Appendix 18

Hydrology and hydrogeology of Blaydin Point, Darwin

REPORT

Ichthys Gas Field Development Project

Hydrology and Hydrogeology of Blaydin Point, Darwin

Prepared for

INPEX Browse, Ltd

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Section 1 Introduction

1.1 Background

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

The two reservoirs which make up the field are estimated to contain 12.8 tcf (trillion cubic feet) of sales gas and 527 MMbbl (million barrels) of condensate. INPEX will process the gas and condensate to produce liquefied natural gas (LNG), liquefied petroleum gas (LPG) and condensate for export to overseas markets.

For the Ichthys Gas Field Development Project (the Project), the company plans to install offshore facilities for the extraction of the natural gas and condensate at the Ichthys Field and a subsea gas pipeline from the field to onshore facilities at Blaydin Point in Darwin Harbour in the Northern Territory. A two-train LNG plant, an LPG fractionation plant, a condensate stabilisation plant and a product loading jetty will be constructed at a site zoned for development on Blaydin Point. Around 85% of the condensate will be extracted and exported directly from the offshore facilities while the remaining 15% will be processed at and exported from Blaydin Point.

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

Assessment will be undertaken in accordance with the Environment Protection and Biodiversity Conservation Act 1999 (Cwlth) (EPBC Act) and the Environmental Assessment Act (NT) (EA Act). It was agreed that INPEX should submit a single EIS document to the two responsible government departments for assessment.

URS Australia Pty Ltd was commissioned to carry out environmental work associated with INPEX's preparation of the EIS and this technical report, Ichthys Gas Development; Hydrology and Hydrogeology of Blaydin Point, Darwin, was prepared in part fulfilment of that commission.

1.2 Scope of Work

The scope of work to be covered by this report includes the following;

- Review previous reports and other publically available information, related to hydrogeology at Blaydin Point,
- Review of the geotechnical drilling program carried out by ARUP on behalf of INPEX,
- Undertake low-flow permeability testing of selected bores,
- Construct a conceptual Hydrological model of the Project site[1],

[1] The Project site refers to the onshore facilities of the Project located at Blaydin Point. The Project site extends to the same limits as the proposed plant

- Construct a basic numerical model from the available data to quantify the water resources and assess potential impacts to the water regime, and
- Report on the results.

The groundwater dependency of vegetation communities at Blaydin Point is not within the scope of this study. Refer to Chapter 8 *Terrestrial impacts and management* of the Draft EIS for a discussion on the potential impact of changes in surface water and groundwater to vegetation.

1.3 Previous Reports

1.3.1 General

Reports that were available during the review and were applicable to Blaydin Point and surrounding areas were;

- Environmental Studies for the Second Darwin Power Station, East Arm, Port Darwin, Environmental Resources of Australia, 1973.
- Channel Island to Katherine Transmission Line- Preliminary Environmental Report, Dames & Moore International, 1988.
- Water Main Cochrane Road to East Arm Port- Geotechnical Investigation, Ullman & Nolan Geotechnic, 1996.
- Blackmore River (East) Aquaculture Project, Middle Arm, Darwin Harbour, NT- Public Environment Report, URS, 2001.
- Aussie Prawns Aquaculture Development- Public Environment Report, Kellogg Brown & Root, 2005.

1.3.2 Surface Water

Reports that were available during the review and were applicable to Blaydin Point and surrounding areas were;

- Middle Arm Peninsula Industrial Subdivision Preliminary Environmental Report, Dames & Moore, 1990.
- Middle Arm Stormwater Drainage Study, Willing & Partners, 1991.
- Middle Arm Peninsula Industrial Subdivision Preliminary Environmental Report, Dames & Moore, 1990.
- Hidden Valley/ East Arm/ Berrmiah- Stormwater Drainage Study, Willing & Partners, 1991.
- Berrimah/ East Arm Industrial Area- Stormwater Drainage Study, Willing & Partners, 1999.

1.3.3 Groundwater

Available reports for groundwater are;

- Wickham Point Water Main Chainage 0 km - CH 4.6 Km (Channel Island Road) Geotechnical Investigation Report, Ullman & Nolan Geotechnic, 2002.
- Middle Arm Peninsula Industrial Subdivision Preliminary Environmental Report, Dames & Moore, 1990.

- Cox Peninsula Hydrogeology Report, Verma, M.N., 1982.
- Proposed Wickham Point Water Main- Part B: Ch 4.6 km to Ch 9.0 km, Adjacent to Channel Island Road, Middle Arm, NT- Geotechnical Report, Douglas Partners, 2002.

1.4 The Project Area

The Project site refers to the land on which the onshore plant is proposed to be built. It is located within Litchfield Shire on the southern banks of East Arm Harbour. The Project site consists of a raised section of land forming a 'peninsula' that supports terrestrial vegetation communities. This land is surrounded by tidal flats typically 300-1000 m wide that support mangrove communities and salt flats. The Project site is bound on the western side by Lightning Creek, by East Arm that is part of Darwin Harbour to the north and on the east by the mouth of the Elizabeth River (Figure 1).

The vegetation communities and the proposed LNG plant footprint are shown in Figure 2 and are described below.

Terrestrial Vegetation Communities

An investigation into the vegetation types at Blaydin Point was carried out by GHD (2008). The terrestrial vegetation communities are presented in Figure 2 and consist of:

- Melaleuca communities (vegetation mapping units 1 and 2): forests and mixed species low woodlands that typically occur at lower elevation than adjacent Eucalypt woodlands or Monsoon Vine Forest.
- Eucalyptus communities (vegetation mapping unit 3): The central peninsula area is composed of *Eucalyptus miniata* and *Eucalyptus tetrodonta* woodlands to the north and along a narrow corridor along the western boundary.
- Monsoon Vine Forest (vegetation mapping unit 4): Located in the south eastern quarter of the Project site.
- Casuarina and Beach Forest (vegetation mapping unit 14): Located along a sandy deposit (at an elevation above tidal influences) that forms a promontory on the northern tip of Blaydin Point.

Mangrove and Tidal Flat Communities

The distribution of mangrove communities at Blaydin Point and elsewhere in Darwin Harbour, reflects differences in tidal level, tidal inundation frequency, tidal erosion and sedimentation, wave action and freshwater recharge (for hinterland fringing mangroves) that creates a variety of environmental conditions. Mangrove species tend to assemble in distinct communities which form a predictable pattern of zones or assemblages from landward to seaward. The main mangrove communities that occur along the intertidal gradient are:

- Hinterland Fringe (vegetation mapping unit 12): A mixed species community that occurs as a narrow fringe (~20-30 m wide) at the interface between the hinterland (terrestrial) and the main tidal flat. Soils are often waterlogged during the wet season (by freshwater inflow) that this community receives in frequent tidal inundation.
- Salt Flats (vegetation mapping unit 8): These are areas composed of either bare mud flat or may support areas of sparse samphire shrublands. The salt flats are located at higher elevations on the

tidal flat and receive tidal inundation during spring tides[2], hence saline soils generally preclude mangrove growth.

- *Ceriops* Closed forest (vegetation mapping unit 5): *Ceriops australis* is the dominant species often forming very extensive stands. Height varies from 3-6m depending on salinity regime. Soils are mainly muds and muddy sands. This community occurs across much of the tidal flat area adjacent to Blaydin Point and elsewhere on the Middle Arm peninsula. Tidal inundation in this zone is daily.

- *Rhizophora* Closed Forest (vegetation mapping unit 10): Also referred to as “Tidal Creek Forest” in the mapping, however, it also occurs on the eastern side of Blaydin Point in areas where no tidal creeks occur. In this case the *Rhizophora* zone occurs as shore parallel band between the *Ceriops* and *Sonneratia* zones. The dominant species is *Rhizophora stylosa,* which typically forms a closed canopy forest 6-10m in height. Soils are waterlogged (due to daily tidal inundation), root structured muds.

- *Sonneratia* Woodland (vegetation mapping unit 13): Seaward-most mangrove zone that occurs along the harbour shoreline. *Sonneratia alba* is the dominant species typically occurring as large widely spaced trees in an open woodland community. Areas of bare mudflat, devoid of vegetation are common between the large trees and sediments consist of unconsolidated marine mud.

Mangrove and tidal flat communities have been classified as a wetland zone by the Northern Territory Department of Infrastructure, Planning and Environment (DIPE, 2004b).

The Hinterland Fringe has an increasing slope and is composed of organic rich soils (URS, 2008). Should the water levels within the Hinterland Fringe Zone decline, seasonal variation within groundwater levels is likely to provide wetting and drying cycles. This has the potential to produce a moderate risk of acid producing soils developing in the Hinterland Fringe Zone (DIPE, 2004a).

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[2] Spring tides occur over a fortnightly cycle. When there is a new moon or a full moon, the effects of the sun and the moon on the tides produces a maximum range in tides. The alternative is when the moon is in it first or third quarter when a minimum range in tide occurs, this is known as a neap tide.

Section 2 Groundwater Drilling and Testing Program

2.1 Groundwater Drilling

2.1.1 Pre-Existing Groundwater Monitoring Bores

Limited groundwater drilling has occurred in the near vicinity of the proposed Project site. Two pre-existing bores are present in the immediate area of the Project, with bore logs available for one. RN21856 is 2.7 km to the south-south east of ONBH10 on the Project site and intersected shallow laterite to 3 metres below ground level (m bgl). The lithology listed on the RN21856 bore log indicates the laterite overlies shale and schist to a depth of 60 m.

Groundwater quality maps produced of the Project site and surrounding land by NRETA (Verma *et al*, 2004) indicates groundwater below the Project site is generally brackish. Based on the available information, bores in the area may be expected to yield less than 5 L/sec encountered from weathered and fractured bedrock.

2.1.2 Groundwater Monitoring Bores

Ten groundwater monitoring bores were drilled and constructed by J & S Drilling using a hollow auger drilling method. Construction details are available in Table 2-1. Bore logs and core photographs are available in ARUP's report titled "Ichthys Gas Field Development Onshore Ground Investigation Factual Report" prepared in June 2008 for INPEX Browse, Ltd.

Ten groundwater monitoring bores were installed at the Project site between April and June 2008. The bores are grouped into northern bores (ONBH01, ONBH02, ONBH03, ONBH04, ONBH05 and ONBH06) and southern bores (ONBH07, ONBH08, ONBH09 and ONBH10) (Figure 1).

Groundwater monitoring bores are cased using Class 18 uPVC pipe with a diameter of 50mm. Screened intervals comprise machine slotted Class 18 uPVC slotted pipe with a filter sock. The annuli of the bores are lined with washed, 4 mm diameter gravel pack adjacent to the slotted intervals with a one metre bentonite seal set above the gravel pack. The remainder of the annuli was filled with a grout seal to ground surface.

Where a confining layer of clay or siltstone was encountered, a shallow bore was installed to monitor possible perched aquifers. Four shallow groundwater monitoring bores, denoted by the letter 'A', were installed adjacent observation bores ONBH01, ONBH02, ONBH05 and ONBH07.

Table 2-1 Groundwater Bores - Construction Details

Bore	Collar Co-ordinates			Total Cased Depth (m bgl**)	Screened interval (m bgl**)	Screened Interval Lithology
	Easting	Northing	Ground Elevation (m AHD*)			
ONBH01	708484.8	8615807.4	7.699	19.5	13.5 - 19.5	Silt, Clay, Sand and Gravel
ONBH01A	708484.8	8615807.4	7.699	6.0	2.5 - 6.0	Silt, Clay, Sand and Gravel
ONBH02	708327.3	8615755.0	7.734	20.0	14.0 - 20.0	Gravel/Sand
ONBH02A	708327.3	8615755.0	7.734	10.0	6.8 - 10.0	Gravel/Sand
ONBH03	708084.8	8615435.9	5.246	10.0	7.00 - 10.0	Sand and Gravel
ONBH04	708185.0	8615454.1	7.789	17.0	11.0 - 17.0	Sand and Silt
ONBH05	708602.2	8615393.0	10.617	20.0	14.0 - 20.0	Sand and Gravel
ONBH05A	708602.2	8615393.0	10.617	10.0	6.7 - 10.0	Sand and Gravel
ONBH06	708846.9	8615421.3	7.858	16.0	10.0 - 16.0	Clay, Sand and Silt
ONBH07	708890.7	8615147.6	8.801	15.0	12.0 - 15.0	Sand and Gravel
ONBH07A	708890.7	8615147.6	8.801	9.0	6.8 - 9.0	Sand and Gravel
ONBH08	709142.4	8615000.8	6.321	9.0	3.0 - 9.0	Silty Sand and Gravel
ONBH09	708902.2	8614670.1	7.704	6.5	3.5 - 6.5	Sand/Silt
ONBH10	709001.4	8614204.3	8.071	6.0	3.0 - 6.0	Silty Clay

* AHD = Australian Height Datum   ** bgl = below ground level

A brief description of the intersected lithology is provided below.

ONBH01

ONBH01 intersected sandy clays in the upper portion of the bore hole. The underlying phyllite bedrock has been variously weathered.

A shallow bore was constructed 3.5 m from bore ONBH01.

ONBH02

ONBH02 intersected gravelly sediments. The underlying phyllite and siltstone bedrock has been variously weathered.

A shallow bore was constructed 1.9 m from bore ONBH02.

ONBH03

ONBH03 intersected clay, siltstone and minor gravelly sediments. The underlying bedrock is phyllite.

ONBH04

ONBH04 intersected sand, silt and gravel. The underlying phyllite and siltstone bedrock has been variably weathered.

ONBH05

ONBH05 intersected sand, silt and gravel sediments. The underlying phyllite bedrock has been variably weathered.

A shallow bore was constructed 2.1 m from bore ONBH05.

ONBH06

ONBH06 intersected clay, silt, sand and gravel sediments. The underlying phyllite bedrock has been variably weathered.

ONBH07

ONBH07 intersected clay, silt, sand and gravel sediments. The underlying phyllite bedrock has been variably weathered.

A shallow bore was constructed 2.3 m from bore ONBH07.

ONBH08

ONBH08 intersected sand, silty sand and gravel sediments. The underlying bedrock is phyllite.

ONBH09

ONBH09 intersected clay, silt and sand sediments. The underlying bedrock is phyllite and siltstone.

ONBH10

ONBH10 intersected silty clay sediments. The underlying bedrock is phyllite and siltstone.

2.2 Bore and Aquifer Testing

2.2.1 Constant Discharge and Recovery Tests

A constant discharge rate pump test was carried out at each deep bore site. Bores which had an accompanying shallow bore were monitored during pumping for a decline in standing water level. Prior to carrying out the pump test, details relating to the bore were recorded such as initial water levels, bore depths, stand pipe heights and the pump inlet depth.

The pump used was a 12V electric submersible pump. Pumping rates were measured through a manual tipping bucket flow meter. Electric contact meters (dip meters) were used to measure groundwater levels in both the pumped bore and available observation bores.

The constant discharge rate pump test enables the hydraulic characteristics of the aquifer intersected by the screened section of the monitoring bores to be determined. The screened interval extends the full depth of the aquifer where possible, thereby providing depth averaged hydraulic parameters for the aquifer. Results of the constant discharge rate pump test are presented below in Table 2-2.

Transmissivity values for the aquifer at each bore hole were calculated using the Cooper Jacob Method, using water level recovery data.

Table 2-2 Constant Rate Discharge Pump Test Results

Bore	Date of Test	Pumping Rate (kL/d)	Final Drawdown (m)	Transmissivity (m^2/d)
ONBH01	2/07/2008	11.7	1.18	43
ONBH02	2/07/2008	11.9	0.37	217
ONBH03	3/07/2008	10.5	5.56	0.5
ONBH04	3/07/2008	12.1	3.12	2
ONBH05	4/07/2008	11.1	0.08	38
ONBH06	4/07/2008	11.5	0.60	6
ONBH07	5/07/2008	10.3	7.40	0.3
ONBH08	5/07/2008	7.7	2.48	2
ONBH09	6/07/2008	8.6	1.01	3
ONBH10	6/07/2008	8.6	1.28	13

ONBH01

ONBH01 was pumped at a constant pump rate of 11.7 kL/d. After two minutes of pumping the drawdown was relatively linear and followed a downwards sloping trend (Figure 3). The test was terminated after four hours followed by monitoring of groundwater level recovery for half an hour. During this time, the groundwater level returned to within 10% of the original standing groundwater level. The recovery of the bore followed an approximate linear trend. Analysis of the recovery data indicated a transmissivity of 43 m^2/d.

ONBH02

ONBH02 was pumped at a constant rate of 11.9 kL/d for two hours. The initial drawdown in the bore was 0.18 m, after which the drawdown remained relatively constant with the water level fluctuating between 5.66 and 5.67 m bgl. The pump test ceased after 116 minutes. Transmissivity was calculated to be 217 m^2/d (Figure 4).

ONBH03

ONBH03 was pumped at a constant rate of 10.5 kL/d for four hours. The drawdown of 3.3 m occurred in the first 35 minutes. The pumping water level then stabilised at a depth of 4.56 m bgl (Figure 5).

Recovery was monitored for half an hour until the water level was close to the standing water level measured prior to the pump test being carried out. A transmissivity value of 0.5 m^2/d calculated from the recovery data.

ONBH04

ONBH04 was pumped at a constant rate of 12.1 kL/d. Pumping groundwater levels began to recover after 60 minutes of continuous pumping (Figure 6), most likely due to bore development. Transmissivity for the recovery data was 2 m^2/d.

ONBH05

ONBH05 was pumped at a constant rate of 11.1 kL/d. The drawdown response of ONBH05 followed a stepped pattern with an overall draw down of 0.08 m from the initial standing water level (Figure 7).

Groundwater recovery followed a very rapid linear trend over five minutes. Monitoring of the groundwater recovery was terminated when the water level reached pre-pumping levels. Transmissivity values from the recovery data was calculated at 38 m^2/d.

ONBH06

ONBH06 was pumped for four hours at 11.5 kL/d. The drawdown followed a rapid linear decline over the first ten minutes (Figure 8).

Groundwater recovery was very rapid and returned to within 1 cm of the initial water level within ten minutes. Transmissivity calculated from the recovery data was 6 m^2/d.

ONBH07

ONBH07 was pumped at a constant rate of 10 kL/d for four minutes. The pump test was stopped due to the rapid decline in groundwater levels (Figure 9).

Recovery of the water level was gradual and returned to within 0.03 m of the initial water level in 90 minutes. Transmissivity was calculated at 0.3 m^2/d.

ONBH08

ONBH08 was pumped at a rate of 7.7 kL/d for four hours. Drawdown occurred rapidly for the first ten minutes to 6.75 m bgl. The rate of drawdown then slowed, with a total drawdown of 0.17 m at the end of the test (Figure 10).

Recovery was monitored for 35 minutes until the water level was within 10% of the initial standing water level. Transmissivity was 2 m^2/d.

ONBH09 & ONBH10

Both ONBH09 and ONBH10 had rapid draw downs where the water level declined to the level of the pump before readings could be taken. Groundwater recovery was monitored and both bores showed similar sinusoidal response patterns. ONBH09 recovered over 45 minutes to within 0.05 m of the initial standing water level (Figure 11). ONBH10 took longer to recover (Figure 12) and was monitored for 120 minutes, with an additional observation made 240 minutes after pumping ceased. Transmissivity calculated from the recovery data was 3 m^2/d for ONBH09 and 13 m^2/d for ONBH10.

2.3 Groundwater Quality

The results of the water quality analysis for dry season and wet season water quality represent pre-development water quality. It is likely that the concentration of metals within the groundwater is reflective of hydrogeochemical interactions within the aquifer.

Methods

Dry season groundwater samples were collected at the end of the pump tests carried out by URS. Wet season groundwater samples were collected as part of a specific groundwater sampling round. Groundwater was pumped from the groundwater monitoring bores using a low flow, centrifugal pump. In-situ water quality parameters were monitored during groundwater extraction. Variation in the in-situ parameters was observed, and groundwater samples were collected when there was little variation between parameter readings.

Groundwater samples were chilled in ice and sent to the Northern Territory Environmental Laboratories (NTEL), a NATA accredited laboratory, for analysis. The following sections detail the results of the in-situ and laboratory analysis of the groundwater samples.

Physicochemical Parameters

Groundwater quality was sampled in July 2008 (dry season) and in March 2009 (wet season).

Water samples analysed for the dry season groundwater quality found the groundwater was of low salinity through the central portions of the Project site. Groundwater salinity was highest in ONBH03 near the mangroves, compared to bores located closer to the central portions of the site (Figure 13). ONBH02, ONBH04, ONBH05 and ONBH09 have low salinity readings and are similar salinity ranges for rainwater and drinking water. Generally, most other bores are brackish to saline.

Water samples analysed for the wet season found a similar groundwater salinity distribution compared to the dry season. Groundwater salinity was highest in ONBH03 compared to other bores ONBH01, ONBH02, ONBH04, ONBH05 and ONBH06 that have low salinity readings similar to rainwater and drinking water. Brackish water occurred in all other bores.

