Technical Appendix S4

Ichthys Gas Field Development Project: Gunn Reef Blue Holes and Howard River—water quality and coral survey

Report

Ichthys Gas Field Development Project:

Gunn Reef Blue Holes and Howard River - water quality and coral survey

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Prepared for

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Introduction

INPEX Browse, Ltd. (INPEX) proposes to develop the natural gas and associated condensate contained in the Ichthys Field in the Browse Basin at the western edge of the Timor Sea about 200 km off Western Australia's Kimberley coast. The field is about 850 km west-south-west of Darwin in the Northern Territory.

In May 2008 INPEX referred its proposal to develop the Ichthys Field to the Commonwealth's Department of the Environment, Water, Heritage and the Arts and the Northern Territory's Department of Natural Resources, Environment and the Arts. The Commonwealth and Northern Territory ministers responsible for environmental matters both determined that the Project should be formally assessed at the Environmental Impact Statement (EIS) level to ensure that potential impacts associated with the Project are identified and appropriately addressed.

A Draft EIS has since been assessed in accordance with the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) (EPBC Act) and the *Environmental Assessment Act* (NT) (EA Act). It was submitted as a single Draft EIS document to the two responsible government departments for assessment. Submissions have been received and a supplementary EIS is currently under development to ensure submissions are addressed and to present additional information collected since publication of the Draft EIS.

URS Australia Pty Ltd was commissioned to carry out environmental studies associated with INPEX's preparation of the supplementary EIS and this technical report, INPEX Gas Field Development Project: Gunn Reef Blue Holes and Howard River - water quality and coral survey, was prepared in part fulfilment of that commission.

1.1 Background

INPEX proposes to undertake dredging operations during the development of the gas processing and export facilities within Darwin Harbour. Dredging activities will be required to create safe access to facilities at Blaydin Point. Trenching will be required along the pipeline route through Darwin Harbour and at the pipeline shore crossing on Middle Arm Peninsula. Disposal of the dredge spoil material is proposed to be at a site offshore from Darwin Harbour (Figure 1-1).

Section 7.3.3 of the Draft EIS contains details of a risk assessment associated with spoil disposal activities. The current study provides further detail on particular marine and estuarine habitats identified in stakeholder submissions on the Draft EIS and is intended to support further risk assessment as part of the EIS Supplement to which this report is appended.

The current study investigates background water quality characteristics at Howard River / Hope Inlet and the Blue Holes of Gunn Reef, with particular emphasis on turbidity (measured as nephelometric turbidity units (NTU)), along with identifying seabed and coral community characteristics within the Blue Holes (Maps 1 – 3, Appendix A). The purpose of the study was to provide background data to allow for site specific impact assessment within the EIS Supplement.

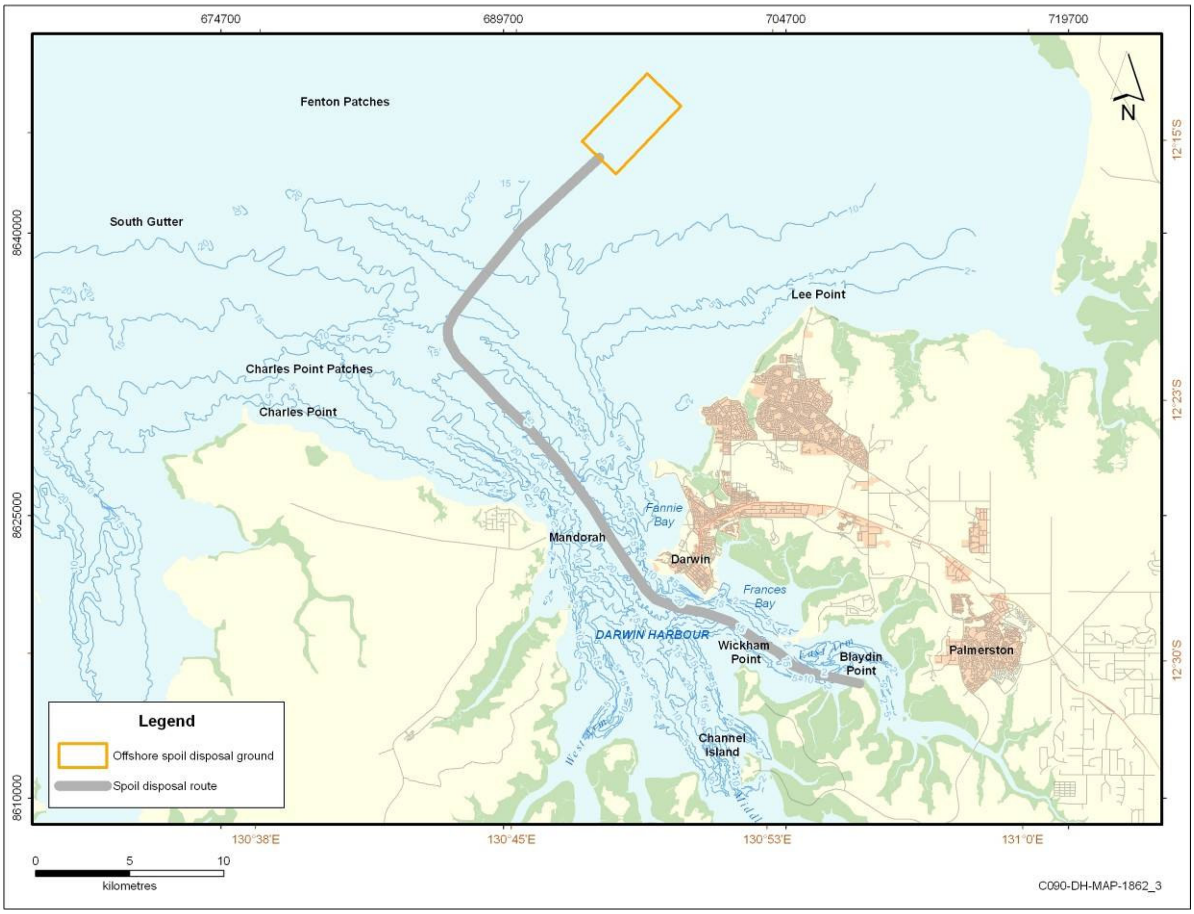

Figure 1-1 Proposed dredge spoil disposal site and spoil disposal route

1.2 Survey Objectives

URS, in conjunction with Tek Ventures, undertook the survey with the following objectives:

- To characterise the natural water quality characteristics within the Howard River / Hope Inlet system and the Blue Holes of Gunn Reef, with a focus on turbidity levels.
- To determine the typical broad community composition of hard corals within the Blue Holes.
- To sample sediment at selected locations within the Northern Blue Hole (NBH).

Methods

2.1 Survey Locations and Investigations

The following sections describe in detail the locations and sites surveyed. Survey locations and sites are depicted and described in Appendix A (Maps 1-3) and Appendix B (Tables 1 and 2).

2.1.1 Howard River / Hope Inlet System

Water quality profiles were measured at 36 water quality sites, extending from the Howard River mouth, through Hope Inlet and River and into the Hope Creek systems (sites HR1 to HR36 on Map 1, Appendix A). Sites HR-1 to HR-9 and HR-13 to HR-21 formed an ‘upstream transect’, with profiles measured on the flood tide as the survey vessel moved upstream. Sites HR-22 to HR-29 and HR-31 to HR-36 formed a ‘downstream transect’, with profiles measured on the ebb tide as the survey vessel returned to the mouth of the Howard River. Sites HR-10 to HR-12 and HR-30 and HR-31 were within smaller creek arms extending north from Hope River (locally termed Third Creek and Second Creek, respectively).

The survey commenced at 1220 hrs (HR-1) and ceased at 1530 hrs (HR-36) on 1 December 2010. This was during the neap phase of the tidal cycle, with low water of 2.1 m at 0751 hrs and high water of 5.2 m at 1407 hrs (Nightcliff tide charts, depths relative to Lowest Astronomical Tide [LAT]). Whilst local knowledge suggested that Nightcliff tides were approximately two hours behind Shoal Bay the water depth recorded on the extended deployment logger showed high tide at approximately 1415 hrs.

Physico-chemical parameter data (except turbidity) measured during water profiling throughout the Howard River / Hope Inlet system were combined for analysis. Turbidity levels recorded during sampling within the system were combined for analysis of the overall Howard River / Hope Inlet system, as well as divided into smaller areas for a finer scale analysis. These areas are displayed in Map 1 (Appendix A) and are termed:

- Howard River
- Hope Inlet
- Hope River
- Hope Creeks (including Second, Third, No Hope and Little Hope Creeks)

2.1.2 Howard River Mouth

An extended deployment logger was deployed at the Howard River mouth (“HR Logger” on Map 1, Appendix A) on 1 December 2010 at 1215 hrs and retrieved on 28 December 2010. A second logger attached to the same mooring was removed by an unknown third party during the deployment period and was not recovered.

Six filtered water samples for suspended sediment concentration (SSC) determination were collected on 1 December 2010 between 1315 hrs and 1545 hrs. The samples were collected in the immediate vicinity of the extended deployment logger (HRL1 to HRL7 on Map 1, Appendix A).

2.1.3 Blue Holes on Gunn Reef

Northern Blue Hole

Sampling at the NBH commenced at approximately 1015 hrs and ceased at 1640 hrs on 7 December 2010. This was during the spring phase of the tidal cycle, when tide height predictions (relative to LAT) for Glyde Point (the nearest prediction station to the Blue Holes) were a high water of 4.7 m at 0642 hrs, a low water of 0.6 m at 1343 hrs and a second high water of 5.5 m at 2003 hrs. An ADCP deployed in the NBH for a separate data collection program showed a high water (relative to approximate Mean Sea Level) of 2.1 m at 0609 hrs, a low water of -3.5 m at 1254 hrs and a second high water of 3.0 m at 1918 hrs. Due to depth limitations at the western entrance of the NBH, the vessel was only able to enter and exit on a (Glyde Point) tide height of 3.5 m or higher. Over the sampling period, there was a steady flow of water out through the western entrance of the NBH up until the rising tide was sufficiently high to reverse the flow through this entrance.

Water quality profiles were measured at 12 sites within the NBH (NB1 to NB12 on Map 2, Appendix A). Two profiles were measured at each of sites NB2 – NB6 at different phases of the tide cycle, and six profiles were measured at site NB1, allowing analysis of temporal variation in water quality. Three filtered water samples for SSC determination were also collected (NBTSS1 to NBTSS3 on Map 2, Appendix A).

Seafloor sediment characteristics were investigated at seven sites within the NBH (SED_BH01 to SED_BH07 on Map 3, Appendix A). Only three sediment samples were collected for particle size analysis; the other four sites returned rubble with no sediment, or no sample (indicative of hard substrate).

Nine sites within the NBH (NBHV01 to NBHV09 on Map 3, Appendix A) were selected for the identification of broad composition, semi-quantitative coral community characteristics using drop camera video transects. Sites were selected to characterise the communities along the length of the NBH within the limitations imposed by the restricted mobility of the camera equipment and prevailing wind conditions. At each site, vertical transects were recorded down the steep walls of the Hole, to test the assumption that hard coral communities were limited to the upper slopes of the walls.

Southern Blue Hole

Sampling at the Southern Blue Hole (SBH) commenced at approximately 0937 hrs and ceased at 1651 hrs on 8 December 2010. This was during the spring phase of the tidal cycle, when tide height predictions (relative to LAT) for Glyde Point were a high water of 4.7 m at 0725 hrs, a low water of 0.7 m at 1422 hrs and a second high water of 5.4 m at 2038 hrs. Due to depth limitations at the eastern entrance of the SBH, the vessel was only able to enter and exit on a tide height of 3.5 m or higher. Over the sampling period, there was a steady flow of water out through the eastern entrance of the SBH during the ebb tide, with a reverse flow during the flood tide.

Water quality profiles were measured at eight sites within the SBH (SB1 to SB8 on Map 2, Appendix A). Four profiles were measured at each of sites SB1 to SB5 at different phases of the tide cycle, allowing analysis of temporal variation in water quality.

Four sites within the SBH (SBHV01 to SBHV04 on Map 3, Appendix A) were selected for the identification of broad composition, semi-quantitative coral community characteristics using drop camera video transects. These were the only locations at which substantial coral communities were evident from surface observations.

2.2 Survey Equipment and Parameters

2.2.1 Physico-chemical water quality profiles

Vertical water profiles within the Blue Holes and Howard River / Hope Inlet system were measured at selected locations and times to assess spatial and temporal variations in water quality. YSI 6600EDS sondes with YSI 650MDS handheld display units and profile loggers were used (specifications can be found in Appendix C). The sondes recorded the following parameters at one second intervals through the profile:

- turbidity (NTU)
- pH
- dissolved oxygen (% saturation)
- electrical conductivity (mS/cm)
- temperature (°C)
- depth (m)
- time (mm/dd/yyyy and hrs:min:sec).

2.2.2 Extended deployment physico-chemical water quality logging

To assess changes in water quality characteristics over tidal cycles at the mouth of the Howard River, two water quality loggers were deployed on a temporary mooring for 28 days. The water quality loggers were YSI 6600EDS sondes (Appendix C) calibrated and programmed for deployment using a Panasonic Toughbook CF-19 laptop to record some or all of the following parameters at 15 minute intervals:

- turbidity (NTU)
- pH
- dissolved oxygen (% saturation)
- electrical conductivity (mS/cm)
- temperature (°C)
- depth (m)
- time (mm/dd/yyyy and hrs:min:sec).

2.2.3 Drop video camera system

A drop camera video system and operator were provided by Tek Ventures to record vertical transects across the coral communities on the walls of the Blue Holes. The system comprised of:

- a Seaoptics Hi definition 3 CCD video camera with switchable remote lighting
- a Seatrak GPS RCA video overlay displayed in degrees and decimals of degrees in WGS84
- a Tek Ventures designed and fabricated towfish
- a Nextar DVR monitor and hard drive for recording data.

A two person team was required to operate the camera system, one recording the video footage while the other operated the positioning of the camera. The camera was deployed at the edge of the hole and suspended approximately 0.5 – 1.0 m from the substrate, with the tender vessel maintaining an appropriate position as the camera was lowered down the transect. The transect continued down to a depth where either visibility was reduced to near zero, or the bottom of the wall was reached. The video record was later analysed to describe, semi-quantitatively, the broad characteristics of the coral communities.

