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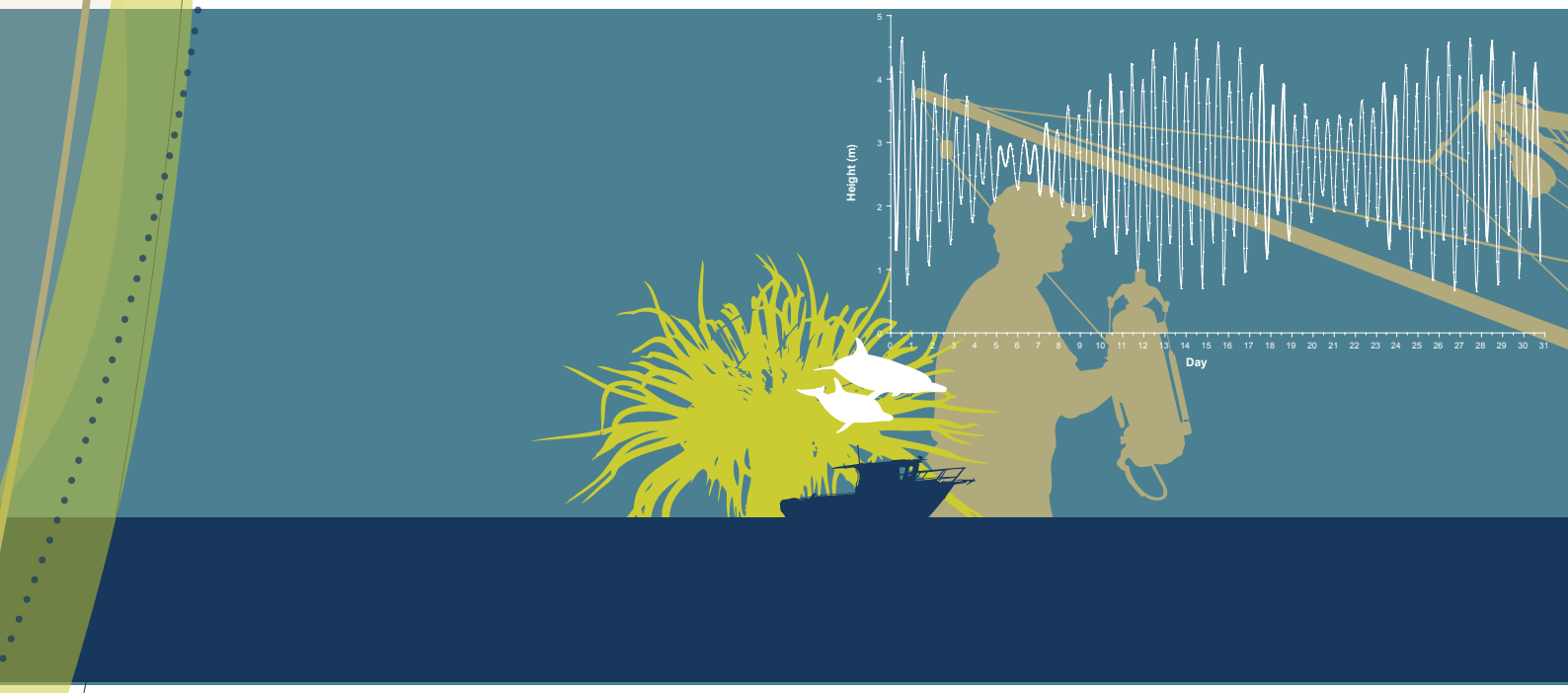
MTR 5

Nutrient-related water quality at selected sites in the coastal waters of the Kimberley Region

Marine Technical Report Series



February 2012

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Abstract

A water quality survey was undertaken in December 2008 at two locations on the Western Australian Kimberley coast that were shortlisted as potential sites for the construction of an LNG processing precinct. Water samples were collected and processed to determine total suspended solids (TSS), chlorophyll *a, b* and *c*, ammonia, total phosphorous (P), total nitrogen (N), nitrate plus nitrite (NO_3+NO_2) and orthophosphate concentrations at selected sites across both study areas. The sampling program was designed to obtain a water quality snapshot of the early wet season.

Results indicate that chlorophyll *a* and *c* concentrations and total phosphorus concentrations were consistently higher in bottom waters at both sites, but highest at James Price Point. TSS concentrations in surface waters were found to be higher at James Price Point than at Perpendicular Head and total nitrogen concentrations were similar across all sites and depths.

As a result of this survey it was found that the default guideline trigger values from ANZECC & ARMCANZ (2000) for Australian tropical marine waters may not be relevant to the Kimberley region for chlorophyll *a* and total nitrogen concentrations, at least during the early wet season. In these situations the approach recommended in ANZECC & ARMCANZ (2000) is to derive site specific guideline trigger values using local reference sites or baseline data. However, fully characterising these waters would require a significant allocation of resources.

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1. Introduction

The Kimberley region consists of over 13,000 km of coastline, largely due to its highly dissected shoreline and over 2,500 mapped islands. The coastal zone of the Kimberley region is the most extensive area of largely un-impacted tropical marine coastline in the world. Not only is there very little development along the coast, the inland catchments of the rivers are also essentially undeveloped. As a consequence the region has very high wilderness, conservation, scientific and cultural values that could be impacted in the longer-term as human usage pressures increase in the region.

The climate of the area is monsoonal with the rains occurring mainly over the summer period. The area is also prone to cyclonic weather which can result in periods of very high, but localised, river flow. Average rainfall varies from approximately 800 mm in the west to 1500 mm in the central and east Kimberley.

The geology of the Dampier Peninsula is relatively simple and composed mainly of quaternary sands and silts, however the geology becomes very complex to the east of King Sound. Here the catchment is mainly composed of sandstones and quaternary sediments, but with significant outcrops of basaltic and granitic rock. As a result, the coastal topography is very different between the two sub-regions and this is recognised in the Interim Marine Coastal Regionalisation of Australia (IMCRA Version 4.0) bioregional boundaries. The coastline of the Canning and King Sound IMCRA bioregions have a relatively gentle topography with shallow sloping offshore bathymetry. On the other hand, the coastline of the Kimberley bioregion east of King Sound is relatively elevated and highly dissected with deep gulfs, steep shores and island archipelagos. All three bioregions are characterised by extensive tidal flats, but the composition of the flats may vary with the location. For example, tidal flats in the mouths of rivers are generally muddy with extensive mangrove forest cover, tidal lagoons are generally silty to sandy with isolated clumps of mangroves, and offshore tidal flats are generally biogenic in origin, formed by calcareous algae, coral reef or a combination of both.

The area experiences the largest tides in Australia, and some of the largest in the world, with spring tides ranging up to 11 m in amplitude. The tidal regime is semi-diurnal (i.e. two high tides and two low tides each day) and as a result of this tidal regime and amplitude there are some strong tidal currents in both the nearshore and offshore waters. In the nearshore environments these can cause significant resuspension of sediment resulting in nearshore waters that are significantly more turbid than offshore. This natural turbidity is significantly less during neap tides when tidal amplitudes can be as little as one metre.

The relative remoteness of the Kimberley coast is the main reason the area remains largely undeveloped, but it has also contributed to a lack of research and understanding of the marine environment. Recent interest by the oil and gas industry to develop nearby oil and gas fields (e.g. Browse Basin) and find suitable sites along the Kimberley coast to build liquefied natural gas processing plants has triggered broad concern about this apparent *ad hoc* approach to development of the Kimberley coastline. As a result the State and Commonwealth Governments have agreed to jointly undertake a strategic assessment of the area to identify a suitable site for a single liquefied natural gas processing precinct.

Studies for the strategic assessment have largely been focused on broad-scale benthic habitat mapping of selected sites. However, later in the environmental impact assessment process it will be necessary to consider potential impacts from waste discharges to the marine environment and the monitoring and management strategies required to minimise any impacts. It is expected that any proposed developments would be considered within the context of the environmental quality management framework established in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ, 2000) and the Western Australia State Water Quality Management Strategy, Report 6. Application of this framework requires identification of environmental values that are to be protected in the area and the environmental quality objectives that must be achieved for the values to be protected. These values and objectives represent the community's long-term desires or goals for the marine waters and should recognise and accommodate the range of uses to which the waters are subject. Environmental water quality criteria are then established to represent the performance benchmarks used to determine whether the environmental quality objectives have been achieved. Environmental quality criteria are based on the guidelines, or derived from the approaches, recommended in ANZECC & ARMCANZ (2000) and their development requires an understanding of natural background water quality.