Dry season pH levels were neutral to slightly acidic and varied between 4.69 and 6.30. Dry season pH contours are presented in Figure 14. Wet season pH levels were neutral to slightly acidic and varied from 4.63 to 6.18.

Major Ions

Wet season water samples analysed found ONBH01, ONBH02, ONBH04, ONBH05, ONBH06 and ONBH8 had decreased concentrations of chloride, calcium, potassium, magnesium, sodium, alkalinity and total dissolved solids compared to the dry season samples (Table 2-3).

Wet season water samples in ONBH03, ONBH07, ONBH09 and ONBH10 had increases in chloride, magnesium and total dissolved solids compared to dry season results. Potassium concentrations declined in all bores, while sodium declined in ONBH03. Alkalinity declined in ONBH07, ONBH09 and ONBH10.

Metals and Metalloids

Groundwater quality parameters for metals and metalloids have been compared to ANZECC (2000) trigger value guidelines for toxicity for fresh water and marine water (Table 2-4). Comparisons with freshwater trigger values have been used to asses the baseline quality of the freshwater aquifer system. Groundwater from the peninsula may be naturally discharging to the marine environment based on groundwater level data to date, therefore comparisons with marine water trigger values have also been made.

Water quality sampled for wet and dry seasons were within freshwater and marine ANZECC guidelines for mercury and vanadium. Wet season and dry season water quality samples analysed for arsenic and lead were within freshwater and marine ANZECC guidelines. Wet season groundwater samples were within ANZECC guidelines for aluminium.

Groundwater concentrations of copper and zinc were above fresh and marine water ANZECC guidelines for wet and dry season in most bores. In the majority of bores, concentrations of cadmium, manganese and nickel were above fresh water ANZECC guidelines during dry season and wet season results (Table 2-4).

Some metal concentrations are above fresh and marine water ANZECC guidelines, therefore any potential groundwater abstraction from site will be required to be managed to meet environmental objectives.

Table 2-3 Laboratory Analysis of Groundwater Quality - Major Ions

		pH	EC	TDS	CO3	HCO3	Alkalinity	Cl	Ca	K	Mg	Na	SO4
		units	µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
ANZECC Guideline *		7 - 8.5	90 - 900										
Date	**Bore ID**												
2/07/08	ONBH01	NA	NA	1900	NA	NA	4.1	1100	59	8.2	95	550	NA
31/03/09	ONBH01	**4.6**	**1370**	670	<1	<1	<1	359	20	4.6	33.1	182	79.1
31/03/09	ONBH01A	**6.4**	255	150	<1	61	61	31.4	14	1.3	3	32.6	10.4
2/07/08	ONBH02	NA	NA	230	NA	NA	33	41	5.6	1.7	2.3	51	NA
31/03/09	ONBH02	**5.6**	183	120	<1	7	7	36.6	2.7	1.1	2.1	26.9	12.4
31/03/09	ONBH02A	**5.1**	224	140	<1	1	1	57.2	1.5	2.3	2.7	31.2	3.9
2/07/08	ONBH03	NA	NA	7000	NA	NA	16	4000	65	110	200	2400	NA
31/03/09	ONBH03	**5.6**	**12400**	7150	<1	23	23	4090	78	91.3	229	2240	500
2/07/08	ONBH04	NA	NA	730	NA	NA	28	380	13	12	22	240	NA
31/03/09	ONBH04	**5.1**	**79**	50	<1	<1	<1	16.3	3.3	0.5	0.8	6.4	0.5
2/07/08	ONBH05	NA	NA	160	NA	NA	10	58	3.3	1.7	3	42	NA
30/03/09	ONBH05	**5.2**	154	120	<1	1	1	37.1	1.4	1.2	2.6	20.3	6.5
30/03/09	ONBH05A	**5.1**	**39**	30	<1	<1	<1	6.4	1.2	0.3	0.5	3.4	0.6
2/07/08	ONBH06	NA	NA	1400	NA	NA	15	790	41	11	51	440	NA
30/03/09	ONBH06	**5.6**	334	200	<1	8	8	69.4	7.7	1.5	5.5	44.2	34.5
2/07/08	ONBH07	NA	NA	1800	NA	NA	82	1000	77	20	65	630	NA
30/03/09	ONBH07	**5.9**	**4350**	2190	<1	40	40	1310	78	18.2	80.4	655	218
30/03/09	ONBH07A	**5.5**	**3300**	1820	<1	11	11	932	48.8	7.5	50.7	538	249
2/07/08	ONBH08	NA	NA	1500	NA	NA	31	890	50	9.2	70	520	NA
30/03/09	ONBH08	**4.9**	**1600**	850	<1	1	1	468	26.5	2.7	40	206	58.2
2/07/08	ONBH09	NA	NA	990	NA	NA	130	490	44	11	32	340	NA
30/03/09	ONBH09	**5.9**	**3020**	1550	<1	30	30	923	36.8	10.9	54	472	107
2/07/08	ONBH10	NA	NA	1300	NA	NA	89	360	32	6	19	320	NA
30/03/09	ONBH10	**5.5**	**2730**	1460	<1	5	5	851	19.5	2.3	45.7	439	55.7
30/03/09	QC101 (ONBH06)	**5.7**	316	190	<1	9	9	66.4	7.4	1.5	5.3	41.7	34.6
30/03/09	QC201 (ONBH06)	**5.4**	332	200	<1	7	7	68.3	7.5	1.5	5.4	42.9	34.6

* Default trigger values for physical and chemical stressors for slightly disturbed estuaries in tropical Australia

BDL = Below Detection Limit NA = Not Analysed

Table 2-4 Laboratory Analysis of Groundwater Quality - Metals and Metalloids (ANZECC Freshwater and Marine Water Trigger Values)

		pH	Al	As	Ba	Cd	Cr	Cu	Ga	Hg	Mn	Mo	Ni	Pb	U	V	Zn
		units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
ANZECC Marine*						5.5	4.4	1.3		0.4			70	4.4		100	15
ANZECC Fresh**			55 ^	13		0.2	1	1.4		0.6	1900		11	3.4			8
Date	**Bore ID**																
2/07/08	ONBH01	NA	NA	1.1	NA	0.62	BDL	1	NA	BDL	2100	NA	14	1.6	NA	BDL	61
31/03/09	ONBH01	4.6	303	BDL	64.6	0.74	BDL	0.8	BDL	BDL	677	BDL	9.9	0.85	0.063	BDL	51.5
31/03/09	ONBH01A	6.4	13.8	2	75.6	0.04	0.4	0.51	BDL	BDL	11.1	0.15	1.29	0.05	0.003	5.4	8.1
2/07/08	ONBH02	NA	NA	1.1	NA	BDL	BDL	2	NA	BDL	200	NA	1.5	BDL	NA	2.3	9.9
31/03/09	ONBH02	5.6	9.8	0.15	63	0.04	0.2	0.23	0.03	BDL	382	BDL	2.61	0.02	BDL	BDL	14.3
31/03/09	ONBH02A	5.1	55.8	0.2	101	0.18	0.2	0.76	0.02	BDL	255	BDL	15.1	0.62	0.01	BDL	14.5
2/07/08	ONBH03	NA	NA	1.2	NA	BDL	BDL	4.1	NA	BDL	650	NA	7.5	BDL	NA	BDL	36
31/03/09	ONBH03	5.6	10.7	1.2	106	0.46	1.4	2.31	0.16	BDL	3160	BDL	33.2	BDL	BDL	BDL	42
2/07/08	ONBH04	NA	NA	BDL	NA	BDL	BDL	2.8	NA	BDL	400	NA	9.8	BDL	NA	BDL	37
31/03/09	ONBH04	5.1	13.8	0.1	68.8	0.32	0.5	0.29	0.01	BDL	168	BDL	2.72	0.08	0.007	0.2	7.7
2/07/08	ONBH05	NA	NA	BDL	NA	BDL	BDL	3.6	NA	BDL	170	NA	4.3	BDL	NA	BDL	20
30/03/09	ONBH05	5.2	15.5	0.1	11	0.08	0.3	1.33	BDL	BDL	94.4	BDL	2.17	0.09	0.016	0.1	20.5
30/03/09	ONBH05A	5.1	21.7	0.05	75.8	0.1	0.3	0.58	BDL	BDL	82.9	BDL	2.26	0.12	0.049	0.2	4.3
2/07/08	ONBH06	NA	NA	BDL	NA	0.48	BDL	8.1	NA	BDL	1800	NA	27	BDL	NA	BDL	170
30/03/09	ONBH06	5.6	9.2	BDL	70.6	0.24	BDL	1.38	BDL	BDL	583	BDL	9.18	0.1	BDL	BDL	46.9
2/07/08	ONBH07	NA	NA	1.6	NA	0.2	BDL	BDL	NA	BDL	4300	NA	22	BDL	NA	3.3	51
30/03/09	ONBH07	5.9	10.4	1.3	143	BDL	BDL	1.52	0.45	BDL	8780	BDL	36.8	BDL	BDL	BDL	61.7
30/03/09	ONBH07A	5.5	35.4	BDL	76.4	0.72	BDL	3.91	BDL	BDL	2100	BDL	43.6	BDL	BDL	BDL	64.4
2/07/08	ONBH08	NA	NA	2	NA	0.18	BDL	BDL	NA	BDL	3000	NA	34	BDL	NA	1.3	110
30/03/09	ONBH08	4.9	270	1	44.2	0.46	BDL	1.81	0.3	BDL	2010	BDL	31.4	0.69	0.051	BDL	186
2/07/08	ONBH09	NA	NA	9.7	NA	BDL	BDL	4.6	NA	BDL	980	NA	7.5	BDL	NA	16	15
30/03/09	ONBH09	5.9	74.2	1.3	126	BDL	BDL	3.42	BDL	BDL	1840	BDL	27.4	BDL	BDL	BDL	122
2/07/08	ONBH10	NA	NA	5.9	NA	BDL	BDL	3.5	NA	BDL	430	NA	3.1	BDL	NA	5.6	7.2
30/03/09	ONBH10	5.5	210	<1	299	0.74	BDL	4.09	BDL	BDL	2280	BDL	43.5	0.45	BDL	BDL	52.4
30/03/09	QC101 (ONBH06)	5.7	9.5	BDL	73.4	BDL	BDL	1.57	BDL	BDL	593	BDL	9.47	BDL	BDL	BDL	53.8
30/03/09	QC201 (ONBH06)	5.4	11.3	BDL	69.8	BDL	BDL	1.67	BDL	BDL	577	BDL	8.95	BDL	BDL	BDL	44.9

* 95% Species protection for moderately disturbed tropical marine ecosystems

** 95% Species protection for moderately disturbed tropical fresh water ecosystems

^ Guideline applies if pH is >6.5

BDL = Below Detection Limit

NA = Not Analysed

Nutrients

The nutrient status of the groundwater at Blaydin Point was assessed during the wet season sampling round (Table 2-5). All groundwater samples collected were within the ANZECC guidelines for physical and chemical stressors for slightly disturbed estuaries in tropical Australia.

Table 2-5 Laboratory Analysis of Groundwater Quality - Nutrients

		NO2_N	NO3_N	PO4_P	Total N	Total P
		mg/L	mg/L	mg/L	mg/L	mg/L
ANZECC Guideline *					250	20
Date	**Bore ID**					
2/07/08	ONBH01	NA	NA	NA	NA	NA
31/03/09	ONBH01	BDL	BDL	BDL	0.05	0.005
31/03/09	ONBH01A	BDL	0.19	1.17	0.25	1.16
2/07/08	ONBH02	NA	NA	NA	NA	NA
31/03/09	ONBH02	BDL	0.01	0.005	0.04	0.025
31/03/09	ONBH02A	BDL	0.19	BDL	0.28	0.005
2/07/08	ONBH03	NA	NA	NA	NA	NA
31/03/09	ONBH03	BDL	0.03	BDL	0.17	0.005
2/07/08	ONBH04	NA	NA	NA	NA	NA
31/03/09	ONBH04	BDL	0.015	0.005	0.02	0.01
2/07/08	ONBH05	NA	NA	NA	NA	NA
30/03/09	ONBH05	BDL	0.025	0.005	0.04	0.015
30/03/09	ONBH05A	BDL	0.09	0.01	0.11	0.015
2/07/08	ONBH06	NA	NA	NA	NA	NA
30/03/09	ONBH06	BDL	0.05	0.005	0.1	0.01
2/07/08	ONBH07	NA	NA	NA	NA	NA
30/03/09	ONBH07	BDL	BDL	BDL	0.48	0.015
30/03/09	ONBH07A	BDL	1.3	0.02	1.58	0.025
2/07/08	ONBH08	NA	NA	NA	NA	NA
30/03/09	ONBH08	BDL	0.03	BDL	0.07	BDL
2/07/08	ONBH09	NA	NA	NA	NA	NA
30/03/09	ONBH09	BDL	0.01	0.005	0.08	0.055
2/07/08	ONBH10	NA	NA	NA	NA	NA
30/03/09	ONBH10	BDL	0.065	0.005	0.15	0.055
30/03/09	QC101 (ONBH06)	BDL	0.05	BDL	0.11	0.01
30/03/09	QC201 (ONBH06)	BDL	0.05	0.005	0.09	0.01

* Default trigger values for physical and chemical stressors for slightly disturbed estuaries in tropical Australia

BDL = Below Detection Limit

NA = Not Analysed

NO2_N = Nitrite nitrogen

NO3_N = Nitrate nitrogen

PO4_P = Phosphate nitrogen

Section 3 Geology, Hydrology and Hydrogeology

3.1 Geology

The Darwin region forms part of the Australian Precambrian shield which has been comparatively stable since middle Proterozoic times (Stuart-Smith et al. 1980). Metasediments of the Pine Creek geosyncline that overlie the Archaean basement were successively folded and uplifted during the early to middle Proterozoic. Flat bedded Mesozoic and Cainozoic strata were deposited following erosion of the Proterozoic rocks.

Proterozoic strata in the Darwin region vary according to metamorphic grade. To the west, near Cox Peninsula the unconformable Cretaceous strata overlie upper greenschist to amphibolite facies quartzofeldspathic and mica schists, gneiss and minor quartzite. To the east, near Gunn Point, lower greenschist facies metasediments occur. The Proterozoic strata underwent one major deformation approximately 1800 Ma resulting in tight folds with limbs dipping steeply at more than 50° (Pietsch 1983).

The Darwin Member of the early Cretaceous Bathurst Island Formation dominates Mesozoic strata in the Darwin region, the shore margin of which is exposed at Blaydin Point. Other units within the Bathurst Island formation include the Wangarlu Mudstone Member and overlying Mookinu Member. The Wangarlu Mudstone Member does not crop out in the urban Darwin area and is restricted to the region near Gunn Point. The Mookinu Member is not present at all on the mainland but lies stratigraphically above the Wangarlu Member which in turn overlies the Darwin Member on Bathurst Island to the north of Darwin.

In the Darwin region, the Darwin Member is composed dominantly of a white siliceous siltstone containing numerous radiolarians. At the base, resting unconformably upon the Proterozoic Burrell Creek Formation, is a coarser-grained facies composed of a layer of lag gravels, generally no greater than 1–2 m thick, which grades upwards into sandstone and then siltstone. The texture of the Darwin Member coarsens westwards to Cox Peninsula, to the west of Darwin, where it is dominated by fine to coarse–grained sands.

Cainozoic sediments cover much of the Darwin area. These can be divided into two main groups, namely tertiary weathering products or regolith and Quaternary sediments. Deeply weathered Cretaceous strata form a slightly elevated plain, while the Quaternary sediments are restricted in area to coastal beach and dune sands and minor amounts of alluvium in creek valleys and colluvium on shallow slopes. Sea level stabilised in the region by approximately 6500 years before present.

The Darwin Member of the early Cretaceous Bathurst Island Formation dominates Mesozoic strata in the Darwin region, the shore margin of which is exposed at Blaydin Point. The Bathurst Island Group nonconformably overlies the Precambrian basement.

The upper part of the Bathurst Island group comprises of bioturbated glauconitic and quartzose sandstone displaying sedimentary evidence of high-energy depositional conditions consistent with regression. It is viewed as a prograding/ aggrading, shelf margin systems tract. Three eustatic episodes related to global patterns are recognised: late Aptian (125 – 112 Ma) transgressive onlap, early Albian (112 – 99.6 Ma) maximum flooding and late Turonian (93.5 – 89.3 Ma) regression (Henderson 1998). Pedogenic clay minerals in the underlying radiolarian mudstone are associated with weathering of moderate intensity on a poorly drained, low relief landscape. The interrupted sedimentary record reflects Mid-Cretaceous landscape rejuvenation events.

Other units within the Bathurst Island formation include the Wangarlu Mudstone Member and overlying Mookinu Member. The Wangarlu Mudstone Member does not crop out in the urban Darwin area and is restricted to the region near Gunn Point. The Mookinu Member is not present at all on the mainland but lies stratigraphically above the Wangarlu Member which in turn overlies the Darwin Member on Bathurst Island to the north of Darwin.

The base of the Darwin Member Group consists of a layer of lag gravels, 1–2 m thick rests unconformably upon the Proterozoic Burrell Creek Formation. This coarser-grained facies grades upwards into sandstone and then siltstone. Glauconitic sandstone and radiolarian mudstone are characteristic facies, indicative of the sedimentary environment in the shallow transgressive sea which received wind-driven, plankton-bearing currents from the shelf edge 400 km to the north.

3.2 Hydrology

The Project site is a generally flat peninsula that varies 10 m in topography over 100 ha. The site can be divided into approximately 12 catchments that supply the mangroves with surface runoff (Figure 15). From field observations of the site, there exists a relatively shallow sandy surface layer of soil.

Permeability tests (Table 3-1) indicate that the surface soil layer rapidly absorbs water from rainfall when the profile is dry. After a certain amount of rainfall occurs and the surface layer has become saturated, overland flows occur on the soil surface. Due to the low undulating topography of the Project site and the anticipated nature of overland flows, surface flows are most likely to consist of non-turbulent sheet flow over the soil surface. Where water accumulates at the boundaries of the study area, the flow is likely to become increasingly turbulent and occupy temporary drainage channels which become the ephemeral sections of the tributary creeks that feed into Lightning Creek to the west and the Elizabeth River in the east.

Table 3-1 Soil infiltration rates

		Infiltration rate (mm min-1)		
Location	**Site**	**dry soil**	**wet soil**	**bore hole**
Peninsula	1	36.91	12.86	70.03
Peninsula	2	39.00	14.35	12.42
Mangroves	5	56.34	27.31	75.48
Peninsula	8	19.53	8.61	16.54
Mangroves	9	57.39	13.32	12.44
Mangroves	10	35.98	13.76	7.40
Peninsula	12	46.27	14.34	9.04
Salt flat	23	23.46	9.06	28.63
Peninsula	46	75.73	27.50	37.54
Peninsula	56	21.66	5.47	15.40

3.2.1 Flooding and Storm Surge

Available data shows flood levels due to storm surges do not cover the Project site. URS (2002) estimated cyclone storm surge and astronomical tide heights of to be 3.8 m agl (10 year return period), 5.1 m agl (100 year) and 6.4 m agl (1,000 year) (Dames and Moore 1998). Parts of the onshore pre-development Project site is below 6.4 m AHD (Figures 1 and 15) and under current, pre-development conditions, the storm surge for a 1,000 year event could potentially inundate the site. The lowest portion of the proposed post-development site will be 6.5 m AHD (JGC/Chiyoda Drawing D-500-1312-D020: Plant Site Bulk Earthworks Plan). This will be 0.1 m above the 1,000 year return period flood levels due to storm surge.

3.3 Hydrogeology

3.3.1 Groundwater Geology and Aquifer Occurrence

Aquifers within the Project are occur both locally within unconfined sediments and within weathered or fractured bedrock.

Cross section locations are based on the exploration drilling and are presented in Figure 16. Sectional views are presented in Figures 17 to 20. Based on the cross sections developed from the bore logs, a gravel layer is present at the interface between the sediments and the underlying bedrock that is variably weathered. Sediments that overlie the gravel horizon comprise of sand, clay and silt. The bedrock elevation is generally below 0 m AHD and is deepest at ONBH04 at -15 m AHD.

The most prominent aquifer on site is the sand and gravel horizons within Bathurst Island Group with minor weathered or fractured rock aquifers contained in the underlying Burrell Creek Formation. It is probable that semi-confined conditions may exist within the Bathurst Island Group with confining layers consist of either clay or siltstone.

3.3.2 Groundwater Flow

Groundwater levels generally follow topography, and are highest at ONBH04 at 5.06 m AHD and lower towards the coast, to 0 m AHD. Groundwater level contours are presented in Figure 21.

Seepage pathways that may allow the transport of contaminants from the proposed Project include:

- Transmissive sand aquifers beneath the Project site.
- Weathered bedrock.
- Fractures, faults within the fresh bedrock.

As transmissive aquifers are located below sea level, any potential contaminants entering the water table could migrate both laterally and vertically, propagating from the source, potentially discharging to Darwin Harbour.

