APPENDIX O12

Desalination plant construction

APPENDIX O12.1

Port Bonython Desalination Plant – Construction Plume Impacts (report by BMT WBM, 2008)

See overleaf for report.

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Port Bonython Desalination Plant – Construction Plume Impacts

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December 2008

Port Bonython Desalination Plant – Construction Plume Impacts

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Prepared By:	BMT WBM Pty Ltd (Member of the BMT group of companies)

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

BHP Billiton (BHP) is considering the construction of a desalination facility at Port Bonython/Point Lowly in the Spencer Gulf region of South Australia (see Figure 1-1) to supply water to the proposed expansion of the Olympic Dam project. The desalination plant will require intake pipeline/s in order to source “raw” seawater from the Gulf and outlet pipeline/s in order to discharge the return brine into the Gulf. The brine discharge impacts associated with the proposed desalination plant have been the subject of a comprehensive modelling study undertaken by BMT WBM as part of the EIS (BMT WBM 2007a).

Construction of the desalination plant intake and outlet pipelines will involve temporary marine works with the potential to generate turbid plumes. This study is an assessment of the potential impacts associated with the generation of turbid plumes during pipeline construction.

In-situ bed sediment testing was performed along the proposed pipeline alignments (HLA, 2006; Cooe, 2008), in order to assist with the development of likely pipeline construction methodologies.

BMT WBM have undertaken field measurements to characterise the ambient turbidity and suspended sediment concentrations at Point Lowly.

A sediment plume numerical model was developed by BMT WBM and the Centre for Water Research (CWR) in order to predict the sediment plumes generated by the proposed construction methodologies. The numerical model is based on the Estuary, Lake and Coastal Ocean Model (ELCOM) which was developed for the brine dispersion modelling (BMT WBM 2007a). The Computational Aquatic Ecosystem Dynamics Model (CAEDYM) was coupled to the ELCOM in order to simulate sediment deposition and re-suspension processes.

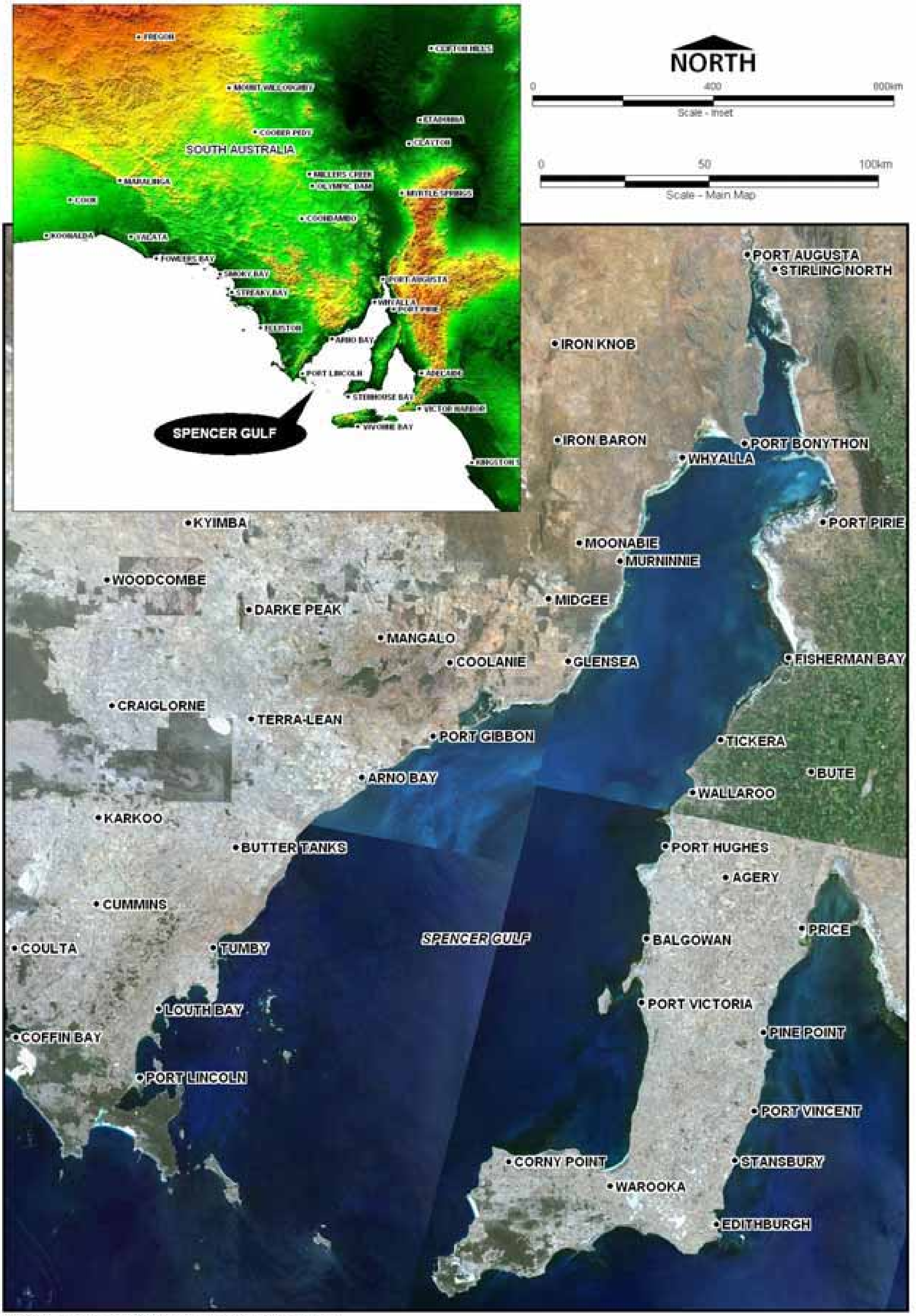

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Figure 1-1 Spencer Gulf Locality Plan.

2 IN-SITU BED SEDIMENTS

Sampling and testing of bed sediments has been undertaken at Point Lowly on two separate occasions.

HLA-Envirosciences undertook surficial sampling and laboratory analysis including determination of Particle Size Distributions (PSD) and testing for contaminants (HLA, 2006). The sampling layout is shown in Figure 2-1 and the PSD results are reproduced in Table 2-1. The surficial sedimentary material was generally coarse silty or slightly clayey sand, with numerous angular shell fragments. Fines content (grain size less than 0.075mm) ranged between 2% and 41%, with the higher silt/clay content typically occurring at locations experiencing relatively low tidal and wave energy conditions.

Table 2-1 Particle Size Distributions – % passing (HLA, 2006)

Sample	Grain size (mm)									
	0.075	0.15	0.30	0.425	0.60	1.18	2.36	4.75	9.5	19.0
D2	11	10	31	14	11	13	3	2	3	2
D4	6	5	24	10	9	19	12	5	5	5
D5	2	0	1	18	24	40	11	1	2	1
D6	11	8	28	17	13	16	5	1	1	
D7	41	18	26	7	3	3	1	1		
D8	12	5	14	9	10	25	19	4	2	
D20	37	1	1	4	5	24	23	3	1	1
D22	6	1	1	4	8	28	30	14	6	2
D24	31	13	14	6	4	10	9	6	2	5
D28	16	6	8	6	8	20	15	10	7	4
D30	2	1	50	37	8	1	1			
D31	3	1	4	7	12	43	25	4	1	
D32	31	10	13	6	7	12	9	5	4	3
D35	11	10	31	13	10	17	6	1	1	
Average	16	6	18	11	9	19	12	4	3	2

Further sediment core sampling was undertaken by COOE during March 2008 in order to describe sub-surface sediment properties and to determine the relative depth of underlying bedrock. The distribution of core samples are shown in Figure 2-2. Maximum core lengths were 2m long and typically three PSDs were obtained at equal depth increments for each core and are summarised in Table 2-2. In cases where the corer could not be driven to a depth of 2m a steel bar was used to determine the bedrock depth below the seabed, which are summarised for the selected pipeline alignment sampling locations in Table 2-3.

Table 2-2 Sediment Core Particle Size Distribution (COOE, 2008).

Sample ID	Percent Gravel (+2 mm)	Percent Sand (2mm-0.060 mm)	Percent Silt (0.060-0.002 mm)	Percent Clay (-0.002 mm)
CS01/1 PSD	0	98	2	
CS01/2 PSD	0	98	2	
CS01/3 PSD	1	93	2	4
CS03/1 PSD	35	59	3	3
CS03/2 PSD	79	19	2	
CS03/3 PSD	54	35	4	7
CS04/OM PSD	29	62	7	2
CS05/1 PSD	62	22	10	6
CS05/2 PSD	60	29	5	6
CS05/3 PSD	51	26	11	12
CS06/1 PSD	24	32	22	22
CS06/2 PSD	17	35	22	26
CS06/3 PSD	19	42	19	20
CS07/1 PSD	0	98	2	
CS07/2 PSD	7	89	4	
CS07/3 PSD	2	94	4	
CS08/1 PSD	1	92	3	4
CS08/2 PSD	21	72	3	4
CS08/3 PSD	1	90	3	6
CS09/1 PSD	3	81	10	6
CS09/2 PSD	19	53	11	17
CS09/3 PSD	1	42	19	38
CS010/1 PSD	11	67	9	13
CS010/2 PSD	10	53	15	22
CS010/3 PSD	35	42	9	14
CS011/1 PSD	8	46	20	26
CS011/2 PSD	9	56	15	20
CS011/3 PSD	5	54	17	24
CS012/1 PSD	10	79	4	7
CS012/2 PSD	33	57	5	5
CS012/3 PSD	4	75	9	12
CS013/1 PSD	16	53	15	16
CS013/2 PSD	12	51	16	21
CS013/3 PSD	18	48	16	18
CS014/1 PSD	12	50	18	20
CS014/2 PSD	23	40	17	20
CS014/3 PSD	9	49	19	23
CS015/1 PSD	12	43	20	25
CS015/2 PSD	7	45	22	26
CS015/3 PSD	8	37	27	28
CS016/1 PSD	14	48	18	20
CS016/2 PSD	13	36	25	26
CS016/3 PSD	14	28	25	33
Average	18	56	12	14

Table 2-3 Bedrock Depth at Core Sampling Locations (COOE, 2008).

Location	Steel Rod Probe Depth (m)
Outfall – CS01	1.3
Outfall – CS02	0.0
Outfall – CS03	0.6
Outfall – CS04	0.0
Outfall – CS05	0.6
Outfall – CS06	1.3
Intake – CS12	1.5
Intake – CS13	2.0+
Intake – CS14	2.0+
Intake – CS15	1.5
Intake – CS16	2.0+

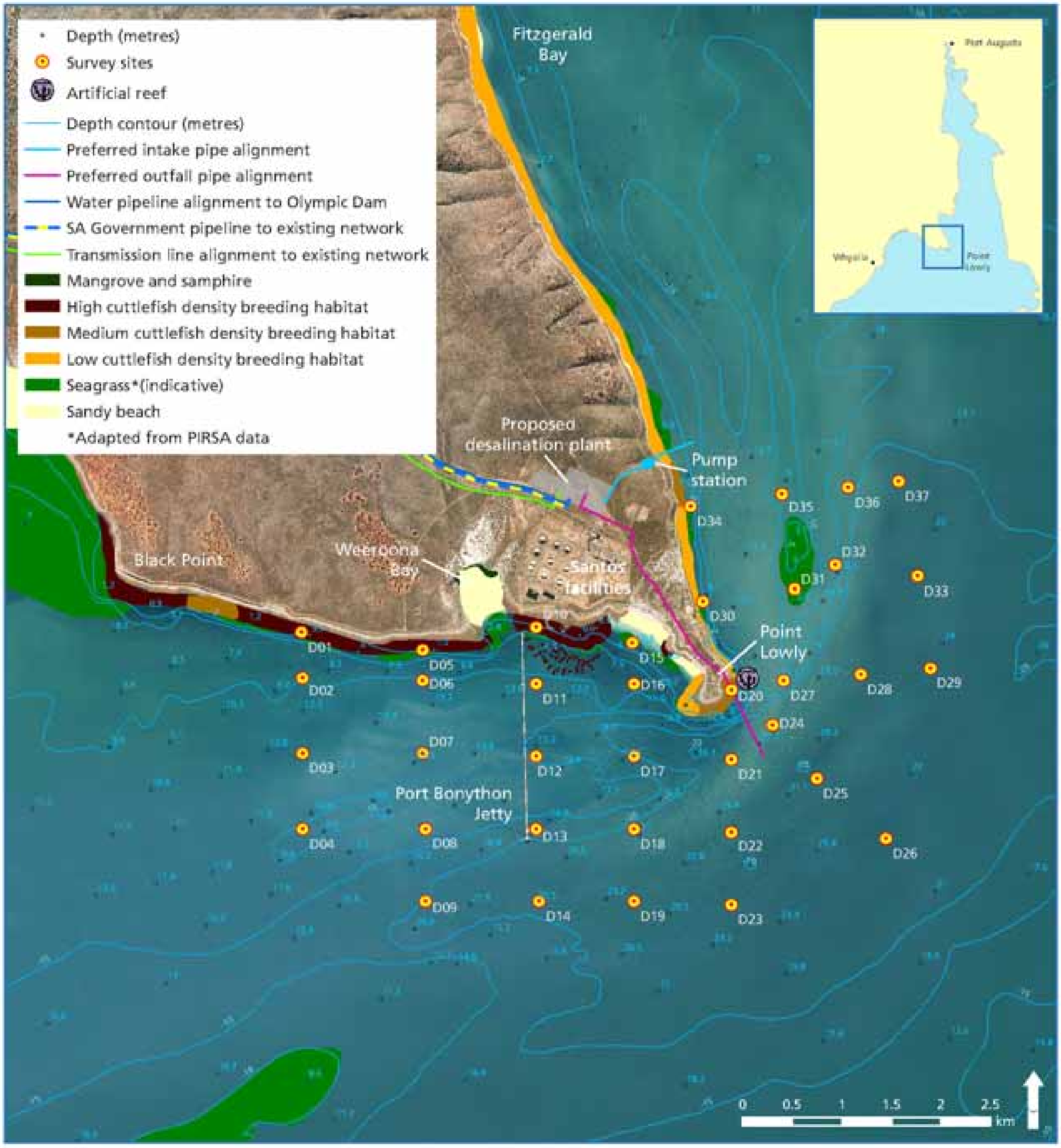
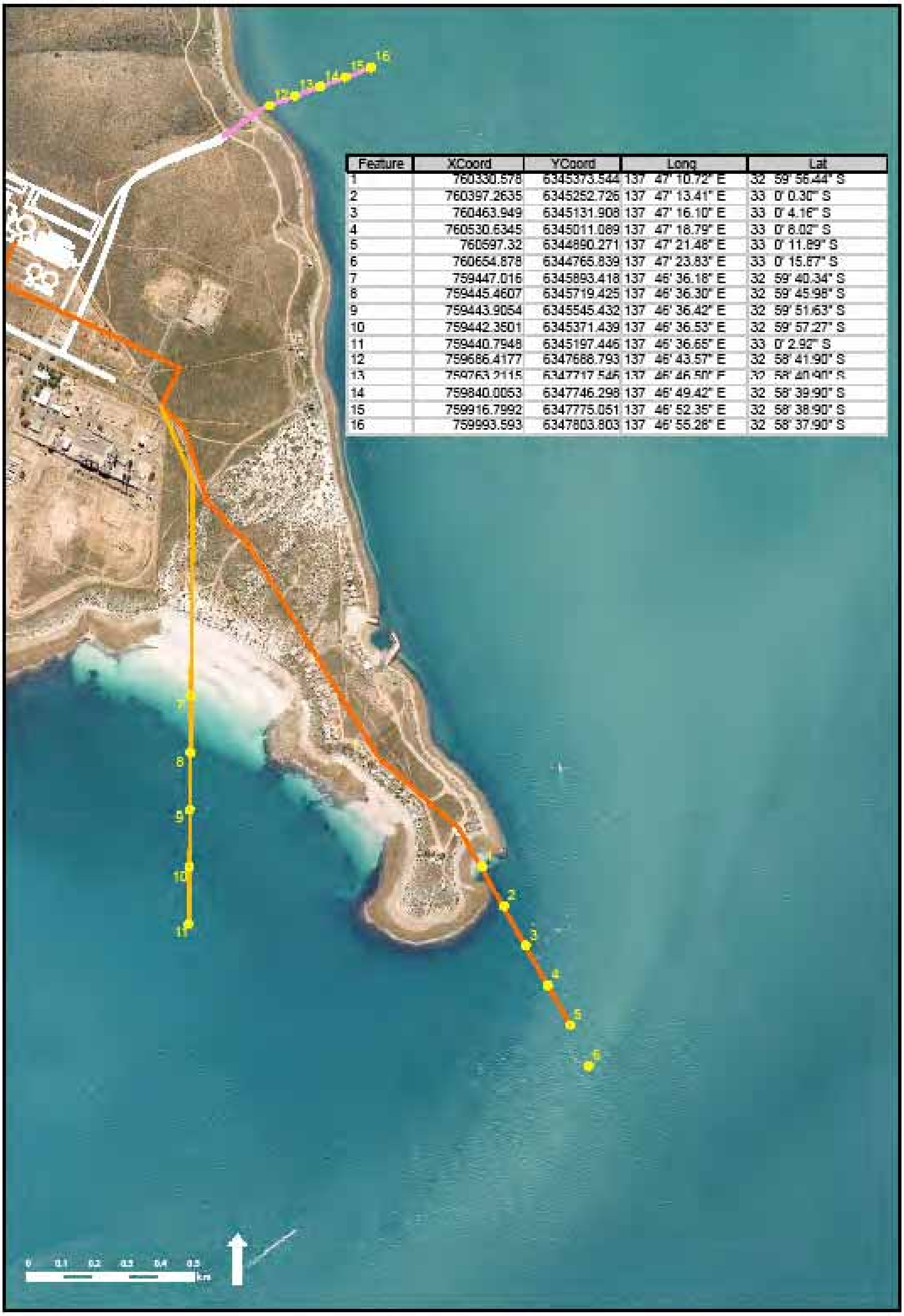


Figure 2-1 Surficial sediment sampling locations (HLA, 2006).



Feature	XCoord	YCoord	Long	Lat
1	760330.578	6345373.544	137 47' 10.72" E	32 59' 56.44" S
2	760397.2635	6345252.726	137 47' 13.41" E	33 0' 0.30" S
3	760463.949	6345131.908	137 47' 16.10" E	33 0' 4.16" S
4	760530.6345	6345011.089	137 47' 18.79" E	33 0' 8.02" S
5	760597.32	6344890.271	137 47' 21.48" E	33 0' 11.89" S
6	760654.878	6344765.839	137 47' 23.83" E	33 0' 15.87" S
7	759447.016	6345893.418	137 46' 36.18" E	32 59' 40.34" S
8	759445.4607	6345719.425	137 46' 36.30" E	32 59' 45.98" S
9	759443.9054	6345545.432	137 46' 36.42" E	32 59' 51.63" S
10	759442.3501	6345371.439	137 46' 36.53" E	32 59' 57.27" S
11	759440.7948	6345197.446	137 46' 36.65" E	33 0' 2.92" S
12	759686.4177	6347688.793	137 46' 43.57" E	32 58' 41.90" S
13	759763.2115	6347717.546	137 46' 46.50" E	32 58' 40.90" S
14	759840.0053	6347746.298	137 46' 49.42" E	32 58' 39.90" S
15	759916.7992	6347775.051	137 46' 52.35" E	32 58' 38.90" S
16	759993.593	6347803.803	137 46' 55.28" E	32 58' 37.90" S

Figure 2-2 Sediment core sample locations (COOE, 2008).

3 AMBIENT TURBIDITY AND SUSPENDED SEDIMENT DATA

Turbidity and suspended sediment data have been collected by BMT WBM in order to help characterise the natural variation of these parameters, as a baseline for comparison of predicted construction plume impacts.

3.1 Turbidity Data

A nephelometer was deployed on the Santos Jetty at Port Bonython for the six week period between the 2/3/2008 and 13/4/2008 (refer Figure 3-8 for location). The instrument was located at approximately the middle of the water column and approximately measures the depth-averaged turbidity due to the well-mixed nature of the location. Data from the instrument is plotted in Figure 3-1, which shows that turbidity typically varied between 2 and 12 NTU at this site. A strong spring/neap tidal signal is apparent in the turbidity timeseries, with turbidity levels up to 12 NTU occurring during peak spring tidal flows, whereas during neap tides the turbidity is generally below 8 NTU.

Some southern sector wind events occurred during the deployment period on the 19th March and the 26-27th March. The waves generated by these winds have driven sediment re-suspension and are responsible for turbidity levels up to around 17 NTU at the measurement site. As expected, strong offshore winds from the northern and western sectors are not accompanied by sediment re-suspension events.

Figure 3-2 is a three day close-up of the turbidity timeseries during a spring tide period and shows that turbidity levels vary significantly between around 4 and 12 NTU during the semi-diurnal tidal cycle. Peak turbidity levels occur during both the flood and ebb tide runs while the turbidity minima occur at both high and low water slacks. This data indicates that there is significant mobilisation of the local bed material by the spring tidal currents.

A second deployment of two nephelometers on the Santos jetty occurred for a month long period during June 2008. The location of the two instruments during this deployment is also shown in Figure 3-8, and they were again placed vertically at around the middle of the water-column. Turbidity levels during the June period appear to be generally less than during the March deployment, with turbidity levels at the offshore site typically less than 4 NTU. The inshore location generally has turbidity levels similar to the offshore site except during southerly wind/wave events during which turbidity levels up to 15-20 NTU were measured.

Turbidity profiling was undertaken along the four transects shown in Figure 3-8 on the 23rd-24th July. These profiles indicate that turbidity generally ranged between 1-2 NTU around the high water slack (21:00) before increasing on the falling tide to levels of 6-7 NTU. There are only slight increases in turbidity apparent with depth, indicating that the water column is well-mixed by the tide.

