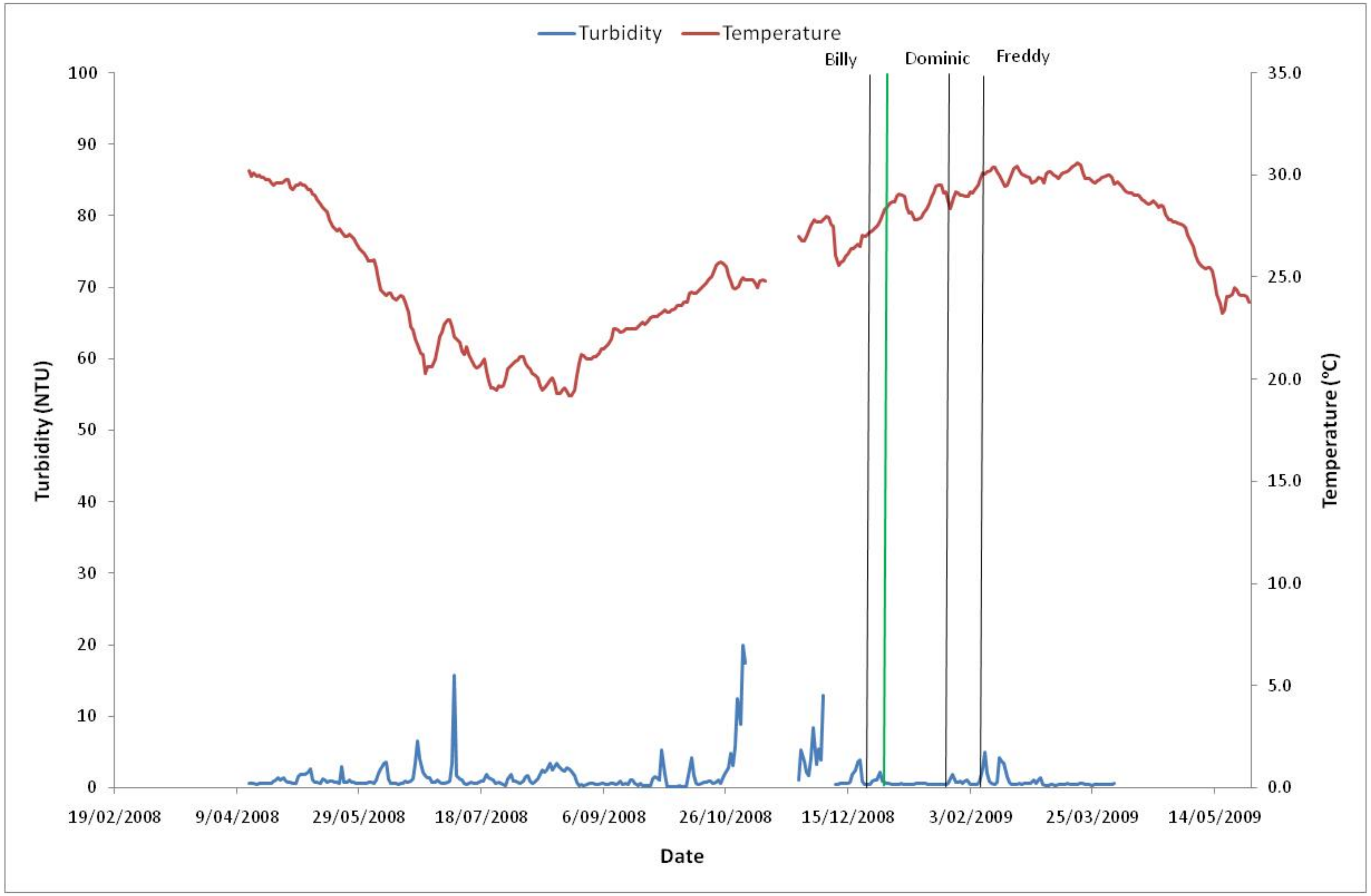
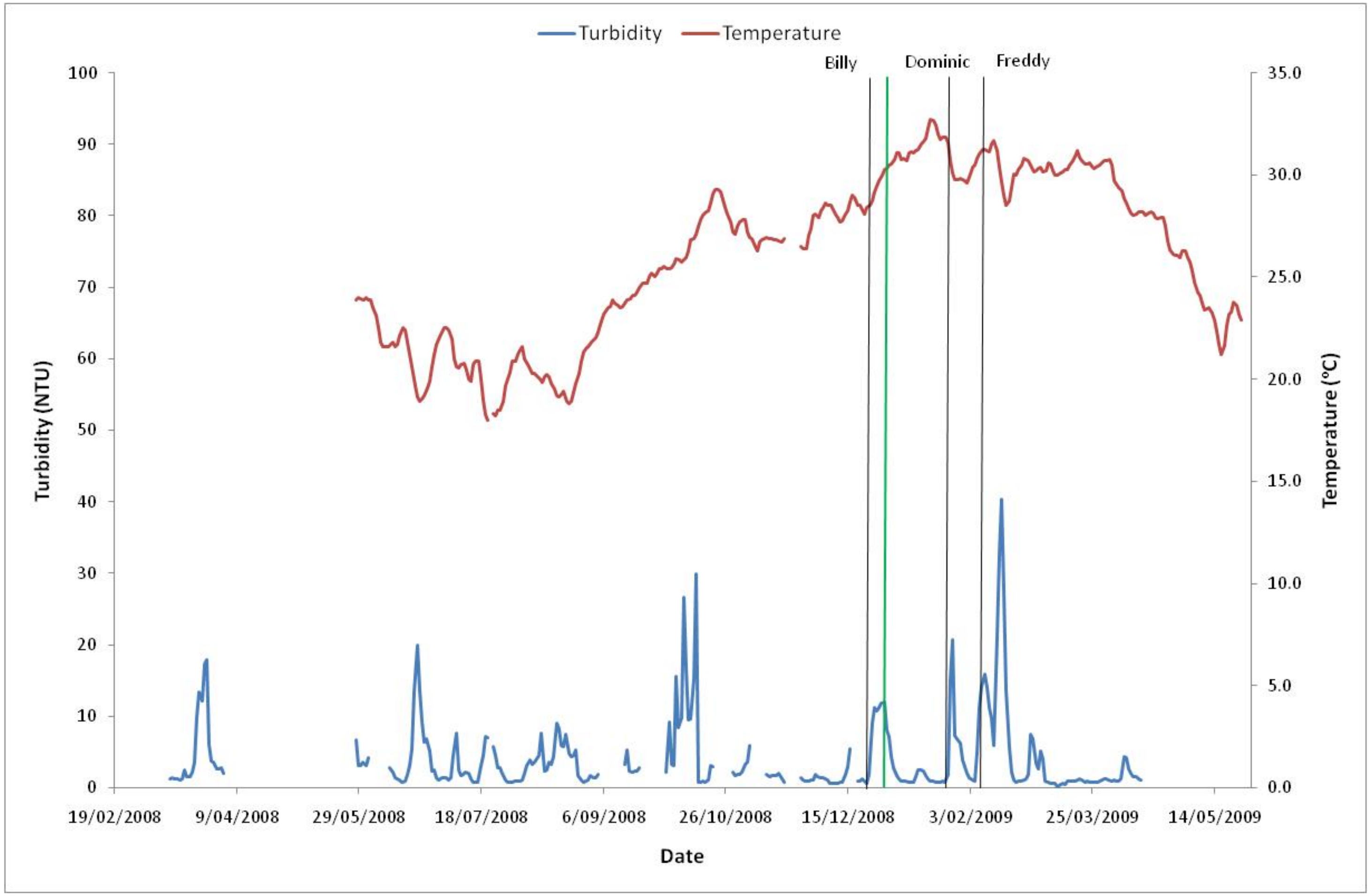
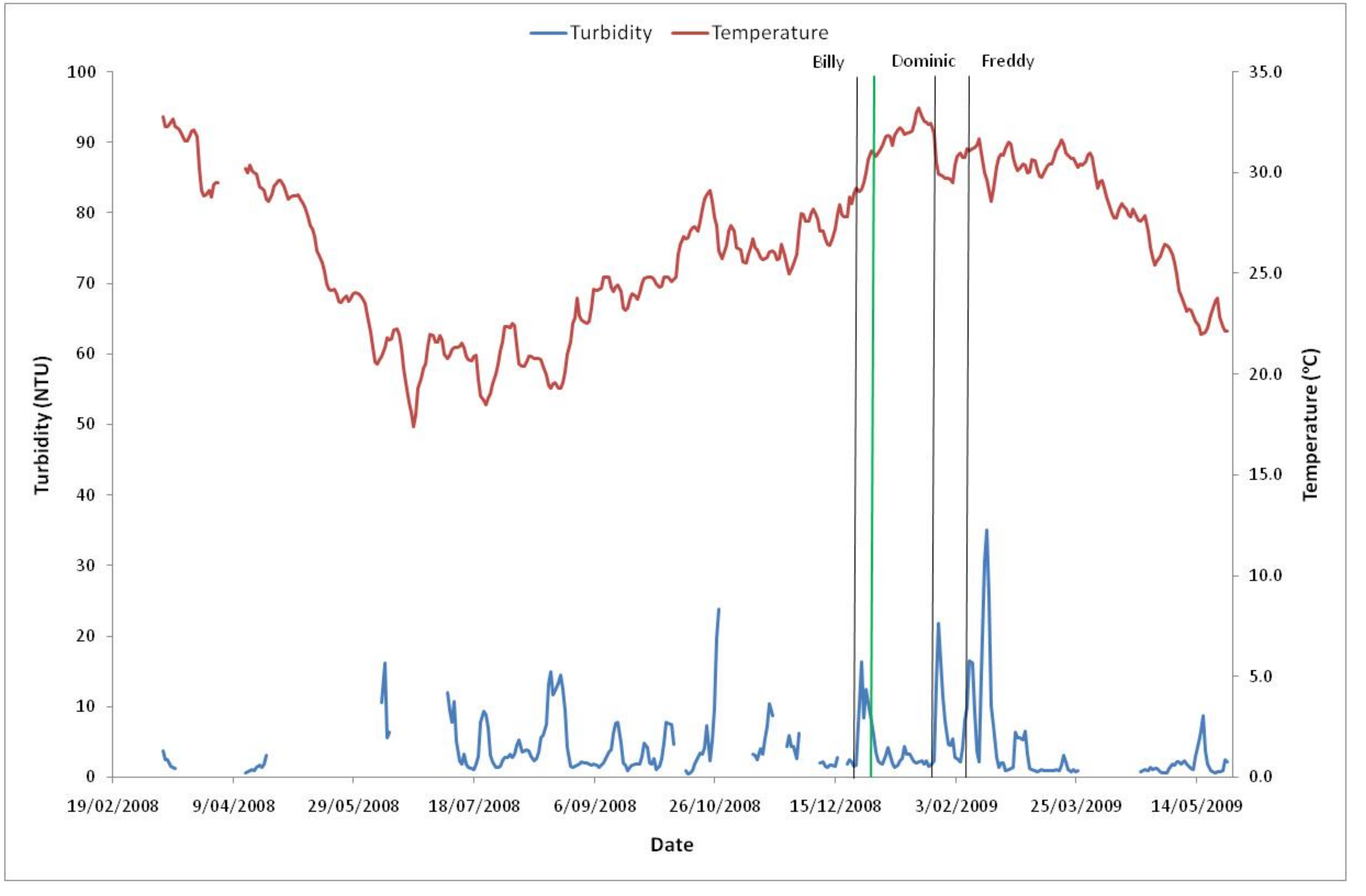


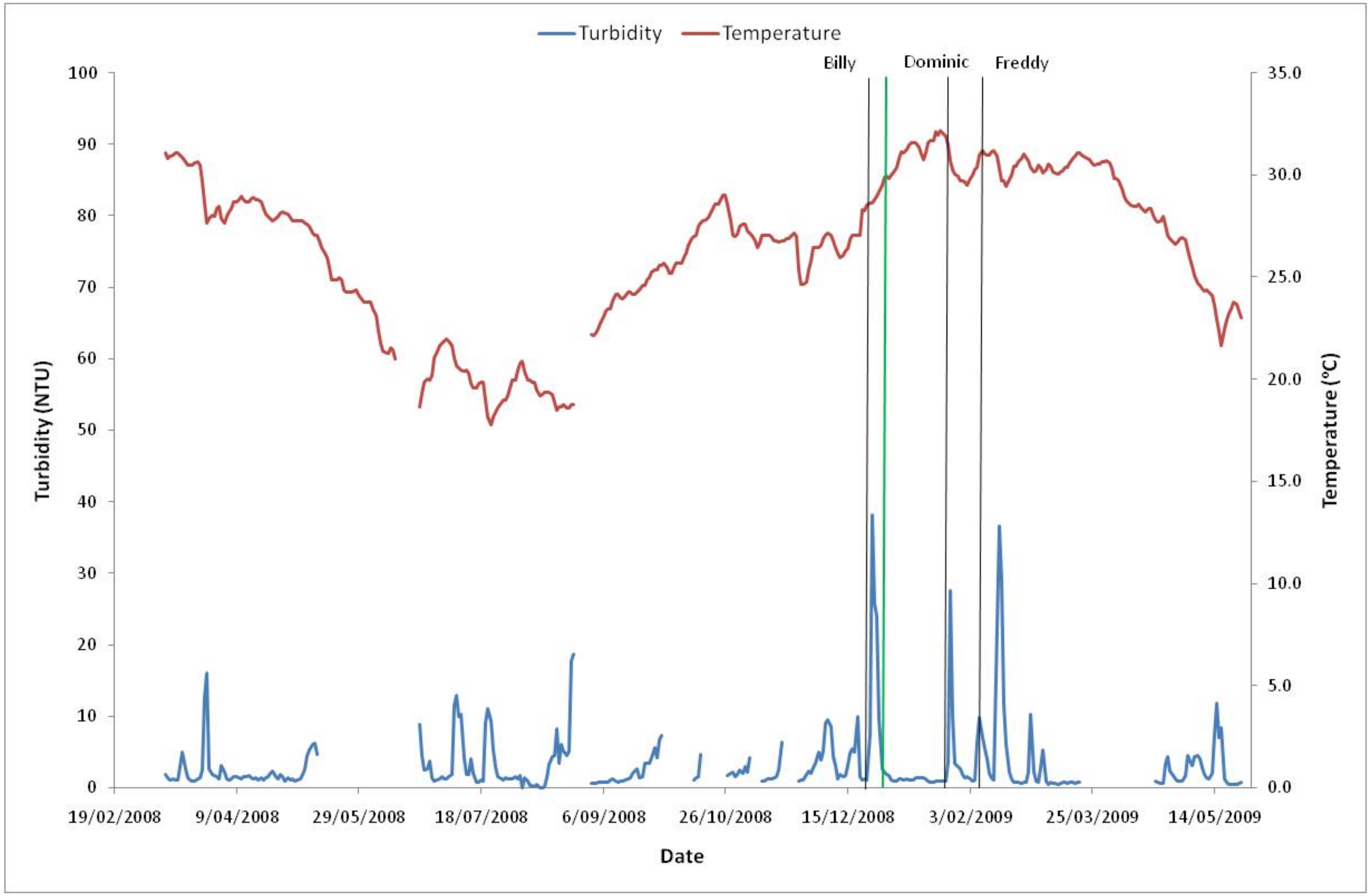
- **Figure 3-7 Median turbidity and temperature (determined from 1 day periods) recorded at DLI for the baseline monitoring period**



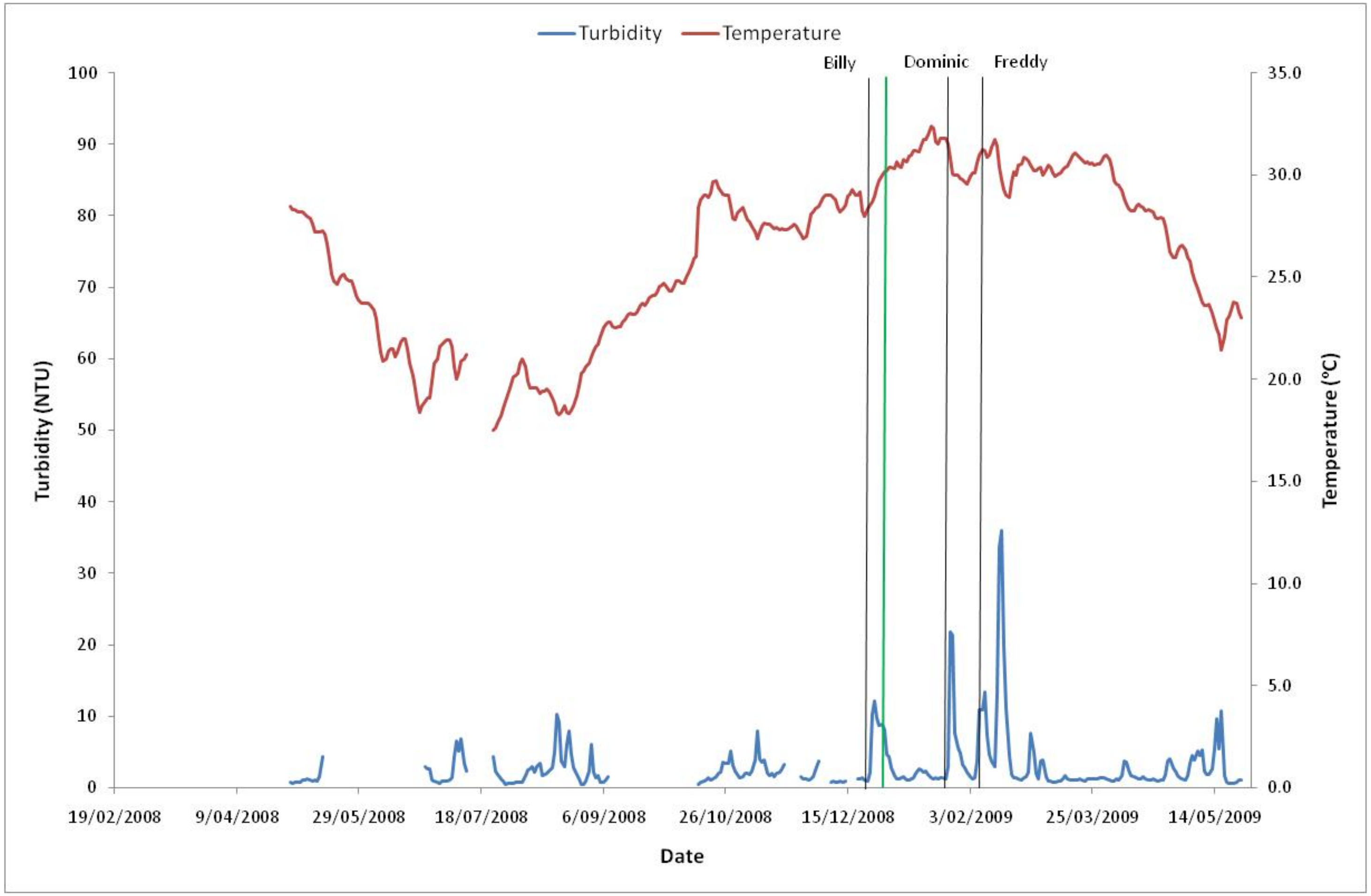
- **Figure 3-8 Median turbidity and temperature (determined from 1 day periods) recorded at HAT for the baseline monitoring period**



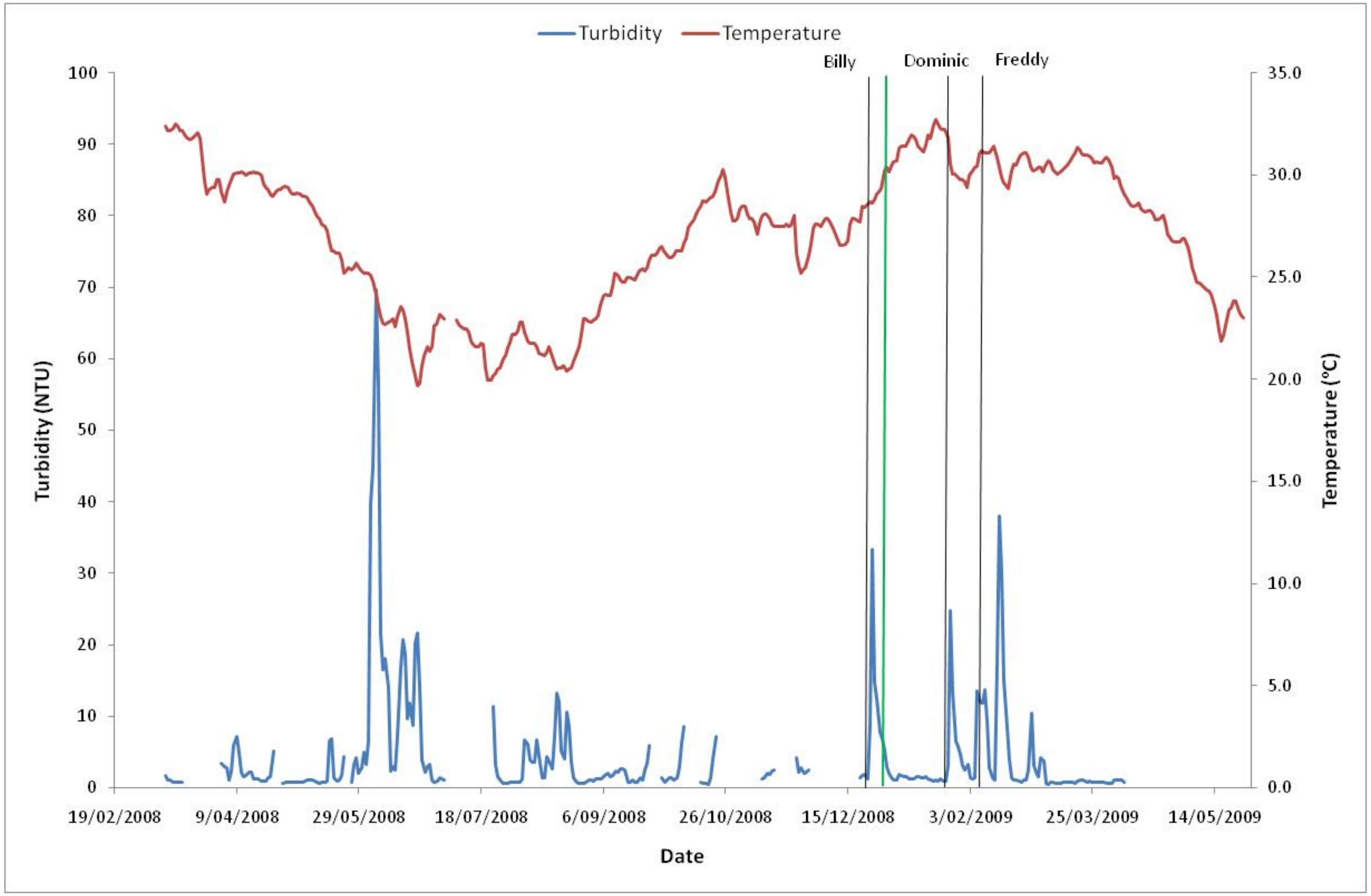
- **Figure 3-9 Median turbidity and temperature (determined from 1 day periods) recorded at MAN for the baseline monitoring period**



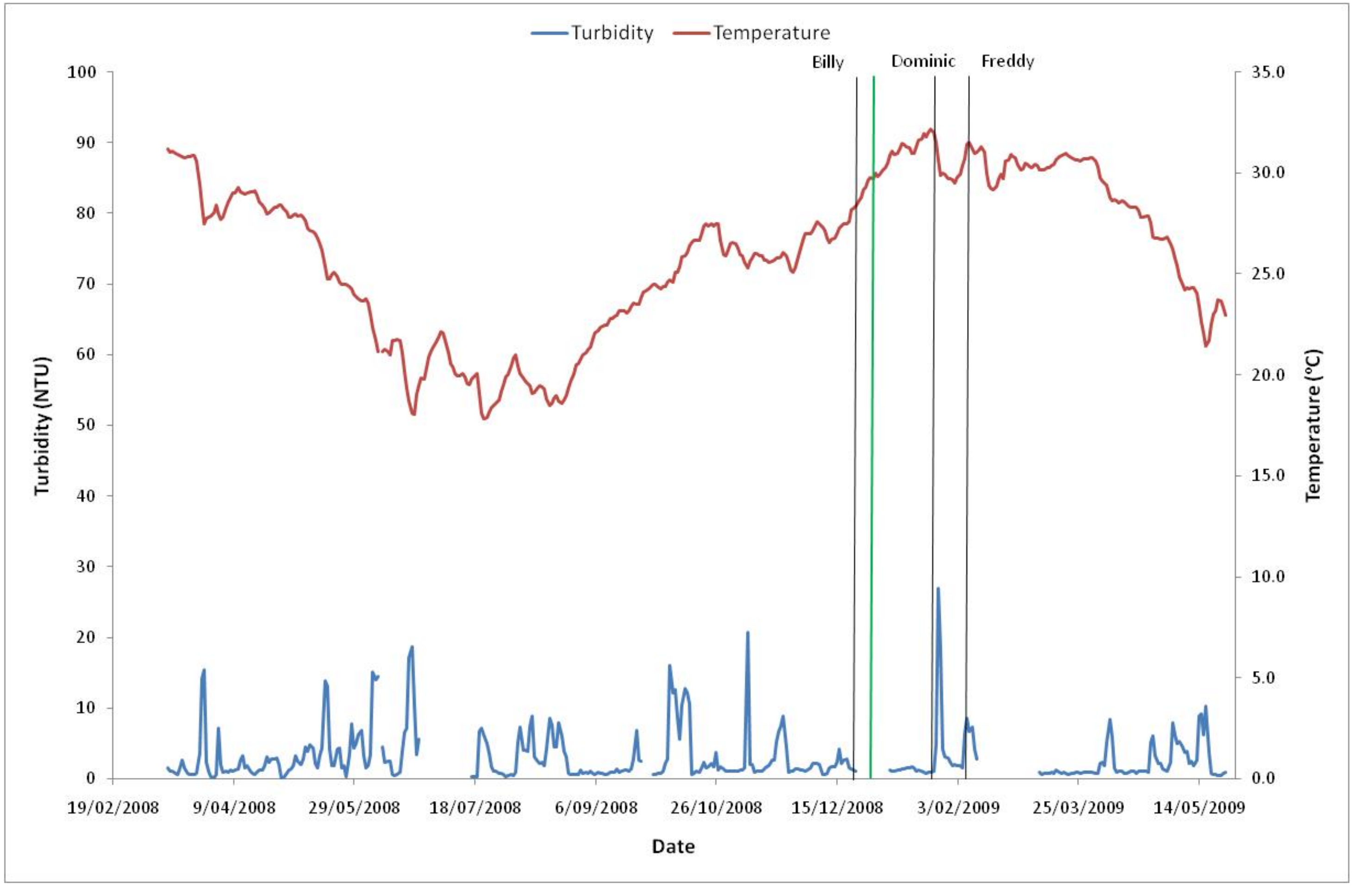
- **Figure 3-10 Median turbidity and temperature (determined from 1 day periods) recorded at MDR for the baseline monitoring period**



- **Figure 3-11 Median turbidity and temperature (determined from 1 day periods) recorded at PLR for the baseline monitoring period**



- **Figure 3-12 Median turbidity and temperature (determined from 1 day periods) recorded at PWR STN for the baseline monitoring period**



- **Figure 3-13 Median turbidity and temperature (determined from 1 day periods) recorded at SMSB for the baseline monitoring period**

3.3. Temperature

Monitoring of water temperatures for the Port B development baseline monitoring program recorded spatial and temporal variation at all sites during the monitoring period. The median water temperature recorded over the baseline monitoring period ranged from 27.8 ºC at PWR STN to 26.4 ºC at DLI (**Table 3-3**). All of the monitoring sites followed the same general trend of reflecting the seasonal trends in air temperature (**Figure 3-14**); where higher air temperatures were experienced during summer, and lower in the winter. Nearshore sites SMSB (16.5 ºC) and MAN (33.9 ºC) recorded the lowest minimum and the highest maximum respectively, while offshore sites BTR (19.5 ºC) and DLI (31.0 ºC) recorded the highest minimum and lowest maximum respectively (**Table 3-3**). Monitoring sites MAN (17.1 ºC) and CLW (16.5 ºC) had the largest range of water temperature recorded over the baseline period with DLI (12.5 ºC) and BTR (13.0 ºC) recording the lowest range.

A temperature relationship between sites of similar spatial distribution was observed from seasonal variation down to diurnal variations. The nearshore sites recorded the greatest range of water temperatures between the wet and dry seasons and through diurnal variations. The tidal regime appeared to have an effect on the water temperatures at the sites with smaller diurnal variation observed during spring tide periods and in general a small decrease in water temperatures during spring tide events.

The median water temperatures at all the sites increased from winter (dry season) to summer (wet season) by up to >10 ºC (**Table 3-4**). The effect of seasonal factors such as climate (air temperature) on the water temperatures was observed following weather events (including high rainfall) on the 26 January, 14 February and 30 March 2009 in which all monitoring sites, with the exception of DLI, experienced a decrease in median water temperature. These weather events caused a significant amount of rainfall and were associated with a decrease in both the minimum and maximum air temperatures.