Seepage pathways that may allow the transport of contaminants from the proposed Project site include:

- Transmissive sand aquifers beneath the Project site.
- Weathered bedrock.
- Fractures, faults within the fresh bedrock.

An interpretation of the groundwater velocity (Darcy Flux) is determined by the hydraulic conductivity and porosity of the porous media in the flow path and the hydraulic gradient.

Based on adopted hydraulic conductivity of 2 to 30 m/day for the superficial alluvial deposits, an estimated porosity of 0.1 (dimensionless) and an interpreted average hydraulic gradient of 0.004 (dimensionless), the groundwater flux is approximated in the range 0.08 to 1.2 m/day, or 29 to 438 m/year.

3.3.3 Conceptual Hydrogeology Model

The conceptual hydrogeological model of the area comprises the following features:

- The groundwater flow direction is radial from the peninsular.
- Groundwater levels were within about 5 m of the ground surface.
- The conceptual hydrogeological model incorporates alluvial successions of sandy silt/silty sand and gravel underlain by weathered bedrock.
- Transmissivity is greatest within the sand and gravel horizons. Within the bedrock, transmissivity occurs where faults/fractures, or weathered strata exist.

3.4 Beneficial Uses

Currently declared beneficial usages for Darwin Harbour include:

- Aquatic ecosystems protection.
- Recreational water quality and aesthetics.

The Project site is located within the Darwin Rural Water Control District (NRETAS, 1999). The beneficial usage of groundwater at the Project may include:

- Raw water for non-potable water supply (Water would require treatment for potable uses, Table 3-2).
- Raw water for agricultural water use.
- Raw water for industrial use.

Based on NRETAS fact sheet (NRETAS, 2007) the beneficial usage of groundwater and surface water will be determined through community consultation. This is a legislated process that forms a part of the protection and management of water resources and will form the basis of water allocation plans.

Categories of beneficial uses that may apply to the site are listed below:

- Agriculture- The provision of irrigation water for primary production, including related research.
- Aquaculture- The provision of water for commercial production of aquatic animals including related research.
- Public water supply- Provision of water for drinking purposes delivered through community water supply systems. It is noted that groundwater on the site is unlikely to be used as a source of drinking water due to elevated concentrations of arsenic, manganese and nickel (Table 3-2). Water quality of surface water has not been established.
- Environment- Provision of water to maintain the health of aquatic ecosystems.
- Cultural- Provision of water to meet aesthetic, recreational and cultural needs.
- Industry- Provision of water for industry, including secondary industry and a mining or petroleum activity, and other industry uses.
- Rural Stock and Domestic- Public rights and ownership rights to take water for domestic and/or stock purposes.

Table 3-2 Groundwater Quality – Metals and Metalloids (NHMRC Drinking water guidelines)

Bore ID	Arsenic µg/L	Cadmium µg/L	Chromium µg/L	Copper µg/L	Lead µg/L	Manganese µg/L	Nickel µg/L	Vanadium µg/L	Zinc µg/L	Mercury (Dissolved) µg/L
NHMRC Drinking Water Guidelines	**7**	**2**	**50**	**2000**	**10**	**500**	**20**	--	--	**1**
ONBH 1	1.1	0.62	BDL	1	1.6	**2100**	14	BDL	61	BDL
ONBH 2	1.1	BDL	BDL	2	BDL	200	1.5	2.3	9.9	BDL
ONBH 3	1.2	BDL	BDL	4.1	BDL	**650**	7.5	BDL	36	BDL
ONBH 4	BDL	BDL	BDL	2.8	BDL	400	9.8	BDL	37	BDL
ONBH 5	BDL	BDL	BDL	3.6	BDL	170	4.3	BDL	20	BDL
ONBH 6	BDL	0.48	BDL	8.1	BDL	**1800**	**27**	BDL	170	BDL
ONBH 7	1.6	0.2	BDL	BDL	BDL	**4300**	**22**	3.3	51	BDL
ONBH 8	2	0.18	BDL	BDL	BDL	**3000**	**34**	1.3	110	BDL
ONBH 9	**9.7**	BDL	BDL	4.6	BDL	**980**	7.5	16	15	BDL
ONBH 10	5.9	BDL	BDL	3.5	BDL	430	3.1	5.6	7.2	BDL

* BDL = Below Detection Limit of 1 ug/L

Section 4 Water Balance Model

4.1 Conceptual Model

4.1.1 Overview

A water balance spreadsheet model was developed to predict possible changes in the hydrological regime due to different methods of construction of the Project on the Project site.

Three scenarios were modelled to provide a range of responses to changed land use. The first scenario simulates pre-development conditions to provide a baseline for comparative purposes. The second scenario simulates the impact of introducing an area of impermeable ground cover, such as bitumen or concrete to the Project site where no recharge occurs. The third scenario simulates the effect of increasing the amount of recharge, either through artificial means or permeable ground cover where all rainfall becomes recharge and no runoff occurs[3]. The second and third scenarios assume no vegetation is present at the Project site.

It is expected that the actual outcomes of the proposed development will lie within the range illustrated by these example scenarios depending on the final construction of the Project.

The hydrological changes that could occur as a result of land use change include;

- No recharge occurs due to an impermeable surface over the Project site;
  - Groundwater levels lower due to reduced recharge (impermeable hard stands).
  - Increased run-off/surface water flow due to a reduction of vegetation cover and impermeable hard stands.
- All rainfall becomes recharge due to artificial recharge methods and/or increased permeable ground surfaces;
  - Groundwater level rises due to the exclusion of vegetation evaportranspiration consuming groundwater and intercepting surface water.

The conceptual model of the linkages between surface water, groundwater and root zone stores is presented in Figure 22.

The flow paths and stores were modelled using basic water balance equations to estimate the volume of water flowing in the hydrological system.

4.1.2 Scenario Modelling

Pre-development

The most sensitive hydrological input into the system is rainfall. During a rainfall event, water falls onto vegetation within the Project site and is either retained on the plant surface, or falls through the vegetation canopy to the ground. Water retained on the plant surface is assumed to evaporate to the atmosphere.

Water passing the vegetation layer, known as the Interception Store, reaches the soil surface and may either infiltrate into the soil profile or run over the soil surface. If the soil is capable of absorbing the moisture, the water immediately infiltrates.

If the soil profile is already saturated, or rain is falling during a heavy downpour, water flows over the ground surface and becomes trapped in undulations on the soil surface. Water trapped on the soil

[3] It is important to note that these example scenarios were to determine changes in groundwater levels, and do not address changes to surface water flows and the resulting impacts of changed surface hydrology.

surface may either evaporate to the atmosphere or slowly infiltrate into the soil profile. The processes associated with water infiltrating through the soil surface is referred to as the Soil Surface Store.

Water that filters past the Soil Surface Store and into the soil profile, enters the Root Zone Store. Vegetation is assumed to extract a constant amount of water from the Root Zone Store which is equal to the amount of water being transpired by the plants. An annual average transpiration rate for tropical ecosystems in Howard Springs has been applied.

Water that filters past the deepest extent of plant roots and is beyond the reach of the plants is considered to enter the Groundwater Store. Deep drainage below the Root Zone Store is the main mechanism causing the water table to fluctuate.

These major processes and water flow paths are illustrated in the flow-chart diagram in Figure 23(A).

Post development

Two post development scenarios have been modelled. The first scenario assumes vegetation is entirely removed from the project site and the ground surface is sealed by an impermeable covering. All rainfall becomes runoff and rapidly flows away via concrete lined drains. Therefore, the installation of an impermeable ground covering isolates the groundwater system from local recharge Figure 23(B).

The second scenario assumes artificial recharge ponds provide 100% infiltration of rainfall at the Project site. All surface water runoff is directed into the recharge ponds, where water seeps into the soil profile and recharges the underlying groundwater table Figure 23(C).

It is important to note that the water balance can only account for average volumes over the study area and cannot be used to determine spatial effects of the land use changes. The effects of groundwater mounding and alterations to groundwater flow paths require modelling using a numerical flow model.

4.1.3 Results

Post Development without Artificial Recharge

Simulated results are presented in Figure 23.

The water balance indicates that the groundwater level changes seasonally, responding to rainfall recharge. Post development with no artificial recharge predicts groundwater levels will generally decline and are likely to stabilise near mean sea level. This has the potential for the landward migration of the freshwater/seawater interface and may affect groundwater dependent ecosystems (GDEs) (Figure 24).

Post Development with Artificial Recharge Scenario

The Post development scenario assumes all rainfall run-off is artificially recharged the aquifer system, and is likely to increase groundwater levels (Figure 23). The rise in groundwater levels is attributed to the availability of water that would normally be used or intercepted by the existing vegetation (Figure 2).

Consideration with respect to the proportion of rainfall run-off allocated to artificial recharge of the aquifer system is required to maintain pre-development groundwater levels as well as surface water run-off discharge from the Project site. The spatial distribution of artificial groundwater recharge points would also need to be considered. Numerical modelling would be required in the design of artificial recharge systems required to keep the post development hydrological system similar to that of the current hydrological regime.

Section 5 Conclusions and Recommendations

5.1 Conclusions

- Groundwater salinity at the Project site varies from fresh to saline with elevated arsenic, zinc, copper and cadmium. The higher salinity groundwater is located closest to the coast. pH levels were neutral to slightly acidic.
- The Project site is a generally flat peninsula that varies 10 m in topography over 100 ha. The Project site can be divided into approximately 12 catchments that supply the mangroves with surface runoff. Due to the low undulating topography of the Project site and the anticipated nature of overland flows, surface flows are most likely to consist of non-turbulent sheet flow over the soil surface.
- The lowest portion of the proposed post development site will be 6.5 m AHD. This will be 0.1 m above the above the 1,000 year return period flood levels due to storm surge.
- Groundwater levels generally follow topography, and are highest at ONBH04 at 5.06 m AHD and lower toward the coast to 0 m AHD.
- Aquifers at the Project site occur both locally within unconfined sediments and within weathered or fractured bedrock. The bedrock elevation is generally below 0 m AHD and is deepest at ONBH04 at -15 m AHD.
- The most prominent aquifer on the Project site is the sand and gravel horizons within Bathurst Island Group with minor weathered or fractured rock aquifers contained in the underlying Burrell Creek Formation.
- Transmissivity is greatest within the sand and gravel horizons. Within the bedrock, transmissivity occurs where faults/fractures, or weathered strata exist.
- Seepage pathways that may allow the transport of contaminants from the proposed Project site include:
  - Transmissive sand aquifers beneath the Project site.
  - Weathered bedrock.
  - Fractures, faults within the fresh bedrock.
- Transmissive aquifers are located below sea level. Any potential contaminants entering the water table could migrate both laterally and vertically, propagating from the source, potentially discharging to Darwin Harbour.
- Groundwater flux is approximated in the range 0.08 to 1.2 m/day, or 29 to 438 m/year at the Project site.
- Simulated post development modelling (no artificial recharge, hardstand in place) groundwater levels are likely to lower over time, whereas post development (artificial recharge of all surface water run-off) is likely to increase groundwater mounding. Under these scenarios, the changes in the groundwater hydraulic gradient could change groundwater flow discharge mechanisms at the Project site.
- Appropriate engineering and site planning would enable the correct fraction of rainfall landing within the development area to be infiltrated into aquifers below the Project site, to maintain groundwater at levels similar to levels pre-development.

5.2 Recommendations

- Consideration with respect to the proportions of rainfall run-off artificially recharged to the aquifer system is required to maintain pre-development groundwater levels as well as surface water run-off from the Project site. This is recommended for the maintenance of groundwater dependent ecosystems. The spatial distribution of artificial groundwater recharge points should also be considered.
- Beneficial Uses of groundwater and surface water on the site may be attributed to aquacultural, environmental, cultural and industrial uses. It is recommended to discuss the importance of the site with the NT Government and the community in terms of beneficial uses, as part of the planning process.
- Numerical modelling would be required to determine artificial recharge systems to keep the post development hydrological system similar to that of the current system.

Section 6 References

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Section 7 Limitations

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

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

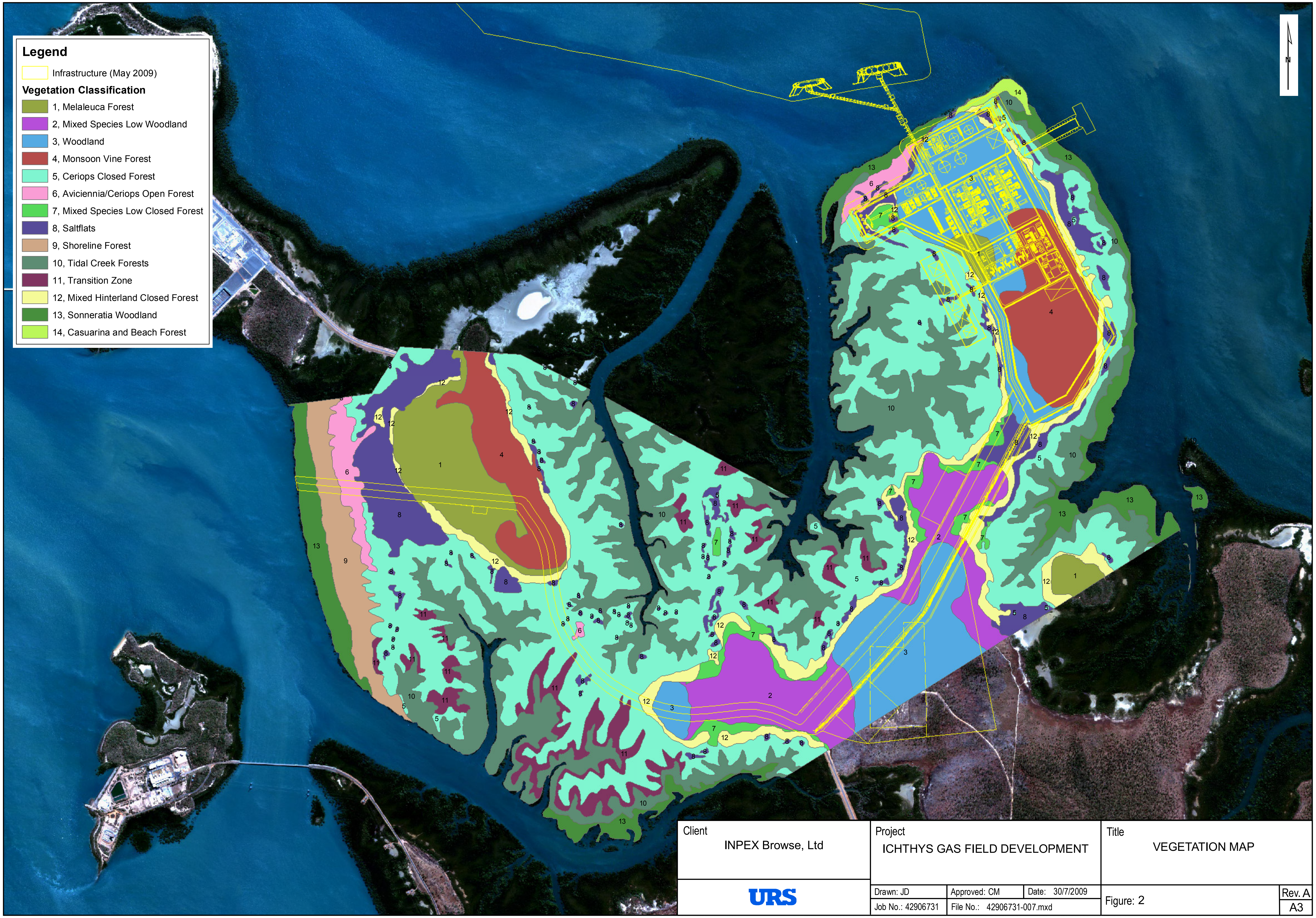
This report was prepared between July and October 2008 and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

This report contains information obtained by inspection, sampling, testing or other means of investigation. This information is directly relevant only to the points in the ground where they were obtained at the time of the assessment. The borehole logs indicate the inferred ground conditions only at the specific locations tested. The precision with which conditions are indicated depends largely on the frequency and method of sampling, and the uniformity of conditions as constrained by the project budget limitations. The behaviour of groundwater and some aspects of contaminants in soil and groundwater are complex. Our conclusions are based upon the analytical data presented in this report and our experience. Future advances in regard to the understanding of chemicals and their behaviour, and changes in regulations affecting their management, could impact on our conclusions and recommendations regarding their potential presence on this site.

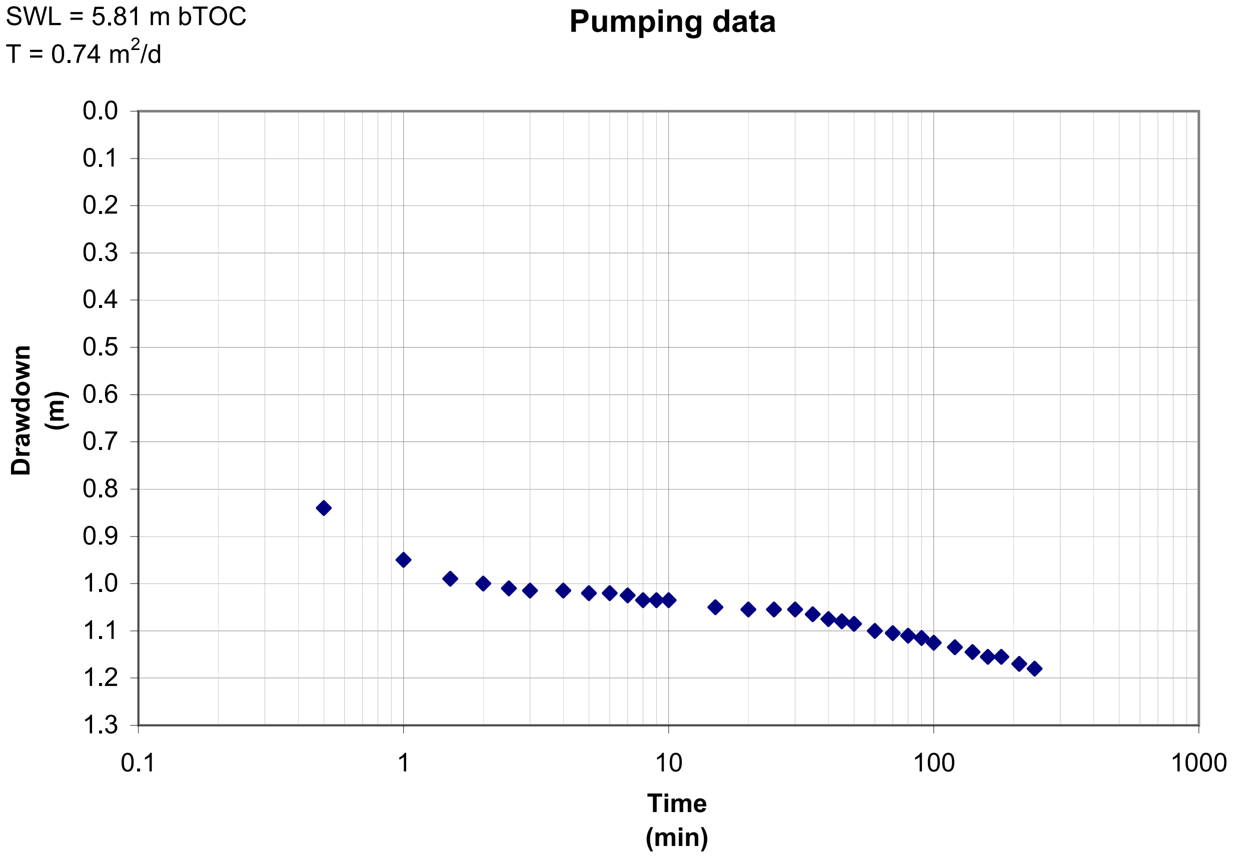
Whilst to the best of our knowledge information contained in this report is accurate at the date of issue, subsurface conditions, including groundwater levels can change in a limited time. Therefore this document and the information contained herein should only be regarded as valid at the time of the investigation unless otherwise explicitly stated in this report.