2.2.4 Suspended sediment concentration and particle size analysis

Using a Niskin water sampler, samples were taken in the water column 1 m above the seafloor at the Howard River mouth and at the NBH sites (Maps 1 and 2, respectively, Appendix A). One litre sub-samples were decanted and filtered in the field using pre-weighed 0.45 µm glass fibre filter papers. The filter paper was chilled in the field and then frozen within 12 hours. They were then air freighted to the Marine and Freshwater Research Laboratory, Murdoch University, Perth, a National Association of Testing Authorities (NATA) qualified laboratory, where the material on the filter paper was desiccated and weighed to determine the SSC. SSC is a measurement of both inorganic material such as silts, clay and sand, together with organic material such as algae and other biological matter present in suspension in water bodies.

Sediment samples were collected within the NBH using a hand held sediment grab sampler. Samples were photographed, bagged, labelled and stored on ice whilst in the field. Post survey, the samples were frozen and delivered to Microanalysis Australia for particle size analysis.

Results and Discussion

3.1 Water Quality

3.1.1 Hope Inlet and Howard River

Physico-chemical water quality profiles

Table 3-1 outlines the summary statistics and a description of variation in each parameter is provided below. Figures 3-1 and 3-2 display the variation, with respect to distance upstream, of each parameter at the surface (depth = 50 cm) and near the seafloor (depth = seafloor minus 50 cm).

Table 3-1 Summary statistics for physico-chemical water quality parameters around neap tide high water, Howard River / Hope Inlet system

Summary Statistic	Temperature	Conductivity	pH	Dissolved Oxygen
	°Celsius	mS/cm	pH	% Saturation
Mean	30.5	47.5	8.0	97.8
Median	30.5	50.3	8.1	100.6
Minimum	28.6 (HR-21)	19.2 (HR-21)	7.4 (HR-21)	50.8 (HR-21)
Maximum	31.3 (HR-26)	50.9 (HR-29)	8.2 (HR-1)	117.6 (HR-27)

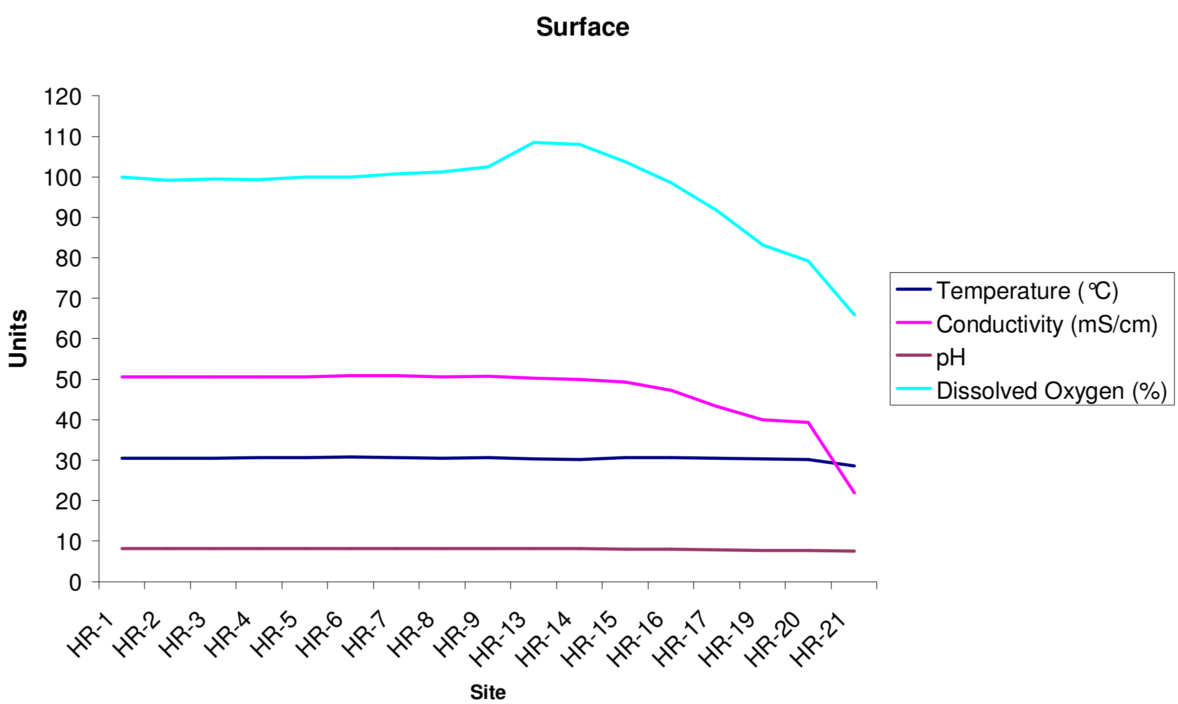

Figure 3-1 Surface water physico-chemical parameters, Howard River / Hope Inlet system, neap flood tide, 1 December 2010

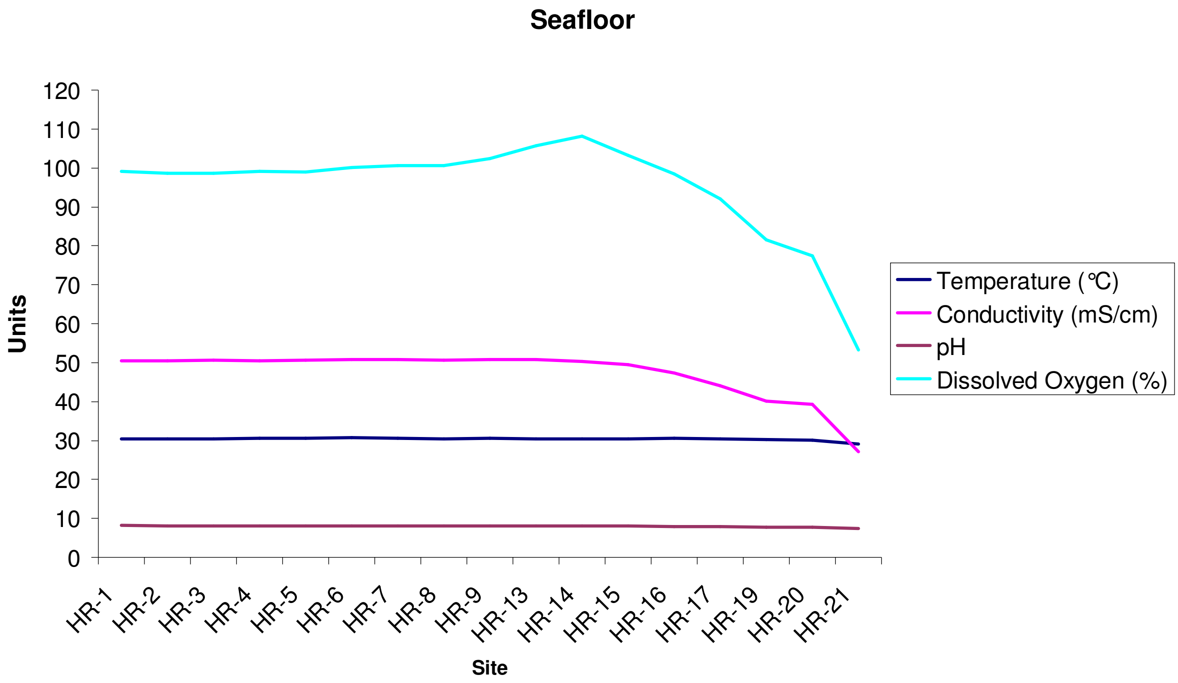

Figure 3-2 Near-seafloor water physico-chemical parameters, Howard River / Hope Inlet system, neap flood tide, 1 December 2010

Temperature

Figure 3-3 shows temperature profiles from selected sites within the Howard River / Hope Inlet system. A slight decrease in temperature is apparent between site HR-6 (within Hope Inlet) and site HR-20 (mid No Hope Creek), with a more marked decrease (approximately 1.5°C) between sites HR-20 and HR-21 (in the upper reaches of No Hope Creek). The lower temperature at HR-21 is associated with fresh water at this site (see following section). Limited stratification with depth was evident in the profiles at some of the sites (e.g. HR-21, Figure 3-3) but no thermoclines (marked changes in temperature over a small depth range) were detected.

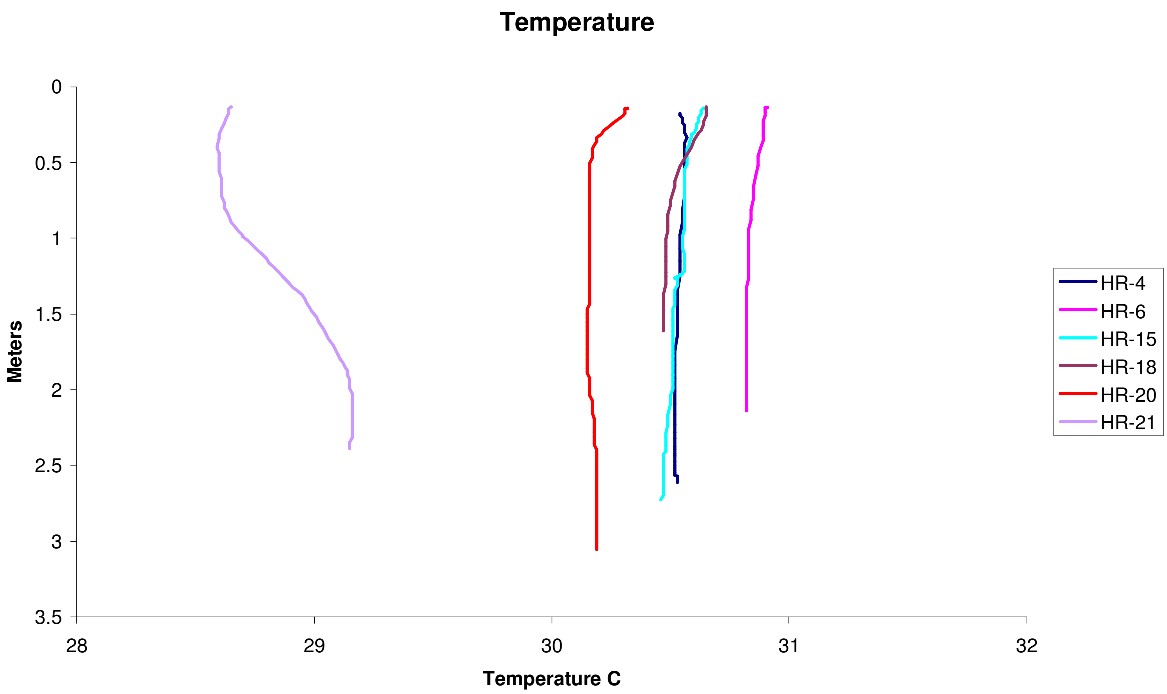

Figure 3-3 Temperature profiles in Howard River / Hope Inlet system, neap flood tide, 1 December 2010

Conductivity

Analysis of results indicated a strong decreasing trend in conductivity levels between mid Hope River (site HR-13) and the upper reaches of No Hope Creek (site HR-21) (Figures 3-1, 3-2 and 3-4). Conductivity levels recorded between the Howard River mouth and mid Hope River (HR-1 to HR-9) varied little, indicating the lower reaches of the system are well mixed. Stratification was present in some profiles from mid Hope River to No Hope Creek, with lower conductivity levels recorded at the surface and increasing conductivity with depth (e.g. sites HR-18 and HR-21, Figure 3-4).

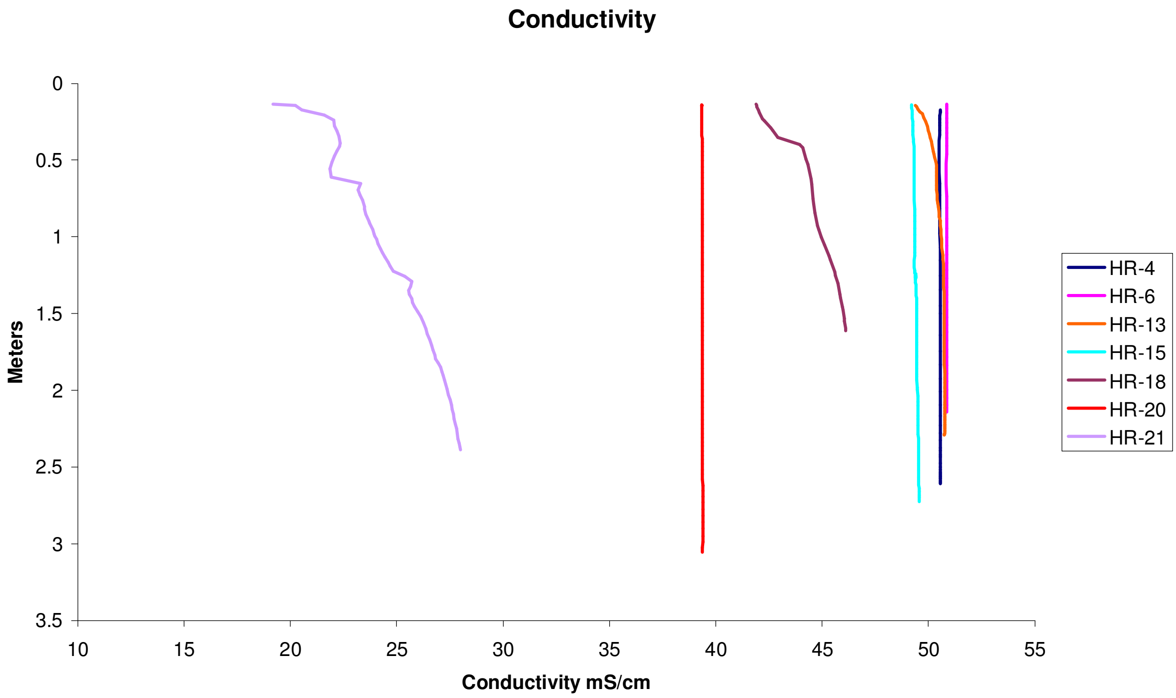

Figure 3-4 Conductivity profiles in Howard River / Hope Inlet system, neap flood tide, 1 December 2010

pH

There was a slight decreasing trend in pH values with distance upstream from the mouth (Figure 3-5), which may have been associated with fresh water flowing in from upstream. No stratification with depth occurred at any of the sampling locations, and pH was typically uniform throughout the profile (Figure 3-5).