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- **Table 3-3 Summary statistics for combined temperature data (Analite and TibBit loggers) from each monitoring location for the entire monitoring period.**

Site	Site protected from east/west winds	Water Temperature (ºC) Entire Sampling Period 21/12/08 to 28/05/09					
		Median	20th %ile	80th %ile	Minimum	Maximum	n
BLR	east	27.6	23.1	30.3	17.9	32.4	21889
BTR	west	26.9	22.9	30.0	19.5	32.5	20354
BZI	east	27.5	23.5	30.1	17.8	33.7	20696
BZR	east	27.1	22.5	30.4	18.7	32.5	20799
CLW	east	27.5	21.5	30.3	17.0	33.5	18936
DIE	east	27.4	22.5	30.2	18.5	33.1	18155
DLI	east	26.4	22.3	29.4	18.5	31.0	18924
HAT	west	26.8	21.7	30.2	17.5	32.9	16949
MAN	east	26.7	22.4	30.4	16.8	33.9	20654
MDR	west	27.2	23.4	30.2	17.2	32.9	20217
PLR	west	27.4	21.8	30.1	16.9	32.7	18114
PWR STN	east	27.8	23.3	30.3	19.0	33.7	20898
SMSB	west	26.7	21.9	30.0	16.5	32.7	20898

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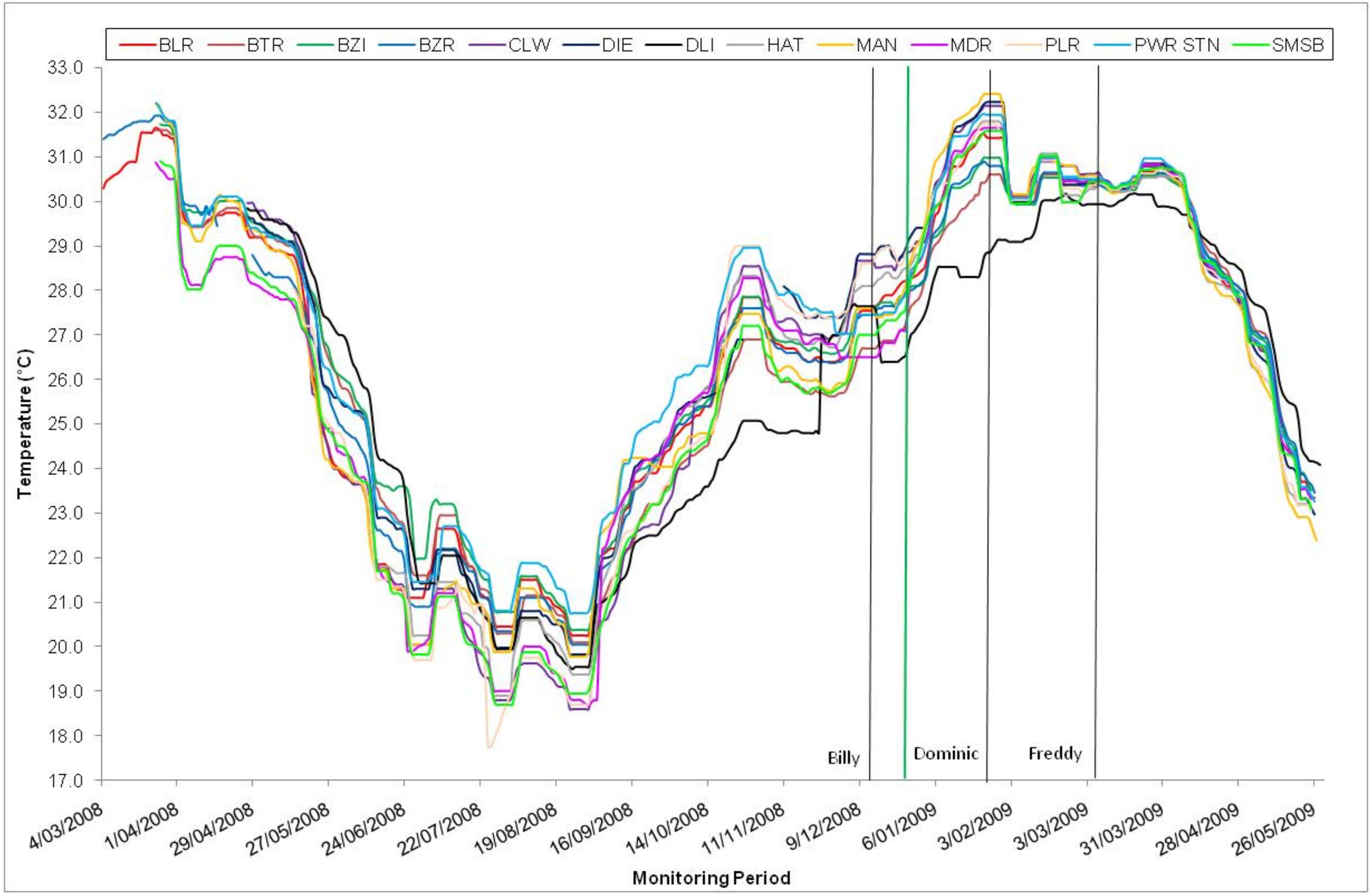
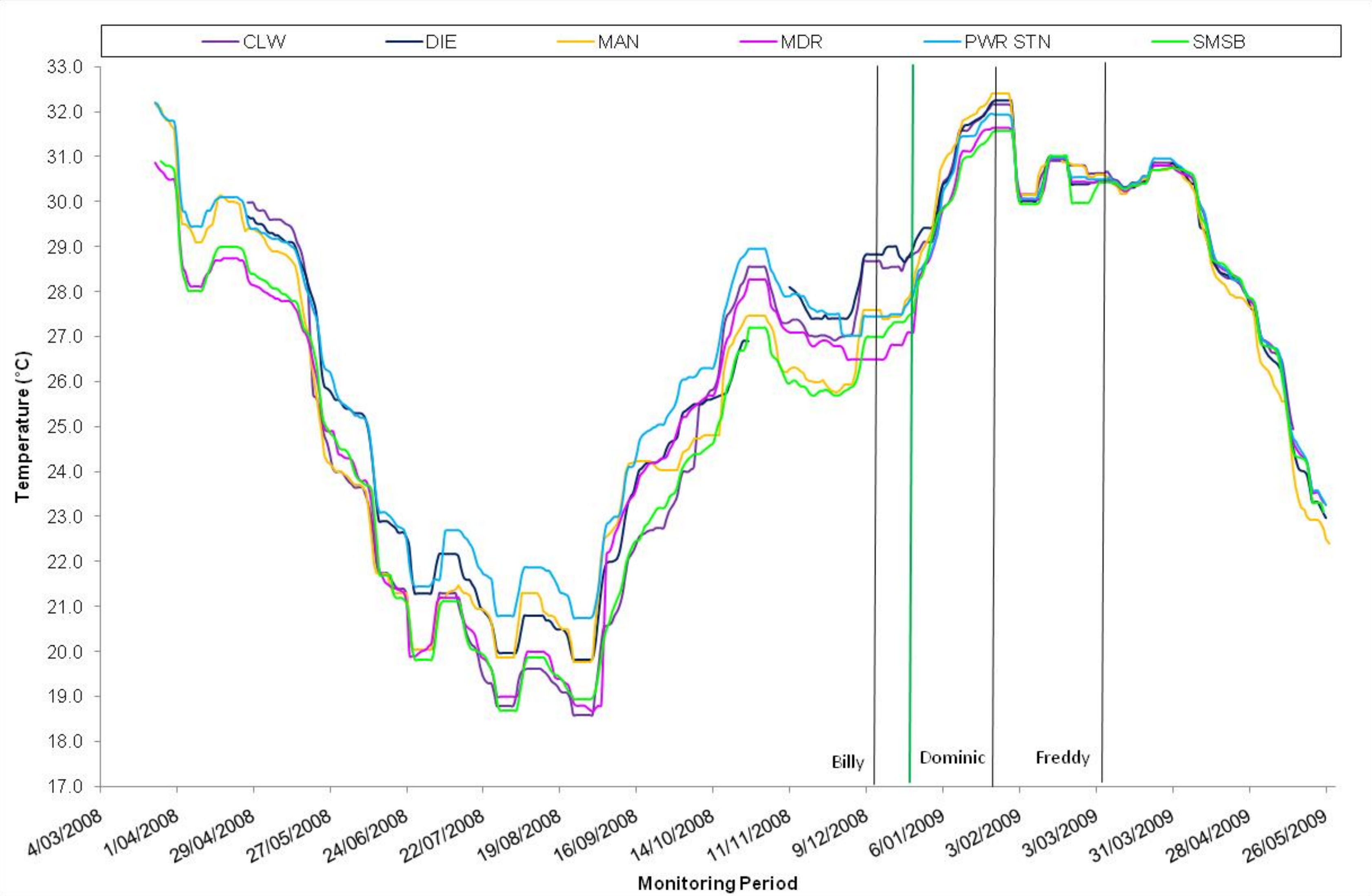
- **Table 3-4 Summary statistics for combined temperature data (Analite and TibBit loggers) from each monitoring location during the wet season and the dry season.**

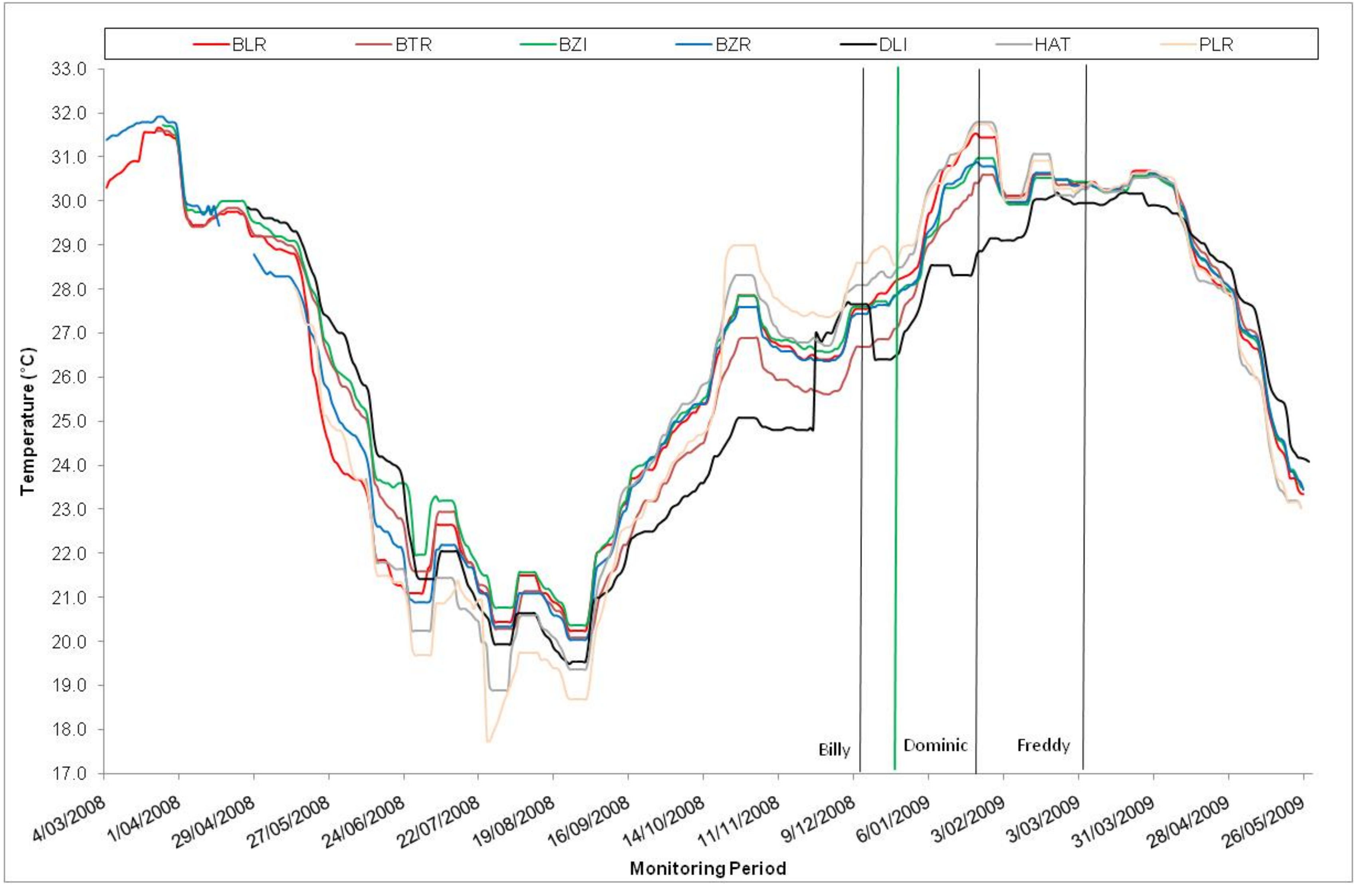
Site	Water Temperature (ºC) Dry Season 01/06/08 to 31/08/08						Water Temperature (ºC) Wet Season 01/12/08 to 28/02/09					
	Median	20th %ile	80th %ile	Min	Max	n	Median	20th %ile	80th %ile	Min	Max	n
BLR	21.3	20.3	22.2	17.9	24.0	4282	30.1	28.1	31.0	26.9	32.4	4314
BTR	21.4	20.4	23.0	19.5	25.4	4410	29.7	27.2	30.5	25.9	31.4	4311
BZI	21.8	20.7	23.3	17.8	25.6	4057	29.9	28.0	30.6	26.2	32.0	4314
BZR	21.2	20.3	22.3	18.7	24.7	4410	30.0	28.0	30.7	26.6	32.2	4310
CLW	20.0	18.8	21.5	17.0	24.0	4409	30.4	29.0	31.6	27.0	33.5	4315
DIE	21.2	20.0	22.7	18.5	25.5	4409	30.3	29.2	31.6	27.4	33.1	4313
DLI	20.9	19.9	23.0	18.5	26.3	4409	28.7	27.5	29.7	24.8	31.0	4309
HAT	20.6	19.5	21.8	17.5	24.3	4319	30.2	28.5	31.3	27.1	32.9	4316
MAN	21.0	19.6	22.0	16.8	24.8	4407	30.6	28.3	31.8	25.5	33.9	4315
MDR	20.0	18.9	21.4	17.2	24.1	3576	30.1	27.3	31.2	25.4	32.9	4312
PLR	20.2	18.8	21.5	16.9	23.9	3868	30.1	28.9	31.2	27.7	32.7	4316
PWR STN	21.8	20.8	23.0	19.0	25.5	4169	30.3	28.0	31.4	26.0	33.0	4309
SMSB	19.9	18.9	21.3	16.5	24.3	4304	30.0	27.7	31.2	26.1	32.7	4316



- **Figure 3-14 Fourteen day rolling median temperature (°C) values (determined from 1 day periods) recorded at each monitoring location during Port B monitoring period**



- **Figure 3-15 Fourteen day rolling median temperature (°C) values (determined from 1 day periods) recorded at nearshore monitoring locations during Port B monitoring period**



- **Figure 3-16 Fourteen day rolling median temperature (°C) values (determined from 1 day periods) recorded at offshore monitoring locations during Port B monitoring period**

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3.4. Light

Spatial and temporal variation between and within the monitoring sites was recorded for light during the monitoring period. Light was not recorded at all monitoring sites, loggers were deployed at four sites at any given time and six sites in total during the monitoring period. Summary statistics are provided below (**Table 3-5**) with CLW recording the highest median total photosynthetically active radiation (PAR) per day (13,327,685 µm/m^2/day), while HAT recorded the lowest median PAR per day (5,897,644 µm/m^2/day). The shallow nearshore sites of CLW and MDR recorded higher light levels than the deeper offshore (greater than 2.5 km from shore) sites (**Figure 3-17** and **Figure 3-18**). Although BZI is not a nearshore site, it is situated in shallow water at a depth of three meters and therefore is expected to have higher light levels as per the nearshore sites. This indicates that depth has a large influence on the light climate experienced at the monitoring sites.

- **Table 3-5 Summary statistics for total PAR per day from each monitoring location for the entire monitoring period**

Site	Period of sampling	Total PAR per day (µm/m^2/day)				Average logger depth
		Median	20th %ile	80th %ile	n	
BZI	29/04/08 - 16/09/08	12920220	8271958	15573480	116	3
CLW	29/04/08 - 14/05/09	13327685	9960705	16310640	168	4
DLI	30/04/08 - 28/05/09	7312812	5132644	9225829	192	9
HAT	07/04/09 - 24/05/09	5897644	2789848	8339922	48	6
MDR	28/04/08 - 25/05/09	1134808	4490618	14910144	161	5
PLR	23/03/09 - 06/04/09	7652552	5503354	9413385	15	6

The greatest range of light levels was recorded at the nearshore monitoring sites compared to the offshore sites and in particular DLI (**Figure 3-17** and **Figure 3-18**). The light climate at the nearshore locations fluctuated on a daily basis whereas DLI and the other offshore sites were relatively constant. The light levels at nearshore and offshore monitoring sites appeared to be significantly influenced by the turbidity levels recorded, with decreases and increases in turbidity having a direct effect on the light climate at the site (**Figure 3-19** to **Figure 3-22)**. This is supported by the light climate at BZI (**Figure 3-18)**, where the site is of equal or lesser depth to the nearshore monitoring sites yet the light levels recorded did not fluctuate or have the same range as the nearshore sites. Monitoring site BZI recorded generally one of the lowest median turbidity throughout the baseline monitoring period, see **Section 3.2**.

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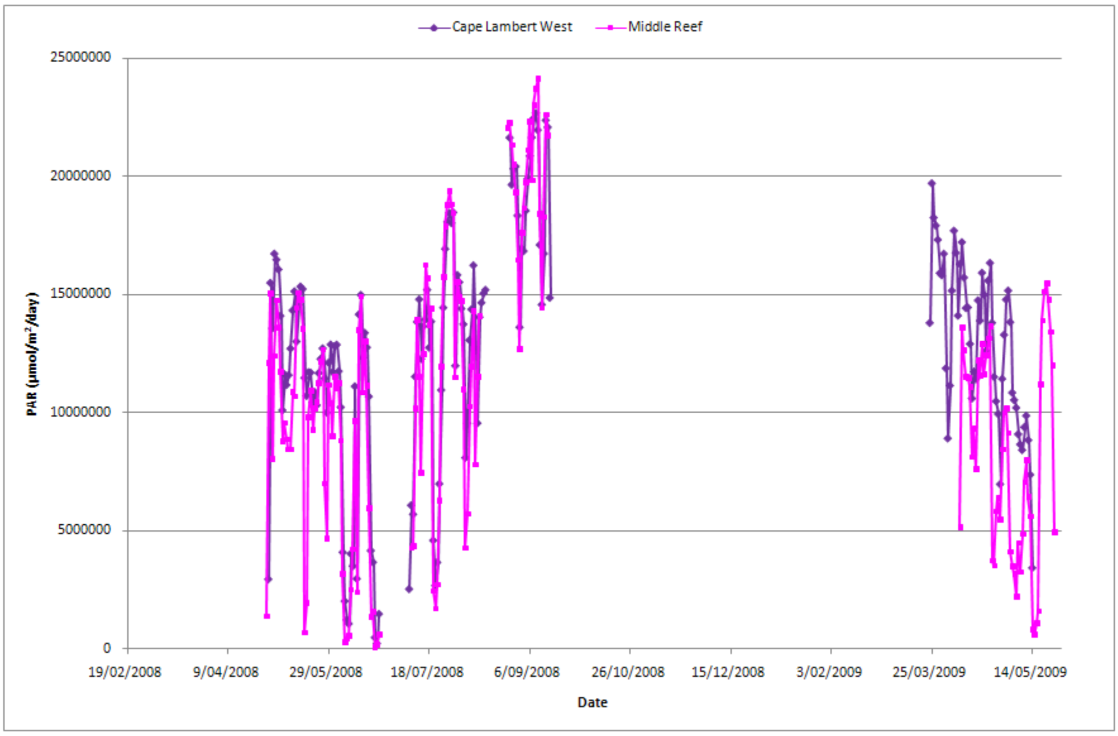
The seasonal effect and the difference in light climate between the dry season and wet season could not be measured as no data was recorded during the summer months. This was a result of technical issues with the loggers where all of the instruments were reported as having an internal error by the supplier. The loggers were sent back to the suppliers for calibration which took an extended period of time. This resulted in a large gap in data whilst the loggers were being serviced. The time of year and hence the angle of the sun, cloud cover, sea state and light scattering caused by material dissolved and suspended in the water column are all factors controlling the total amount of light available during a day. One or a combination of these factors can potentially reduce the amount of light recorded.



- **Figure 3-17 Daily light at nearshore monitoring locations CLW and MDR**

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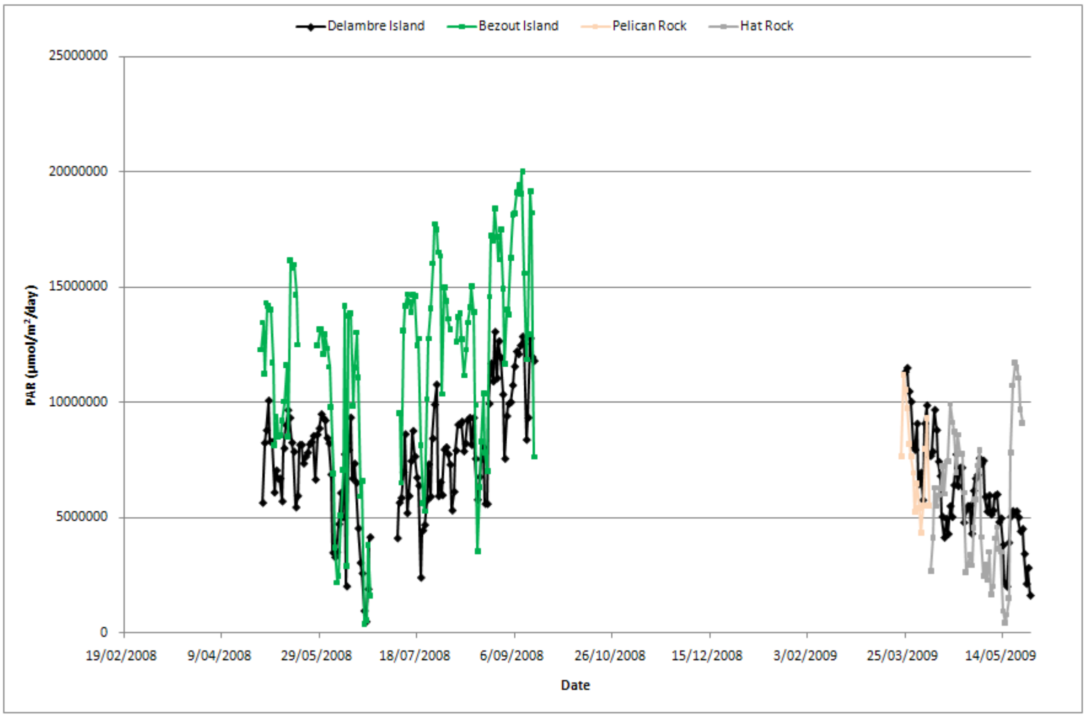
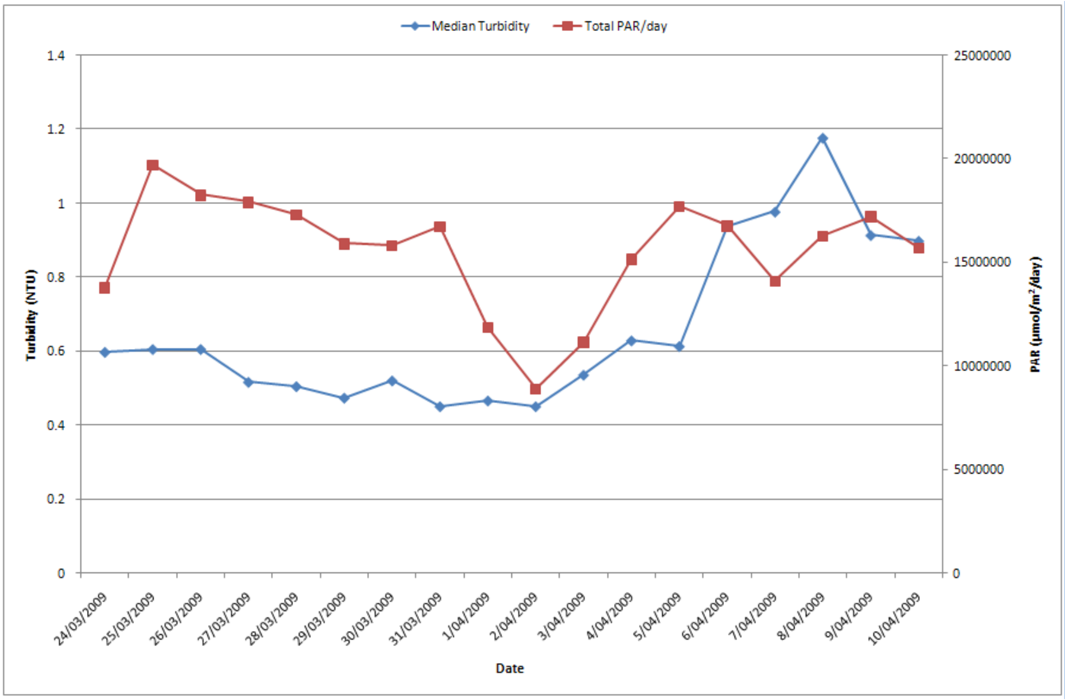
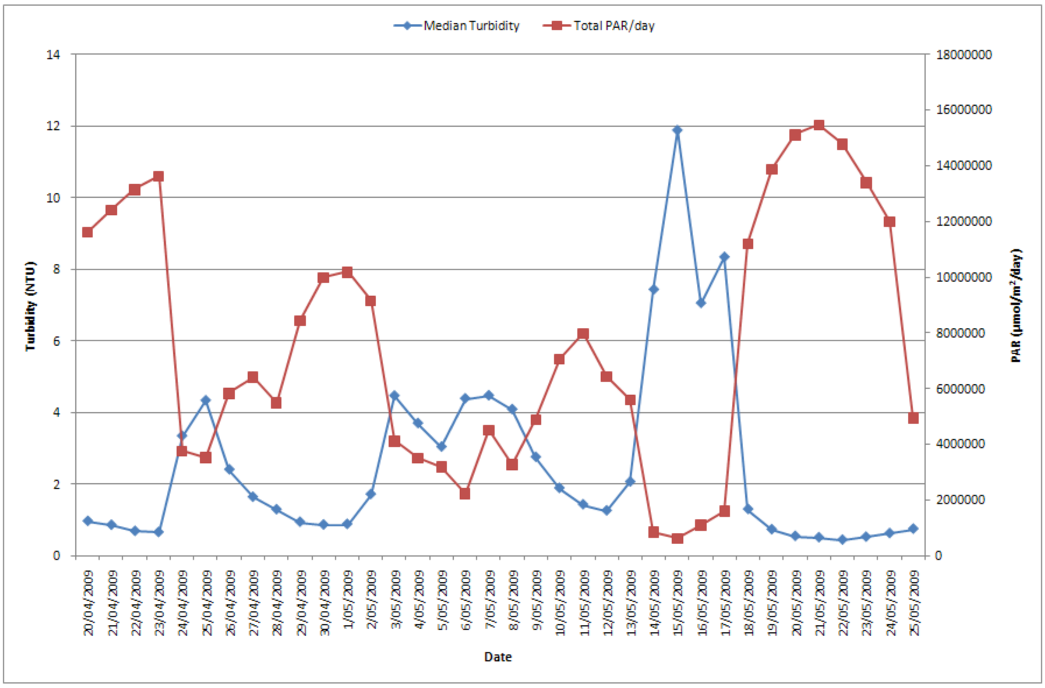


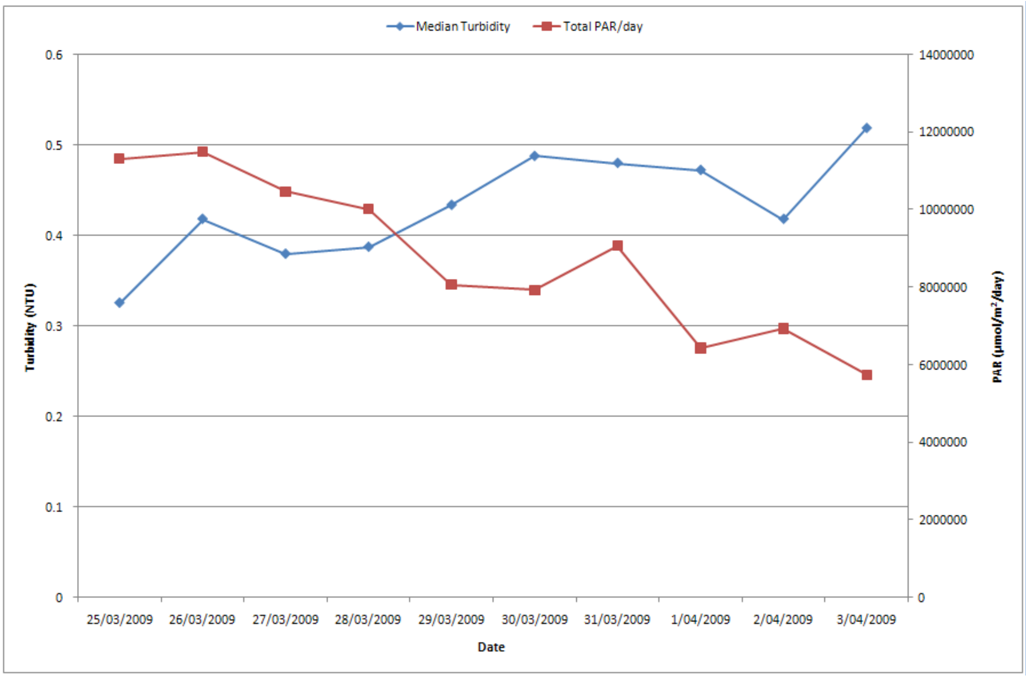
- **Figure 3-18 Daily light at offshore monitoring locations - BZI, DLI, HAT and PLR**



