REPORT ON

LAKE MACLEOD OPERATIONS
HYDROGEOLOGICAL EXPANSION
PRE-FEASIBILITY STUDY

Prepared for

Dampier Salt Limited

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Report Distribution

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GLOSSARY OF HYDROGEOLOGICAL TERMS

Aquifer	A saturated geological unit that is permeable enough to yield economic quantities of water.
Aquitard	A geological unit that is permeable enough to transmit water but not sufficient to yield economic quantities.
Aquiclude	A geological unit that is impermeable, *i.e.* cannot transmit water.
Confined Aquifer	An aquifer bounded above and below by an aquiclude, where the water level in the aquifer extends above the aquifer top and is represented by a pressure head, *i.e.* the aquifer is completely saturated.
Leaky Aquifer or Semi-Confined Aquifer	An aquifer with upper and/or lower boundaries as an aquitard, where the water level in the aquifer extends above the aquifer top and is represented by a pressure head. Pumping from the aquifer induces leakage from the neighbouring aquitard units.
Unconfined or Watertable Aquifer	An aquifer that is bounded below by an aquiclude, but is not restricted on its upper boundary, which is represented by the water table.
Hydraulic Conductivity (K) ***[Permeability]***	The volume of water that will flow in a unit time under a unit hydraulic gradient through a unit area. Analogous to the permeability with respect to fresh water (units commonly m/d or m/s).
Transmissivity (T)	The product of the hydraulic conductivity and the saturated aquifer thickness (units commonly m^3/d/m or m^2/d)
Specific Storage (S_s)	The volume of water released from a unit volume of aquifer under a unit decline in hydraulic head, assuming confined aquifer conditions. Water is released because of compaction of the aquifer under effective stress and expansion of the water due to decreasing pressure (units commonly m^{-1}).
Storativity (S)	The volume of water released from a unit area of aquifer, i.e the aquifer column, per unit decline in hydraulic head (dimensionless parameter).
Specific Yield (S_y)	The volume of water released from an unconfined aquifer per unit decline in the water table. The release of water is mostly from aquifer draining. Contributions from aquifer compaction are generally small. Analogous with effective porosity (dimensionless parameter).

Terms referenced from Kruseman GP and deRidder NA (1994) 2nd edition, Analysis and Evaluation of Pumping Test Data. ILRI Publication 47 The Netherlands.

1.0 INTRODUCTION

Dampier Salt Ltd manages the Lake MacLeod Operation, located about 75 km north of Carnarvon in the Gascoyne Region of Western Australia (Figure 1). Dampier Salt Ltd is investigating expansion options for the operation and has engaged Groundwater Resource Management to assist them with hydrogeological components of the investigation (contract number 5600021629).

This report presents the results of the hydrogeological investigations completed for the expansion Pre-Feasibility Study assuming the expansion will be limited to further development of the existing gravity fed system of Brine Recovery Trenches with a single abstraction point at the approximate location of the current Pump Station 3. The investigations included extensive groundwater modelling of the lake groundwater and surface water systems completed by CyMod Systems Ltd (CyMod). CyMod also undertook groundwater modelling of the raw water supply for the Lake MacLeod Operation to investigate the security of supply for the expansion.

4.0 BACKGROUND

4.1 Current Lake MacLeod Operation

The current Lake MacLeod Operation comprises:

- the Brine Recovery Trenches;
- Pump Station 3, which pumps feed brine from the Brine Recovery Trenches;
- Pump Station 4 and Pump Station 5, which transfers recovered brine to ditches feeding the crystallisers;
- a series of crystallisers that are used to grow the salt product;
- the Northeast Sump, an area used to store excess brine/salt for re-use when the lake is flooded;
- Pump Station 7, which transfers bitterns from ditches located down-stream of the crystallisers to the Bitterns Storage Area;
- Bitterns Storage Area, an area used to contain bitterns that is located against the western margin of the lake south of the crystallisers;
- the wet salt haul road that links the crystallisers to the Wash Plant;
- the Wash Plant (that removes unwanted gypsum and bitterns salts) and wet salt stockpile;
- three duty and two standby production bores used to supply raw water to the operation;
- the dry salt haul road that links the wet salt stockpile and the port facility at Cape Cuvier;
- the ship loader facility at Cape Cuvier.