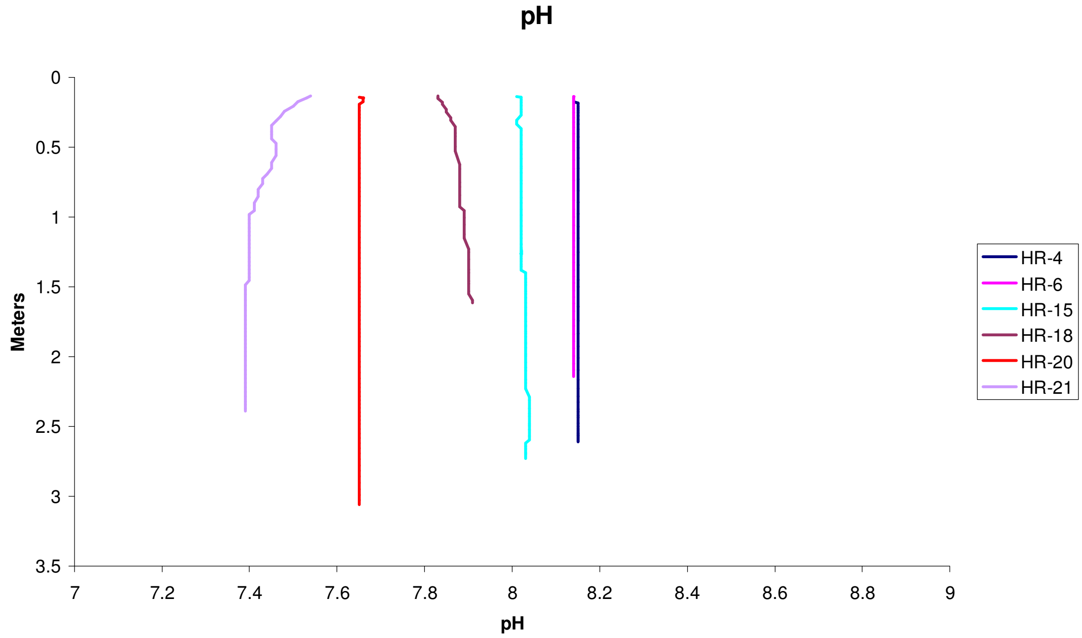

Figure 3-5 pH profiles in Howard River / Hope Inlet system, neap flood tide, 1 December 2010

Dissolved Oxygen

Figure 3-6 shows profiles of dissolved oxygen (as percentage saturation, DO%) at selected sites within the Howard River / Hope Inlet system. DO% followed a similar pattern as conductivity, with sites between Howard River mouth (HR-1) and mid Hope River (HR-15) sharing similar characteristics (99-105%) and sites between mid Hope River (HR-16) and No Hope Creek (HR-21) showing a decrease in DO% with distance upstream (Figures 3-1, 3-2 and 3-6). The marked reduction in DO% below 0.6 m at site HR-21 coincided with a slight increase in conductivity, indicating that the fresher surface water layer was more highly oxygenated than the underlying brackish water.

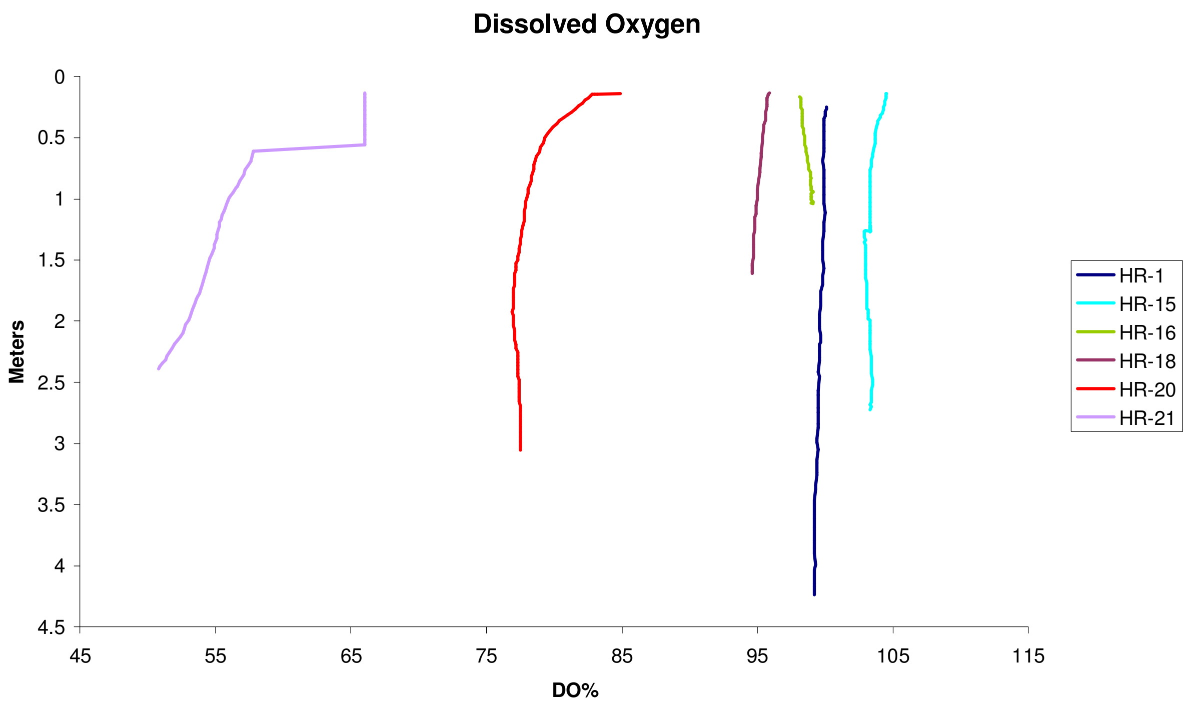

Figure 3-6 Dissolved Oxygen profiles in Howard River / Hope Inlet system, neap flood tide, 1 December 2010

Turbidity

Analysis of data and field observations during *in situ* sampling showed differences in turbidity characteristics between four areas within the Howard River / Hope Inlet system (i.e. Howard River, Hope Inlet, Hope River and Hope Creeks). Table 3-2 outlines the summary statistics for the data set representing the system ("Grouped Data") and the four separate areas.

Table 3-2 Summary *in situ* turbidity (NTU) statistics, Howard River / Hope Inlet system, neap tide high water period, December 2010

Summary Statistic	Grouped Data	Howard River Data	Hope Inlet Data	Hope River Data	Hope Creeks Data
Mean	25.6	0.5	1.2	23.7	52.8
Median	11.6	0.5	1.1	18.1	48.5
Minimum	0.0	0.0	0.5	0.4	5.8
Maximum	188.6	2.6	2.8	67.8	188.6

Minimum turbidity levels (0 NTU) were recorded at three Howard River sites (HR-1, HR-34 and HR-35) and at site HR-33 at the mouth of Hope Inlet. The highest turbidity level (188.6 NTU) was recorded in No Hope Creek (site HR-22). The grouped mean for the system was 25.6 NTU, with means analysed by area increasing considerably from Howard River (0.5 NTU) to Hope Creeks (52.8 NTU). Figures 3-7 to 3-9 depict turbidity profiles for the four areas as measured during the 'upstream transect' on the flood tide. The increase in turbidity levels from Howard River (Figure 3-7) to Hope River and No Hope Creek (Figure 3-8) is clearly evident in the profiles. In the No Hope Creek profiles (Figure 3-8), turbidity levels are markedly higher in the lower water column than at the surface; probably reflecting the suspension of creek bed sediments by the flood tide currents.

Repeated measurements were taken at some sites just before high water on the flood tide ('upstream transect'), and just after high water on the ebb tide ('downstream transect'). Higher turbidity levels were evident during the late flood tide than on the early ebb tide at each of these sites, as clearly shown in Figures 3-10 and 3-11. These observations likely reflect suspended sediments settling out of the water column during slack high water periods.

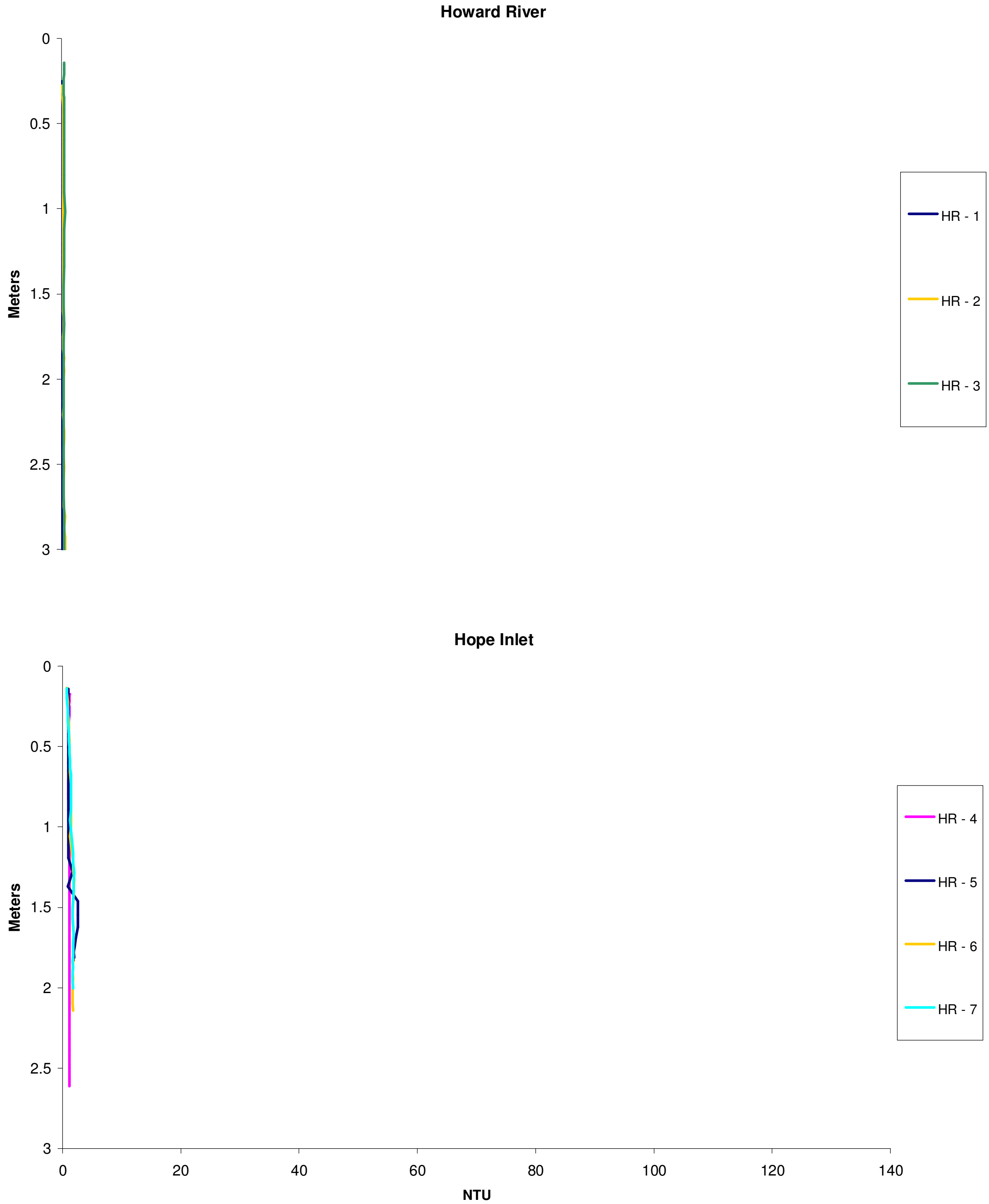

Figure 3-7 Howard River and Hope Inlet turbidity profiles, neap flood tide, 1 December 2010

Note: Large scale on X-axis is to allow ready comparison between Figures 3-7 to 3-9, rather than to show the minor differences between profiles within this figure

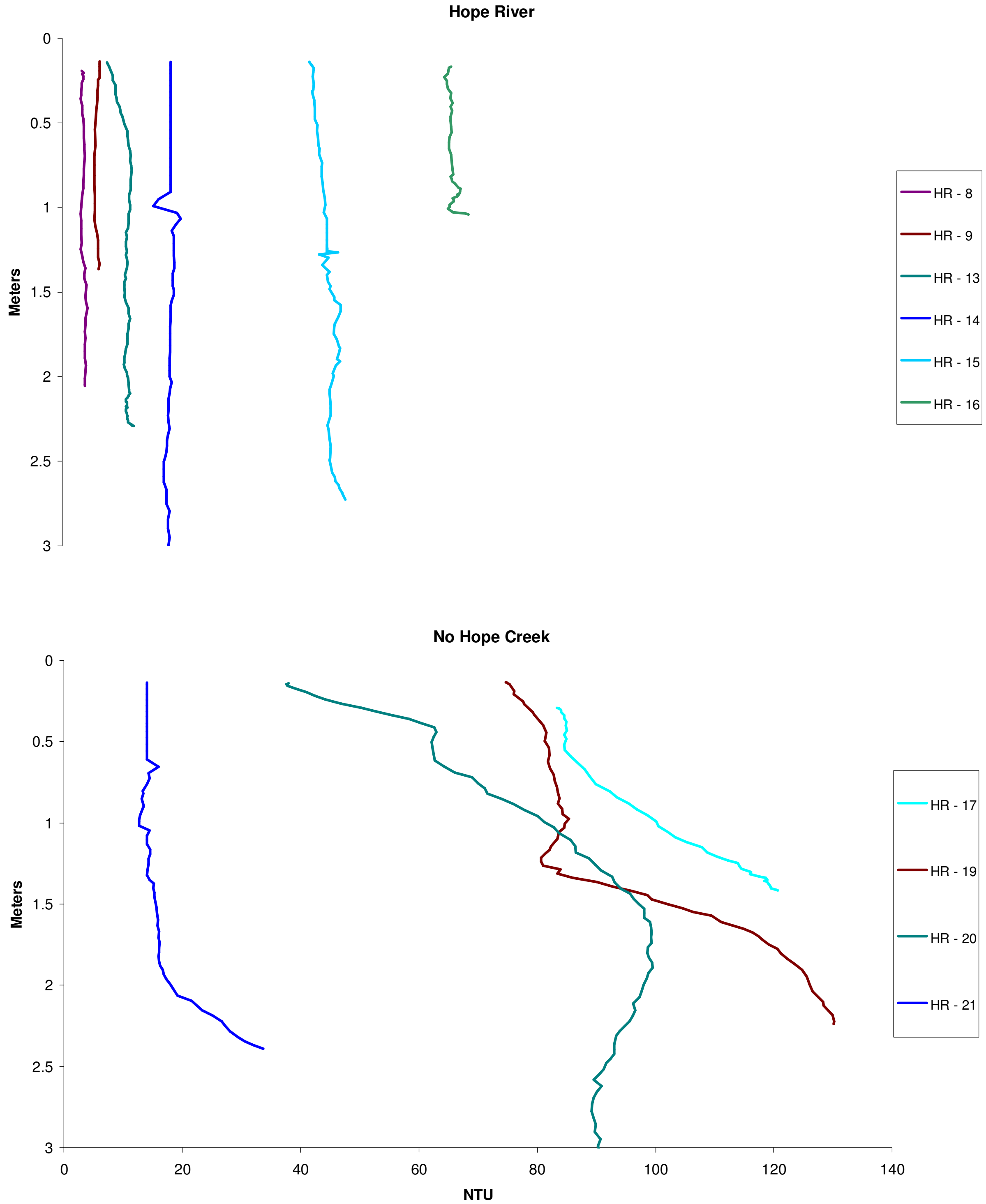

Figure 3-8 Hope River and No Hope Creek turbidity profiles neap flood tide, 1 December 2010