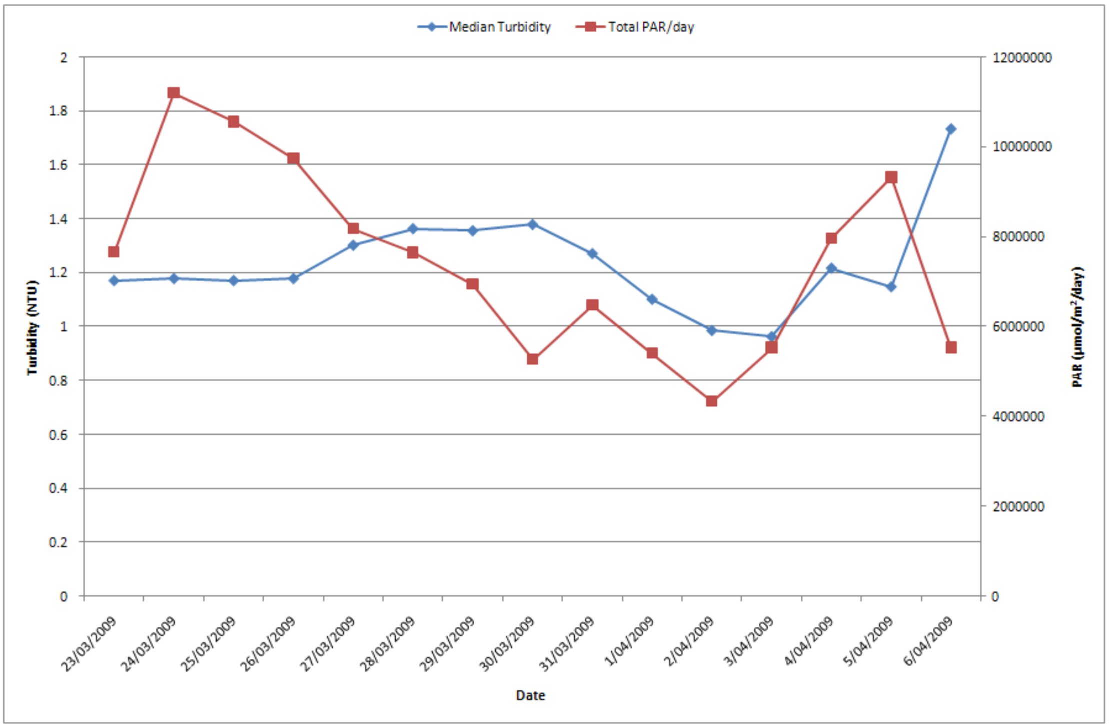
- **Figure 3-19 Total PAR per day *versus* turbidity during the same time period at nearshore monitoring site CLW**



■ **Figure 3-20 Total PAR per day *versus* turbidity during the same time period at nearshore monitoring site MDR**



■ **Figure 3-21 Total PAR per day *versus* turbidity during the same time period at offshore monitoring site DLI**



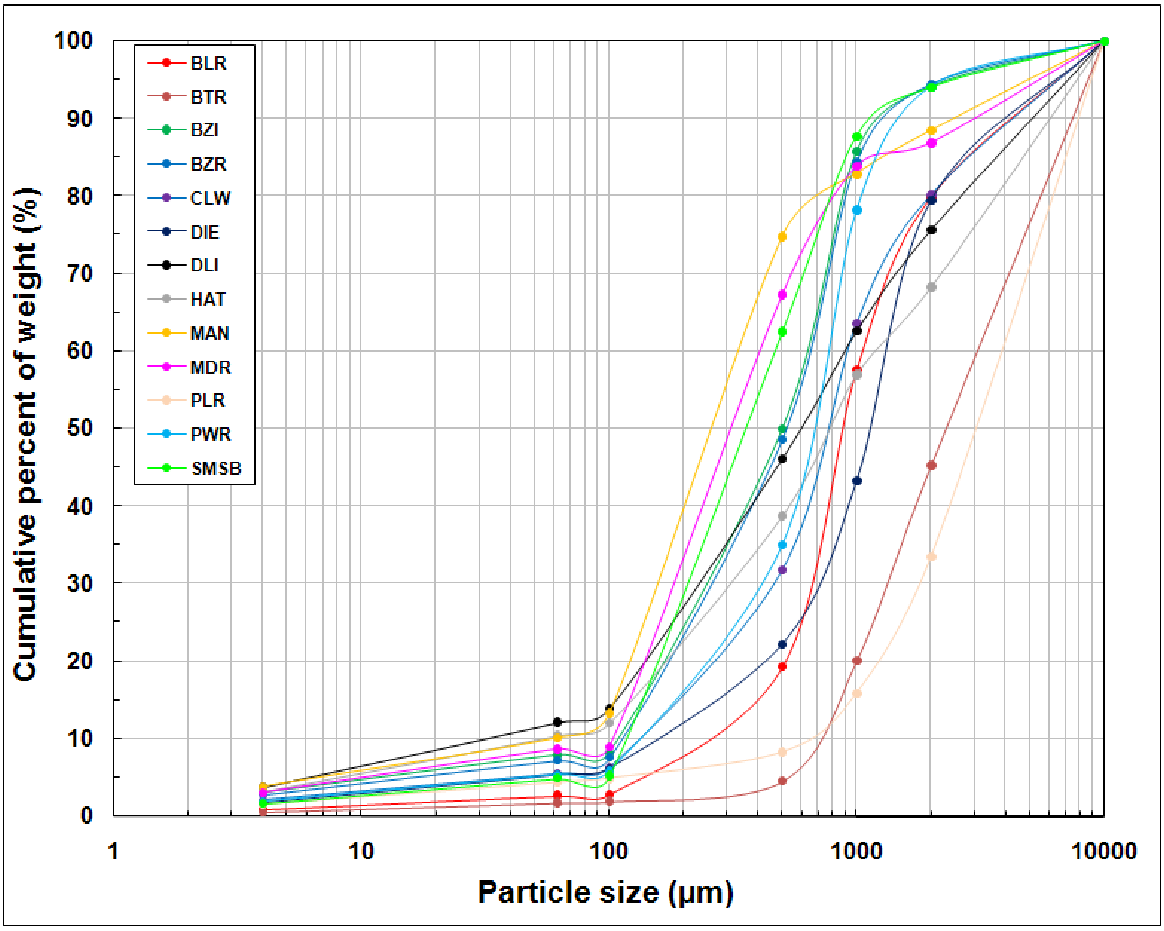
- **Figure 3-22 Total PAR per day *versus* turbidity during the same time period at offshore monitoring site PLR**

3.5. Particle Size Distribution

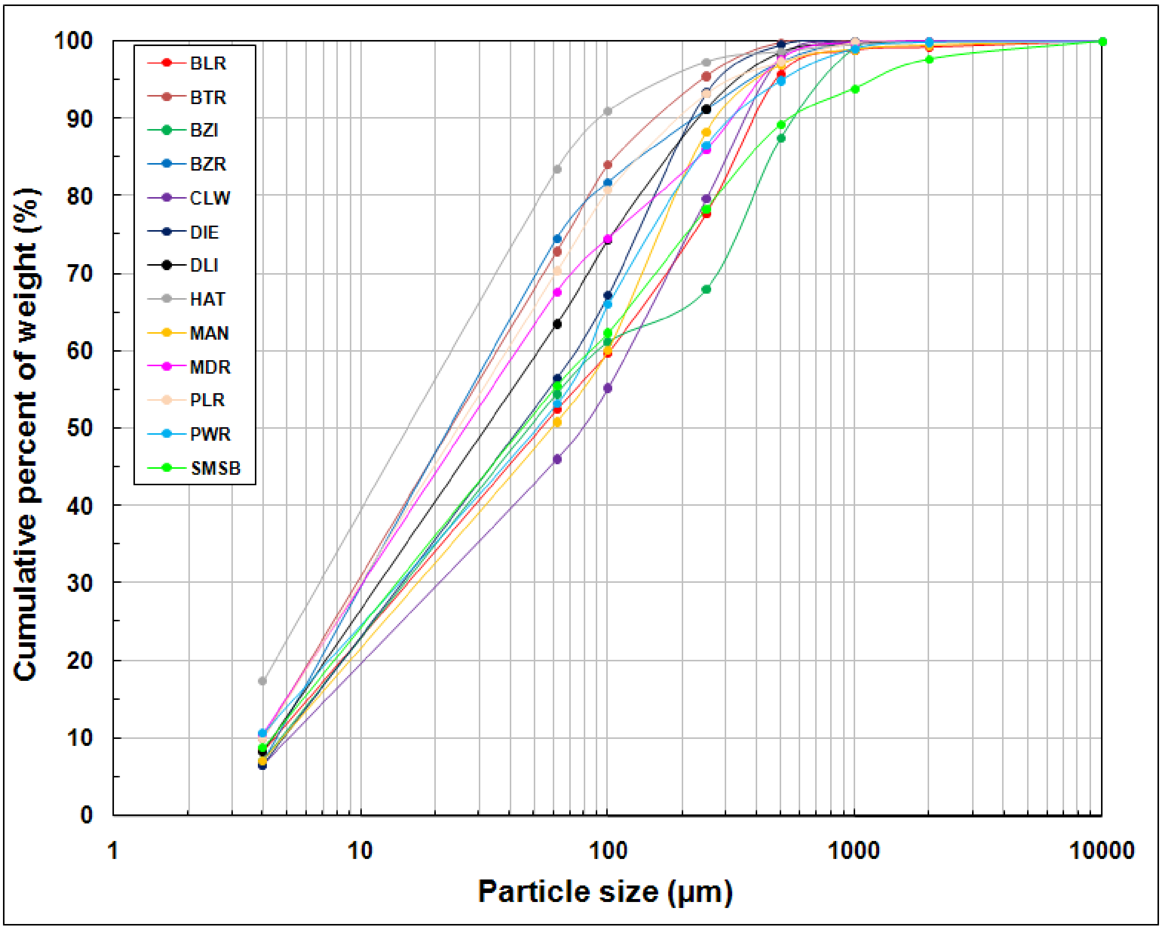
The PSD of the naturally occurring sediments at each monitoring location was sampled quarterly during the baseline survey period by two different methods: sediment cores to look at surface sediments and sediment traps to examine suspended sediments.

Surface sediments for the majority of locations are dominated by the medium to course sediments (**Table 2-2**) ranging between the 500 - 2000 µm size categories (**Figure 3-23**). PLR has the highest percentage of course sand with approximately 65% of the sediment >2000 µm. In comparison, DLI displays the highest percentage of silts and clays in the surface sediment when compared to other locations, followed by HAT and MAN respectively. However, at these sites, the level of silts and clays are still low (<10%) (**Figure 3-23**).

The particle size distribution of sediments in the water column ranged from 4–1000 µm (**Figure 3-24**), with approximately 80% of the sediment below 200 µm. This categorises the suspended sediment as predominantly ranging from very fine sand to clay. The highest percentage of silts and clays in the suspended sediment was found at HAT, where approximately 83 % of all suspended sediments fall into the silt to clay category (4–62 µm). This is followed closely by BZR, BZI and PLR with CLW having the lowest percentage of silts/clays (**Figure 3-24**).



- **Figure 3-23 Average particle size distribution measured by sediment cores at all monitoring locations during baseline Port B monitoring**



- **Figure 3-24 Average particle size distribution measured by sediment traps at all monitoring locations during baseline Port B monitoring**

3.6. Sedimentation

Sedimentation is the deposition of suspended sediment under the influence of gravity (Abdel-Salam and Porter 1988). Sedimentation rates recorded during the program varied both spatially and temporally. Monthly median sedimentation values ranged from 36400.36 mg/cm^2/d in July 2008 at SMSB, to 1.42 mg/cm^2/d in May 2008 at CLW (**Figure 3-25**, and **Table 3-6**). Observed sedimentation rates were consistently higher at SMSB, MAN, BZI, and MDR (in order of largest measured maximum monthly sedimentation rate) in comparison to all the remaining locations ranging from 36400.36 mg/cm^2/d in July 2008 at SMSB, to 20579.62 mg/cm^2/d in January 2009 at MDR (**Figure 3-25**, and **Table 3-6**). In contrast, PLR, DLI, BLR, and BZR (in order of highest measured maximum monthly sedimentation rates), all recorded consistent low maximum

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sedimentation rates ranging from 2843.59 mg/cm^2/d in February 2009 at PLR, to 1462.24 mg/cm^2/d in January 2009 at BZR (**Figure 3-25**, and **Table 3-6**). The mean sedimentation measured during each month for all monitoring locations show that when sedimentation rates are higher, in winter and summer, the associated standard errors are also high (**Figure 3-26**).

- **Table 3-6 Median monthly sedimentation range for all monitoring sites (mg/cm^2/d^{-1})**

	Median monthly sedimentation rates (mg/cm2/d) and month observed			
Site	**Max**	**Month**	**Min**	**Month**
BLR	2118.63	Feb 09	61.10	May 08
BTR	13094.68	July 08	17.76	Nov 08
BZI	25181.85	Jan 09	46.42	Oct 08
BZR	1462.24	Jan 09	9.95	May 08
CLW	6925.45	Jan 09	1.42	May 08
DIE	4804.49	Feb 09	6.39	Nov 08
DLI	2551.28	Feb 09	106.58	Mar/Apr 09
HAT	3887.78	Jan 09	24.87	Oct 08
MAN	31126.16	July 08	511.57	Apr 09
MDR	20579.62	Jan 09	132.16	Oct 08
PLR	2843.59	Feb 09	5.68	Nov 08
PWR STN	13581.78	Jun 08	27.13	Oct 08
SMSB	36400.36	Jul 08	57.55	Nov 08

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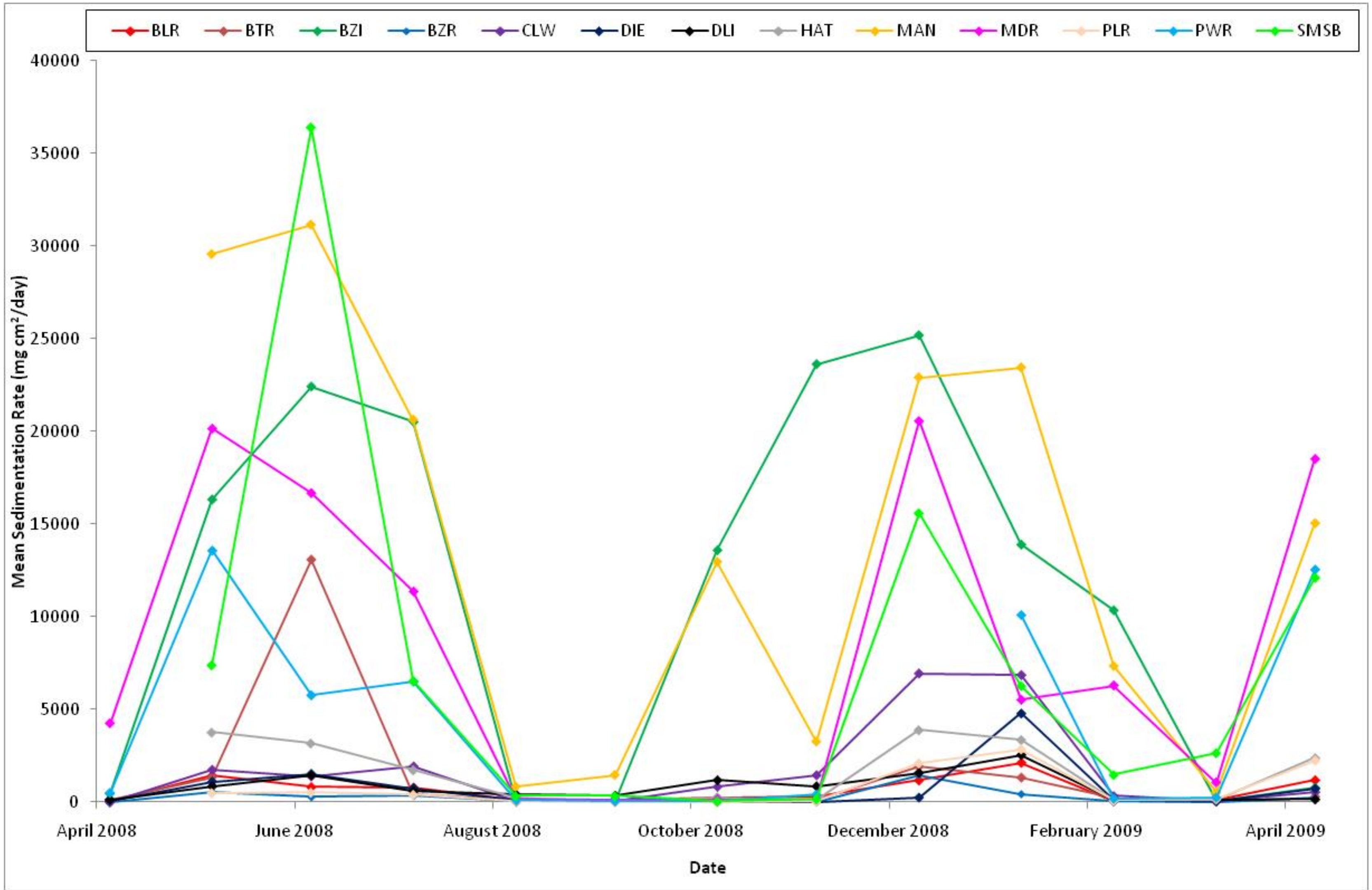
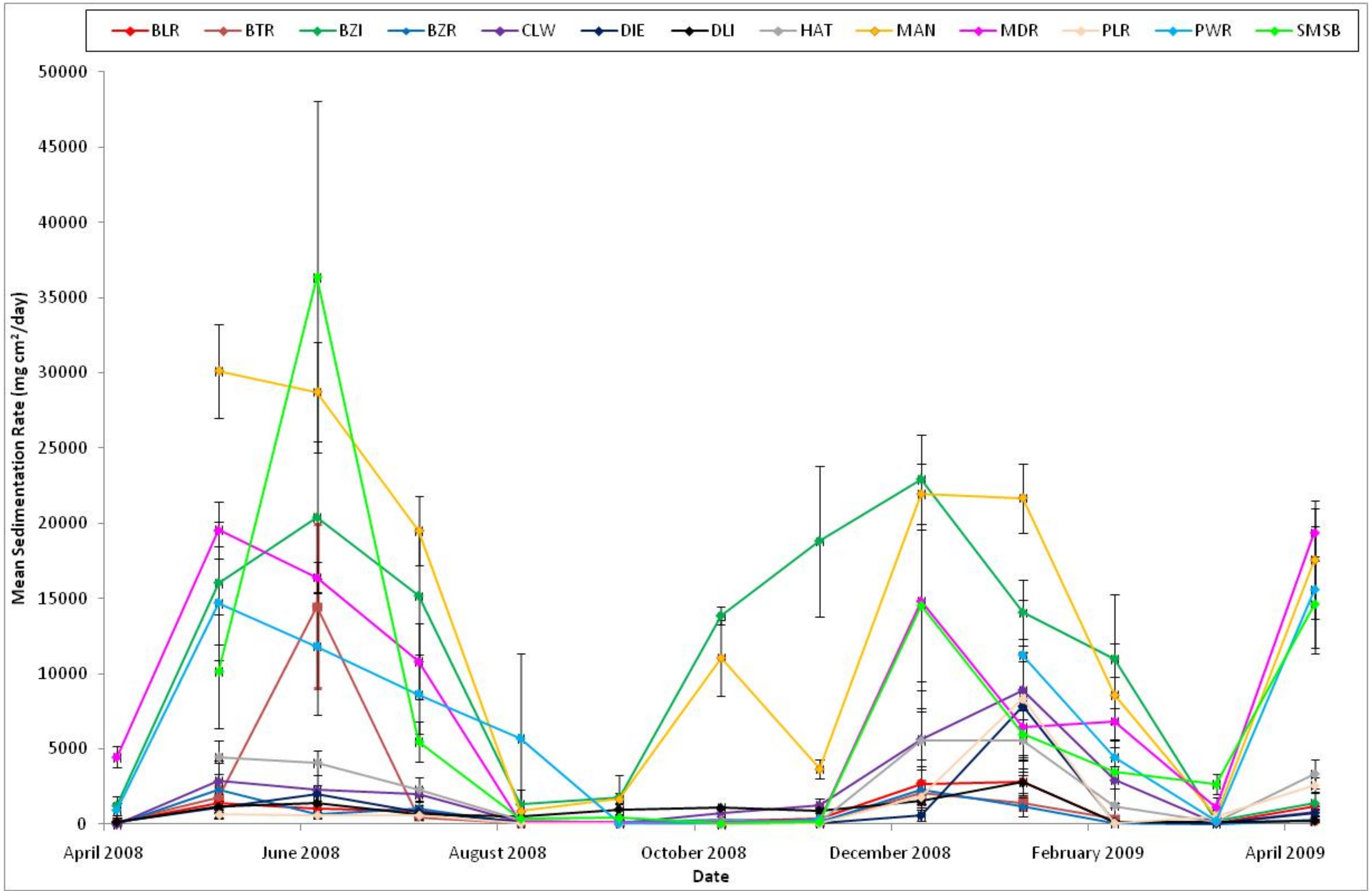


- **Figure 3-25 Median sedimentation rates at each monitoring location during baseline Port B monitoring**



- **Figure 3-26 Mean (± SE) sedimentation rates at each monitoring location during baseline Port B monitoring**

4. Discussion

4.1. Water Quality Parameters

4.1.1. Introduction

The Port B development baseline water quality monitoring program aimed to document the baseline water quality through investigating turbidity, temperature, light, PSD and sedimentation in the Cape Lambert region. Spatial and temporal variation occurred for all of the parameters measured and in some cases across a range of levels.

4.1.2. Turbidity

The turbidity recorded during the baseline monitoring period showed spatial variation between monitoring sites that were closely associated with each other through geographical similarities. Distinct trends between nearshore monitoring sites and the sites located further offshore were observed, during this report any site greater than 2.5 km from land is classified as offshore (**Section 3.1**). The nearshore sites regularly experienced turbidity higher than the offshore sites. Nearshore sites are influenced to a greater extent by regional wind and tidal conditions, where wind and tidal generated water movement re-suspends fine sediments resulting in increased levels of turbidity.

Monitoring site MAN recorded the highest median turbidity over the baseline monitoring period and consistently had one of the highest medians from the fortnightly survey periods. MAN is located closer nearshore than other sites with more influence from the effects of terrestrial runoff. The site had one of the highest percentages of silts and clays in the surface sediment (**Figure 3-23**), and consistently had one of the highest sedimentation rates (**Figure 3-25**). In addition, the intertidal environment at MAN consists of finer unconsolidated material than other nearshore sites which have rocky or sandy shores. Therefore the influence of wind, swell or rain could suspend the particles in the water column easier than at other sites.

Both HAT and PLR behaved differently when compared to that of other offshore sites with turbidity levels exceeding the other offshore sites as well as nearshore sites on occasions. This in part may be due to HAT having the highest percentage of silts and clays in the suspended sediment, followed closely by PLR, and one of the highest percentages of silts and clays in the surface sediment. HAT and PLR are located near major drainage creeks in the area which would influence the PSD at the sites. Some of the most elevated and sustained turbidity peaks were observed at HAT and PLR following the occurrence of cyclones and rainfall events illustrating the influence the location and season has on the turbidity. The high turbidity at HAT and PLR during the wet season (opposed to the dry season) despite the Analite loggers generally recording higher turbidity readings than the Wetlabs loggers supports this observation.

Turbidity peaks were seen at all monitoring sites following cyclone and storm events in the region. Cyclones are intense low pressure systems which are accompanied by increased winds and wave turbulence. In a similar, naturally turbid nearshore marine environment to that off Cape Lambert, Orpin *et al*. (2004) concluded that there was a strong correlation between increased wind speeds and wave climate with elevated periods of turbidity (NTU). Monitoring site DLI, however, recorded the smallest elevations in turbidity following such events. DLI is located further offshore than the other sites with less influence from the effects of terrestrial runoff (**Figure 2-1**). This along with the protection that Delambre Island offers to the site from offshore sea state (including conditions such as wind and wave turbulence) may have resulted in the lower turbidity levels recorded than shallower, nearshore locations.

The ability to make correlations between turbidity and tides or wind over a considerable monitoring duration is made difficult due to the amount of interfering factors involved (for example: wind, swell, tides, waves height and individual site characteristics like bathymetry and local oceanography). Tidal and wind strength relationships similar to those described by Orpin *et al*. (2004) would be expected at Cape Lambert as a result of local bed shear stress on water column turbidity (caused by currents as a result of tidal movement and sea surface wind). The spatial variability and fluctuations associated with natural turbidity cycles should, therefore, be considered when setting water quality targets. This is particularly the case where tide-dominated waters are concerned, as natural turbidity regimes are often highly variable over space and time in a macro-tidal tropical marine environment (Orpin *et al*. 2004).

Turbidity levels influence coral composition with less turbid waters in offshore areas generally having higher coral cover and diversity than the naturally highly turbid nearshore waters (SKM 2009b). The benthic cover and benthic primary producer habitat (BPPH) at the thirteen monitoring sites were studied in a parallel survey (SKM 2009a). Spatial variability was observed between sites and in some cases was strongly correlated to the environmental variables (water temperature, sedimentation and turbidity). Sites DIE, BLR and BZR, which are all to the west of Cape Lambert and exposed to westerly winds, were similar. While SMSB and MDR showed similarities as well as PLR and HAT.

4.1.3. Light

Light is the primary resource for most BPPHs and provides the basis for the high productivity of tropical coral reefs (Barnes and Chalker 1990). The seasonal pattern of daily surface irradiance and hence the angle of the sun, cloud cover, sea state and light scattering caused by material dissolved and suspended in the water column are all key factors affecting the temporal patterns of light variation in benthic habitats. A considerable trend was observed from the baseline turbidity and light data measured during the monitoring period indicating the influence of turbidity on the light climates at the sites. In a study by Anthony *et al*. (2004), it was concluded that the variance contribution by turbidity to fluctuations in average daily irradiance far outweighed that of clouds and tides. Furthermore it indicated that with increasing depth the variance contribution from turbidity to the light levels recorded increased (Anthony *et al*. 2004), which would explain the substantially lower light levels at HAT and PLR monitoring sites.

4.1.4. Sedimentation

Strong wave climate and large tidal currents at most of the monitoring locations means that there is a continual re-suspension of sediments throughout the Cape Lambert region, especially at exposed sites.

The different rates of sedimentation at adjacent monitoring locations as indicated in the graphs above may be the result of the prevailing oceanography at each location. With the exception of BZI and BTR, all of the offshore locations exhibit generally lower rates of sedimentation. High sedimentation rates are typical of nearshore sites where there is the opportunity for large volumes of sediment to be suspended as a consequence of turbulent mixing associated with wind and tidal driven currents, and terrestrial runoff. It is suggested that sedimentation rates (and type of sediment retained) are determined in large part by local physical processes such as wave climate and strength of tidal currents experienced at the monitoring location.

These data also indicate periods of elevated turbidity during the winter and the summer months, with the lowest sedimentation rates being measured during September, October and November. The physical evidence of elevated turbidity during this time is supported by diver observations as part of SKMs QAQC process (**Appendix A**), which suggest that during the winter and the summer months the water is more turbid and the winds experienced are stronger. Previous studies performed in the area (SKM 2008b) found a similar pattern with higher exhibited sedimentation rates during the winter months. These findings indicate that local weather conditions increase the suspension and movement of sediment within the water column during the winter months.

In addition, the influence of cyclones during these months will affect the amount of sediment recorded in the sediment trap and therefore the sedimentation rate calculated. However, it must be noted that the method employed does not allow for any estimation of the net sedimentation rate. The sediment traps do not measure net sedimentation as the amount of material dropping out of suspension is measured but the resuspension of that material is not accounted for. An increased amount of sediment in the traps during the summer months does not necessarily mean the net sedimentation rates are higher at sites over the summer.

4.1.5. Particle Size Distribution

There is a clear difference between the sediment sizes that are collected by the sediment traps and the sediment cores at each site. The sampling techniques are measuring different processes that occur on the reef. The sediment cores sample the sediment that is deposited on the reef while the sediment traps are sampling sediments that are suspended in the water column. The larger sand particles being distributed on the reef will collect in the depressions and channels within the reef where samples using the core technique were collected. Re-suspension of the fine sediments will also take place at these locations which will reduce the quantity of fine sediments in the sediments.

The sediment traps will only collect material that is small enough to be suspended into the water column. Apart from extreme weather events, it is unlikely the course sediments that are sampled by the core technique would be re-suspended into the water column where they could be collected in the traps.

Due to the distance of the monitoring sites from the potential dredging operations it would be expected that course sediments from any dredge related plume would drop out of the plume within a relatively short distance. However, the fine sediments could remain in the water column and potentially be transported to the monitoring sites. This outcome could be quantified by measuring any increase in the proportion of silt and very fine sediments collected from the core samples that correlate with the timing of dredging activities. Currently the percentage of silt and very fine sediments collected in the core samples is below 15% of the total sample at all the sites.

An increase in the smaller particle size of sediments at sites close to dredging operations has occurred in the past at this location. Sampling during Port A found that sites within a one kilometre radius of where dredging took place revealed the largest changes in particle size distribution. The majority of particle sizes within this area changed from coarse sand/gravel to fine and medium sand (SKM 2008b).

4.1.6. Temperature

Climate, in particular air temperature, appeared to have the greatest influence on the water temperatures recorded at the monitoring sites during the baseline period. Water temperatures at the monitoring sites followed the seasonal trend with temperatures lowest at the end of winter and highest towards the end of summer. Decreases in water temperature were observed following seasonal weather events such as cyclones and large rainfall events. Monitoring sites DLI and BTR

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recorded smaller fluctuations following such events and range between seasons. This may be attributed to the depth, location and open water currents the sites are affected by, indicating that they are less likely to be influenced by air temperatures.

Water temperatures of between 16.5–33.9 ºC were recorded at the monitoring sites during the baseline period. Corals exhibit a temperature tolerance range and below the lower range the coral polyps have difficulty producing calcium carbonate for skeletal structure hindering growth (Veron 1986). Elevated water temperatures can result in coral bleaching as was observed at some of the monitoring sites during a parallel study (SKM 2009a). Coral bleaching is a stress response culminating in the loss of symbiotic dinoflagellate algae, zooxanthellae, from coral tissues (Maynard *et al*. 2009).