The crystallisers, used to grow the salt product, are fed from brine recovered from below the lake. The brine is abstracted from near surface deposits of halite and gypsite using a series of six trenches (BRT1 to 6), which extend north of the crystallisers across the so called “salt field”. The brine within the trenches is transferred to the crystallisers via a series of ditches and pumps. Any excess feed brine is discharged into the Northeast Sump, where evaporative concentration is used to provide a backup resource for the operation that can be activated when brine is not available from the Brine Recovery Trenches (commonly in times of flooding).

Brine is fed into the crystallisers, where it is retained at a set depth to optimise the precipitation of salt. The brine is retained in the crystallisers until the majority of the salt has been precipitated (based upon the specific gravity of the brine). It is then removed from the crystallisers and pumped to the Bitterns Storage Area.

The crystallisers are drained and harvested once sufficient thickness of salt has been precipitated. The wet salt is then hauled to the wash plant where impurities are removed, before stacking in the wet salt stockpile. The wet salt is allowed to gravity drain to remove excess brine, then hauled to the port facility at Cape Cuvier for export.

Raw water for the wash plant is drawn from three operating production bores that draw groundwater from the Birdrong Aquifer, with a further two production bores available that are not currently in use.

Previous Dampier Salt Ltd operations at Lake MacLeod included the mining of gypsum from shallow ponds located north of the salt operation. Gypsum mining was put on care and maintenance in 2008 and may be re-opened in the future if the economics are suitable.

The locations of the various components of the Lake MacLeod Operation are shown in Figure 2.

4.2 Climate

The climate of the Carnarvon Basin region is arid, with a mean annual rainfall below 250 mm. However, recorded annual rainfall varies considerably from less than one-third to approximately three times the annual mean. The rainfall that occurs during the early winter months of May to July tends to be more reliable and generally of a greater total amount than the less dependable, but more intense summer cyclonic rainfall from December to March.

Daily rainfall and evaporation has been measured at the Lake MacLeod Operation since late 1986, although the data between July 1979 and late 1986 is incomplete. In January 2006 an automatic weather station was installed which included a tipping bucket rain gauge, and instruments recording relative humidity, temperature, wind speed and wind direction. A longer period of recorded rainfall (1952 to 2010) is also available for the Quobba Meteorological Station (number 6095), located 17 km to the west northwest of the Lake MacLeod Operation. Rainfall statistics for Quobba Station are presented in Table 3.

Table 3: Monthly Rainfall Statistics for Quobba Station

Month	Mean Monthly Rainfall (mm)	Median Monthly Rainfall (mm)	Maximum Monthly Rainfall and Year (mm)	Minimum Monthly Rainfall (mm)	No. of Complete Months
January	6.6	0.0	63.2 (1963)	0.0	55
February	19.8	0.0	205.2 (1970)	0.0	55
March	18.5	0.0	218.0 (2000)	0.0	55
April	12.9	3.8	90.0 (1992)	0.0	55
May	34.6	20.0	254.1 (1953)	0.0	53
June	56.3	47.0	208.0 (2005)	0.0	53
July	40.8	22.5	226.0 1998)	0.0	54
August	14.4	12.0	51.0 (1990)	0.0	55
September	4.4	0.0	40.0 (1981)	0.0	55
October	3.6	0.0	44.5 (1998)	0.0	56
November	0.8	0.0	15.0 (2007)	0.0	55
December	1.7	0.0	77.0 (1995)	0.0	55
Total no. of complete months in data set					656

Table 3 shows that the three months from May to July is the wettest period of the year based on both mean and median monthly rainfall values. The wettest month of the year at Quobba is June with a mean monthly value of 56.3 mm and a median value of 47.0 mm.