Client	Project	Title	
INPEX Browse, Ltd	ICHTHYS GAS FIELD DEVELOPMENT HYDROLOGY AND HYDROGEOLOGY	SITE AND BOREHOLE LOCATION PLAN	
	Drawn: JD · Approved: CM · Date: 30/7/2009	Figure: 1	Rev. A
	Job No.: 42906731 · File No.: 42906731-005.mxd		A4

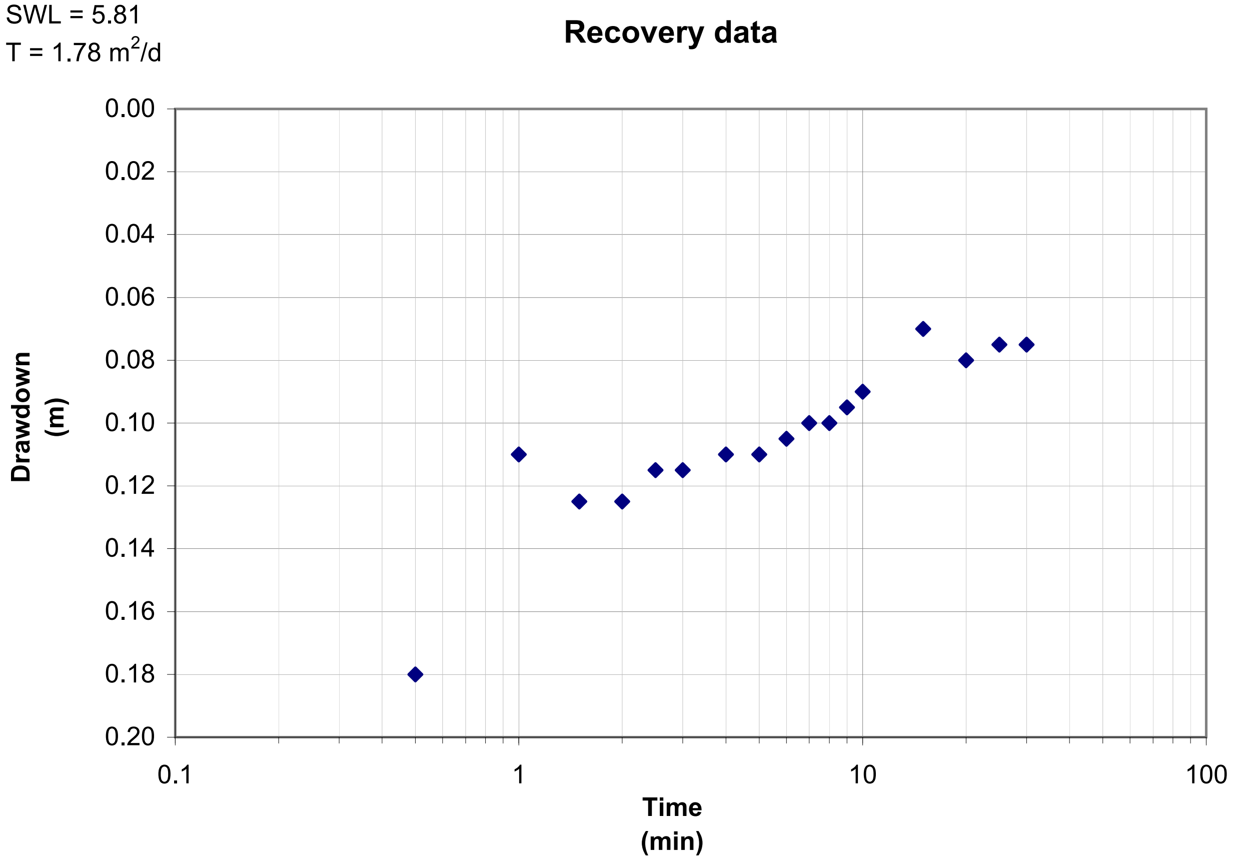


Client	Project	Title
INPEX Browse, Ltd	ICHTHYS GAS FIELD DEVELOPMENT	VEGETATION MAP
URS	Drawn: JD; Approved: CM; Date: 30/7/2009; Job No.: 42906731; File No.: 42906731-007.mxd	Figure: 2; Rev. A; A3

ONBH01
SWL = 5.81 m bTOC
T = 0.74 m^2/d



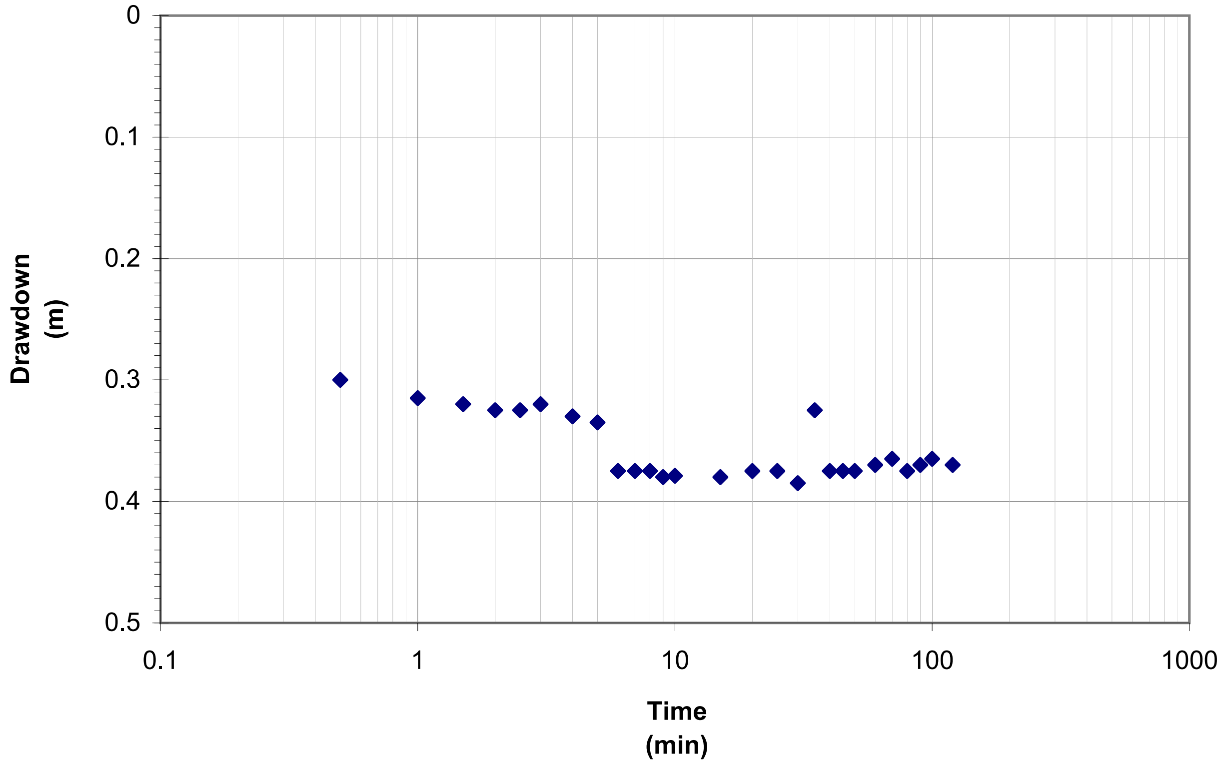
ONBH01
SWL = 5.81
T = 1.78 m^2/d



Client: INPEX Browse Ltd	Project: HYDROGEOLOGY OF BLAYDIN POINT MIDDLE ARM HARBOUR, DARWIN		Title: ONBH01 Constant Rate Pumping Test, Groundwater Drawdown and Recovery
URS	Drawn: SEVT	Approved: CMAC	Date: 18/08/2008
	Job No. 42906731	File No. Figures.xls	Figure: 3
			Rev. A
			A4

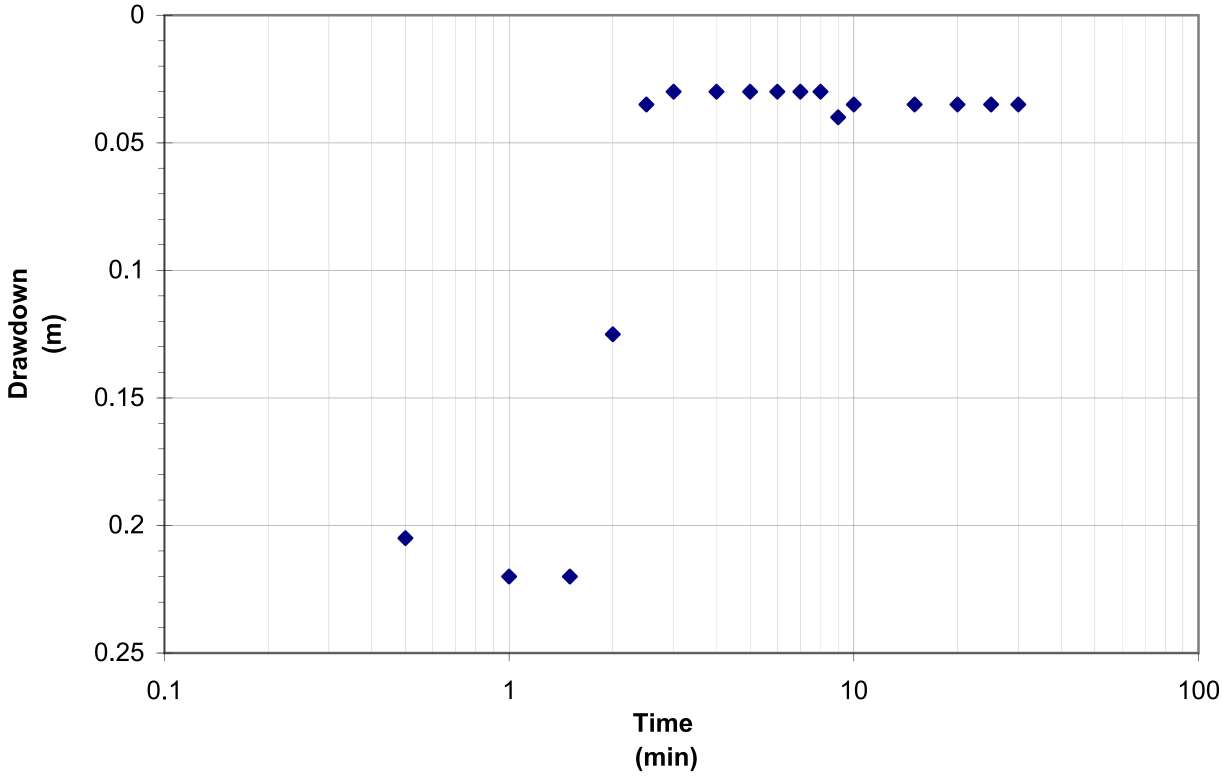
ONBH02
SWL = 5.955 m bTOC
T = 3.62 m^2/d

Pumping data



ONBH02
SWL = 5.955 m bTOC
T = 9.05 m^2/d

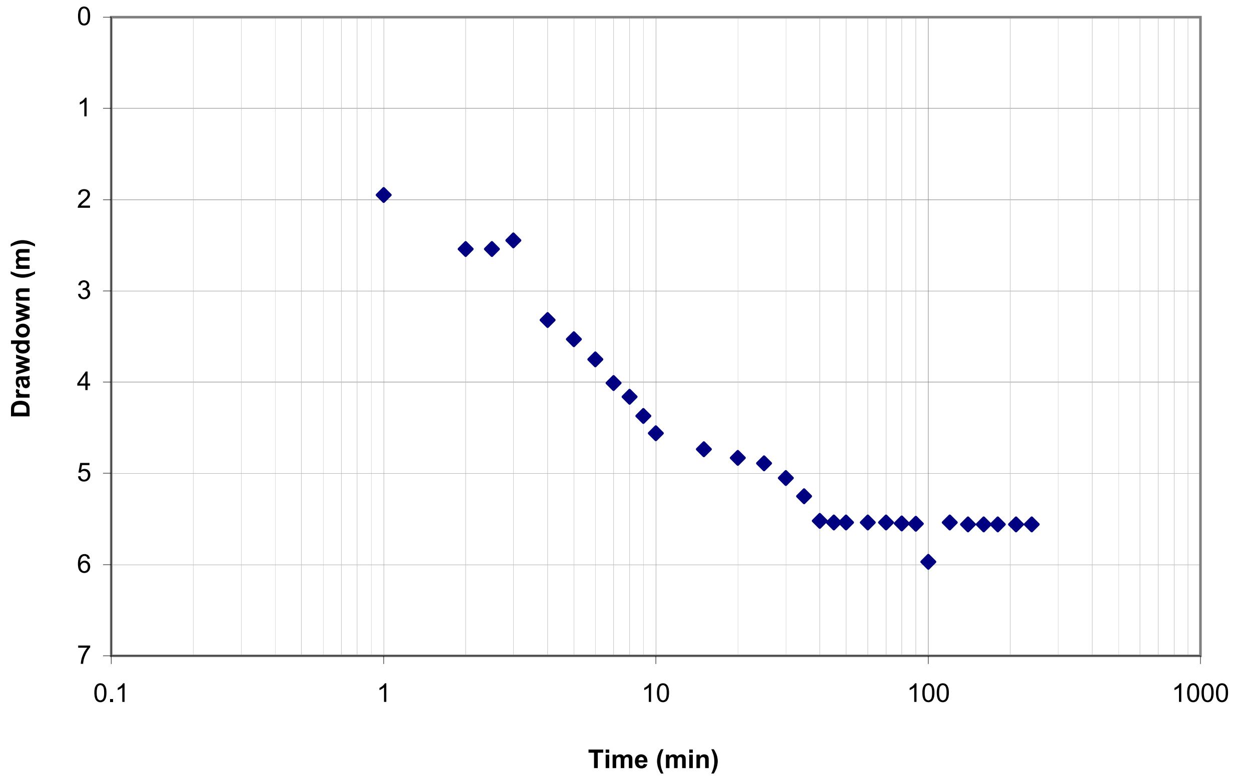
Recovery data



Client: INPEX Browse Ltd	Project: HYDROGEOLOGY OF BLAYDIN POINT MIDDLE ARM HARBOUR, DARWIN			Title: ONBH02 Constant Rate Pumping Test, Groundwater Drawdown and Recovery	
URS	Drawn: SEVT	Approved: CMAC	Date: 18/08/2008	Figure: 4	Rev. A
	Job No. 42906731	File No. Figures.xls			A4