Given the lack of information on natural background concentrations for most constituents in Kimberley seawater, staff from the Office of the Environmental Protection Authority (formerly Department of Environment and Conservation) collected seawater samples during a benthic habitat field survey so they could be analysed for a range of physical and nutrient-related parameters to give some understanding of baseline conditions.

The main objective of the baseline water quality survey was to determine natural, early wet season concentrations of the selected parameters in two areas shortlisted for locating an LNG processing precinct and to consider suitable guideline trigger values for the area. Human induced changes or trends in water quality can be assessed by evaluating changes from baseline conditions.

2. Methods

2.1 Field sampling

Sampling was undertaken from 18 December 2008 to 21 December 2008 from the Sentosa charter vessel *Equalizer*.

Water samples and other environmental data (Table 1) were collected from 13 sites consisting of seven sites in the Perpendicular Head area and six sites adjacent to James Price Point (Figure 1). Of the 13 sites sampled, 11 were a subset of locations visited during video benthic habitat surveys in 2007 and 2008. The other two sites, one site at Perpendicular Head and one at James Price Point, were chosen to be adjacent to oceanographic monitoring equipment that had been deployed for the Northern Development Taskforce by consultants RPS - MetOcean Engineers Pty Ltd. The coordinates for each site are presented in Table 2.

All samples were taken during daylight hours and the sampling period fell mid-way between spring and neap tides. Meteorological information from the temporary meteorological station set up at North Head by the Northern Development Taskforce is provided for December 2008 in Appendix B and the tidal predictions for the

sampling period are shown in Appendix C. The predicted tidal data are for Broome Port and are expected to approximate tidal conditions at the study sites during sampling. Given the relative proximity of the study sites to Broome any differences are likely to be minimal.

Surface and bottom samples were collected from within one metre of the surface and from within two metres of the seabed at each site. Water was collected using a five litre Niskin bottle. Samples were collected from the Nisken bottle and processed to determine total suspended solids (TSS), chlorophyll *a*, *b* and *c*, ammonia, total phosphorous (P), total nitrogen (N), nitrate plus nitrite (NO_3+NO_2), and orthophosphate concentrations at sites across the study areas. The sampling program was designed to obtain a water quality snapshot of the study areas for the early wet season.

TSS and chlorophyll concentrations were determined by filtering a known volume of water, typically two litres, through 47 mm diameter, 1.2 µm, GFC glass fibre filter papers using a filter tower and 12v vacuum pump. The filter papers used for TSS were pre-weighed before the trip.

After filtering, distilled water was drawn through the pre-weighed TSS filters to remove salts. The filter papers were removed from the filter tower using plastic forceps, folded into quarters then wrapped in a second filter paper. They were then wrapped in aluminium foil before being placed into seed envelopes. The water volume, date and site name were recorded in the field log and written on the seed envelopes. The envelopes containing the filter papers were placed in the freezer as soon as possible after sampling.

Ammonia, orthophosphate and NO_3+NO_2 were sampled using a syringe filter with a 0.45 µm cellulose acetate membrane filter. The filter was rinsed by filtering ~20 mL of sample through it. This was then used to rinse 2 x 10 mL tubes. The tubes were then filled with a filtered sample.

Total nitrogen and total phosphorous were sampled by rinsing, then 80% filling, 2 x 125 mL HDPE bottles with unfiltered sea water.

Table 1: Sampling information

Site Number*	Time	Depth (m)	Secchi depth (m)	Chl Vol. filtered (L)	TSS Vol. filtered (L)	Wind speed (knots)	Wind direction	Cloud Cover (%)
18-12-08								
1	1320	13.8	4.5			10	W	90
S		1		2	2			
B		10		2	2			
2	1430	19	4.5			8	W	90
S		1		2	2			
B		17		2	2			
3	1450	14.0	3.5			10	W	90
S		1		2	2			
B		11		2	2			
4	1638	19.1	4.5			12	W	90
S		1		2	2			
M		11		2	2			
B		18		2	2			

Table 1: Sampling information *(continued)*

19-12-08								
5	0830	18.0	4.8			10	W	40
S		1		2	2			
B		15		2	2			
6	0940	13.5	4.5			10	W	50
S		1		2	2			
B		10		2	2			
20-12-08								
7	0827	10.0	7.5			1	SE	95
S		1		3	3			
B		7		2	2			
8	1004	16.2	6.5			15	SW	95
S		1		2	2			
B		14		2	2			
9	1105	20.0				15	WSW	95
S		1		2	2			
B		18		2	2			
10	1318	20.5				25	WSW	95
S		1		2	2			
B		19		2	2			
21-12-08								
11	0845	17.0	6.5			15	SE	80
S		1		2	2			
B		15		2	2			
12	1050	19.3	5			15	S	80
S		1		2	2			
B		17		2	2			
13	1210	16.9	7			15	S	80
S		1		2	2			
B		15		2	2			

* S = Surface, M = Middle, B = Bottom

Note: Water quality sites 4 and 12 are adjacent to monitoring equipment deployed by the Northern Development Taskforce. *(S. Buchan pers. comm.. 2008)*

2.2 Sample analysis

Analysis was carried out by the Marine and Freshwater Research Laboratory (MAFRL) at Murdoch University in Western Australia using the standard methods listed in Appendix A.

TSS samples were dried and weighed and the original weight of the filter subtracted to determine the amount of solids per litre of seawater. The samples were then heated to 550 ºC to determine the percentage lost on ignition. The portion of the

sample that is lost on ignition is the organic fraction and therefore provides information about the organic and inorganic content of the TSS sample.

Chlorophyll was extracted from the filter papers after grinding in 90% acetone and measured spectrophotometrically. This method does not detect chlorophyll present in picoplankton less than 0.8 µm in diameter.

Filterable reactive phosphorus was analysed by the ascorbic acid method, NO_3+NO_2 by copper-cadmium reduction, and ammonium by the alkaline phenate method. Total nitrogen and total phosphorus were determined from autoclave digests with potassium persulphate. These analyses were carried out on a Lachat Quick-Chem 8000 Automated Flow Injection Analyser.

2.3 Statistical analysis

The data for total phosphorous, total nitrogen, chlorophyll *a*, chlorophyll *c*, total suspended solids and loss on ignition were subject to simple T-test analysis to determine if there were any significant ($p \leq 0.5$) differences between sites and between surface and bottom waters within sites. T-tests were not conducted on ammonia, orthophosphate, NO_3+NO_2 and chlorophyll *b* because most samples were below the analytical level of reporting (LOR).

The data for each water quality indicator have been amalgamated according to the T-tests results in Table 4 and simple non-parametric statistics provided in Table 5.

Table 2: Site coordinates.

Site name	Benthic habitat site number*	Longitude (E)	Latitude (S)	Date
1	2276	122° 08.1’	17° 31.5’	18-12-08
2	2353	122° 07.2’	17° 30.0’	18-12-08
3	2188	122° 08.4’	17° 31.5’	18-12-08
4	James Price Point monitoring equipment	122° 05.0	16° 28.3’	18-12-08
5	2171	122° 05.1’	17° 27.9’	19-12-08
6	2092	122° 06.6’	17° 26.1’	19-12-08
7	1244	122° 38.1’	16° 46.8’	20-12-08
8	993	122° 38.3’	16° 44.6’	20-12-08
9	753	122° 36.6’	16° 42.6’	20-12-08
10	PHT 10	122° 36.4’	16° 44.5’	20-12-08
11	1277	122° 33.3’	16° 47.1’	21-12-08
12	Perpendicular Head monitoring equipment	122° 32.2’	16° 47.2’	21-12-08
13	1400	122° 32.1’	16° 48.6’	21-12-08
Datum is WGS84.				