Sea surface temperatures of even 1°C above the normal summer maxima and lasting for more than 2–3 days can lead to subsequent bleaching (Goreau & Hayes 1994; Strong *et al*. 1998). Although there are differences in response among coral species and populations, most corals are likely to bleach but survive and recover if temperature anomalies persist for less than a month (Reaser *et al*. 2000). This was seen to be the case during the surveys at the monitoring sites as demonstrated by the corals ability to recover (SKM 2009a). The temperature tolerance of the corals around Cape Lambert is undetermined and therefore the length of time coral species could withstand elevated temperatures is not known.

4.1.7. Summary

The spatial variation at the monitoring sites of the water quality parameters measured during the baseline program at times showed distinct similarities between sites. These similarities were seen between a number of nearshore sites and also at sites located at a greater distance from the mainland. Sites exposed to prevailing wind directions and sites located in close geographical proximity to one another were also similar at times. Sites BLR, BZI and BZR; PLR and HAT; SMSB and MDR; CLW and PWR; and to some extent BTR and DLI are examples of sites indicating signs of comparability. Strong correlations between the benthic cover and water quality parameters were also recorded between certain sites during the Port B BPPH subtidal study (SKM 2009a).

The data collected as part of this study provides a comprehensive baseline water quality data set for the Cape Lambert region. Water quality is impacted by the local oceanography of the monitoring sites and any number of other factors including wind, tidal movements, depth, and rainfall.

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4.2. Site specific water quality triggers

A statistical method to calculate potential impact and influence water quality thresholds for the Port B PER using water quality data collected during Port A was developed and presented in the Port B PER (SKM 2009b). The method was based on the principles of the approach described by McArthur *et al*. (2002). These values were used in the dredge modelling to predict impact and influence to BPPH. The Port A data included water quality data during the dredging campaign. This data captured high values of turbidity experienced during dredging and no associated coral mortality. This allowed ‘maximum’ values to be used that could be directly related to no decline in coral health.

In the draft DSDMP it was proposed that the same statistical method could be used to develop the water quality monitoring triggers for the DSDMP. While the statistical methods are still valid and of value, a limitation has been identified during preliminary analysis of the data. These are described below.

1) Over the duration of the Port A dredging program and Port B baseline data collection three types of loggers were utilised. The Troll 9500 loggers used in the Port A project were replaced with Analite NEP loggers for the start of Port B baseline program as they were considered more reliable. However due to persistent technical issues with the Analite loggers, Wetlabs ECO-NTU-SB loggers were purchased for use for the remainder of the baseline program. An overlap of time for each of the loggers deployed in the field was implemented to allow necessary comparisons of data.

   The three logger types were compared using a Pearson correlation. Correlation measures the strength of the linear relationship between two variables. Pearson's Correlation Coefficient is usually signified by r (rho), and can take on the values from -1.0 to 1.0. Where -1.0 is a perfect negative (inverse) correlation, 0.0 is no correlation, and 1.0 is a perfect positive correlation. R2 (called the coefficient of determination or r squared) can be interpreted as the proportion of variance in Y that is contained in X.

   The results of the comparisons are as follows;

   Analite and Trolls: R=0.6256, r2=0.3914

   Wet Lab and Analite Loggers: R = 0.8510, r2=0.7242

   The R value for the first comparison is moderate; however given the low r2 value and the amount of erroneous data, it does not provide much confidence when trying to remove the “logger effect”. In addition, the correlation between Analites and Trolls was based on less than a month's worth of data at one site due to the unreliability of the Troll data. It is recommended that the Troll data is not used in developing the thresholds.

In contrast, the correlation between the Wetlab and Analite loggers is much stronger (R value of 0.85) indicating there is a relatively constant variability between the data sets. Additionally the r2 value is higher and the relationship is based on a much longer time period spanning over months from 4 different sites. It is recommended that both Analite and Wetlab data be included in the development of site specific thresholds.

2) If the recommendations (above) to remove the Troll 9500 are followed (ie Port A data is not included in the analysis) it means that no data collected during dredging (high turbidity) would be included in the calculation of monitoring thresholds. That is, no data that represents extremes that corals have been exposed to were included. Preliminary analysis of the data excluding Port A data, has found that the trigger values for impact (and influence) are unrealistically low. Further statistical analysis is required to investigate these values further. However the preliminary values are in fact lower than the model predictions for the PER (SKM 2009b) (and lower than for the previous dredge monitoring program). With these trigger values, exeedances would occur all the time. Currently these values do not represent meaningful or useful management triggers.

The final monitoring program and monitoring trigger levels will be developed through the consultation with the Department of Environment and Conservation (DEC).

5. Conclusions

The following conclusions are based on the data collected during the Cape Lambert Port B baseline water quality monitoring program. Data collected captured the natural range of water quality conditions over approximately 12 months (February 2008 to May 2009).

- Spatial and temporal variation at monitoring sites occurred for all parameters measured during the baseline water quality monitoring program.
- Turbidity showed seasonal fluctuation along with being strongly influenced by weather events.
- Turbidity displayed spatial similarities between nearshore sites and those situated further offshore, sites protected by prevailing easterlies and westerlies, and sites in close geographical proximity.
- Shallow sites tended to display the highest light climate, while the deeper offshore sites recorded a smaller range with less fluctuation in daily light levels.
- Light climate and turbidity displayed strong trends during monitoring indicating a potential direct influence of turbidity on light climate.
- Factors influencing the light climate and the amount of light available during the day includes time of year (angle of the sun), cloud cover, sea state and light scattering caused by suspended sediments and dissolved material in the water column.
- Silts and very fine material was predominately present in the water column; however, they only appear to have a minor contribution to the sedimentation on the reef.
- It is suggested that local oceanographic conditions play a large role in sediment deposition and re-suspension at the monitoring sites.
- Sedimentation rates were lower offshore, while the highest rates were experienced at all sites during the winter and the summer months.
- The temporal variability in water temperature follows the same pattern as air temperature with a slight temporal lag.
- Nearshore sites recorded a larger range and fluctuation in water temperature compared to the sites located further offshore.
- Coral bleaching, attributed to high the water temperatures, was observed and was followed by recovery and survival of the corals.
- Preliminary water quality trigger values will be refined and established after further investigation and consultation with the DEC.

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6. References

Abdel-Salam, H.A. and Porter, A.W. 1988. *Physiological effects of sediment rejection on photosynthesis and respiration in three Caribbean Reef Corals*. Proceedings of the 6th International Coral Reef Symposium, Australia. Vol. 2

Anthony, K.R.N., Ridd, P.V., Orpin, A.R., Larcombe, P., and Lough, J. 2004. Temporal variation of light availability in coastal benthic habitats: Effects of clouds, turbidity, and tides. *Limnol. Oceanogr.*, 49(6)

Barnes, D.J., and Chalker, B.E. 1990. *Calcification and photosynthesis in reef-building corals and algae*. p. 109–131. In Z. Dubinsky [ed.], Ecosystems of the world: Coral reefs. Elsevier.

Goreau, T.J., and Hayes, R.L. 1994. Coral bleaching and ocean “hot spots.” *Ambio* 23:176-180.

In-Situ Marine Optics. 2007. *Plume-specific Optical Water Quality Relationships for Cape Lambert dredge operations (Trip 2)*. In-Situ Marine Optics Pty. Ltd.

Maynard, J.A., Johnson, J.E., Marshall, P.A., Eakin, C.M., Goby, G., Schuttenberg, H., and Spillman, C.M., 2009. A Strategic Framework for Responding to Coral Bleaching Events in a Changing Climate. *Environmental Management* DOI 10.1007.

McArthur, P.E., Ferry, R., and Proni, J. 2002. *Development of guidelines for dredged material disposal based on abiotic determinants of coral reef community structure.* Proceedings of the Third Specialty Conference on Dredging and Dredging Material Disposal. Coasts, Oceans, Ports and River Institute (COPRI) of ASCE May 5, 2002, Orlando, FL, USA.

Orpin, A.R., Ridd, P.V., Thomas, S., Anthony, K.R.N., Marshall, P. and Oliver, J. 2004. Natural turbidity variability and weather forecasts in risk management of anthropogenic sediment discharge near sensitive environments. *Marine Pollution Bulletin* 413: 602-614.

Reaser, J.K., Pomerance, R., Thomas, P.O. 2000. Coral bleaching and global climate change: Scientific findings and policy recommendations. *Conservation Biology* 14, 1500-1511.

Sinclair Knight Merz, 2008a. *Cape Lambert Port B Development Dredging and Dredge Spoil Management Plan*, Revision 1.

Sinclair Knight Merz, 2008b. *Dredging program for the Cape Lambert Port Upgrade 85 Mtpa – Particle Size Distribution Report, Revision 2*. Sinclair Knight Merz, Perth.

Sinclair Knight Merz, 2009a. *Cape Lambert Port B Development Benthic Primary Producer Habitat (BPPH) Monitoring Report (Subtidal) for 2009* Sinclair Knight Merz, Perth.

Sinclair Knight Merz, 2009b. *Cape Lambert Port B Development Public Environmental Review and Draft Public Environment Report*. EPBC Referral Number 2008/4032. Prepared for Rio Tinto Iron Ore.

Strong, A. E., Goreau, T.J., and Hayes, R.L. 1998. Ocean Hotspots and coral reef bleaching: January-July 1998. *Reef Encounters* 24:20-22.

Veron, J.E.N. 1986. *Corals of Australia and the Indo-Pacific*. North Ryde, N.S.W.: Angus & Robertson.

Appendix A Quality Assurance Checklist

Purpose

As a part of the water quality monitoring regime for the Cape Lambert Port B development, Sinclair Knight Merz (SKM) is committed to providing thorough details of actions carried out during the program, to provide documentation and data for quality assurance and quality control (QAQC) purposes. SKM ensure that the following points were adhered to throughout the life of the monitoring program, given the importance of the data collection.

- All data sheets forwarded between parties were accompanied with corresponding 'metadata' which outlines the key details of the data obtained.
- All types of data collected were aligned against a consisting time-stamp to allow accurate comparisons and analysis using computer modelling.
- In cases where data gaps are present, the time series was continued to remain consistent so that any data gaps are obvious.
- The original downloaded data will always be stored as a 'raw' copy and will not be altered in any way; all modification and analysis of the data will be made from a copy of the 'raw' data
- Details of deployment, data retrieval, photographs, observations, etc were recorded on field sheets for the turbidity and temperature loggers for QAQC purposes (Field QAQC example given below)
- Maintenance regime for the loggers was recorded.

Example of Field QAQC

During each fortnight for the baseline monitoring period, the field team for SKM completed field QAQC sheets. An example of a completed QAQC sheet is given below, along with the photographs taken to examine fouling on the loggers. This data is retained as hard and/or digital copies and is available upon request.

The example selected was from Baseline Survey 27 (23-26 March 2009) due to the fairly good underwater visibility experienced during this trip. This allows for clear photographs enabling the loggers to be clearly shown *in situ*. Similarly, DLI was selected as during this time all logger types (Wetlabs and Analite turbidity loggers, TidBit temperature loggers, and the ALEC light loggers) can be seen in the photographs.

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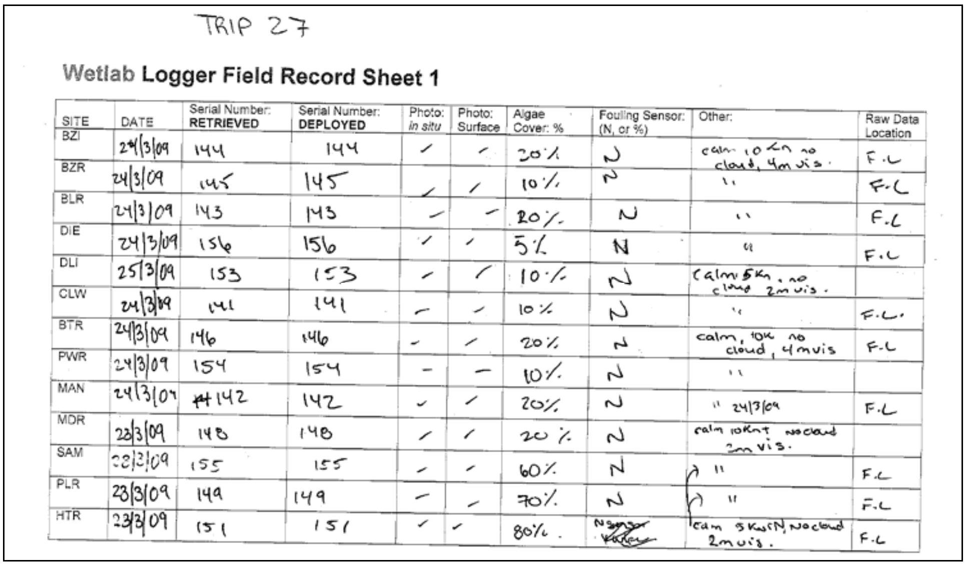

TRIP 27

Wetlab Logger Field Record Sheet 1

SITE	DATE	Serial Number: RETRIEVED	Serial Number: DEPLOYED	Photo: *in situ*	Photo: Surface	Algae Cover: %	Fouling Sensor: (N, or %)	Other:	Raw Data Location
BZI	24/3/09	144	144	✓	✓	20%	N	calm 10 kn no cloud, 4m vis.	F.L
BZR	24/3/09	145	145	✓	✓	10%	N	"	F.L
BLR	24/3/09	143	143	✓	✓	20%	N	"	F.L
DIE	24/3/09	156	156	✓	✓	5%	N	"	F.L
DLI	25/3/09	153	153	✓	✓	10%	N	Calm 5kn, no cloud 2m vis.	
CLW	24/3/09	141	141	✓	✓	10%	N	"	F.L.
BTR	24/3/09	146	146	✓	✓	20%	N	calm, 10k no cloud, 4m vis	F.L
PWR	24/3/09	154	154	✓	✓	10%	N	"	
MAN	24/3/09	142	142	✓	✓	20%	N	" 24/3/09	F.L
MDR	23/3/09	148	148	✓	✓	20%	N	calm 10knt no cloud 2m vis.	
SAM	23/3/09	155	155	✓	✓	60%	N	"	F.L
PLR	23/3/09	149	149	✓	✓	70%	N	"	F.L
HTR	23/3/09	151	151	✓	✓	80%	N sensor [illegible]	calm 5knts N, no cloud 2m vis.	F.L

Figure A1 Wetlab Turbidity Logger Record QAQC Sheet

Figure A2 DLI logger photographs (Baseline Survey 27 – 25/03/09)

Appendix B Logger Comparison

Introduction

During baseline water quality monitoring, turbidity and temperature data was collected from three different brands of loggers; turbidity data was collected from Troll, Analite and Wetlabs, while temperature data was collected by Troll, Analite and TidBit temperature loggers. At the beginning of the monitoring period, both Analite and Troll loggers were simultaneously deployed to obtain a period of overlapping data. Similarly, when it was necessary to replace the Analite loggers due to issues with the data which arose over time, the new Wetlabs (turbidity) and TidBit (temperature) loggers were deployed at the same time as continuing to obtain data from the Analite loggers. These periods of direct overlap in readings obtained at the same time by two different logger types allow for a direct comparison of the data.

Methods

All data from each logger type was tabulated for each site, and areas of data overlap were established. Data indicated an overlap in:

- Analite and Troll data, both turbidity and temperature, from the beginning of the monitoring period for a few months, or
- Analite and Wetlabs turbidity and temperature data from approximately December 2008 to the end of the baseline survey period in May 2009.

If the data sets were missing data, this data was then manipulated by removing any time codes and all associated data values for each set of turbidity and temperature readings. Temperature data was not manipulated in any way prior to analysis, and the overall regressions given below are the result of combining all available data from each site from December 2008 to May 2009.

However, following initial analyses performed on raw turbidity data, all subsequent regression analyses were performed on smoothed turbidity data to minimise the effect of outliers. Multiple regression analyses were performed for both sets of loggers to determine if the turbidity data obtained by these loggers is comparable, and if so to establish a formula to manipulate the data in order to examine all turbidity data as a whole rather than three (3) separate turbidity data sets.

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The regression analyses performed on the data are explained below.

- Raw turbidity data: regression analyses were applied to the raw data prior to smoothing equations application.
- Smoothed turbidity data: regression analyses were applied to the smoothed turbidity data (methods described in **Section 2.5**)
- Site specific smoothed turbidity data: diver observations and turbidity results throughout the study period indicate that there are site differences between turbidity data recorded. Therefore, regression analyses were performed by site.
- 7 days post-deployment smoothed turbidity data: diver observations indicate that fouling within the study area has been an on-going problem with turbidity readings. In addition, diver observations confirm that bi-fouling on the loggers greatly increases with the length of time the loggers are deployed. Therefore, regression analyses were performed selecting only the smoothed turbidity data available from the first 7 days following logger deployment, for both site specific regressions and an overall regression combining all data.
- 1 month post-deployment smoothed turbidity data: diver observations and turbidity data results indicate that over time the reliability of data obtained by each logger type decreases. Regression analyses were performed (both overall and site specific smoothed turbidity data) selecting only the smoothed turbidity data from the first month of logger deployment.
- Smoothed turbidity data up to date of first data emission: diver observations and turbidity data suggests that the reliability of the data obtained by various individual loggers can vary greatly. Therefore, all smoothed turbidity data was selected up until the first time the data obtained by individual loggers required omitting before regression statistics were applied (for both overall and site specific analyses).
- Reliable logger smoothed turbidity data: diver observations and turbidity data during the periods when multiple loggers types at each site were deployed, suggests that the loggers deployed at individual sites consistently provide more reliable data with less omitting of data required. The smoothed turbidity data obtained from the sites with reliable loggers was combined and regression analyses were applied.

Results and Interpretation

Tabular and graphical summaries of the logger comparisons performed during baseline water quality monitoring are presented within this section. The regression analyses performed on turbidity data are summarised in **Table B1**, while regression analyses for temperature data are shown in **Table B2**.

Table B1 Regression statistics on analyses performed for turbidity data

	Analite/Troll		Analite/Wetlabs	
Regression analysis performed	**Regression equation**	**R2 value**	**Regression equation**	**R2 value**
Raw turbidity data	y=0.0121x + 18.375	0.0001	y=0.0953x + 2.3871	0.1304
Smoothed turbidity data	y=0.1779x + 14.293	0.0258	y=0.3851x + 0.6543	0.5227
BLR smoothed turbidity data	y=1.0581x + 4.5356	0.6315	y=0.1756x + 0.9063	0.1668
BTR smoothed turbidity data	-	-	y=0.4359x – 0.0950	0.5115
BZI smoothed turbidity data	y=-0.0592x + 14.658	0.0031	y=0.3939x + 0.8280	0.4312
CLW smoothed turbidity data	-	-	y=0.1269x + 2.4889	0.2455
DIE smoothed turbidity data	-	-	y=0.5841x – 1.2988	0.4579
DLI smoothed turbidity data	-	-	y=0.3297x + 0.0889	0.3668
HAT smoothed turbidity data	-	-	y=0.4639x – 0.3377	0.6987
MAN smoothed turbidity data	-	-	y=0.5450x + 0.0743	0.7538
MDR smoothed turbidity data	-	-	y=0.4794x + 0.1609	0.6961
PLR smoothed turbidity data	-	-	y=0.0429x + 1.5162	0.1327
SMSB smoothed turbidity data	-	-	y=0.5314x + 0.6395	0.8061
7 days post-deployment smoothed turbidity data regression analyses				
Smoothed turbidity data	y=0.0247x + 5.8578	0.0031	y=0.3344x + 0.5553	0.3649
BLR smoothed turbidity data	y=0.9170x + 5.4590	0.6138	y=0.1621x + 0.9734	0.1418
BTR smoothed turbidity data	-	-	y=0.4674x + 0.1556	0.4329
BZI smoothed turbidity data	y=0.0248x + 5.9673	0.0031	y=0.5392x + 0.3157	0.6118
CLW smoothed turbidity data	-	-	y=0.5021x – 0.0879	0.6692

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	Analite/Troll		Analite/Wetlabs	
Regression analysis performed	Regression equation	R2 value	Regression equation	R2 value
DIE smoothed turbidity data	-	-	y=0.5633x – 1.0823	0.4193
DLI smoothed turbidity data	-	-	y=0.0664x + 0.7790	0.0595
HAT smoothed turbidity data	-	-	y=0.0510x + 1.0419	0.0484
MAN smoothed turbidity data	-	-	y=0.5734x + 0.2507	0.8705
MDR smoothed turbidity data	-	-	y=0.1202x + 1.4358	0.1665
PLR smoothed turbidity data	-	-	y=0.0416x + 1.4764	0.1333
SMSB smoothed turbidity data	-	-	y=0.5193x + 0.6169	0.8120
1 month post-deployment smoothed turbidity data				
Smoothed turbidity data	y=0.1729x + 14.534	0.0246	y=0.3112x + 0.3594	0.2857
BLR smoothed turbidity data	y=0.8018x + 8.9878	0.3914	y=0.0010x + 0.7575	0.0007
BTR smoothed turbidity data	-	-	y=0.4102x – 0.0371	0.3433
BZI smoothed turbidity data	y= - 0.0624x + 15.09	0.0035	y=0.6719x + 0.0529	0.7784
CLW smoothed turbidity data	-	-	-	-
DIE smoothed turbidity data	-	-	y=0.5834x – 1.2852	0.4581
DLI smoothed turbidity data	-	-	y= - 0.0039x + 0.7048	0.0024
HAT smoothed turbidity data	-	-	y= 0.2754x + 0.5040	0.3473
MAN smoothed turbidity data	-	-	-	-
MDR smoothed turbidity data	-	-	y=0.0296x + 1.3472	0.0688
PLR smoothed turbidity data	-	-	y=0.0086x + 1.5469	0.0112
SMSB smoothed turbidity data	-	-	y=0.4639x + 0.5364	0.7662

	Analite/Troll		Analite/Wetlabs	
Regression analysis performed	**Regression equation**	**R2 value**	**Regression equation**	**R2 value**
Smoothed turbidity data up to date of first data emission				
Smoothed turbidity data	y=0.8831x + 7.6081	0.4533	y=0.4100x + 0.1298	0.3883
BLR smoothed turbidity data	y=0.7145x + 11.074	0.3418	y=0.0065x + 0.6706	0.0037
BTR smoothed turbidity data	-	-	y=0.4169x – 0.1686	0.3788
BZI smoothed turbidity data	y= - 0.3377x + 5.8732	0.0017	y=0.6606x + 0.5432	0.7837
CLW smoothed turbidity data	-	-	-	-
DIE smoothed turbidity data	-	-	y=0.5841x – 1.2988	0.4579
DLI smoothed turbidity data	-	-	y=0.0579x + 0.6352	0.0450
HAT smoothed turbidity data	-	-	y=0.4653x + 0.8649	0.7420
MAN smoothed turbidity data	-	-	-	-
MDR smoothed turbidity data	-	-	y=0.0796x + 1.1961	0.2045
PLR smoothed turbidity data	-	-	y=0.0065x + 1.6519	0.0072
SMSB smoothed turbidity data	-	-	y=0.0611x + 1.0476	0.0561
Reliable logger smoothed turbidity data				
Smoothed turbidity data	y=1.0581x + 4.5356	0.6315	y=0.5085x + 0.0573	0.7242

Table B2 Regression statistics on analyses performed for temperature data

	Analite/Troll		Analite/TidBit	
Regression analysis performed	Regression equation	R2 value	Regression equation	R2 value
All temperature data	y=0.9673x + 0.8115	0.8942	y=0.7371x + 7.8358	0.7899
BLR	y=0.5160x + 14.9105	0.5910	y=0.7371x + 7.8358	0.7899
BTR	-	-	y=0.9663x + 1.4594	0.9883
BZI	y=1.0275x - 0.8462	0.8083	y=0.9879x – 0.1553	0.9914
BZR	y=0.9950x – 0.3457	0.9876	y=0.6949x + 8.6121	0.6445
CLW	-	-	y=0.9718x + 0.2697	0.9973
DIE	-	-	y=0.9836x – 0.6449	0.9983
DLI	-	-	y=0.9785x + 1.0356	0.9969
HAT	-	-	y=0.9592x + 0.6042	0.9833
MAN	-	-	y=0.9723x + 1.2185	0.9973
MDR	-	-	y=0.9714x + 1.8675	0.9954
PLR	-	-	y=0.9769x – 0.4200	0.9987
PWR STN	-	-	y=0.9551x + 1.8206	0.9969
SMSB	-	-	y=0.9693x + 1.4317	0.9976

Regression analysis for both turbidity data collected for the Analite/Troll and Analite/Wetlabs comparisons indicated that there is a relationship between data recorded by the different logger types. This relationship is not always strong or even consistent and will vary between individual loggers. Data, along with diver observations, indicated that certain individual loggers for all logger types consistently recorded more reliable data (i.e. smoothed data that was assessed to be reliable with no obvious erroneous data, for example, where data was observed to plateau or reach the upper limit of the recording range). Therefore, a regression equation to apply to data obtained by the turbidity logger types was determined from loggers which were shown to be reliable during the period when multiple loggers were recording turbidity at each site.

However, all temperature data obtained for both the Analite/Troll and the Analite/Wetlabs comparison demonstrated a strong relationship between the data recorded by different loggers. Unlike turbidity, where certain individual sensors within the loggers were shown to be more reliable, it is suggested that the temperature sensors within the loggers generally have less variability in the readings recorded and so the data obtained from various loggers is more reliable.

Analite and Troll

Troll and Analite logger sets were deployed at the beginning of the monitoring period at BLR (2 sets), BZI and BZR (both had 1 set). The loggers deployed at BZR experienced issues during the time they were deployed and did not record any reliable data at the same time as each other for the duration of the monitoring period, so no further analyses were performed. Investigation into the data from BZI, showed large sections were necessary to be removed, and in addition QAQC records indicate that it was necessary to replace the Analite logger with another individual. For these reasons, the data obtained from both BZI and BZR was assessed to be unreliable and so removed from analysis. Reliable data was obtained only from loggers deployed at BLR; this is for a variety of reasons, namely the issues arising from the Analite logger. Using reliable turbidity data, a strong positive correlation (R^2 = 0.6315) is established between the turbidity data for the Analite/Troll comparison (**Figure B1**). The correlation exhibited between temperature data recorded at all sites by the Troll and Analite loggers was significantly stronger, where R^2 is 0.8942 (**Figure B2**)

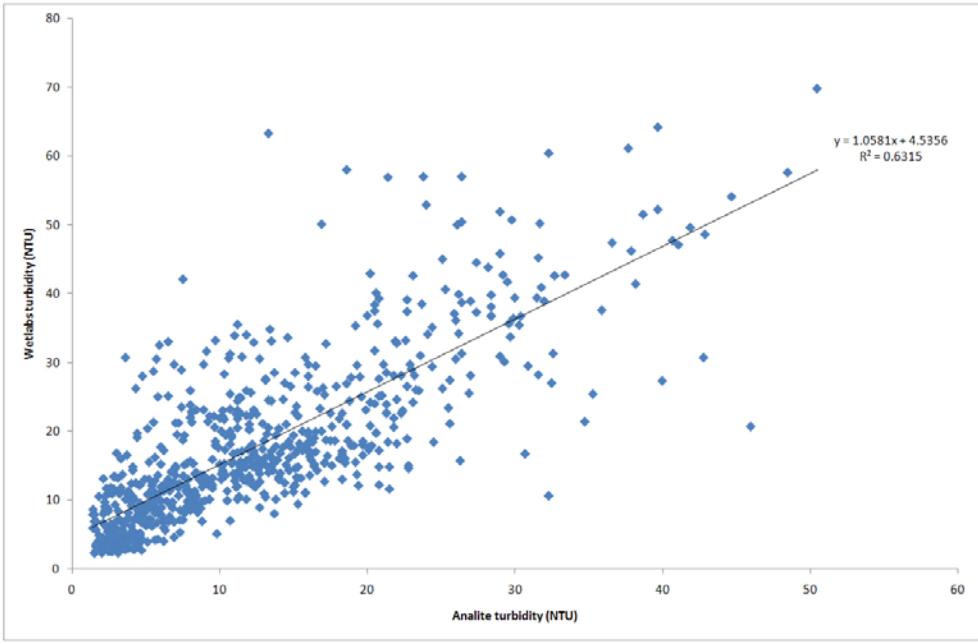

Figure B1 Regression between Analite and Troll turbidity data

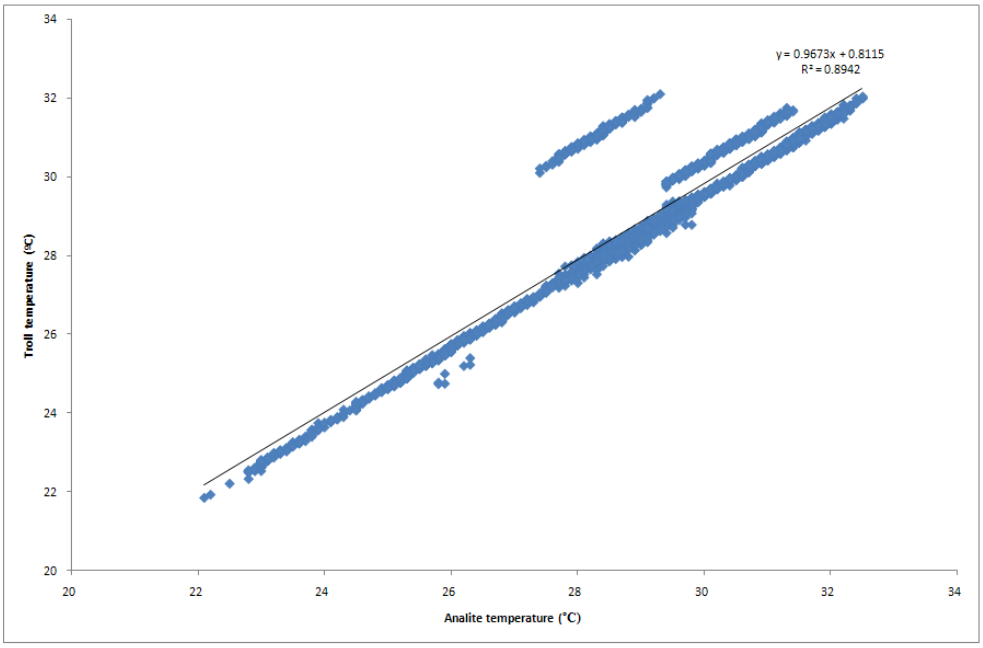

Figure B2 Regression between Analite and Troll temperature data

Analite and Wetlabs

In December 2008, Wetlabs and Analite logger sets were deployed at all of the monitoring locations to obtain a period of concurrent turbidity data. Data obtained from BZR and PWR was unsuitable for analyses due to malfunctions with one or the other of the loggers throughout the entire length of time the set of loggers was deployed. Therefore, these sites were removed from further analyses.