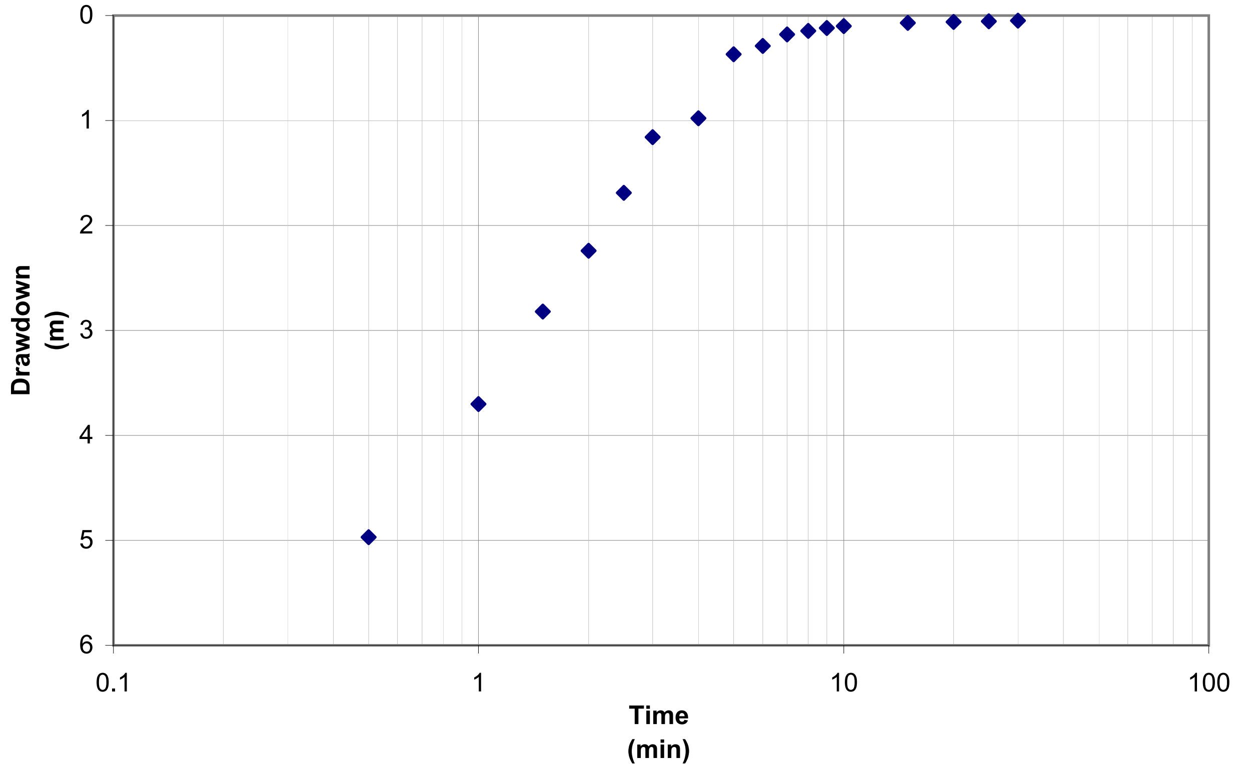
ONBH03
SWL = 3.48 m bTOC
T = 0.04 m^2/d

Pump data

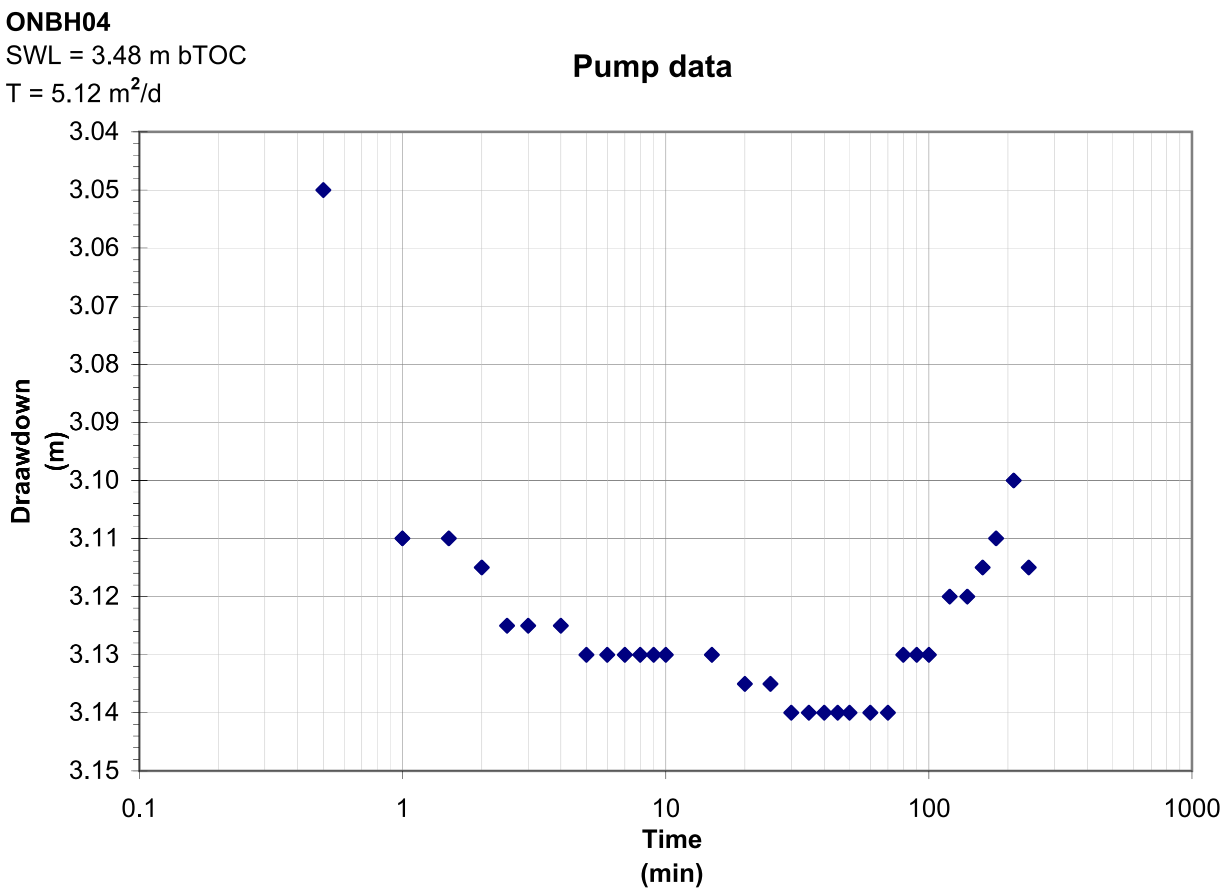


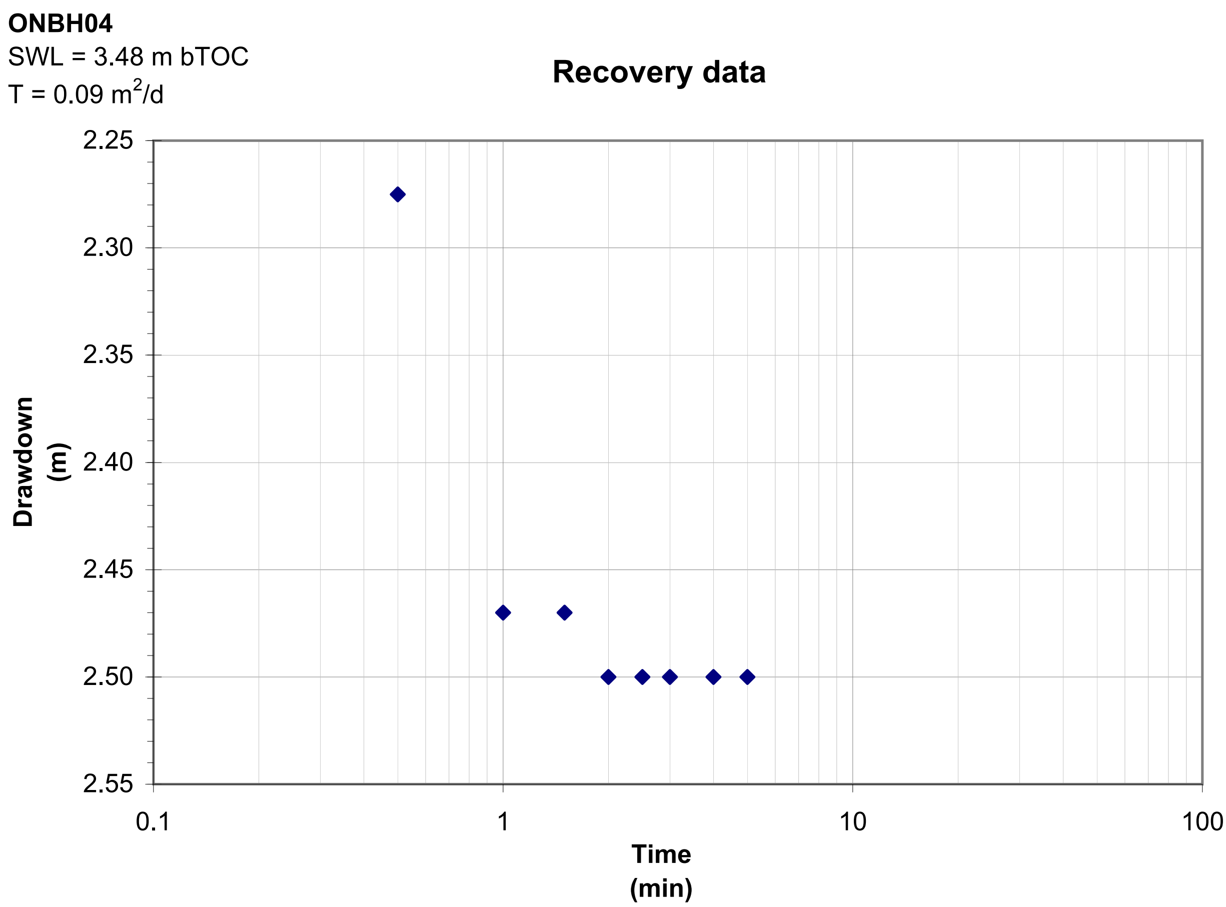
ONBH03
SWL = 3.48 m bTOC
T = 0.02 m^2/d

Recovery data



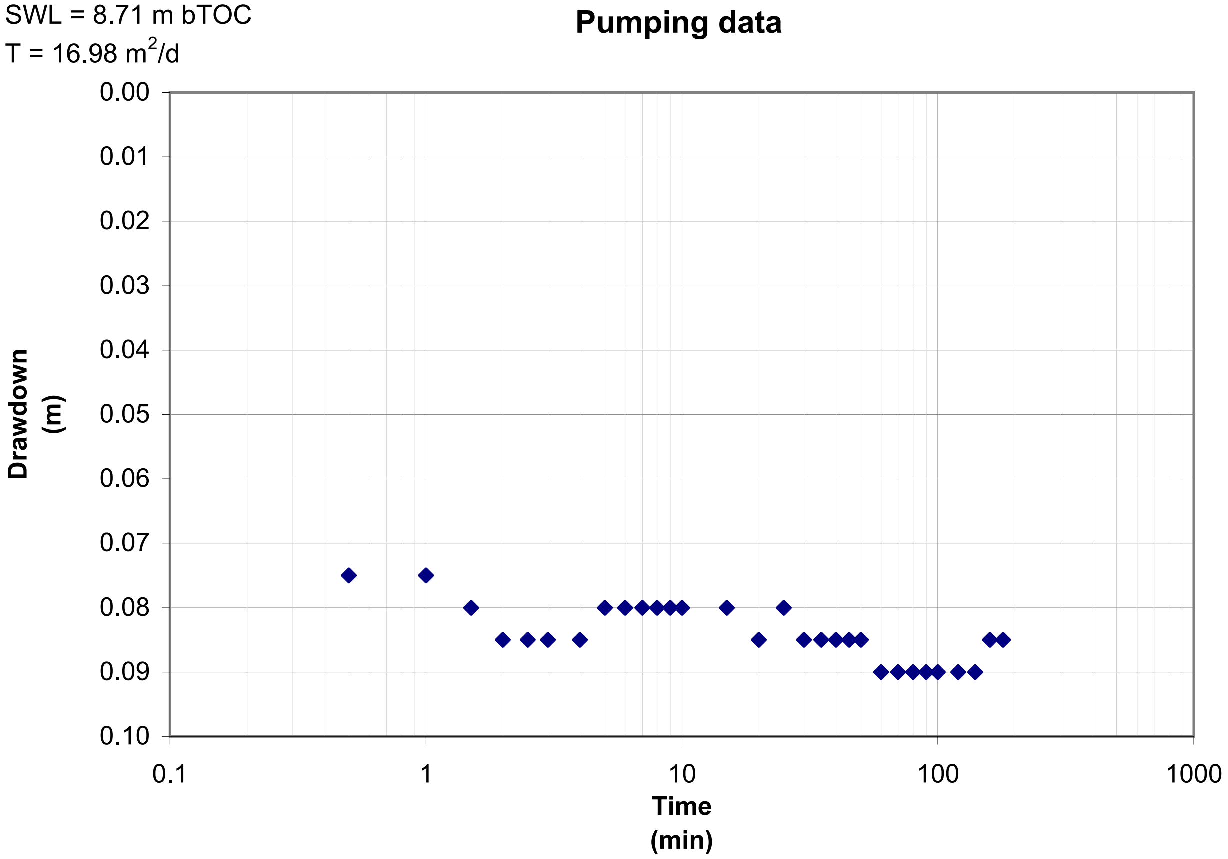
Client: INPEX Browse Ltd	Project: HYDROGEOLOGY OF BLAYDIN POINT MIDDLE ARM HARBOUR, DARWIN	Title: ONBH03 Constant Rate Pumping Test, Groundwater Drawdown and Recovery
URS	Drawn: SEVT / Approved: CMAC / Date: 18/08/2008	Figure: 5 / Rev. A
	Job No. 42906731 / File No. Figures.xls	A4



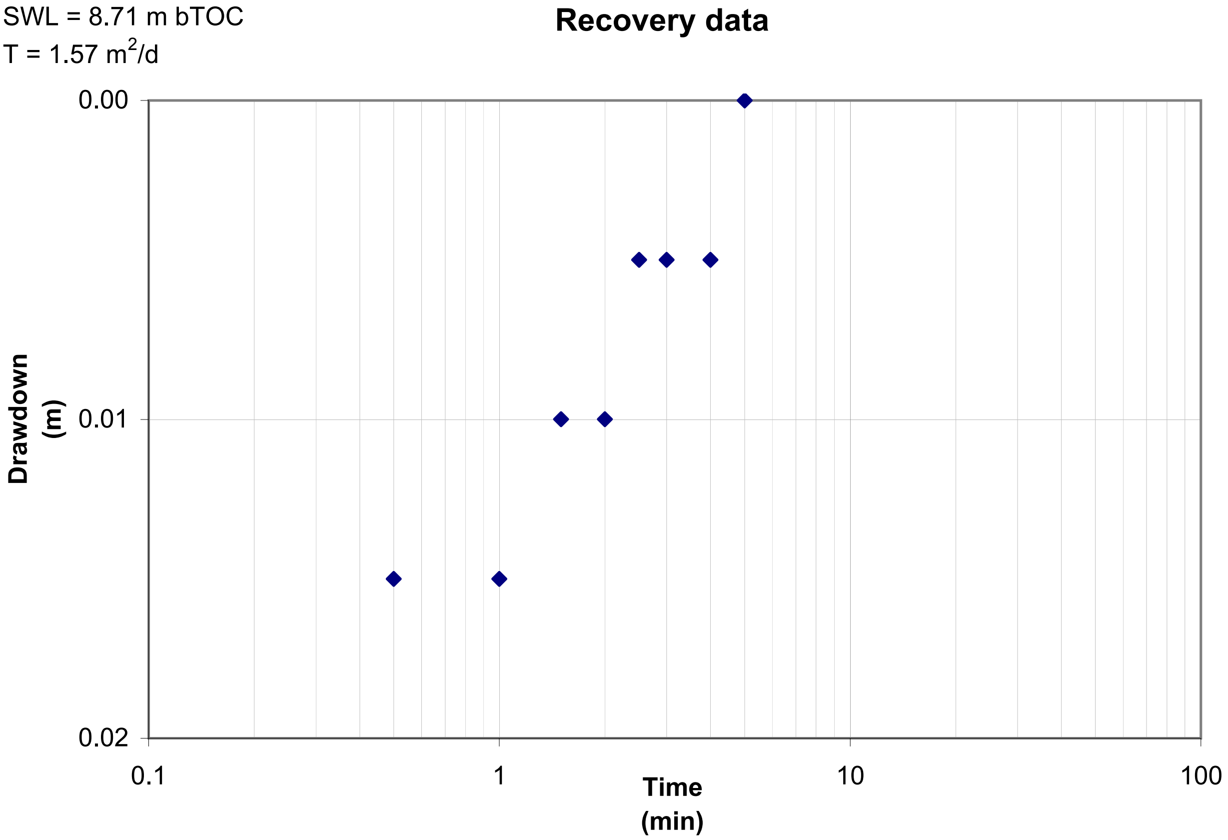


Client: INPEX Browse Ltd	Project: HYDROGEOLOGY OF BLAYDIN POINT MIDDLE ARM HARBOUR, DARWIN	Title: ONBH04 Constant Rate Pumping Test, Groundwater Drawdown and Recovery
URS	Drawn: SEVT / Approved: CMAC / Date: 18/08/2008	Figure: 6 / Rev. A
	Job No. 42906731 / File No. Figures.xls	A4

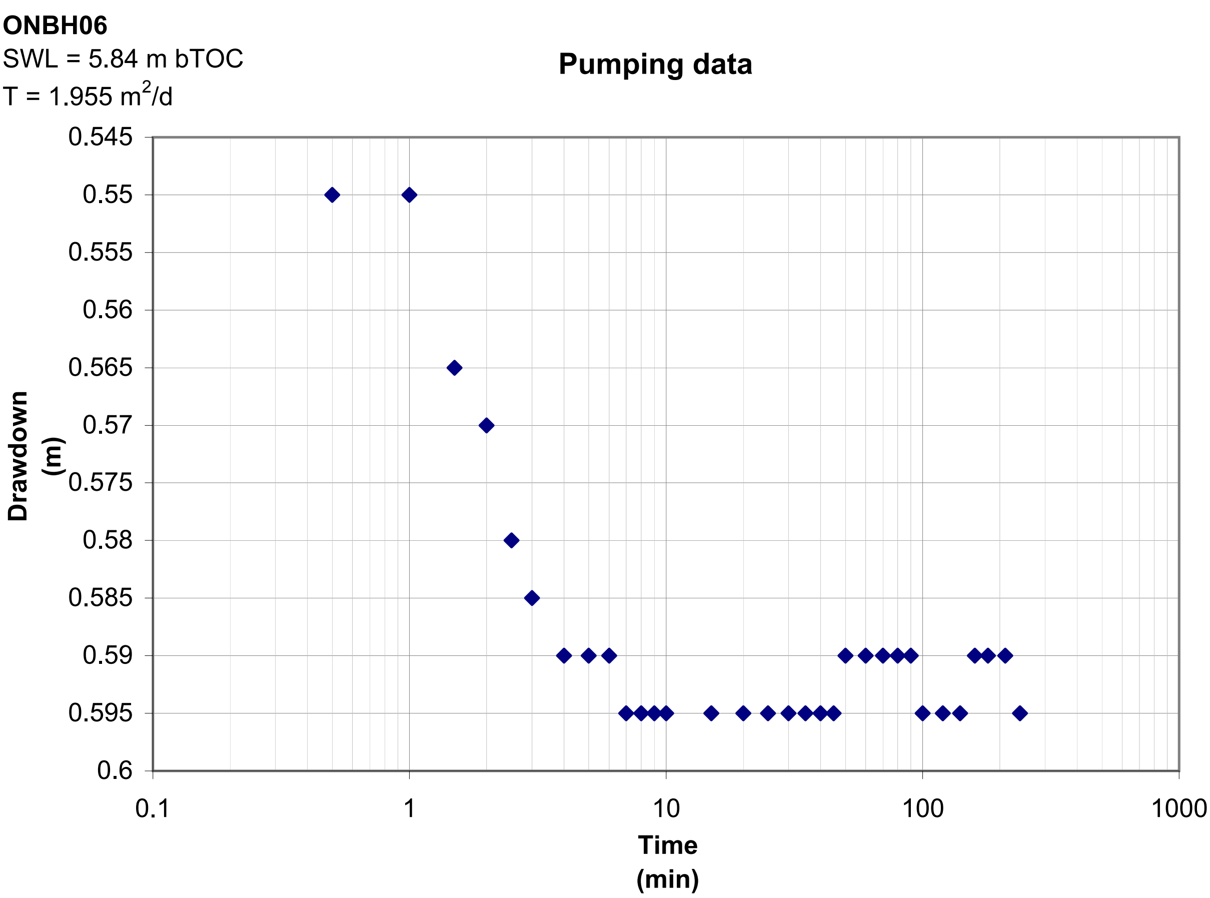
ONBH05
SWL = 8.71 m bTOC
T = 16.98 m^2/d