** Most of the sites were visited in June 2008 for a benthic habitat survey (Fry et al. 2008). Benthic habitat survey site numbers are provided for cross referencing if required.*

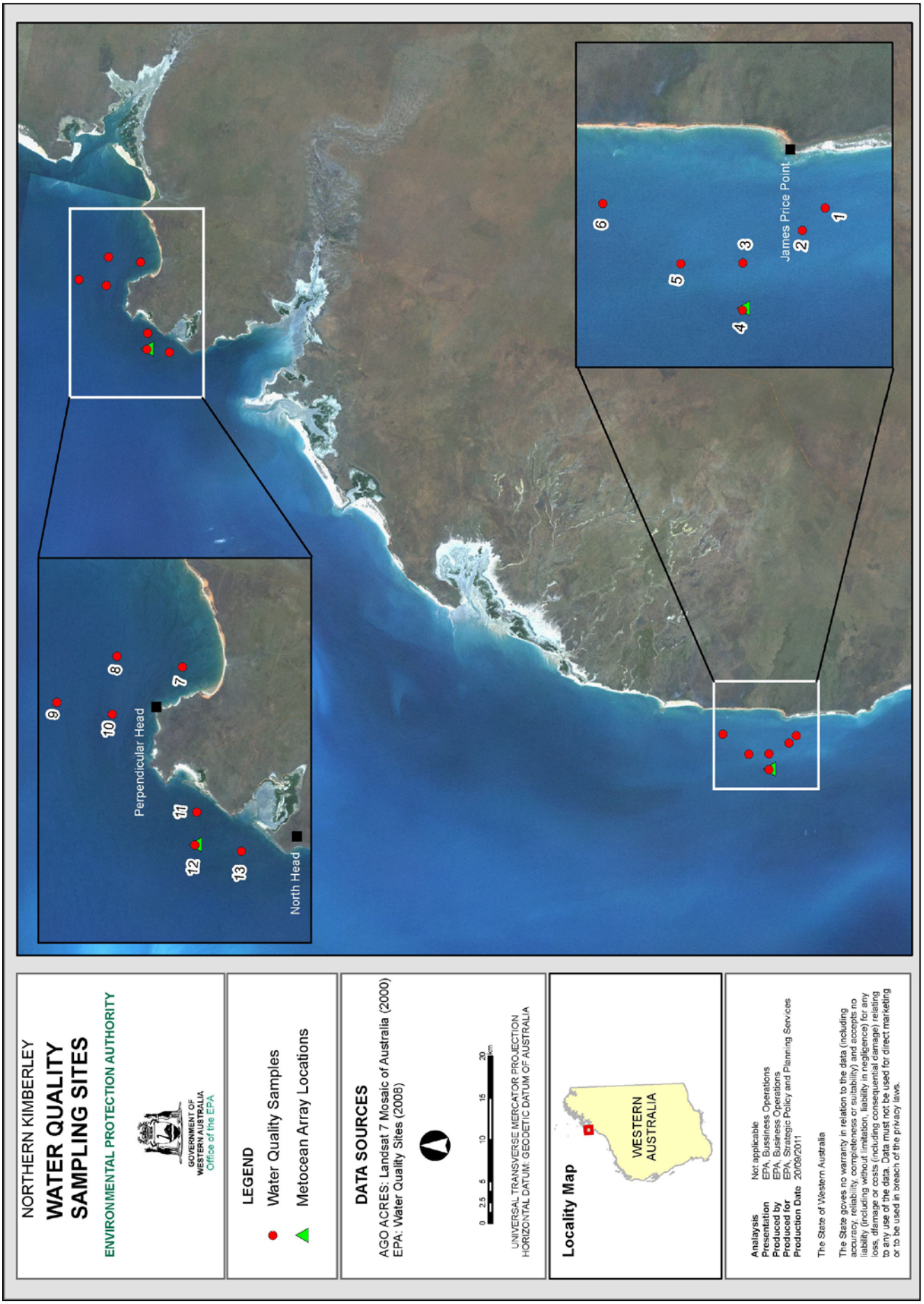


Figure 1. Locality map of the study area showing the sampling sites, Kimberly region.

3. Results

Conditions throughout the sampling period were fairly typical of the early wet season in this region. Winds were generally light to moderate in the mornings becoming fresh in the afternoon with a high percentage cloud cover (Table 1 and Appendix B).

Results from the sample analyses are presented in Table 3. The results of simple T-tests comparing the analyses for total phosphorus, total nitrogen, chlorophyll *a*, chlorophyll *c*, TSS and loss on ignition at the two locations and for surface versus bottom waters are provided in Table 4. Significant results ($p \leq 0.05$) are in bold.

3.1 Nutrients

Dissolved nutrient concentrations were very low and found to be below the analytical limit of reporting (LOR) in both surface and bottom waters at most sites. Total phosphorus concentrations exhibited the greatest variability at James Price Point, but generally the concentrations were similar at both sites and were below the recommended guideline of 15 µg/L (ANZECC & ARMCANZ 2000). However, total nitrogen concentrations were slightly elevated above the recommended guideline of 100 µg/L, with the highest concentrations and greatest variability also measured at James Price Point.

Results from T-test analysis (Table 4) indicate that total phosphorus concentrations were significantly different between surface and bottom waters at both locations and that the bottom waters at James Price Point were also significantly different from those of Perpendicular Head. Total nitrogen concentrations were similar across all sites and depths.

3.2 Chlorophyll

Samples were analysed to determine levels of chlorophyll *a*, *b* and *c*. Chlorophyll *a* ranged from 1.7 µg/L to 3.1 µg/L at James Price Point and 0.7 µg/L to 2.2 µg/L at Perpendicular Head. Chlorophyll *b* concentrations were below the LOR for almost all samples. Chlorophyll *c* concentrations ranged from 0.2 – 0.5 µg/L at James Price Point and from 0.1 – 0.3 µg/L at Perpendicular Head. Chlorophyll *a* concentrations exceeded the recommended guideline of 0.7 – 1.4 µg/L for tropical inshore marine waters (ANZECC & ARMCANZ, 2000) at both locations.

Results indicate that both chlorophyll *a* and *c* concentrations were significantly greater in bottom waters at both locations and that concentrations were higher in bottom waters at James Price Point than at Perpendicular Head. There were no significant differences in chlorophyll *a* or *c* concentrations in the surface waters across both locations.

Table 3: Results

		AMMONIA µg.N/L	ORTHO-P µg.P/L	NO3+NO2 µg.N/L	TOTAL-P µg.P/L	TOTAL-N µg.N/L	Chl 'a' µg/L	Chl 'b' µg/L	Chl 'c' µg/L	TSS mg/L	% LOSS ON IGNITION AT 550°C
GUIDELINE*		**1 - 10**	**5**	**2 - 8**	**15**	**100**	**0.7 – 1.4**	**-**	**-**	**-**	
LIMIT OF REPORTING		**<3**	**<2**	**<2**	**<5**	**<50**	**<0.1**	**<0.1**	**<0.1**	**<0.5**	
SAMPLE CODE	**DATE**										
1 S	18/12/2008	3	<2	3	13	170	1.9	<0.1	0.3	3.3	34.6
1 B	18/12/2008	<3	<2	3	14	150	2.2	<0.1	0.4	3.3	41.5
2 S	18/12/2008	<3	<2	<2	14	120	1.7	<0.1	0.2	3.1	44.0
2 B	18/12/2008	<3	<2	4	15	170	3.1	<0.1	0.5	5.1	39.5
3 S	18/12/2008	<3	<2	2	11	120	1.7	<0.1	0.3	2.5	44.7
3 B	18/12/2008	<3	3	3	13	130	2.8	<0.1	0.5	5.3	33.8
4 S	18/12/2008	<3	<2	<2	13	120	1.8	<0.1	0.2	2.5	49.4
4 M	18/12/2008	3	<2	<2	14	140	2.0	<0.1	0.3	1.9	46.0
4 B	18/12/2008	<3	<2	<2	14	130	2.2	0.1	0.5	2.0	45.0
5 S	19/12/2008	4	<2	2	14	140	2.0	<0.1	0.3	4.4	44.5
5 B	19/12/2008	<3	<2	2	18	130	2.5	<0.1	0.4	7.4	35.7
6 S	19/12/2008	<3	<2	<2	12	120	2.4	<0.1	0.4	4.0	36.8
6 B	19/12/2008	<3	<2	<2	14	120	2.8	<0.1	0.5	3.1	40.0
7 S	20/12/2008	<3	<2	<2	12	150	0.7	<0.1	0.1	1.4	51.0
7 B	20/12/2008	<3	<2	<2	13	120	1.5	<0.1	0.2	2.3	44.7
8 S	20/12/2008	<3	<2	<2	12	120	2.1	<0.1	0.2	1.7	51.9
8 B	20/12/2008	<3	<2	<2	12	130	2.1	<0.1	0.2	2.4	46.8
9 S	20/12/2008	<3	<2	<2	13	120	1.9	<0.1	0.2	2.5	42.9
9 B	20/12/2008	<3	<2	<2	14	130	2.1	<0.1	0.3	2.4	47.0
10 S	20/12/2008	<3	<2	<2	12	120	1.9	<0.1	0.3	2.3	48.3
10 B	20/12/2008	<3	<2	2	12	120	2.2	<0.1	0.3	4.1	38.1

Table 3: Results (continued)

11 S	21/12/2008	<3	<2	<2	12	130	2.1	<0.1	0.2	2.9	44.3
11 B	21/12/2008	<3	2	2	13	120	2.1	<0.1	0.3	2.1	37.6
12 S	21/12/2008	<3	<2	<2	12	120	2.1	<0.1	0.2	2.3	48.1
12 B	21/12/2008	<3	<2	<2	13	140	2.2	<0.1	0.3	2.1	46.5
13 S	21/12/2008	<3	<2	2	12	140	1.7	<0.1	0.2	3.1	39.8
13 B	21/12/2008	<3	<2	<2	12	120	2.0	<0.1	0.3	2.7	38.7

From ANZECC & ARMCANZ (2000). Where a range is provided the higher values may be typical for turbid macrotidal systems.