Diver observations as part of SKMs QAQC process indicate that four (4) sites were shown to have loggers that generally recorded turbidity data which was considered to be more reliable. The data from these sites (HAT, MAN, MDR and SMSB) was combined to determine a suitable regression equation. A strong positive correlation exists between the data collected by the Analite and Wetlabs turbidity loggers (**Figure B3**). In comparison, the temperature sensors in both the Analite and TidBit loggers were shown to be closely aligned without removing data from unreliable loggers where R^2 is 0.7899 (**Figure B4**).

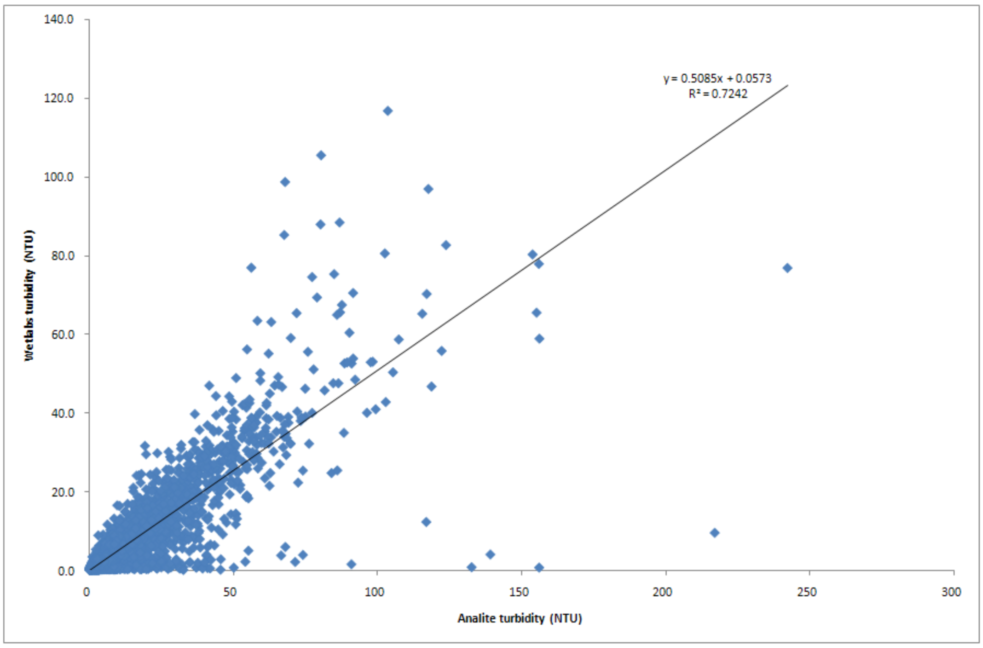

Figure B3 Regression between Analite and Wetlabs turbidity data

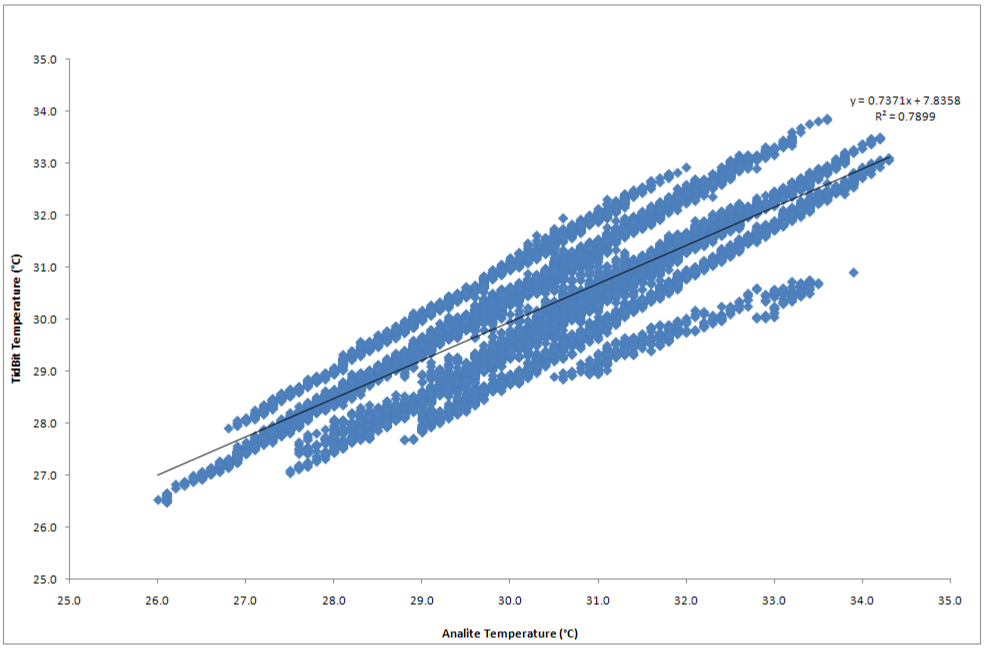

Figure B4 Regression between Analite and TidBit temperature data

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Appendix C Tropical Cyclone Events

Summary

There were five (5) tropical cyclones (listed below) which occurred around Cape Lambert area during the baseline monitoring period. The first (Nicholas) occurred just prior to the deployment of the Analite loggers in February 2008, while the rest of the tropical cyclones occurred during periods when the turbidity loggers were deployed so obtaining data throughout the period of influence. These are summarised below, followed by detailed information about each cyclone.

Table C1 Summary details of tropical cyclones which occurred during baseline water quality monitoring

Date [1]	Tropical Cyclone Name [1]	Maximum Category [1]	Maximum Sustained Wind Gust (km/h) [1]	Total Rainfall (Karratha) (mm) [2]
10/02/08 – 20/02/08	Nicholas	3	130	N/A
25/02/08 – 17/03/08	Ophelia	2	100	N/A
15/12/08 – 28/12/08	Billy	4	175	0.0
24/01/09 – 27/01/09	Dominic	2	95	181.6
04/03/09 – 11/03/09	Freddy	2	95	5.2

N.B. Climate and tropical cyclone information was obtained via the Australian Government Bureau of Meteorology (BOM) WebPages.

- [1] http://www.bom.gov.au/announcements/sevwx/
- [2] **Total rainfall (mm) was calculated by adding each daily rainfall total for the dates given in Table C1.** http://www.bom.gov.au/climate/dwo/IDCJDW6064.latest.shtml\

Appendix D Remote Sensing Water Quality Survey Report

SINCLAIR KNIGHT MERZ

SKM

Rio Tinto

Cape Lambert Port B

REMOTE SENSING SURVEYS WATER QUALITY MONITORING REPORT

- Rev 1
- 23 July 2009

Cape Lambert Port B

REMOTE SENSING SURVEYS WATER QUALITY MONITORING REPORT

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1. Introduction

The proposed Cape Lambert Port B development (the Port B development) will involve the construction of new facilities adjacent to the existing Cape Lambert Operations. The dredging and spoil disposal program associated with the development may potentially influence water quality in close proximity to the Port B development. The aim of this survey is to investigate the potential to use satellite images using MODIS imagery to measure temporal and spatial variation in turbidity around Cape Lambert.

MODIS Satellite imagery is an ideal tool to assess turbidity due to its frequency of return and near world coverage. Sensors on board measure solar radiation reflected by the surface water which can be correlated to quality parameters (Hellweger *et al.* 2004). The 250m Band 1 (620–670 nm) has sufficient sensitivity to detect a range of variations to map the concentration of TSS in the study area of coastal waters (Chen *et al.* 2007) and can be used to create a linear relationship with in-situ measurements

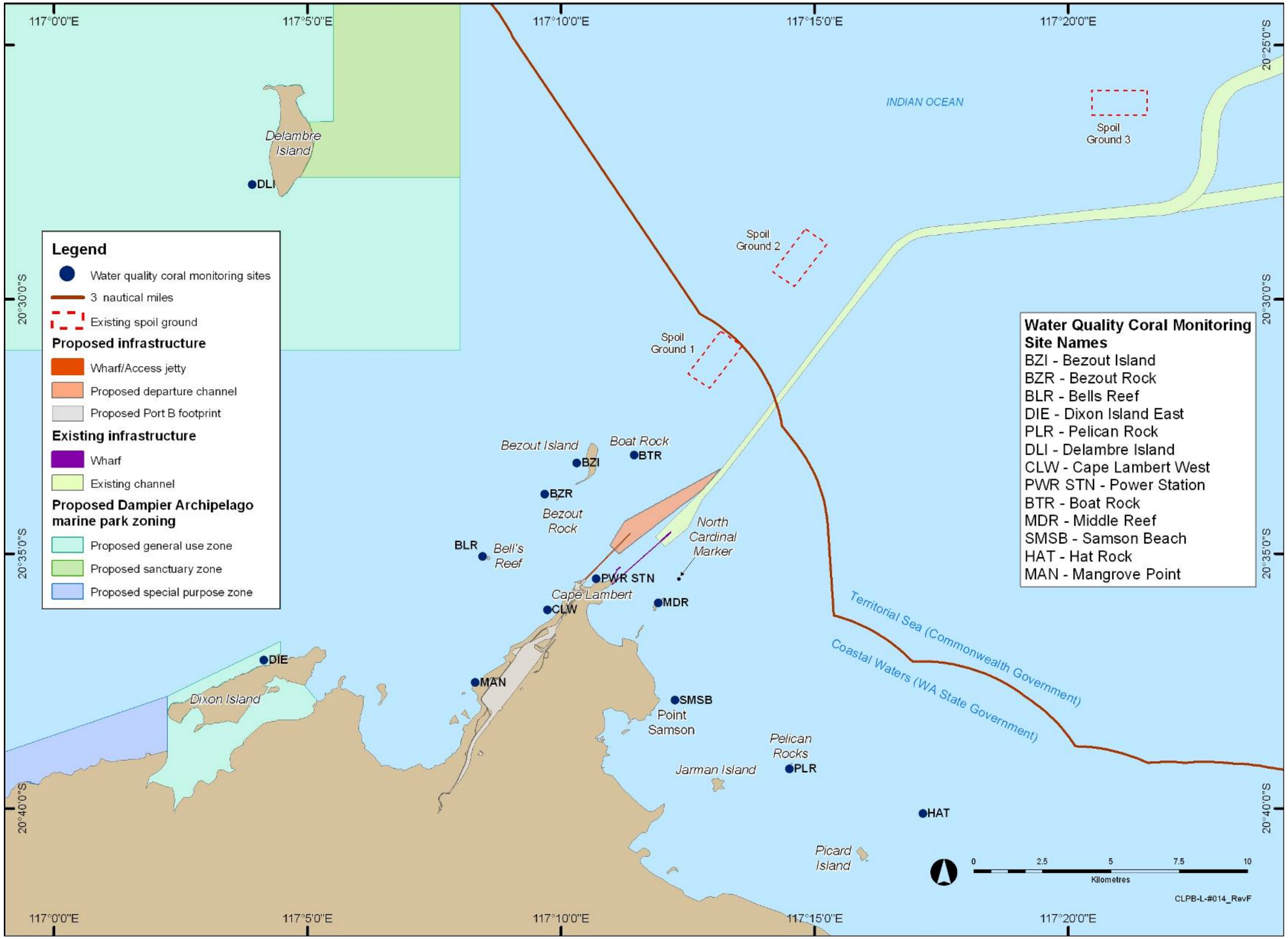
The objectives of this work were as follows:

To capture satellite images of surface water quality conditions in the Cape Lambert area while there was no dredging in the region. Images were to be captured post dredging from CLU 85 and pre dredging for CL Port B. These images/data will be useful to document the natural variability in turbidity in the Cape Lambert Region during a 12 month cycle.

Dates were to be selected during the year to include high turbidity events such as during or after cyclones or high tidal ranges. These will be able to directly compare to during a dredging program. Satellite imagery is preferred over aerial images captured from a light aircraft due to the ability to obtain images from an earlier time period, and also as the data can be utilised in future for model verification exercises. The data acquired from the Satellite images will be processed and results will be important information to feed into the future monitoring programs and the DSDMP.

This report represents a comparison of the turbidity observed on satellite images to that of the turbidity recorded during the Port B water quality monitoring program (SKM 2009). The turbidity data set available for use in this report is comprised of two sets of data: the first, baseline data collected for the Cape Lambert Port B development from 21 February 2008 to 28 May 2009; and the second, data collected as part of the Cape Lambert Port Upgrade 85Mtpa (Port A) monitoring study, data that includes baseline data and periods of dredge activity and influence running from 7 February 2007 to 08 January 2008. Turbidity loggers were deployed at 13 monitoring sites in the vicinity of Cape Lambert during the Port B baseline monitoring program.

The water quality monitoring sites located near Cape Lambert are illustrated in **Figure 1**.



- **Figure 1 Study area and monitoring locations at Cape Lambert, Western Australia.**

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2. Methods

Satellite images were captured by Earth Observation and Mapping (EOMAP's) using MODIS imagery. The images were selected to capture a range of 'natural turbidity' events across seasons for a duration of over 12 months (**Table 1**).

MODIS satellite images were processed using image analysis techniques to map the concentration of TSS in the study area. In this study, land areas were masked to focus analysis on the target area and the raw satellite data in 12-bit format was stretched into 8-bit to enhance the contrast difference on water surface. Unsupervised image classification was then undertaken using 10 data classes. Successful classes that adequately represented spectral variation of the water surface were retained and the remaining classes were submitted to a further unsupervised classification until all classes represented the spectral variation on the water surface successfully.

The MODIS image classification values (Low, Medium, High) were compared to Port B water quality values. An indicative range of turbidity values are provided in **Table 2**.

The turbidity graphs presented in **Appendix A** of this report were configured to align with the period leading up to and dates in which the satellite images were classified. The methods used to collect the turbidity data is outlined in detail in the Cape Lambert Port B Marine Water Quality Baseline Monitoring Report (SKM 2009).

- **Table 1 Dates and information relative to the satellite images captured.**

Season	Weather Conditions	Satellite Image
Summer Cyclone	Light winds on day of image capture during a spring tide cycle. Captured image following on from Tropical Cyclone Nicholas.	**Figure 2**
Autumn	Light to calm wind conditions at the start of a neap tide cycle.	**Figure 3**
Winter	Light to moderate north east winds at the end of a neap tide cycle.	**Figure 4**
Winter	Strong easterly winds on a spring tide cycle.	**Figure 5**
Spring	Light strengthening to moderate northerly winds on a spring tide cycle.	**Figure 6**
Spring	Light to moderate westerly winds on neap tide cycle.	**Figure 7**
Summer Cyclone	Cyclone Billy passed through region, medium tide on date of classification.	**Figure 8**
Summer	Moderate westerly winds (previous day- light winds) on a neap tide cycle.	**Figure 9**
Summer	Moderate westerly winds on date of classification, spring tide. Cyclone Dominic passed though region (26-01-09).	**Figure 10**
Summer	Moderate winds on a medium tide. Large rainfall event on the 15-02-09 which resulted in elevated turbidity readings.	**Figure 11**

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- **Table 2 Indicative range of turbidity**

Wetlab loggers	
Range	**NTU Values**
Low	0 - 1.5
Medium	1.5 - 5
High	5+
Analite loggers	
Range	**NTU Values**
Low	0 - 3
Medium	3 - 7
High	7+

3. Results

3.1. MODIS Images and Turbidity Data

Ten satellite images were captured across a range of tide, wind and weather events. A description of each of the processed images is presented in **Table 3**.

A discussion on the processed image, with reference to the Port B water quality data (**Figure A 1** through to **Figure A 8** (**Appendix A** of this report) is also provided. The turbidity graphs correspond to the water quality recorded at each monitoring site leading up to the dates of classification of the satellite images (**Table 1**).

The results show that there is a strong correlation between the satellite image and the water quality values. Some key examples include:

- Elevated turbidity in the study area captured in **Figure 2** and **Figure 8** following Cyclone Nicholas and Billy (**Appendix B** of this report) was also captured by the turbidity loggers during the Port B baseline monitoring period **Figure A 1** and **Figure A 8**.
- Low levels of turbidity were captured by **Figure 3**, **Figure 7** and **Figure 10** during times of low to moderate wind across a range of seasons and tides (**Appendix C** of this report). Turbidity levels measured by the loggers also recorded low levels of turbidity during these dates (**Figure A 2**, **Figure A 5** and **Figure A 8**).

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- **Table 3 Summary of satellite images captured**

Satellite Image	Summary Description	Corresponding Turbidity Graph (Appendix A)
Figure 2	The image indicates medium to high turbidity at all of the monitoring sites. Medium to low turbidity was classified throughout the remaining study area and extended beyond Delambre Island, the most offshore of the monitoring sites for the Port B Baseline Water Quality Monitoring program. The image was captured several days after Tropical Cyclone Nicholas passed through the region (**Appendix B**). Elevated turbidity was observed on 21 February 2008 during an aerial survey following the passing of the cyclone. This coincided with the commencement of the Port B water quality monitoring program. Elevated turbidity was recorded by the *in situ* loggers with a peak in turbidity on 24 February following strong winds and rainfall on a spring tide. The turbidity recorded remained elevated for the date of classification of the satellite image (26 February 2008). The factors outlined above support the turbidity observed on the satellite image.	**Figure A 1**
Figure 3	The image indicates very low to low turbidity across the study area during Autumn. The areas of low turbidity are observed in close proximity to the mainland and other land masses. This reflects the light to calm winds and neap tide cycle at the time the image was captured. The water quality data supports image classification with low turbidity recorded at all monitoring sites.	**Figure A 2**
Figure 4	This image was captured during Winter on a day with light to moderate winds during a neap tide cycle resulting in low turbidity surrounding the majority of sites. A band of medium turbidity is captured offshore of the study area. The water quality data recorded low turbidity levels during this period.	**Figure A 3**
Figure 5	This image was also captured during Winter although it was taken on a day of strong easterly winds and during a spring tide cycle. Individually or a combination of these two factors could have contributed to the medium to high turbidity observed at the nearshore and easterly exposed monitoring locations. The image clearly depicts increased levels of turbidity on the east side of Cape Lambert, Bezout Island and Delambre Island. The water quality data for the corresponding period also recorded elevated turbidity at nearshore and easterly exposed locations.	**Figure A 4**
Figure 6	The following two images were captured in Spring, the first during a spring tide cycle and the second on a neap tide cycle. Periods of light to moderate winds were experienced on both occasions the images were taken. The two images taken ten days apart appear very similar, as was the case with the available data recorded by the turbidity loggers on those dates. This implies that in this instance the difference between the spring and neap tide cycle was not considerable.	**Figure A 5**
Figure 7		**Figure A 5**
Figure 8	The image was captured during Summer while the study area was under the influence of Tropical Cyclone Billy which was passing through the region (**Appendix B**). High to median turbidity was classified at all of the monitoring sites with the exception of DLI. Monitoring sites HAT, PLR and MAN are surrounded by high turbidity in the image. The in water measurements support the turbidity observed on the satellite image classification. The recorded data peaked on 25 December 2008 with levels remaining elevated three days later on 28 December when the satellite image was captured. Monitoring sites HAT, MAN and PLR had the highest turbidity while DLI was considerably lower than the rest.	**Figure A 6**
Figure 9	The image taken during Summer indicates low turbidity around the monitoring sites on the date of classification. However medium turbidity is observed at monitoring site MAN. This was also reflected in the turbidity data recorded with MAN having the highest turbidity and the remaining sites having an overall low turbidity. The large amount of activity observed on the image offshore would be attributed to cloud cover.	**Figure A 7**
Figure 10	Tropical Cyclone Dominic had passed through the region six days prior to the satellite image being captured. However this was not reflect in the MODIS image, rather the image only indicated low turbidity across the study area. This was not supported by the *in situ* loggers, where turbidity was still slightly elevated. This may be a result of surface turbidity differing to turbidity at depth.	**Figure A 7**
Figure 11	This image was also captured during Summer, low turbidity was visible across all of the monitoring sites on the image. This was also reflected in the *in situ* water quality data, where low turbidity was recorded at all of the sites. The observed low turbidity was to be expected during a period of moderate winds on a mid tide cycle. The image was originally intended to capture the effects of a large rainfall event in the region (15 February 2009) which resulted in a large peak in turbidity being recorded at all but one of the sites. However, the image taken on 23 February 2009 was the first available image to be captured following this event. As a result the influence the event had on turbidity in the study area was not able to be documented by means of the satellite image survey technique.	**Figure A 8**

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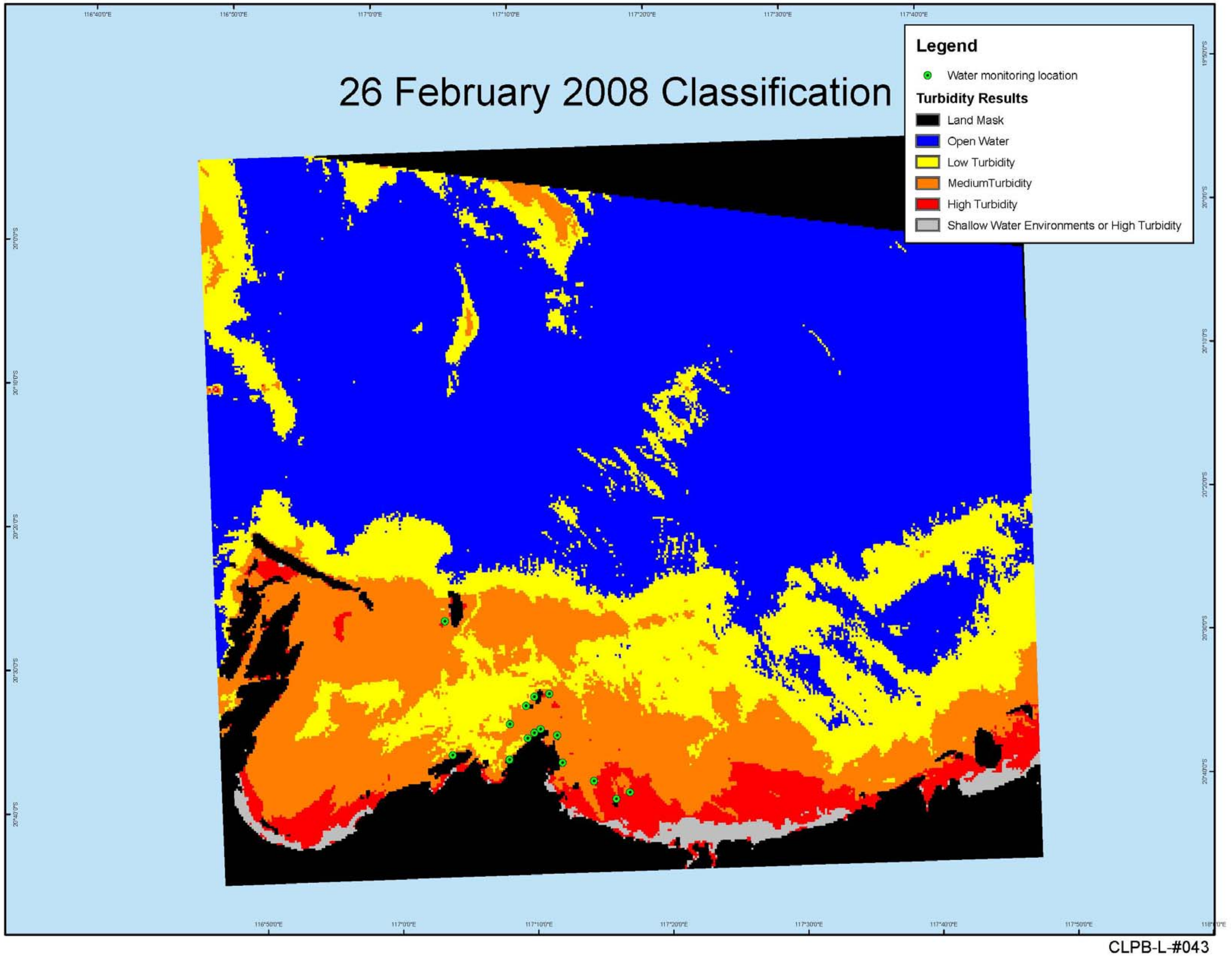

- **Figure 2 Satellite image capturing surface water quality conditions in the Cape Lambert area- 26 February 2008**

*Note: **Figure 2** and **Figure 3** were processed at the completion of Port A, equating to the differences seen in the images*

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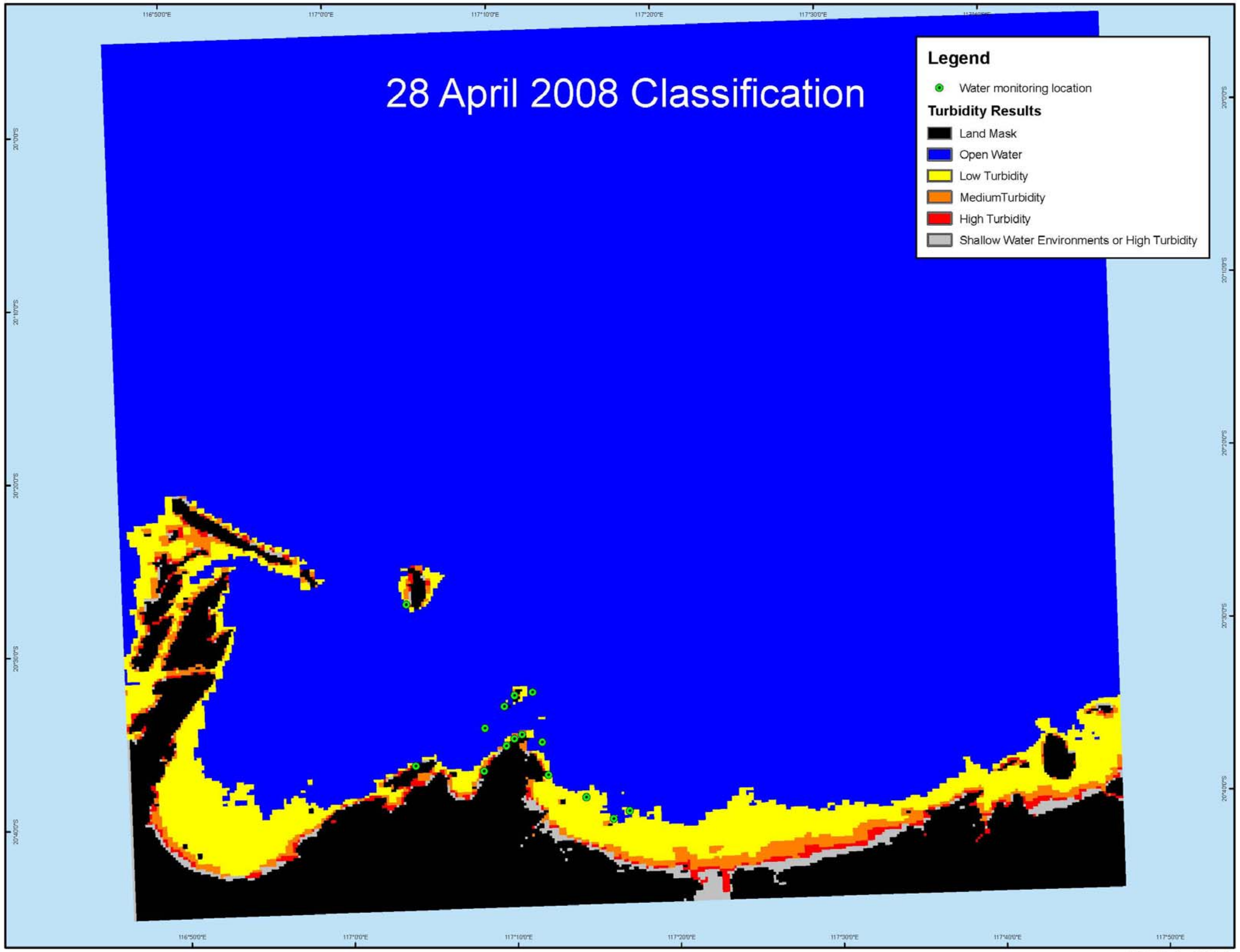

- **Figure 3 Satellite image capturing surface water quality conditions in the Cape Lambert area- 28 April 2008**

*Note: **Figure 2** and **Figure 3** were processed at the completion of Port A, equating to the differences seen in the images*