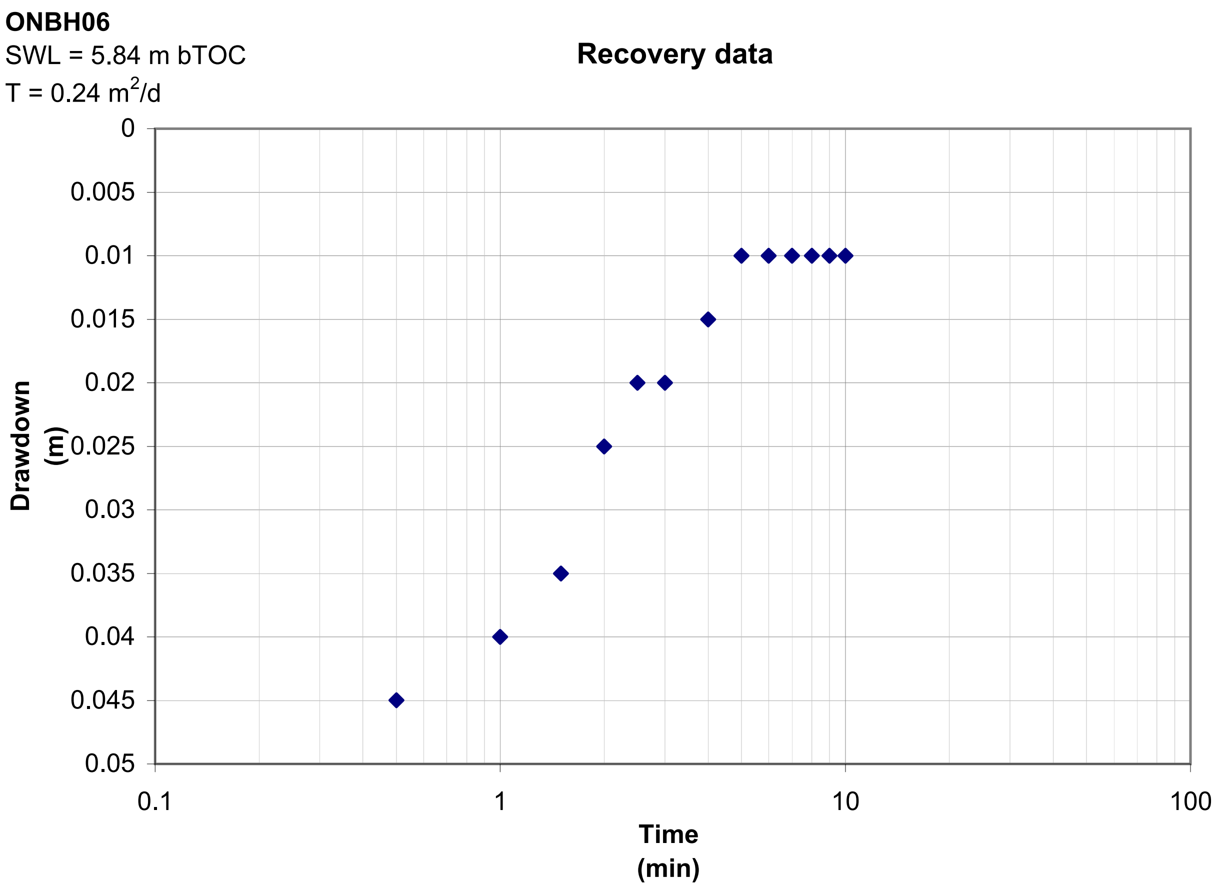


ONBH05
SWL = 8.71 m bTOC
T = 1.57 m^2/d

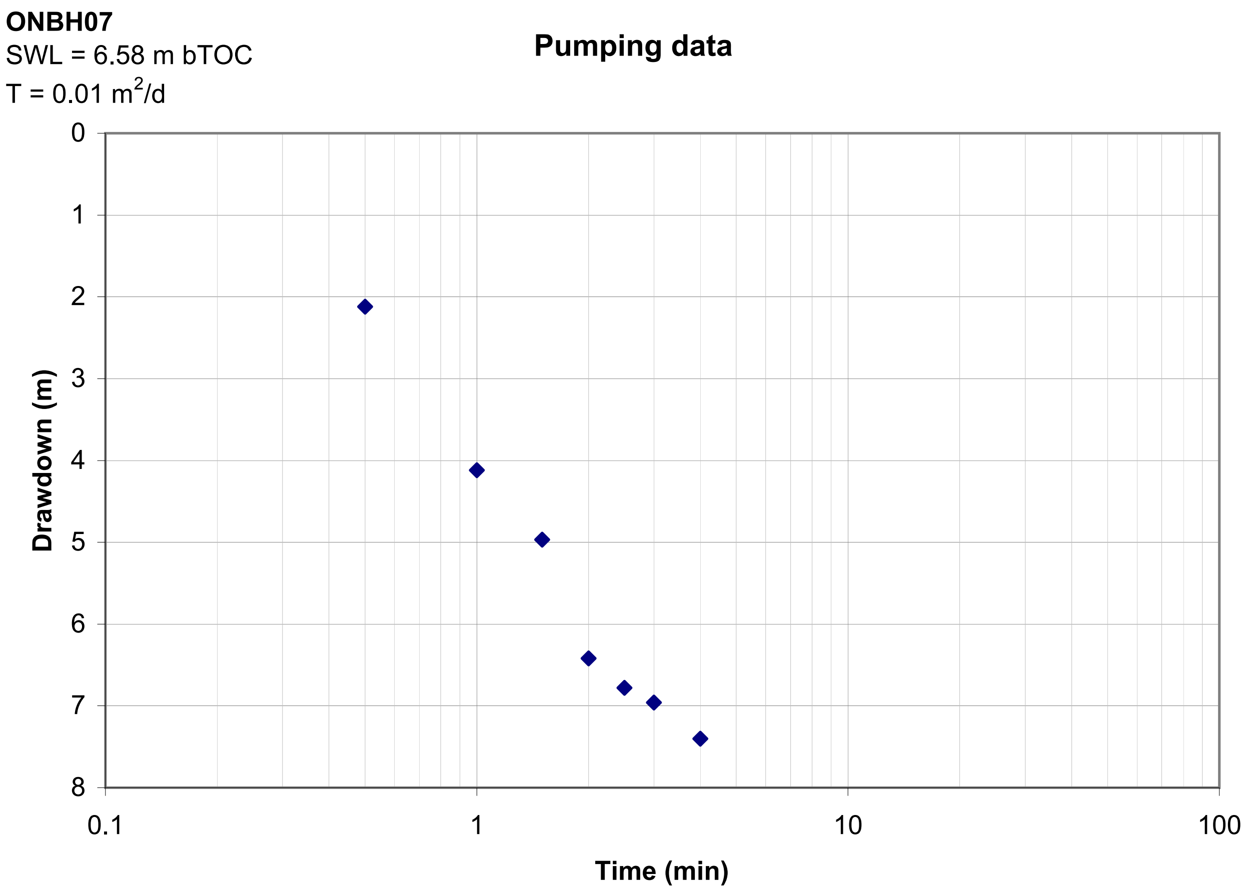


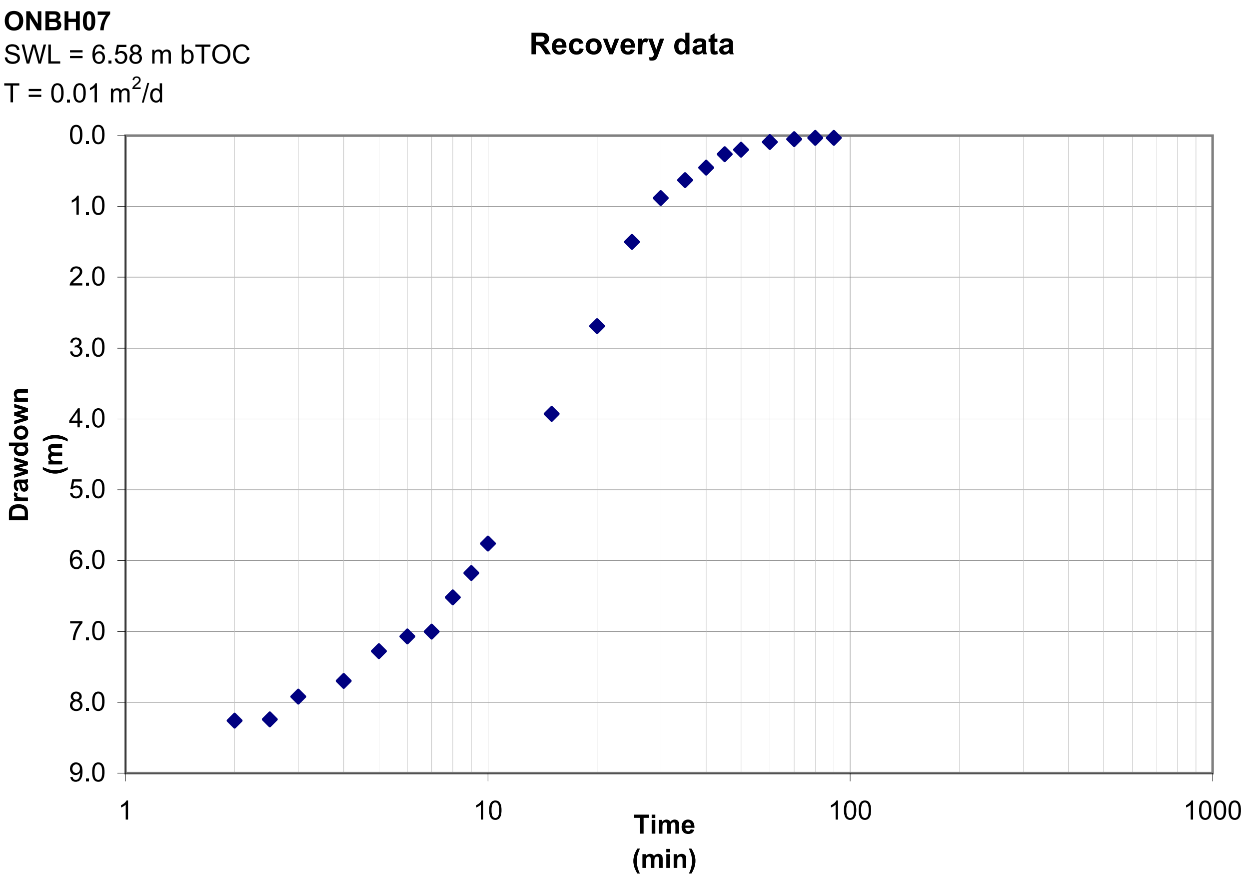
Client: INPEX Browse Ltd	Project: HYDROGEOLOGY OF BLAYDIN POINT MIDDLE ARM HARBOUR, DARWIN	Title: ONBH05 Constant Rate Pumping Test, Groundwater Drawdown and Recovery
URS	Drawn: SEVT; Approved: CMAC; Date: 18/08/2008	Figure: 7
	Job No. 42906731; File No. Figures.xls	Rev. A; A4





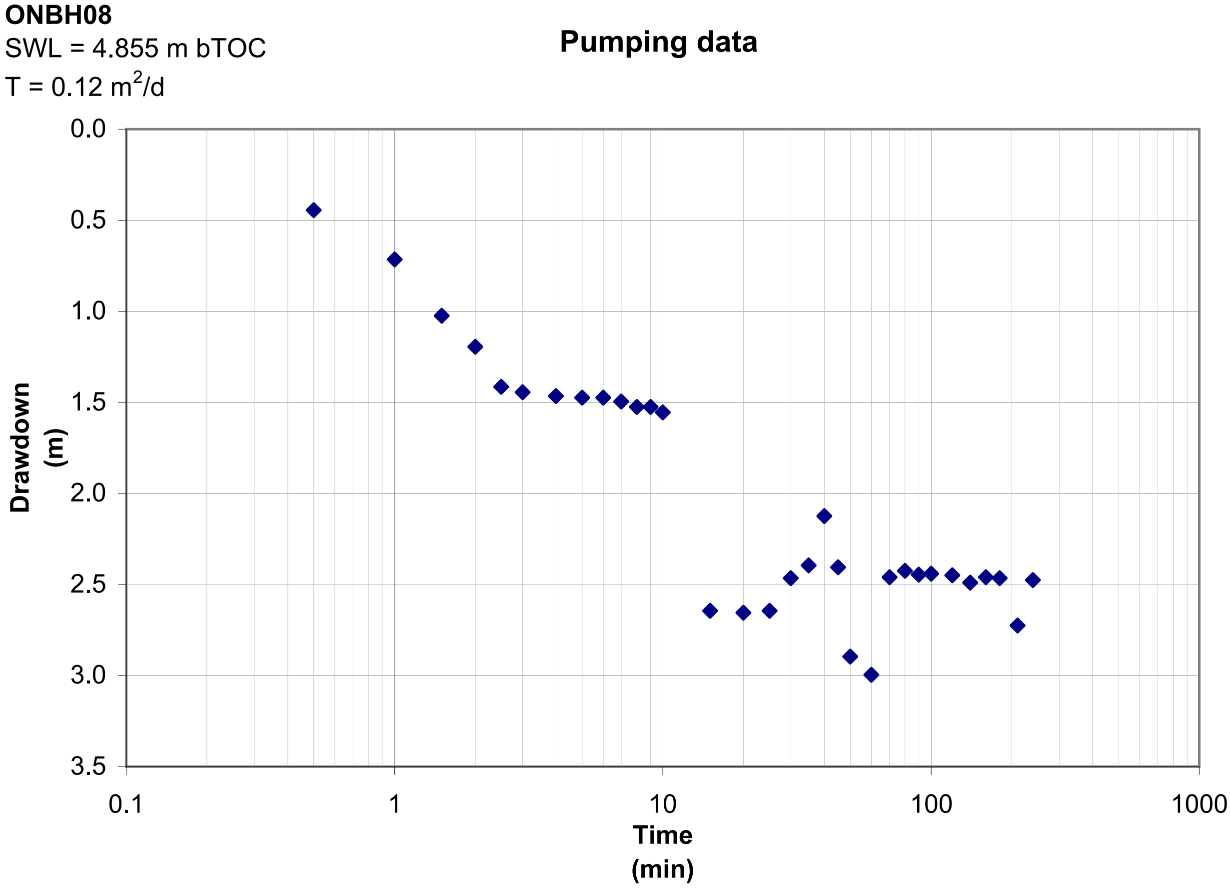
Client: INPEX Browse Ltd	Project: HYDROGEOLOGY OF BLAYDIN POINT MIDDLE ARM HARBOUR, DARWIN			Title: ONBH 06 Constant Rate Pumping Test, Groundwater Drawdown and Recovery
URS	Drawn: SEVT	Approved: CMAC	Date: 18/08/2008	Figure: 8 — Rev. A
	Job No. 42906731	File No. Figures.xls		A4



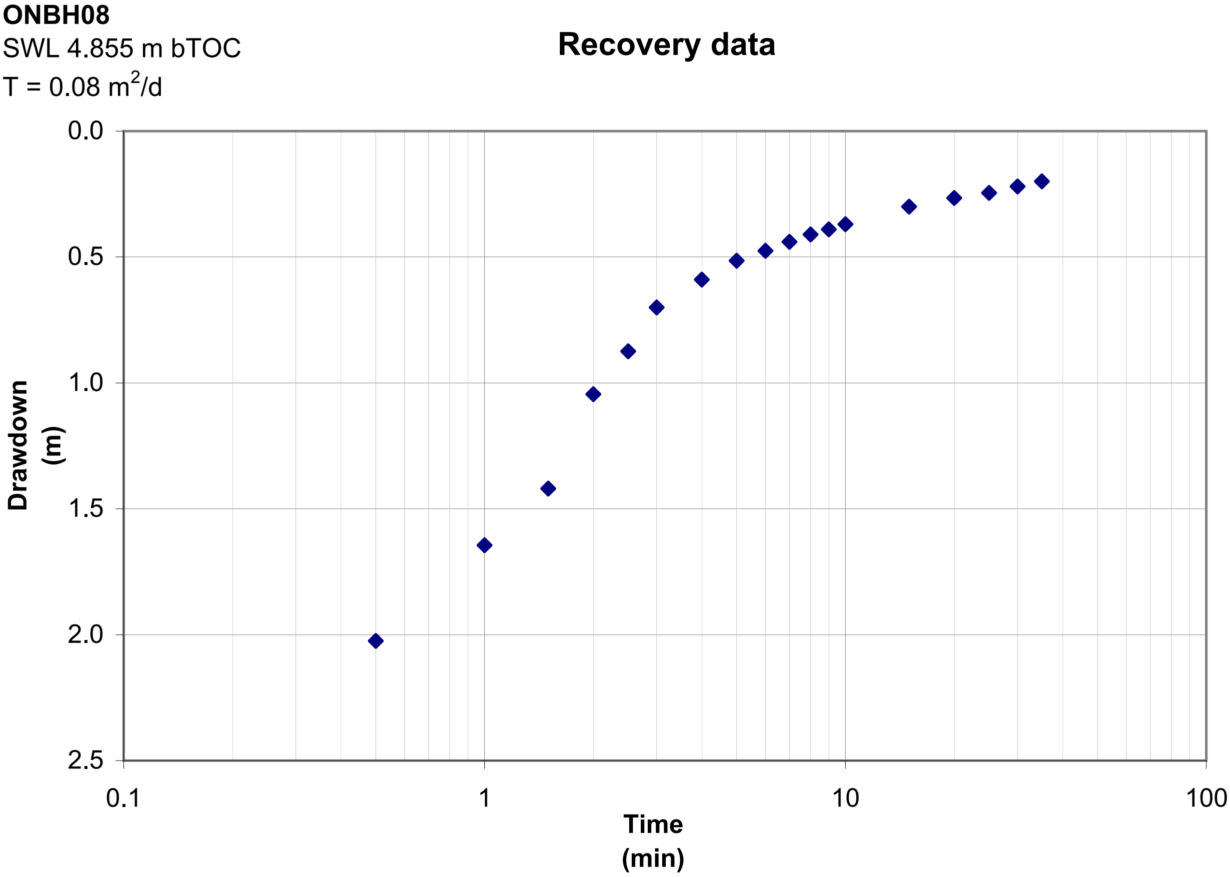


Client: INPEX Browse Ltd	Project: HYDROGEOLOGY OF BLAYDIN POINT MIDDLE ARM HARBOUR, DARWIN		Title: ONBH07 Constant Rate Pumping Test, Groundwater Drawdown and Recovery
URS	Drawn: SEVT	Approved: CMAC	Date: 18/08/2008
	Job No. 42906731	File No. Figures.xls	Figure: 9
			Rev. A
			A4

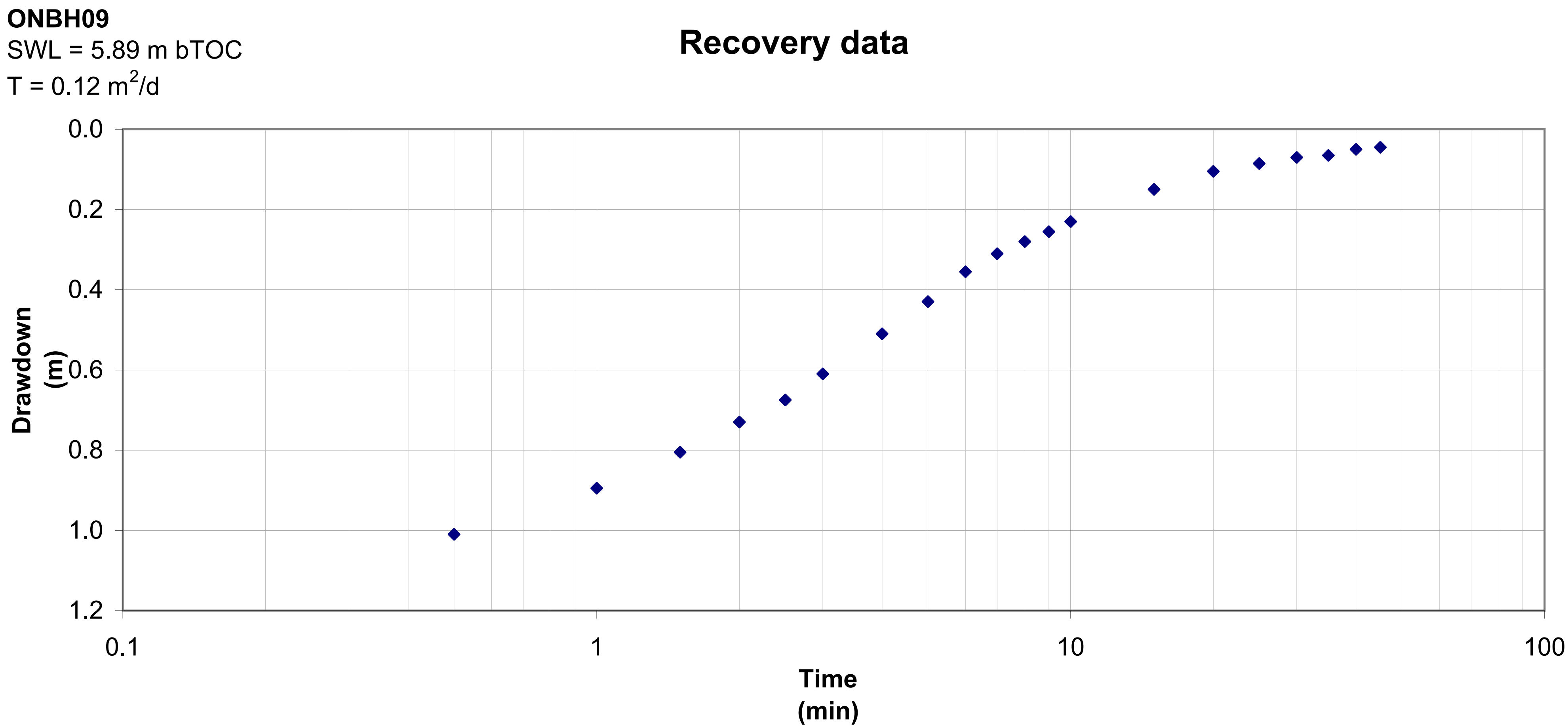
ONBH08
SWL = 4.855 m bTOC
$T = 0.12\ m^2/d$



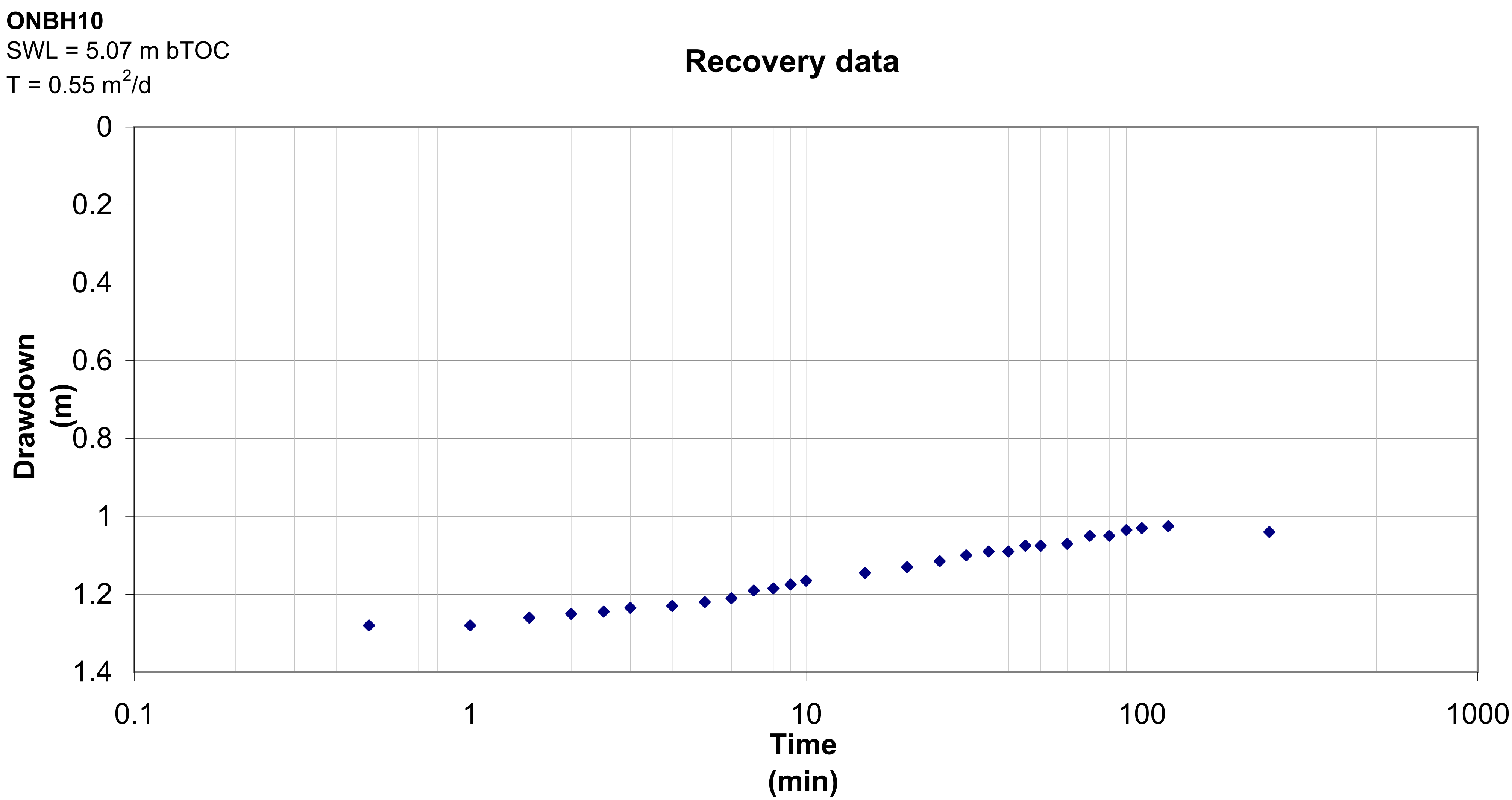
ONBH08
SWL 4.855 m bTOC
$T = 0.08\ m^2/d$



Client: INPEX Browse Ltd	Project: HYDROGEOLOGY OF BLAYDIN POINT MIDDLE ARM HARBOUR, DARWIN		Title: ONBH08 Constant Rate Pumping Test, Groundwater Drawdown and Recovery
URS	Drawn: SEVT	Approved: CMAC	Date: 18/08/2008
	Job No. 42906731	File No. Figures.xls	Figure: 10 / Rev. A / A4



Client: INPEX Browse Ltd	Project: HYDROGEOLOGY OF BLAYDIN POINT MIDDLE ARM HARBOUR, DARWIN			Title: ONBH09 Constant Rate Pumping Test Recovery Data
URS	Drawn: SEVT	Approved: CMAC	Date: 13/08/2008	Figure 11
	Job No: 42906731	File No: Figures.xls		