Table 4. T. tests (p. values) comparing surface and bottom water quality within sites and between locations.

T.Test	P	N	Chl 'a'	Chl 'c'	TSS	LOI
PH surface vs. PH bottom	**0.015**	0.345	**0.029**	**0.004**	0.228	**0.037**
JPP surface vs. JPP bottom	**0.006**	0.265	**0.007**	**0.003**	0.096	0.160
JPP surface vs. PH surface	0.164	0.102	0.321	0.071	**0.010**	0.070
JPP bottom vs. PH bottom	**0.040**	0.119	**0.005**	**0.000**	0.068	0.094

3.3 Total Suspended Solids

TSS concentrations ranged from 1.9 – 7.4 mg/L at James Price Point and from 1.4 – 4.1 mg/L at Perpendicular Head. There was no significant difference between surface and bottom concentrations at either location, but TSS concentrations in surface waters at James Price Point were significantly higher than the surface concentrations at Perpendicular Head at the time of sampling.

The loss on ignition data indicate that the organic component of the total suspended solids ranged from 33.8% to 49.4% at James Price Point and from 42.9% to 51.9% at Perpendicular Head. However, there was no significant difference in the percentage of suspended organic matter between locations and only a small, but significant, difference between surface and bottom waters at Perpendicular Head, where the organic component was greater in the surface waters.

4. General discussion

Each site in this survey was only sampled once and the sampling was undertaken over a range of flood and ebb tidal conditions at a period mid-way between full spring and full neap tidal conditions (Appendix C). Tide state was not expected to have any great influence on water quality at the two sampling locations given the open coastline and lack of bathymetric features that might cause differential strengths between flood and ebb tides. Although there was insufficient data to undertake a definitive analysis, the data do seem to support this hypothesis.

Because of the small data set (six sites at James Price Point and seven sites at Perpendicular Head) it is difficult to identify significant trends in the data with any confidence. Nevertheless, there do appear to be some relatively consistent patterns in the data. For example, there appears to be a significant difference in some of the water quality indicators between the two sampled locations, particularly in bottom waters (Table 4). Total phosphorus, chlorophyll *a* and chlorophyll *c* concentrations were all higher in bottom waters at James Price Point than at Perpendicular Head. TSS concentration, however, was higher in the surface waters at James Price Point, which is consistent with our visual observations that water clarity appeared to be poorer at James Price Point than at Perpendicular Head. A significant difference was also apparent between surface and bottom waters for total phosphorus, chlorophyll *a* and chlorophyll *c*, and this was consistent across both sampling locations. Concentrations were higher in bottom waters for all three parameters. These findings probably reflect the different positions of the two locations on the Dampier Peninsula and the relative differences in the topography of the adjacent shorelines. Perpendicular Head is a relatively exposed rocky promontory that juts out from the general coastline into deeper offshore waters whereas James Price Point is a typical shelving shoreline located further inshore along the Dampier Peninsula.

Video footage from previous benthic habitat surveys in the area revealed a layer of microphytobenthos (MPB) covering a large proportion of the sediments and it is likely that mobilisation of this MPB layer by tide, wind and wave induced currents explains the higher levels of chlorophyll measured in the bottom waters at both locations.

Like chlorophyll, total phosphorus concentrations were higher in bottom waters at both locations and also higher in bottom waters at James Price Point than at Perpendicular Head. Total phosphorus concentration appears to be correlated with chlorophyll *a* and *c* measurements which reflect algal densities, suggesting that total phosphorus concentration may be strongly influenced by the phosphorus content of

the algal cells. It is unlikely that suspended sediment is the main source of the total phosphorus concentrations because of the poor correlation in the T-tests results. Total nitrogen concentrations, on the other hand, were similar across both locations, suggesting that much of the nitrogen may have been in dissolved organic form (dissolved inorganic nitrogen concentrations were largely below the LoR).

T-test results for the LOI data suggest that the organic component of TSS was significantly higher in surface waters than bottom waters at Perpendicular Head, but suggest no differences at James Price Point or between the two locations. In absolute terms the differences were very small and there does not appear to be a correlation with any of the other measured variables.

Simple non-parametric statistics have been calculated in Table 5 for those water quality indicators that could be consistently measured above the LoR. The statistics have been calculated according to the groupings suggested by the T-test results. While statistically significant differences have been found, these differences are only minor in absolute terms and it may be valid to combine the data sets for both locations if the intention was to develop a regional baseline for water quality. Simple statistics have therefore been calculated for the combined data set and presented at the bottom of Table 5. These non-parametric statistics can be used to generate guideline trigger values for the area using the recommended approaches from the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ, 2000).

Table 5: Simple non-parametric statistics

	TOTAL-P µg.P/L	TOTAL-N µg.N/L	Chl 'a' µg/L	Chl 'c' µg/L	TSS mg/L	% LOSS ON IGNITION
James Price Point (all)						
Median					3.3	
80th percentile					4.8	
95th percentile					6.1	
n					12	
James Price Point (bottom)						
Median	14.0		2.7	0.5		
80th percentile	15.0		2.8	0.5		
95th percentile	17.3		3.0	0.5		
n	6		6	6		
95th percentile	17.3		3.0	0.5		
n	6		6	6		

Table 5: Simple non-parametric statistics (continued)

Perpendicular Head (all)						
Median					2.4	
80th percentile					2.8	
95th percentile					3.5	
n					14	
Perpendicular Head (bottom)						
Median	13.0		2.1	0.3		
80th percentile	13.0		2.1	0.3		
95th percentile	13.7		2.2	0.3		
n	7		7	7		
All Surface						
Median	12.0		1.9	0.2		44.5
80th percentile	13.0		2.1	0.3		49.0
95th percentile	14.0		2.2	0.34		51.3
n	13		13	13		13
All Bottom						
Median						40.0
80th percentile						45.9
95th percentile						46.9
n						13
All Data						
Median	13.0	130.0	2.1	0.3	2.5	44.3
80th percentile	14.0	140.0	2.2	0.4	3.9	47.0
95th percentile	14.7	164.0	2.8	0.5	5.2	50.5
n	26	26	26	26	26	26

The data collected during this survey have been used to derive 80th and 95th percentiles in Table 6 for comparison with the default trigger values from ANZECC & ARMCANZ (2000). Given the limited amount of data, including long-term seasonal data, the surface and bottom concentrations from both sites have been combined for these calculations. A comparison with the default guidelines recommended in ANZECC & ARMCANZ (2000) suggests that water quality on the west side of the Dampier Peninsula at the time of sampling was typical of tropical coastal waters across Australia, except for total nitrogen and chlorophyll *a*. Total nitrogen and

chlorophyll *a* concentrations are both slightly higher than the recommended default guidelines of 140 µg/L and 0.7 – 1.4 µg/L respectively.

Nevertheless, nutrient concentrations by themselves are generally poor indicators of marine water quality because concentrations are influenced by a range of factors and elevated concentrations do not necessarily result in enhanced algal biomass. Chlorophyll *a* is generally considered to be a better indicator of nutrient status in marine waters because of its position further along the cause-effect pathway. High chlorophyll *a* levels suggest high levels of phytoplankton which can stress benthic habitats by reducing the amount of light exposure and by loading the sediments with organic matter, leading to enhanced bacterial activity and reduced dissolved oxygen levels.

Of the parameters measured in this survey, chlorophyll *a* and TSS are the most relevant indicators of water quality. If the chlorophyll *a* and TSS concentrations measured in this survey are found to be typical of wet season conditions then locality specific guidelines for chlorophyll *a* would need to be derived from un-impacted local background water quality data. Ideally, two years of data should be collected across each season to derive suitable guideline trigger values for the area.

Table 6: Interim guideline trigger values for high and moderate levels of ecological protection at James Price Point and Perpendicular Head.