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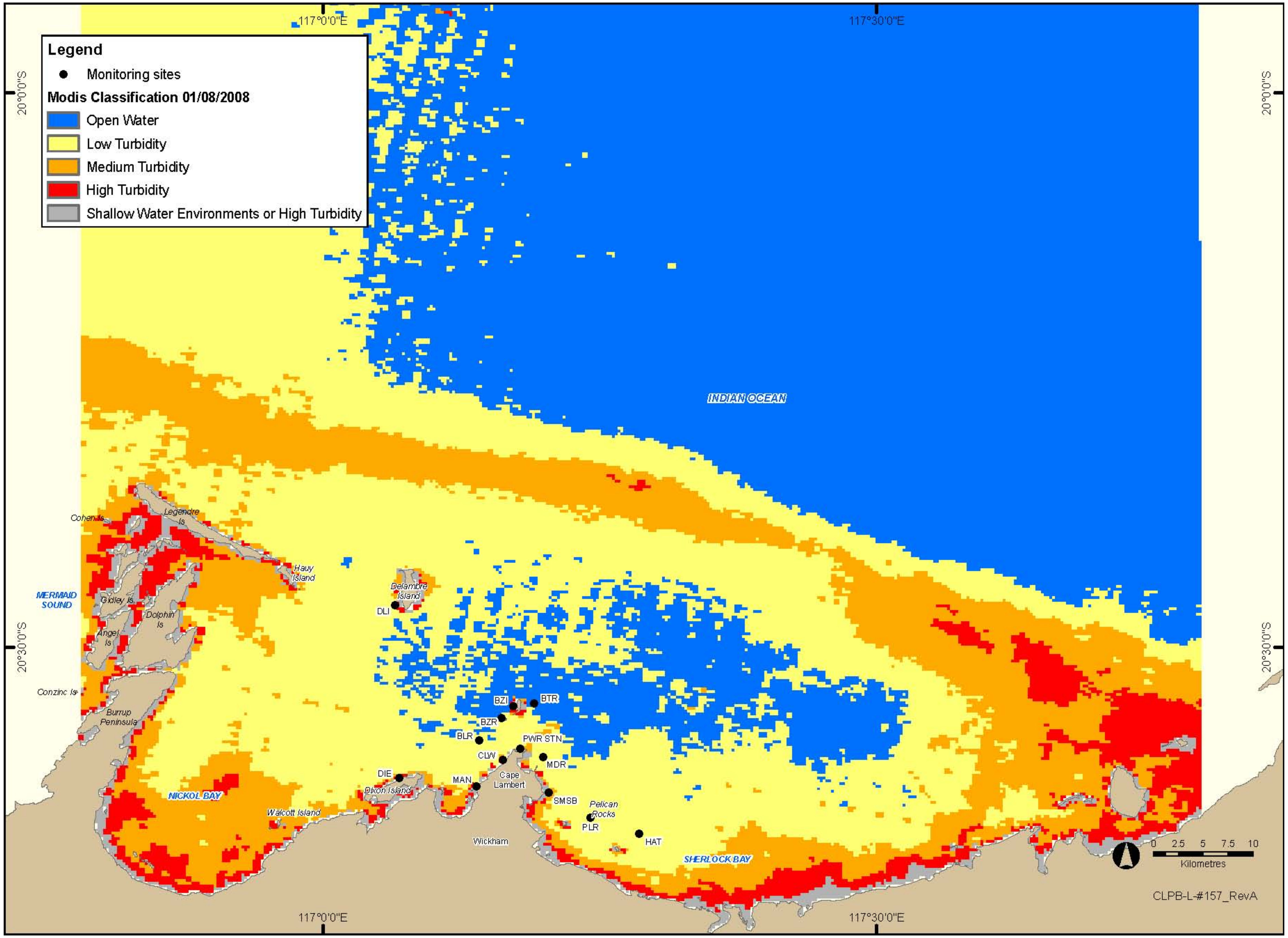

- **Figure 4 Satellite image capturing surface water quality conditions in the Cape Lambert area- 01 August 2008**

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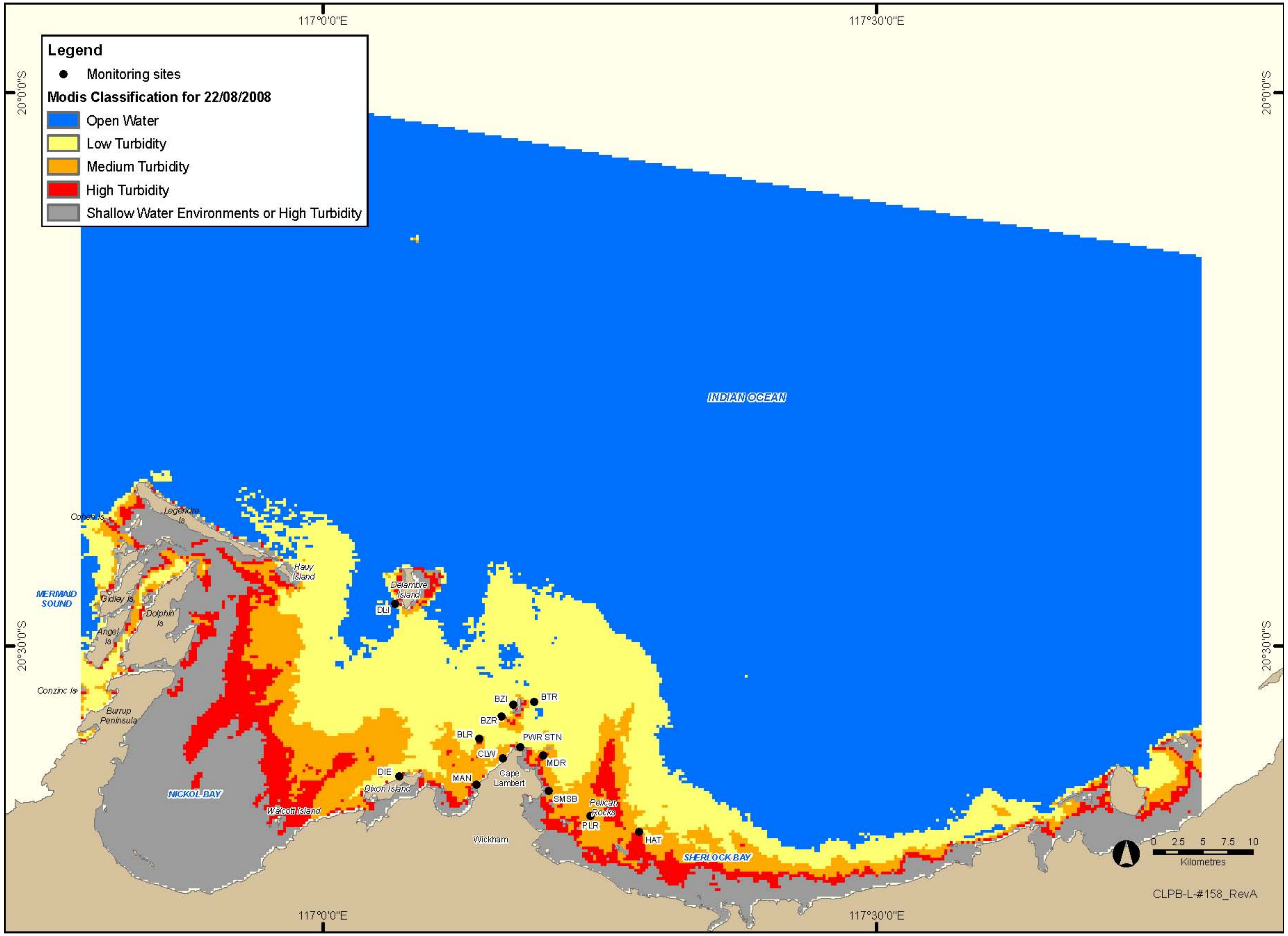

- **Figure 5 Satellite image capturing surface water quality conditions in the Cape Lambert area- 22 August 2008**

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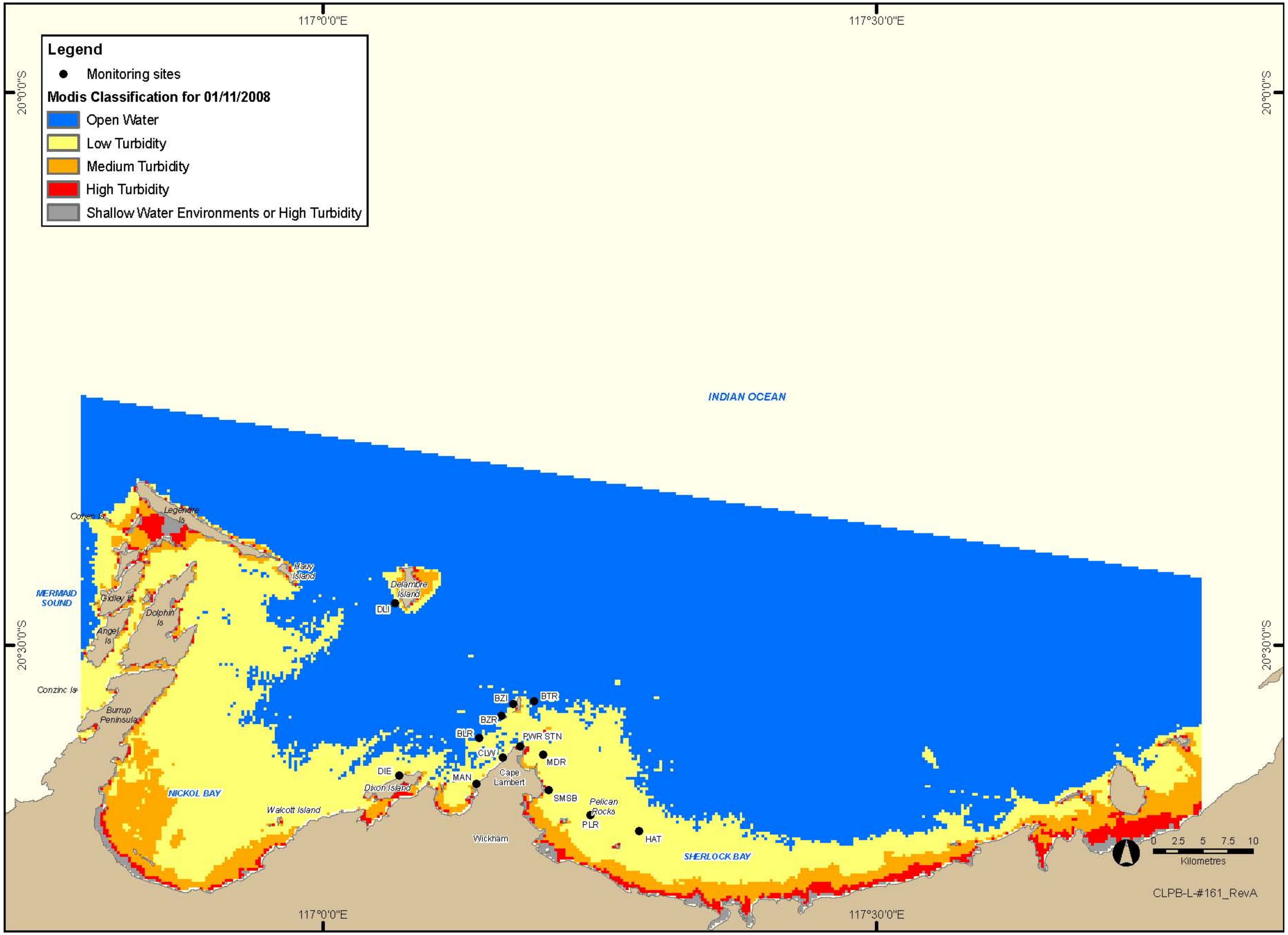

- **Figure 6 Satellite image capturing surface water quality conditions in the Cape Lambert area- 01 November 2008**

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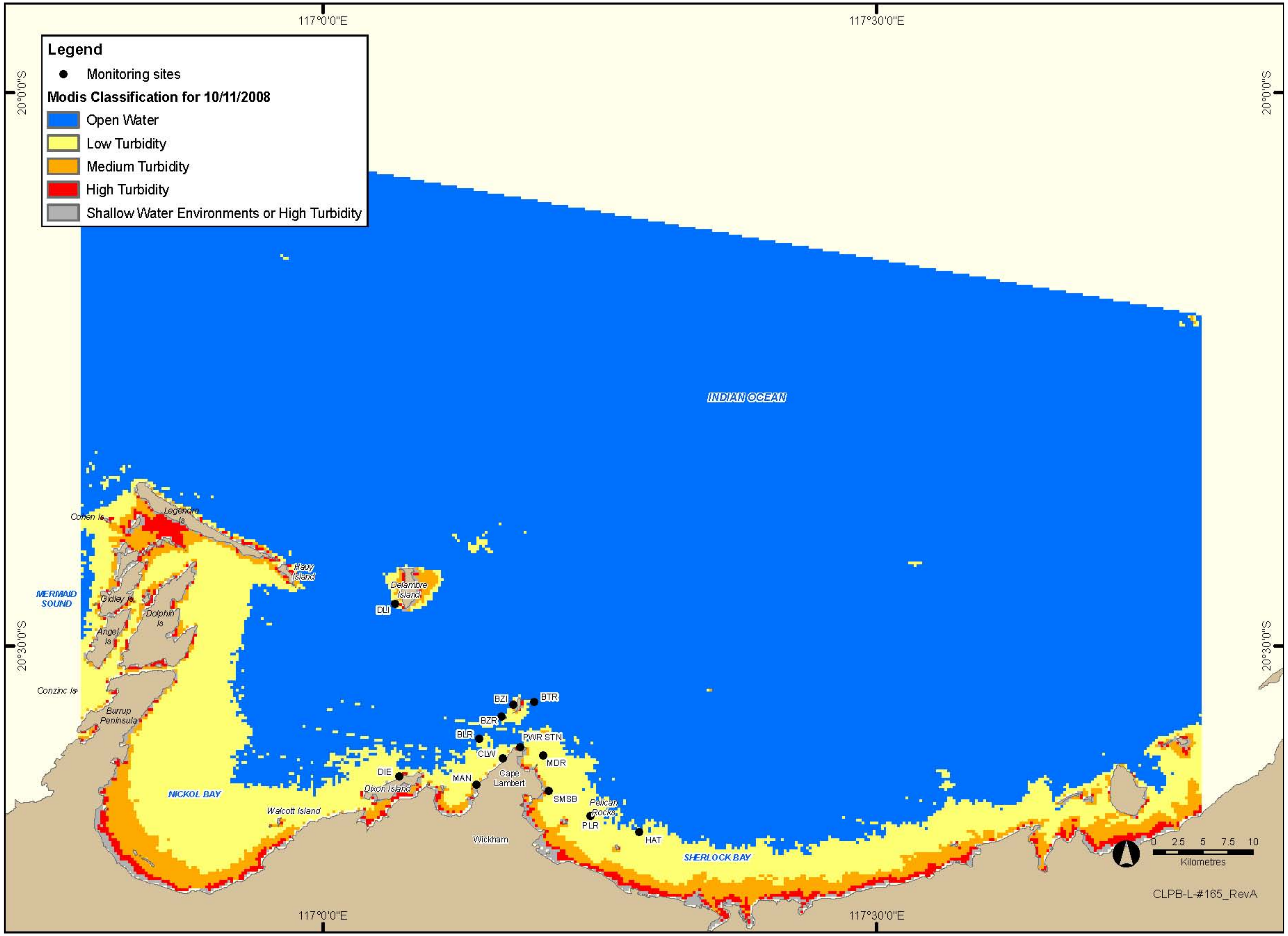

▪ **Figure 7 Satellite image capturing surface water quality conditions in the Cape Lambert area- 10 November 2008**

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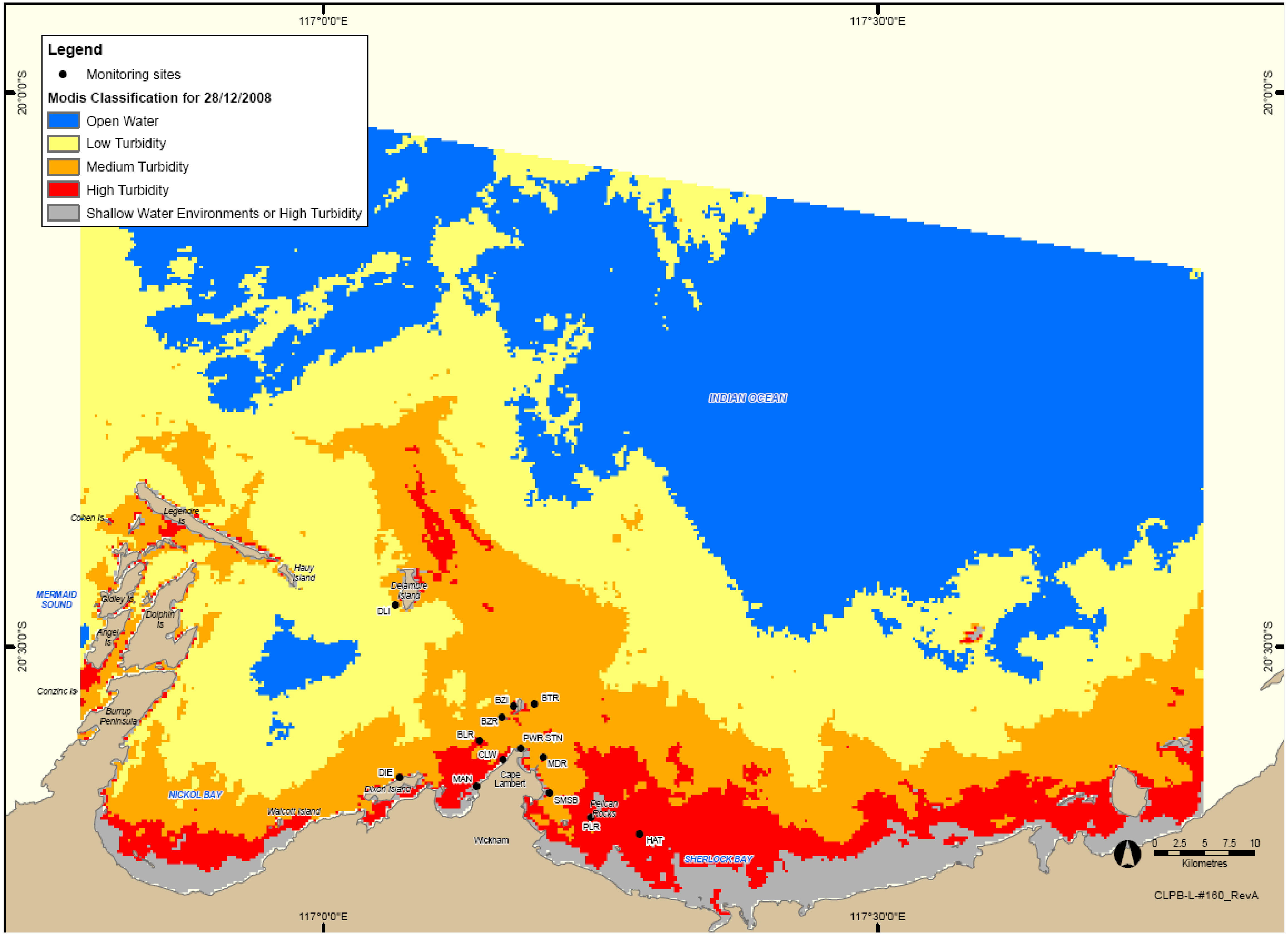
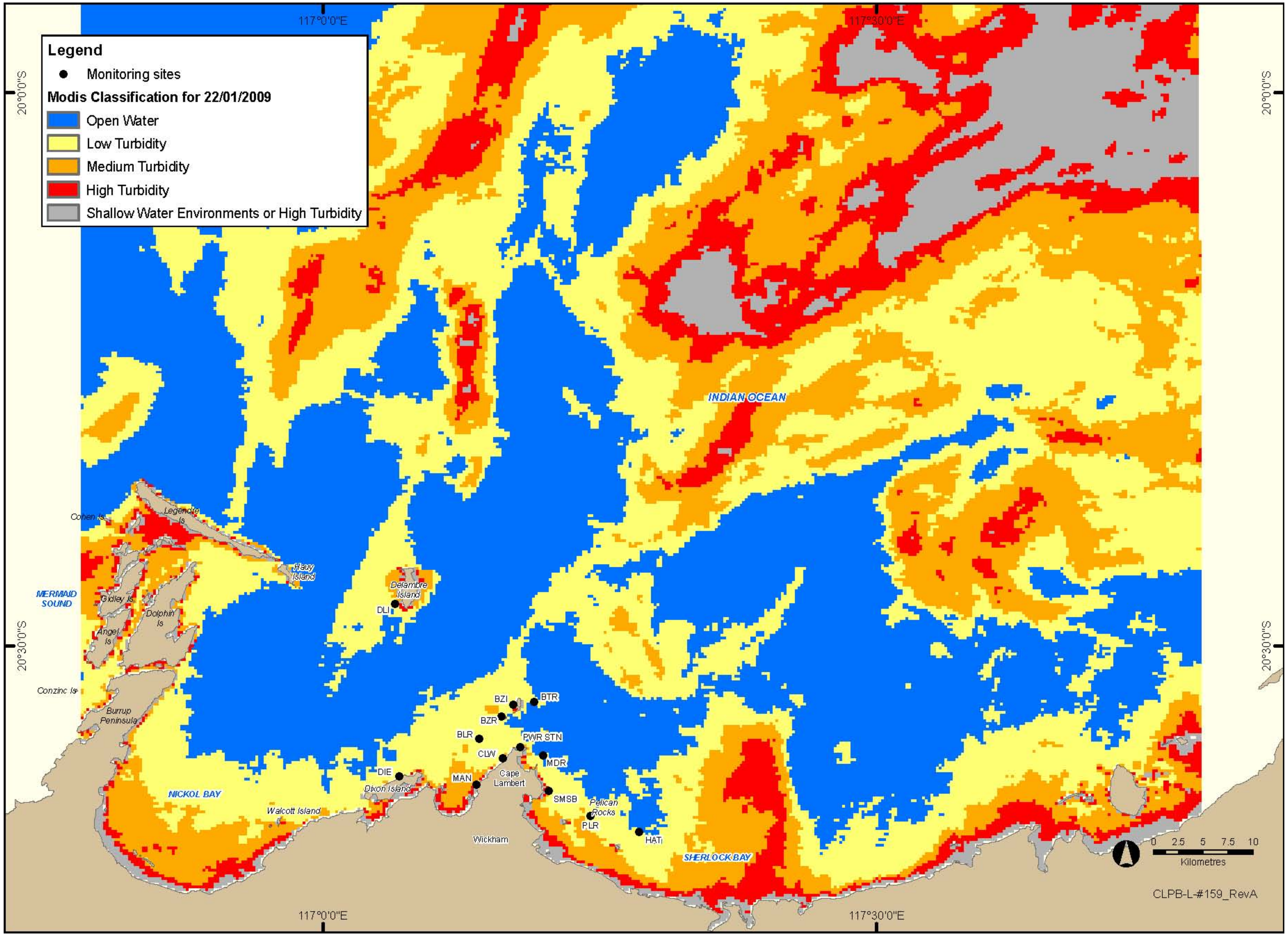


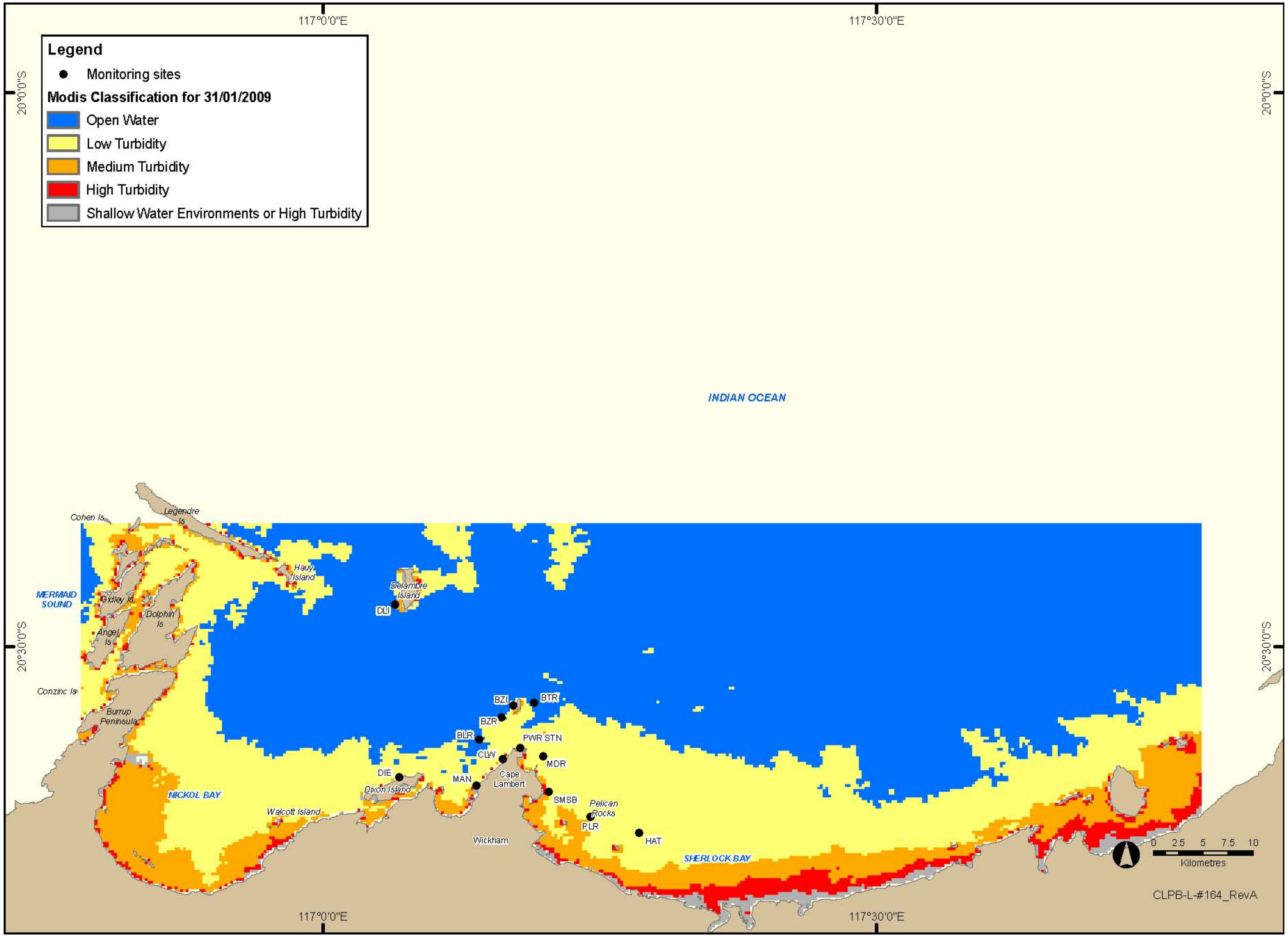
- **Figure 8 Satellite image capturing surface water quality conditions in the Cape Lambert area- 28 December 2008**

SKM



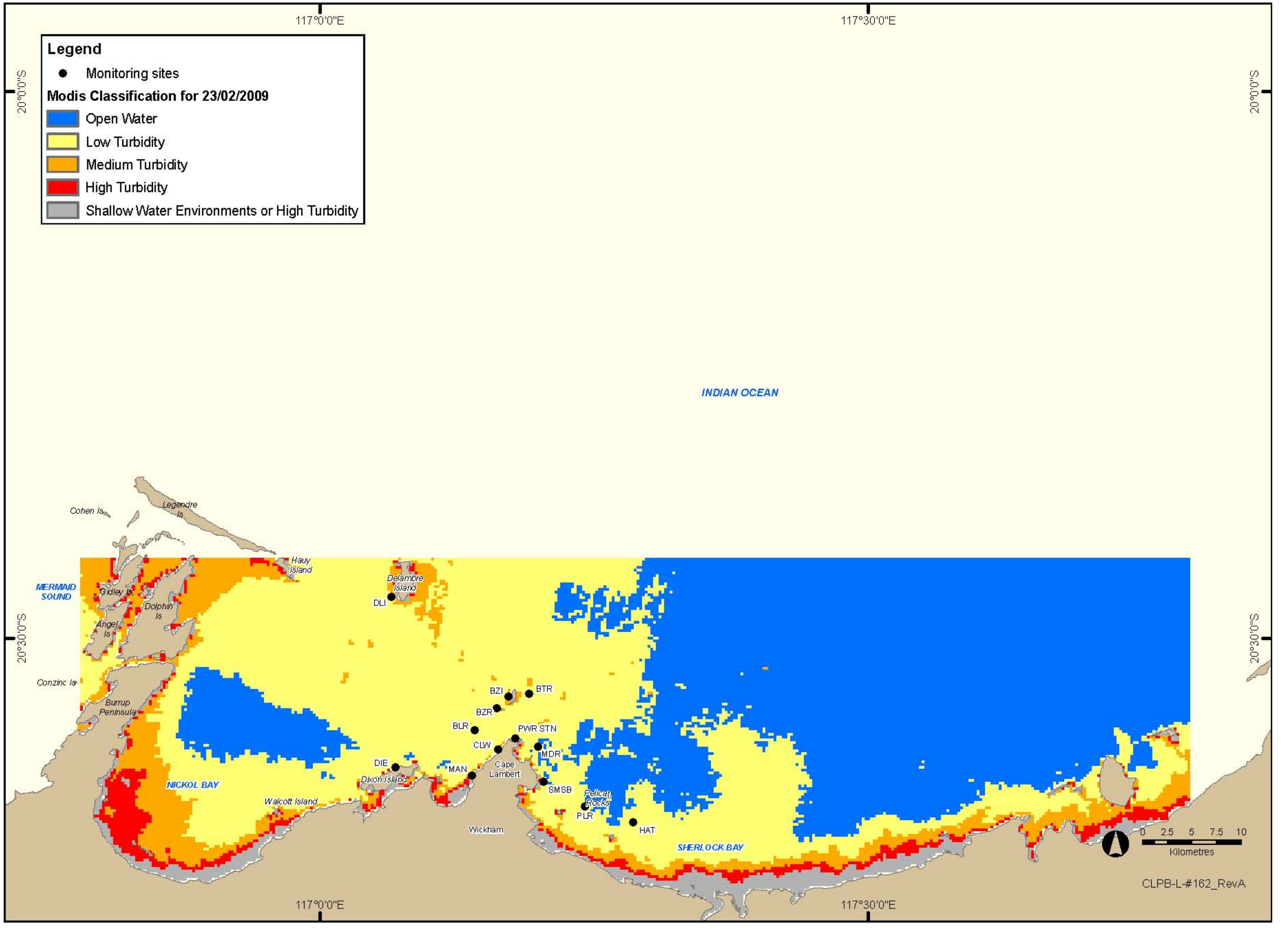
- **Figure 9 Satellite image capturing surface water quality conditions in the Cape Lambert area- 22 January 2009**

SKM



- **Figure 10 Satellite image capturing surface water quality conditions in the Cape Lambert area- 31 January 2009**

SKM



▪ **Figure 11 Satellite image capturing surface water quality conditions in the Cape Lambert area- 23 February 2009**

4. Discussion

4.1. MODIS Images

The MODIS images that were selected captured a range of turbidity levels across the different seasons. They were also able to illustrate spatial variation between the monitoring sites (**Figure 2** to **Figure 11**). The highest turbidity levels captured were during summer (wet season) following tropical cyclone events. Whilst low levels of turbidity were captured across a range of seasons as illustrated in **Figure 3**, **Figure 7** and **Figure 10** (**Table 3**).