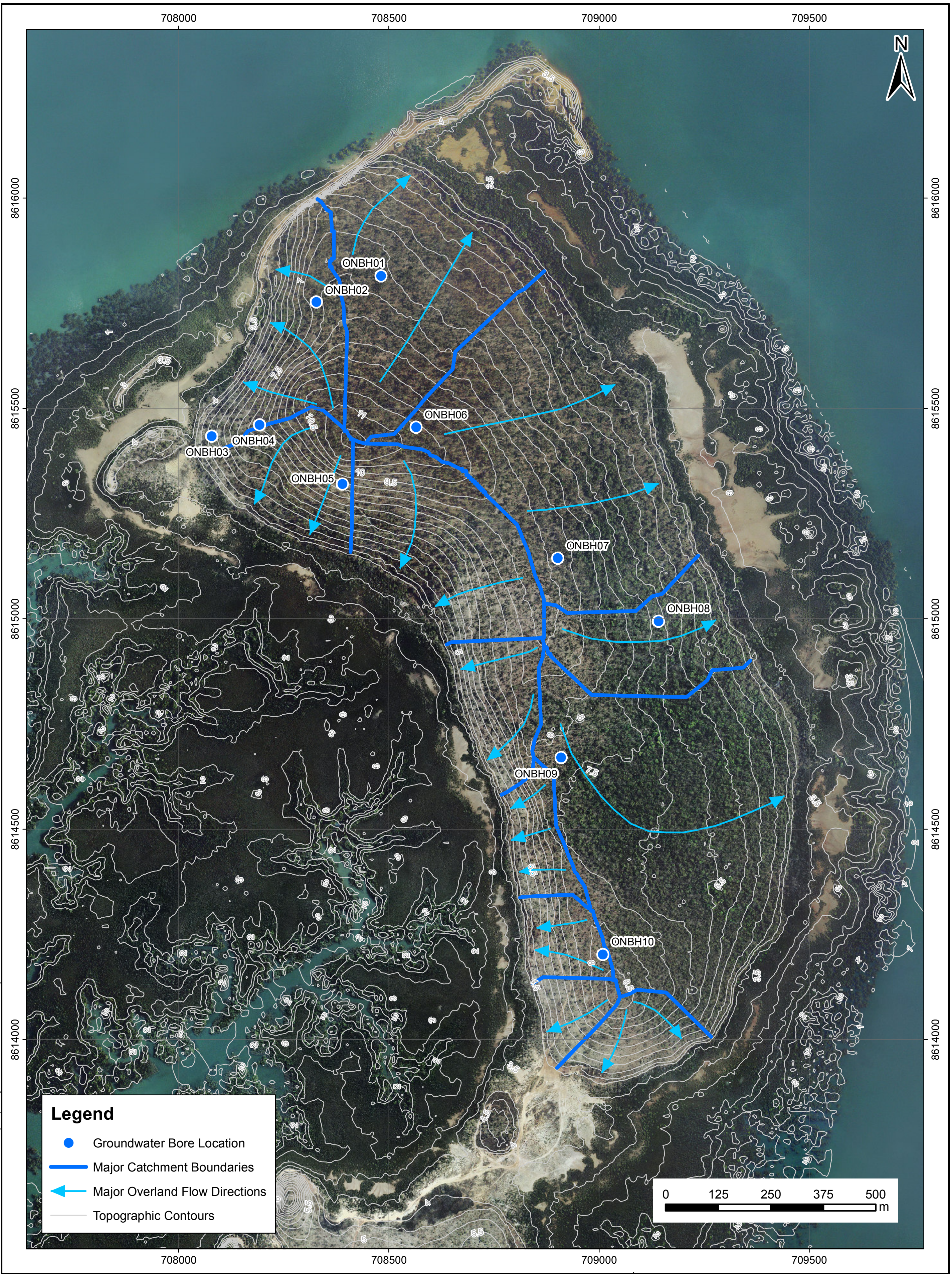
Client: INPEX Browse Ltd	Project: HYDROGEOLOGY OF BLAYDIN POINT MIDDLE ARM HARBOUR, DARWIN			Title: ONBH10 Constant Rate Pumping Test Recovery Data
URS	Drawn: SEVT	Approved: CMAC	Date: 13/08/2008	Figure 12
	Job No: 42906731	File No: Figures.xls		

Client	Project	Title
INPEX Browse, Ltd	ICHTHYS GAS FIELD DEVELOPMENT HYDROLOGY AND HYDROGEOLOGY	GROUNDWATER SALINITY CONTOURS

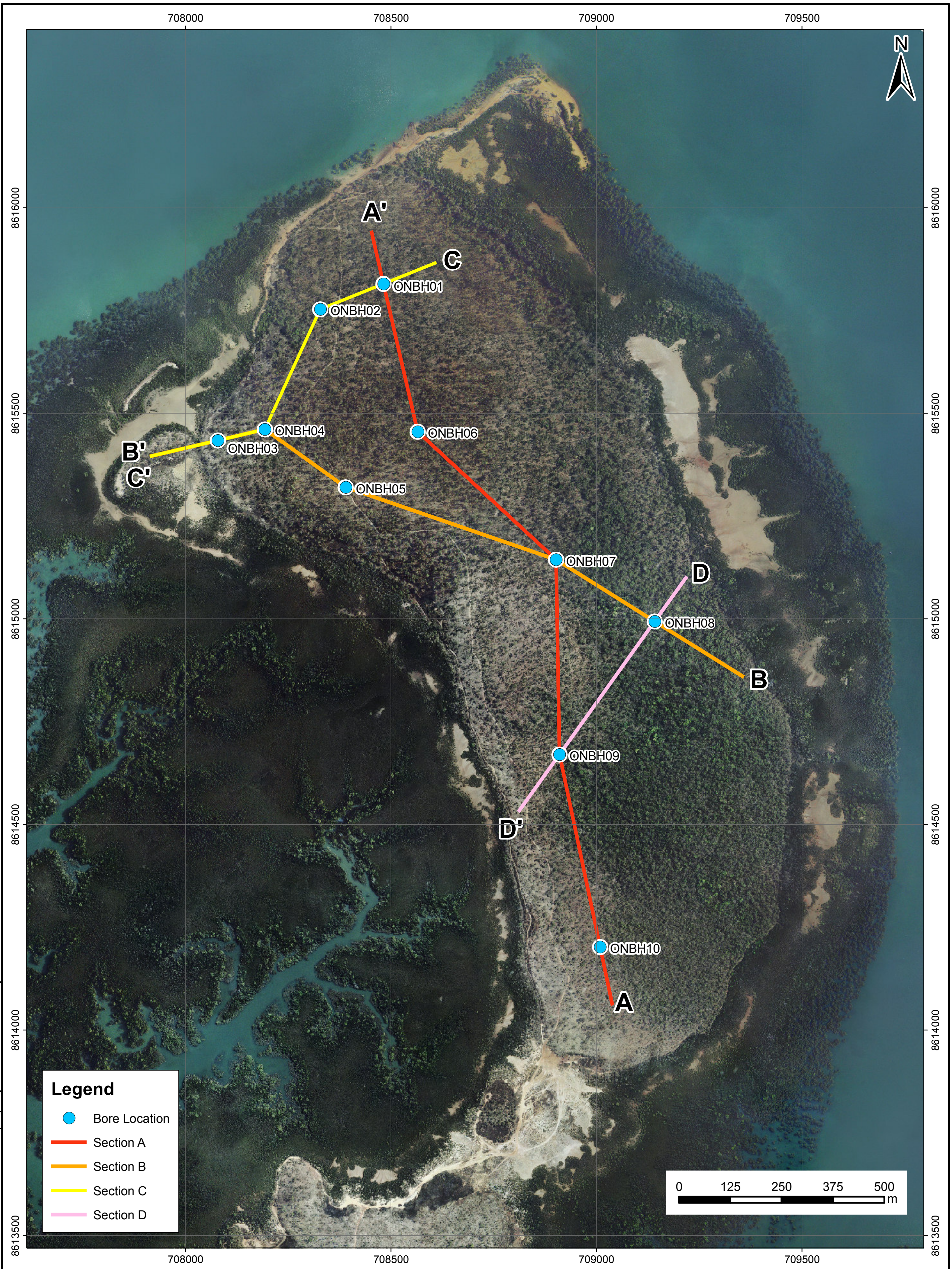
URS

Drawn: JD	Approved: CM	Date: 19/8/2008	Figure: 13	Rev. A
Job No.: 42906731	File No.: 42906731-003.mxd			A4

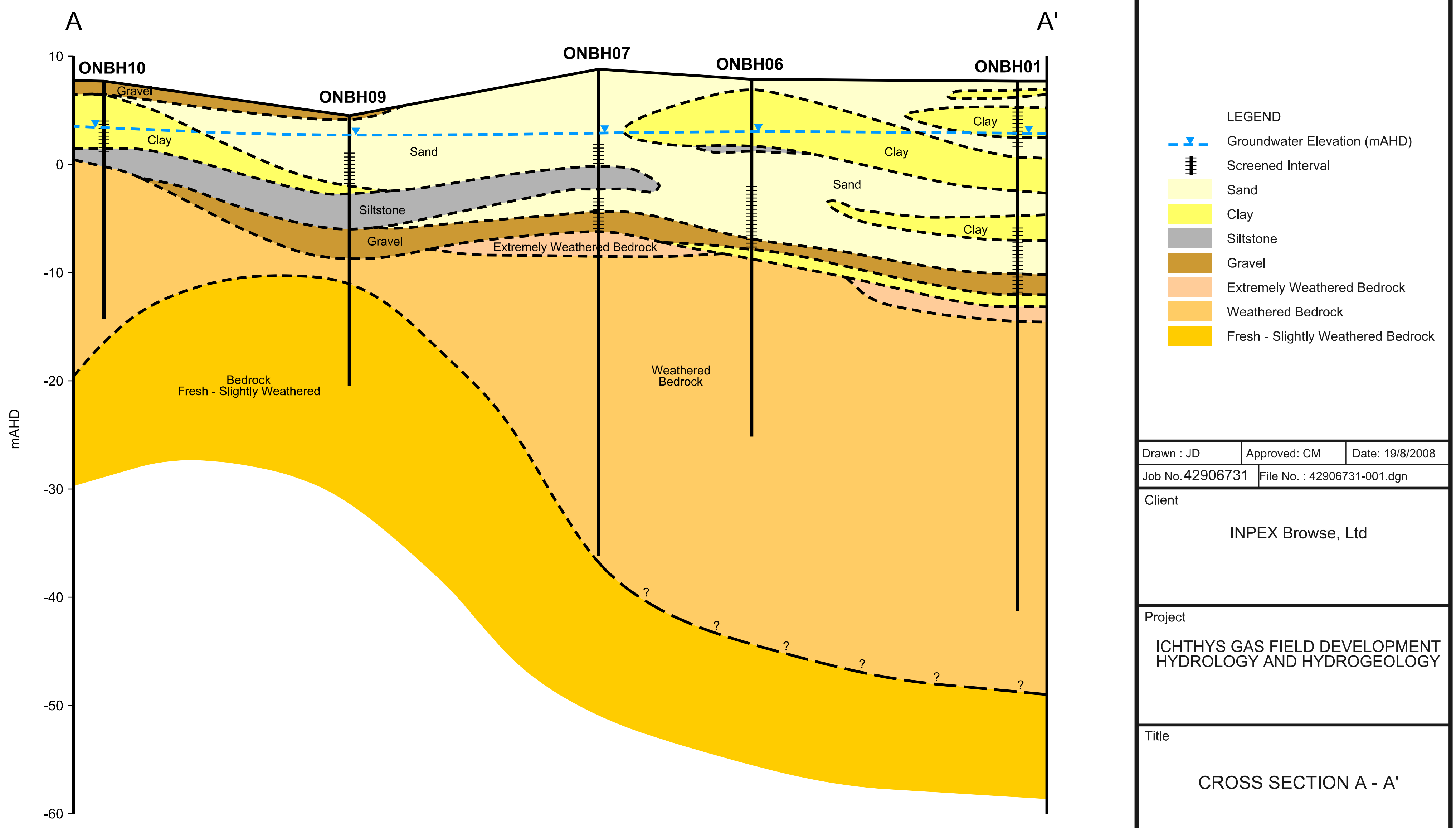
Client INPEX Browse, Ltd	Project ICHTHYS GAS FIELD DEVELOPMENT HYDROLOGY AND HYDROGEOLOGY		Title GROUNDWATER FIELD pH CONTOURS
URS	Drawn: JD	Approved: CM	Date: 19/8/2008
	Job No.: 42906731	File No.: 42906731-004.mxd	Figure: 14 — Rev. A — A4



Client	Project	Title
INPEX Browse, Ltd	ICHTHYS GAS FIELD DEVELOPMENT HYDROLOGY AND HYDROGEOLOGY	TOPOGRAPHY AND CATCHMENT BOUNDARIES
URS	Drawn: JD / Approved: CM / Date: 19/8/2008	Figure: 15 / Rev. A
	Job No.: 42906731 / File No.: 42906731-004.mxd	A4



Client	Project	Title	
INPEX Browse, Ltd	ICHTHYS GAS FIELD DEVELOPMENT HYDROLOGY AND HYDROGEOLOGY	CROSS SECTION LOCATION PLAN	
URS	Drawn: JD / Approved: CM / Date: 20/8/2008	Figure: 16	Rev. A
	Job No.: 42906731 / File No.: 42906731-001.mxd		A4



Drawn : JD	Approved: CM	Date: 19/8/2008
Job No. 42906731	File No. : 42906731-001.dgn	

Client

INPEX Browse, Ltd

Project

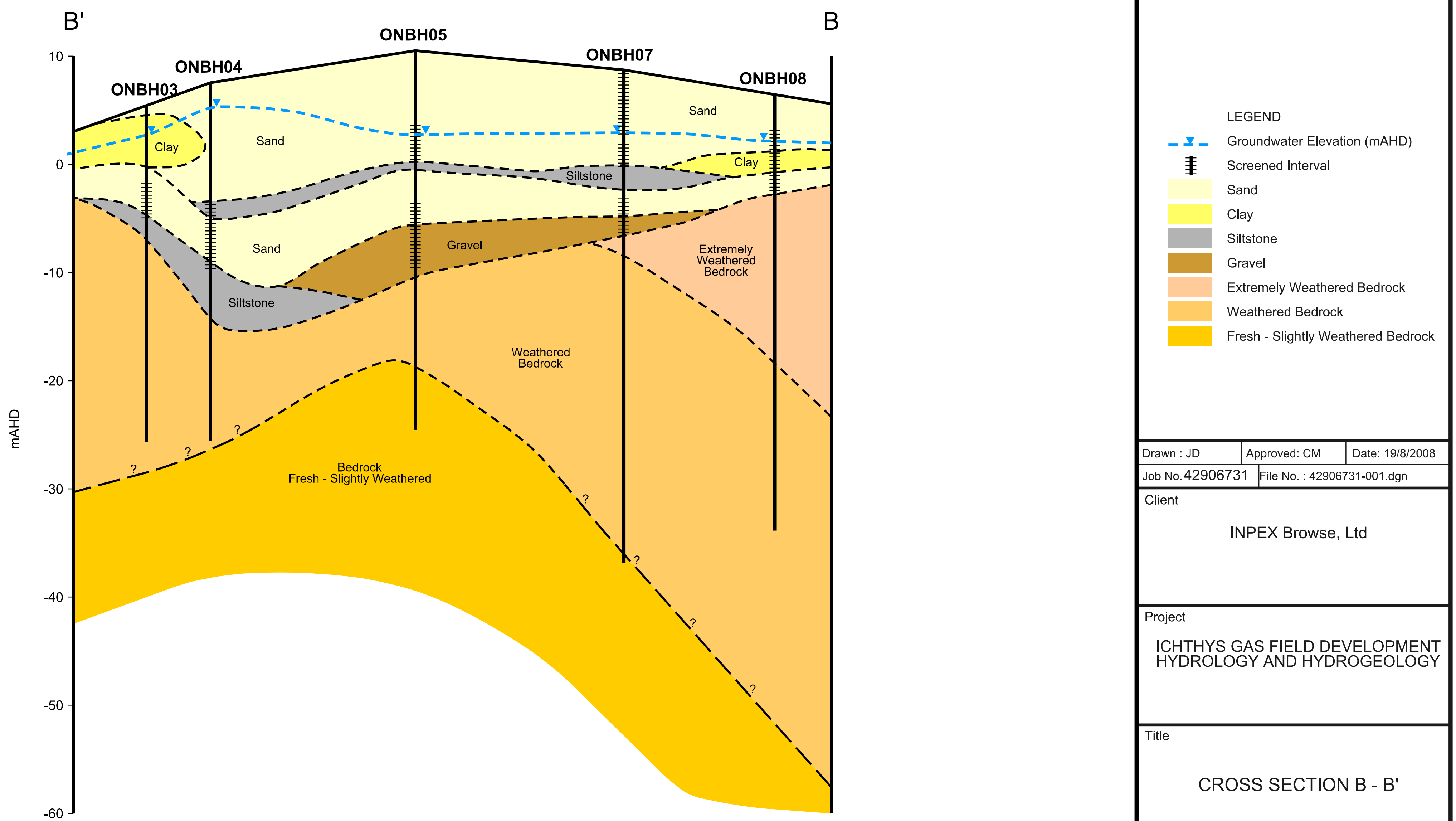
ICHTHYS GAS FIELD DEVELOPMENT
HYDROLOGY AND HYDROGEOLOGY

Title

CROSS SECTION A - A'

Figure: 17 | Rev. A | A4

URS



Drawn : JD	Approved: CM	Date: 19/8/2008
Job No.42906731	File No. : 42906731-001.dgn	

Client

INPEX Browse, Ltd

Project

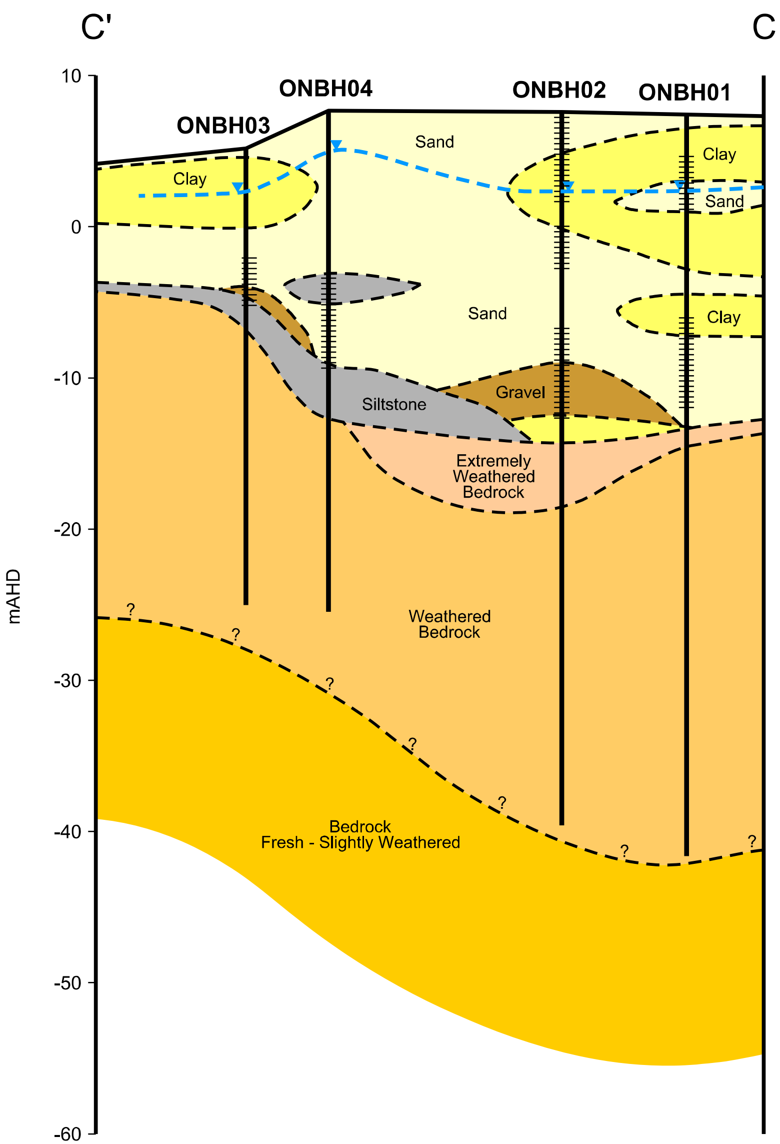
ICHTHYS GAS FIELD DEVELOPMENT
HYDROLOGY AND HYDROGEOLOGY

Title

CROSS SECTION B - B'

Figure: 18 | Rev. A | A4

URS



LEGEND
- Groundwater Elevation (mAHD)
- Screened Interval
- Sand
- Clay
- Siltstone
- Gravel
- Extremely Weathered Bedrock
- Weathered Bedrock
- Fresh - Slightly Weathered Bedrock

Drawn : JD	Approved: CM	Date: 19/8/2008
Job No. 42906731	File No. : 42906731-001.dgn	

Client

INPEX Browse, Ltd

Project

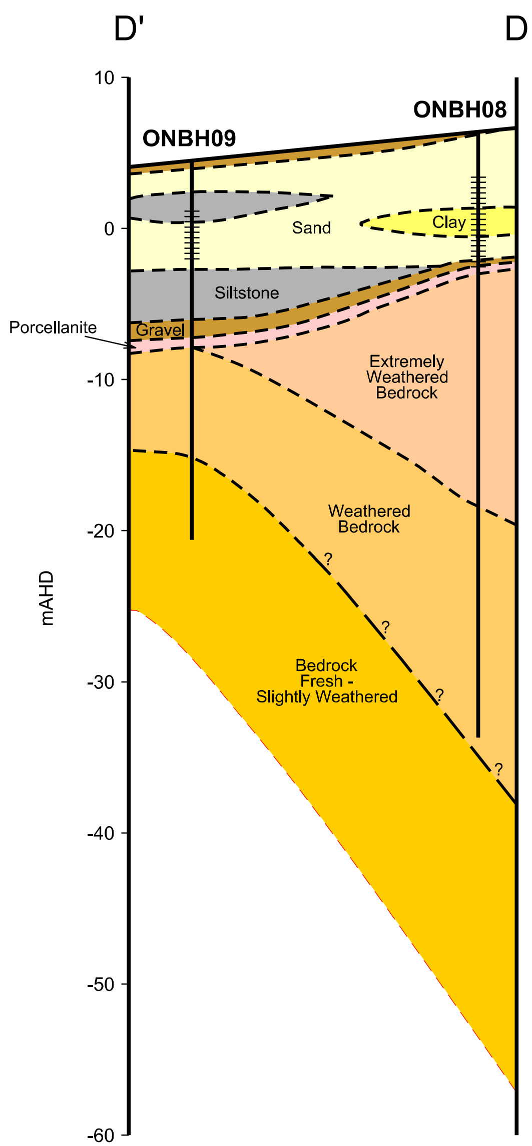
ICHTHYS GAS FIELD DEVELOPMENT
HYDROLOGY AND HYDROGEOLOGY

Title

CROSS SECTION C - C'