It is interesting to note that the median monthly rainfall for the seven months from September to March is zero, while inspection of the mean monthly values for February and March show rainfalls in the order of 20 mm each month. These results show the positive skewing effect that extreme cyclonic rainfall events can have on the mean rainfall values compared to median values, especially during the summer months.

Pan evaporation data for Dampier Salt Ltd's evaporation pan at the Lake MacLeod Operation were analysed. The annual analysis was based on 21 complete years of data between 1990 and 2010, while the monthly analysis used 268 complete months of data collected between January 1988 and December 2010 (incomplete months were discarded). The results of the monthly analysis are presented in Table 4 below.

Table 4: Lake MacLeod Operation Monthly Pan Evaporation

Month	Mean Monthly Evaporation (mm)	Median Monthly Evaporation (mm)	Maximum Monthly Evaporation (mm)	Minimum Monthly Evaporation (mm)	No. of Complete Months
January	377.8	385.0	429.7	292.1	23
February	329.5	333.3	409.8	269.7	23
March	337.9	335.4	401.7	296.8	21
April	260.7	262.5	323.0	218.6	23
May	194.8	199.5	226.8	137.8	22
June	145.9	146.7	174.9	111.1	22
July	153.7	151.3	181.4	123.2	21
August	186.1	184.2	232.4	151.9	23
September	239.7	241.7	275.0	204.7	21
October	310.8	308.0	356.9	261.9	23
November	335.1	336.4	368.2	298.4	23
December	376.5	372.8	408.5	339.3	23
Total no. of complete months in data set					268

The analysis of the 21 years of complete data provided a mean annual pan evaporation at Lake MacLeod Operation of 3,244 mm (median 3,265 mm per annum).

4.3 Geomorphology

Lake MacLeod has formed within a shallow elongated basin that trends to the north northeast. The lake covers an area of about 2,000 km^2 with a length of around 140 km (Figure 3). The narrow northern third of the lake is partially isolated from the southern part of the lake by the Sandy Bluff Sill. South of the sill the lake is at its widest (approximately 40 km) with Minilya Bay forming its eastern margin. The lake narrows again to the south.

The lake occupies the lake MacLeod graben, a complex fault controlled Quaternary depression bounded to the west by the Barrier and to the east by the Hinterland (Logan 1987B). The elevation of the lake surface ranges from 0 to -4.3 mAHD, sloping gently to the south and east at a gradient of between about 0.002% and 0.003%.

The lowest points on the lake are Ralph Sink to the east (minimum elevation -3.4 mAHD) and Texada Sink to the south (minimum elevation -4.3 mAHD). There are a number of other low points on the lake. These include the depressions now occupied by the Cygnet and Ibis Ponds that lie near the northern end of the lake on its western margin and south of Sandy Bluff Sill. A subtle ridge, termed the Cygnet Sill separates the two ponds. Similarly, the northern limit of the Texada Sink is defined by the Texada Sill, which lies south of the Bitterns Storage Area at the Lake MacLeod Operation.

The lake is cut off from the Indian Ocean to the west by the Barrier, which is formed by the Quobba Ridge to the north and Bejaling Ridge to the south. The ridges comprise a series of low dunal breakaways, which extend north from the mouth of the Gascoyne River, 180 km to the Giralia Range. The height of the Barrier ranges from about 20 to 90 mAHD and the width from 3 to 15 km.

The southern lake boundary, marked by the Boolathanna Basin, is defined as the northern levee of the Gascoyne River. The levee generally protects the lake from river inflows when the river is running. However, during periods of peak flooding overflows from the Gascoyne can occur via a number of braided channel systems with inverts close to sea level. These systems, which include the Yalkatharra, Yandoo, Nyrinde and McGlade floodways, report to the Boolathanna Basin and from there into the main body of the lake.