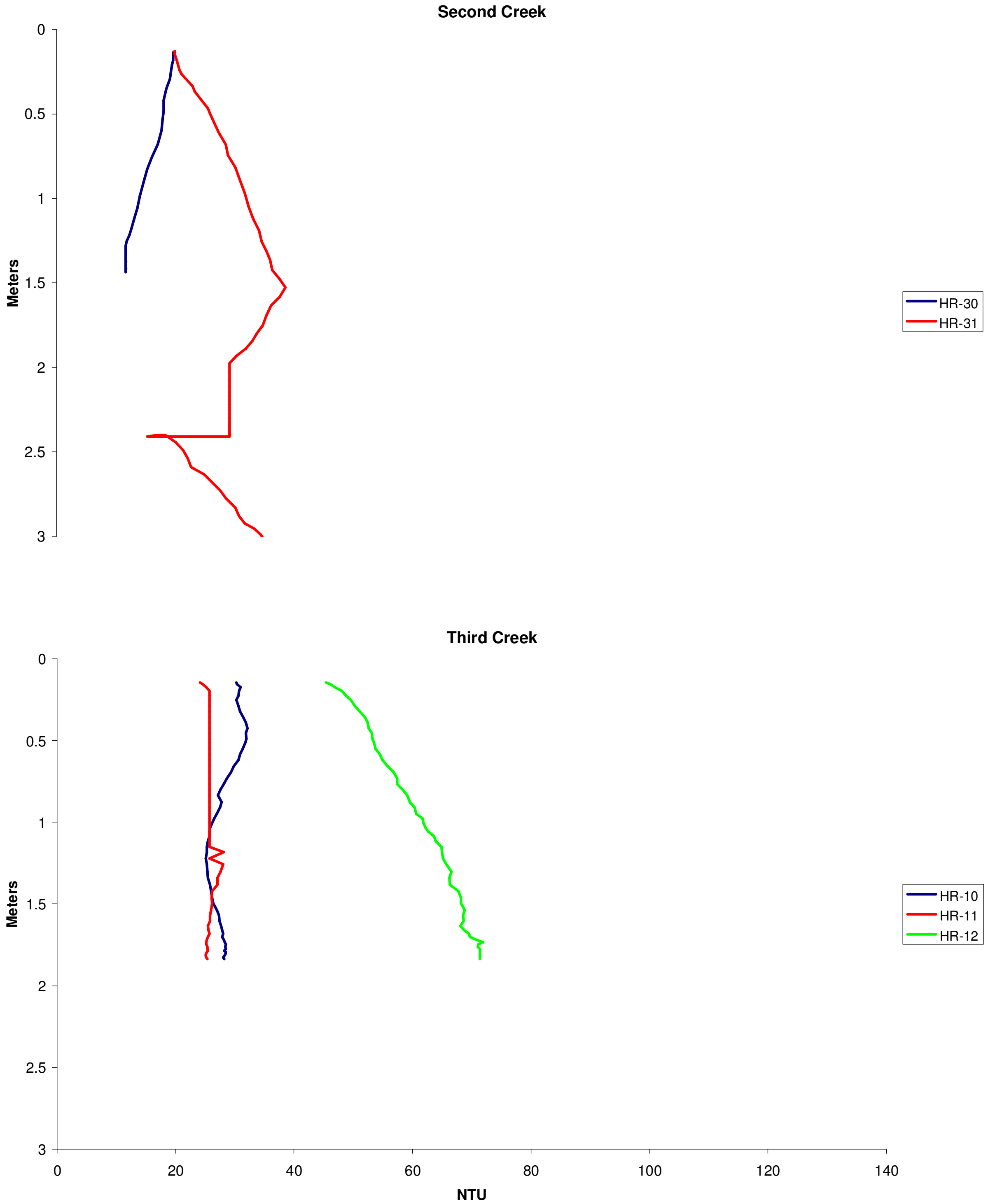

Figure 3-9 Second Creek and Third Creek turbidity profiles, neap flood tide, 1 December 2010

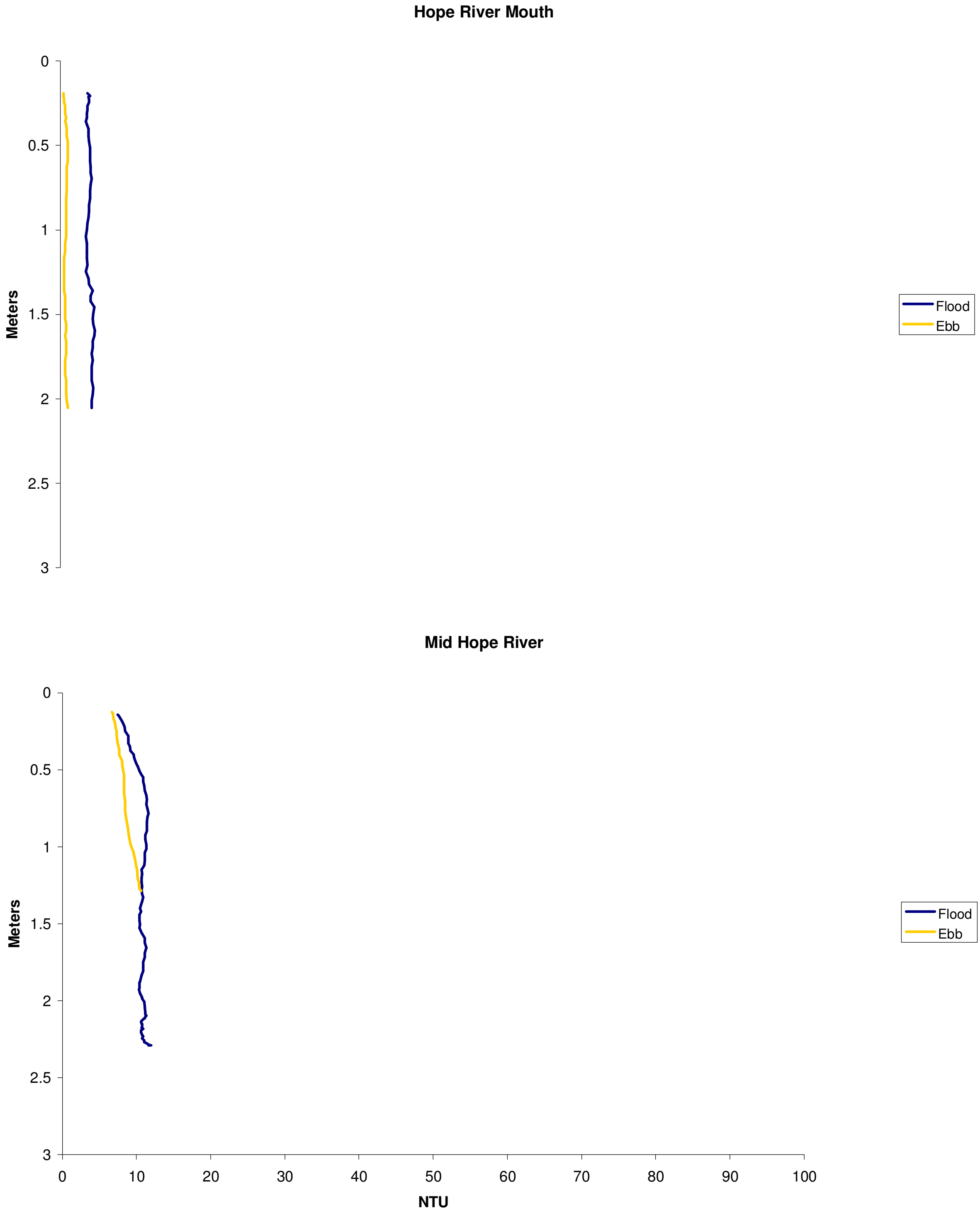

Figure 3-10 Howard River and Mid Hope River turbidity profiles, measured before and after high tide during a neap tide cycle, 1 December 2010

Note: Large scale of X-axis is to permit easy comparison between profiles in Figures 3-10 and 3-11.

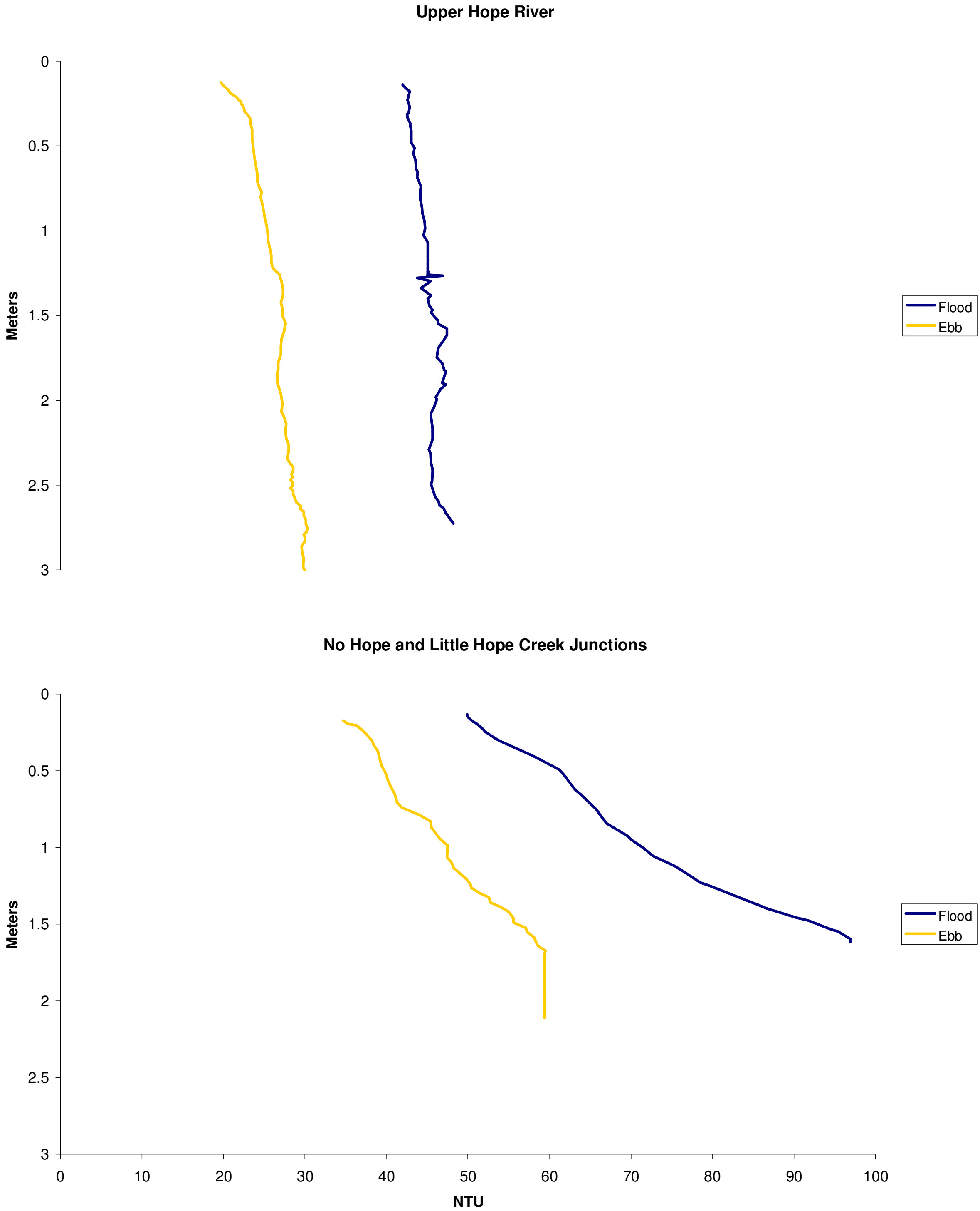

Figure 3-11 Upper Hope River and Creek junction turbidity profiles, measured before and after high tide during a neap tide cycle, 1 December 2010

Extended deployment water quality logging

Data were recorded between 1 and 28 December 2010, with a total of 2590 data points logged. All parameters were recorded by the sonde for the full duration of deployment, though heavy marine growth around the sensors and wiper units (Plate 3-1) caused data anomalies from around 11 days post-deployment through to the retrieval date. As a result, all data from this day forward were omitted from analysis.

Plate 3-1 Extended deployment logger probe and wiper assembly displaying heavy fouling after 28 days at Howard River mouth

Summary statistics for the data recorded during the deployment are presented in Table 3-3.