Water quality indicator		High ecological protection (80th percentile)	Moderate ecological protection (95th percentile)
NH_4^+	(µg N/L)	<3	3
NO_3 + NO_2	(µg N/L)	2	3
Total N	(µg N/L)	140	164
PO_4	(µg P/L)	<2	2
Total P	(µg P/L)	14.0	14.7
Chl *a*	(µg/L)	2.2	2.8
Chl *b*	(µg/L)	<0.1	<0.1
Chl *c*	(µg/L)	0.4	0.5
TSS	(mg/L)	3.9	5.2
LOI	(%)	47.0	50.5

5. Conclusion

The marine waters of the Kimberley coast are essentially unimpacted by any anthropogenic activities so the data reported from this survey are considered to represent unimpacted background conditions. Ammonia, nitrate and nitrite, ortho-phosphate and total phosphorus concentrations were all less than the recommended default guideline trigger values from ANZECC & ARMCANZ (2000). However, the data suggest that total nitrogen and chlorophyll *a* concentrations in the areas sampled may naturally exceed the recommended default guideline trigger values for Australian tropical marine waters during the wet season. Chlorophyll *b* and *c*, total suspended solids and loss on ignition were also measured, but there are no guideline trigger values available for these indicators. Chlorophyll *a* and TSS are the most relevant indicators of water quality and guideline trigger values for these

indicators may need to be derived from local reference site data using the recommended approaches in ANZECC & ARMCANZ (2000).

Small differences in water quality were apparent between James Price Point and Perpendicular Head with slightly higher concentrations of total phosphorus, chlorophyll *a*, chlorophyll *c* and total suspended solids at James Price Point. The data suggest that there could be a decreasing trend in water quality for these indicators from south to north, but additional survey work would be required to confirm this hypothesis.

The sampling data also show statistically higher levels of total phosphorus, chlorophyll *a* and chlorophyll *c* concentrations in bottom waters at both locations which may be caused by the suspension of microphytobenthos from the seabed.

Characterising these waters to adequately understand tidal, seasonal and inter-annual variability would require a significant allocation of resources.

6. References

ANZECC & ARMCANZ (2000). *Australian and New Zealand guidelines for fresh and marine water quality.* National Water Quality Management Strategy No 4, Australian and New Zealand Environment and Conservation Council and Agricultural and Resource Management Council of Australia and New Zealand, Canberra, ACT.

Government of Western Australia (2004). *Implementation Framework for Western Australia for the Australian and New Zealand Guidelines for Fresh and Marine Water Quality and Water Quality Monitoring and Reporting (Guidelines No.s 4 & 7: National Water Quality Management Strategy)*. State Water Quality Management Strategy, Report No. 6.

Fry G., Heyward A., Wassenberg T., Ellis N., Taranto T., Keesing J., Irvine T., Stieglitz T., Colquhoun J. (2008) *Benthic habitat surveys of potential LNG hub locations in the Kimberley region.* CSIRO and AIMS joint final report for the Western Australian Marine Science Institution.

Appendix A - Laboratory test methods

Index of Laboratory Test Methods

Ammonia in natural waters by FIA, MAFRL Method 2000

(Limit of Reporting (LOR) = 3 µg.N.L-1) (Range = 3 – 500 µg.N.L-1)

Lachat Automated Flow Injection Analyser

Lachat Instruments QuickChem Method 31-107-06-1-A (29 July 1994) Ammonia in Brackish or Seawater. (Lachat Instruments, 6645 West Mill Road, Millwaaukee, WI 53218, USA)

Chlorophyll *a*, *b* and *c* determined trichromatically, MAFRL Method 3020

Manual Colorimetric: Chlorophyll a, b, and c is determined by filtration onto a GF/C filtered paper (pore size 1.2 µm, Whatman Ltd, England) followed by grinding in 90% acetone and the chlorophyll a, b, and c concentration measured spectrophotometrically (Varian Cary 50 Spectrophotometer, Varian Techron Pty Ltd, Springvale, Australia) according to the method of Strickland and Parsons (1972) A Practical Handbook of Seawater Analysis, Second Edition. Bulletin No 167, Fisheries Research Board of Canada, Ottawa.

Orthophosphate in natural waters by FIA, MAFRL Method 4100

(LOR = 2 µg.P.L^{-1}) (Range = 2 – 500 µg.P.L^{-1})

Lachat Automated Flow Injection Analyser

Lachat Instruments QuickChem Method 31-115-01-3-A (17 August 1994). *Phosphate in Brackish or Seawater.* (Lachat Instruments, 6645 West Mill Road, Millwaaukee, WI 53218, USA)

Nitrate and nitrite in natural waters by FIA, MAFRL Method 2100

(LOR = 2 µg.N.L-1) (Range = 2 – 500 µg.N.L-1)

Lachat Automated Flow Injection Analyser

Lachat Instruments QuickChem Method 31-107-04-1-A (18 July 1996) Nitrate and/or Nitrite in Brackish Waters or Seawater (Lachat Instruments, 6645 West Mill Road, Millwaaukee, WI 53218, USA)

Total nitrogen in natural waters by autoclave digestion, MAFRL Method 2700

(LOR = 50 µg.N.L-1) (Range = 50 – 1000 µg.N.L-1)

Lachat Automated Flow Injection Analyser

Lachat Instruments QuickChem Method 31-107-04-1-A (18 July 1996) Nitrate and/or Nitrite in Brackish Waters or Seawater (Lachat Instruments, 6645 West Mill Road, Millwaaukee, WI 53218, USA)

Total phosphorus in natural waters by autoclave digestion, MAFRL Method 4700

(LOR = 5 µg.P.L-1) (Range = 5– 500 µg.P.L-1)

Lachat Automated Flow Injection Analyser

Lachat Instruments QuickChem Method 31-115-01-3-A (17 August 1994). Phosphate in Brackish or Seawater. (Lachat Instruments, 6645 West Mill Road, Millwaaukee, WI 53218, USA)

Total Suspended Solids dried at 103-105°C, APHA Method 2540D.

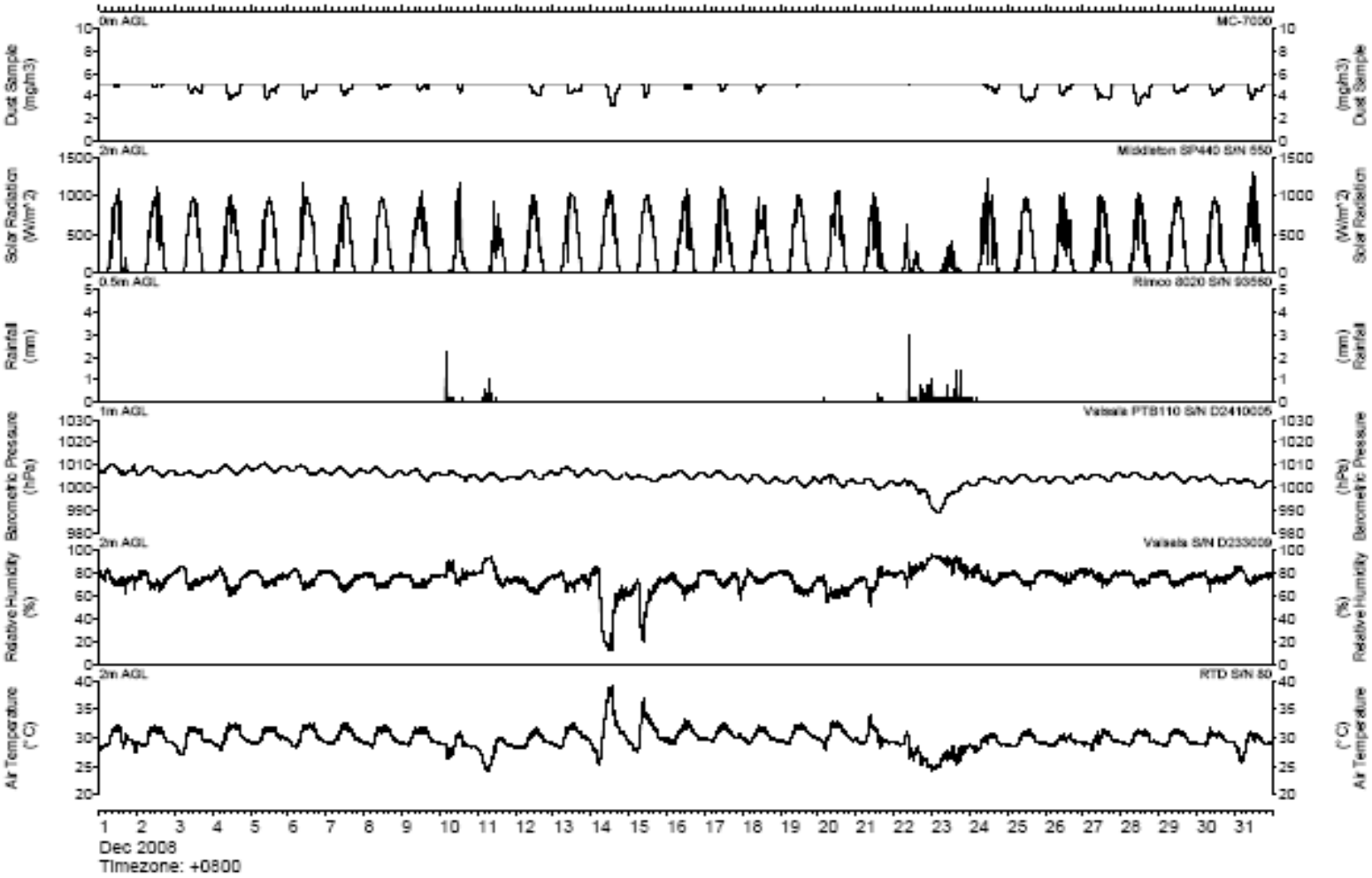
APHA (2005) Standard Methods for the Examination of Water and Wastewater (21st Ed) Washington,D.C USA (pp2-58,59)