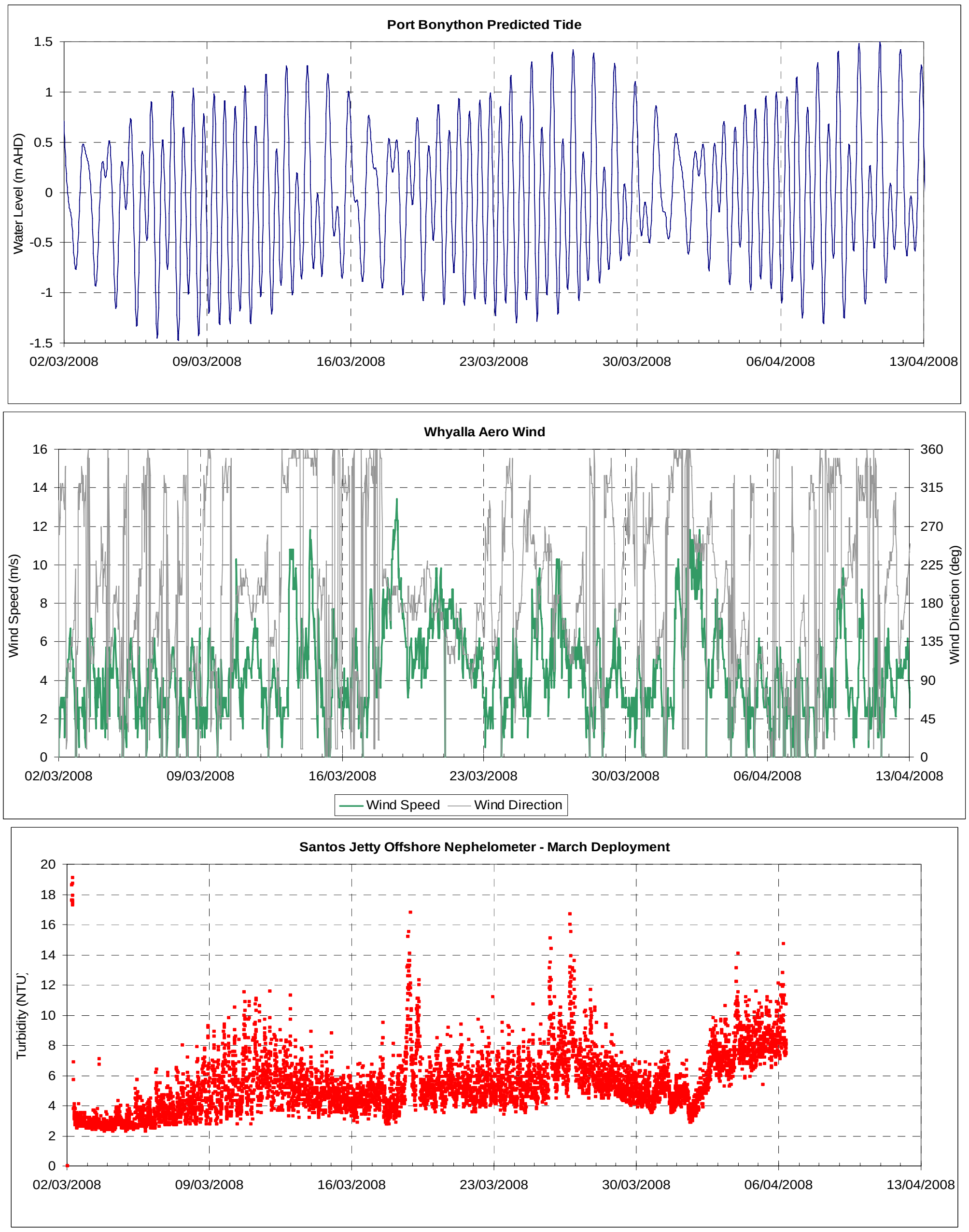


Figure 3-1 March Turbidity Timeseries

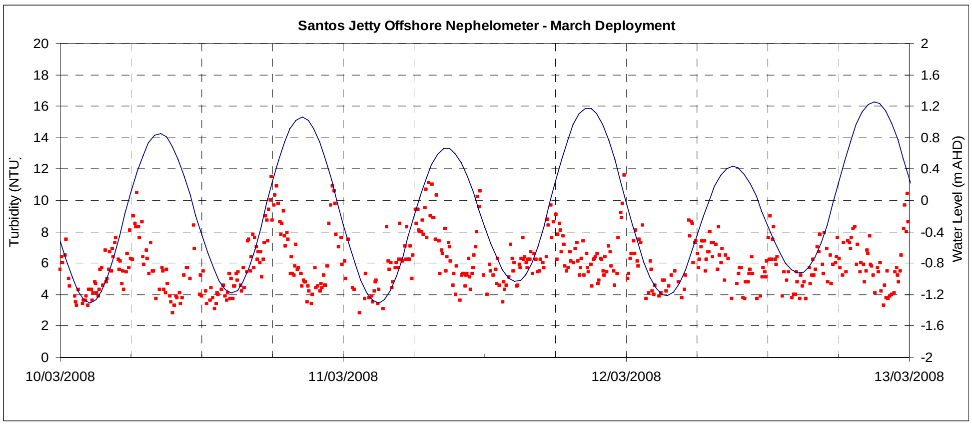


Figure 3-2 Spring Tide Turbidity Timeseries

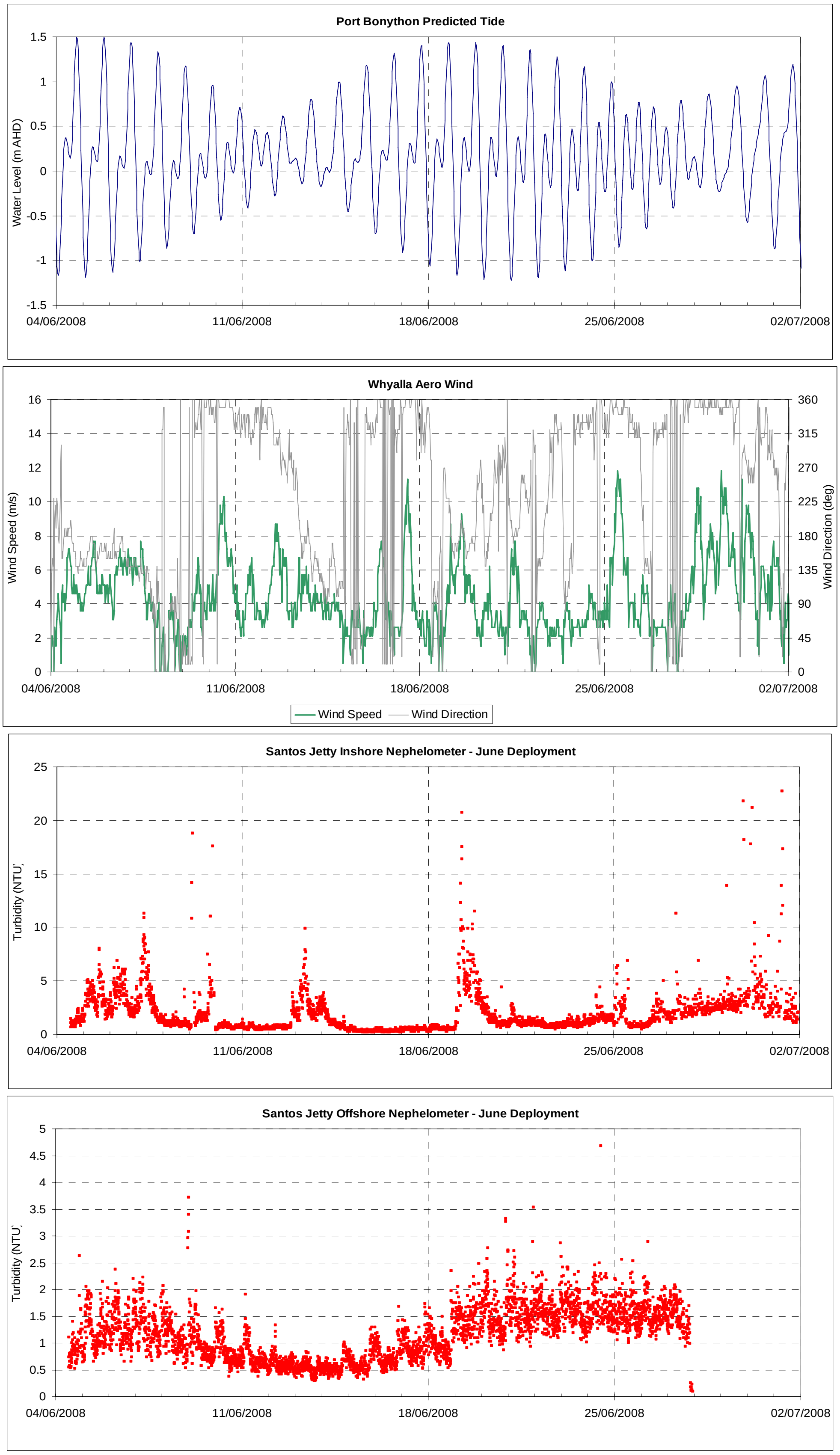


Figure 3-3 June Turbidity Timeseries

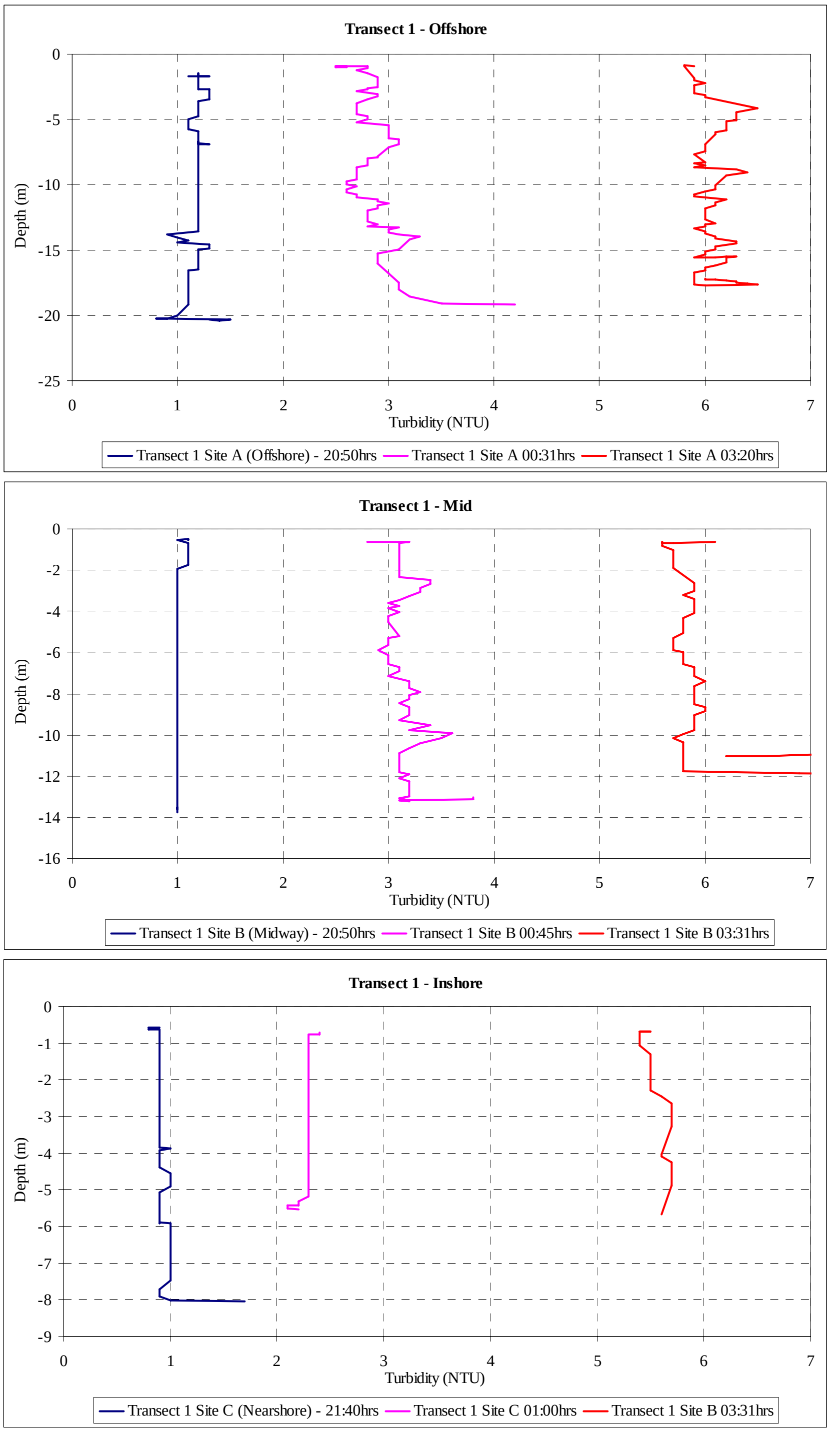


Figure 3-4 23rd-24th July Turbidity Profiles - Transect 1

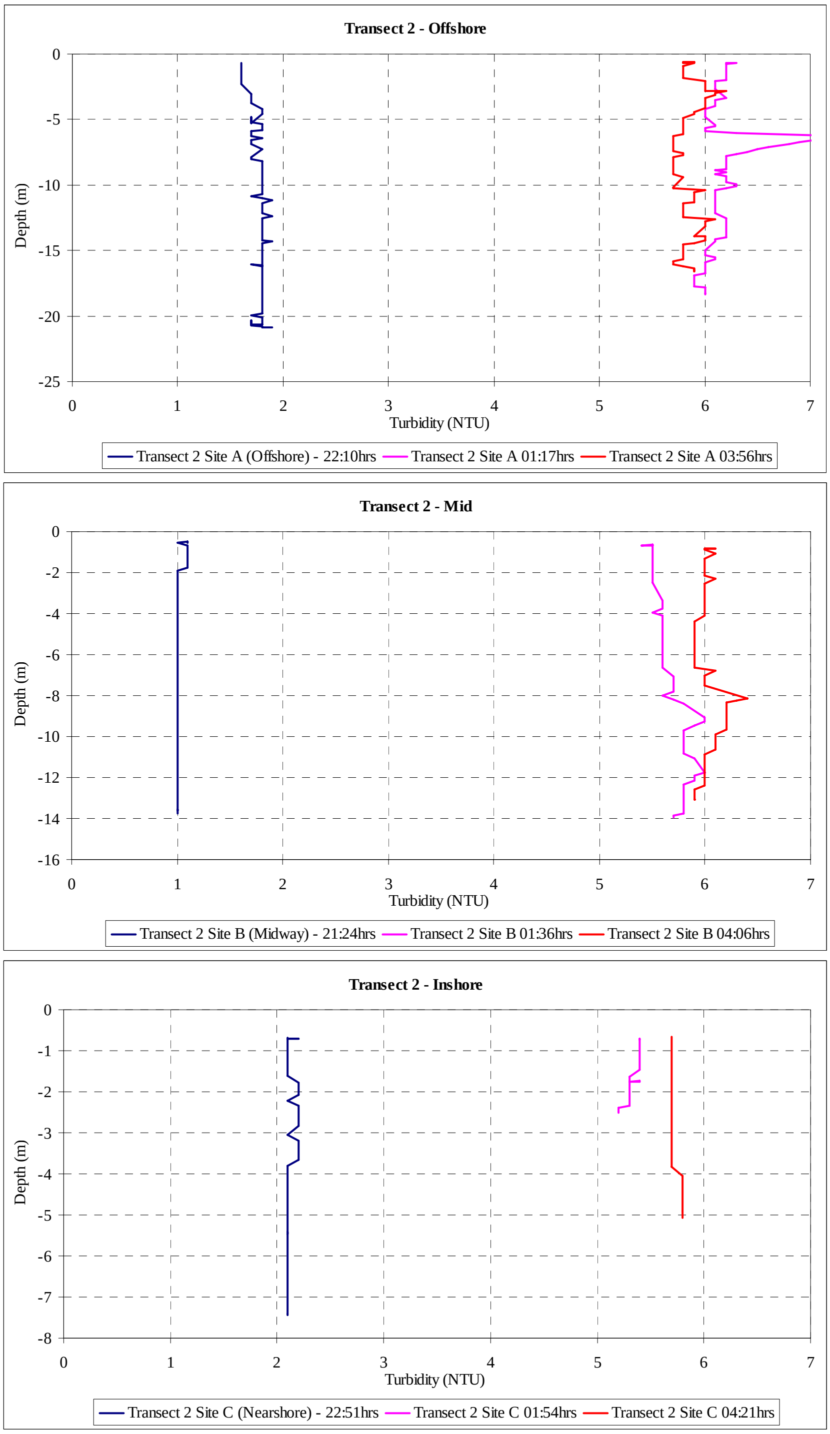


Figure 3-5 23rd-24th July Turbidity Profiles - Transect 2

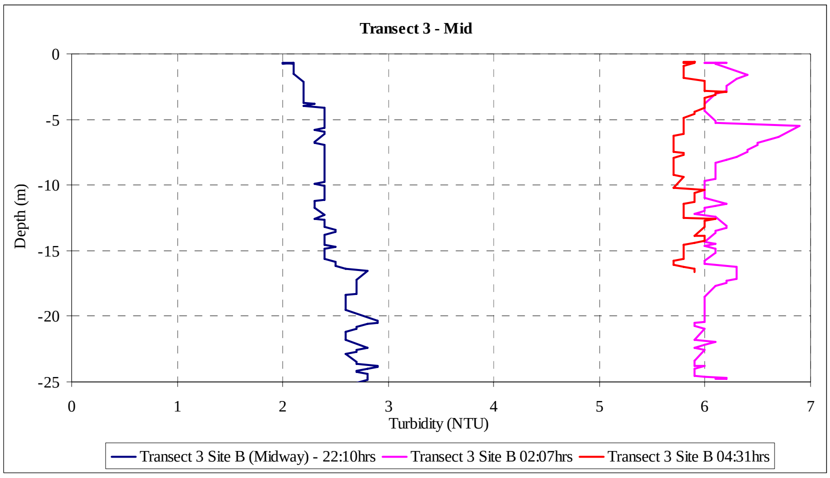


Figure 3-6 23rd-24th July Turbidity Profiles - Transect 3

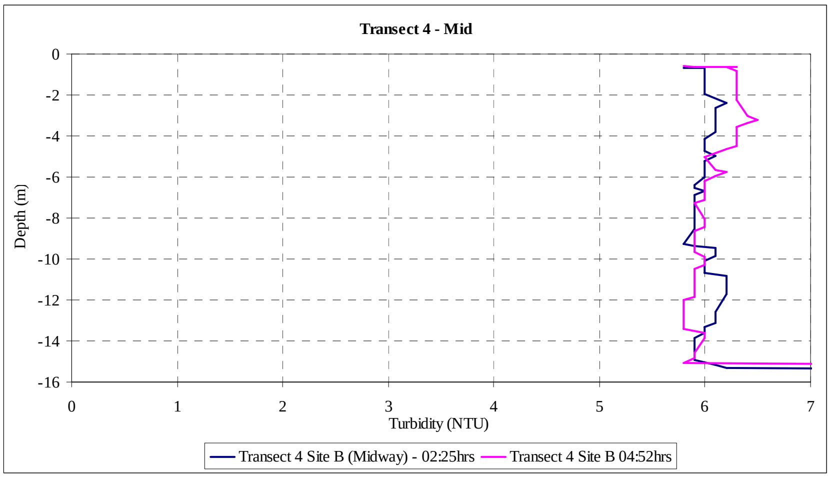


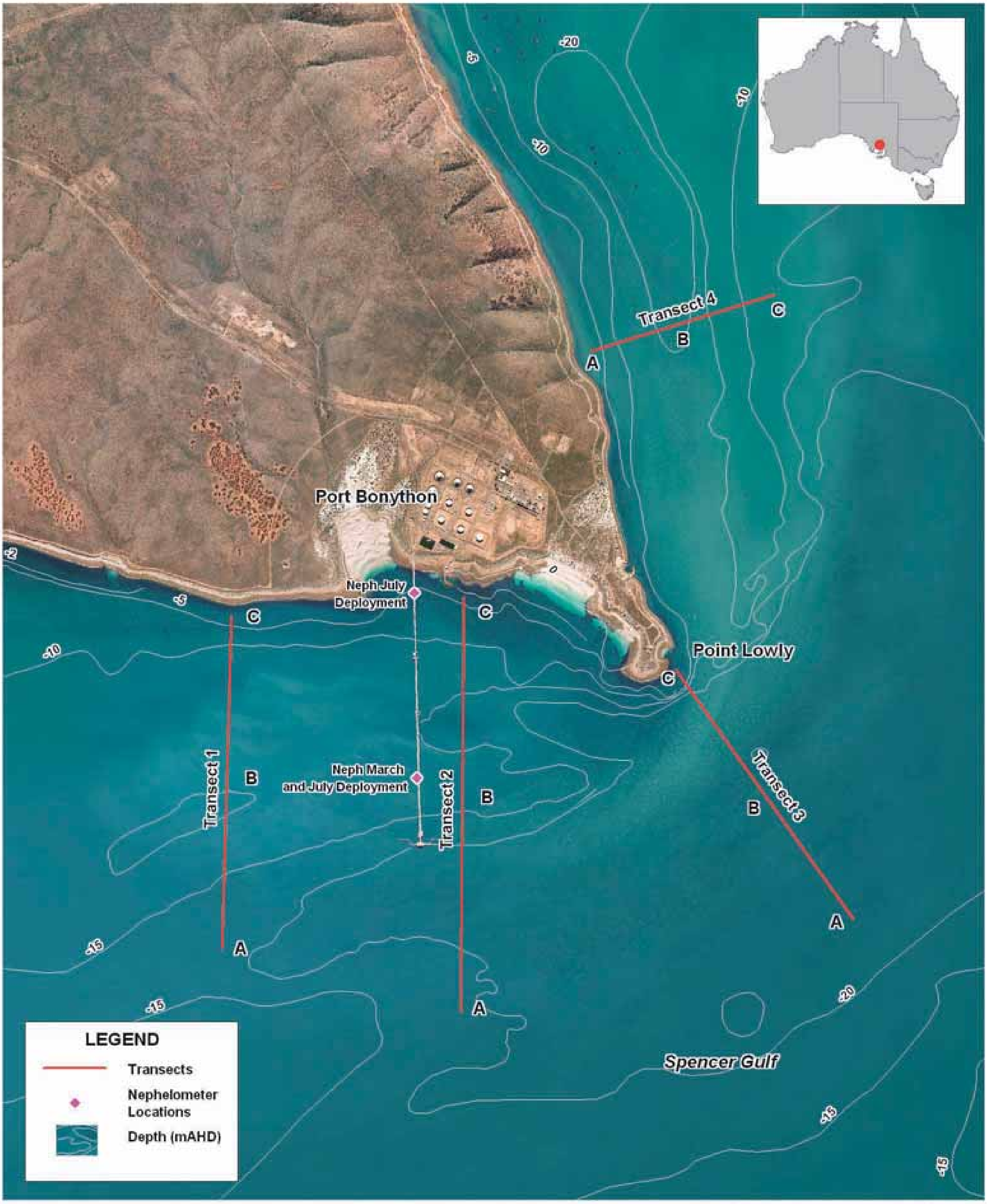
Figure 3-7 23rd-24th July Turbidity Profiles - Transect 4

3.2 Total Suspended Solids Data

Twenty mid-depth water samples were collected on the 23rd and 24th July and subsequently analysed for Total Suspended Solids (TSS) by Queensland Health Laboratories. The sample locations are shown in Figure 3-8 and the measured TSS levels are summarised in Table 3-1. The measured TSS levels range between <1 – 4 mg/L at times when turbidity ranged up to 6 NTU.

Table 3-1 TSS Measurements 23-24 July 2008.

Sample	Location	Collection Time	TSS (mg/L)
1	Transect 1-a	23/7/2008 21:05	2
2	Transect 1-a	21:15	4
3	Transect 1-b	21:38	< 1
4	Transect 1-c	21:46	< 1
5	Transect 2-a	22:15	< 1
6	Transect 2-a	22:19	< 1
7	Transect 2-b	22:35	< 1
8	Transect 3-b	23:30	2
9	Transect 1-a	24/7/2008 00:31	< 1
10	Transect 1-b	00:47	4
11	Transect 1-c	01:00	2
12	Transect 2-a	01:25	3
13	Transect 2-b	01:42	2
14	Transect 2-c	01:56	2
15	Transect 2-b	01:44	3
16	Transect 3-b	02:12	2
17	Transect 1-a	03:24	1
18	Transect 1-c	03:43	1
19	Transect 2-b	04:12	1
20	Transect 3-b	04:40	3



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Turbidity and TSS measurement Locations: 23-24 July 2008

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4 CONSTRUCTION METHODOLOGY AND PLUME GENERATION ASSUMPTIONS

4.1 Intake and Outfall Pipeline Alignments

The preferred intake and outfall pipeline alignments that have been used as the basis for the construction plume modelling assessments are shown in Figure 4-1.

4.2 Construction Methodology Workshop

A pipeline construction methodology workshop was conducted by BHP on the 22 August 2008 with the aims of establishing:

- Intake/outfall marine construction requirements;
- Feasible construction windows, durations and constraints;
- Suitable construction methodology and plant/equipment.

The workshop outcomes were summarised by BHP and are reproduced below (Craig Headon pers comm.).

> *The method for installing the intake and outfall pipelines has not been finalised. Two options exist. The first option would see the intake and outfall pipelines installed completely within a trench to prevent damage by tidal currents. Alternatively the pipelines would be buried within the tidal zone and laid on the surface in deep water with adequate stabilisation to prevent movement. The final construction methodology is dependent on the pipe material chosen and geotechnical surveys conducted prior to construction.*
>
> *Assuming a completely trenched solution, the most likely method of excavation is by clamshell bucket. The clamshell will be operated by a crane on a flat top barge secured by a temporary mooring system. The barge would operate in the marine environment to allow excavation and assist in the placing of the pipe sections, armouring and backfilling activities. Trenching closer to shore will require a temporary jetty to allow crane and excavator access. It is anticipated that a temporary load out facility and short jetty will be provided at the landfall of the inlet pipe. This facility would provide for the load out of materials and allow trench excavation in the shallow water where the barge cannot operate. The intake pumping station site will be utilised for the temporary storage of materials and pipes on land. A similar short section of temporary jetty will be required for the outlet pipe to allow trenching of the section in shallow water.*
>
> *The dredged trench would be formed in sections to allow the pipe sections to be placed. When dredging the trench the excavated material will be placed over the completed sections of pipe to complete the backfill. The dredged trench may accumulate some sand infill prior to placing the pipe sections and this will be removed just before installation. The pipe sections will be weighted to provide temporary stability during installation and prevent uplift during backfill. The pipe sections would be lowered into the trench and jointed to the previous section using mechanical means. Once the pipe section has been installed, the gravel backfill and armouring will be placed as soon as possible to stabilise the pipe.*

The risk of sediment plume impacts is obviously greater for the trenched pipeline option and therefore the plume modelling assessments undertaken relate to this scenario. The development of a numerical model to simulate the sediment plumes generated by construction activities requires a number of key assumptions relating to the specific construction methodology and furthermore the in-situ bed material properties.

The key trenched pipeline construction methodology assumptions that were arrived at through the workshop are:

- Excavation of trench by a 3 cubic meter clamshell bucket;
- Excavation for intake and outfall to assume a worst case of all soft material equivalent to 50m^3 of excavation per meter of pipeline;
- Excavation rate 1,000m^3 per day over 15 hours (i.e. 67m^3/hour) commencing 7am (20m of pipeline);
- Excavation of natural material continues for 5 days during a 14 day tidal cycle to expose 100m of trench;
- Excavation occurs during spring tides leaving dodge tide periods for laying pipeline in recently exposed trench;
- Excavated material will be transferred into a hopper of 250m^3 capacity which will be emptied every 4 hours. Hopper material will be emptied over installed sections of pipe in a 5 minute period;
- Following 5 days of excavation 2-3 days will be spent cleaning the trench to remove any drift sand and armouring the previous sections of pipe.

4.3 Plume Generation Assumptions

In addition to the construction methodology assumptions determined at the August workshop, the plume simulations also require various assumptions regarding:

- In-situ bed material properties; and,
- Sediment entrainment generated by the proposed construction activities.

4.3.1 Bed material properties

The in-situ bed material along the intake and outlet pipeline alignments has been assumed to have the following particle size distribution, which is based on the surficial sediment and bed core sampling discussed in Section 2.

- Coarse sand/gravel fraction (not modelled) 30%
- Medium sand fraction (d_{50} = 0.22 mm) 15%
- Fine sand fraction (d_{50} = 0.11 mm) 15%
- Silt fraction (d_{50} = 0.03 mm) 20%
- Clay fraction (d_{50} = 0.001 mm) 20%

Based on the nature of the bed material, the bulk density of the in-situ bed material has been assumed to be 1800 kg/m^3 with a corresponding dry density of 1200 kg/m^3.

It should be noted that the assumption of 40% silt/clay material is generally a conservative (high) representation of the fines content found along the pipeline alignments (refer Table 2-1 and Table 2-2). In some locations it is a gross over-estimate of the fine material, in particular along the inshore portion of the outfall pipeline where there is little or no loose sediments overlying the bedrock layer and where, if present, this material is generally comprised of gravels and coarse sands that are relatively devoid of fines.

4.3.2 Trenching

Sediments may be entrained in the water column during trenching by release from the bucket of excess water containing high concentrations of fine sediments. A sediment entrainment rate of 50 kg per bulk cubic metre of material excavated has been conservatively assumed based on typical published values for clamshell dredging operations. For instance John et al (2000) provided indicative entrainment rates for grab dredgers of 11–25 kg/m^3. Tavolaro (1984) derived a sediment entrainment rate of 2% of the total dry mass removed during clamshell dredging, which is broadly consistent with the previous values assuming realistic dry-densities (400-1200 kg/m^3).

A sediment entrainment rate of 0.93kg/s is obtained for a trench construction rate of 67m^3/hour. The assumed sediment entrainment rate of 50 kg/m^3 is twice the high-end literature values just stated. This introduces some conservatism into the model predictions given the high current speeds experienced at Point Lowly. That is, the model predictions are expected to be at the high end of likely plume concentrations.

The particle size distribution of the entrained sediment is assumed to be identical to the bed material. In practice the sand fractions tend to immediately deposit out of the water column while the silt and clay fractions comprising 40% of the bulk material will be maintained in suspension for some time.

4.3.3 Backfilling

The trench backfilling operation involving hopper dumping of excavated material will also contribute to sediment plume generation. Tavolaro (1984) identified that 3-7% of dredged material was lost to sediment plumes during disposal. BMT WBM (2007b) identified that around 2% of dumped material left the dumpsite in a suspended sediment plume during detailed monitoring of a spoil disposal event.

For the current modelling assessment it has been assumed that 10% (approximately 31,500 kg per hopper load) of the bulk material dumped is available for transport as a sediment plume, of which the coarser fractions will settle out quickly and the finer material will remain in suspension and be subject to advection, dispersion and slow settling to the bed. The particle size distribution of the sediment made available to the plume is again assumed to be identical to the bed material. The sand fractions will tend to settle immediately at the dump site while the silt and clay fractions (comprising 40% of the material) will be maintained in suspension for some time and will be transported away from the dump-site as a sediment plume.

4.3.4 Discussion

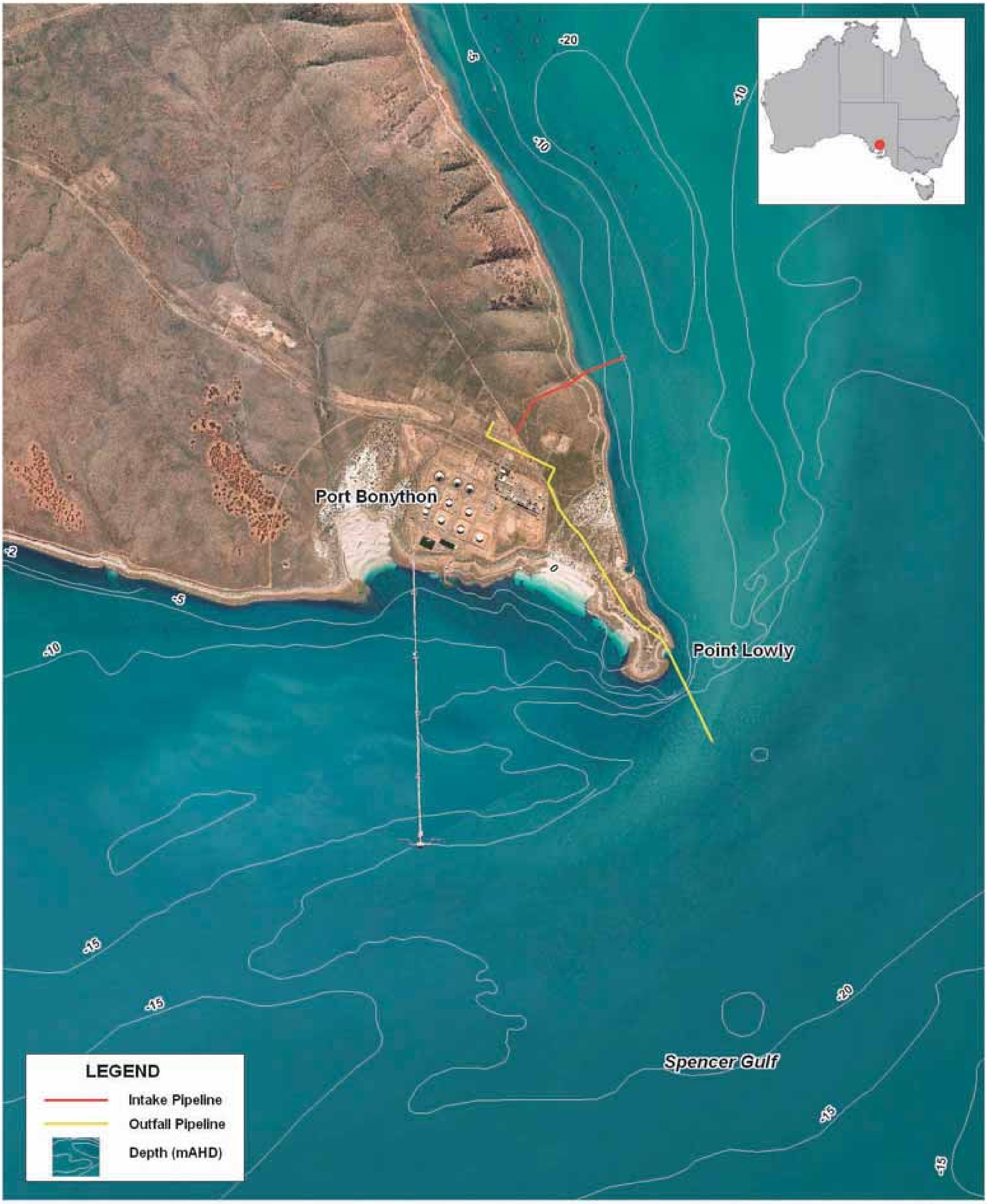
The key assumptions made to develop silt plume model prediction scenarios have been:

- Total volume of material excavated;
- Material composition and in particular the percentage fines;
- Proportion of excavated material that is entrained into a suspended sediment plume.

The estimates regarding these key assumptions have tended to be on the conservative (high) side with respect to plume generation.

Based on the initial steel probing (Table 2-3) it is likely that rock will be encountered along the inshore part of the outfall pipeline and this would significantly reduce the volume of material that would be excavated for the pipeline here. Likewise the composition of nearshore sediment at the outfall site is likely to have much lower fines content than the values adopted for modelling purposes.

The plume impacts predicted by the model will be approximately proportional to the rate of fine sediment entrainment that is assumed. That is, a 50% reduction in entrained silt and clay would result in an approximate 50% reduction in predicted plume concentrations.



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Preferred Intake and Outfall Pipeline Alignments

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5 SEDIMENT PLUME MODEL

The sediment plume numerical simulations have been undertaken using a coupled ELCOM-CAEDYM model. ELCOM (Estuary, Lake and Coastal Ocean Model) is a 3-dimensional hydrodynamic model developed by the Centre for Water Research (CWR), University of Western Australia (Hodges et al., 2000). This model has been previously used for the brine dispersion component of the Olympic Dam EIS (BMT WBM, 2007). CAEDYM (Computational Aquatic Ecosystem Dynamics Model) is a model also developed by CWR (Hipsey et al., 2007) that, when coupled with a suitable hydrodynamic model, has the capability of simulating the transport of suspended sediments.

5.1 Hydrodynamic Model – ELCOM

As part of the brine dispersion study two ELCOM model domains were established, calibrated and extensively validated, as follows;

- Far-field model of the entire Spencer Gulf with a horizontal grid resolution of 2 km.
- Nested mid-field model of the Spencer Gulf between Whyalla and Port Augusta with a horizontal grid resolution of 200 m.

For the current study the nested mid-field model has been further refined using a plaided grid with resolution of 100 m in the vicinity of the study area at Port Bonython. The layout of the 2 nested ELCOM model domains used in the sediment plume assessment is shown in Figure 5-1. The plaided mid-field model grid is shown in Figure 5-2. As such, the model resolves the processes occurring over a spatial scale of 100+ metres, but not near-field processes at distances less than 50-100m.

Earlier studies (BMT WBM, 2007; BMT WBM 2008) have validated both the far-field and mid-field ELCOM models against measured tide and current data and further validation of the hydrodynamic model has not been considered necessary as part of the current assessment of sediment plume impacts.

5.2 Suspended Sediment Model – CAEDYM

CAEDYM is a broadly functional aquatic ecology model which, when coupled to a suitable hydrodynamic model, is capable of simulating the re-suspension, deposition and vertical mixing of suspended sediments.

Four sediment fractions comprising 70% (by mass) of the in-situ bed material have been simulated using CAEDYM (refer Section 4.3.1). CAEDYM requires the specification of sediment density, sediment diameter and critical shear stress for erosion/deposition for each simulated sediment fraction. The parameters used in the CAEDYM simulations are given in Table 5-1. The settling velocity of each sediment fraction is calculated using a Stokes law drag relationship.

Table 5-1 CAEDYM model sediment parameters

Sediment Fraction	Diameter (mm)
1 (Clay)	0.001
2 (Silt)	0.030
3 (Fine Sand)	0.11
4 (Medium Sand)	0.22

The CAEDYM model used in this assessment simulates the plume suspended sediment in isolation from the naturally occurring suspended sediment. That is, the simulated results represent the increase above background levels due to the re-suspension of sediment generated by the pipeline construction activities. Measured background levels of turbidity and TSS are discussed in Section 3.