Table 3-3 Summary statistics for physico-chemical water quality parameters measured at Howard River mouth during extended deployment between 1 and 12 December 2010

Summary Statistics	**Turbidity** NTU	**Temperature** °Celsius	**Electrical Conductivity** mS/cm	**Depth** m
Mean	17.6	31.5	51.7	3.2
Median	10.0	31.6	51.9	3.2
Minimum	0.3	29.0	48.3	0.0
Maximum	158.5	34.6	53.1	6.0

Figure 3-12 displays the turbidity and depth results recorded from the water quality logger during the deployment period. NTU variations occurred both diurnally (flood versus ebb tides) and between tidal phases (spring versus neap). Highest NTU values (>100 NTU) corresponded directly with the largest spring tides, peaking as the water commenced flooding back into river system after low water. Elevated NTU values were most likely due to resuspension of fine sediments which had settled to the floors of the river channels during the preceding slack water period.

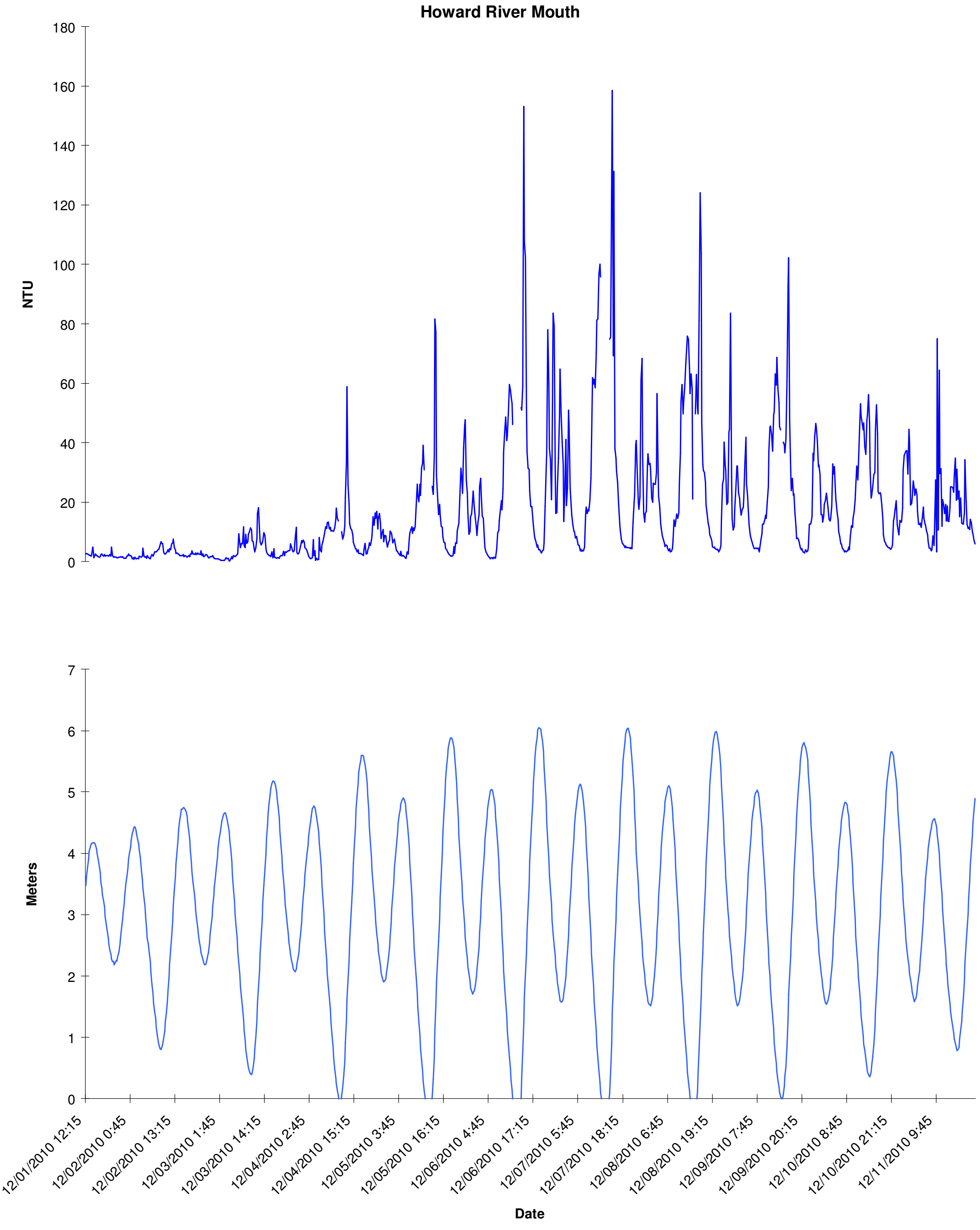

Figure 3-12 Howard River mouth extended deployment turbidity levels and tidal fluctuations, early wet season (1 – 12 December 2010)

Suspended sediment concentrations

Six water samples were collected from the Howard River mouth for SSC analysis (Table 3-4). The maximum SSC level recorded was 23 mg/L with the minimum being 6 mg/L.

Table 3-4 Suspended sediment concentrations in water samples collected at the extended deployment logger location (Howard River mouth) around neap high water

Site	Date	Time	Type	SSC (mg/L)
HRL1	1/12/2010	1315	1L filtered water sample	22
HRL2	1/12/2010	1400	1L filtered water sample	23
HRL3	1/12/2010	1430	1L filtered water sample	11
HRL5	1/12/2010	1515	1L filtered water sample	13
HRL6	1/12/2010	1530	1L filtered water sample	8
HRL7	1/12/2010	1545	1L filtered water sample	6

3.1.2 Northern Blue Hole

Physico-chemical water quality profiles

Table 3-5 presents the summary statistics and a description of variation in each parameter is provided below.

Table 3-5 Summary statistics for physico-chemical water quality parameters, Northern Blue Hole, spring ebb tide, 7 December 2010

Summary Statistic	Temperature	Conductivity	pH	Dissolved Oxygen	Turbidity
	°Celsius	mS/cm	pH	% Saturation	NTU
Mean	31.6	50.1	8.2	100.1	1.1
Median	31.4	50.1	8.2	97.5	0.9
Minimum	31.2	49.4	8.0	89.8	0.0
Maximum	35.1	50.5	8.4	132.3	7.8

The following observations were made with respect to each parameter:

- The maximum **temperature** recorded during the survey was at NB-3 (35.1°C), with the minimum temperature recorded at site NB-1 and sites NB-6 to NB-11 (all recording 31.2°C) (Table 3-5). Temporal variation within the NBH was measured by repeating profiles at six sites at different times. At all six sites, temperatures within the surface 4 m of the water column increased through the day due to increasing insolation (radiant heat from the Sun), resulting in some stratification.

- **Conductivity** varied little, with a range of only 0.9 mS/cm (Table 3-5). Both the maximum (50.5 mS/cm) and the minimum (49.4 mS/cm) were recorded at site NB-3. No stratification with depth was evident at any of the sites.
- **pH** varied little, with a range of only 0.4 (Table 3-5). Maximum pH values were recorded at sites NB-3, NB-11 and NB-12 (all 8.4), with minimum values recorded at sites NB-3 and NB-6 (8.0).

- The minimum **DO** saturation within the system was recorded at site NB-10 (89.8 %) with the maximum recorded at site NB-12 (132.3 %) (Table 3-5). Analysis of the data indicated an initial increase in DO% with depth until around 1.5 – 2.0 m, where maximum levels were recorded, and then a steady decrease with depth to the seafloor.

- **Turbidity** levels within the system were low with 75% of values below 2 NTU and a mean of 1.1 NTU (Table 3-5). A maximum level of 7.8 NTU was recorded on the flood tide in the surface water layer at site NB-10 (Figure 3-13), most likely indicating the incursion of slightly more turbid water from outside of the NBH. Few variations were recorded with depth, or between sampling locations. During the low water period, when the NBH was landlocked and isolated from the surrounding waters and tidal currents were low, repeated measurements taken at sites NB-1 to NB-6 showed that NTU levels decreased slightly (generally by <2 NTU, Figure 3-14) as suspended sediments settled out of the water column.

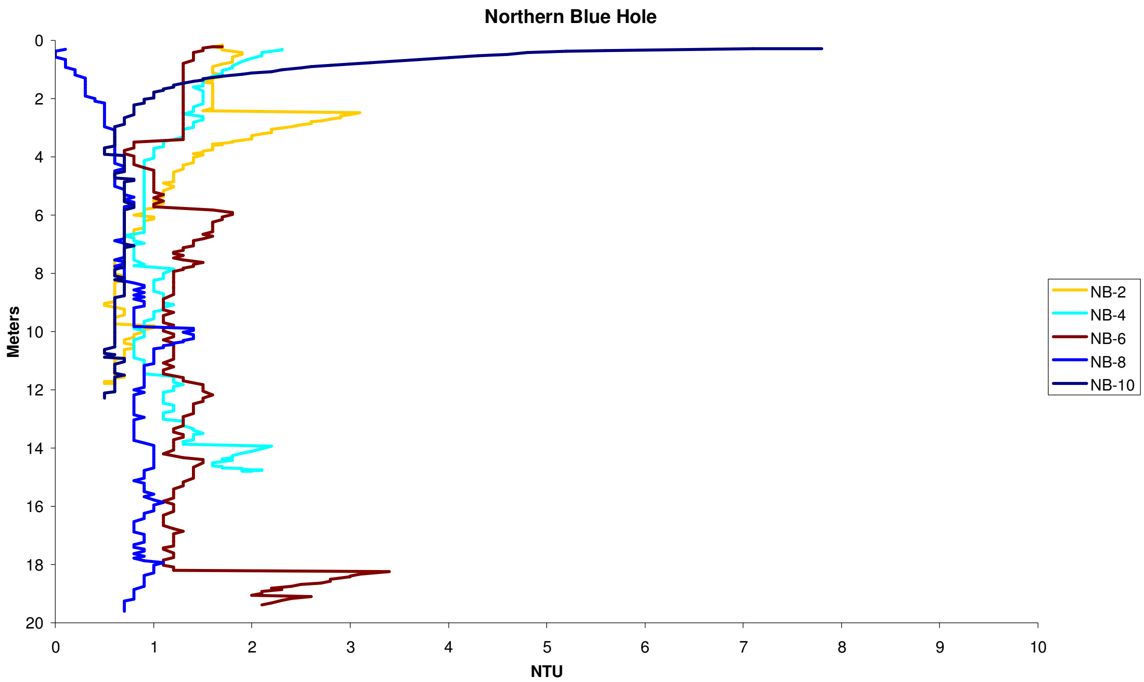

Figure 3-13 Northern Blue Hole turbidity profiles, spring ebb tide, 7 December 2010

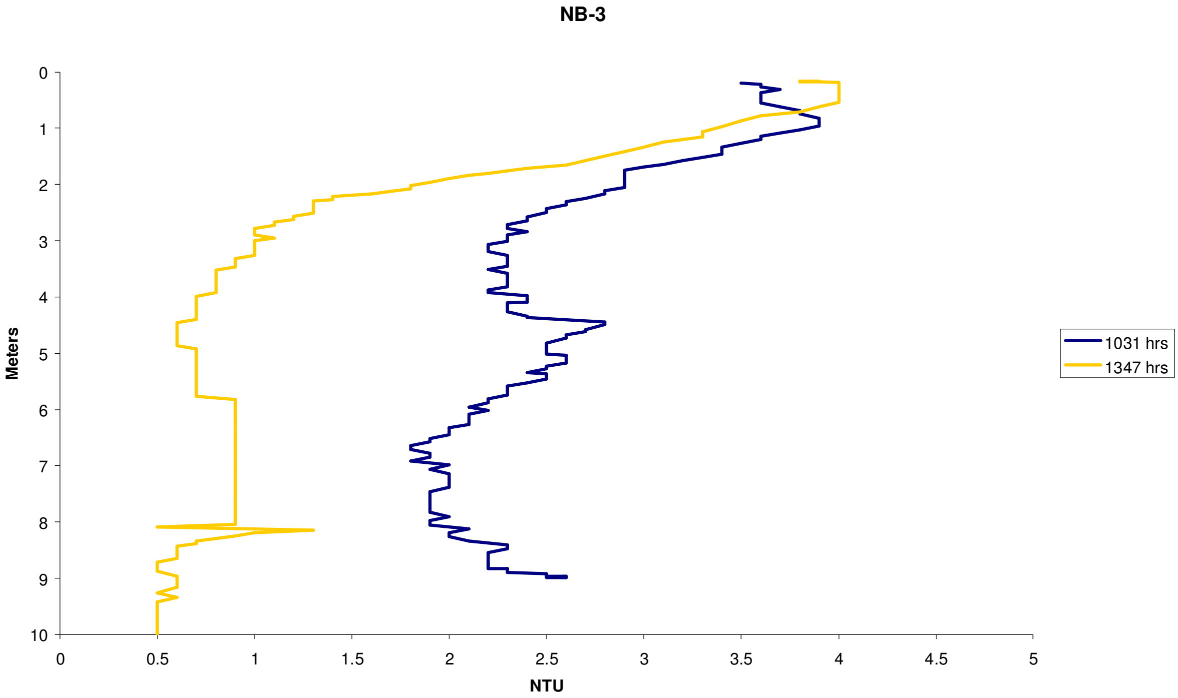

Figure 3-14 Turbidity profiles at site NB-3 in NBH during ebb tide (1031 hrs) and at spring slack low water (1347 hrs), 7 December 2010

Particle size analysis

Table 3-6 displays the particle size distribution data for three sediment samples collected from the NBH.

Table 3-6 Northern Blue Hole sediment sample particle size analysis results

LAB ID	CLIENT ID	Date	Derived diameter			% < 75 µm
			D10	D50	D90	
			µm			%
10_619_01	SED_BH01	7/12/2010	3.5	330	657	39.1
10_619_02	SED_BH02	7/12/2010	2.8	101	370	46.8
10_619_03	SED_BH03	7/12/2010	158	299	513	5.3

D10= 10% of sample smaller than
D50= 50% of sample smaller than
D90= 90% of sample smaller than
% < 75 µm= percent of sample less than 75 µm

The sample with the highest proportion of large particles (SED_BH01) was collected from the centre of the NBH in approximately 19.8 m of water. The sample with the highest proportion of fine particles (SED_BH02) was collected near the eastern entrance to the NBH in water of approximately 6.0 m depth. Sample SED_BH03 was collected close to the western entrance channel, in the vicinity of sites where rubble (but no sediment) was recovered by the grab; the proportion of fines was markedly lower than in the other two samples.