4.2. Comparison with Logger Turbidity Data

In the majority of cases the turbidity observed from the satellite images reflects the data recorded from the *in situ* loggers at the monitoring sites. The comparison of the satellite images with the turbidity recorded by the *in situ* loggers signifies that the survey method provides a good indication of the turbidity patterns throughout the study area. The survey method, however, does not present the capacity to interpret turbidity on a fine spatial scale. However, spatial variation between monitoring sites was still able to be determined in some instances. **Figure 8** classified monitoring sites Hat Rock (HAT), Pelican Rock (PLR) and Mangrove Point (MAN) as high turbidity, these three sites recorded the highest turbidity levels on the date of classification (28-12-2008) from the *in situ* loggers (**Figure A 6**).

4.3. Conclusion

The results from this preliminary investigation suggest that there is potential for this survey method to monitor turbidity in the study area. However due to the limitations described in **Section 4.4**, it would be better used to help interpret site specific data on a broader scale. There is potential to utilise this method to distinguish approximate turbidity boundaries of a dredge related turbidity plume which can be of assistance in dredge monitoring and management. It is not recommended that the survey type be used as a replacement for *in situ* water quality monitoring. Currently it enables trends in turbidity to be observed within the study area that can be correlated to turbidity loggers.

4.4. Limitations

There are a number of limitations identified with remote sensing of water quality, these are provided below:

a) Satellite images of the study area are not always available in close proximity to required dates. For example, in some cases the first available image during/following a cyclone event can only be captured days after the event once the elevated turbidity had subsided (**Table 1** and **Figure 10**). The unavailability of set dates is usually related to cloud cover. In this example, the MODIS image in Figure 10 only indicated low turbidity across the study area. This was not supported by the *in situ* loggers, where turbidity was still slightly elevated. This may be a result of surface turbidity differing to turbidity at depth. **Figure 11** and **Figure A 8** further illustrate this limitation. In this example the elevated turbidity levels recorded from the cyclone/weather event had subsided by the time an image was available.

b) The ability to differentiate between high turbidity areas and shallow water is not always possible or can be difficult when classifying the images.

c) The satellite images enable a broad overview of turbidity over a large study area although variation at smaller spatial scale is not able to be assessed with any finite certainty.

d) The classification used for the MODIS images is only a general categorisation of the turbidity levels (e.g. low, medium, high). The predictive relationship used to model/classify the images requires further data comparisons to improve the accuracy.

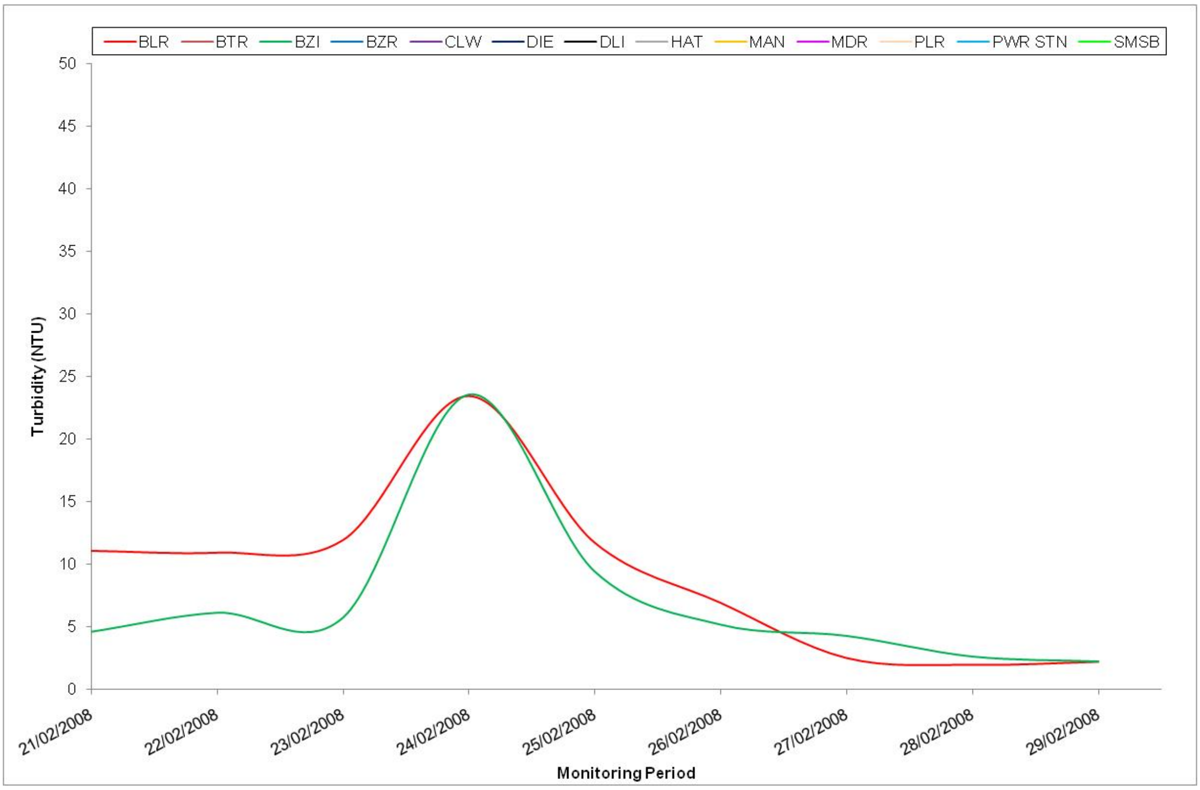
5. References

Chen, Z., Hu, C. & Muller-Karger, F. 2007. Monitoring turbidity in Tampa Bay using MODIS/Aqua 250-m imagery, *Remote Sensing of Environment*, 109; 207-220.

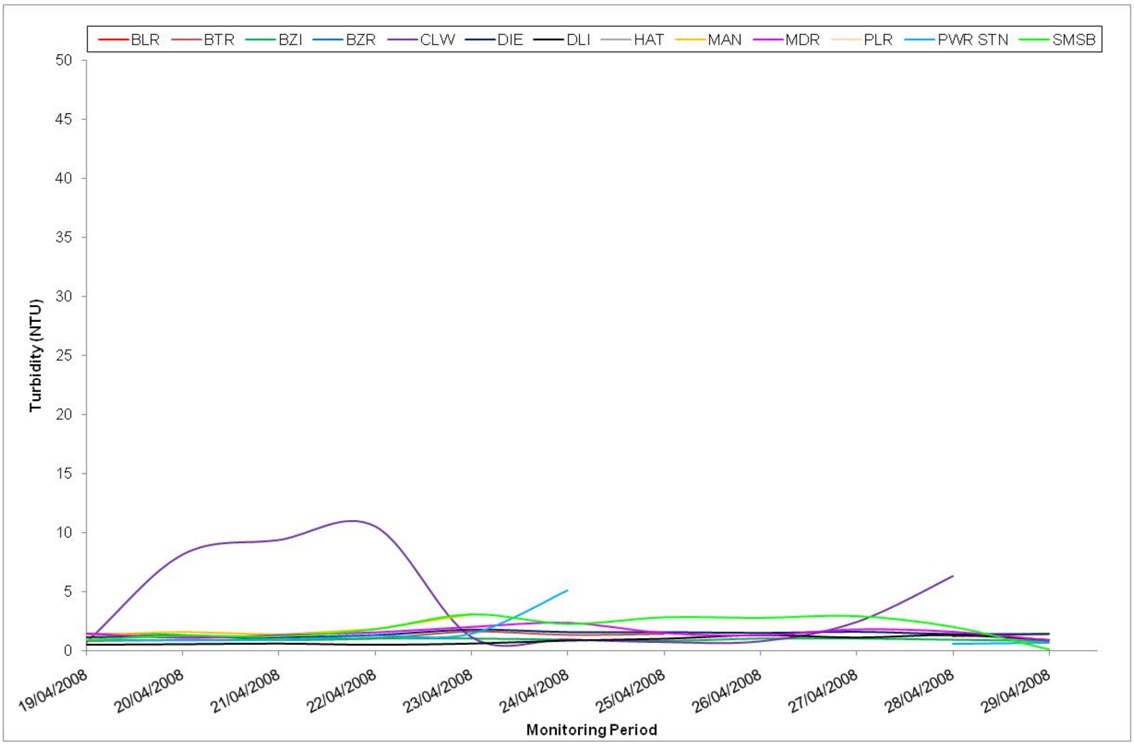
Hellweger, F.L., Schlosser, P., Lall, U. and Weissel, J.K. 2004. Use of satellite imagery for water quality studies in New York Harbor, *Estuarine Coastal and Shelf Science*, 61; 437–448.

Sinclair Knight Merz 2009. *Cape Lambert Port B Development Marine Water Quality Baseline Monitoring Report.* Sinclair Knight Merz, Perth.

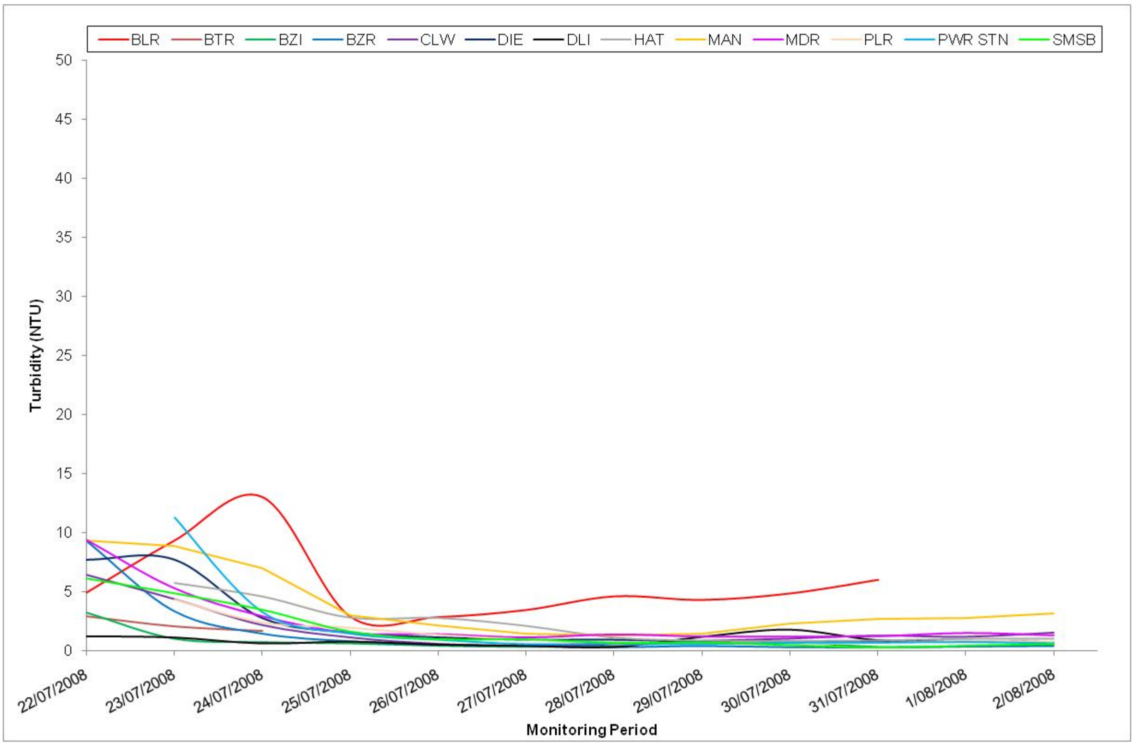
Appendix A Port B Water Quality data



- **Figure A 1 Median turbidity (NTU; determined from 1 day periods) recorded at each monitoring location from 21 to 29 February 2008- Cyclone Nicholas**

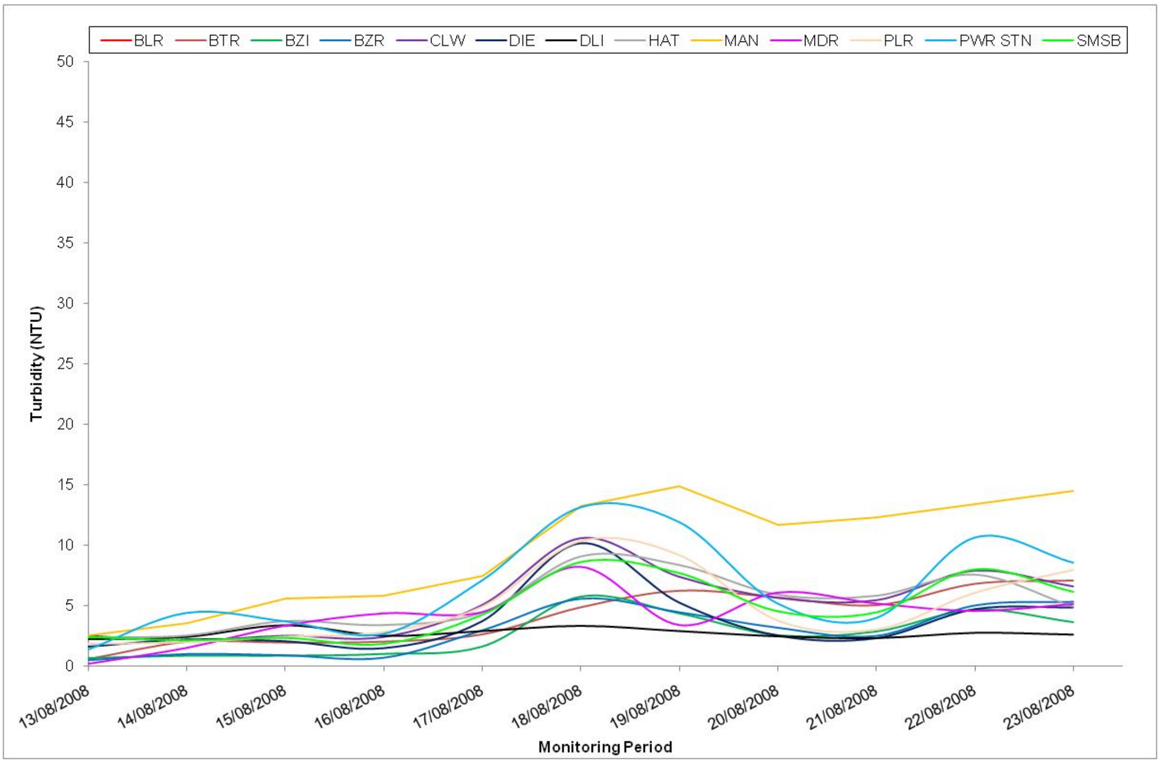


- **Figure A 2 Median turbidity (NTU; determined from 1 day periods) recorded at each monitoring location from 19 to 29 April 2008**

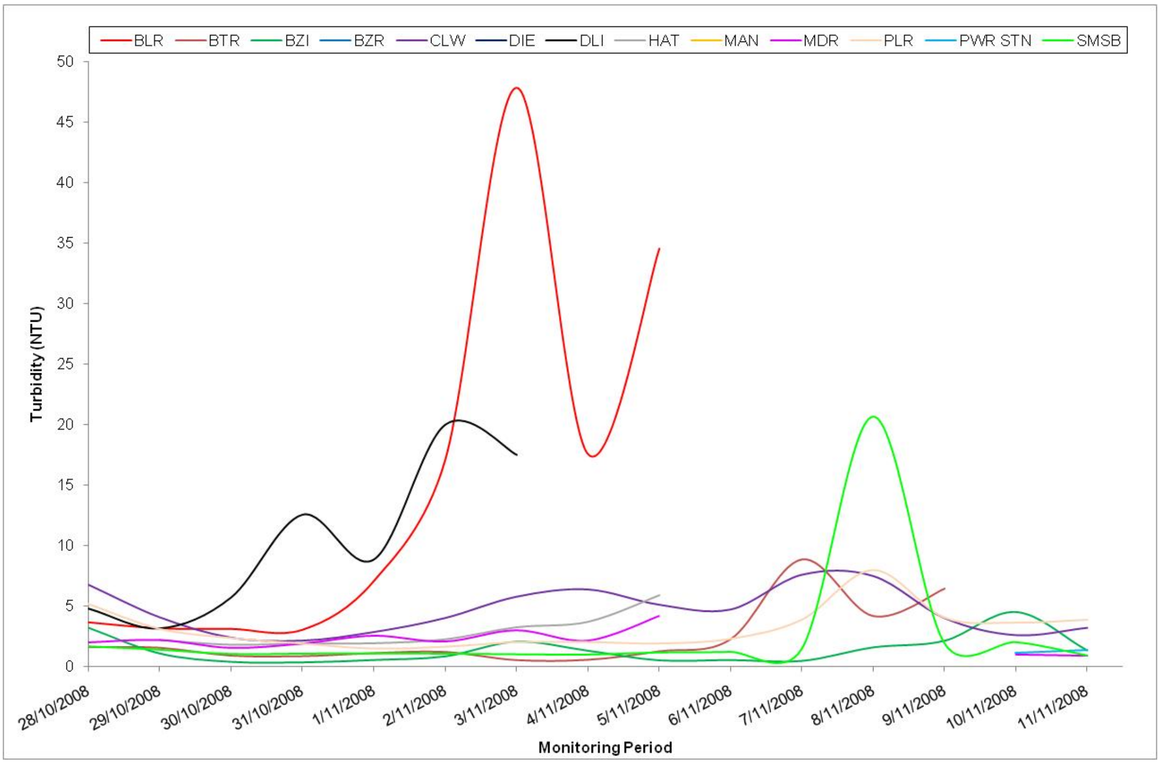


- **Figure A 3 Median turbidity (NTU; determined from 1 day periods) recorded at each monitoring location from 22 July to 02 August 2008**

SKM

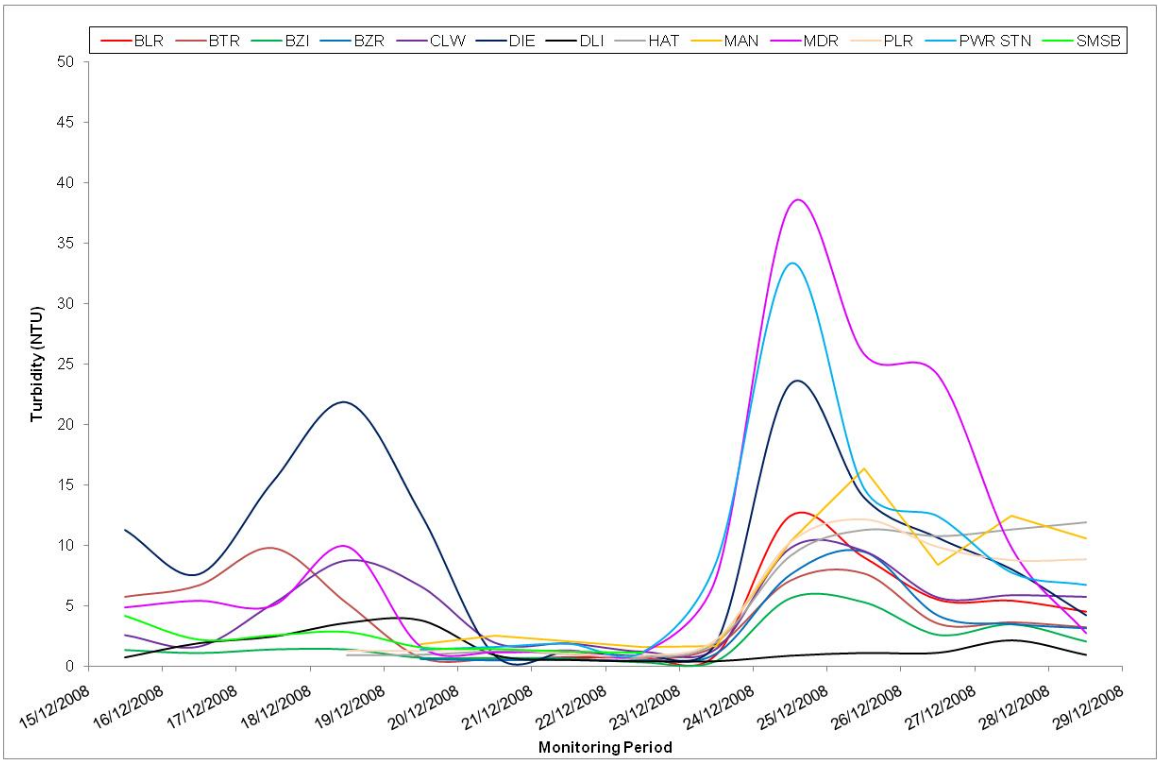


- **Figure A 4 Median turbidity (NTU; determined from 1 day periods) recorded at each monitoring location from 13 to 23 August 2008**

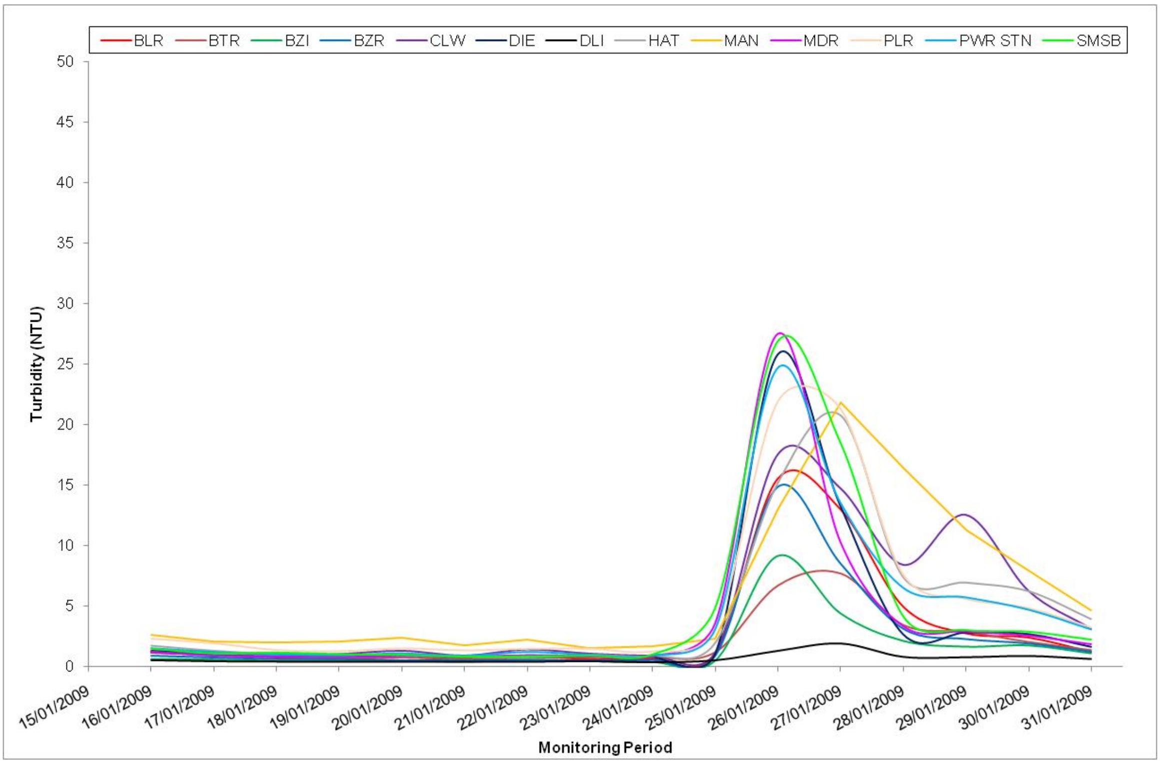


- **Figure A 5 Median turbidity (NTU; determined from 1 day periods) recorded at each monitoring location from 28 October to 11 November 2008**

SKM

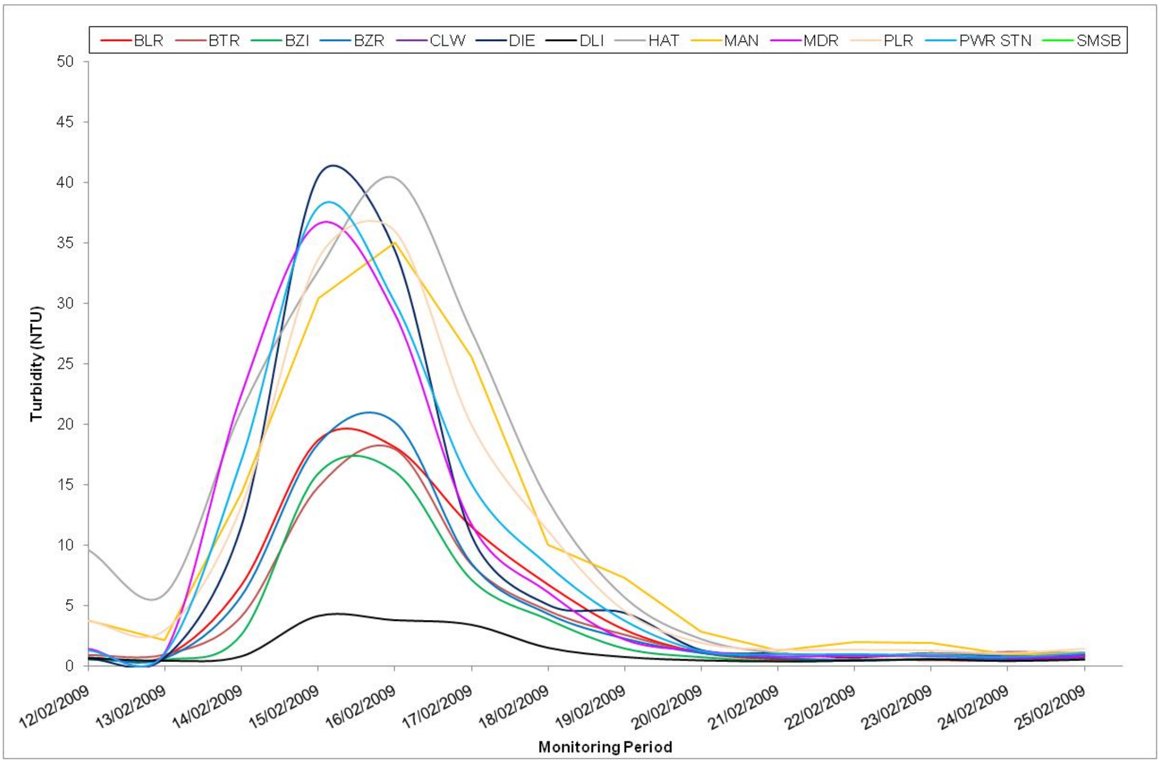


- **Figure A 6 Median turbidity (NTU; determined from 1 day periods) recorded at each monitoring location from 15 to 29 December 2008- Cyclone Billy**



- **Figure A 7 Median turbidity (NTU; determined from 1 day periods) recorded at each monitoring location from 16 to 31 January 2009**

SKM



- **Figure A 8 Median turbidity (NTU; determined from 1 day periods) recorded at each monitoring location from 12 to 25 February 2009**

SKM

Appendix B Tropical Cyclone Events

Summary

There were five (5) tropical cyclones (listed below) which occurred around Cape Lambert area during the baseline monitoring period. The first (Nicholas) occurred just prior to the deployment of the Analite loggers in February 2008, while the rest of the tropical cyclones occurred during periods when the turbidity loggers were deployed so obtaining data throughout the period of influence. These are summarised below, followed by detailed information about each cyclone.

- **Table A 1 Summary details of tropical cyclones which occurred during baseline water quality monitoring**

Date [1]	Tropical Cyclone Name [1]	Maximum Category [1]	Maximum Sustained Wind Gust (km/h) [1]	Total Rainfall (Karratha) (mm) [2]
10/02/08 – 20/02/08	Nicholas	3	130	34.6
25/02/08 – 17/03/08	Ophelia	2	100	N/A
15/12/08 – 28/12/08	Billy	4	175	0.0
24/01/09 – 27/01/09	Dominic	2	95	181.6
04/03/09 – 11/03/09	Freddy	2	95	5.2

N.B. Climate and tropical cyclone information was obtained via the Australian Government Bureau of Meteorology (BOM) WebPages.