The principal CAEDYM outputs related to suspended sediment are;

- TSS levels (mg/L) in each ELCOM computational cell;
- Mass of sediment deposited (g/m^2) on the bed at each ELCOM grid point.

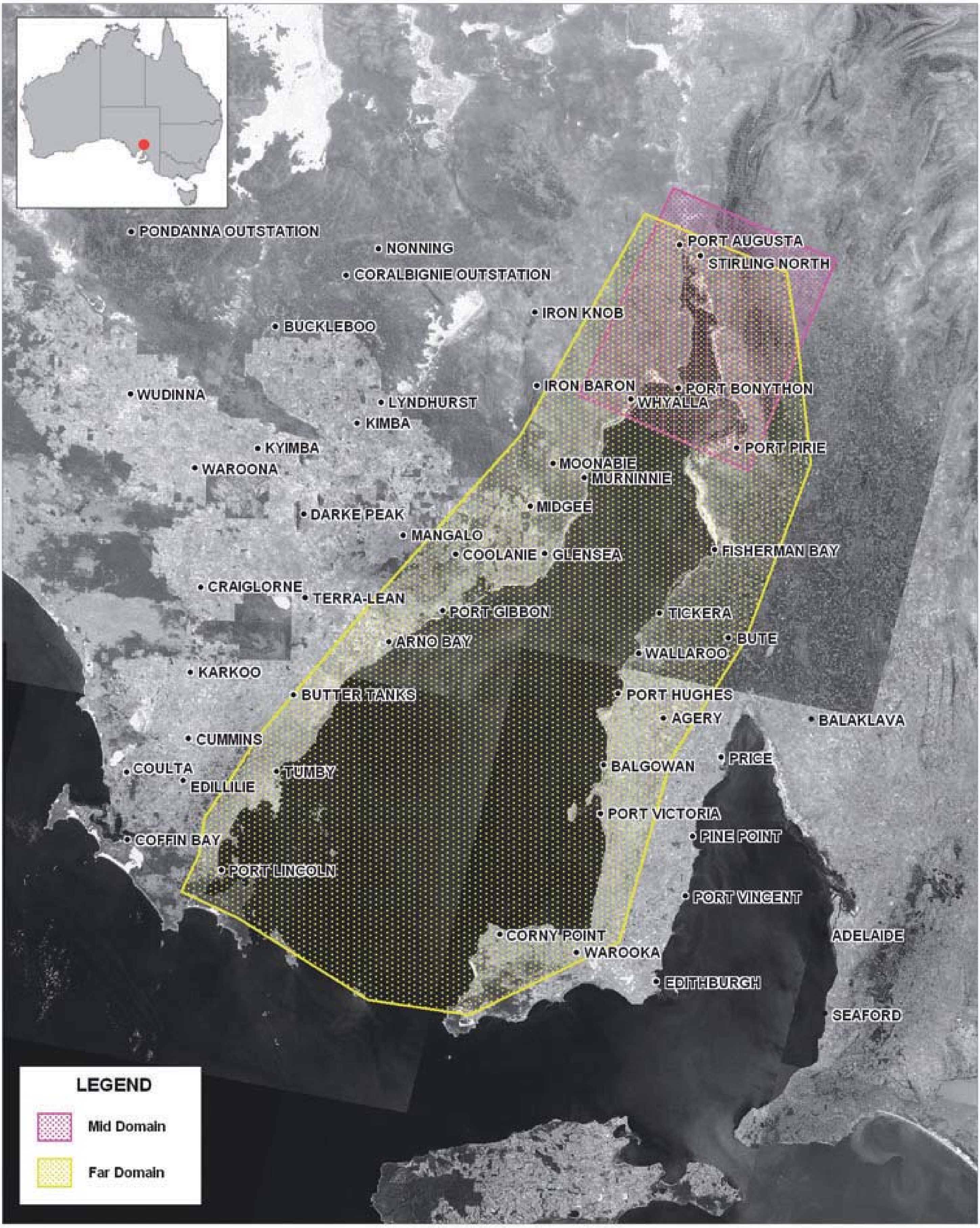
5.3 Scenarios

As discussed in Section 4, a 14 day construction cycle is expected to involve trenching for 5 days during the spring tide period, followed by 3 days of trench cleanout, and subsequently laying of the pipeline during the dodge tides. This sequence is expected to achieve a pipeline construction rate of 100 m per 14 day period.

The computational expense of the ELCOM/CAEDYM simulations limits a viable model run to the simulation of a 14 day construction sequence. Four such 14 day construction periods have been simulated as summarised in Table 5-2. All construction scenarios have been modelled for a 14 day period corresponding to 1st-15th January 2008, which represents a fairly typical spring-neap cycle for Port Bonython. During this simulation period, trenching (and backfilling) occurs from the 7th January through to the end of the 11th January (between 07:00 and 22:00 each day), and during this trenching period, ebb tides with a vertical excursion of around 2.5m occur during the morning and flood tides with a vertical excursion of around 1.8m occur during the afternoon/evening as shown in Figure 5-3.

Table 5-2 ELCOM/CAEDYM simulation details.

Scenario ID	Construction Sequence
A	Outfall pipeline – inshore construction
B	Intake pipeline – inshore construction
C	Outfall pipeline – offshore construction
D	Intake pipeline – offshore construction



Title:

Nested ELCOM Model Domains

Figure:
5-1

Rev:
A

N
0 50 100km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_036_081023_Nested_Model_Domains.WOR

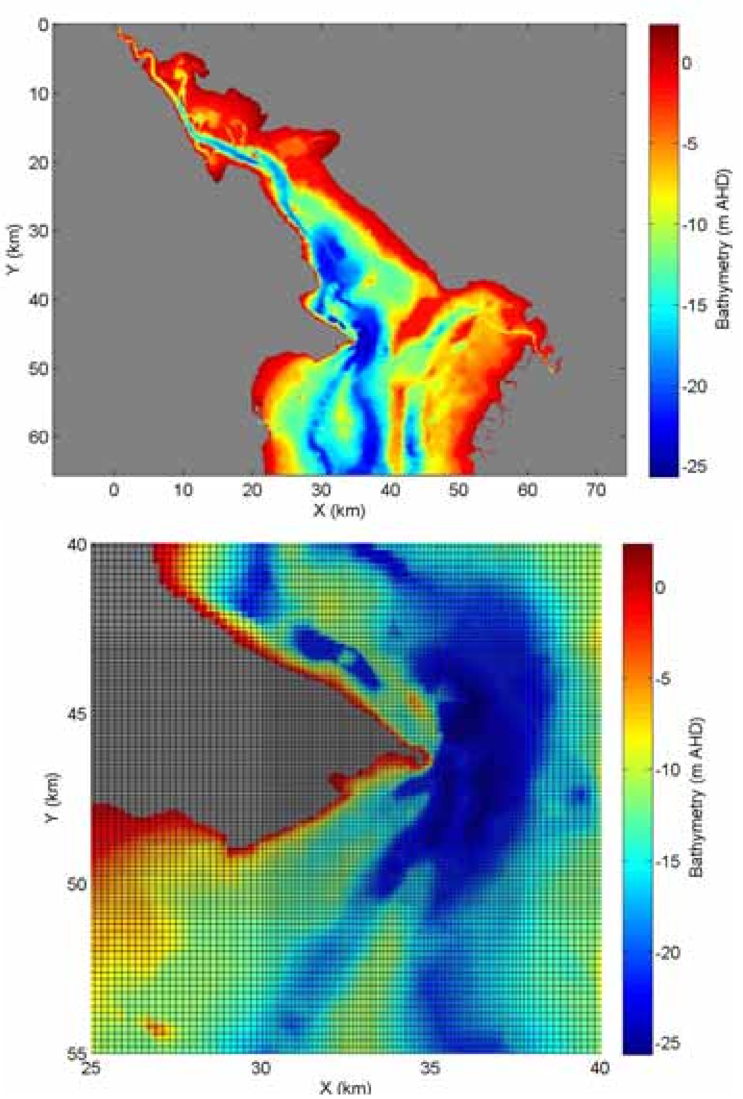


Figure 5-2 Plaided Mid-field ELCOM Model.
a) Entire Domain
b) Zoom of Point Lowly

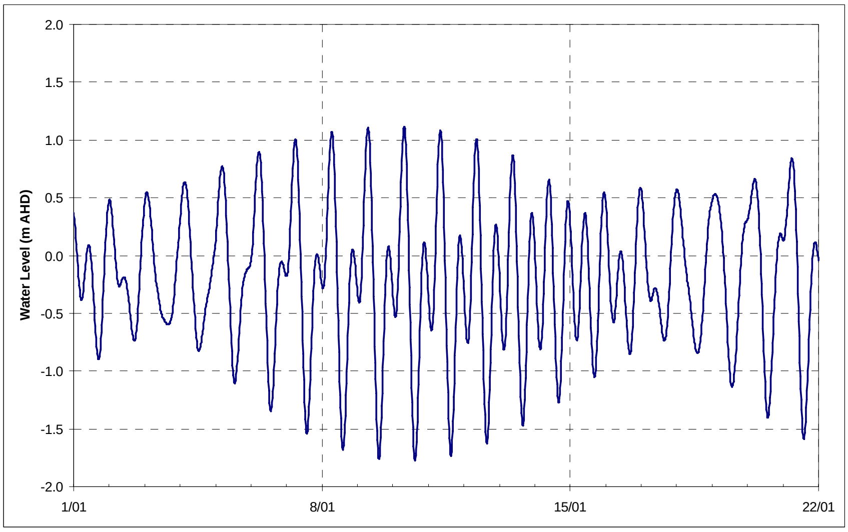
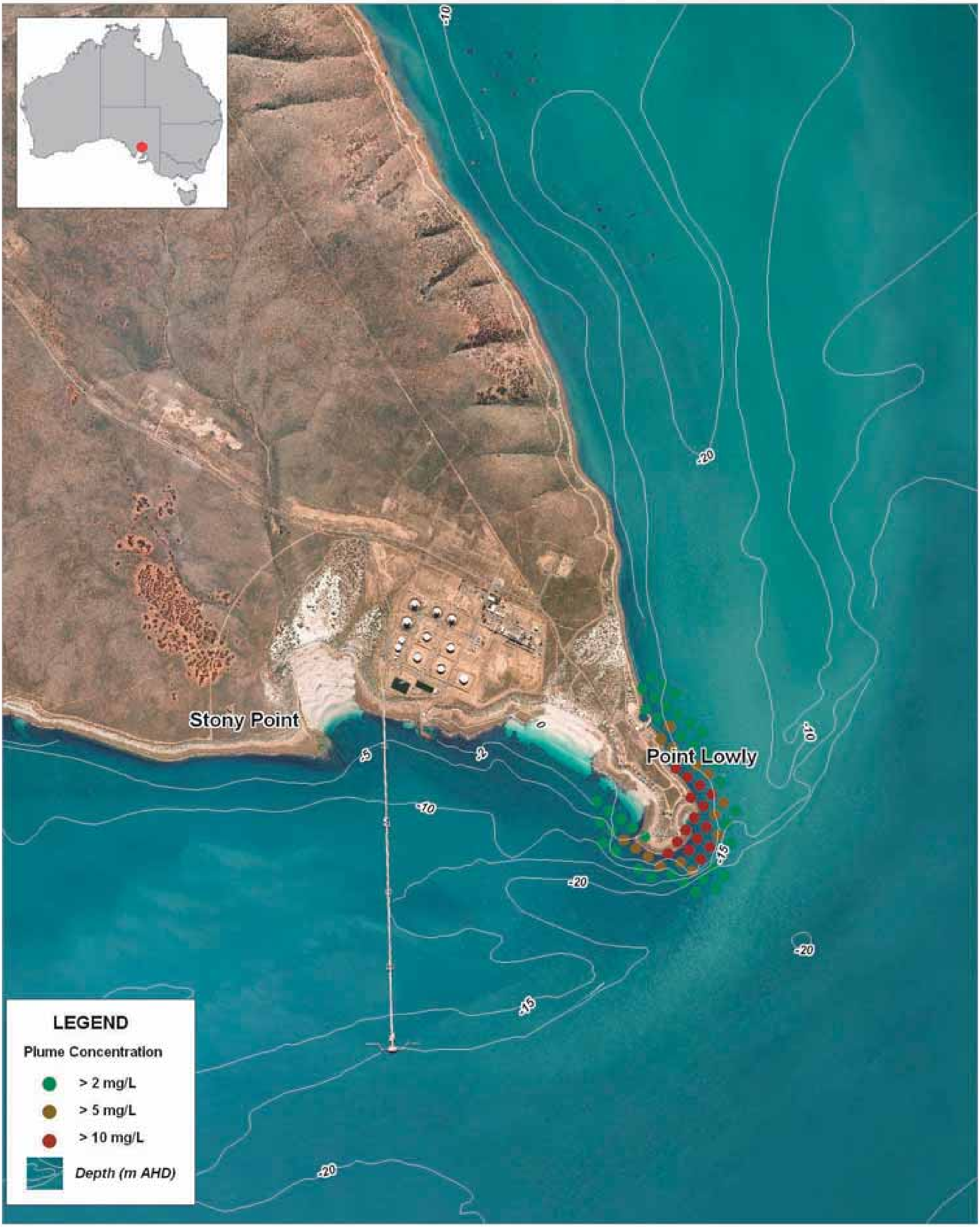


Figure 5-3 Predicted Tide at Port Bonython During Simulation Period.

6 SEDIMENT PLUME AND DEPOSITION RESULTS

For each scenario simulated the following output has been generated to illustrate the construction plume impacts:

- Spatial distributions of depth-averaged TSS levels cumulatively exceeded for more than 1, 4 and 24 hour periods during the 14 day construction period;
- Spatial distribution of sediment deposition depths accumulating from sediment entrained during the 14 day construction period;
- Timeseries of depth-averaged TSS levels at specified receptor locations. The timeseries model outputs are provided in Appendix A.



Title:

Construction Scenario A : Plume Concentration Exceeded for 1 or More Hours per fortnight (0.3 Percentile)

Figure: 6-1

Rev: A

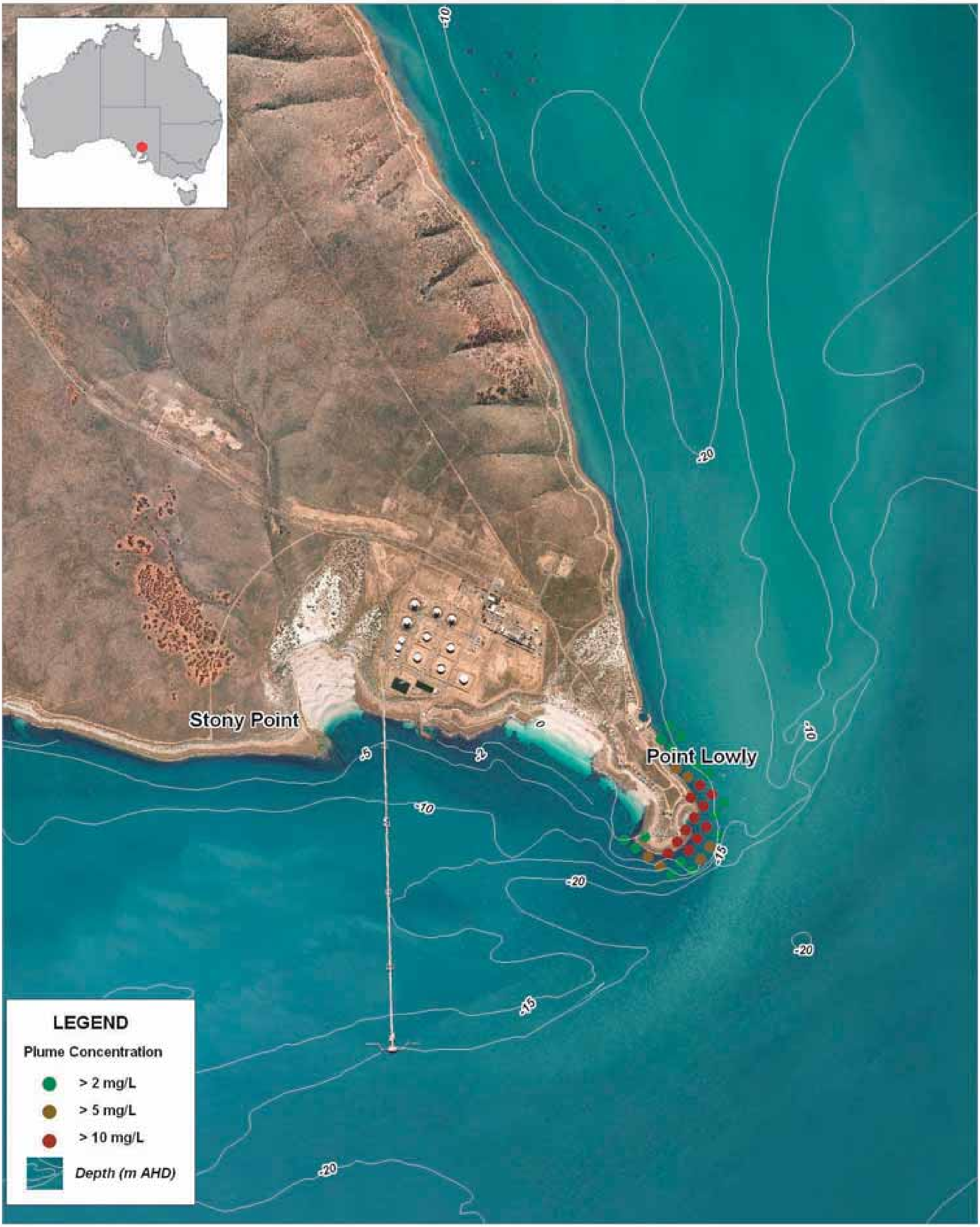
N 0 1 2km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_028_081015 Plume Construction SC A.wor



Title:

Construction Scenario A : Plume Concentration Exceeded for 4 or More Hours per fortnight (1.2 Percentile)

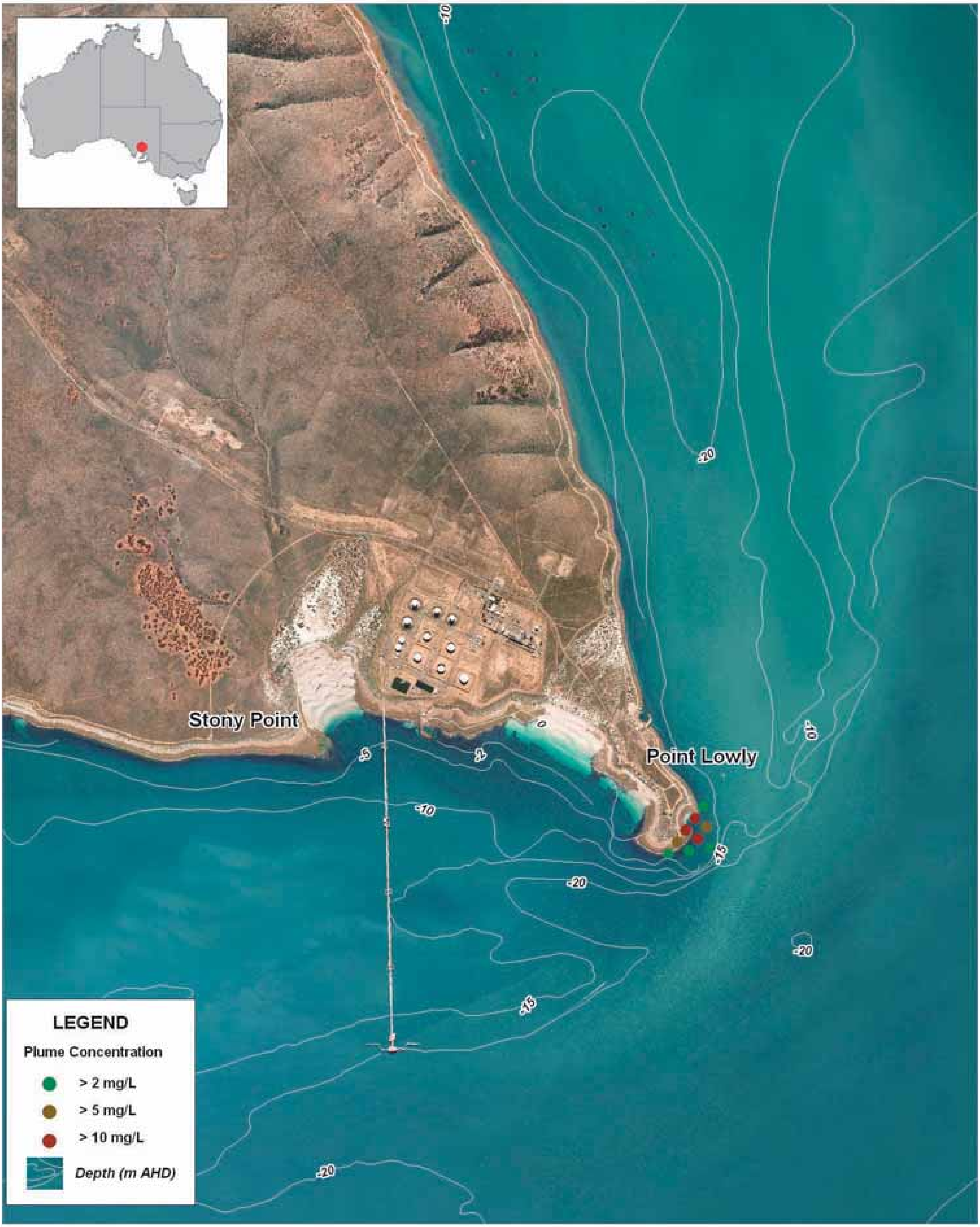
Figure: 6-2

Rev: A

N
0 1 2km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_028_081015 Plume Construction SC A.wor



Title:

Construction Scenario A : Plume Concentration Exceeded for 24 or More Hours per fortnight (7.1 Percentile)

Figure: 6-3

Rev: A

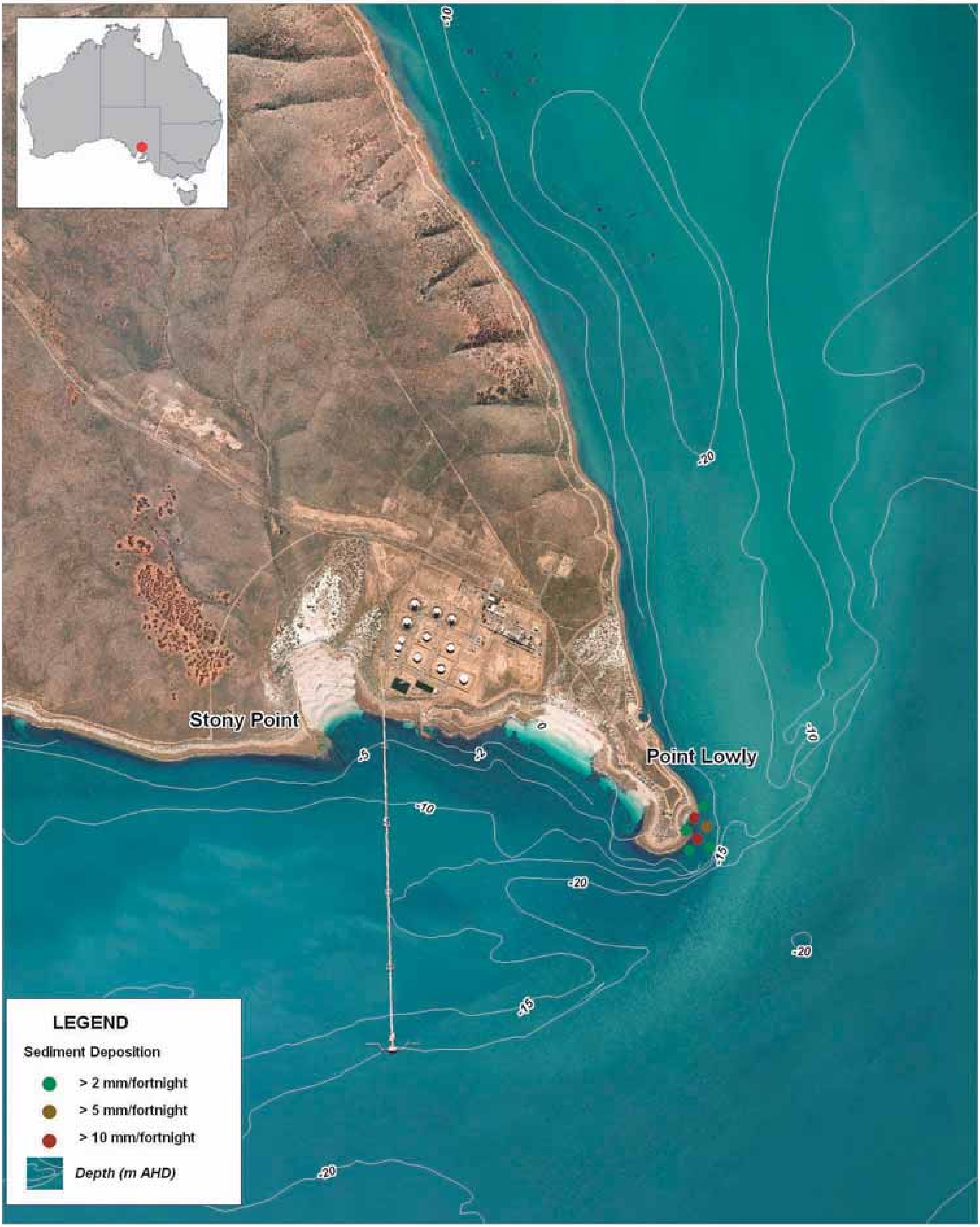
N 0 1 2km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_028_081015 Plume Construction SC A.wor



Title:

Construction Scenario A : Sediment Deposition per fortnight

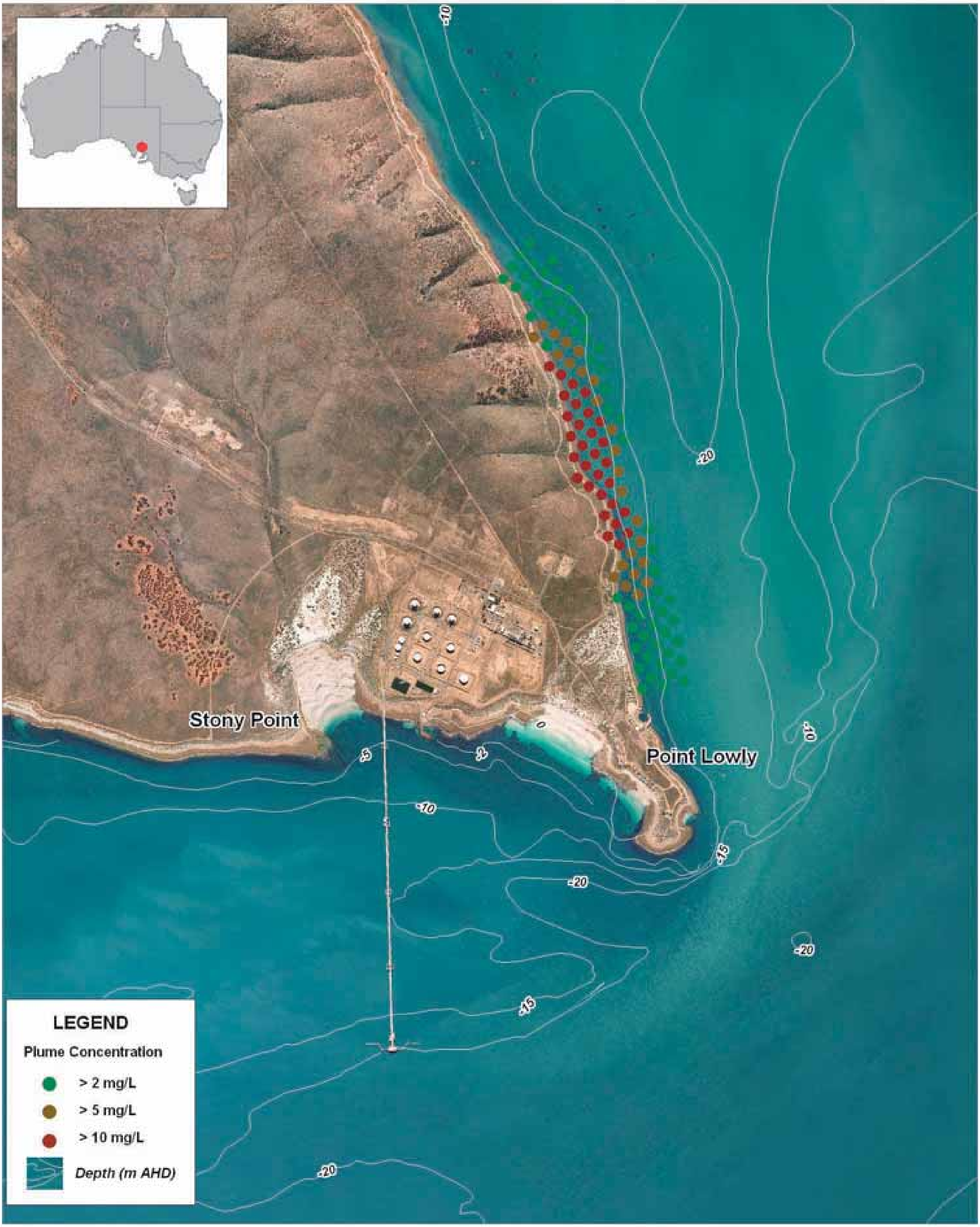
Figure: 6-4

Rev: A

N 0 1 2km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_028_081015 Plume Construction SC A.wor



Title:

Construction Scenario B : Plume Concentration Exceeded for 1 or More Hours per fortnight (0.3 Percentile)