Fixed and Volatile Solids Ignited at 550°C, APHA Method 2540E.

APHA (2005) Standard Methods for the Examination of Water and Wastewater (21st Ed) Washington,D.C USA (pp2-59)

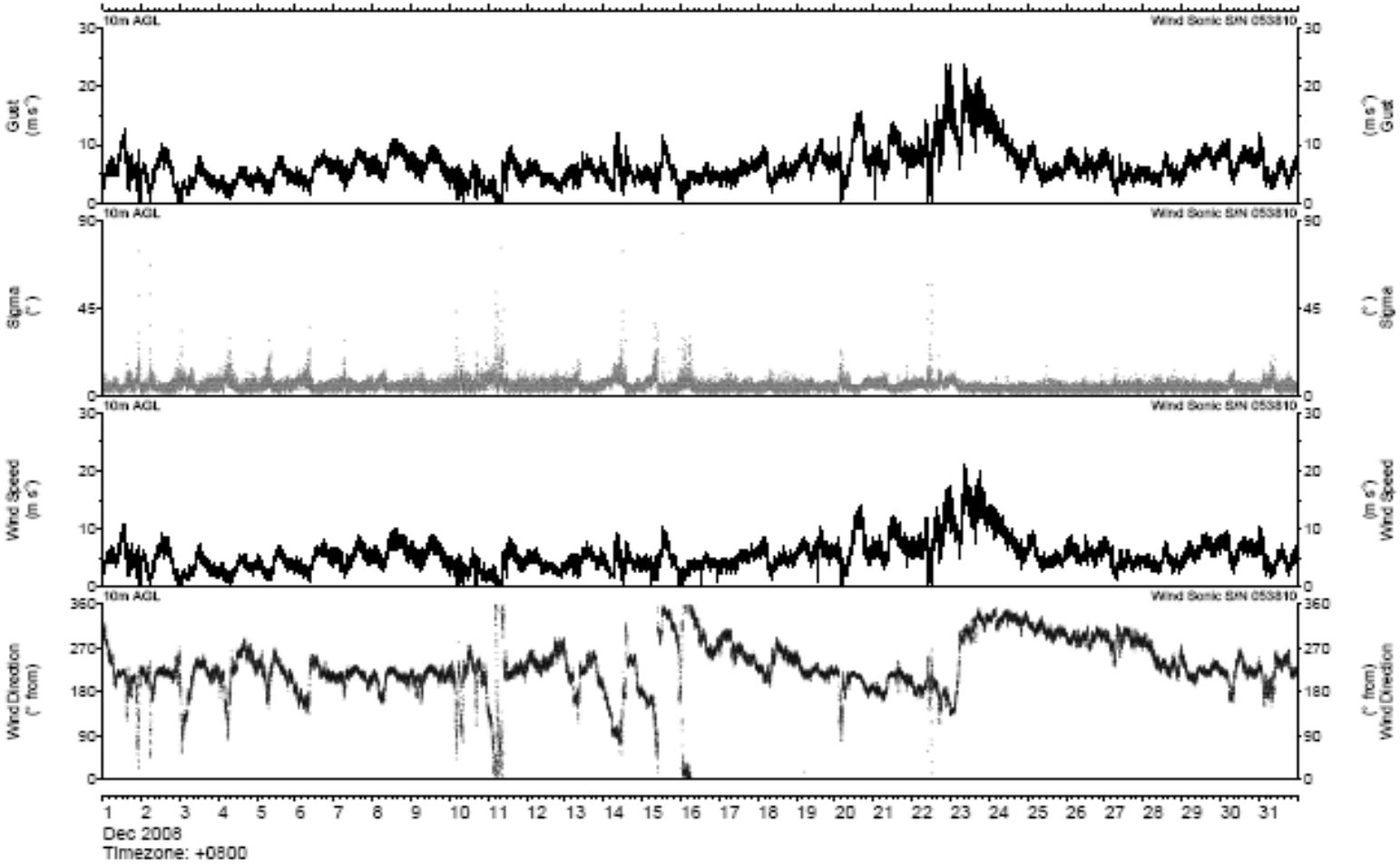
Appendix B - Meteorological data

Location:	**North Head**		
Latitude:	16° 49' 55" S	Client:	Northern Development Task Force
Longitude:	122° 32' 15" E	Project:	J2715
Location Height:	0.00 m AHD		



Time Zone: UTC +08:00 hours	Data Source: (jobs/J2715/measured/met/metstation_NorthHead_00603_2008_{10_11_12}.c.nc
© RPS MetOcean Engineers Pty Ltd	moetimehist: 16:55 29/Jan/2009 by jonty (timehist.J2715.NorthHead.argos.oct_dec.month.c.ps)

Location:	**North Head**		
Latitude:	16° 49' 55" S	Client:	Northern Development Task Force
Longitude:	122° 32' 15" E	Project:	J2715
Location Height:	0.00 m AHD		