- [1] http://www.bom.gov.au/announcements/sevwx/
- [2] **Total rainfall (mm) was calculated by adding each daily rainfall total for the dates given in Table C1.** http://www.bom.gov.au/climate/dwo/IDCJDW6064.latest.shtml\

Appendix C Tide Data

PORT WALCOTT

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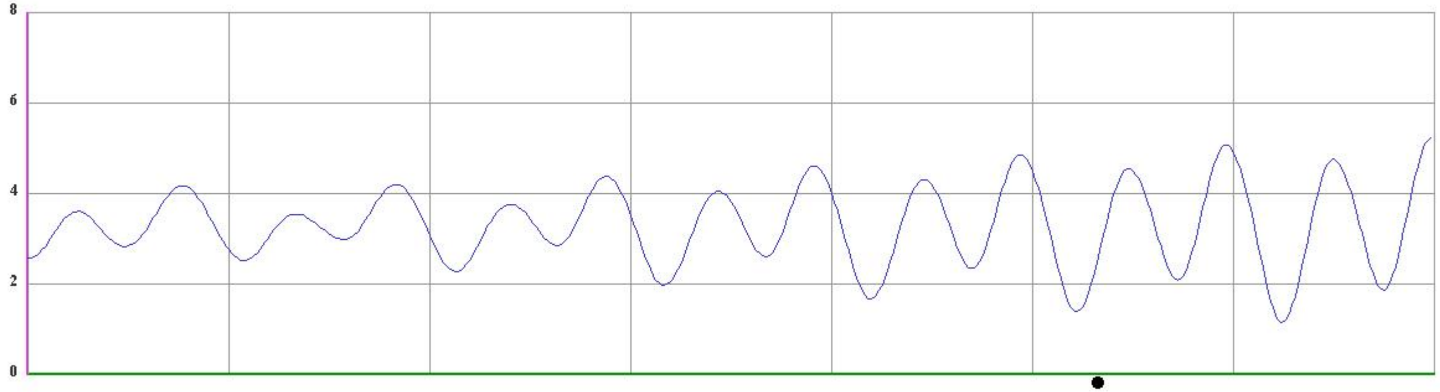
Timezone: -8:00 U.T.

20° 35' S 117° 11' E

Year 2008

PREDICTION DATUM below MSL: 3.27 (m)

Port 62550



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0007	2.6	0146	2.5	0303	2.3	0357	2.0	0438	1.7	0514	1.4	0547	1.2
0554	3.6	0758	3.5	0935	3.8	1025	4.0	1059	4.3	1128	4.5	1155	4.7
1133	2.8	1336	3.0	1509	2.8	1602	2.6	1644	2.3	1718	2.1	1752	1.9
1826	4.2	1954	4.2	2102	4.4	2152	4.6	2231	4.9	2306	5.1	2339	5.2

Moon phases supplied by Sydney Observatory

No Account is taken of Daylight Saving Time

NOTE:Prediction Datum may not be Chart Datum.
Correction to Chart Datum can be found at: HELP/Contents/Tides Reference - Additional Tidal Levels and Source of Data for Standard Ports.

SKM

PORT WALCOTT

Local Standard
Timezone: -8:00 U.T.

20° 35' S 117° 11' E

Year 2008

PREDICTION DATUM below MSL: 3.27 (m)

Port 62550

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Time	m	Time	m	Time	m	Time	m	Time	m	Time	m	Time	m
0243	2.0	0359	1.7	0454	1.3	0539	0.9	0618	0.7	0015	5.6	0049	5.5
0917	3.8	1025	4.2	1107	4.6	1142	4.9	1215	5.2	0653	0.6	0725	0.7
1456	2.8	1614	2.4	1707	2.0	1751	1.6	1830	1.3	1245	5.4	1315	5.5
2100	4.6	2207	5.0	2256	5.3	2337	5.5			1906	1.2	1939	1.2

Moon phases supplied by Sydney Observatory

No Account is taken of Daylight Saving Time

NOTE:Prediction Datum may not be Chart Datum.
Correction to Chart Datum can be found at: HELP/Contents/Tides Reference - Additional Tidal Levels and Source of Data for Standard Ports.

SKM

PORT WALCOTT

Local Standard
Timezone: -8:00 U.T.

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Year 2008

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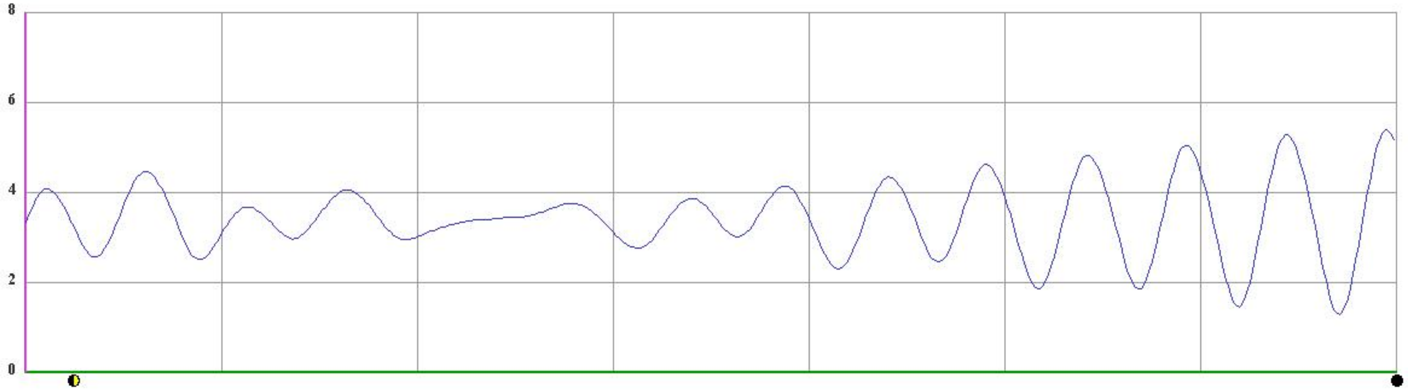
Port 62550



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0828	2.5	0841	3.0			0934	3.9	0948	4.3	1007	4.8	1030	5.3
1440	4.5	1516	4.0			1512	3.0	1550	2.4	1623	1.8	1656	1.3
2116	2.5	2230	2.9			2059	4.1	2141	4.6	2214	5.0	2245	5.4

Moon phases supplied by Sydney Observatory

No Account is taken of Daylight Saving Time

NOTE:Prediction Datum may not be Chart Datum.
Correction to Chart Datum can be found at: HELP/Contents/Tides Reference - Additional Tidal Levels and Source of Data for Standard Ports.

SKM

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Local Standard
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Year 2008

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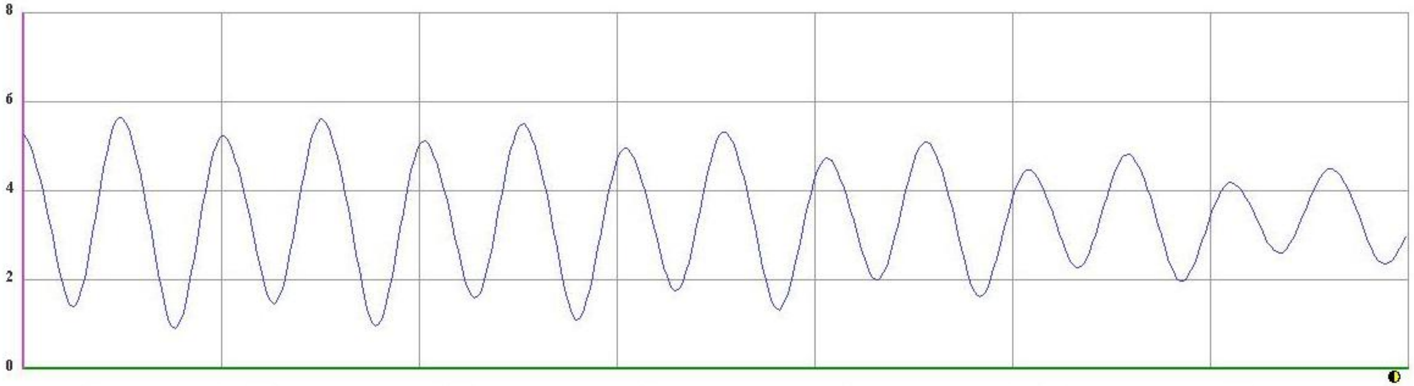

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1141	5.6	0621	1.5	0644	1.6	0706	1.8	0730	2.0	0754	2.3	0823	2.6
1818	0.9	1206	5.6	1232	5.5	1259	5.3	1327	5.1	1357	4.8	1433	4.5
		1843	0.9	1907	1.1	1932	1.3	2000	1.6	2030	2.0	2109	2.3

Moon phases supplied by Sydney Observatory

No Account is taken of Daylight Saving Time

NOTE: Prediction Datum may not be Chart Datum.
Correction to Chart Datum can be found at: HELP/Contents/Tides Reference - Additional Tidal Levels and Source of Data for Standard Ports.

SKM

PORT WALCOTT

Local Standard
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20° 35' S 117° 11' E

Year 2008

PREDICTION DATUM below MSL: 3.27 (m)

Port 62550

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Jul 26 Sa		27 Su		28 Mo		29 Tu		30 We		31 Th		Aug 1 Fr	
Time	m	Time	m	Time	m	Time	m	Time	m	Time	m	Time	m
0302	4.9	0345	4.7	0448	4.4	0631	4.2	0208	2.7	0344	2.4	0442	1.9
0940	1.6	1034	1.9	1159	2.1	1348	2.1	0820	4.3	0940	4.7	1034	5.1
1530	4.3	1624	3.9	1757	3.6	2021	3.5	1524	1.8	1628	1.4	1715	0.9
2134	1.9	2215	2.3	2340	2.7			2156	3.9	2242	4.4	2317	4.8

Moon phases supplied by Sydney Observatory

No Account is taken of Daylight Saving Time

NOTE:Prediction Datum may not be Chart Datum.
Correction to Chart Datum can be found at: HELP/Contents/Tides Reference - Additional Tidal Levels and Source of Data for Standard Ports.

SKM

PORT WALCOTT

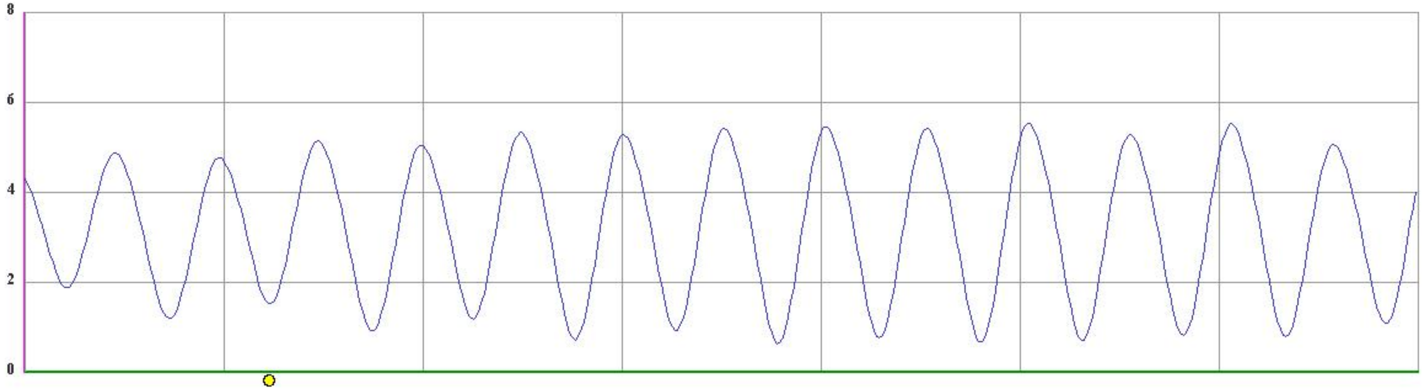
Local Standard
Timezone: -8:00 U.T.

20° 35' S 117° 11' E

Year 2008

PREDICTION DATUM below MSL: 3.27 (m)

Port 62550



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1048	4.9	1116	5.1	1145	5.3	0629	0.9	0659	0.8	0730	0.7	0800	0.8
1722	1.2	1750	0.9	1817	0.7	1215	5.4	1245	5.4	1315	5.3	1346	5.1
2322	4.8	2345	5.1			1845	0.6	1913	0.7	1939	0.8	2005	1.1

Moon phases supplied by Sydney Observatory

No Account is taken of Daylight Saving Time

NOTE: Prediction Datum may not be Chart Datum.
Correction to Chart Datum can be found at: HELP/Contents/Tides Reference - Additional Tidal Levels and Source of Data for Standard Ports.

SKM

PORT WALCOTT

Local Standard
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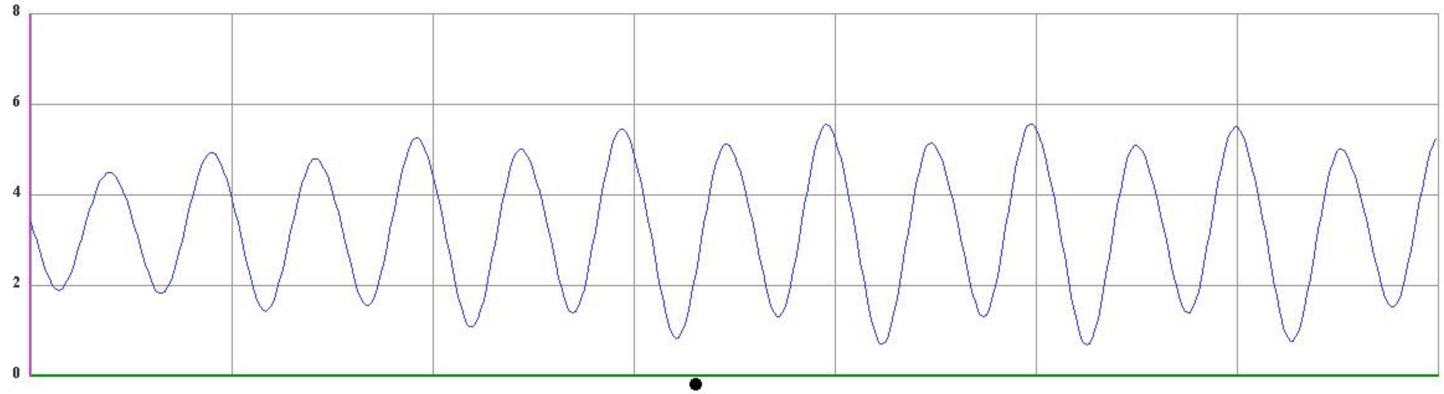
20° 35' S 117° 11' E

Year 2008

PREDICTION DATUM below MSL: 3.27 (m)

Port 62550



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0319	1.9	0358	1.4	0432	1.1	0504	0.8	0533	0.7	0601	0.7	0628	0.8
0919	4.5	0956	4.8	1028	5.0	1058	5.1	1126	5.1	1154	5.1	1221	5.0
1530	1.8	1608	1.5	1641	1.4	1712	1.3	1740	1.3	1806	1.4	1830	1.5
2131	4.9	2200	5.2	2228	5.5	2255	5.6	2322	5.6	2348	5.5		

Moon phases supplied by Sydney Observatory

No Account is taken of Daylight Saving Time

NOTE: Prediction Datum may not be Chart Datum.
Correction to Chart Datum can be found at: HELP/Contents/Tides Reference - Additional Tidal Levels and Source of Data for Standard Ports.

SKM

PORT WALCOTT

Local Standard
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20° 35' S 117° 11' E

Year 2008

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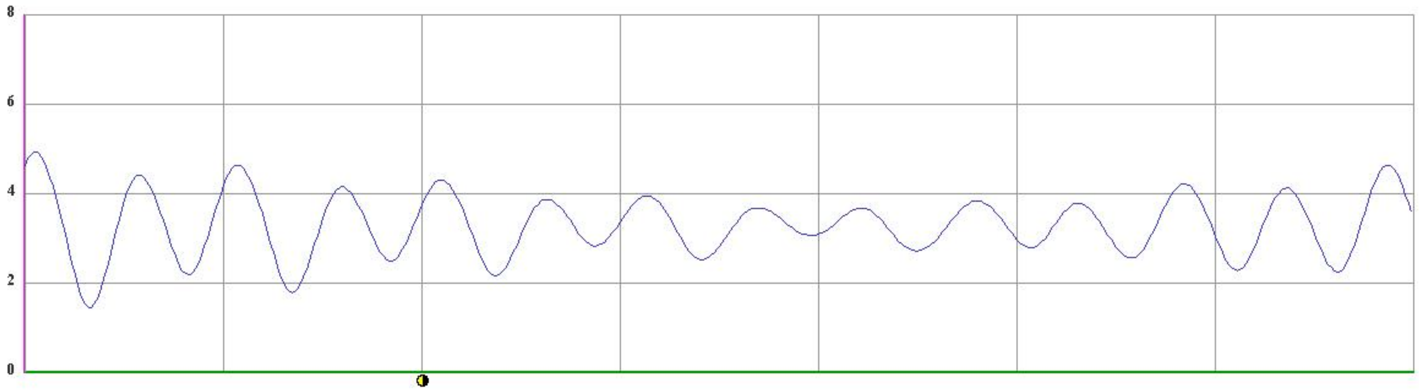
Port 62550



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0747	1.4	0817	1.8	0854	2.2	0949	2.5	1154	2.7	0725	3.8	0837	4.1
1346	4.4	1420	4.1	1506	3.9	1645	3.7	1910	3.8	1349	2.5	1447	2.2
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Moon phases supplied by Sydney Observatory

No Account is taken of Daylight Saving Time

NOTE:Prediction Datum may not be Chart Datum.
Correction to Chart Datum can be found at: HELP/Contents/Tides Reference - Additional Tidal Levels and Source of Data for Standard Ports.

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PORT WALCOTT

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Year 2008

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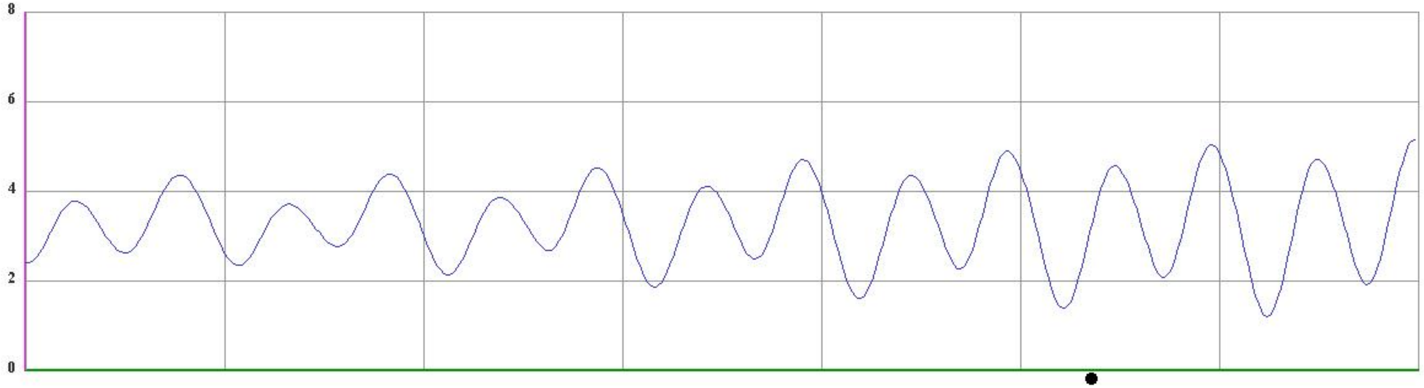
Port 62550



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0558	3.8	0742	3.7	0910	3.9	1006	4.1	1045	4.4	1118	4.6	1147	4.7
1156	2.6	1335	2.8	1500	2.7	1556	2.5	1638	2.3	1714	2.1	1745	1.9
1832	4.4	1951	4.4	2054	4.5	2143	4.7	2224	4.9	2300	5.0	2332	5.2

Moon phases supplied by Sydney Observatory

No Account is taken of Daylight Saving Time

NOTE:Prediction Datum may not be Chart Datum.
Correction to Chart Datum can be found at: HELP/Contents/Tides Reference - Additional Tidal Levels and Source of Data for Standard Ports.

SKM

PORT WALCOTT

Local Standard
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Year 2009

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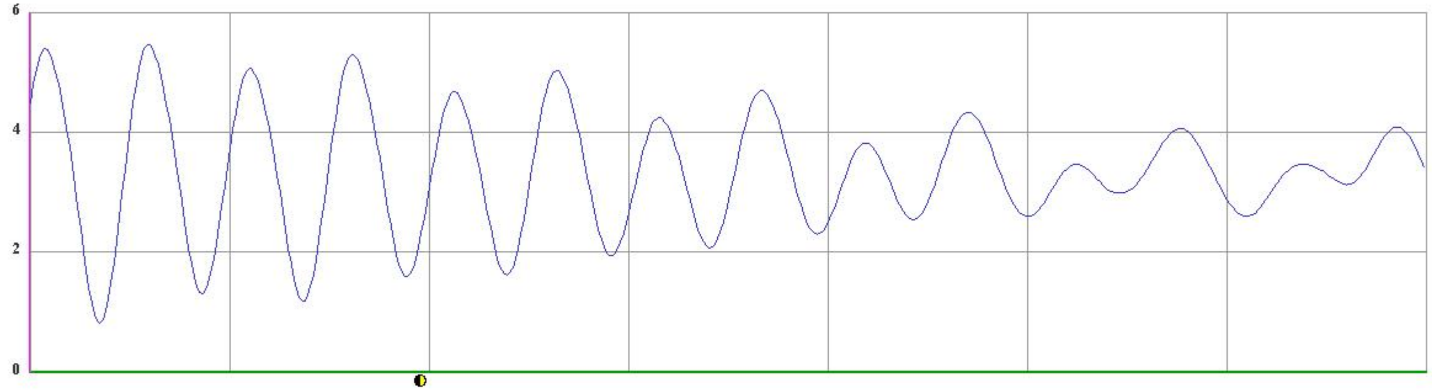
Port 62550



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1408	5.5	1443	5.3	1517	5.0	1556	4.7	1648	4.3	1104	3.0	1425	3.1
2036	1.3	2114	1.6	2152	1.9	2240	2.3			1824	4.1	2027	4.1

Moon phases supplied by Sydney Observatory

No Account is taken of Daylight Saving Time

NOTE:Prediction Datum may not be Chart Datum.
Correction to Chart Datum can be found at: HELP/Contents/Tides Reference - Additional Tidal Levels and Source of Data for Standard Ports.

SKM

PORT WALCOTT

Local Standard
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20° 35' S 117° 11' E

Year 2009

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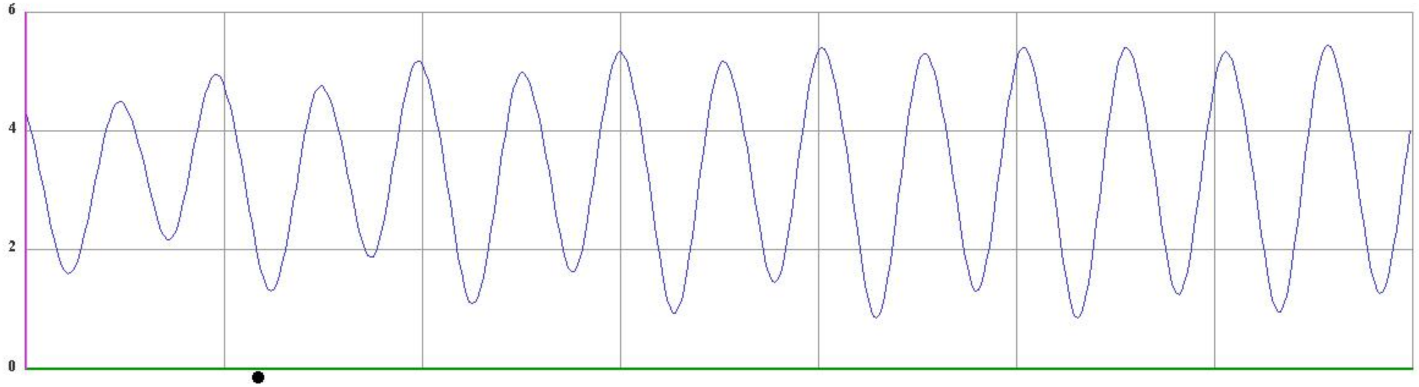
Port 62550



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1116	4.5	1140	4.8	1203	5.0	1227	5.2	0657	0.9	0722	0.9	0747	1.0
1713	2.2	1743	1.9	1811	1.6	1839	1.4	1251	5.3	1315	5.4	1341	5.4
2257	5.0	2327	5.2	2355	5.3			1907	1.3	1935	1.2	2004	1.3

Moon phases supplied by Sydney Observatory

No Account is taken of Daylight Saving Time

NOTE:Prediction Datum may not be Chart Datum.
Correction to Chart Datum can be found at: HELP/Contents/Tides Reference - Additional Tidal Levels and Source of Data for Standard Ports.

SKM

PORT WALCOTT

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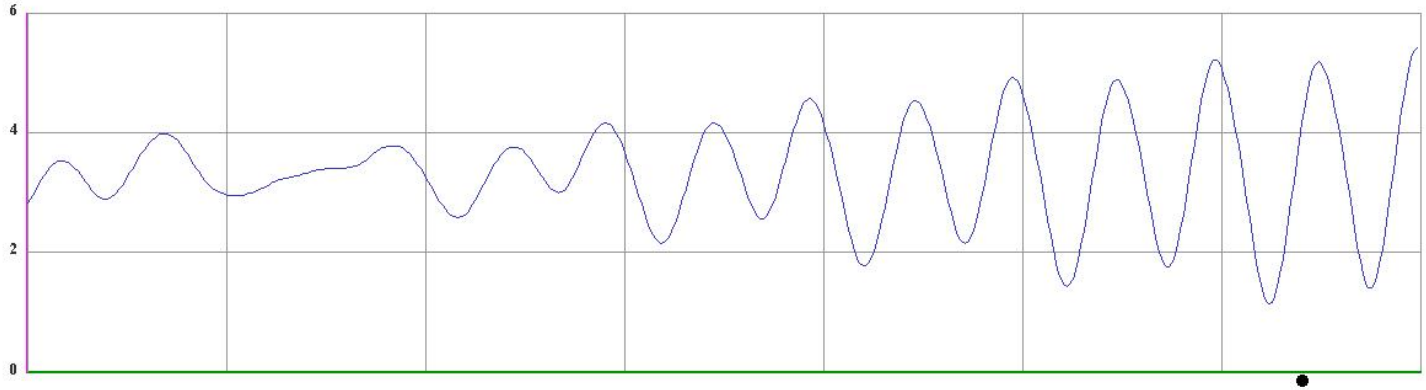
Timezone: -8:00 U.T.

20° 35' S 117° 11' E

Year 2009

PREDICTION DATUM below MSL: 3.27 (m)

Port 62550



00:00 2.8m

Feb 19 Th		20 Fr		21 Sa		22 Su		23 Mo		24 Tu		25 We	
Time	m	Time	m	Time	m	Time	m	Time	m	Time	m	Time	m
0403	3.5	0057	2.9	0350	2.6	0425	2.2	0451	1.8	0516	1.4	0542	1.1
0919	2.9	1956	3.8	1035	3.8	1043	4.2	1059	4.5	1117	4.9	1138	5.2
1624	4.0			1559	3.0	1631	2.6	1700	2.1	1726	1.7	1752	1.4
				2138	4.2	2215	4.6	2245	4.9	2311	5.2	2337	5.4

Moon phases supplied by Sydney Observatory

No Account is taken of Daylight Saving Time

NOTE:Prediction Datum may not be Chart Datum.
Correction to Chart Datum can be found at: HELP/Contents/Tides Reference - Additional Tidal Levels and Source of Data for Standard Ports.

PORT WALCOTT

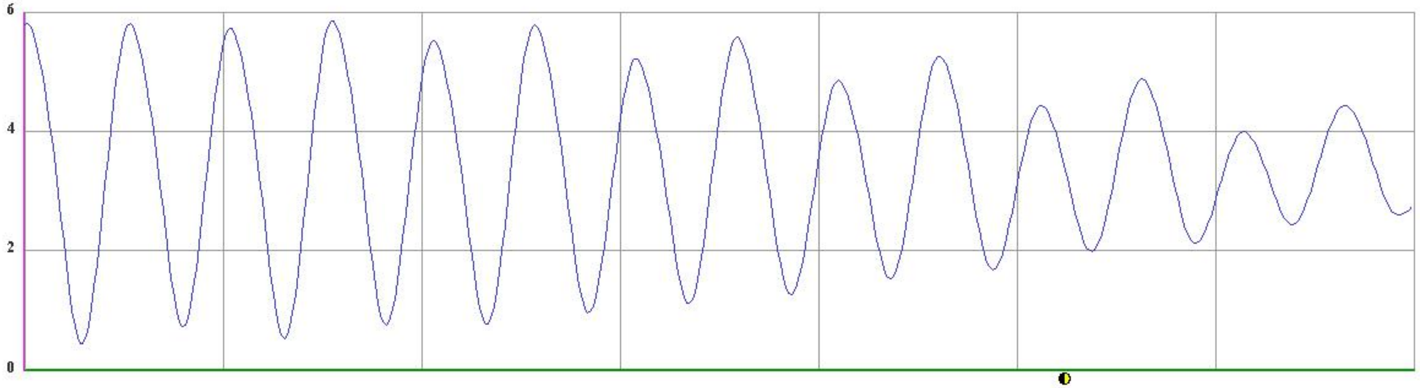
Local Standard
Timezone: -8:00 U.T.

20° 35' S 117° 11' E

Year 2009

PREDICTION DATUM below MSL: 3.27 (m)

Port 62550



00:00 5.8m

Feb 12 Th Time	m	13 Fr Time	m	14 Sa Time	m	15 Su Time	m	16 Mo Time	m	17 Tu Time	m	18 We Time	m
0015	5.8	0048	5.7	0121	5.5	0152	5.2	0221	4.9	0251	4.4	0322	4.0
0649	0.4	0720	0.5	0749	0.8	0815	1.1	0837	1.5	0857	2.0	0912	2.4
1238	5.8	1308	5.9	1337	5.8	1405	5.6	1433	5.3	1501	4.9	1532	4.4
1905	0.7	1937	0.8	2008	1.0	2036	1.3	2103	1.7	2131	2.1	2210	2.6

Moon phases supplied by Sydney Observatory

No Account is taken of Daylight Saving Time

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