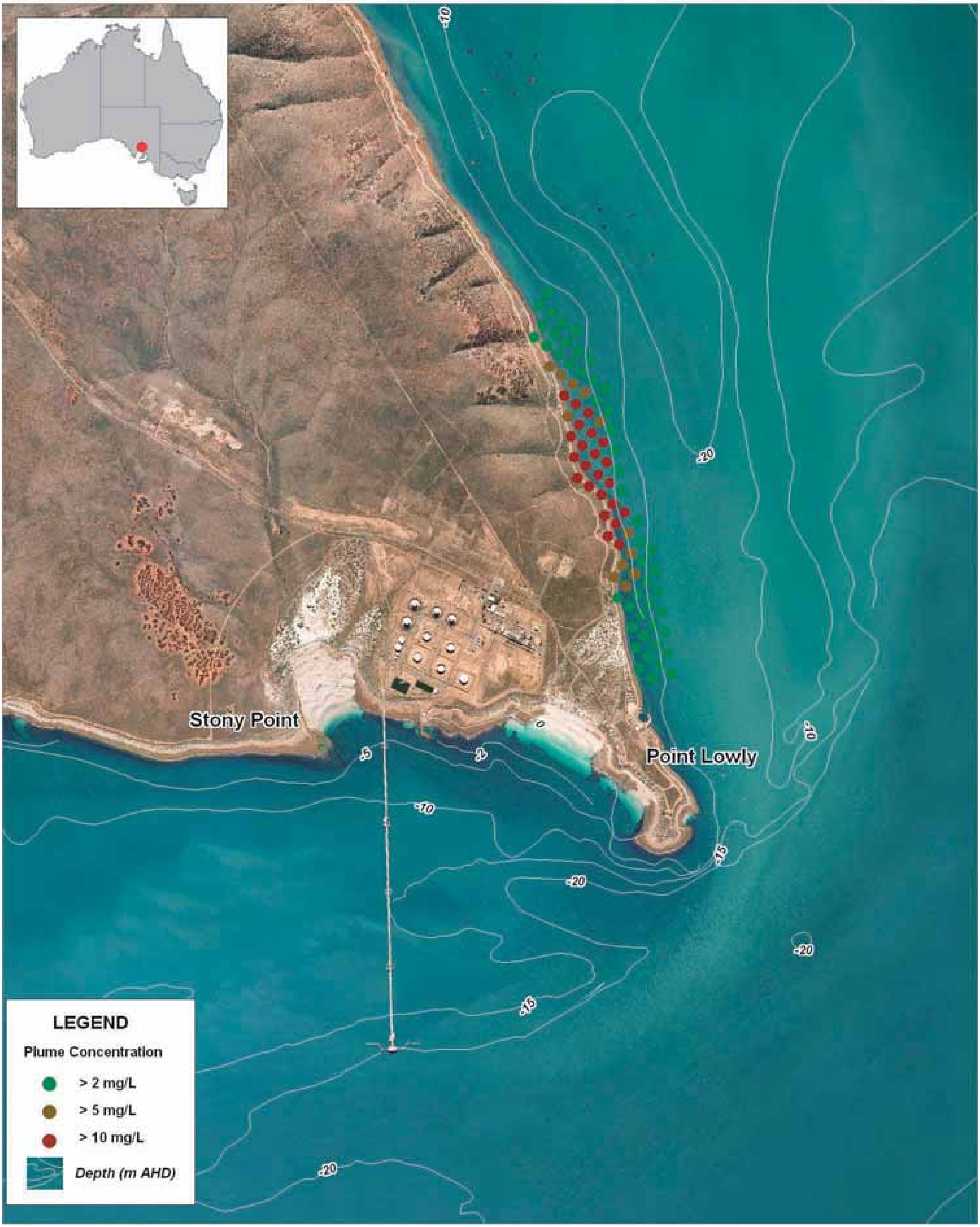
Figure:
6-5

Rev:
A

N
0 1 2km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_025_081015 Plume Construction SC B.wor



Title:

Construction Scenario B : Plume Concentration Exceeded for 4 or More Hours per fortnight (1.2 Percentile)

Figure: 6-6

Rev: A

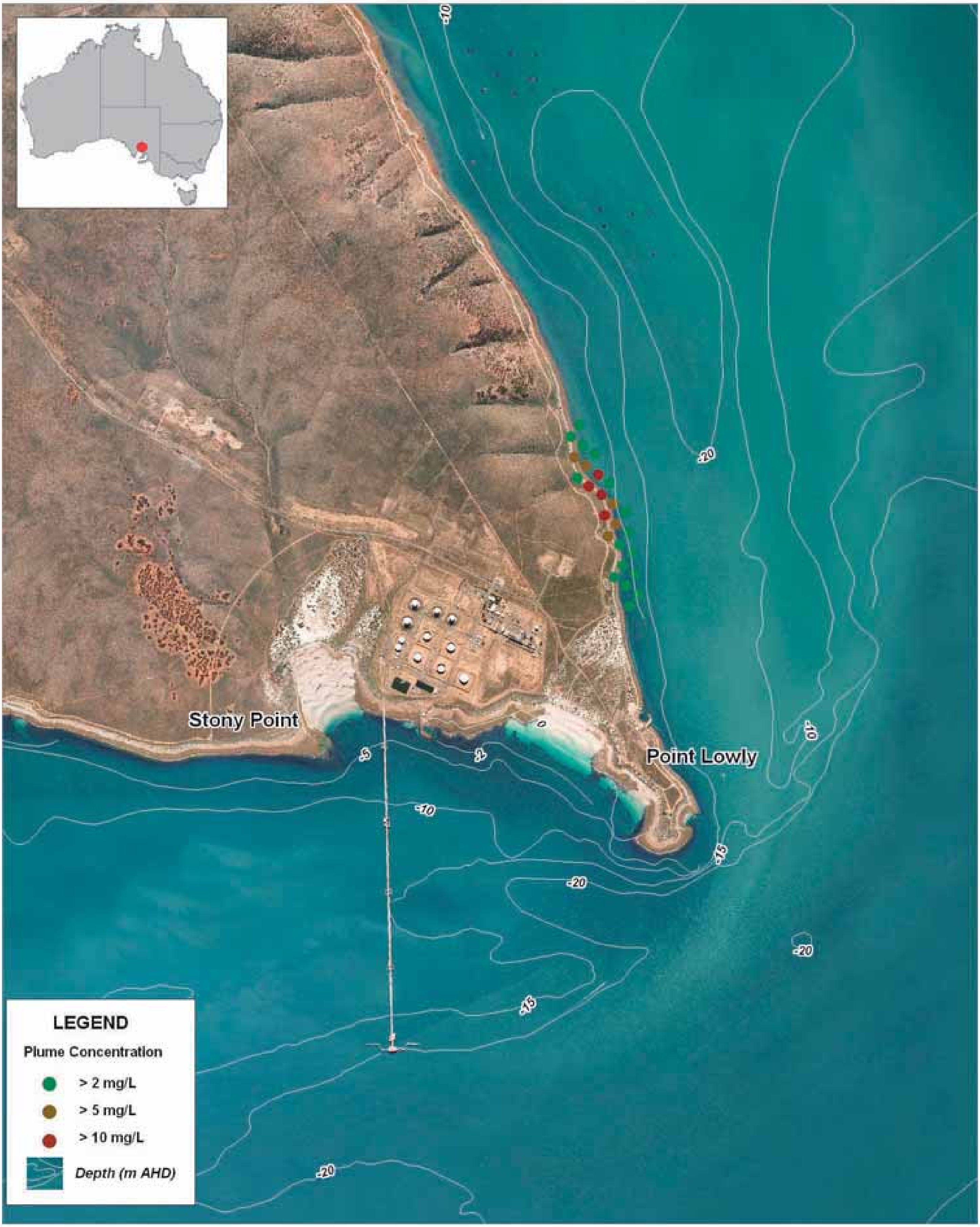
N 0 1 2km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_025_081015 Plume Construction SC B.wor



Title:

Construction Scenario B : Plume Concentration Exceeded for 24 or More Hours per fortnight (7.1 Percentile)

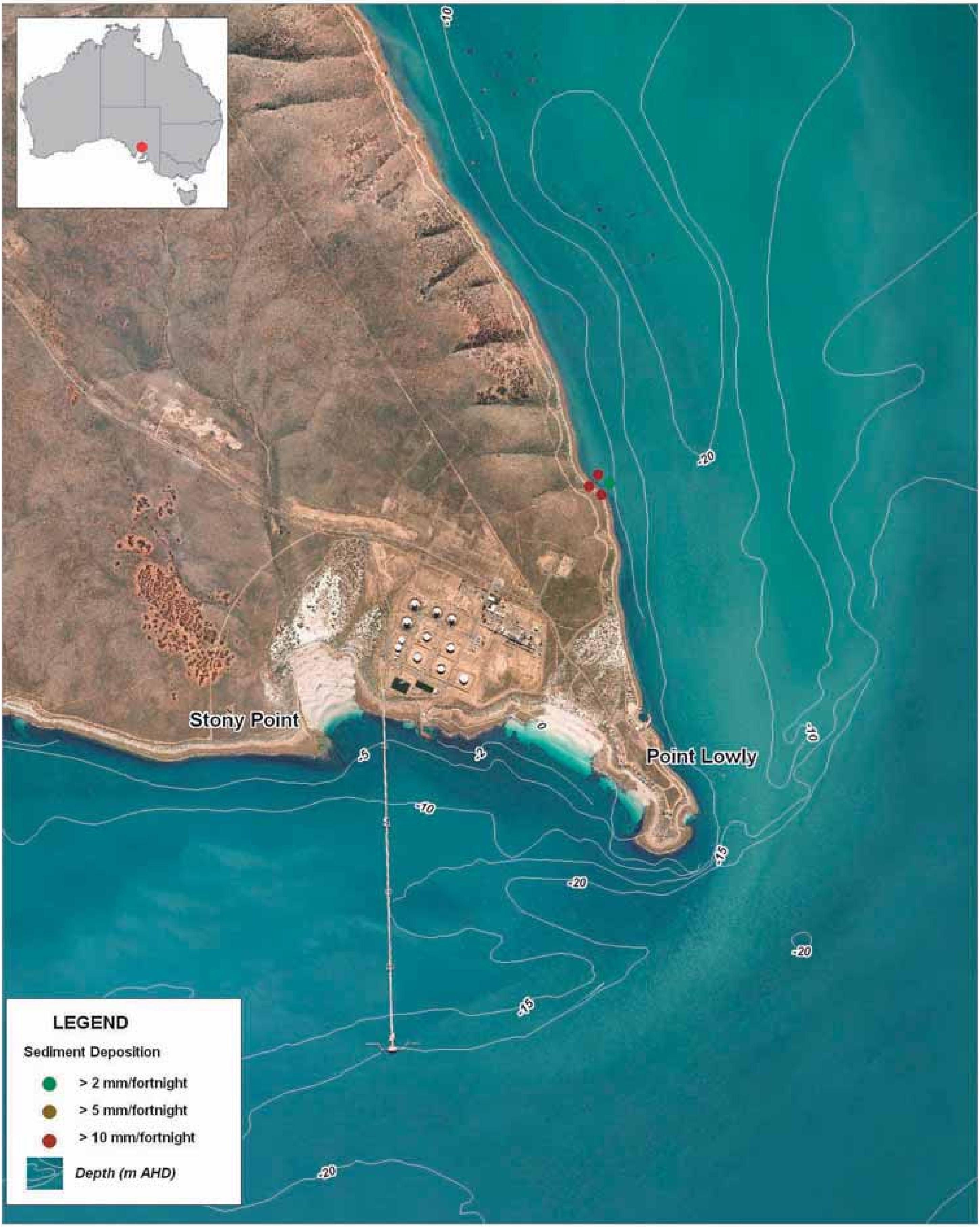
Figure: 6-7

Rev: A

N 0 1 2km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_025_081015 Plume Construction SC B.wor



Title:

Construction Scenario B : Sediment Deposition per fortnight

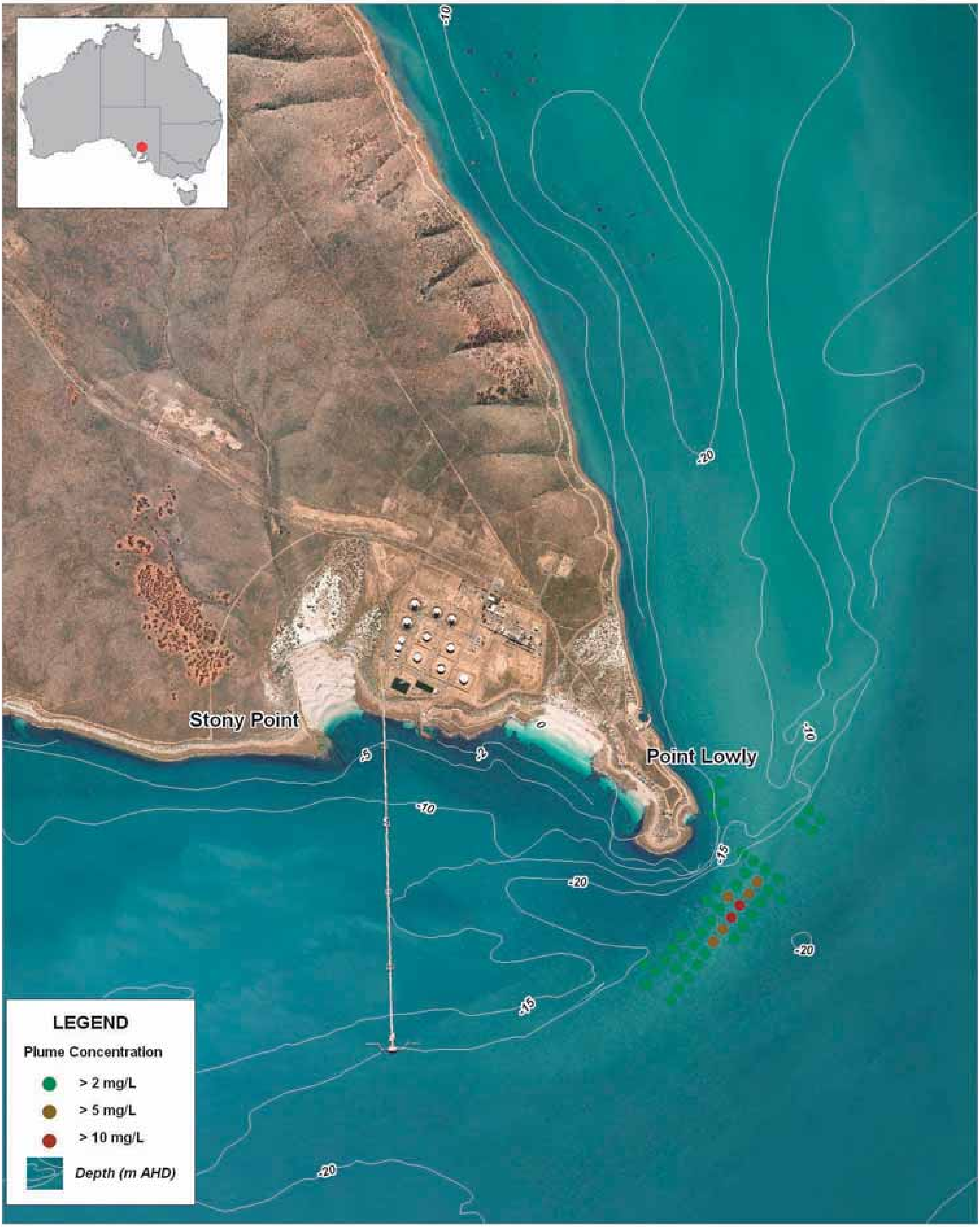
Figure:
6-8

Rev:
A

N
0 1 2km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_025_081015 Plume Construction SC B.wor



Title:

Construction Scenario C : Plume Concentration Exceeded for 1 or More Hours per fortnight (0.3 Percentile)

Figure:

6-9

Rev:

A

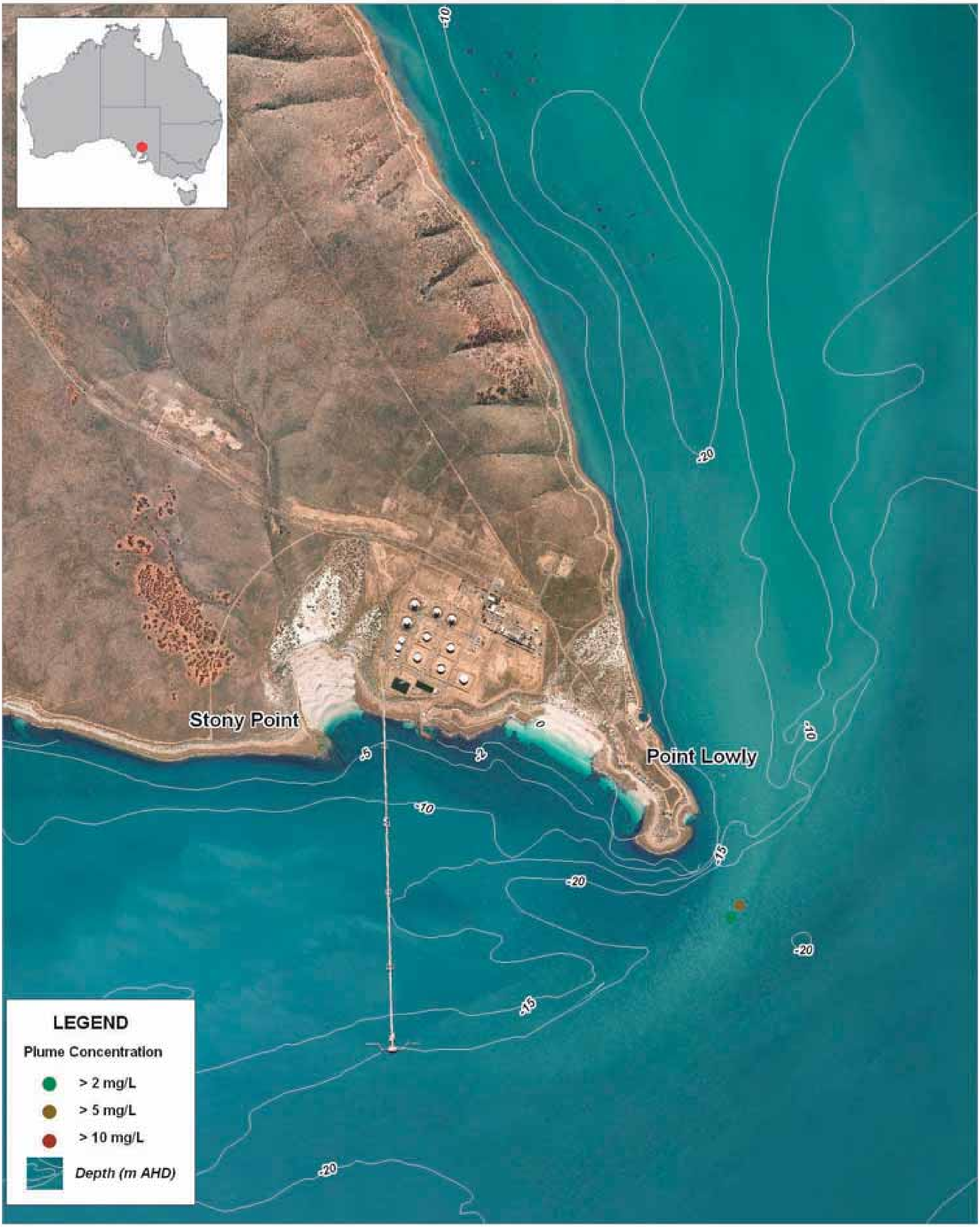
N 0 1 2km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_031_081015 Plume Construction SC C.wor



Title:

Construction Scenario C : Plume Concentration Exceeded for 4 or More Hours per fortnight (1.2 Percentile)

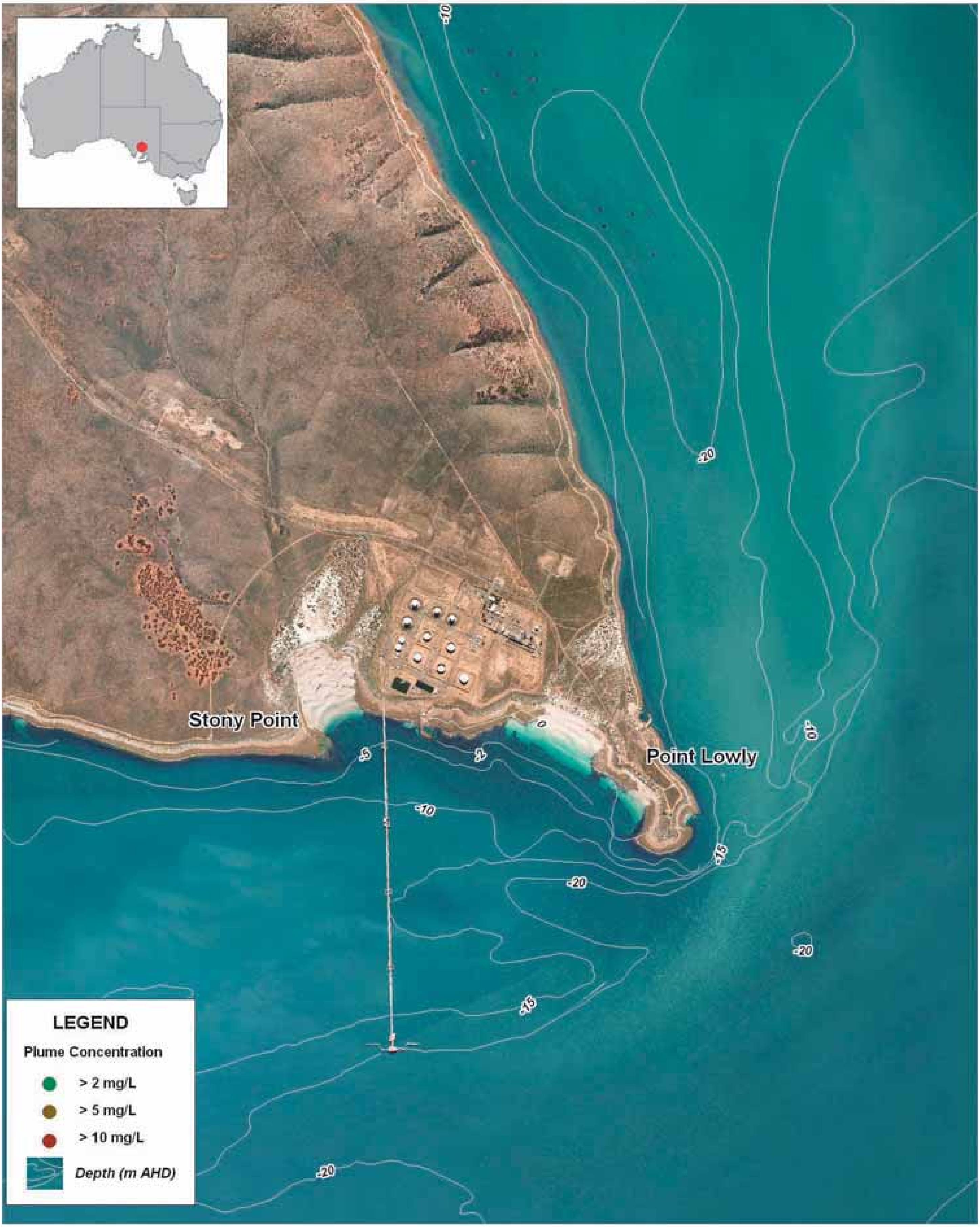
Figure:
6-10

Rev:
A

N 0 1 2km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_031_081015 Plume Construction SC C.wor



Title:

Construction Scenario C : Plume Concentration Exceeded for 24 or More Hours per fortnight (7.1 Percentile)

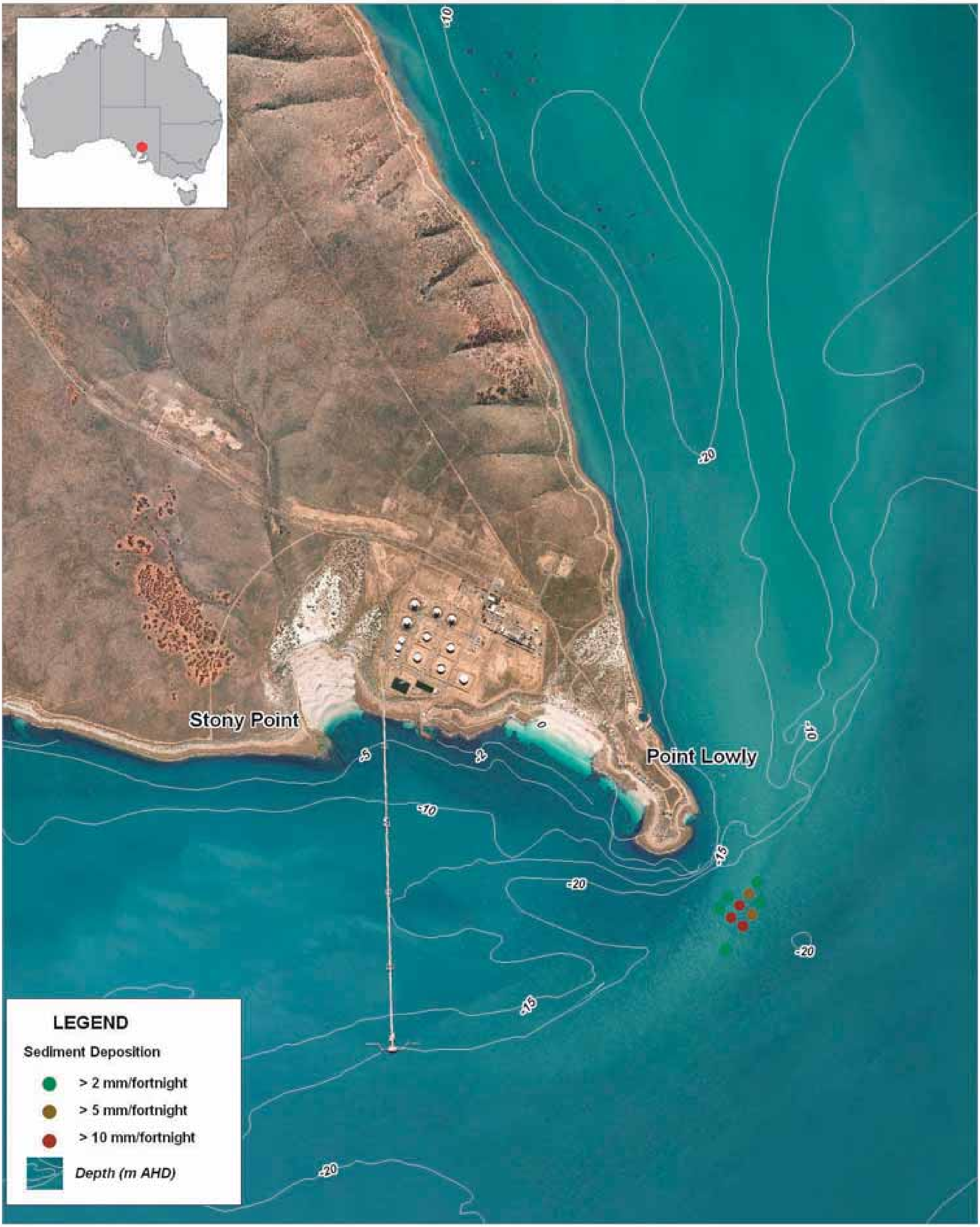
Figure:
6-11

Rev:
A

N 0 1 2km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_031_081015 Plume Construction SC C.wor



Title:

Construction Scenario C : Sediment Deposition per fortnight

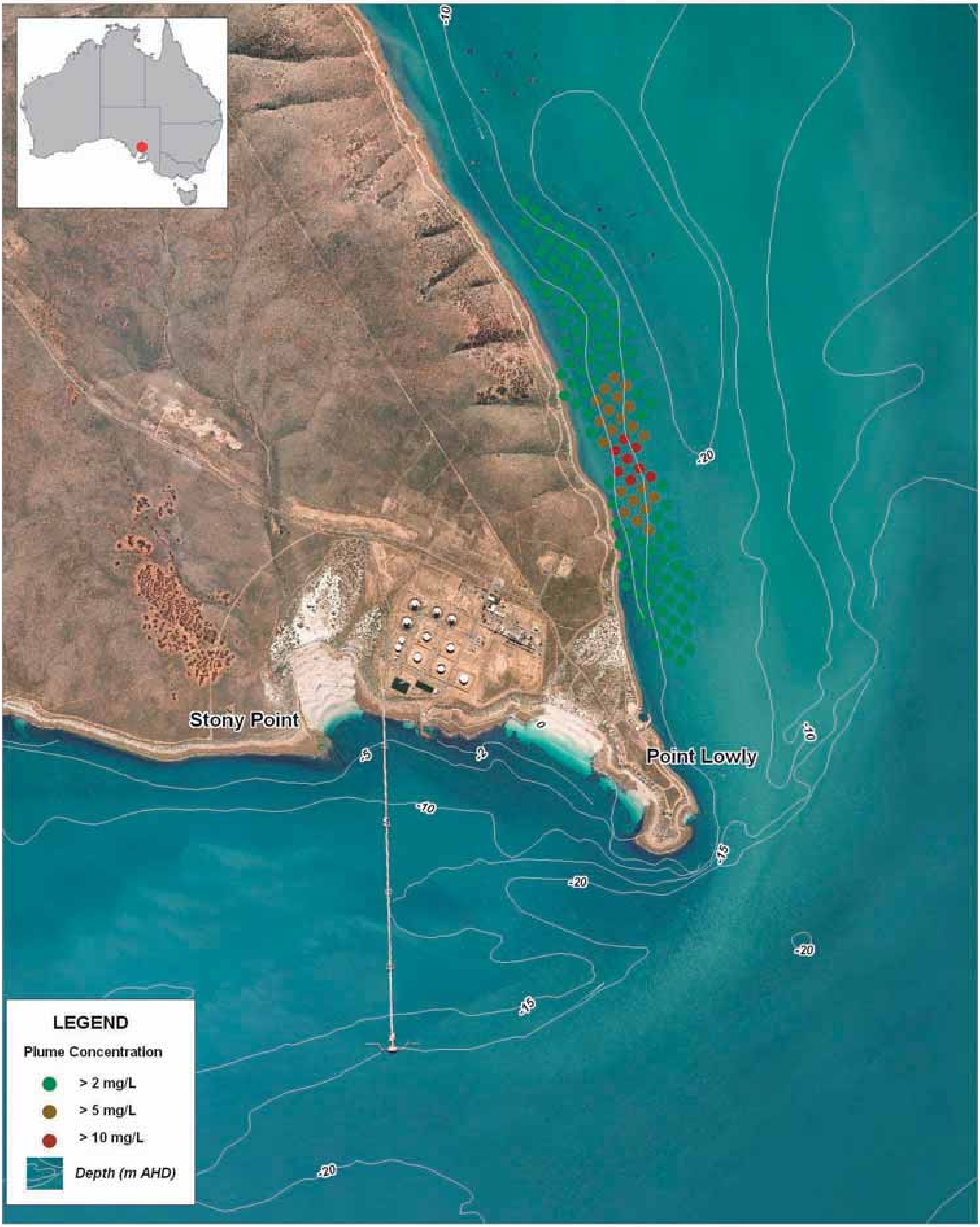
Figure: 6-12

Rev: A

N 0 1 2km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_031_081015 Plume Construction SC C.wor