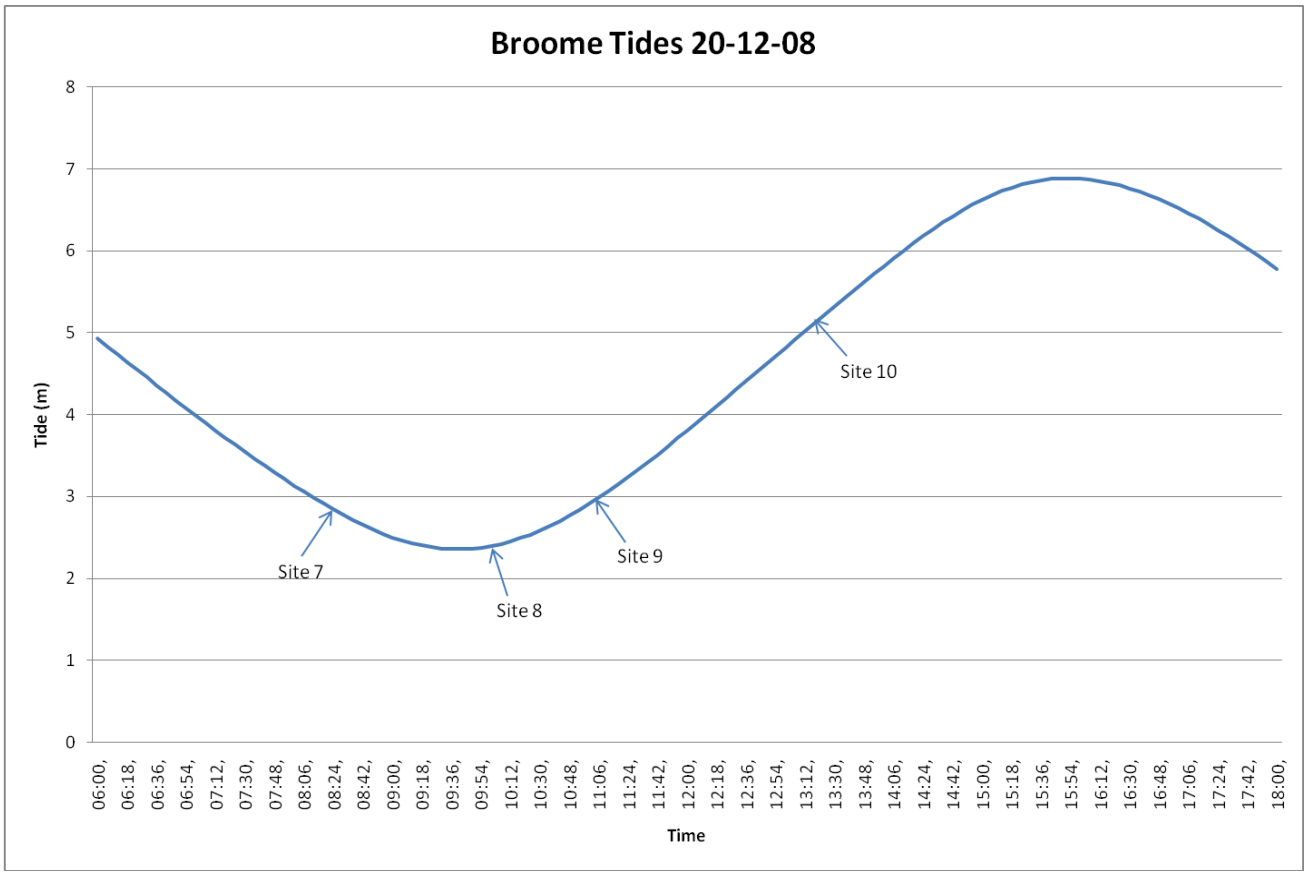


Time Zone: UTC +08:00 hours	Data Source: (jobs/J2715/measured/met/metstation_NorthHead_00603_2008_{10_11_12}.c.nc
© RPS MetOcean Engineers Pty Ltd	moetimehist: 16:55 29/Jan/2009 by jonty (timehist.J2715.NorthHead.argos.oct_dec.month.c.ps)

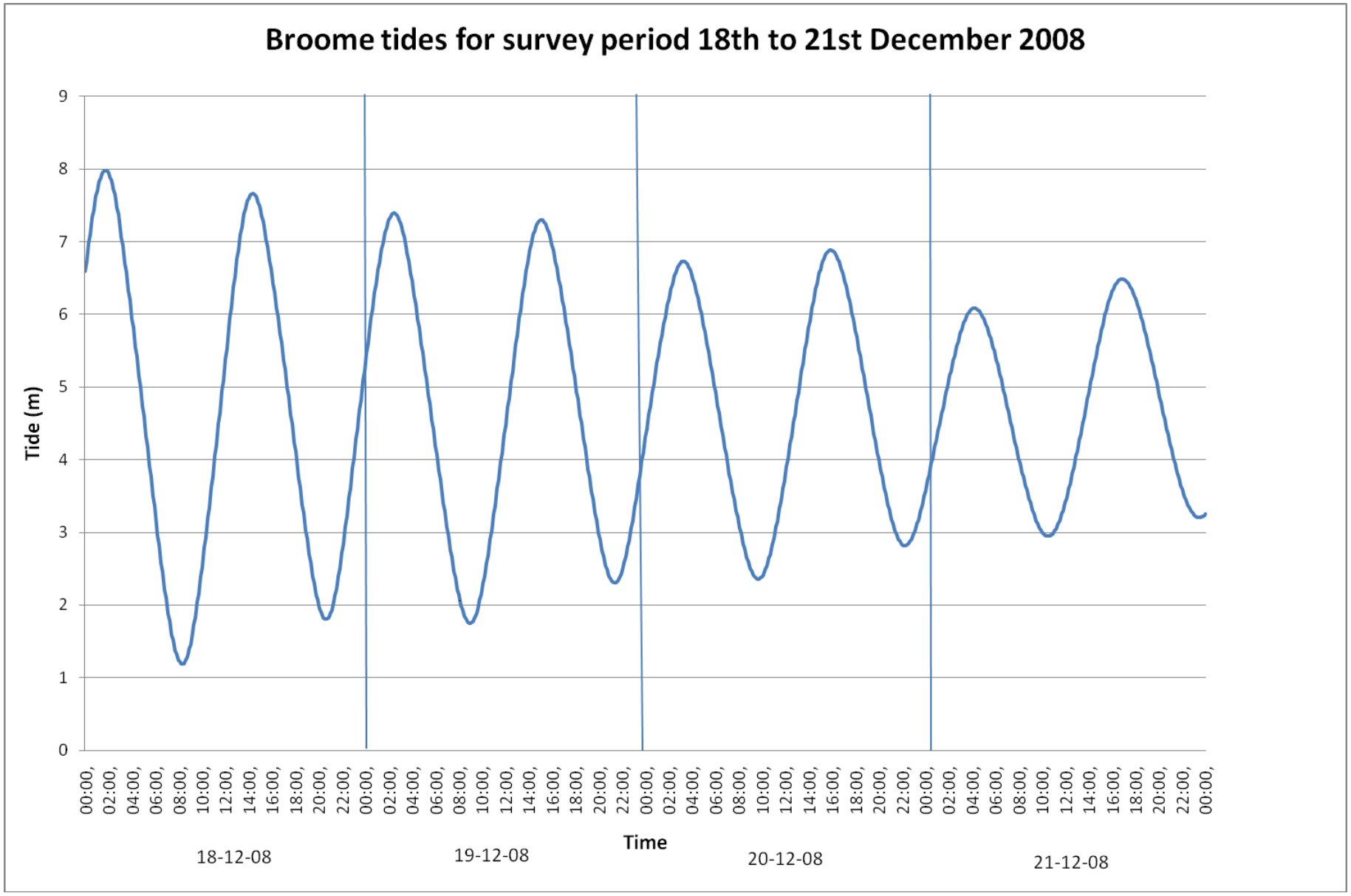
Appendix C -
Tidal predictions for Broome during study period


Broome Tides 18-12-08
Tide (m)
Time
Site 1
Site 2
Site 3
Site 4


Broome Tides 19-12-08
Tide (m)
Time
Site 5
Site 6


Broome Tides 20-12-08
Tide (m)
Time
Site 7
Site 8
Site 9
Site 10


Broome Tides 21-12-08
Tide (m)
Time
Site 11
Site 12
Site 13


Broome tides for survey period 18th to 21st December 2008
Tide (m)
9
8
7
6
5
4
3
2
1
0
00:00, 02:00, 04:00, 06:00, 08:00, 10:00, 12:00, 14:00, 16:00, 18:00, 20:00, 22:00, 00:00, 02:00, 04:00, 06:00, 08:00, 10:00, 12:00, 14:00, 16:00, 18:00, 20:00, 22:00, 00:00, 02:00, 04:00, 06:00, 08:00, 10:00, 12:00, 14:00, 16:00, 18:00, 20:00, 22:00, 00:00, 02:00, 04:00, 06:00, 08:00, 10:00, 12:00, 14:00, 16:00, 18:00, 20:00, 22:00, 00:00,
Time
18-12-08
19-12-08
20-12-08
21-12-08

Appendix D - T Tests

James Price Point. Surface vs Bottom

METHOD SAMPLE CODE		2000 AMMONIA µg.N/L	4100 ORTHO-P µg.P/L	2100 NO3+NO2 µg.N/L	4700 TOTAL-P µg.P/L	2700 TOTAL-N µg.N/L	3020 CHLORO 'a' µg/L	3020 CHLORO 'b' µg/L	3020 CHLORO 'c' µg/L	2540D TSS mg/L	% LOSS ON IGNITION AT 550°C
Reporting Limit	**Sampling Date**	**<3**	**<2**	**<2**	**<5**	**<50**	**<0.1**	**<0.1**	**<0.1**	**<0.5**	
File			**09021801**		**09021002**			**09020401**		**090202**	**090202**
1 S	18/12/2008	3	<2	3	13	170	1.9	<0.1	0.3	3.3	34.6
2 S	18/12/2008	<3	<2	<2	14	120	1.7	<0.1	0.2	3.1	44.0
3 S	18/12/2008	<3	<2	2	11	120	1.7	<0.1	0.3	2.5	44.7
4 S	18/12/2008	<3	<2	<2	13	120	1.8	<0.1	0.2	2.5	49.4
5 S	19/12/2008	4	<2	2	14	140	2	<0.1	0.3	4.4	44.5
6 S	19/12/2008	<3	<2	<2	12	120	2.4	<0.1	0.4	4	36.8
Means					**13**	**131.7**	**1.9**		**0.3**	**3.3**	**42.3**
1 B	18/12/2008	<3	<2	3	14	150	2.2	<0.1	0.4	3.3	41.5
2 B	18/12/2008	<3	<2	4	15	170	3.1	<0.1	0.5	5.1	39.5
3 B	18/12/2008	<3	3	3	13	130	2.8	<0.1	0.5	5.3	33.8
4 B	18/12/2008	<3	<2	<2	14	130	2.2	0.1	0.5	2	45.0
5 B	19/12/2008	<3	<2	2	18	130	2.5	<0.1	0.4	7.4	35.7
6 B	19/12/2008	<3	<2	<2	14	120	2.8	<0.1	0.5	3.1	40.0
Means					**15**	**138.3**	**2.6**		**0.5**	**4.4**	**39.3**
T Test p value					**0.006**	**0.265**	**0.007**		**0.003**	**0.096**	**0.160**