Field observations noted that the greatest exchange of water between the surrounding ocean and the Blue Hole was occurring through the western entrance channel and water flow was highly turbulent. Differences in particle size distribution and sediment presence/absence between the eastern and western channels suggest that entrained sediment associated with inflowing oceanic water is settling out towards the eastern channel, where velocity and turbulence are reduced.

Suspended sediment concentration

Three water samples were collected from the NBH for SSC analysis, with results presented in Table 3-7. As the concurrently recorded NTU levels were so low, it was recognised that the range of values would be inadequate for a valid NTU/SSC relationship to be developed, so no further samples were collected. Data presented in Table 3-7 show that SSC in the samples were also low.

Table 3-7 Northern Blue Hole suspended sediment concentrations

Site	Date	Time	Type	SSC (mg/L)
NBTSS-1	7/12/2011	1020 hrs	1L filtered water sample	5
NBTSS-2	7/12/2011	1110 hrs	1L filtered water sample	4
NBTSS-3	7/12/2011	1125 hrs	1L filtered water sample	4

3.1.3 Southern Blue Hole

Physico-chemical water quality profiles

Table 3-8 outlines the summary statistics and a description of variation in each parameter is provided below.

Table 3-8 Summary statistics for physico-chemical water quality parameters, Southern Blue Hole, spring ebb tide, 8 December 2010

Summary Statistic	Temperature	Conductivity	pH	Dissolved Oxygen	Turbidity
	°Celsius	mS/cm	pH	% Saturation	NTU
Mean	31.2	50.4	8.1	85.7	1.8
Median	31.0	50.4	8.1	83.4	0.8
Minimum	30.6	48.3	7.8	72.2	0.0
Maximum	35.1	51.1	8.5	141.9	17.8

The following observations were made with respect to each parameter:

- The maximum **temperature** recorded during the survey was at site SB-1 (35.1°C), with the minimum temperature recorded at site SB-2 (30.6°C) (Table 3-8). Temperature data from the SBH showed that during the ebb tide, characterised by a steady flow of water out of the eastern entrance (unlike the turbulent flow observed during the flood tide, Plate 3-2), surface temperatures increased through the day due to insolation. Unlike within the NBH, the increases were not limited to the surface of the water column at all sites, with some sites showing an increase throughout the water column.

Plate 3-2 Turbulent currents produced by spring flood tide flowing through eastern entrance to Southern Blue Hole, 8 December 2010

- **Conductivity** varied little, with a range of 2.8 mS/cm (Table 3-8). The maximum was recorded at site SB-1 (51.1 mS/cm) and the minimum was recorded at site SB-4 (48.3 mS/cm). Analysis of the data revealed there was no stratification with depth and no haloclines were present.

- **pH** varied little across the sampling sites, with a range of only 0.7 (Table 3-8). The maximum and minimum pH values (8.5 and 7.8) were recorded at site SB-1. No stratification was present with depth.

- The minimum **DO** saturation within the system was recorded at site SB-4 (72.2 %) with the maximum recorded in the surface waters of site SB-1 (141.9 %) (Table 3-8). Water was cascading over a rock slope just upstream from site SB-1, at the western end of the SBH; this would have contributed to the entrainment of oxygen into the water column. A general decrease in DO saturation from the water surface to the seafloor was evident at all sites.

- **Turbidity** levels within the system were low (typically <2 NTU) (Figure 3-15) with a mean of 1.8 NTU (Table 3-8). With the exception of site SB-5, few variations with time, and between sampling locations were apparent. At site SB-5 (near the eastern entrance) marked differences in turbidity levels were recorded between ebb tide (<3 NTU) and flood tide (up to 17.8 NTU) when there was strong, turbulent flow through the entrance (Plate 3-1). Figure 3-15 displays turbidity profile data recorded during the ebb tide.

  In the SBH, an eastwards flow of water was observed within the hole throughout the low water period. This was fed by clear water flowing off of the reef flat to the west of the hole. The strong flow of this water out through the eastern entrance to the SBH prevented the incursion of the highly turbid water that moves through South Channel on the flood tide. By the time the flood tide had risen sufficiently to reverse the flow of water through the eastern entrance, the most turbid of the South Channel water had moved further east, away from the entrance to the SBH. This hydrodynamic pattern prevented the entry of highly turbid water into the SBH and is likely to be a major contributing factor to the higher water clarity in the SBH than in the surrounding waters.

As expected, turbidity levels within the SBH were generally higher than those in the NBH; the SBH is flanked by intertidal mudflats, supporting an almost continuous mangrove community around the perimeter, that are potential sources of substantial sediment input under certain meteorological and hydrodynamic conditions. In contrast, the NBH is incised into a rock platform with only isolated areas of sediment deposition.

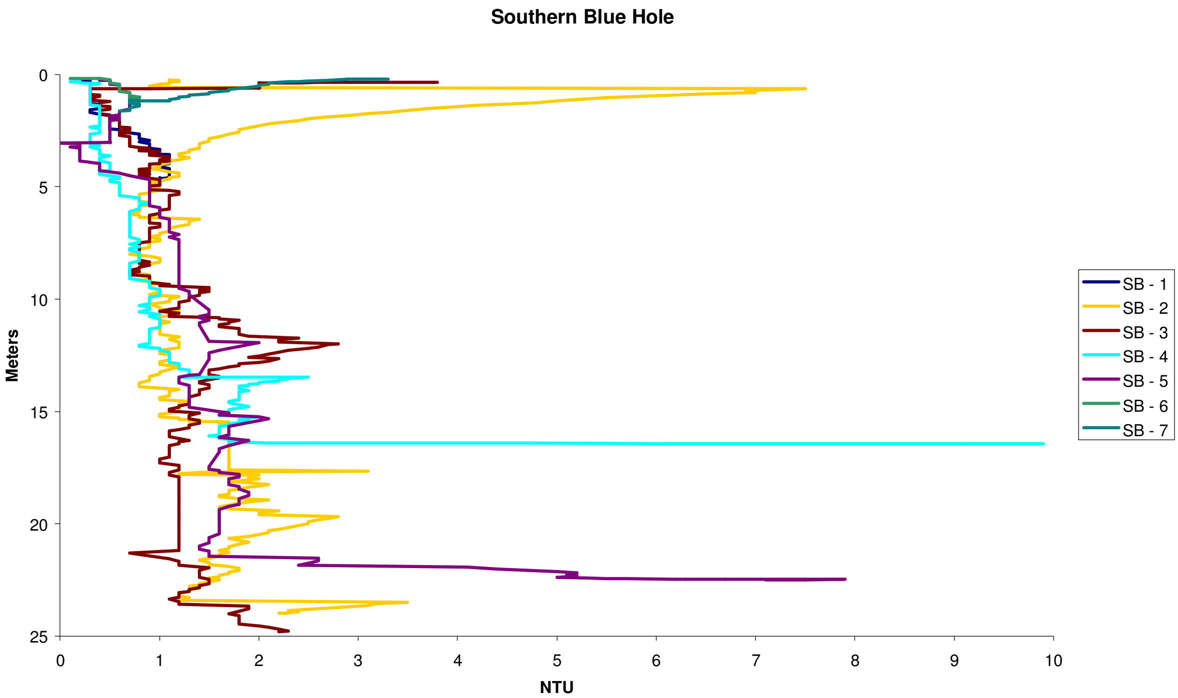

Figure 3-15 Southern Blue Hole turbidity profiles recorded at ebb tide during a spring tide cycle

3.2 Characterisation of Coral Communities

The reefs of the Northern Territory are little known, although surveys conducted along the Arnhem Land Coast found extensive coral communities linking the eastern and western Australian coastal coral communities (Veron 2004). The coral reef communities of the Gunn Reef Blue Holes are at the southern end of a coral reef complex extending north through the Vernon Islands to the southern shores of Melville Island (Veron 2004). Qualitative descriptions of the benthic assemblages are presented in Table 3-9 and described in more detail in the following sections.

Table 3-9 Benthic communities – Northern and Southern Blue Holes

Locations	Reef Edge	Entrance Channel Reef Edge	Upper slope	Lower slope
Relative depth (below reef flat)	~0-3m	~0-3m	~3-8	~8-20m
Northern Blue Hole	Dense corymbose/ tabulate *Acropora* corals	Low to moderate cover mixed *Montipora* and *Acropora*	Low cover foliose/ encrusting *Montipora*	Coral Fragments and rubble, filter feeders
Southern Blue Hole	Low cover small Faviid corals	Moderate cover mixed hard corals	Low cover filter feeders	Patchy bare rock and coarse sand

3.2.1 Northern Blue Hole

A narrow band of high cover (60-80%) monogeneric stands of tabulate and corymbose (short branching) *Acropora* colonies extend some 10-50 m from the edge of the hole onto the reef flat, around the perimeter of the NBH (Plate 3-3). *Acropora tenuis* and *A. valida* have previously been recorded on the coral reefs at Gunn Point (Wolstenholme et al. 1997). *Acropora* typically grow in an environment of presumed maximum oxygen saturation and light availability (Riegl & Pillar 1997) such as that at the western entrance channel to NBH.

Plate 3-3 Typical edge of the Northern Blue Hole showing partially exposed high *Acropora* cover extending onto reef flat

Acropora cover increases (up to 90%) along the gradual slope towards the edge of the vertical section of the wall, then decreases over the edge, where *Acropora* morphology becomes slightly more diverse. The *Acropora* zone ends abruptly at the upper reaches of the vertical slope, some 2-3 m below the reef flat, where foliose and encrusting *Montipora* colonies become the dominant coral community, interspersed with sponges and ascidians. However, the slope is predominantly unconsolidated rubble and coral cover is generally low but patchy. A fine layer of sediment particles was present on the surface of the benthos, including the *Montipora* colonies, and sediments were present in the overlying water column, both of which may limit the depth to which the *Montipora* zone can extend. *Monitipora aequituberculata* may be the dominant species of coral in this zone as it has previously been recorded at Gunn Point reefs (Wolstenholme et al. 1997).

Occasional soft corals such as gorgonians and seapens, as well as infrequent sponges, ascidians and macroalgae were identified on elevated platforms on the bottom of the NBH. The physical structure of the seafloor is interspersed with patchy coarse sand and sedimentary rock.

High cover of unconsolidated rubble at the base of the NBH wall indicates coral fragments are frequently washed off shallow reef slopes by strong hydrodynamic forces. Rapid growth, including fast repair growth in the event of damage (Riegl & Pillar 1997), enables *Acropora* communities to proliferate on the shallow crest of the NBH. Breakage due to strong hydrodynamic forces is actually a mechanism for asexual reproduction (if the broken fragments are sufficiently large and are carried to areas where environmental conditions such as light and sedimentation are conducive to their survival) and may be a contributing factor to the maintenance of the *Acropora*-dominated coral community around the margins of the main body of the NBH. However, the cover of both *Acropora* and *Montipora* is reduced at the western entrance of the NBH (NBHV04 and NBHV05), possibly due to damage caused from sediment and rubble mobilised by turbulent tidal exchange between the NBH and the ocean through the narrow entrance. The frequency and intensity of the tidal exchange is likely to regulate the cover that these coral communities can attain.

3.2.2 Southern Blue Hole

The zonation and distribution of coral communities within the SBH are less defined, although noticeably different from assemblages within the NBH. The coral cover in the four video transects is generally low (<10 %), increasing slightly towards the eastern entrance. A mixed coral community is dominated by small Faviid colonies with massive morphology. The gradual shallow slope is sedimentary rock covered by a visible layer of coarse sand and rubble which is more prevalent towards the western end of the hole. Coral communities are sparsely distributed in the lower intertidal and shallow subtidal zones to maximum depths of about 5-8 m below the reef flat. A low cover of non-coral taxa, such as *Millepora*, sponges, hydroids, seapens, gorgonians and ascidians, occur in deeper water where the hard substrate is patchy. These taxa occur more frequently toward the eastern entrance channel.

SBH is in close proximity to mangrove communities and mangrove leaves were present on the rock slopes and in the water column. Leaves were more prevalent at the western end, where they were accumulating due to the prevailing easterly winds. As mentioned in Section 3.1.3, sediment originating from the intertidal mudflats around the perimeter of the SBH is likely to be responsible for the higher turbidity in the SBH when compared to the NBH. Differences in coral cover between the two locations are likely to be attributable to the difference in turbidity and associated light attenuation with depth.

Corals identified in the video transects at the western end (SBHV01 and SBHV02) of SBH included small Faviid genera: *Goniastrea, Favia, Montastrea* and *Caulastrea*. A central SBH video transect (SBHV03) showed the assemblage was more diverse, although still low in cover. Coral cover was higher along the northern edge of the eastern entrance of SBH (SBHV04), with a higher cover (up to 75%) of tabulate *Acropora* and Faviids (including *Goniastrea*, some of which were partially bleached) on the upper sections of the near-vertical walls, and on the adjacent reef flat (Plate 3-4). A similar community was also present along the southern edge of the entrance. Coral genera identified within the central and eastern transects included a branching Pocilloporid (genus *Stylophora*), encrusting Pectinids (genera *Oxypora* and *Echinophyllia*), massive Faviids (genus *Favites*) and foliose/encrusting Acroporids (genus *Montipora*). The majority of these coral genera, with the exception of *Stylophora*, are generally either found in deeper water or are well adapted to turbid waters (Dikou & van Woesik 2006). *Stylophora* are generally found on reefs exposed to high energy environments (Riegl & Piller 1997).

Plate 3-4 Intertidal coral community (massive Faviids and corymbose *Acropora*) near eastern entrance of Southern Blue Hole

Summary

The data presented in this report describe water quality, coral community and sediment characteristics at the Gunn Reef Blue Holes and the Howard River / Hope Inlet system near Darwin, Northern Territory.

Water quality monitoring and sampling were undertaken at 58 sites within the two localities. Water quality assessment involved *in situ* measurements of turbidity, electrical conductivity, temperature, pH and DO, and laboratory analysis to determine SSC; as well as extended deployment logging, at the mouth of the Howard River, of turbidity, electrical conductivity, temperature, pH, DO and depth over a 28 day period.