Title:

Construction Scenario D : Plume Concentration Exceeded for 1 or More Hours per fortnight (0.3 Percentile)

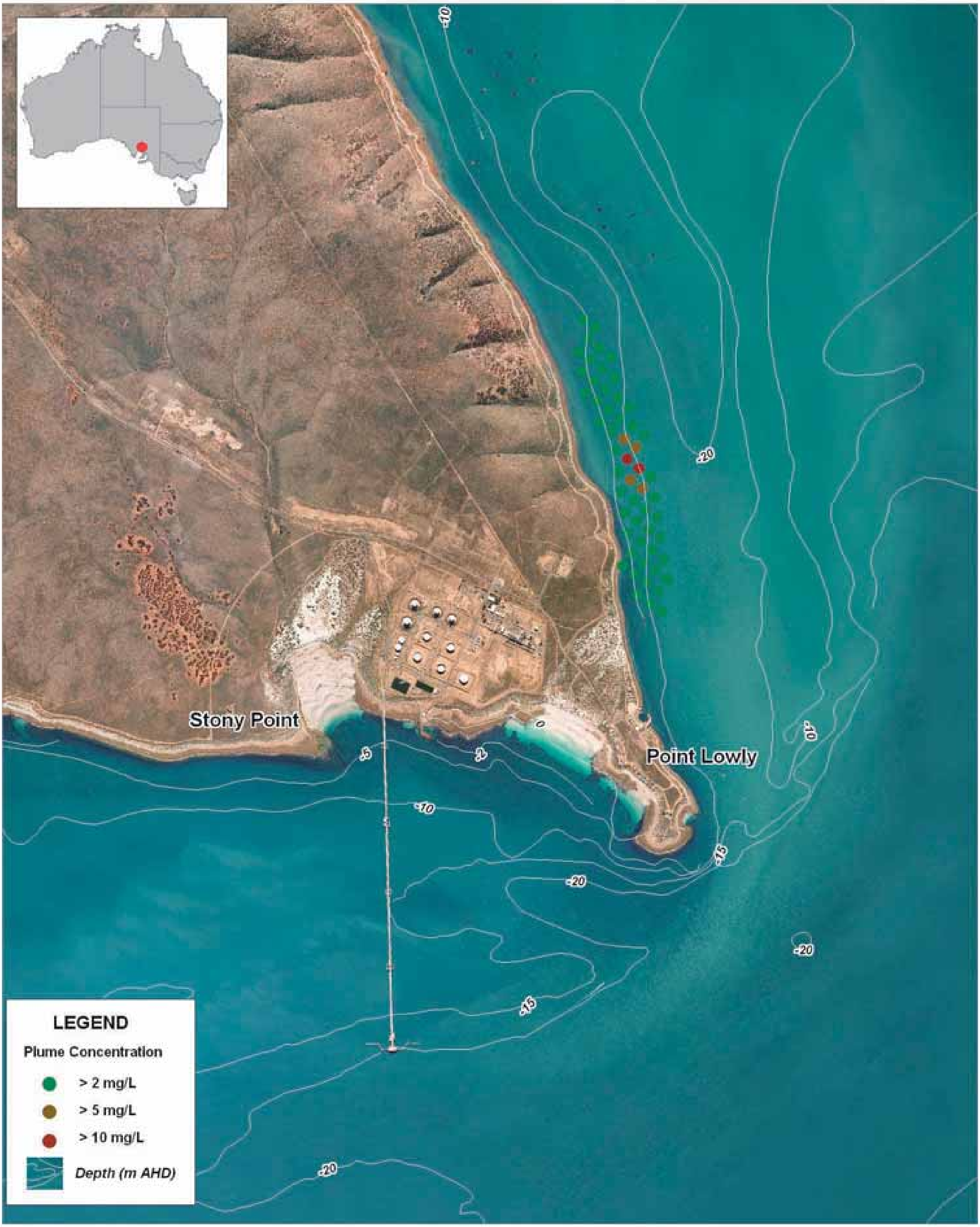
Figure:
6-13

Rev:
A

N
0 1 2km
Approx. Scale

BMT WBM
www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_034_081015 Plume Construction SC D.wor



Title:

Construction Scenario D : Plume Concentration Exceeded for 4 or More Hours per fortnight (1.2 Percentile)

Figure: 6-14

Rev: A

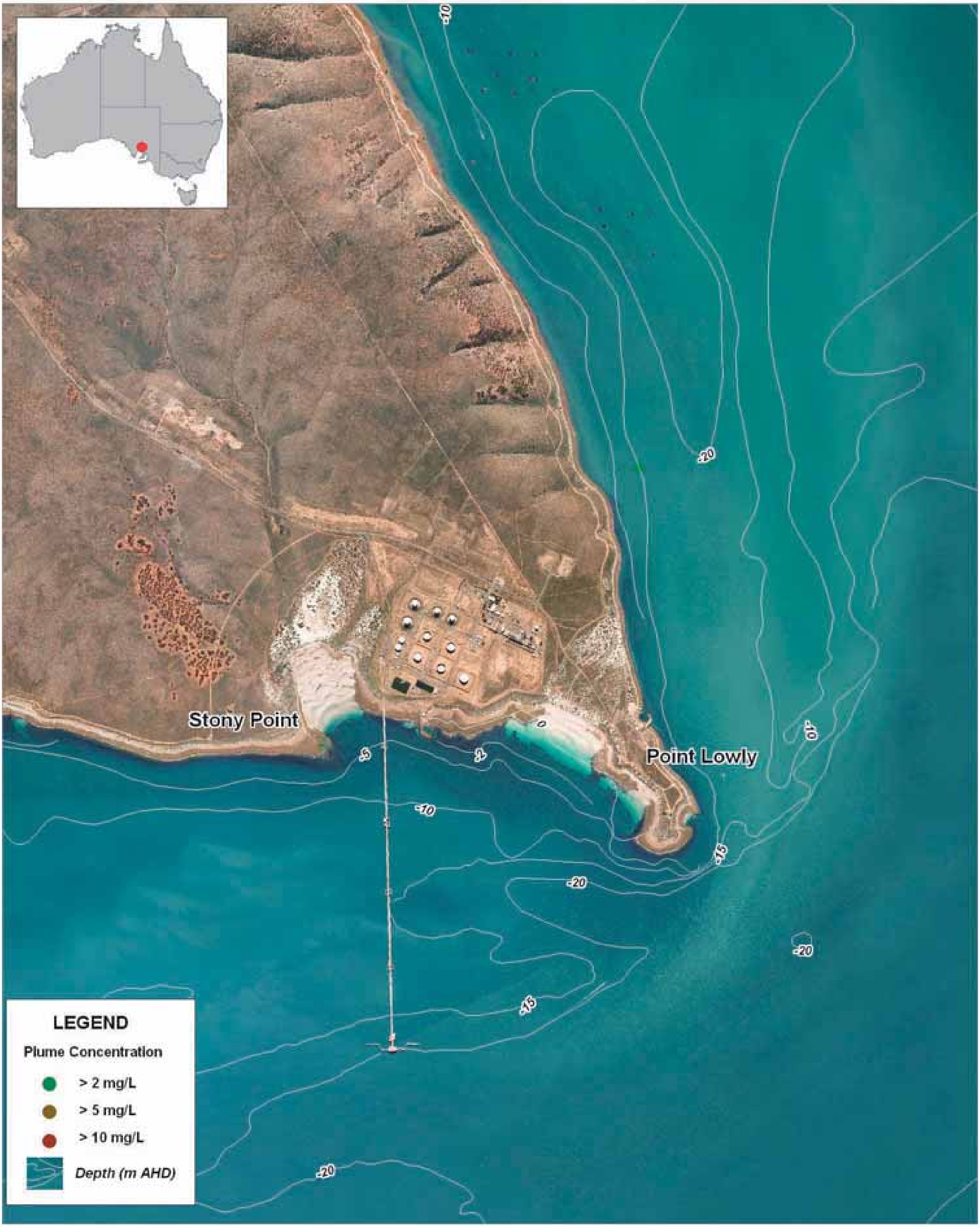
N 0 1 2km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_034_081015 Plume Construction SC D.wor



Title:

Construction Scenario D : Plume Concentration Exceeded for 24 or More Hours per fortnight (7.1 Percentile)

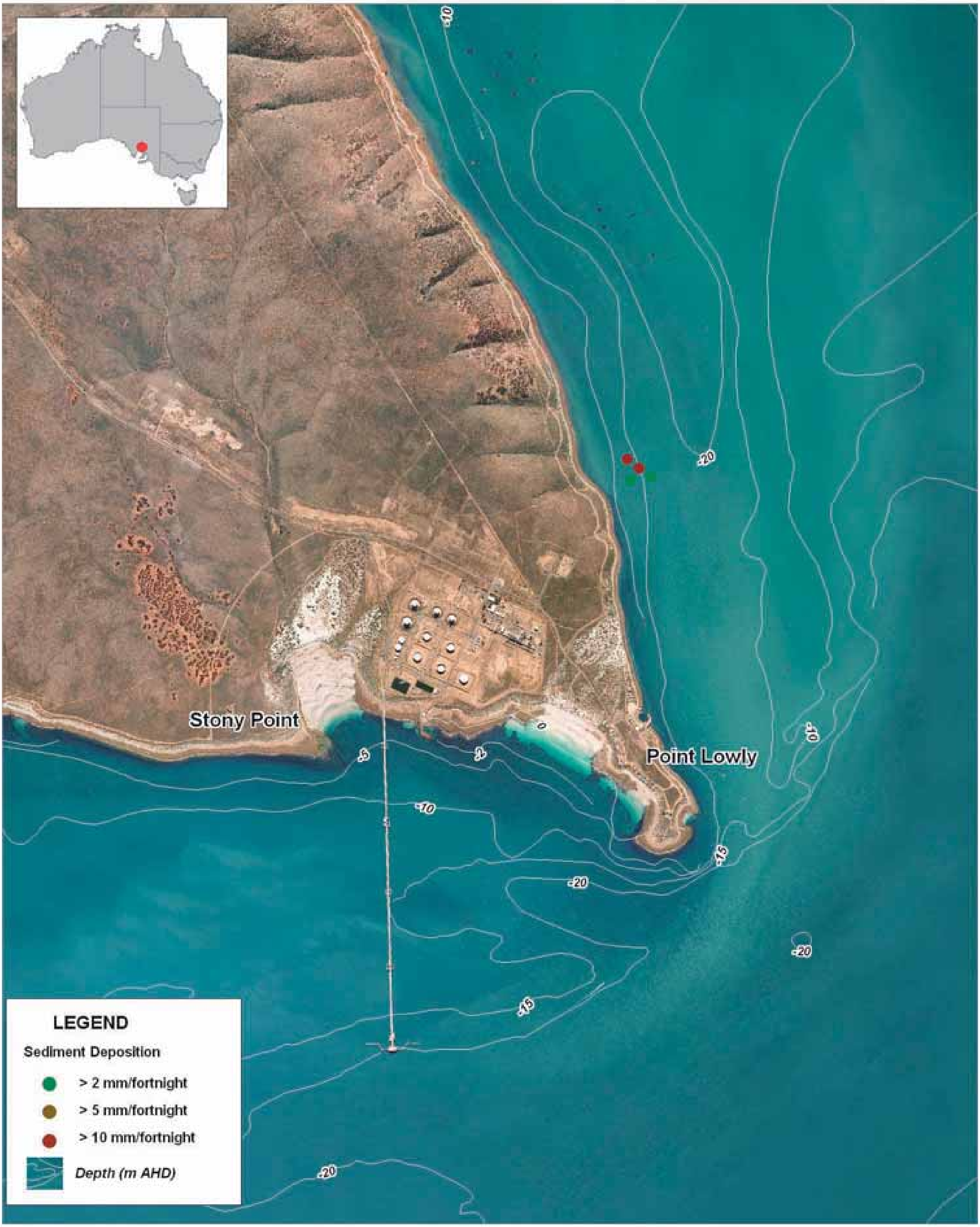
Figure: 6-15

Rev: A

N 0 1 2km
Approx. Scale

www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_034_081015 Plume Construction SC D.wor



Title:

Construction Scenario D : Sediment Deposition per fortnight

Figure: 6-16

Rev: A

N 0 1 2km

Approx. Scale

BMT WBM

www.wbmpl.com.au

Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_034_081015 Plume Construction SC D.wor

7 DISCUSSION AND CONCLUSIONS

ELCOM/CAEDYM modelling has been undertaken as part of the Olympic Dam EIS in order to simulate the sediment plumes that may potentially be generated by marine pipeline construction activities at Point Lowly.

Background turbidity levels have been measured in the range 2-12 NTU during conditions without significant wave action. Turbidity levels up to approximately 20 NTU have been observed to regularly occur during southerly wind events where waves re-suspend sediment from the nearshore zone.

Background TSS levels of up to 4 mg/L have been measured during calm weather (23rd–24th July 2008) at times when turbidities were measured up to about 6 NTU. It is probable that significantly higher TSS levels would be generated at the study site during southerly wind/wave events. Insufficient data exists to correlate turbidity (NTU) and TSS (mg/L) levels for the study area. However, previous investigations undertaken by BMT WBM where sufficient data has been available to perform a robust correlation analysis indicate that a roughly 1:1 relationship often exists, particularly for higher TSS/turbidity levels (e.g. BMT WBM, 2007b), consistent with the above site measurements.

A TSS level above background of 2 mg/L has been adopted as an appropriate threshold for delineating the maximum significant plume extent. It should be noted that plumes can remain visible to the human eye even when their measurement above background turbidity or TSS levels is no longer possible with standard instruments or laboratory testing procedures. However, a visible plume without measurably increased turbidity levels is unlikely to generate ecological impacts as it relates to colour rather than suspended sediment load and does not affect light penetration or cause sediment deposition. The temporal persistence of elevated TSS/turbidity levels is another important factor that must be considered in estimating the ecological impacts generated by suspended sediment plumes.

These simulations have quantified the spatial extent of plume concentrations (TSS levels above background levels) that may be exceeded cumulatively for 1, 4 and 24 hour durations during a typical 14 day construction cycle.

The ELCOM/CAEDYM modelling indicates that further than 1 km from the construction activities plume concentrations would be expected to exceed a 2 mg/L threshold for a cumulative period less than 24 hours per fortnight. At distances greater than 2 km from the construction activities the same 2 mg/L threshold would be exceeded cumulatively for less than 1 hour per fortnight.

The plume concentration timeseries provided in Appendix A demonstrate the typically short duration that plume concentrations remain significantly elevated above background levels during each individual plume occurrence at each location. During storm events naturally elevated turbidity/TSS levels of the order twice normal background levels will be generated by wave re-suspension and may persist for hours to days under the present natural regime. Therefore the natural ecosystem is acclimatised to short periods of elevated turbidity/TSS such as would be experienced due to the construction plumes.

Comparison of the in-shore and off-shore construction scenarios demonstrates that construction of the near-shore pipeline sections will have more potential for generating elevated plume concentrations than the offshore sections due to the greater plume dilution that occurs in deeper water and stronger currents. Measures to limit the amount of sediment entrained during pipeline trenching and backfilling would be more achievable in the shallower, more quiescent near-shore zone than in deeper water. However initial steel probing near shore at the outfall site indicates the likely presence of hard material. Should this be encountered then the generation of potential plumes will be minimised due to a reduction in the amount of material excavated.

The ELCOM/CAEDYM modelling has also simulated the fallout of sediment and associated deposition on the seabed from the construction plumes. This indicates that sediment-plume deposition at detectable rates (>10mm/fortnight) would be restricted to within 200 m of the construction activities. Wave re-suspension was not explicitly modelled in this assessment, however any fine sediment initially deposited in rocky near-shore habitats, would be readily re-suspended and removed by wave and current action.

The medium and fine sand fractions are observed to fall immediately out of suspension at their source (entrainment due to trenching or backfilling activities), the silt fraction tends to largely deposit within several hundred metres of its source, while the clay fraction remains largely suspended in the water column and gradually disperses away from the source. Hence, the far-field plume (>1km from source) is almost exclusively comprised of the clay fraction.

The modelled sediment plume concentrations and deposition rates are sensitive to the assumptions about plume generation. These assumptions were derived and discussed in Section 4.3 and in general are believed to be relatively conservative. The plume impacts predicted by the model will be approximately proportional to the rate of fine sediment entrainment that is assumed. That is, a 50% reduction in entrained silt and clay would result in an approximate 50% reduction in predicted plume concentrations.

8 REFERENCES

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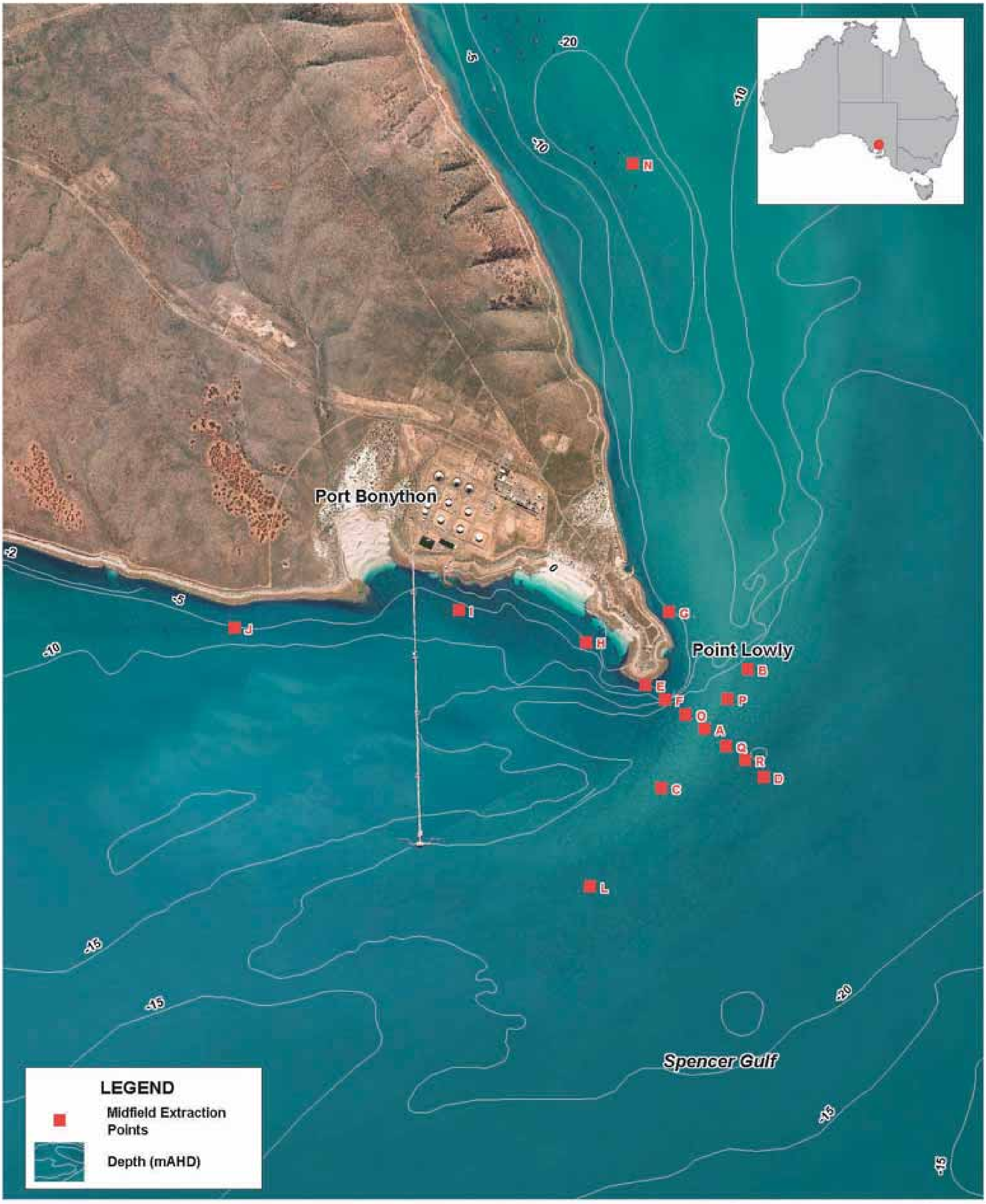
APPENDIX A: TSS TIMESERIES



Title:

Receptor Location Points

Figure:
A-1

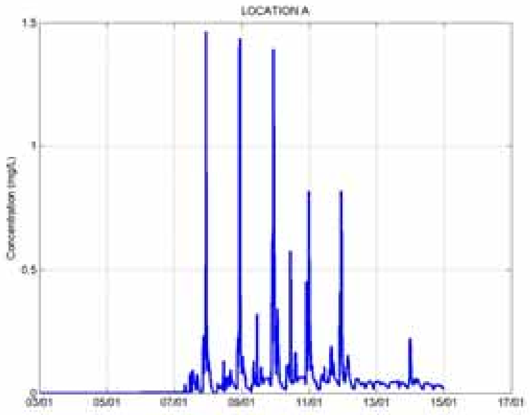
Rev:
A

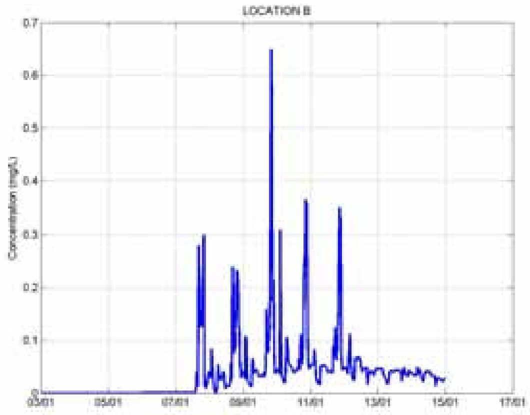
N
0 1 2km
Approx. Scale

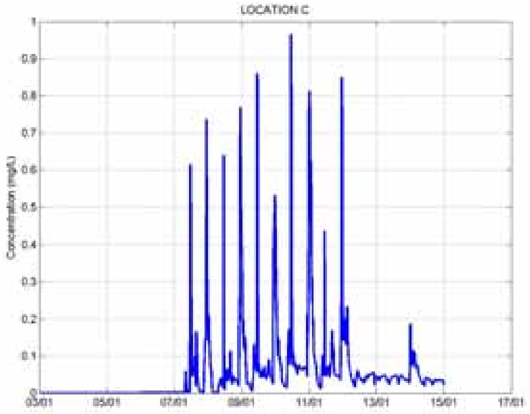
BMT WBM
www.wbmpl.com.au

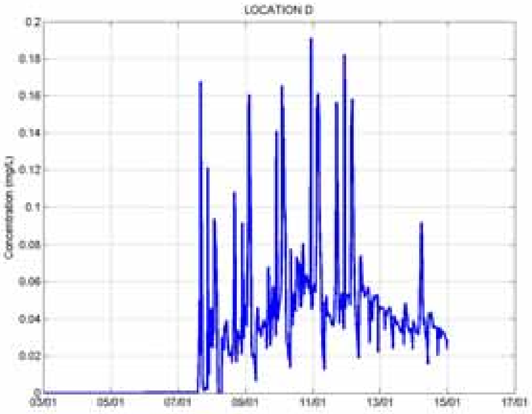
Filepath : I:\B16727_I_IAT Spencer Gulf\DRG\COA_038_081023_Point receptor Locations.wor

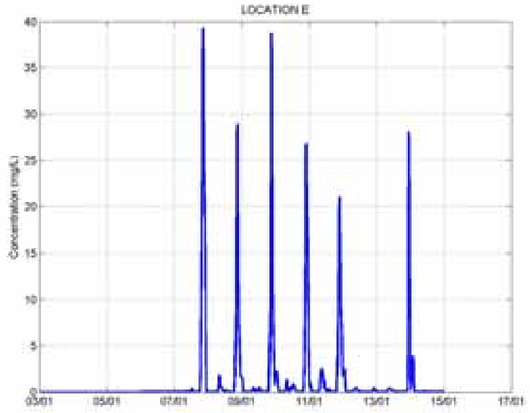
Scenario A:

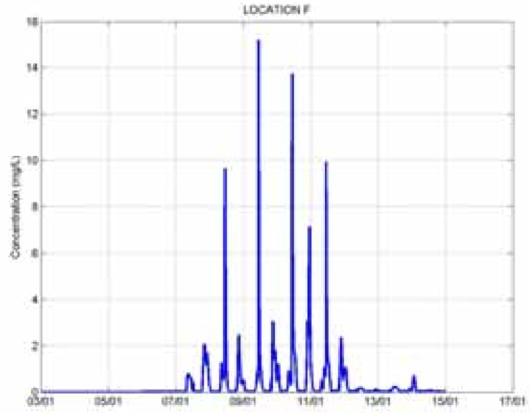

LOCATION A
Concentration (mg/L)
0
0.5
1
1.5
03/01
05/01
07/01
09/01
11/01
13/01
15/01
17/01


LOCATION B
Concentration (mg/L)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
03/01
05/01
07/01
09/01
11/01
13/01
15/01
17/01


LOCATION C
Concentration (mg/L)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
03/01
05/01
07/01
09/01
11/01
13/01
15/01
17/01


LOCATION D
Concentration (mg/L)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
03/01
05/01
07/01
09/01
11/01
13/01
15/01
17/01


LOCATION E
Concentration (mg/L)
0
5
10
15
20
25
30
35
40
03/01
05/01
07/01
09/01
11/01
13/01
15/01
17/01


LOCATION F
Concentration (mg/L)
0
2
4
6
8
10
12
14
16
03/01
05/01
07/01
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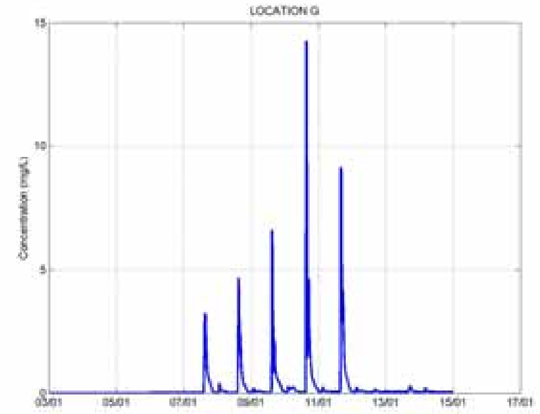
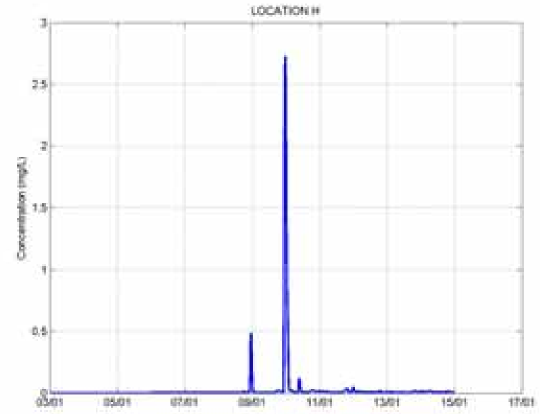
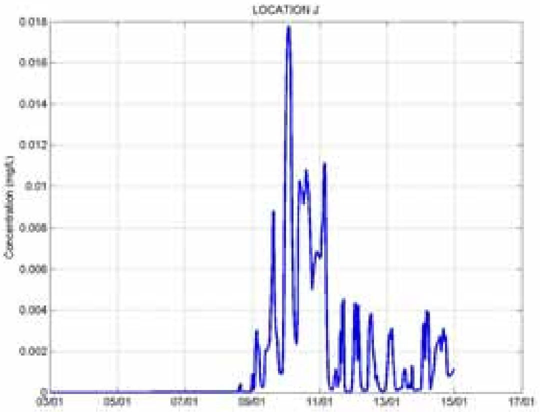
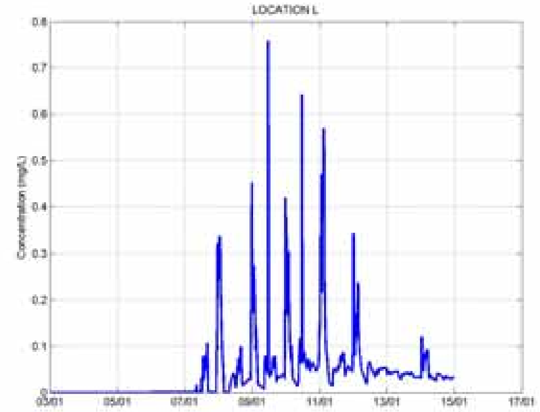
13/01
15/01
17/01

Scenario A, continued:









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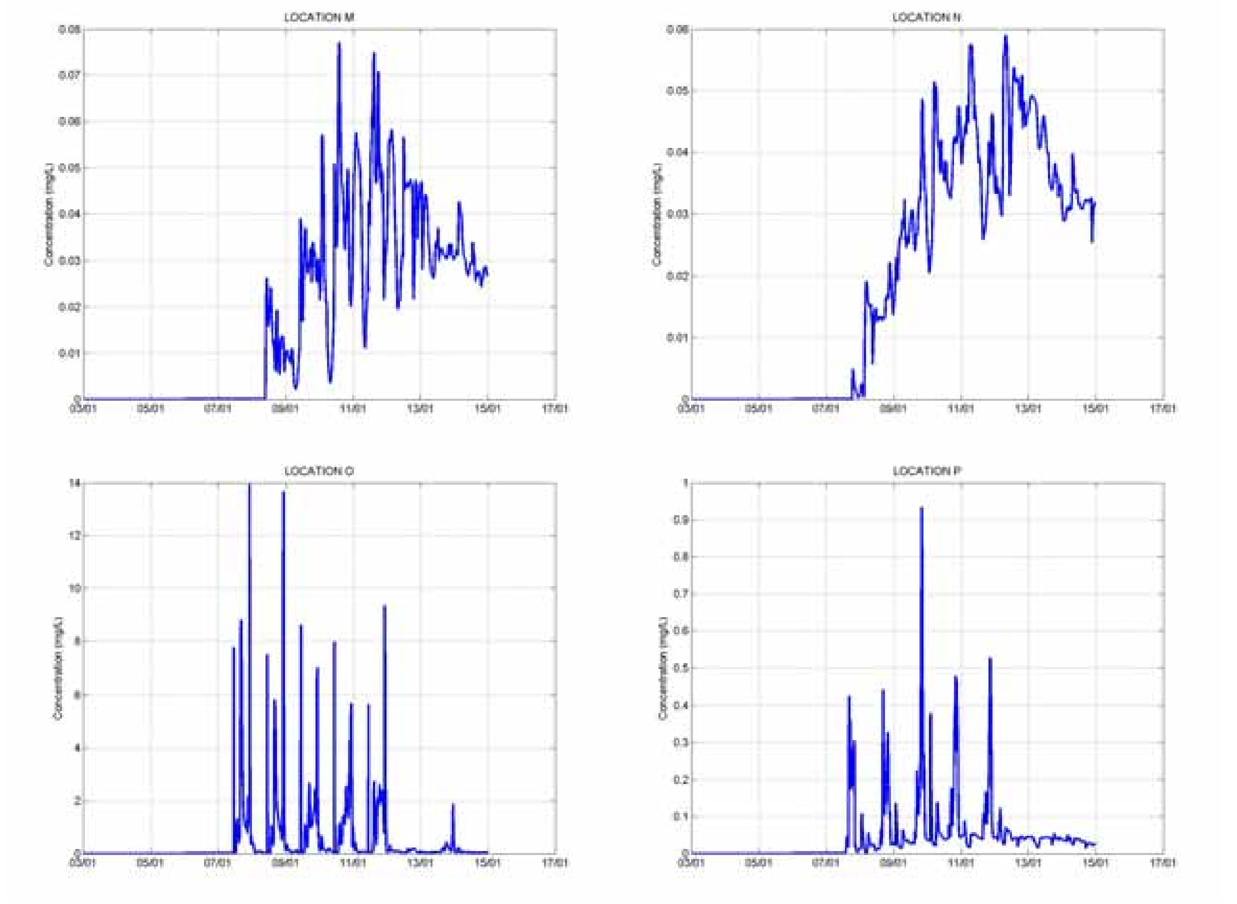
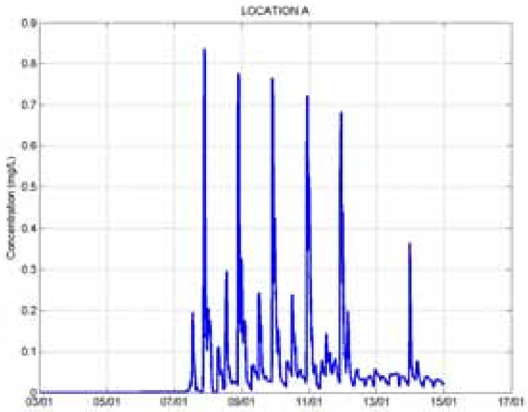
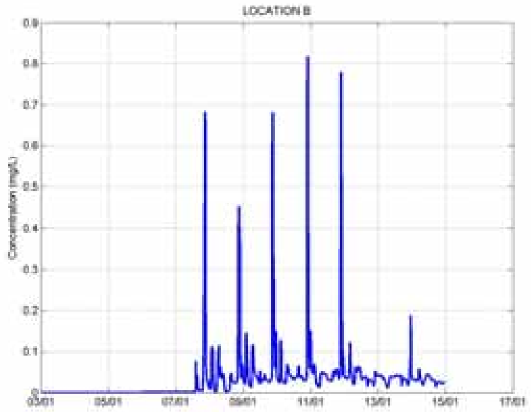


Scenario B:


LOCATION A
Concentration (mg/L)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
03/01
05/01
07/01
09/01
11/01
13/01
15/01
17/01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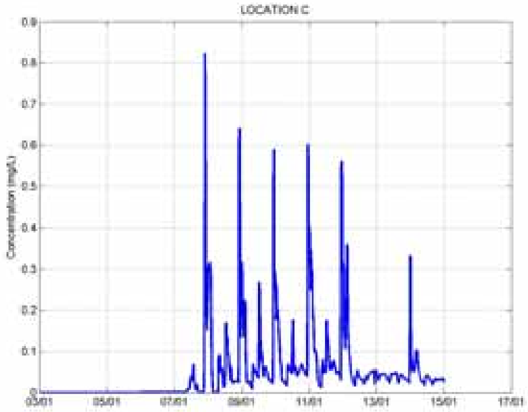
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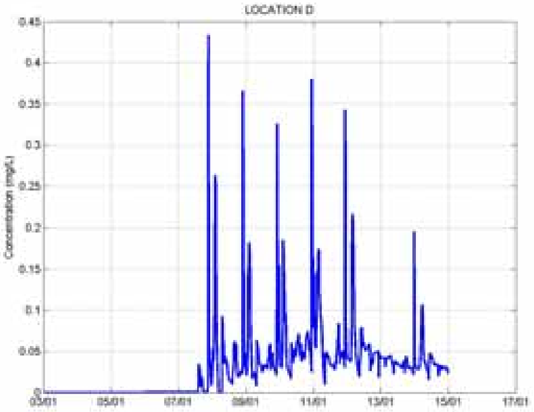
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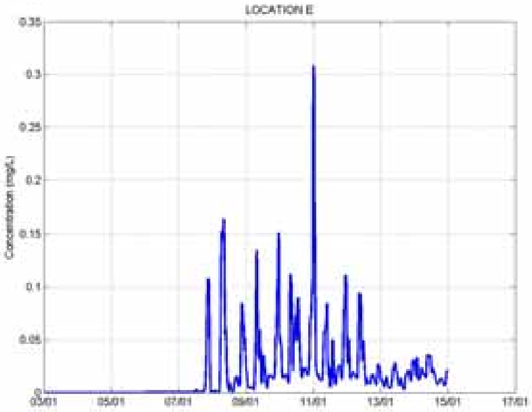
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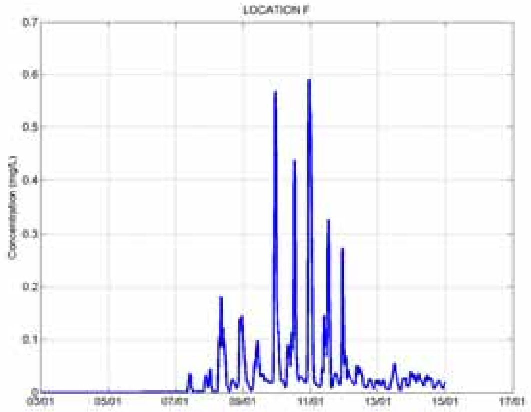
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17/01

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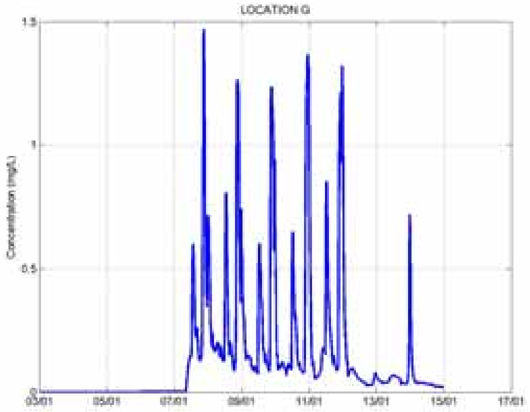

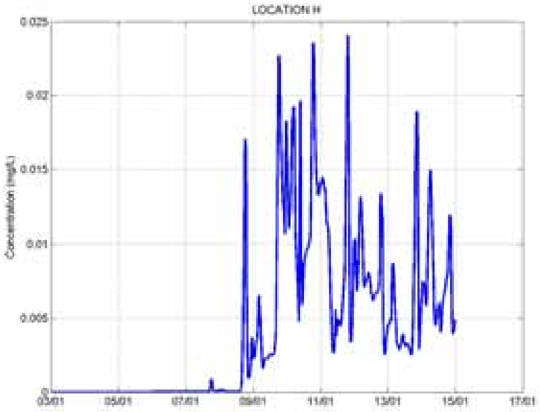

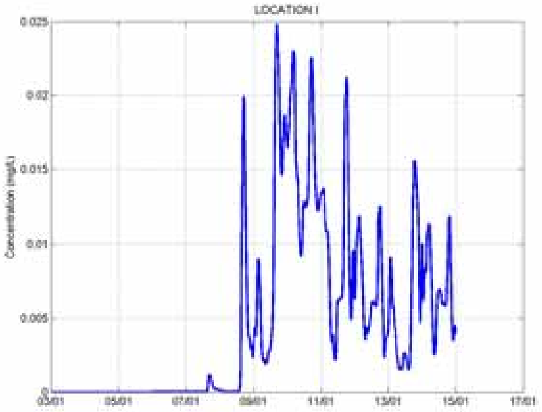

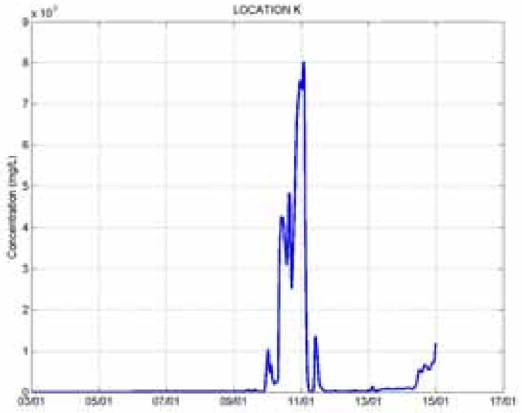

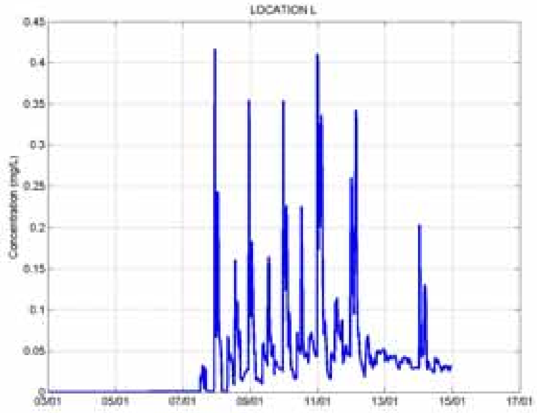

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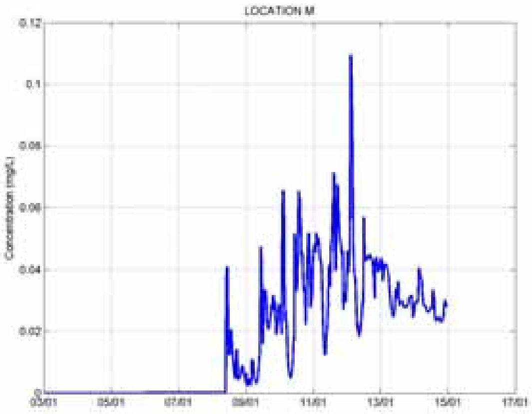

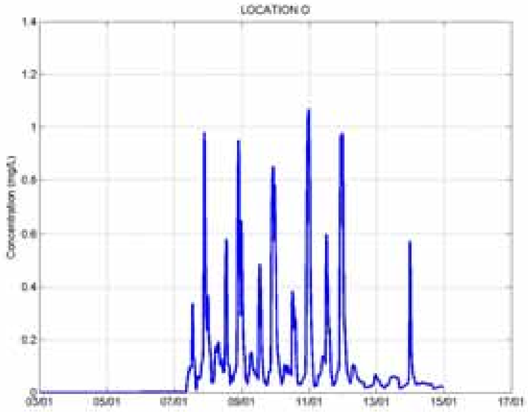

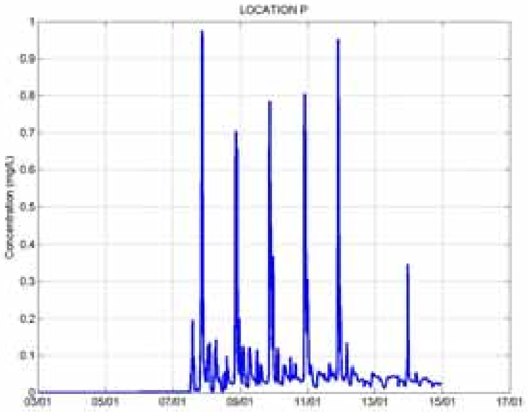

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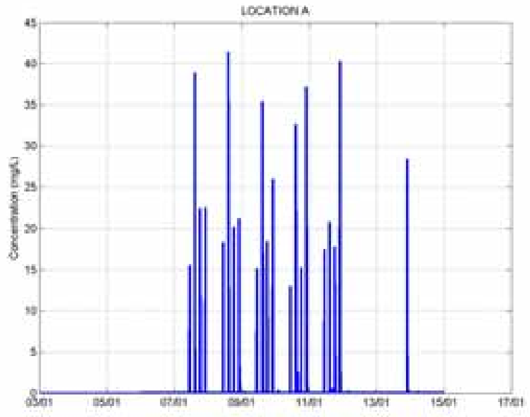
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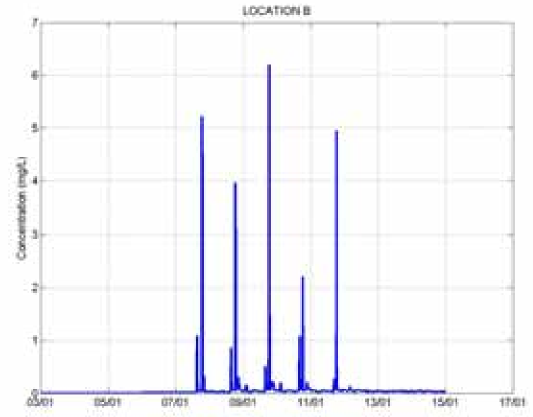
17/01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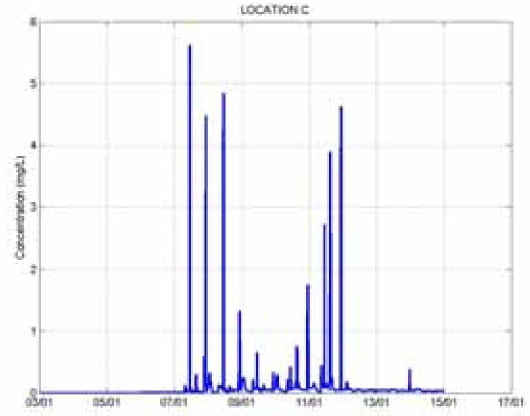
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17/01


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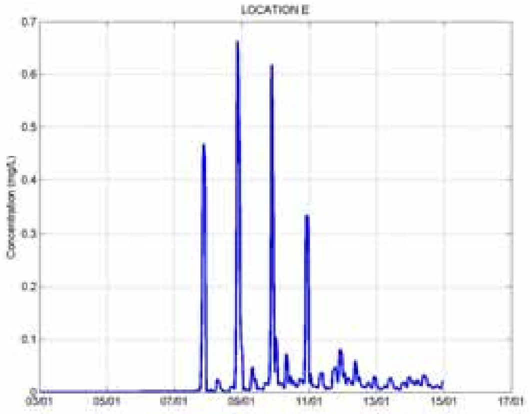
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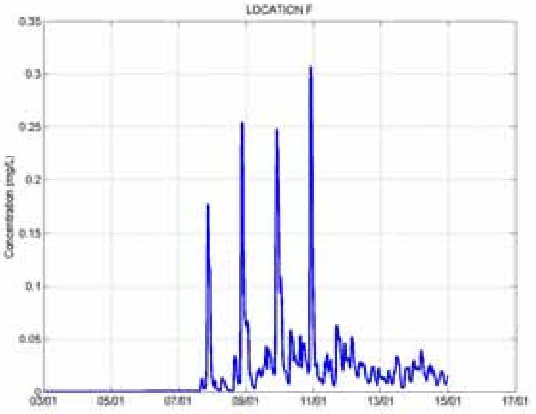
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17/01

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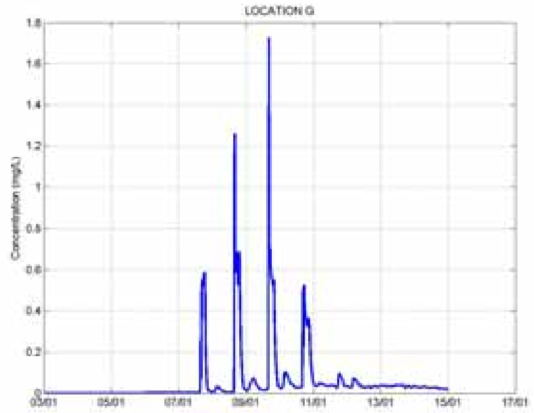

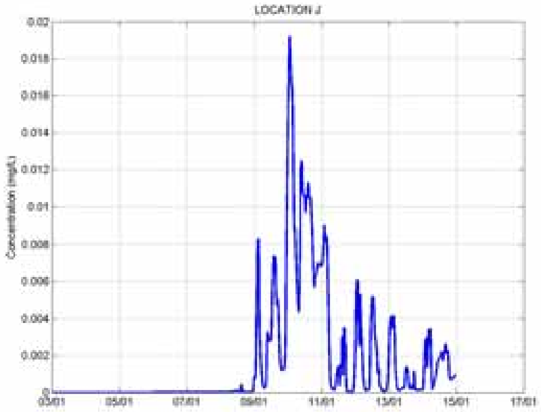

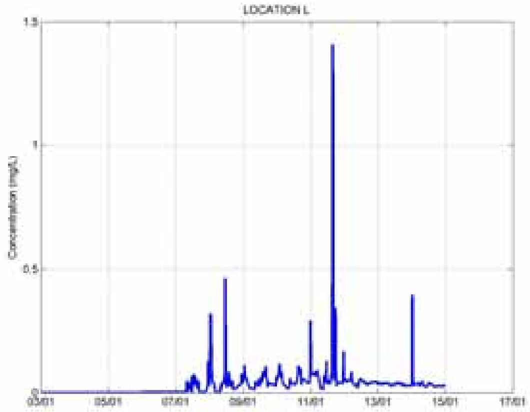

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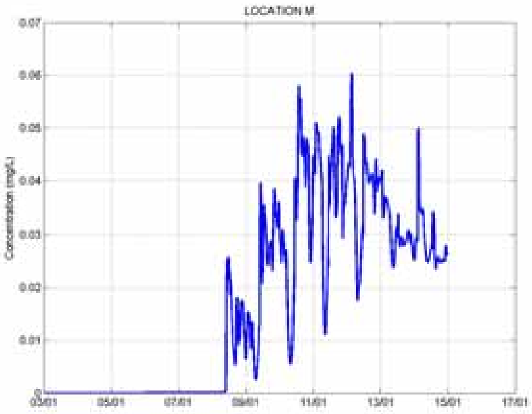

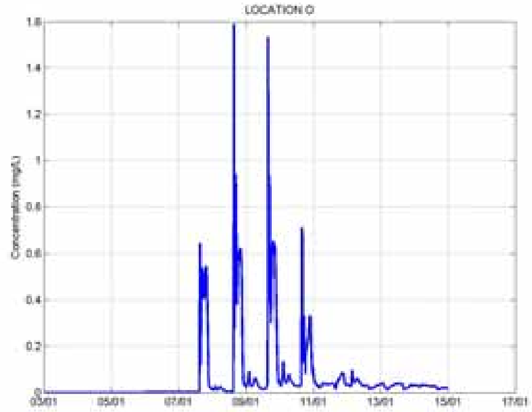

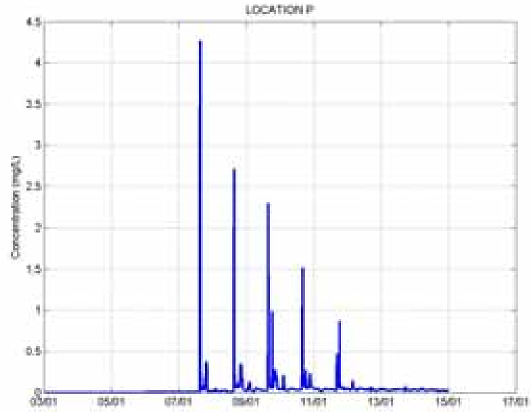

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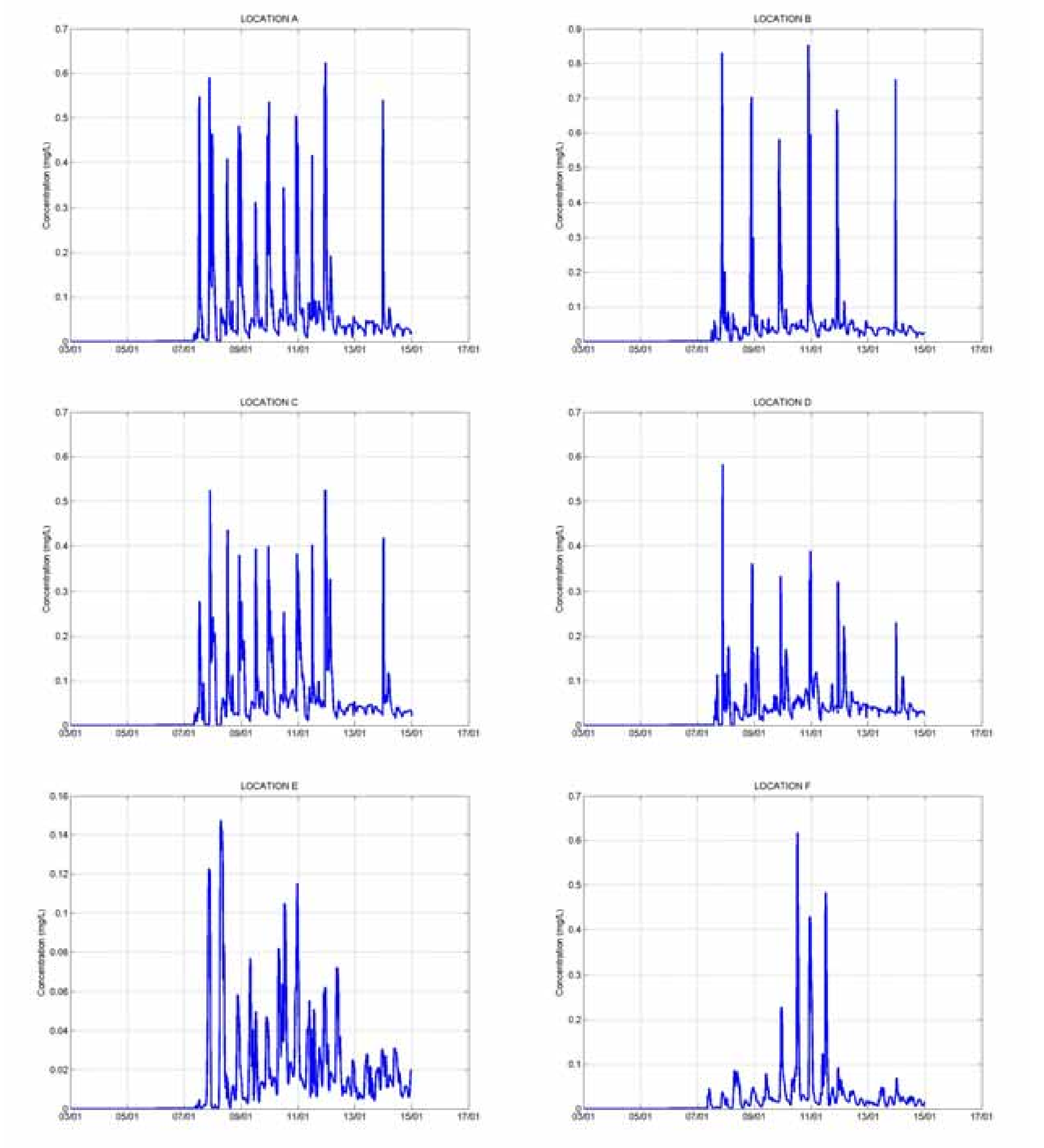
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LOCATION B
LOCATION C
LOCATION D
LOCATION E
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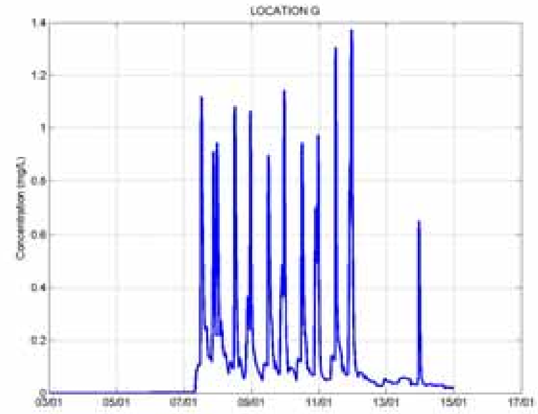

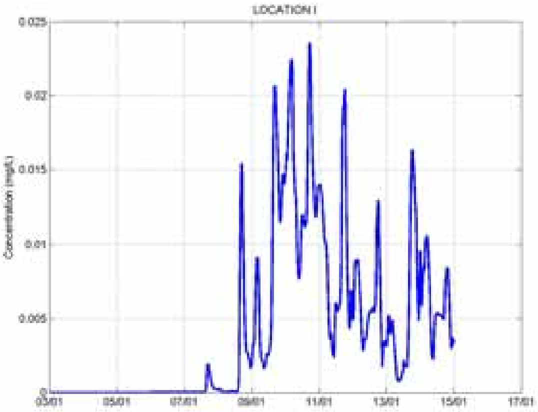

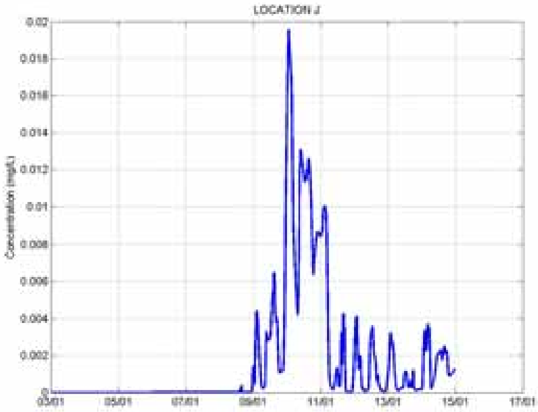

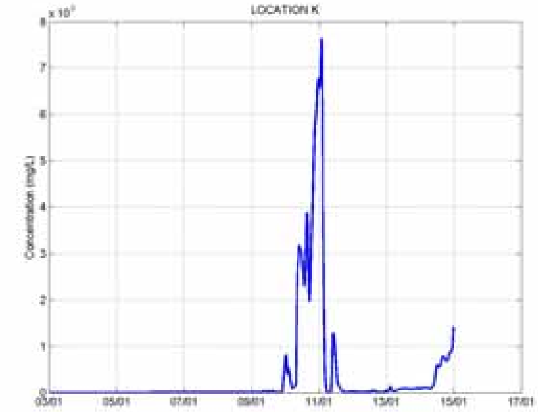

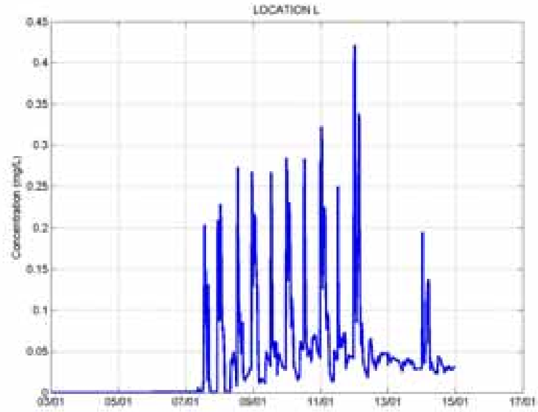

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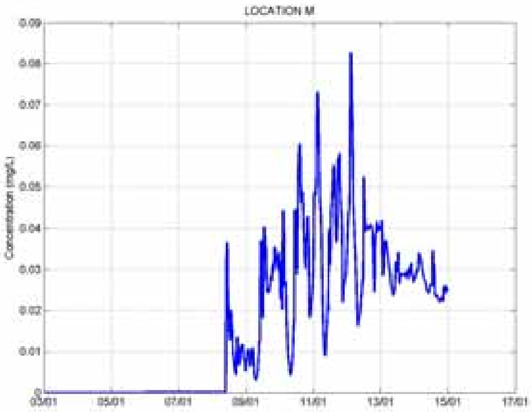

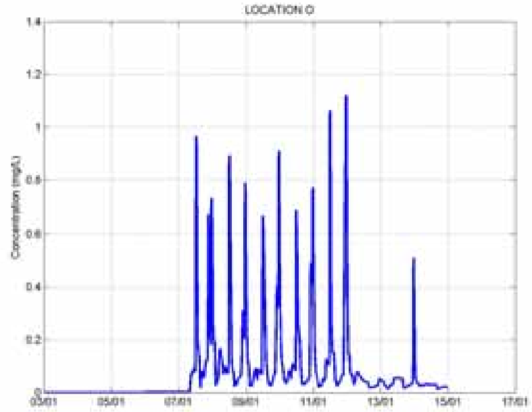

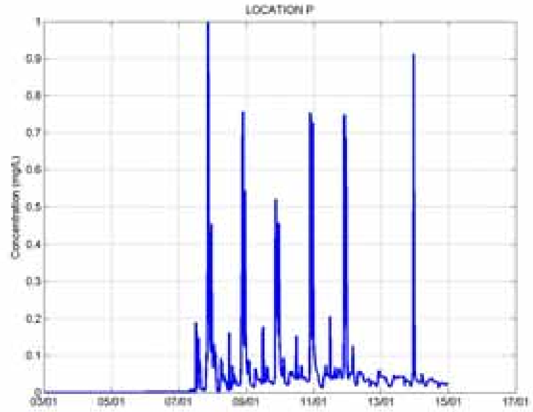

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British Columbia V6E 3W1 Canada
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APPENDIX O12.2

Study of effects of blasting for the desalination plant intake and outfall pipes (report by Arup, 2008)

See overleaf for report.