Figure: 19 | Rev. A | A4

URS



LEGEND

- Groundwater Elevation (mAHD)
- Screened Interval
- Sand
- Clay
- Siltstone
- Gravel
- Porcellanite
- Extremely Weathered Bedrock
- Weathered Bedrock
- Fresh - Slightly Weathered Bedrock

Drawn : JD	Approved: CM	Date: 19/8/2008
Job No. 42906731	File No. : 42906731-001.dgn	

Client

INPEX Browse, Ltd

Project

ICHTHYS GAS FIELD DEVELOPMENT
HYDROLOGY AND HYDROGEOLOGY

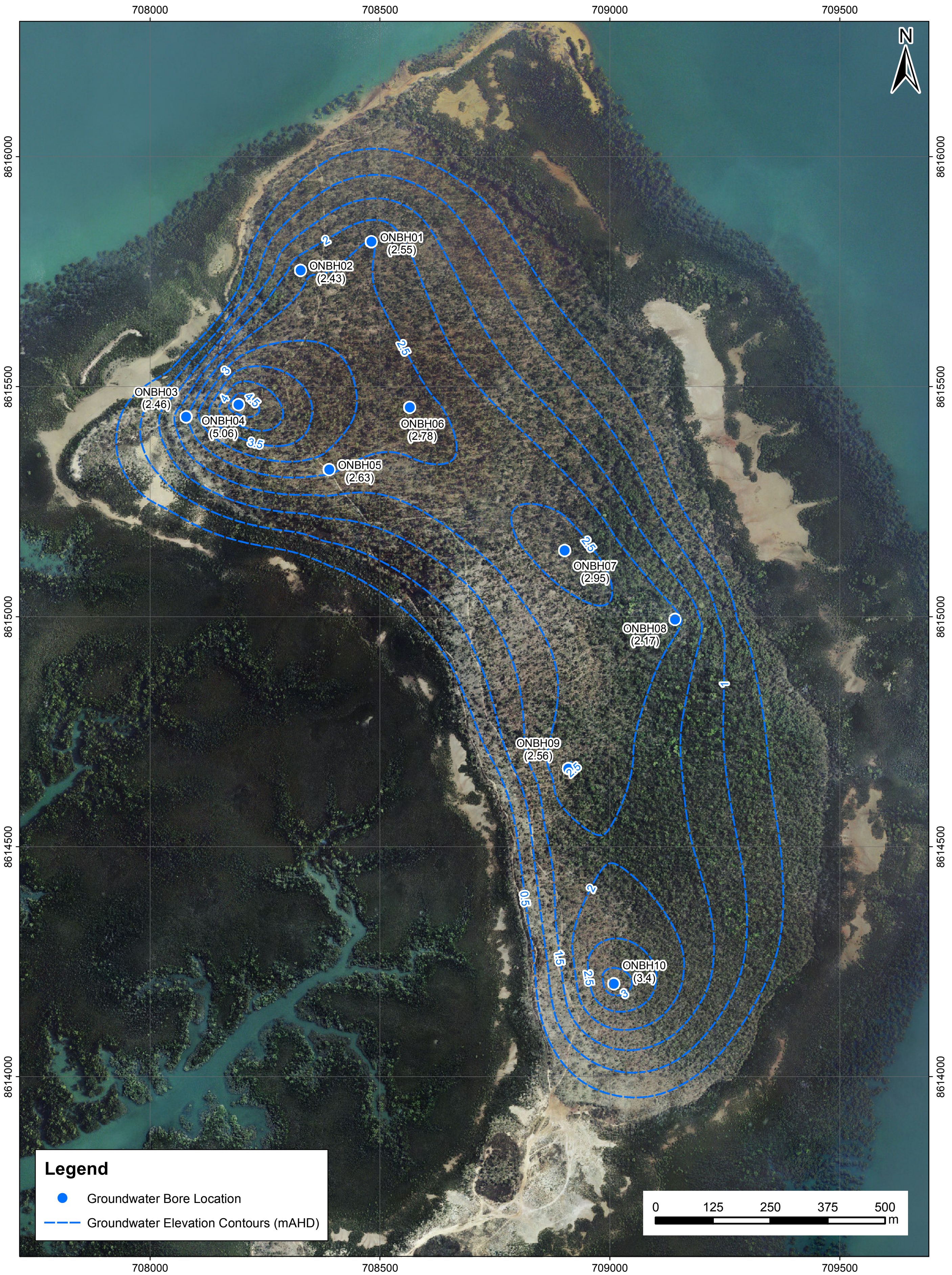
Title

CROSS SECTION D - D'

Figure: 20

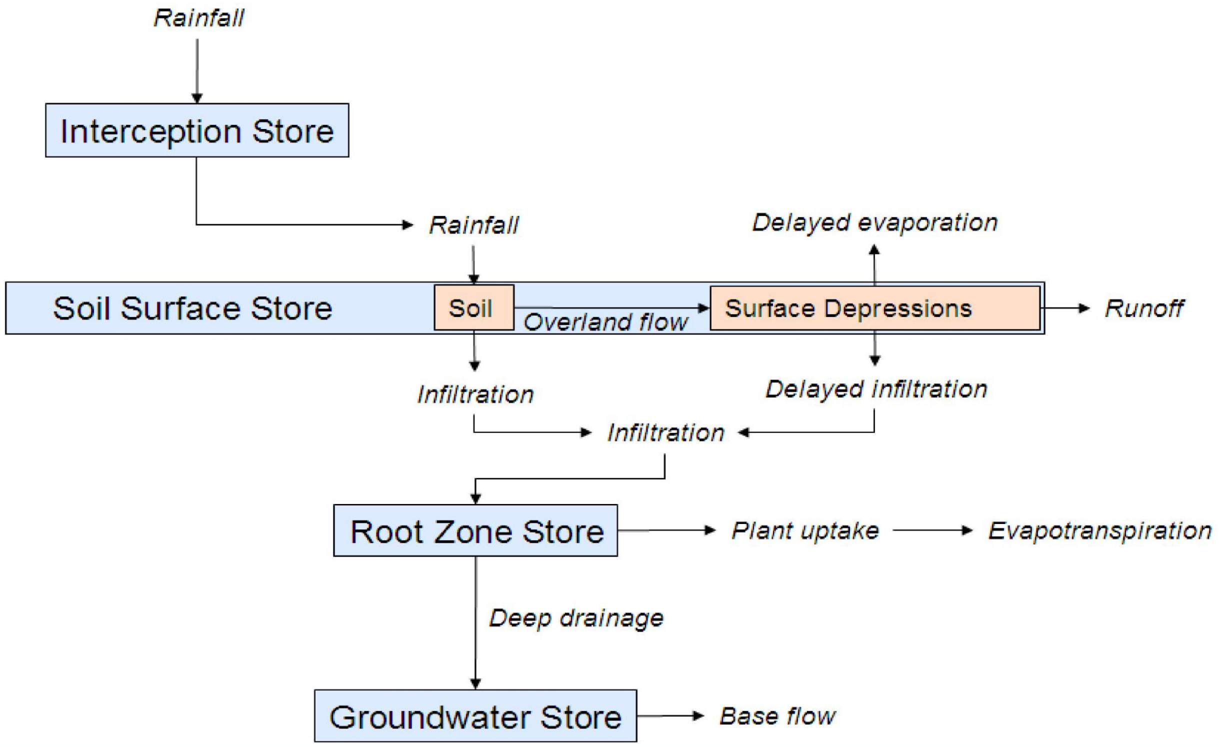
Rev. A

A4

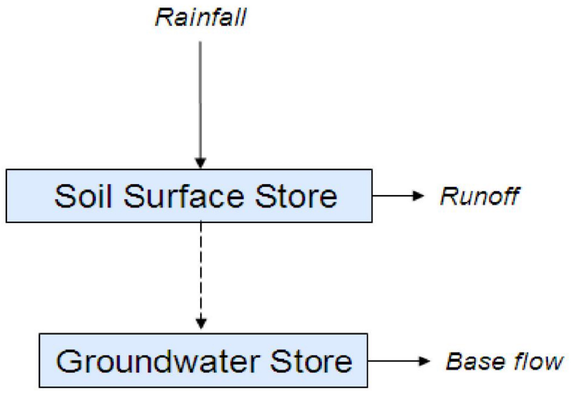


Client	Project	Title
INPEX Browse, Ltd	ICHTHYS GAS FIELD DEVELOPMENT HYDROLOGY AND HYDROGEOLOGY	GROUNDWATER ELEVATION CONTOURS (mAHD)
URS	Drawn: JD / Approved: CM / Date: 19/8/2008	Figure: 21 / Rev. A
	Job No.: 42906731 / File No.: 42906731-002.mxd	A4

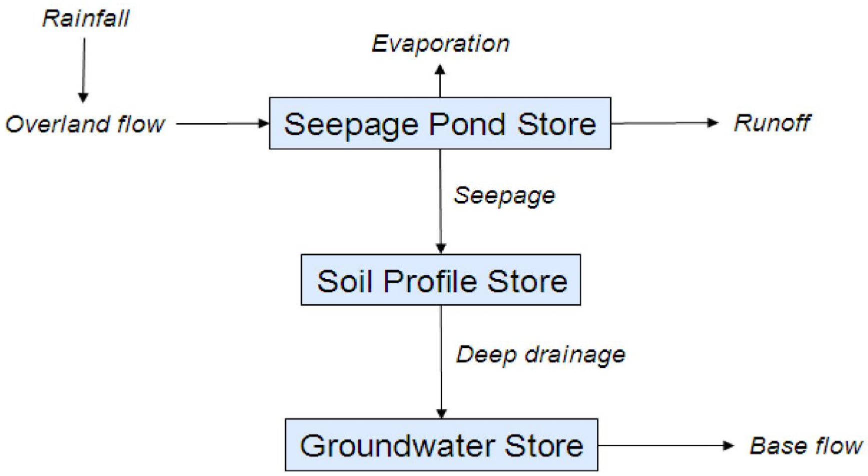
A. Pre-development



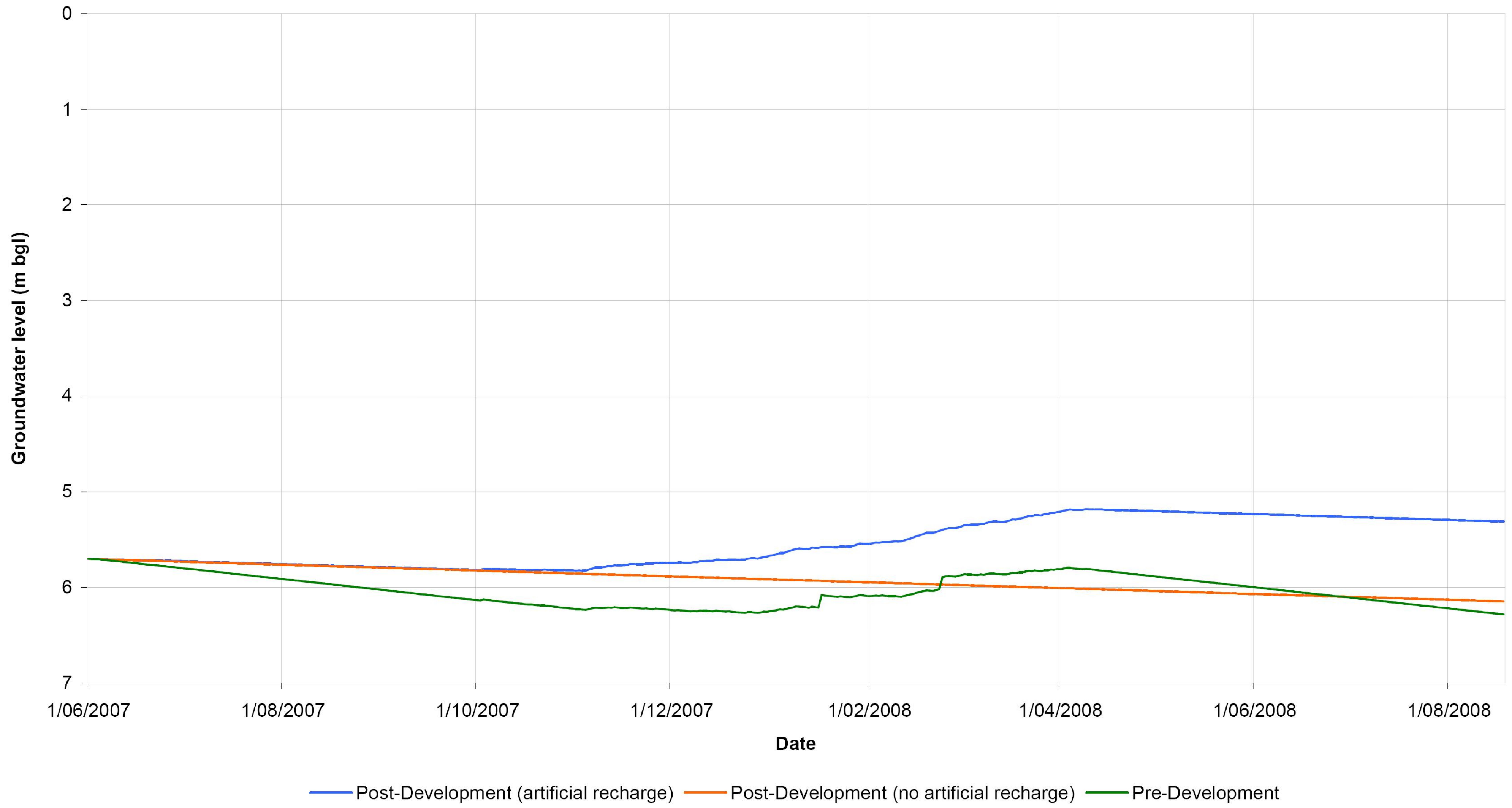
B. Post-development



C. Post-development with artificial seepage ponds

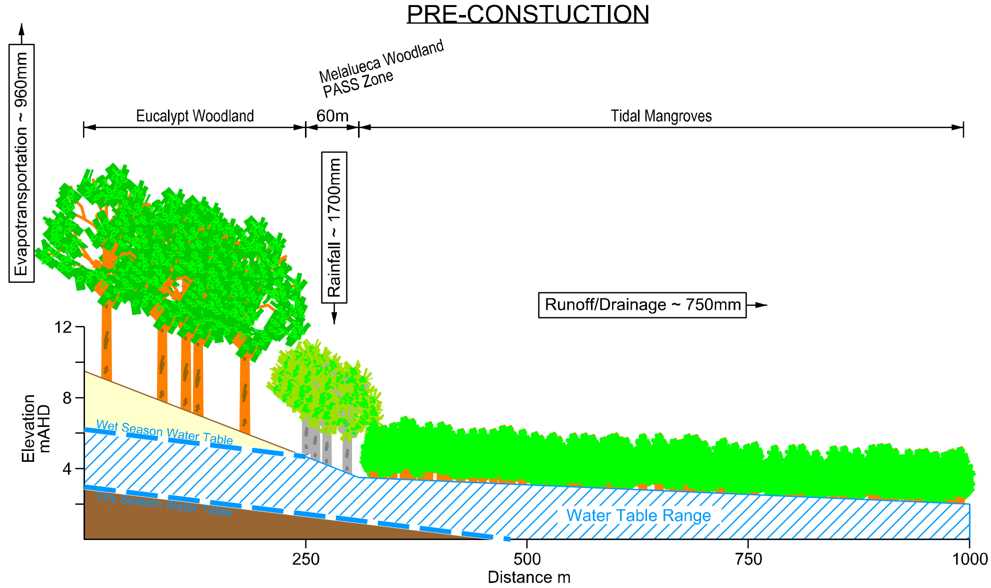


Client	Project	Title	
INPEX Browse Ltd	BLAYDIN POINT LNG PLANT	BLAYDIN POINT CONCEPTUAL MODELS	
URS	Drawn: JD / Approved: CM / Date: 7/10/2008	Figure: 22	Rev. A
	Job No.:42906731 / File No.: 42906731-002.dgn		A4

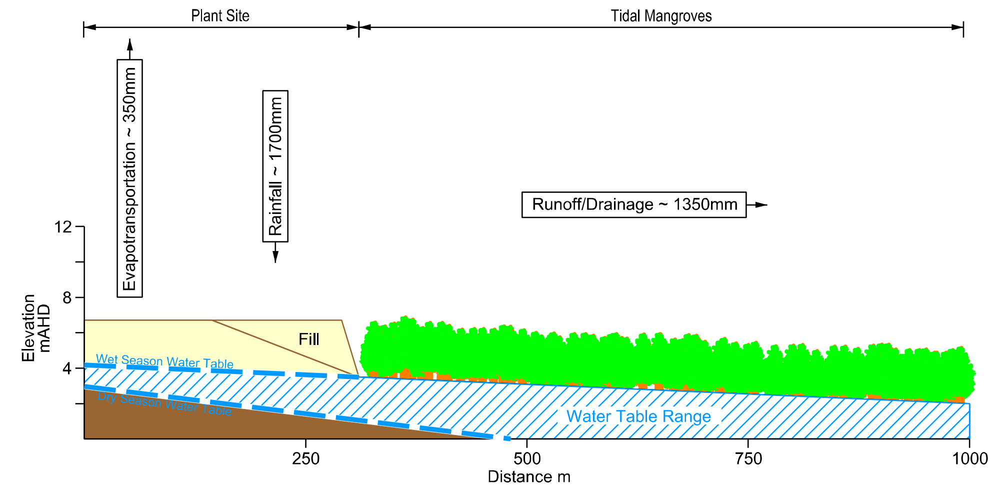


Client	Project			Title	
INPEX Browse Ltd	BLAYDIN POINT LNG PLANT			BLAYDIN POINT WATER BALANCE	
URS	Drawn: JD	Approved: CM	Date: 7/10/2008	Figure: 23	Rev. A
	Job No.:42906731	File No.: 42906731-003.dgn			A4

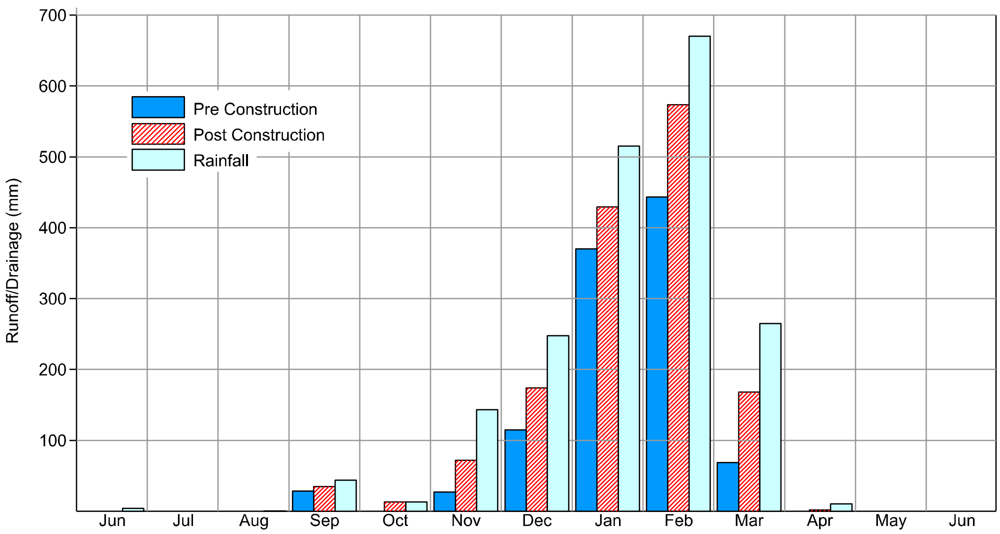
PRE-CONSTUCTION



POST-CONSTUCTION



SURFACE WATER HYDROGRAPH



Based on 2007-08 data from the waterbalance

Client	Project			Title	
INPEX Browse Ltd	BLAYDIN POINT LNG PLANT			BLAYDIN POINT CONCEPTUAL CROSS SECTION	
URS	Drawn: JD	Approved: IH	Date: 4/2/2009	Figure: 24	Rev. A
	Job No.:42906724	File No.: 42906724-001.dgn			A4