Within the Howard River / Hope Inlet system, turbidity varied with tidal influence and with distance upstream. Turbidity levels logged at the Howard River mouth fluctuated markedly on a diurnal basis, and were generally highest at the start of flood tides after low water periods. Turbidity decreased towards the end of flood tide periods, as the clearer waters from further offshore in Shoal Bay entered the system, and through the high water period when current velocities decreased and suspended sediments settled to the seafloor. Turbidity also varied considerably with the phase of the tidal cycle with lower NTU values recorded during neap tides; and higher NTU levels (>30 NTU) during spring tides, probably as a result of greater sediment resuspension from the higher bottom sheer stress applied by faster flowing currents during spring tides.

Upstream from the mouth of the Howard River (i.e. within Hope Inlet and Hope River), turbidity increased markedly with distance upstream, then decreased within the creeks. Most other parameters varied little within the system, although conductivity levels decreased with distance from the river mouth, and pH and DO levels were also lower in the upper reaches of the creeks, due to the inflow of fresh water.

The water quality parameters recorded within the Blue Holes also varied little, though due to the sediment contribution from intertidal mudflats and mangrove communities around its perimeter, turbidity levels were slightly higher within the SBH. Repeated temperature measurements also indicated some diurnal variation occurring during ebb tides, whereby surface temperatures were increasing by around 2-4°C in both the SBH and NBH due to insolation.

Sediment characteristics were investigated at seven locations within the NBH, with sediment samples taken from three sites for laboratory analysis of particle size distribution. These showed a trend of decreasing proportions of fine sediments (<75 µm diameter) from west to east within the NBH. The other four sites comprised coral rubble.

Coral communities were investigated at 14 sites within the two Blue Holes. The coral communities within the Blue Holes differed markedly between the NBH and the SBH, and varied with depth. Around the perimeter of the NBH, a high cover (60-90%) of tabulate and corymbose (short branching) *Acropora* colonies extended onto the reef flat from the edge of the hole, as a band some 10-50 m wide. On the near-vertical walls of the NBH, the *Acropora* cover declined markedly 2-3 m below the level of the reef flat, where foliose and encrusting *Montipora* colonies became dominant, interspersed with sponges and ascidians. As the steepness of the wall decreased (at variable depths generally 10-20 m below the level of the reef flat), the slope was comprised of coral rubble, upon which was a diverse range of scattered sponges, soft corals (including gorgonian sea whips and fans) and ascidians.

Within the SBH, continuous coral cover over lateral distances of greater than 10-20 m was mainly limited to the eastern entrance. On both sides of the entrance channel, the upper sections of the near-vertical walls supported a high cover (50-75%) of tabulate *Acropora* colonies which extended onto the adjacent reef flat amongst scattered massive Faviid colonies, some of which were partially bleached. Slightly deeper were colonies of foliose and encrusting corals at a cover of around 25-50%. Below this zone, the slope became more gradual and rubbly, with scattered sponges, soft corals and ascidians. Within the main body of the SBH, there were limited areas of hard substrate on both edges which supported a low cover (typically 10-25%) of hard coral, predominantly faviid genera.

References

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Limitations

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of INPEX Browse Ltd and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the contract dated 11 January 2008.

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between January and March 2011, and is based on the information obtained during the survey and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

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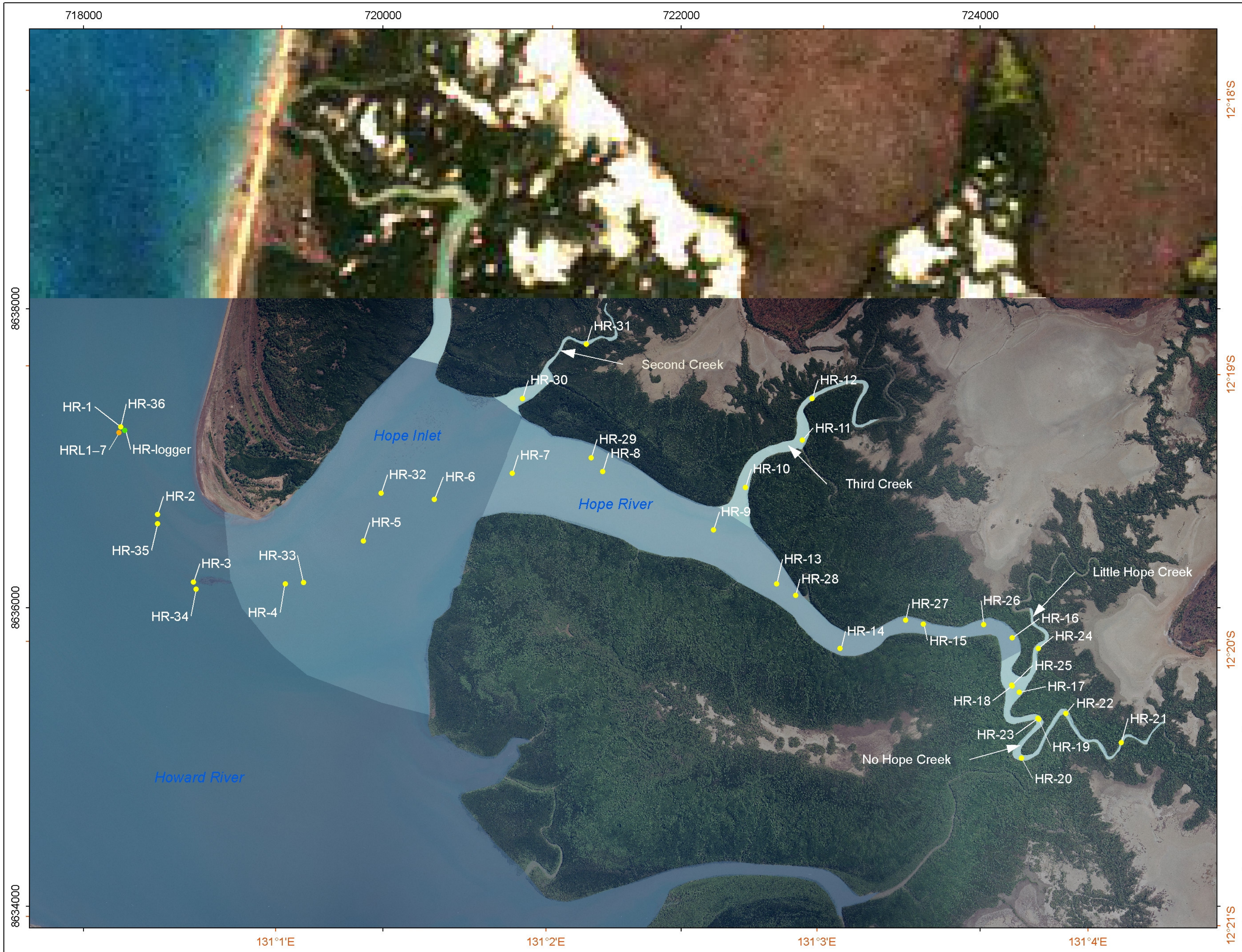
A

Appendix A Survey location figures



Legend

- Extended deployment water-quality logger
- Filtered water sample (suspended-sediment concentration)
- Water-quality profile

Analysis areas

- Hope creeks
- Hope River
- Hope Inlet
- Howard River

Notes

This map incorporates data which is copyright of the Commonwealth of Australia 2006.

INPEX acknowledges the following data sources:

Dataset Name – Custodian – Date

Howard River aerial photo – Department of Lands and Planning – 2010

Landsat 7 Mosaic of Australia – Geoscience Australia – 2004

Geodata Series 3 250k Topo – Geoscience Australia – 2006

INPEX

Projection	MGA94 zone 52
Datum	GDA94
Scale	1:35,000

N

0 0.5 1
kilometres

MAP 1 – HOPE RIVER

Water-quality sampling locations 1/12/10

Date	18 MAR 2011	Paper Size	A4
Security classification		BUSINESS	
Map ID	C090-DH-MAP-2484	Rev	0


716000
718000
720000
722000
8658000
8656000
8654000
12°8'S
12°9'S
12°10'S
130°59'E
131°0'E
131°1'E
131°2'E
Gunn Reef
Eastern entrance
Eastern entrance
Western entrance
Northern Blue Hole
Southern Blue Hole
Gunn Point
NB-1
NB-2
NB-3
NB-4
NB-5
NB-6
NB-7
NB-8
NB-9
NB-10
NB-11
NB-12
NB-TSS1–3
SB-1
SB-2
SB-3
SB-4
SB-5
SB-6
SB-7
SB-8
Darwin
Legend
Filtered water sample (suspended-sediment concentration)
Water-quality profile
Notes
This map incorporates data which is copyright of the Commonwealth of Australia 2006.
INPEX acknowledges the following data sources:
Dataset Name – Custodian – Date
Landsat 7 Mosaic of Australia – Geoscience Australia – 2004
Geodata Series 3 250k Topo – Geoscience Australia – 2006
INPEX
Projection MGA94 zone 52
Datum GDA94
Scale 1:35,000
N
0 0.5 1
kilometres
MAP 2 – BLUE HOLES
Water-quality sampling locations
7–8/12/10
Date 18 MAR 2011
Paper Size A4
Security classification BUSINESS
Map ID C090-DH-MAP-2485
Rev 0

Legend

- Video transect
- Sediment grab sample

Notes

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INPEX acknowledges the following data sources:

Dataset Name – Custodian – Date

Landsat 7 Mosaic of Australia – Geoscience Australia – 2004

Geodata Series 3 250k Topo – Geoscience Australia – 2006

INPEX

Projection	MGA94 zone 52
Datum	GDA94
Scale	1:35,000

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kilometres

MAP 3 – BLUE HOLES

Coral and sediment sampling sites

7–8/12/10

Date	18 MAR 2011	Paper Size	A4
Security classification		BUSINESS	
Map ID	C090-DH-MAP-2491	Rev	0

Appendix B Survey site details

Appendix B

Table 1. Hope Inlet and Howard River water quality sample locations

Site	Date	Type	Latitude	Longitude
HR-1	1 Dec 2010	Water profile	12° 19.220’	131° 00.414’
HR-2	1 Dec 2010	Water profile	12° 19.537’	131° 00.552’
HR-3	1 Dec 2010	Water profile	12° 19.781’	131° 00.687’
HR-4	1 Dec 2010	Water profile	12° 19.785’	131° 01.026’
HR-5	1 Dec 2010	Water profile	12° 19.627’	131° 01.313’
HR-6	1 Dec 2010	Water profile	12° 19.474’	131° 01.573’
HR-7	1 Dec 2010	Water profile	12° 19.378’	131° 01.863’
HR-8	1 Dec 2010	Water profile	12° 19.369’	131° 02.196’
HR-9	1 Dec 2010	Water profile	12° 19.578’	131° 02.605’
HR-10	1 Dec 2010	Water profile	12° 19.422’	131° 02.721’
HR-11	1 Dec 2010	Water profile	12° 19.256’	131° 02.943’
HR-12	1 Dec 2010	Water profile	12° 19.097’	131° 02.966’
HR-13	1 Dec 2010	Water profile	12° 19.771’	131° 02.840’
HR-14	1 Dec 2010	Water profile	12° 20.016’	131° 03.075’
HR-15	1 Dec 2010	Water profile	12° 19.902’	131° 03.384’
HR-16	1 Dec 2010	Water profile	12° 19.957’	131° 03.729’
HR-17	1 Dec 2010	Water profile	12° 20.158’	131° 03.738’
HR-18	1 Dec 2010	Water profile	12° 20.136’	131° 03.712’
HR-19	1 Dec 2010	Water profile	12° 20.251’	131° 03.836’
HR-20	1 Dec 2010	Water profile	12° 20.397’	131° 03.748’
HR-21	1 Dec 2010	Water profile	12° 20.347’	131° 04.132’
HR-22	1 Dec 2010	Water profile	12° 20.222’	131° 03.922’
HR-23	1 Dec 2010	Water profile	12° 20.249’	131° 03.834’
HR-24	1 Dec 2010	Water profile	12° 19.999’	131° 03.807’
HR-25	1 Dec 2010	Water profile	12° 20.132’	131° 03.710’
HR-26	1 Dec 2010	Water profile	12° 19.905’	131° 03.603’
HR-27	1 Dec 2010	Water profile	12° 19.891’	131° 03.316’
HR-28	1 Dec 2010	Water profile	12° 19.806’	131° 02.921’
HR-29	1 Dec 2010	Water profile	12° 19.319’	131° 02.153’
HR-30	1 Dec 2010	Water profile	12° 19.105’	131° 01.898’
HR-31	1 Dec 2010	Water profile	12° 18.907’	131° 02.131’
HR-32	1 Dec 2010	Water profile	12° 19.453’	131° 01.377’
HR-33	1 Dec 2010	Water profile	12° 19.779’	131° 01.093’
HR-34	1 Dec 2010	Water profile	12° 19.807’	131° 00.697’
HR-35	1 Dec 2010	Water profile	12° 19.570’	131° 00.552’
HR-36	1 Dec 2010	Water profile	12° 19.220’	131° 00.414’
HR-Logger	1 – 28 Dec 2010	Extended deployment logger	12° 19.220’	131° 00.414’
HRL-1	1 Dec 2010	Filtered water sample	12° 19.220’	131° 00.414’
HRL-2	1 Dec 2010	Filtered water sample	12° 19.220’	131° 00.414’
HRL-3	1 Dec 2010	Filtered water sample	12° 19.220’	131° 00.414’

Site	Date	Type	Latitude	Longitude
HRL-4	1 Dec 2010	Filtered water sample	12° 19.220’	131° 00.414’
HRL-5	1 Dec 2010	Filtered water sample	12° 19.220’	131° 00.414’
HRL-6	1 Dec 2010	Filtered water sample	12° 19.220’	131° 00.414’
HRL-7	1 Dec 2010	Filtered water sample	12° 19.220’	131° 00.414’