ArupAcoustics

BHP Billiton

Olympic Dam Expansion

Study of Effects of Blasting for the Desalination Plant Intake and Outfall Pipes

Document ref
AAc/85204/01/R01

ArupAcoustics

BHP Billiton

Olympic Dam Expansion

Study of Effects of Blasting for the Desalination Plant Intake and Outfall Pipes

December 2008

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www.arup.com/acoustics

Job number 85204/01

Contents

Executive Summary

Arup Acoustics has been engaged to conduct an investigation of the effect on the human, marine and built environment should underwater blasting be required as part of the construction of the intake and outfall pipes for the proposed desalination plant at Port Lowly, South Australia for the Olympic Dam Expansion.

Existing research into the sensitivity of marine life to underwater blasting has provided guidance for safe distances from underwater blasts for various species. Criteria for human comfort and building damage have been determined from relevant Australian and international standards.

Predictions of the impact of the proposed works on nearby receivers and the marine environment have been made, and where necessary management measures have been proposed to minimise the effect of blasting.

The blasting expert, Mr. Nick Elith of TechNick Consulting Pty, Ltd, has been involved in discussions to set suitable charge sizes and determine suitable safety (i.e. exclusion zones). Exclusion zones and a maximum charge size of 10 kg have been deemed appropriate to meet performance criteria., whilst ensuring human comfort, building safety and marine life impacts are acceptable.

Other proposed mitigative measures include non-simultaneous detonation and blasting outside of the breeding period of the Australian Giant Cuttlefish.

With appropriate blasting design practices, blasting for the intake and outfall pipes at Point Lowly can be successfully undertaken with no impacts to the Point Lowly lighthouse or adjacent structures. With appropriate blast exclusion zones, marine blasting can be undertaken with acceptable impacts to marine species and risks to human safety.

1 Introduction

As part of the proposed expansion to Olympic Dam a desalination plant would be constructed at Point Lowly, South Australia. Intake and outfall pipes for the desalination plant would be excavated through an offshore rocky reef area of Point Lowly. A combination of land based and underwater blasting may be required to excavate the trenches necessary to bury these pipes. Detailed geotechnical investigations prior to detailed design of the intake and outfall works will confirm the requirement for and extent of blasting required.

The area around Point Lowly contains a breeding aggregation of the Australian Giant Cuttlefish, an event which is unique in the world. In addition, several listed threatened or endangered species are potentially found in the area of Upper Spencer Gulf.

Accordingly, Arup Acoustics has been engaged to conduct an assessment of the likely degree of acoustic impacts to sensitive receivers in the vicinity of the proposed blast locations, and to marine life in the Point Lowly area.

Ground vibration and airblast associated with blasting have the potential to adversely affect buildings and human comfort, and as such has also been assessed.

This report contains an investigation of the sensitivity of marine life to underwater noise and blasting; indicative predictions of the degree of impact of the proposed blasting on marine life, the nearby Point Lowly Lighthouse and residential receivers; and mitigation measures proposed to mitigate the impact of the blasting.

This investigation also considers the impacts of terrain blasting, including the risk of damage to surrounding structures and comparisons to acceptable levels of blasting related to human comfort.

1.1 Scope of Assessment

The scope of this assessment is as follows:

- Undertaking an assessment of the proposed blasting at Point Lowly (for the desalination plant pipelines) to review the impact of noise and vibration (waterborne, groundborne and airborne) to marine animals and vegetation including whales / seals / dolphins, the heritage lighthouse; and residential locations.
  This includes:
    - a review of the marine life habitats and behaviours.
    - a national and international literature review to compare blasting procedures that have been conducted for similar locations and for similar scenarios.
    - an investigation of the impact of blasting on marine life, such as whale, seals, dolphins and fish.
    - liaison with relevant experts.
- Provision of mitigation options based on leading practice, State legislation and Australian Standards.
- Determination of maximum blast sizes and appropriate blasting practices / methods.

2 Description of Project

2.1 Site Description

The Draft EIS Chapter 5, Description of the Proposed Expansion, and Chapter 16, Marine Environment, provide details of the proposed works in Upper Spencer Gulf and the existing marine environment, respectively. This section provides a summary of those issues relevant to blasting.

Point Lowly consists of fixed desert seif dunes and associated sand spread, as well as some modern beach and sand dunes. There are fragments of bedrock along the coastline which consist of dense quartzite from the Tent Hill Formation[1].

Coastal buildings and homes are in the vicinity of potential blast sites as well as the heritage listed Point Lowly lighthouse. There is also the existing Santos hydrocarbon processing plant and associated infrastructure, including a jetty from the plant into the Spencer Gulf.

2.2 Aquatic Ecology

The unusual combination of relatively warm water, high salinity and sheltered conditions in the northern reaches of Upper Spencer Gulf has led to the presence of ecological communities with tropical and subtropical affinities. The Gulf supports a productive marine ecosystem and a diversity and abundance of marine organisms, including listed threatened species, species of particular conservation interest (such as the Australian Giant Cuttlefish. *Sepia apama*), and species of commercial or recreational importance.

The Australian Giant Cuttlefish is particularly unique as large numbers are attracted to the shallow rocky reef in the vicinity of Point Lowly to breed between May and October each year. BHP Billiton has committed to installing the intake and outfall pipes for the desalination plant outside of this period to reduce the potential for impact on cuttlefish. Consequently, the impacts of blasting to the Australian Giant Cuttlefish have been considered in conjunction with other marine fauna groups which have been assessed in this study.

Some listed (endangered or vulnerable) marine species occurring or potentially occurring in Upper Spencer Gulf include the Southern Right Whale *Eubalaena australis*, Humpback Whale *Megaptera novaeangliae*, Australian Sea-lion *Neophoca cinerea*, Great White Shark *Carcharodon carcharias*, School Shark *Galeorhinus galeus,* Loggerhead Turtle *Caretta caretta*, Green Turtle *Chelonia mydas* and Hawksbill Turtle *Eretmochelys imbricatea.*

Commercial species include the Western King Prawn *Melicertus latisulcatus*, King George Whiting *Sillaginodes punctatus* and Yellowfin Whiting *Sillago schomburgkii.*

2.3 Proposed Construction Process

In order to bury the intake and outfall pipes for the proposed desalination plant, excavation on land within the marine environment to a depth of 4 metres is necessary. Preliminary investigations undertaken by BHP Billiton indicate the likely presence of rock in the area where excavations would be required. The removal of rock and other spoil material would be via a calm shell bucket or excavator, blasting is likely to be required as it is not practical or efficient to employ mobile excavators and rock breakers in this area.

The intake pipe is expected to be a single 3 metre diameter pipe and the outfall pipe a single 2.1m diameter pipe.

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[1] Santos Limited, *Draft Environmental Impact Statement for Port and Terminal Facilities at Stony Point South Australia*, Social and Ecological Assessment Pty Ltd, 1981 (P 134).

2.3.1 Alignment of Pipelines

The currently preferred alignment for the proposed intake and outfall pipes are shown on Figure 1 with three points along these alignments also shown and summarised in the table below, including the codes used to reference these locations in this report:

	Location ID	**Latitude**	**Longitude**
Intake	I1	32° 58’ 41.891” S	137° 46’ 43.329” E
	I2	32° 58’ 39.459” S	137° 46’ 50.605” E
	I3	32° 58’ 37.882” S	137° 46’ 55.288” E
Outfall	O1	32° 59’ 56.479” S	137° 47’ 11.735” E
	O2	33° 0’ 2.29” S	137° 47’ 15.267” E
	O3	33° 0’ 19.419” S	137° 47’ 25.782” E

Table 1: Proposed intake and outfall pipes

Figure 1: Proposed Desalination Plant Inlet and Outlet Locations

2.3.2 Charge Size

Mr. Nick Elith (TechNick) has been consulted as a blast expert, and has proposed blast sizes based on local conditions following a review of the literature available. Charge weights of 7kg for the intake pipe and 10kg for the outgoing pipe have been proposed. The 10 kg is the maximum charge size that should be used for any blast. In order to minimise shock waves to the local sensitive areas, a larger number of small explosions will be preferred over fewer large explosions i.e. blasts should not be triggered simultaneously.

3 Literature Review

3.1 Introduction

Various studies on marine animal behaviour, including reactions to noise, have been completed. Sound stimuli range from frequency-specific stimuli to explosions/seismic airguns. Unfortunately, most studies have not led to recommendations of disturbing sounds, or even limiting levels, mainly because the studies have not been conclusive. Studies are largely done on animals in captivity, which may represent very different conditions to those experienced in the natural environment.

The following discussion summarises relevant theory and studies in light of the species known to utilise Upper Spencer Gulf.

3.2 Source Characteristics

Due to the lack of available research on the effect of underwater blasting on some species in the literature, it is necessary to consider research investigating the effects of other noise sources on marine life, such as seismic airguns. To allow the results of such studies to be extended to assess the impact of underwater blasting, it is necessary to consider the characteristics of the underwater sound source.

3.2.1 Seismic Airguns

Seismic airguns are frequently used as part of geophysical surveys. Typical configurations include arrays of seismic airguns, which send high-energy impulses of sound into the sea. Measurements of the reflected sound from the ocean floor are then used to gain geophysical information.

In order to obtain reflections of significant energy, source levels from seismic airguns are very high. Airgun arrays can be fired simultaneously so as to generate levels in the region of 235 – 259dB re 1μPa at 1m, which corresponds to a peak pressure of 560 – 8900 kPa.

Airguns produce sound pulses by releasing a bubble of gas into the water medium. Compressed air stored in the airgun pressure chamber is released into the water, causing a shock wave to propagate into the surrounding water.

The efficiency of energy transfer into the surrounding medium is less for airguns than for high explosives[2], due to the lower “explosive cavity formation velocity” of airguns (analogous to the detonation velocity for high explosives). This means that the peak pressure from an airgun pulse would be lower than from a high explosive of equivalent potential energy.

Airguns emit a greater proportion of the potential energy at low frequency (~10 Hz) compared to high explosives. Wave propagation losses underwater are generally reduced at low frequency, and therefore airgun pulses may propagate over long range with low attenuation.

Another significant difference between seismic airgun noise and blast explosions is that seismic airgun ships tend to repeatedly fire, with repetitions as often as every 10 seconds. Survey can last for extended periods of time (test periods of a month are not uncommon). Blasting for the Olympic Dam Expansion would include significantly fewer pressure waves than seismic geophysical surveying.

Parvin et al[3] present a comparison of typical seismic airgun source levels, ranging from approximately 200 - 240 dB re 1μPa at 1 m for single airguns, and from approximately 240 - 265 dB re 1μPa at 1 m for airgun arrays.

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[2] Kedrinskii (1997) *Underwater Explosive Sound Sources*, in Crocker (ed), *Encyclopedia of Acoustics, Volume 1, Chapter 47*

[3] Parvin, Nedwell and Harland (2007) *Lethal and physical injury of marine mammals, and requirements for Passive Acoustic Monitoring*, Subacoustech Report No 565R0212

3.2.2 Impact Piling

Noise from the impact of piling hammers is directly related to the pile diameter[3], with noise levels from large-diameter piles being recorded at approximately 260 dB re 1μPa at 1 m. The energy associated with each impact for large-diameter piling may be approximately equivalent to the energy from an explosion of 8 kg TNT, with piling impacts occurring as frequently as every 1 - 2 s.

The waveform from a piling impact involves reflections and reverberation effects, including resonance of the pile as it is struck, and is generally more tonal than seismic airgun or explosive waveforms. Piling may, in extreme cases, cause damage due to resonance effects on underwater life, such as by exciting the resonant frequency in gaseous areas – such as the 25 Hz resonant frequency of the human lung[4].

3.2.3 Underwater Explosions

Detonation of high-explosives (such as TNT) creates a shock wave propagating out into the surrounding medium, ahead of a bubble of high-temperature gas. The shock wave contains a large proportion of the high-frequency energy of the explosion, with secondary waves (resulting from the oscillation of the gas bubble) containing low-frequency components.

From a 10 kg buried charge, such as is proposed to be used for the underwater blasting component of the Olympic Dam expansion, source levels are given in Nedwell et al[4] to be approximately 255 dB re 1 μPa at 1 m.

It can be seen that the proposed explosive charge size for this project is likely to produce underwater pressure levels comparable to pressure levels given in the literature for seismic airguns.

3.3 Hearing Characteristics of Species

3.3.1 Marine Mammals

The hearing abilities of marine mammals are the best documented of all sea creatures. Behavioural audiograms (animal hearing capability measurements plotted against the frequency of sound, including hearing thresholds) have been taken for several species. The effects of sound masking have been partially investigated, as has the ability of species to discriminate in terms of both frequency and direction of sound.

While the hearing abilities of most marine mammal species have been tested, only one or two individuals have been studied, so variations in hearing ability among individuals is not known. However, available data shows reasonably consistent patters within three groups: small and medium-sized odontocetes (toothed whales and dolphins), phocinids (true seals), and otariids (fur seals and sea lions).

Hearing ranges from existing odontocete data have been shown to range up to approximately 110 kHz, with greatest sensitivity in the range of 8 – 90 kHz. Hearing is generally very accurate in this range – a killer whale tested by Hall and Johnson could detect a 15 kHz signal of approximately 30 dB re 1 μPa[5].

Odontocetes appear to be insensitive to low-frequency sounds, but may be more sensitive to some combination of low-frequency particle motion and pressure fluctuations when in the near-field of the acoustic source.

3.3.2 Fish

Hearing capabilities vary between species of fish. Nedwell et al[6] have broadly split the hearing abilities of fish into three groups of low, medium and high hearing sensitivity. Differences are a result of the anatomy of the swimbladder and its proximity to the inner ear.

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[4] Nedwell, Parvin, Edwards, Workman, Brooker, Kynoch (2007) *Measurement and interpretation of underwater noise during construction and operation of offshore windfarms in UK waters* COWRIE Noise-03-2003

[5] "M*arine Mammals and Noise".* Richardson, Green Jr, Malme, Thomson. p208.

[6] Nedwell, Turnpenny, Lovell and Edwards (2006) *An investigation into the effects of underwater piling noise on salmonids,* Journal of the Acoustic Society of America, Volume 120, Issue 5, pp 2250-2254

Two modes of hearing occur in fish. The stimulation route common to all organs and fish species is known as the “direct” route. In this stimulation mode, acoustic particle motion or hydrodynamic (water) motion accelerates the fish’s soft tissues, including the sensory epithelium, with the surrounding water. This mode of hearing is inherently directional. In this primitive mode of hearing, sound pressure does not play a direct role, and species that apparently hear exclusively in this mode are known as “hearing generalists”, and would fall into the category of low hearing sensitivity. Examples of such species include flat fish such as the plaice (*Pleruronectes platessa*) and dab (*Limanda limanda*).

Some species have an additional mode of hearing that renders them sensitive to sound pressure. In these “hearing specialists,” the swimbladder or other gas bubble is efficiently linked mechanically to the fluid systems of the ear, and thus to the otoliths (small particles in the inner ear of fish which help balance the fish).

As sound is transmitted through the animal’s body, sound pressure fluctuations cause the gas bladder to expand and contract, and the motions of its walls are transmitted to the sensory epithelia of, usually, one of the otolith organs. The hearing specialists are particularly sensitive to sound, with best thresholds in the region of 50 dB re 1 µPa, and hear in a relatively wide frequency range (<100 to 3,000 Hz), with best sensitivity occurring between 200 and 1,000 Hz.

Sensitivity to an animal to sound also depends on sound duration (with approximately equal energy detected up to sound durations of 400 ms), on the level of ambient, or background noise in the frequency region of the signals (Fay, 1988), and on the physiological integrity of the auditory system[7].

Fish with swimbladders can be categorised as having medium or high sensitivity hearing mechanisms, dependent on the size of the swimbladder. In addition, a reduced distance between swimbladder and inner ear corresponds to increased sensitivity of hearing, with the gas-filled cavity of the swimbladder acting as an acoustic pressure-to-motion transformer.

An example of a species of fish with medium sensitivity hearing is the Cod (*Gadus morhua).* Species with high hearing sensitivity include the Herring (*Clupea herringus*) and Sprat (*Sprattus sprattus*).

3.3.3 Chelonians

Sea turtle hearing (hearing ability and dependency on sound) for survival cues is not well documented nor understood. Hearing was shown by Ridgway et al to be most sensitive at around 400 Hz, and to stop at around 1 kHz [8]. Hearing thresholds have not been determined conclusively; each life stage of sea turtles is marked by exceptional differences in auditory structures. These correspond to, for example, the differences between the shallow water habitats of the juvenile and adult which are much noisier than the open ocean environment of the hatchling stage[9].

3.4 Effects of Underwater Noise and Vibration on Species

3.4.1 Marine Mammals

It is thought that noise may affect marine mammals in a number of ways. An IFAW report summarises three main areas of concern for the impact of noise on cetaceans[10] :

1) Intense noise exposure may cause death/physical injury for some species. May also affect immune systems/reproductive health

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[7] *Geological and Geophysical Exploration for Mineral Resources on the Gulf of Mexico Outer Continental Shelf - Final Programmatic Environmental Assessment",* US Dept. of Interior Minerals Management Service Office of Public Affairs (MMS 2004-054)

[8] *Marine Mammal Commission Report to Congress, 2007. “Marine Mammals and Noise: A Sound Approach to Research and Management”.* III-35

[9] Ibid, H-3

[10] *“Ocean Noise: Turn it down - A report on ocean noise pollution”.* IFAW.org report.

2) Noise may mask sounds vital to marine animals - location of prey, predators, males, and navigation

3) Behavioural changes: migration/feeding

However, demonstrating links between noise and animal behaviour are difficult.

3.4.2 Fish

Impacts of noise to fish are less well documented than those of marine mammals. One area in which studies exist is that of the impact of seismic airgun noise on fish. In an investigation into the effects of seismic airgun noise, a US report states the following:

"An additional impact to fishes from seismic airgun blasts is the effects on fish eggs and larvae. Laboratory and field studies have shown that statistically significant mortality of eggs and larvae in close proximity (i.e. 2 and 3 m) to airguns can occur (Dalen and Knutsen, 1986; Holliday et al, 1987). Overall the data indicate that significant impacts on fish eggs and larvae (generalized from studies on northern anchovy) would only result from repeated exposures to full seismic arrays (Holliday et al, 1987)."[11].

3.4.3 Chelonians

A review of scientific information by Fisheries and Oceans Canada [12] concludes the following on the impact of anthropogenic noise on sea turtles:

1) Auditory studies suggest that sea turtles, specifically loggerhead and green turtles, are able to hear and respond to low frequency sound, but their hearing threshold appears to be high. [See Section 3.3.3 above for a discussion on Chelonian hearing].

3) Sea turtles may become accustomed to seismic sound over time, but results of three studies were inconclusive on this matter.

4) Loss of hearing sensitivity and physiological stress response has also been considered as a possible consequence of exposure of sea turtles to seismic sound, but the one study reviewed was inconclusive.

5) The response, if any, of free-ranging sea turtles to seismic sound conducted under field operating conditions is unknown.

6) Based on studies that have been conducted to date, it is considered unlikely that sea turtles are more sensitive to seismic operations than cetaceans or some fish. Therefore, mitigation measures designed to reduce risk or severity of exposure of cetaceans to seismic sounds may be informative about measures to reduce risk or severity of exposure of sea turtles to seismic sounds. However sea turtles are harder to detect both visually and acoustically than many species of cetaceans, so mitigation strategies based on sightings or acoustic detection are expected to be less effective for turtles than for cetaceans.

In addition to these conclusions, in some studies, behavioural responses of sea turtles in enclosures exposed to airgun sounds sometimes included avoidance.

3.4.4 Marine Vegetation

Although little research is available in the literature regarding the effect of underwater blasting on marine vegetation, Lewis[26] cites research by Ludwig[13] on the effects of explosions on seagrass, which found that seagrass was cleared in an area significantly greater than the crater resulting from the explosion. An explosion producing a 45 cm crater caused dieback of seagrass in an approximately 8 m diameter area surrounding the crater – i.e. an area approximately 18 times larger than the direct cratered area.

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[11] *"Geological and Geophysical Exploration..."*, Ibid. III-44

[12] "Review of Scientific Information on Impacts of Seismic Sound on Fish, Invertebrates, Marine Turtles and Marine Mammals, Fisheries and Oceans Canada - Habitat Status Report 2004/002. http://www.dfo-mpo.gc.ca/csas/Csas/status/2004/HSR2004_002_E.pdf

[13] Ludwig , M (1977) *Environmental assessment of the use of explosives for selective removal of eelgrass*. In GA Young (ed) *Proceedings of the second conference on the environmental effects of explosives and explosions (13-14 October 1976)*. Technical Report 77-36, pp63-68, Naval Surface Weapons Center, White Oak, MD

Lewis also discusses indirect effects on the marine environment resulting from underwater blasting, including loss of habitat from vegetation dieback and increased turbidity, which may lead blasted areas to support less marine life than unblasted areas[14].

However, this research was obtained from unburied charges (i.e. charges that are free-floating or resting on the sea floor), and therefore the effects from a buried charge are expected to be less than quoted in the literature.

3.4.5 Invertebrates and Other Species

It is proposed that providing adequate mitigation and measures to protect the above species would suffice for invertebrates and other species.

3.5 Mitigation Measures

The use of acoustic alarms or small underwater blasts to scare away animals from the blast zone prior to the primary blast charge has been suggested[15] for marine mammals, but other research[16] has concluded that explosions have no apparent deterrent effect on fish.

Indeed, the US National Marine Fisheries Service “Generic” requirements regarding protection of sea turtles from the explosive removal of offshore structures (as quoted in Viada et al[16]) specifically warn against the use of scare charges, as turtles (and presumably other animals) may be attracted to the area of the detonation in order to feed on any stunned or dead marine life.

The Marine Mammal Commission (2007) also suggested that the use of sound screening measures around stationary sources (such as blasts) may be effective in minimising the propagation of the blast wave. Bubble curtains, blasting mats and damping screens were suggested as potential control measures; however it is not known whether these measures would be effective for blast waves, which behave differently to underwater sound waves.

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[14] Porter JW and Porter KG (1977) *Quantitative sampling of demersal plankton migrating from different coral reef substrates*, Limnology and Oceanography, Volume 22, pp 553-556

[15] Marine Mammal Commission (2007) *Marine Mammals and Noise: A Sound Approach to Research and Management*, Marine Mammal Commission Report to Congress, http://www.mmc.gov/sound/committee/pdf/soundFACAreport.pdf

[16] Coker CM and Hollis EH (1950) *Fish mortality caused by a series of heavy explosions in Chesapeake Bay*, Journal of Wildlife Management, Volume 14 , pp 435-444

4 Assessment Criteria

Impacts from blasting include fly-rock (rock projected from the explosive source), ground vibration, air blasts, fumes and dust. Impacts relating to noise are ground vibration and air blasts (also referred to as overpressure) are addressed below.

At high levels of ground vibration and airblast, the following may occur:

- Occupants or users of a building may be inconvenienced or adversely disturbed;
- The building contents may be disturbed or affected; or
- Cosmetic or structural building damage may be induced.

4.1 Atmospheric Noise

4.1.1 Groundborne Noise

No criteria for ground borne noise from blasting is given by the South Australia Environment Protection Authority (EPA). As such construction noise criteria for noise generated by this activity would be as per that detailed in the Draft EIS Chapter 14, Noise and Vibration.

4.1.2 Airblast

The impact from an airblast is generally more noticeable than the accompanying ground vibration, and has the potential to cause discomfort, damage buildings and at very high levels, can cause injury. Airblast can be heard by humans if it contains energy in the audible frequency range of between 20 Hz and 20 kHz, and is typically the cause of most blasting related complaints. Airblast that contains energy in sub audible frequencies below 20 Hz may cause secondary effects indoors such as rattling windows or other contents.

For explosions underwater, ground vibration may be more noticeable. High levels of vibration transmitted through the ground and the airblast may be noticed by residents, or in the extreme, cause damage to buildings or structures.

Appendix J of AS2187.2[17] provides general guidance on appropriate limits for ground vibration and airblast overpressure from blasting. AS2187.2 recommends the following criteria:

- A human comfort level of 120 dB (linear, peak) for 95% of blasts (125 dB maximum) at any residence where the total duration of blasting is less than 12 months, or less than 20 blasts
- A human comfort level of 115 dB (lin, peak) for 95% of blasts (120 dB maximum) at any residence where the total duration of blasting is greater than 12 months, or greater than 20 blasts
- A building damage criterion of 133 dB (lin, peak) for all blasting

Recommended limits for blast overpressure are also found in guidelines from the Australian and New Zealand Environment Conservation Council (ANZECC)[18]. These limit blast overpressure to 115 dB (lin, peak) at any residence.

There is provision in the ANZECC document to reflect that there could be some exceedance of the overpressure limit of 115 dBL on infrequent occasions. This should be limited to not more than 5% of total blasts. During this time the overpressure level should not exceed 120 dBL at any time.

The ANZECC guideline also restricts blasting to between 9 am and 5 pm on weekdays and Saturday, and recommends only one detonation per day, although this may not be feasible

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[17] AS 2187.2-2006 *Explosives - Storage, transport and use, Part 2 Use of explosives*, Standards Australia, 2006.

[18] *Technical basis for guidelines to minimise annoyance due to blasting overpressure and ground vibration*, Australia and New Zealand Environment Council, September 1990.

for all projects. Blasting at night should be avoided unless it is absolutely necessary. (These criteria are generally more stringent than those documented in AS2187.2-2006).

Building damage and human discomfort will be minimal below the overpressure limits. ‘Conventional’ blasting at ‘normal’ distances is unlikely to create ground vibration levels of sufficient magnitude to cause building damage. Cracks in buildings are far more likely to be caused by local ground and foundation movements caused by the settlement and swell of the ground due to prolonged wet or dry weather.

4.2 Vibration

There are no current legislative criteria for vibration from construction blasting operations in South Australia. Therefore, vibration criteria have been developed following the advice of relevant Australian and international guidelines and standards.

4.2.1 Human Comfort

AS 2670[19] presents vibration levels that are used in several countries to specify satisfactory magnitudes of building vibration in relation to human response. Vibration criteria are given for continuous, intermittent and transient vibration events as multiplying factors to be applied to a base curve of human response to vibration, shown in Figure 2 below:

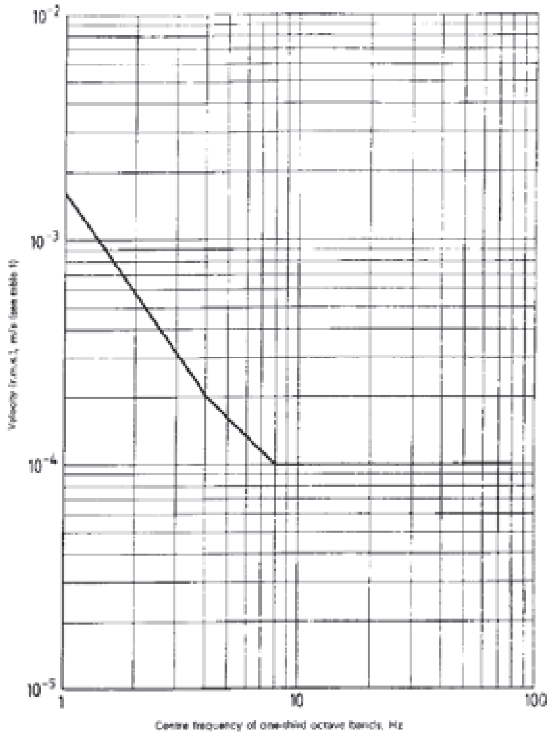

Figure 2: Building vibration z-axis base curve for velocity (Figure 2b of AS2670)

Table 3 shows these recommended multiplying factors for residences, for continuous, intermittent and transient vibration sources. Blasting is considered to be a transient vibration source. The risk of human discomfort is generally considered lower for short duration events and therefore less stringent criteria can be applied.

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[19] Australian Standard AS 2670.2:1990 – *Evaluation of human exposure to whole-body vibration. Part 2: Continuous and shock induced vibration in buildings (1 – 80 Hz)*

AS2187.2 guidance gives the following criteria to minimise the risk of human discomfort from airblast for operations lasting less than 12 months or 20 blasts. These are shown in Table 2.

Receiver Type	Peak component Particle Velocity (PPV)
Residential	120 dBL for 95% blasts and 125 dBL maximum unless agreement is reached with occupier that a higher limit may apply.
Commercial/Industrial	125 dBL maximum unless agreement is reached with the occupier that a higher limit may apply.

Table 2: Peak particle velocity limits set in AS2187.2

At the levels of vibration given in Table 3 the probability of adverse reaction is low.

Type of Building Occupancy	Time	Continuous or intermittent vibration	Transient vibration
Residential	Day	2 to 4	30 to 90
	Night	1.4	1.4 to 20

Table 3 Multiplying factors to be applied to base curves (see Figure 2).

4.2.2 Building Damage

Although vibrations induced in buildings by ground-borne excitation are often noticeable, there is little evidence that minor vibrations result in structural damage.[20] Variability in construction materials/ methods and uncertainty means there is considerable variation between international standards, why the British Standards Institution (BSI) did not provide guidance before 1992 and why there is still no International Organisation for Standardisation (ISO) guidance limits. There are however several standards that can be referred to.

If human comfort limits are met, building damage limits will be met since human comfort limits are generally more onerous.

Table 4 gives a summary of recommended vibration limits for buildings to prevent damage.