The eastern boundary of the lake comprises a series of low ranges, termed the Hinterland by Logan, including (from north to south) the Lyell and Grierson Ranges, and the Warrora Ridge. The northern lake extent coincides with the Giralia Range. Both the eastern and northern Hinterland are dominated by dune-fields with maximum elevations of around 60 mAHD.

The Minilya and Lyndon Rivers discharge directly into the lake from the northeast and north respectively. Catchment areas for the three rivers associated with the lake are summarised in Table 5.

Table 5: River Catchments

River	Catchment Area (km^2)
Gascoyne River	70,000
Minilya River	7,000
Lyndon River	1,500

Note: catchment areas sourced from Logan 1982.

Figures, sourced from reports prepared by Logan and CyMod showing the geomorphology of the lake area, are presented in Appendix A and listed below.

Figure A1. General area contour plan.

Figure A2. Lake surface contour plan.

4.4 Regional Geology

Lake MacLeod Operation lies within the Carnarvon Basin, which forms an elongated basin stretching between Geraldton and Karratha. The basin contains up to 15,000 m of sediments overlying Pre-Cambrian crystalline basement. The sediments range in age from Silurian to Tertiary and comprise marine to fluvial deposits reflecting tectonic activity and various marine transgressions and regressions that have affected the basin.

The stratigraphy of the basin up until the mid-Cretaceous is presented in Appendix B, based upon a groundwater modelling study of the Birdrong Sandstone aquifer completed for the Department of Water (URS, 2007).

4.5 Lake Geology

The geology of the Lake MacLeod area has been described in detail by Logan (1987B) and is summarised below.

The foundation of the Lake MacLeod graben comprises a sequence of Cretaceous carbonate rocks, comprising the Krojon and Toolonga Calcarenites. These formations form a continuous unit of fine grained limestone across the western Carnarvon Basin, ranging in thickness from about 110 m in the northern part of the graben to 370 m in the southern part of the graben.

Overlying the Cretaceous formations is a package of carbonaceous Tertiary units comprising the Carbadia Group, Giralia Calcarenite and Trealla Limestone. The package primarily comprises limestone and is commonly vuggy, which can result in formation of karst structures that are hydrogeologically significant. The thickness of the package is highly variable, but it appears to thin to the north and east. The Trealla Limestone outcrops extensively along the coast adjacent to the basin, with thicknesses of about 25 m.

Overlying the Trealla Limestone is the Westphal Clay, a 20 to 40 m thick discontinuous clay and siltstone unit that occurs within the Lake MacLeod graben, but pinches out against the Barrier and Hinterland.

The early Quaternary units comprise a sequence of dunal sands; and more recent shallow marine and lacustrine deposits. The latter occur mostly within the Lake MacLeod graben.

The dunal sands originally covered the Barrier, Lake MacLeod graben and Hinterland, but were eroded from much of the lower lying areas in the graben. The sands have been sub-divided into three units:

- the Quobba Sands that occur along most of the Barrier separating Lake MacLeod from the Indian Ocean;
- the Lyell Sands that generally occur along the Hinterland which forms the eastern lake margin;
- The Bejaling Sands that occur along the southern edge of the lake and southern part of the Barrier.

Two marine deposits were laid-down during periods when the graben was open to the Indian Ocean from the north. These two periods were separated by a phase of lacustrine deposition, associated with a temporary marine regression. The three formations that were laid down during these periods were:

- The Dampier Formation (marine deposits), comprising skeletal sands and coralline limestone, which occurs commonly along the margins of Lake MacLeod and in discontinuous lenses in the central part of the graben (maximum thickness about 2 m).
- The Little Creek Formation (lacustrine deposits), comprising reworked dunal sands, and fluvial and deltaic sands; which underlies much of the graben with a thickness of up to about 18 m.
- The Bibra Formation (marine deposits), comprising skeletal sands and coralline limestone (similar to the earlier Dampier Formation); which underlies much of the graben and extends onto the Barrier where it pinches out (maximum thickness about 3 m).