Perpendicular Head Surface vs Bottom

METHOD	Sampling	2000	4100	2100	4700	2700	3020	3020	3020	2540D	% LOSS ON
SAMPLE CODE	Date	AMMONIA µg.N/L	ORTHO-P µg.P/L	NO3+NO2 µg.N/L	TOTAL-P µg.P/L	TOTAL-N µg.N/L	CHLORO 'a' µg/L	CHLORO 'b' µg/L	CHLORO 'c' µg/L	TSS mg/L	IGNITION AT 550°C
Reporting Limit		**<3**	**<2**	**<2**	**<5**	**<50**	**<0.1**	**<0.1**	**<0.1**	**<0.5**	
File			**09021801**		**09021002**			**09020401**		**090202**	**090202**
7 S	20/12/2008	<3	<2	<2	12	150	0.7	<0.1	0.1	1.4	51.0
8 S	20/12/2008	<3	<2	<2	12	120	2.1	<0.1	0.2	1.7	51.9
9 S	20/12/2008	<3	<2	<2	13	120	1.9	<0.1	0.2	2.5	42.9
10 S	20/12/2008	<3	<2	<2	12	120	1.9	<0.1	0.3	2.3	48.3
11 S	21/12/2008	<3	<2	<2	12	130	2.1	<0.1	0.2	2.9	44.3
12 S	21/12/2008	<3	<2	<2	12	120	2.1	<0.1	0.2	2.3	48.1
13 S	21/12/2008	<3	<2	2	12	140	1.7	<0.1	0.2	3.1	39.8
Means					**12**	**128.6**	**1.8**		**0.2**	**2.3**	**46.6**
7 B	20/12/2008	<3	<2	<2	13	120	1.5	<0.1	0.2	2.3	44.7
8 B	20/12/2008	<3	<2	<2	12	130	2.1	<0.1	0.2	2.4	46.8
9 B	20/12/2008	<3	<2	<2	14	130	2.1	<0.1	0.3	2.4	47.0
10 B	20/12/2008	<3	<2	2	12	120	2.2	<0.1	0.3	4.1	38.1
11 B	21/12/2008	<3	2	2	13	120	2.1	<0.1	0.3	2.1	37.6
12 B	21/12/2008	<3	<2	<2	13	140	2.2	<0.1	0.3	2.1	46.5
13 B	21/12/2008	<3	<2	<2	12	120	2	<0.1	0.3	2.7	38.7
Means					**13**	**125.7**	**2.0**		**0.3**	**2.6**	**42.8**
T Test p value					**0.015**	**0.345**	**0.029**		**0.004**	**0.228**	**0.037**

James Price Point Surface vs Perpendicular Head Surface

METHOD	Sampling	2000	4100	2100	4700	2700	3020	3020	3020	2540D	% LOSS ON
SAMPLE CODE	Date	AMMONIA µg.N/L	ORTHO-P µg.P/L	NO3+NO2 µg.N/L	TOTAL-P µg.P/L	TOTAL-N µg.N/L	CHLORO 'a' µg/L	CHLORO 'b' µg/L	CHLORO 'c' µg/L	TSS mg/L	IGNITION AT 550°C
Reporting Limit		**<3**	**<2**	**<2**	**<5**	**<50**	**<0.1**	**<0.1**	**<0.1**	**<0.5**	
File			**09021801**		**09021002**			**09020401**		**090202**	**090202**
JPP											
1 S	18/12/2008	3	<2	3	13	170	1.9	<0.1	0.3	3.3	34.6
2 S	18/12/2008	<3	<2	<2	14	120	1.7	<0.1	0.2	3.1	44.0
3 S	18/12/2008	<3	<2	2	11	120	1.7	<0.1	0.3	2.5	44.7
4 S	18/12/2008	<3	<2	<2	13	120	1.8	<0.1	0.2	2.5	49.4
5 S	19/12/2008	4	<2	2	14	140	2	<0.1	0.3	4.4	44.5
6 S	19/12/2008	<3	<2	<2	12	120	2.4	<0.1	0.4	4	36.8
Mean					**12.8**	**131.7**	**1.9**		**0.3**	**3.3**	**42.3**
PH											
7 S	20/12/2008	<3	<2	<2	12	150	0.7	<0.1	0.1	1.4	51.0
8 S	20/12/2008	<3	<2	<2	12	120	2.1	<0.1	0.2	1.7	51.9
9 S	20/12/2008	<3	<2	<2	13	120	1.9	<0.1	0.2	2.5	42.9
10 S	20/12/2008	<3	<2	<2	12	120	1.9	<0.1	0.3	2.3	48.3
11 S	21/12/2008	<3	<2	<2	12	130	2.1	<0.1	0.2	2.9	44.3
12 S	21/12/2008	<3	<2	<2	12	120	2.1	<0.1	0.2	2.3	48.1
13 S	21/12/2008	<3	<2	2	12	140	1.7	<0.1	0.2	3.1	39.8
Mean					**12.1**	**128.6**	**1.8**		**0.2**	**2.3**	**46.6**
T Test p value					**0.164**	**0.102**	**0.321**		**0.071**	**0.010**	**0.070**

James Price Point Bottom vs Perpendicular Head Bottom

METHOD	Sampling	2000	4100	2100	4700	2700	3020	3020	3020	2540D	% LOSS ON
SAMPLE CODE	Date	AMMONIA	ORTHO-P	NO3+NO2	TOTAL-P	TOTAL-N	CHLORO 'a'	CHLORO 'b'	CHLORO 'c'	TSS	IGNITION AT 550°C
		µg.N/L	µg.P/L	µg.N/L	µg.P/L	µg.N/L	µg/L	µg/L	µg/L	mg/L	
Reporting Limit		**<3**	**<2**	**<2**	**<5**	**<50**	**<0.1**	**<0.1**	**<0.1**	**<0.5**	
File			**09021801**		**09021002**			**09020401**		**090202**	**090202**
JPP											
1 B	18/12/2008	<3	<2	3	14	150	2.2	<0.1	0.4	3.3	41.5
2 B	18/12/2008	<3	<2	4	15	170	3.1	<0.1	0.5	5.1	39.5
3 B	18/12/2008	<3	3	3	13	130	2.8	<0.1	0.5	5.3	33.8
4 B	18/12/2008	<3	<2	<2	14	130	2.2	0.1	0.5	2	45.0
5 B	19/12/2008	<3	<2	2	18	130	2.5	<0.1	0.4	7.4	35.7
6 B	19/12/2008	<3	<2	<2	14	120	2.8	<0.1	0.5	3.1	40.0
Mean					**14.7**	**138.3**	**2.6**		**0.5**	**4.4**	**39.3**
PH											
7 B	20/12/2008	<3	<2	<2	13	120	1.5	<0.1	0.2	2.3	44.7
8 B	20/12/2008	<3	<2	<2	12	130	2.1	<0.1	0.2	2.4	46.8
9 B	20/12/2008	<3	<2	<2	14	130	2.1	<0.1	0.3	2.4	47.0
10 B	20/12/2008	<3	<2	2	12	120	2.2	<0.1	0.3	4.1	38.1
11 B	21/12/2008	<3	2	2	13	120	2.1	<0.1	0.3	2.1	37.6
12 B	21/12/2008	<3	<2	<2	13	140	2.2	<0.1	0.3	2.1	46.5
13 B	21/12/2008	<3	<2	<2	12	120	2	<0.1	0.3	2.7	38.7
Mean					**12.7**	**125.7**	**2.0**		**0.3**	**2.6**	**42.8**
T Test (p value)					**0.040**	**0.119**	**0.005**		**0.000**	**0.068**	**0.094**