Appendix B

Table 2. Northern and Southern Blue Holes sample locations

Site	Date	Type	Latitude	Longitude
NBHV01	7/12/2010	Video transect	12° 09.147'	130° 59.722'
NBHV02	7/12/2010	Video transect	12° 09.116'	130° 59.764'
NBHV03	7/12/2010	Video transect	12° 09.331'	130° 59.455'
NBHV04	7/12/2010	Video transect	12° 09.527'	130° 59.219'
NBHV05	7/12/2010	Video transect	12° 09.484'	130° 59.219'
NBHV06	7/12/2010	Video transect	12° 09.355'	130° 59.526'
NBHV07	7/12/2010	Video transect	12° 08.750'	131° 00.279'
NBHV08	7/12/2010	Video transect	12° 08.817'	131° 00.264'
NBHV09	7/12/2010	Video transect	12° 09.007'	130° 59.930'
NBHV10	7/12/2010	Video transect	12° 09.109'	130° 59.769'
SBHV01	8/12/2010	Video transect	12° 09.500'	131° 00.100'
SBHV02	8/12/2010	Video transect	12° 09.467'	131° 00.167'
SBHV03	8/12/2010	Video transect	12° 09.205'	131° 00.896'
SBHV04	8/12/2010	Video transect	12° 08.612'	131° 01.991'
SB-1	8/12/2010	Water profile	12° 09.506'	131° 00.109'
SB-2	8/12/2010	Water profile	12° 09.348'	131° 00.379'
SB-6	8/12/2010	Water profile	12° 09.342'	131° 00.331'
SB-3	8/12/2010	Water profile	12° 09.149'	131° 00.885'
SB-4	8/12/2010	Water profile	12° 08.813'	131° 01.492'
SB-5	8/12/2010	Water profile	12° 08.651'	131° 01.892'
SB-7	8/12/2010	Water profile	12° 09.467'	131° 00.167'
SB-8	8/12/2010	Water profile	12° 09.205'	131° 00.896'
NB-1	7/12/2010	Water profile	12° 09.098'	130° 59.866'
NB-2	7/12/2010	Water profile	12° 08.873'	131° 00.187'
NB-3	7/12/2010	Water profile	12° 08.838'	131° 00.141'
NB-4	7/12/2010	Water profile	12° 08.968'	131° 00.000'
NB-5	7/12/2010	Water profile	12° 09.050'	131° 00.023'
NB-6	7/12/2010	Water profile	12° 09.097'	130° 59.814'
NB-7	7/12/2010	Water profile	12° 09.441'	130° 59.383'
NB-8	7/12/2010	Water profile	12° 09.417'	130° 59.367'
NB-9	7/12/2010	Water profile	12° 09.317'	130° 59.483'
NB-10	7/12/2010	Water profile	12° 09.333'	130° 59.483'
NB-11	7/12/2010	Water profile	12° 09.233'	130° 59.650'
NB-12	7/12/2010	Water profile	12° 09.217'	130° 59.633'
SED_BH01	7/12/2010	Sediment sample	12° 09.111'	130° 59.918'
SED_BH02	7/12/2010	Sediment sample	12° 08.822'	131° 00.128'
SED_BH03	7/12/2010	Sediment sample	12° 09.315'	130° 59.599'
NB-TSS1	7/12/2010	Filtered water sample	12° 09.098'	130° 59.866'
NB-TSS2	7/12/2010	Filtered water sample	12° 09.098'	130° 59.866'
NB-TSS3	7/12/2010	Filtered water sample	12° 09.098'	130° 59.866'

Appendix C YSI specifications

6600EDS Extended Deployment System

Measure over 10 parameters in severe fouling environments Featuring Patented Clean Sweep® Anti-fouling Technology

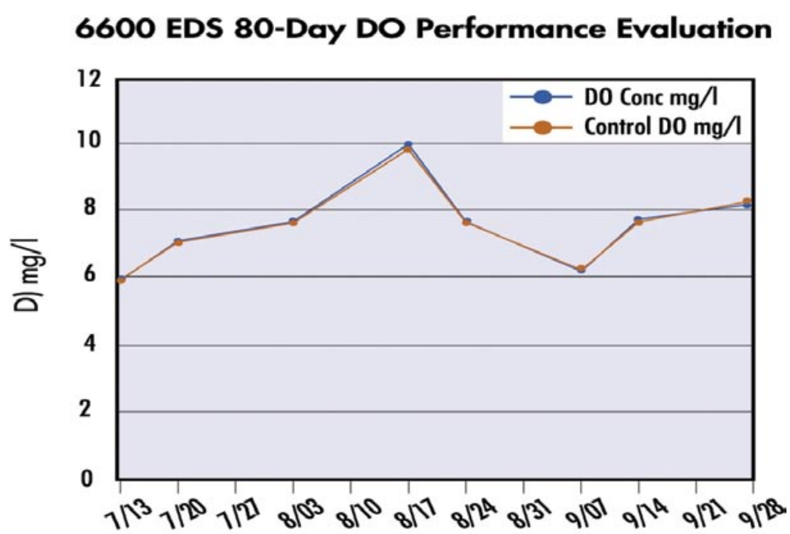
Profile of the 6600EDS depicting (clockwise from bottom) temperature/conductivity, turbidity, Rapid Pulse™ dissolved oxygen, chlorophyll and pH/ORP—all of which (except conductivity) are kept free of fouling by the patented Clean Sweep® universal wiper assembly, as well as individual optical wipers.

Building upon the unprecedented accuracy and reliability of YSI's stirring-independent Rapid Pulse™ dissolved oxygen system, as well as on the improved and proven wiped optical sensors, YSI offers the YSI 6600EDS (Extended Deployment System).

- **Provides unprecedented DO accuracy and longevity in aggressive fouling environments**
- **Patented wiped fouling protection for turbidity, chlorophyll, DO, BGA, pH, and ORP sensors**
- **Ideal for extended, long-term deployments**
- **Virtually maintenance free**
- **Sensors are field-replaceable**
- **Integrates with DCPs (via RS-232 or SDI-12)**

A prototype 6600EDS after continuous deployment for 80 days in Buzzards Bay, MA. The sensor in the foreground is the active DO sensor. The sensor at top-right was used as a non-wiped fouling reference. Note extensive fouling by plant and animal species on the non-wiped sensor.

Initial field studies of the YSI 6600EDS show that the system provides unprecedented DO accuracy and longevity in aggressive fouling environments. The 6600EDS was inspected after 80 days of an ongoing deployment performance evaluation. The Rapid Pulse™ DO sensor performed within specifications throughout this deployment without the need for recalibration or cleaning. During this deployment, the instrument was removed once for battery replacement; none of the sensors was cleaned or recalibrated.



Remarkably close agreement (mean error 0.16mg/l) between the continuously deployed sonde and the control measurements was observed throughout an 80-day deployment.

Pure Data for a Healthy Planet.®

*Sensor Performance verified by the EPA Environmental Technology Verification Program.**

ETV

Sensor performance verified*

The 6600EDS uses sensor technology that was performance-verified through the US EPA's Environmental Technology Verification Program (ETV). For information on which sensors were performance-verified, look for the ETV logo.

YSI 6600EDS Sensor Specifications

	Range	Resolution	Accuracy
Dissolved Oxygen• % Saturation ETV 6562 Rapid Pulse™ Sensor*	0 to 500%	0.1%	0 to 200%: ±2% of reading or 2% air saturation, whichever is greater; 200 to 500%: ±6% of reading
Dissolved Oxygen• mg/L ETV 6562 Rapid Pulse™ Sensor*	0 to 50 mg/L	0.01 mg/L	0 to 20 mg/L: ± 0.2 mg/L or 2% of reading, whichever is greater; 20 to 50 mg/L: ±6% of reading
Conductivity•• ETV 6560 Sensor*	0 to 100 mS/cm	0.001 to 0.1 mS/cm (range dependent)	±0.5% of reading + 0.001 mS/cm
Salinity	0 to 70 ppt	0.01 ppt	±1% of reading or 0.1 ppt, whichever is greater
Temperature ETV 6560 Sensor*	-5 to +50°C	0.01°C	±0.15°C
pH ETV 6561 Sensor*	0 to 14 units	0.01 unit	±0.2 unit
ORP	-999 to +999 mV	0.1 mV	±20 mV
Depth: Deep	0 to 656 ft, 200 m	0.001 ft, 0.001 m	±1 ft, ±0.3 m
Depth: Medium	0 to 200 ft, 61 m	0.001 ft, 0.001 m	±0.4 ft, ±0.12 m
Depth: Shallow	0 to 30 ft, 9.1 m	0.001 ft, 0.001 m	±0.06 ft, ±0.02 m
Depth: Vented Level	0 to 30 ft, 9.1 m	0.001 ft, 0.001 m	±0.01 ft, 0.003 m
Turbidity• ETV 6136 Sensor*	0 to 1,000 NTU	0.1 NTU	±2% of reading or 0.3 NTU, whichever is greater**
Rhodamine•	0-200 µg/L	0.1 µg/L	±5% reading or 1 µg/L, whichever is greater

• Maximum depth rating for all standard optical sensors is 200 feet, 61 m. Also available in Deep Depth option: 656 feet, 200 m.
•• Report outputs of specific conductance (conductivity corrected to 25° C), resistivity, and total dissolved solids are also provided. These values are automatically calculated from conductivity according to algorithms found in *Standard Methods for the Examination of Water and Wastewater* (ed 1989).

**In YSI AMCO-AEPA Polymer Standards.

	Range	Detection Limit	Resolution	Linearity
BGA - Phycocyanin•	~0 to 280,000 cells/mL† 0 to 100 RFU	~220 cells/mL§	1 cell/mL 0.1 RFU	$R^2 > 0.9999$**
BGA - Phycoerythrin•	~0 to 200,000 cells/mL† 0 to 100 RFU	~450 cells/mL§§	1 cell/mL 0.1 RFU	$R^2 > 0.9999$***
Chlorophyll• ETV 6025 Sensor*	~0 to 400 µg/L 0 to 100 RFU	~0.1 µg/L§§§	0.1 µg/L Chl 0.1% RFU	$R^2 > 0.9999$****

• Maximum depth rating for all standard optical probes is 200 feet, 61 m. Also available in Deep Depth option 656 ft 200 m.
BGA = Blue-Green Algae
RFU = Relative Fluorescence Units
~ = Approximately

† Explanation of Ranges can be found in the 'Principles of Operation' section of the 6-Series Manual.

§ Estimated from cultures of *Microcystis aeruginosa*.
§§ Estimated from cultures *Synechococcus sp.*
§§§ Determined from cultures of *Isochrysis sp.* and chlorophyll *a* concentration determined via extractions.

**Relative to serial dilution of Rhodamine WT (0-400 ug/L).
***Relative to serial dilution of Rhodamine WT (0-8 µg/L).
****Relative to serial dilution of Rhodamine WT (0-500 ug/L).

YSI 6600EDS Sonde Specifications

Medium	Fresh, sea or polluted water	Software	EcoWatch®
Temperature: Operating	-5 to +50°C	Dimensions: Diameter	3.5 in, 8.9 cm
Temperature: Storage	-10 to +60°C	Length, no depth	19.6 in, 34.3 cm
		Length, depth	21.6 in, 54.9 cm
		Weight, depth and batteries	7 lbs, 3.18 kg
Communications	RS-232, SDI-12	Power: External	12 V DC
		Internal	8 C-size alkaline batteries

YSI

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ISO 9001
ISO 14001
Yellow Springs, Ohio Facility

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*Sensors with listed with the ETV logo were submitted to the ETV program on the YSI 6600EDS. Information on the performance characteristics of YSI water quality sensors can be found at www.epa.gov/etv, or call YSI at 800.897.4151 for the ETV verification report. Use of the ETV name or logo does not imply approval or certification of this product nor does it make any explicit or implied warranties or guarantees as to product performance.

YSI incorporated
Who's Minding the Planet?®

650 MDS

Battery Life
With the standard alkaline battery configuration of 4 C-cells, the YSI 650 will power itself and a YSI 6600 sonde continuously for approximately 30 hours. Or, choose the rechargeable 120 v battery pack (YSI Part # 6113) option with quick-charge feature.
Optional Barometer
Temperature-compensated barometer readings are displayed and can be used in dissolved oxygen calibration. Measurements can be logged to memory for tracking changes in barometric pressure.
Optional GPS Interface
Designed to NMEA protocol, the YSI 650MDS will display and log real-time GPS readings with a user-supplied GPS interfaced with YSI 6-series sondes.
Memory Options
Standard memory will allow for approximately 150 data sets. Exact logging capacity is dependent on the number of active parameters in the 6-series sonde. Optional high memory (1.5 mB) would make it possible to easily upload the data from 7 sondes, each of which have data files of approximately 75 days at a 15-minute sampling interval.
Features:

- Compatible with EcoWatch® for Windows® data analysis software
- User-upgradable software from YSI's website
- Menu-driven, easy-to-use interface
- Multiple language capabilities
- Graphing feature
- Three-year warranty

YSI650MDS Display & Datalogger Specifications

Temperature	Operating Storage	-10 to +60°C for visible display -20 to +70°C
Waterproof Rating		IP-67 for both the standard alkaline battery configuration and for the rechargeable battery pack option
Connector		MS-8; meets IP-67 specification
Dimensions	Width Length Weight	4.7 in, 11.9 cm 9 in, 22.9 cm 2.1 lbs, 0.91 kg (batteries installed)
Display		VGA; LCD with 320 by 240 pixels with backlight
Power	Standard Optional	4 alkaline C-cells with detachable battery cover Ni metal hydride battery pack with attached battery cover and 110/220 volt charging system
Communications		RS-232 to all sondes, for data transfer to PC, and for software updates
Optional GPS		NMEA 0183; requires user-supplied GPS and YSI 6115 Y-cable
Backlight		4 LEDs illuminating LCD; user-selectable
Keypad		20 keys, including instrument on/off, backlight on/off, enter, esc, 10 number/letter entry keys, 2 vertical arrow keys, 2 horizontal arrow keys, period key, and minus key
Warranty		**3 years**
Certifications		**CE, EU Battery compliance, FCC, IP-67, WEEE, and C-Tick** **Assembled in the USA**

Ordering Information

Item #	Description
650-01	Instrument, standard memory
650-02	Instrument, high memory
650-03	Instrument, standard memory, barometer
650-04	Instrument, high memory, barometer
6113	Rechargeable battery pack kit with 110 volt charger and adapter cable
616	Charger, cigarette lighter
4654	Tripod
614	Ultra clamp, C-clamp mount
5081	Carrying case, hard-sided
5085	Hands-free harness
5065	Form-fitted carrying case
6115	Y-cable for interface with user-supplied GPS system

URS

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