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[20] Building Research Establishment (1995), *Damage to Structures from Ground-borne Vibration*, BRE Digest

Standard/Guideline	Type of building	Recommended vibration limit	Comments
Australian Standard, AS 2187[21]	Houses and low-rise residential, commercial buildings not of reinforced or steel construction	10 mm/s*	For buildings particularly susceptible to vibration. Limit is for peak *resultant* particle velocity, measured on the ground adjacent to the structure
ANZECC Guideline[22]		5 mm/s PPV	Limit may be exceeded by 5% of blasts within a 12-month period, provided that maximum level of 10 mm/s is not exceeded at any time
British Standard, BS 7385[23]	Un-reinforced or light framed	15mm/s @ 4Hz rising to 20mm/s @ 15Hz then rising to 50mm/s @ 40Hz and above[1]	Limit is for peak particle velocity in x, y, and z directions
	Reinforced or framed structures	50 mm/s @ 4 Hz and above	Limit is for peak particle velocity in x, y, and z directions
German Standard, DIN 4150[24]	Structures of particular sensitivity or worthy of protection	3 mm/s to 20 mm/s@ <10Hz 3-40 mm/s @ 10-50Hz 8-50 mm/s @ 50Hz+ Also measurement at the top floor with limit of 8 mm/s to 40 mm/s across frequency range	Limit is for Peak Particle Velocity in x, y, and z directions Measurement on the top floor in x and y directions only
Swiss Standard, SN 640 312[25]	Structures of particular sensitivity	3mm/s to 12mm/s @ 10-30Hz 3mm/s to 18mm/s @ 30-60Hz	Limit is for peak particle velocity in x, y, and z directions

* This standard recommends a maximum of 10 mm/s unless agreement is reached with occupier that a higher limit may apply. The limit of 10 mm/s applies where operations last for less than 12 months, or involve less than 20 blasts, as would be the case for any given property at Lowly Point.

Table 4 Summary of Current Australian and International Standards and Guidelines

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[21] Australian Standard AS 2187.2 - 2006 *Explosives - Storage, transport and use. Part 2: Use of explosives*.

[22] Australian and New Zealand Environment Council (1990) *Technical basis for guidelines to minimise annoyance due to blasting overpressure and ground vibration*

[23] British Standard BS 7385: Part 2: 1993 *Evaluation and Measurement for vibration in Buildings Guide to damage levels from ground-borne vibration*.

[24] German standard DIN 4150: Part 3: 1986.

[25] Swiss Standard SN 640 312

The Australian Standard for storage, transport and use of explosives (AS 2187.2) specifies criteria for ground vibration to evaluate the impact of a blast upon human discomfort levels and structural integrity.

Ground vibration is measured as the peak particle velocity (PPV) at ground level. The likelihood of damage in residential areas starts to increase at ground vibration levels above 10 mm/s (PPV). The standard recommends a maximum level of 10 mm/s at any residential receptor. Experience has shown that damage is unlikely to occur at ground vibration levels below this level. The risk of cosmetic building damage is also lower for short duration events as they are less likely to 'excite' resonant frequencies in a building.

However, the standard cautions that where sensitive structures are identified measurements on the structure itself may be required to prevent damage.

The most stringent limit recommended is 3mm/s in the German and Swiss standards. This criterion is applicable to particularly sensitive constructions such as heritage buildings or structures that may be in a dilapidated state. While the Point Lowly lighthouse and associated cottages are considered to be of significant heritage value, a Conservation Plan for the Point Lowly Lightstation shows the lighthouse to have no apparent structural defects. Therefore, an increased criterion is appropriate for the lighthouse.

A vibration level limit of 5 mm/s has been adopted for the lighthouse and associated heritage cottages, and is unlikely to result in any damage to these buildings. A vibration level limit of 10 mm/s has been adopted for other residential properties. These recommendations, coupled with the limit of 25 mm/s for factories and commercial premises are in line with the ANZECC guideline and AS2187.2.

Table 5 summarises the recommended building damage vibration criteria:

Sensitive Receiver	**Vibration velocity level**
Pt Lowly Lighthouse Complex	5 mm/s PPV
Residential Properties on Port Bonython Road	10 mm/s PPV
SANTOS Industrial Facility	25 mm/s PPV

Table 5: Recommended Vibration Criteria for Building Damage

4.3 Underwater Noise and Overpressure

As discussed in Section 3, research into the effects of underwater noise and blasting on marine animals and plants is frequently inconclusive, and there are difficulties in applying the results of research for one species to another.

Some guidance on recommended exposure criteria for various species is presented in Lewis's[26] review of the effect of underwater explosions on marine life, as detailed below. However, these guidelines should be used as indicative guidance only, and applied with care, as there has not been sufficient research in the field to establish conclusively the safe exposure limits for underwater blasting.

Two criteria have been investigated, one for blast impulses and the other for pressure. Short duration, impulsive blast pulses could cause bodily injury, while high pressure levels may cause other forms of damage including hearing loss.

4.3.1 Marine Mammals

Yelverton et al[27] present damage thresholds for marine mammals expressed as maximum values for the impulse from the explosion blast wave. These results were obtained from tests of the effect of underwater explosions on terrestrial mammals, however marine mammals are expected to be less sensitive to explosions than similarly-sized terrestrial animals, due to their adaptation to the higher-pressures of the marine environment. Therefore, using these thresholds (presented below in Table 6) is expected to be conservative.

Damage Criterion	Impulse Threshold Pa-s[28]	Comments
Safe Level	34	No injuries
Trivial Injuries	69	Low probability of trivial lung injuries and no eardrum rupture
Slight Injuries	138	High incidence of slight blast injuries including eardrum rupture. Animals would recover on their own
Severe Injuries	276	No mortality. High incidence of moderately severe blast injuries including eardrum rupture. Animals should recover on their own

Table 6: Calculated Impulse Thresholds for Marine Mammals exposed to Underwater Explosions, from Yelverton et al

For larger mammals, Lewis presents results by Goertner[29] giving maximum horizontal extents for 'slight injury' (defined here as the threshold for when the animal experiences lung or intestinal injury) for marine mammals (whales, porpoises and manatees), for several explosive charge sizes. Goertner's quoted safe distances were of the order 250 m-3500 m for explosive charge sizes ranging from 545 kg to 18,200 kg.

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[26] Lewis, John A. (1996) *Effects of Underwater Explosions on Life in the Sea*. Defence Science and Technology Organisation

[27] Yelverton, Richmond, Fletcher, Jones (1975) *Safe distances from underwater explosions for mammals and birds* . Report DNA 3114T, Defence Nuclear Agency, Washington DC

[28] Impulse (in this context) is defined as the time integral of the pressure of the blast wavefront – effectively the blast pressure multiplied by duration, and may be considered a measure of the low-frequency energy content of the blast wave.

[29] Goertner, JF (1982) *Prediction of underwater explosion safe ranges for sea mammals* Technical Report NSWC TR-82-188, Naval Surface Weapons Center, Silver Spring, MD [cited in Lewis 1996]

For use in setting indicative safe exposure limits, the blast pressure and impulse corresponding to these safe distances were calculated using the blast data of Arons[30], and the most stringent of these values are given in Table 7 below.

Exposure guidelines for humans were obtained from guidance in O'Keefe and Young (1984)[36], and from the guidance of Gaspin (1983)[31].

Animal	Overpressure Threshold kPa	Impulse Threshold Pa-s
Whales – Large (55 ft length)	650	2000
Whales – Small (20 ft length)	365	1050
Porpoises – Adult	270	715
Porpoises – Calves	185	520
Humans	40	14

Table 7: Calculated Overpressure and Impulse Thresholds for Slight Injury to Mammals, from Goertner (1982), Gaspin (1983) and O'Keefe and Young (1984) data

Parvin et al (2007) present an overview of damage criteria for marine mammals, and recommend overpressure levels of 220 dB re 1μPa (i.e. 100 kPa). This is also in keeping with the guidance of the Canadian Fisheries[32].

The values of 100 kPa and 34 Pa-s have been adopted as conservative criteria for marine mammal exposure to underwater blasts.

An overpressure criterion of 40 kPa and an impulse criterion of 14 Pa-s have been adopted for humans in water.

4.3.2 Fish

Lewis also presents an equation for estimating the maximum horizontal range for fish mortality, obtained from the work of O'Keeffe(1984)[33]. This equation represents the maximum range from the blast of the 10% probability of fish kill contour, and contains constants which are adjusted for different fish sizes and depth of detonation.

An equation is given for estimating the size of the bulk cavitation zone, which corresponds to the "remote damage zone" where fish may be susceptible to tissue damage from the negative pressure wave resulting from reflection of the blast wave from the surface of the water. A combination of these equations may be used to estimate the area where adverse effects to fish from an underwater explosion may be expected.

4.3.3 Chelonians

Viada et al. (2008)[34] present an investigation into the impacts of underwater explosions on sea turtles, and present an equation from Young (1991)[35] estimating the safe range for sea

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[30] Arons, A.B. (1954) *Underwater Explosion Shock Wave Parameters at Large Distances from the Charge*, Journal of Acoustical Society of America, Volume 26, Number 3

[31] Gaspin, J.B. (1983). *Safe simmer ranges from bottom explosions* (Technical report 83-84). White Oak, MD: Naval Surface Weapons Center. [cited in O'Keeffe and Young 1984]

[32] Wright, D.G and Hopky, G.E (1998). *Guidelines for the Use of Explosives In or Near Canadian Fisheries Waters*, Canadian Technical Report of Fisheries and Aquatic Sciences 2107

[33] O'Keeffe, D.J. (1984) *Guidelines for predicting the effects of underwater explosions on swimbladder fish*. Technical Report 82-326, Naval Surface Weapons Center [cited in Lewis 1996]

[34] Viada, Hammer, Racca, Hannay, Thompson, Balcom and Phillips (2008) *Review of potential impacts to sea turtles from underwater explosive removal of offshore structures*. Environmental Impact Assessment Review 28, pp 267-285.

[35] Young, GA (1991) *Concise methods of predicting the effects of underwater explosions on marine life.* NTIS AD A241310 Naval Surface Weapons Center

turtles from an underwater explosion. Viada et al. compared the results of this equation with measured mortality results resulting from buried charges, with good agreement.

4.3.4 Invertebrates and Other Species

Yelverton et al. also present damage criteria for sea birds, both on the surface and diving beneath the surface. These criteria are given as impulse criteria, for several levels of damage, as presented in Table 8 and Table 9 below:

Damage Criterion	Impulse Threshold Pa-s	Comments
Safe Level	207	No injuries
Slight Injuries	276	No mortality. Slight blast injuries
Mortality Threshold	690	Most animals survive; moderate blast injuries experienced and should survive on their own
50% Mortality	896	Survivors seriously injured and might not survive on their own

Table 8: Calculated Impulse Thresholds for Birds (on surface) exposed to Underwater Explosions, from Yelverton et al..

Damage Criterion	Impulse Threshold Pa-s	Comments
Safe Level	41	No injuries
Trivial Injuries	69	Low probability of trivial lung injuries and no eardrum rupture
Slight Injuries	138	No mortality. Slight blast injuries and a low probability of eardrum rupture
Mortality Threshold	248	Most animals survive; moderate blast injuries experienced and should survive on their own
50% Mortality	310	Survivors seriously injured and might not survive on their own

Table 9: Calculated Impulse Thresholds for Birds (diving) exposed to Underwater Explosions, from Yelverton et al..

No damage criteria for invertebrates were available in the searched literature; however O'Keeffe and Young (1984)[36] concluded that commercially-important species, such as crabs and oysters are resistant to shock. Therefore, if the damage criteria for other species are complied with, then it is considered likely that damage to these species would be minimal.

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[36] O'Keeffe DJ and Young GA (1984) *Handbook on the environmental effects of underwater explosions.* Technical Report NSWC TR 83-240. Naval Surface Weapons Center

5 Environmental Impacts – Marine Blasting

5.1 Airblast

Predicting airblast levels from underwater explosions involves assessment of a large number of factors. While AS 2187.2 provides a formula giving airblast levels as a function of charge mass and distance, these relate to blasts in air. Since the blasting being considered will take place in rock, underneath a layer of silt, at the bottom of the ocean, the calculation methods for airblasts in AS 2187.2 are not appropriate.

Based on advice from the project blasting expert Mr Nick Elith (TechNick), an adverse impact to surrounding receivers from the airblast component of underwater blasting is considered to be highly unlikely. Losses from the underwater blast occur in the rock/silt interface (the ocean floor is covered by approximately 0.8m silt), the silt/water interface, and are damped by the pressure of water. Charges will also be spread and detonated non-simultaneously in order to reduce the instantaneous blast energy.

5.2 Vibration

5.2.1 Predicted Levels

Vibration levels from the blasting were predicted using the formula given in Appendix J of AS2187.2, which predicts ground vibration as a function of the explosive charge mass and distance from the charge. The formula can be calibrated to site conditions by modifying constants in the formula; however AS2187.2 gives values for these constants for ‘average’ conditions.

Vibration propagation on-site is highly dependent on the lithology of the site, and it is not known whether this equation is applicable to explosives detonated underwater. Further, when explosives are detonated in a blasthole underwater, the ground vibration component is expected to be higher than an equivalent blast in atmosphere, due to the greater density of seawater and therefore a higher resistance to the blast energy entering the water column. Therefore, this formula may underestimate the ground vibration from the underwater blasting.

Predicted vibration levels at the three nearest sensitive receivers resulting from a detonation of a 10 kg charge (detonated in series) at the most landward and seaward of the outfall pipe are presented in the table below (refer to Figure 1 for locations). The closest and furthest outfall locations were used to give a range of indicative vibration levels at the nearest receivers.

Vibration levels at the nearest sensitive receivers from detonation of a 7 kg charge at the intake locations are expected to be less than those shown in Table 10 and predicted for the outfall pipe locations. This is due to the smaller diameter pipeline, reduced charge size and the greater source-receiver distance between the intake locations and the nearest sensitive receivers.

Source Location	**Receiver**	**Distance**	**Indicative** Vibration Level (PPV)
O1 (Inshore)	Pt. Lowly Lighthouse	130 m	3.0-3.8 mm/s
	Pt. Lowly Cottages	144 m	2.6-3.4 mm/s
	Port Bonython Road Residences	330 m	0.7-0.9 mm/s
O3 (Offshore)	Pt. Lowly Lighthouse	770 m	0.2-0.3 mm/s
	Pt. Lowly Cottages	796 m	0.2-0.3 mm/s
	Port Bonython Road Residences	1061 m	0.1-0.2 mm/s

Table 10: Indicative Vibration Levels from 10 kg charge

These predicted levels are indicative only, as the final discharge location, charge mass and blasting technique would be determined during the detailed design phase. Further investigation will be undertaken at that time to determine the actual vibration propagation characteristics on-site.

5.2.2 Human Comfort

The human comfort criterion for transient vibration (such as blasting) is a multiplier of 30 for the AS2670.2 response curve. The formula in AS2187.2 does not give the frequency at which the vibration lies, and therefore when comparing with the criterion curve it is necessary to check all frequencies on the curve.

The minimum value of the AS2187.2 curve with a multiplier of 30 is 4.22 mm/s PPV, and therefore this value has been adopted as the human comfort criterion, as this represents the most conservative value of the curve.

Source Location	**Receiver**	**Indicative** Vibration Level (PPV)	**Human Comfort Criterion** (PPV)	**Meets Criterion?**
O1 (Inshore)	Pt. Lowly Lighthouse	3.0-3.8 mm/s	N/A	N/A
	Pt. Lowly Cottages	2.6-3.4 mm/s	4.22 mm/s	✓
	Port Bonython Road Residences	0.7-0.9 mm/s	4.22 mm/s	✓
O3 (Offshore)	Pt. Lowly Lighthouse	0.2-0.3 mm/s	N/A	N/A
	Pt. Lowly Cottages	0.2-0.3 mm/s	4.22 mm/s	✓
	Port Bonython Road Residences	0.1-0.2 mm/s	4.22 mm/s	✓

Table 11: Comparison of Indicative Vibration Levels from 10 kg charge with Human Comfort Criteria

The indicative vibration levels are below the human comfort criteria for all receivers and for all source locations, and therefore it is considered likely that little or no adverse impact on human comfort from the blasting operations due to vibration would occur.

5.2.3 Building Damage

Table 12 presents a comparison of indicative vibration levels from a 10 kg charge with the building damage criteria.

Source Location	Receiver	Predicted Vibration Level (PPV)	Building Damage Criterion	Meets Criterion?
O1 (Inshore)	Pt. Lowly Lighthouse	3.0-3.8 mm/s	5 mm/s	✓
	Pt. Lowly Cottages	2.6-3.4 mm/s	5 mm/s	✓
	Port Bonython Road Residences	0.7-0.9 mm/s	10 mm/s	✓
O3 (Offshore)	Pt. Lowly Lighthouse	0.2-0.3 mm/s	5 mm/s	✓
	Pt. Lowly Cottages	0.2-0.3 mm/s	5 mm/s	✓
	Port Bonython Road Residences	0.1-0.2 mm/s	10 mm/s	✓

Table 12: Comparison of Indicative Vibration Levels from 10 kg charge with Building Damage Criteria

5.2.3.1 Residential Receivers

The predicted indicative vibration levels from a 10 kg charge are significantly below the building damage criterion of 5 mm/s PPV for non-heritage residential receivers at the nearest receiver location, being the residential properties on Port Bonython Road. Therefore, no significant building damage impact is expected from the underwater blasting.

5.2.3.2 Heritage Structures

The predicted indicative vibration levels from a 10 kg charge are below the building damage criterion of 5 mm/s PPV for the heritage structures at Point Lowly (the Point Lowly lighthouse and associated cottages), for both source locations considered.

5.3 Underwater Overpressure

5.3.1 Prediction Methodology

The situation of the proposed Olympic Dam desalination plant, with a buried underwater charge, is different to the situation of much of the literature into underwater explosions in that the charge is buried and is located in relatively shallow water. The investigations in the literature were based on unburied charges within the water column, and detonated in deep water such that the blast wave had not reached the surface at the point of measurement.

As an initial estimate of the likely impact of the underwater blasting on marine life, predictions have been made using the published explosion data of Arons[30], and the safe distance equations for fish and turtles presented in Lewis[26] and in Viada et al.[34].

The research of Arons was obtained for deep-water explosions of unconfined charges, which is likely to result in conservative predictions compared to a buried charge (Connor[37] suggests that the peak pressure from a buried charge may be as low as 10% of the pressure for an unconfined charge); however the presence of the sea floor and water/air

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[37] Connor, JG Jr (1990) *Underwater Blast Effects from Explosive Severance of Offshore Platform Legs and Well Conductors*, TR 90-532, Naval Surface Warfare Center

interface will act to largely confine the blast wave to a shallow layer of water, which would increase the blast pressure compared to the deep-water case of Arons.

These two effects tend to act in opposition – the buried charge is likely to decrease the blast pressure, while the shallow water is likely to increase it.

The data from Arons was obtained for TNT and pentolite high explosives. A commercial emulsion explosive ("blasting gel") would be used for any blasting for this project. Blasting gel produces 85% of the pressure and 85% of the impulse of TNT[38], and therefore using the values from Arons results in a conservative assessment.

Nick Elith has been consulted to gain a better understanding of the pressure levels to be expected, and explosive charges of 10kg for the larger outfall pipe, and 7kg for the intake pipe have been ascertained.

5.3.2 Predicted Safe Distances for Marine Life

Indicative safe distances for marine life have been calculated using the pressure and impulse relationships quoted in Arons, and the safe distance formulae presented in Lewis and in Viada et al. Where there are a selection of damage criteria available in the literature (such as for marine mammals), the most stringent (i.e. least impact on marine life) has been adopted in calculating the safe distances.

For some animals, no criteria for safe exposure distances (i.e. the distance at which no damage is expected to the animal) are available in the studied literature (e.g. fish), and the criteria are given based on preventing mortality.

Predicted safe distances for various animals from a 10 kg MIC charge are presented in Table 13. Limits are based on impulse criteria since these are deemed to be most relevant to fish and mammal injury or death, and are more stringent than pressure criteria.

Animal	Criterion	Predicted Safe Distance from Blast
Fish	10% Mortality Threshold	235 m – 285 m
Turtles	Safe Level	450 m – 500 m
Marine Mammals	Safe Level	450 m - 600 m
Humans (in water)	Safe Level	1250 m - 1350 m

Table 13: Indicative Safe Distances for Marine Animals from 10 kg charge

These safe distances may be used to establish exclusion zones around the blast that can be used to minimise the impact of the blast on marine animals.

The commercial fish aquaculture farms in Fitzgerald Bay are located approximately 1.2 km north of Point Lowly[39], and therefore lie beyond the calculated safe distances for fish from the underwater blasts. It is our understanding that divers regularly inspect underwater fish enclosures. To ensure that the aquaculture divers are not adversely affected by the marine blasting operations, there must be co-ordination between aquaculture farm and the marine blasting operations.

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[38] USA National Counterterrorism Center *TNT Equivalents for Various Explosives and Fuel-Air Mixtures* www.nctc.gov/site/images/technical/tnt_equivalents.pdf accessed 20/11/2008

[39] Olympic Dam Draft EIS Chapter 16, *Marine Environment*

Presented in Figure 3 is the proposed marine mammals and humans in water exclusion zone during blasting operations

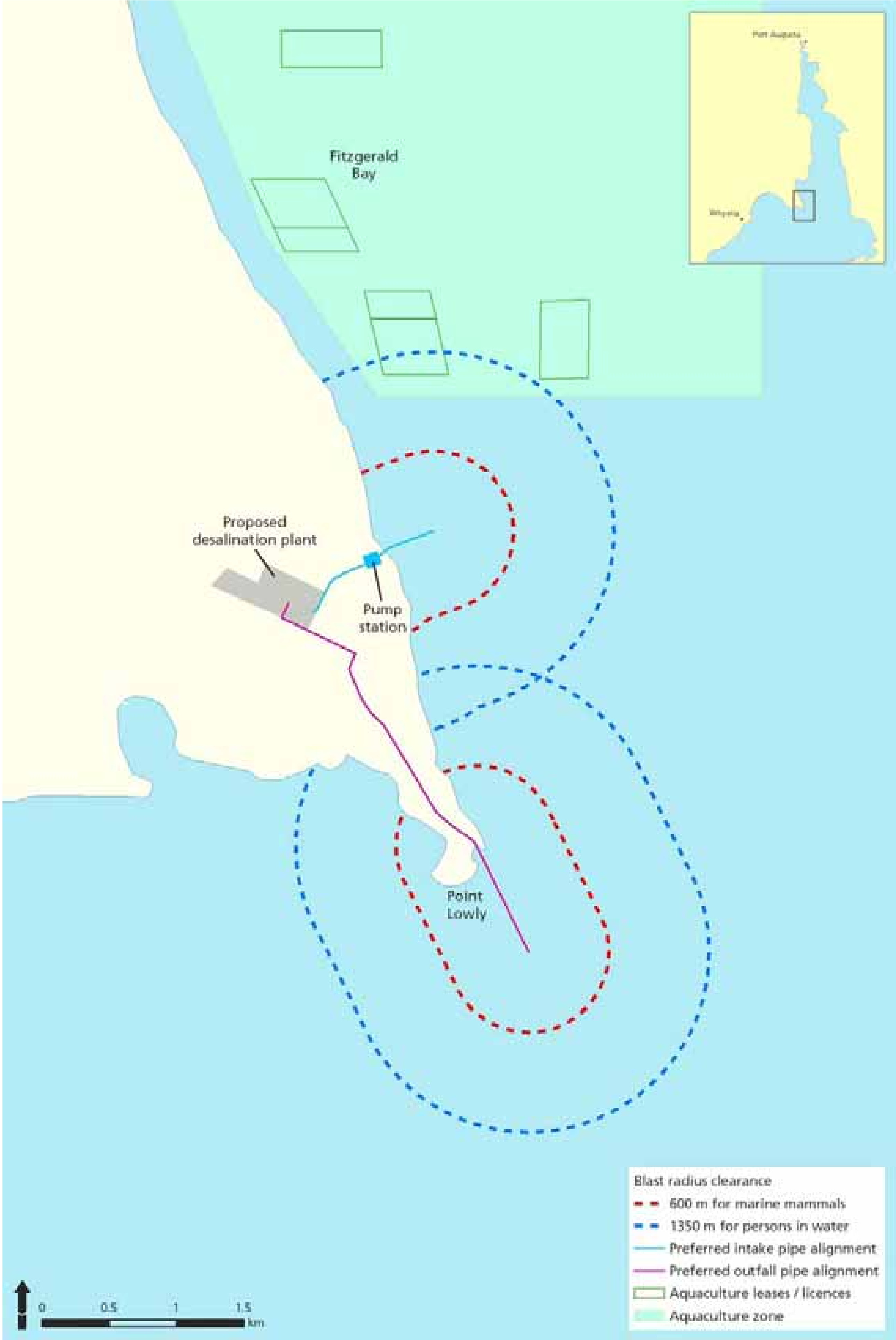

Figure 3 Marine mammals and humans in water exclusion zone

5.3.3 Effect on Marine Vegetation

O'Keeffe and Young[36] formulated equations to predict the radius of catering for bottom explosions. These equations have been used, along with the observations of Ludwig, to estimate the area surrounding each blast site that may be permanently affected by the blasting operation. In the extreme case, this area potentially represents a permanent loss of habitat, particularly for sensitive species.

Using this equation, the cratered zone around the blast size has been estimated to be 1.6 m radius, with the total affected zone (based on Ludwig's observations) estimated to be 29 m radius from the blast location. However, as the proposed blasting for the Olympic Dam project consists of drilled charges, using the O'Keeffe and Young equations is expected to be conservative.

6 Environmental Impacts – Land Blasting

Terrain blasting associated with the installation of a pipeline from shore to the desalination plant may occur. Land based blasting may occur in areas where it is not practical to employ mobile excavators and could only occur during daytime hours.

6.1 Criteria

There are no current legislative criteria for vibration from construction blasting operations in South Australia and therefore guidance has been sort from AS 2187.2[40]. Criteria for airblast and ground vibration from land blasting are therefore the same as for marine blasting, as detailed in Section 4 of this report.

It should be noted that the criteria are based on a low probability of reaction. With close cooperation and liaison with occupants of affected properties, significantly higher levels of short-term vibration could be tolerated by many people for construction projects. In many instances, there may be a trade-off between the magnitude and duration of construction related vibration.

6.2 Airblast and Ground Vibration Impacts

Vibration propagation is dependent on the terrain type between the source and receiver.

Point Lowly consists of fixed desert dunes and associated sand spread, as well as some modern beach and sand dunes. There are fragments of bedrock along the coastline which consist of dense quartzite from the Tent Hill Formation

Coastal buildings and residential dwellings are in the vicinity of potential blast sites as well as the heritage listed Point Lowly lighthouse. There is also an existing refinery and associated infrastructure, including a jetty from the refinery into the Spencer Gulf.

The risk of human discomfort is generally considered lower for short duration events and therefore less stringent criteria can be applied. The risk of cosmetic building damage is also lower for short duration events as they are less likely to 'excite' resonant frequencies in a building.

The airblast and ground vibration impacts of the land blasting component of the construction works will be controlled by designing the blast parameters to achieve the appropriate criteria from AS2187.2.

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[40] Standards Australia, AS2187.2 Explosives – Storage and Use Part 2: Use of Explosives, 2006 (Appendix J).

7 Management Measures

Management measures to mitigate terrain blasting are:

- Provision of advance notice to people in the Point Lowly area.
- Pre- and post- blasting Building Condition Surveys would be undertaken at Point Lowly Lighthouse.
- Development and monitoring of blast patterns to ensure compliance with the appropriate airblast and vibration criteria would be undertaken.
- Accurate records describing the location of each blast and all the blastholes, the design of the blast in terms of explosives and initiating system usage and any ground vibration or airblast measurement data would be kept.

As discussed in Section 3.5, the use of scare blasts is not considered appropriate for this project.

Management measures to mitigate marine blasts are:

- Providing a safe exclusion zone of up to 600m for marine mammals and 1,350m for humans in the water. This zone would be established by measures including:
    - A co-ordinated approach between marine blasting operations and divers at the aquaculture farm in Fitzgerald Bay.
    - Conducting pre- and post-detonation surveys for marine mammals and turtles in the exclusion zone
    - Monitoring the surrounding area for marine mammals and turtles and delaying detonations until the zone is free of such animals
    - Use of boats or similarly noisy operations
- Scheduling blasts during times when marine life in the vicinity is at a minimum as established through consultation with marine biologists or the other researchers with detailed knowledge of the area surrounding Point Lowly.

This would include as a minimum scheduling blasting from 1 November to 1 May when the Australian Giant Cuttlefish is not breeding in the Point Lowly area.

- If any of the listed marine species given in Table 16.4 of the Draft EIS for the Olympic Dam Expansion is found in the exclusion zone around the blast zone, the blasting should be delayed until the animal has departed the exclusion zone
- High-velocity explosives with a detonation rate of 7600 m/s or greater would be used
- Each explosive charge would not exceed 10 kg
- A test blast would be conducted before full-scale blasting commenced, including monitoring of blast parameters (pressure and impulse) at various distances from the charge. A survey of the calculated exclusion zone area surrounding the blast would be conducted both before and after the test blast in order to assess the effect of the blast on local marine life.
- Bubble curtains or other screening measures would be investigated and used if feasible and reasonable to restrict the blast wave propagation underwater.
- The feasibility and extent of likely benefit resulting from conducting blasting during 'dodge tides[41]' - where the water column may be stratified – would be investigated, as this may take advantage of wave refraction through the stratified water column bending

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[41] A feature of Upper Spencer Gulf where the tide cycles result in a fortnightly occurrence of only one tide per day

blast waves towards the water surface and minimise propagation of blast waves within water.

8 Summary

Predictions have been made to investigate the effect of underwater blasting from the construction of the proposed desalination plant for the Olympic Dam Expansion project on nearby residential receivers, heritage structures, and on marine species in the vicinity of the blast. Limits according to AS2187.2 have been set for human comfort, building damage and atmospheric noise. Predicted airblast levels and ground vibration levels at nearby receivers are such that adverse effects on human comfort or structural damage to heritage structures are considered unlikely.

A review of the literature has been undertaken, this has been used to calculate a conservative exclusion zone around the blast site, outside of which adverse effects to marine life are not expected. The safe exclusion zone proposed is 600m for marine animals and 1,350m for humans in the water.

Management measures have been proposed to minimise the effect of the underwater blasting on marine life, including measures aimed to keep marine life outside of the exclusion zone during the blast, and of minimising the blast propagation into the surrounding water. Expert consultation has been sought from Mr. Nick Elith on underwater blasting and a maximum charge size of 10 kg has been proposed.