The near surface deposits below Lake MacLeod comprise the Lake MacLeod evaporites, which occupies the majority of the lake, and the Boolathanna Formation that occurs in the southern part of the lake. The evaporites consist of the following:

- The Cygnet Carbonate, comprising a 1 m thick band of clay and silt that forms the lowest evaporite unit extending under the lake north from Ibis Pond to the Texada Sill in the south.
- The Texada Halite, a lensoid halite unit with minor horizons of gypsum and sand. The halite extends from Ibis Pond to north of the Texada Sill and has a maximum thickness of about 6 m.
- The Ibis Gypsite, comprised of gypsum rock overlain by gypsum sand. The gypsite has an average thickness of about 1 to 1.5 m and extends over most of the lake.
- The Egret Member, which extends along the northern part of the lake grading into the Ibis Gypsite along its southern limit and comprises carbonate mud, silt and sand.
- The Boolathanna Formation comprises a mixed sequence of mudstone, siltstone and sand, with a thickness of around 2 m. The formation outcrops within the Texada Sink and grades into the Ibis Gypsite to the north and Bejaling Sands to the south.

Various figures, sourced from reports prepared by Logan and CyMod showing the stratigraphy and the geometry of the Ibis Gypsite and Texada Halite Formations, are presented in Appendix A and listed below.

Figure A3. Ibis Gypsite area of outcrop.

Figure A4. Texada Halite isopach contour plan.

Figure A5. Ibis Gypsite isopach contour plan.

Figure A6. Stratigraphy of the Barrier, graben and Hinterland.

Figure A7. Lake MacLeod schematic sections.

4.6 Hydrogeology

The hydrogeology of the Lake MacLeod area has been subdivided into two components, which relate to:

i. raw water production for the Lake MacLeod Operation from the Birdrong Aquifer;

ii. feed brine production from the near surface Lake MacLeod evaporites.

4.6.1 Hydrogeology of the Birdrong Aquifer

The Birdrong Sandstone forms the most significant and widely used aquifer in the Carnarvon Artesian Basin. The aquifer has an average thickness of about 20 to 30 m, although the thickness in the vicinity of Lake MacLeod is around 50 m (CyMod, 2012A). The aquifer depth varies from 200 m at Hamelin Pool to greater than 1,000 m at Exmouth. The hydraulic conductivity of the sandstone ranges from 3 to 16 m/d and it has a porosity of up to about 30%. The groundwater is generally brackish but variable. Many of the bores utilising the aquifer are artesian, as is the case at the Lake MacLeod Operation.

Direct rainfall recharge to the Birdrong is likely to be limited to areas of outcrop along the eastern boundary of the Carnarvon Artesian Basin, with groundwater flows from east to west (i.e. towards the coast). Discharge is assumed to be sub-marine.

The Birdrong Sandstone is overlain by the Muderong Shale a low permeability unit that effectively confines the aquifer. There are a number of possible aquifers that underlie the Birdrong Sandstone, but their potential has not generally been assessed due to their greater depth. For the purposes of the Pre-Feasibility Study it is assumed the base of Birdrong is dominated by low permeability units that form an aquitard base to the Birdrong Sandstone aquifer.

4.6.2 Hydrogeology of the Lake MacLeod Near Surface Deposits

Hydrogeological units

Seven hydrogeological units are identified in the near surface groundwater system, which consist of the following:

- Upper Ibis Gypsite, comprising the gypsum sand horizon (unconfined aquifer);
- Holocene Lower Ibis Gypsite, comprising the gypsum rock (aquitard);
- Texada Halite (semi-confined aquifer);
- Holocene Cygnet Carbonate (aquitard);
- The package of Quaternary units that underlie the Cygnet Carbonate below the lake and extend onto the Barrier and Hinterland (Quobba Sands, Lyell Sands, Bejaling Sands, Dampier Formation, Little Creek Formation, Bibra Formation). This mixed sequence of dunal, marine and lacustrine sands and limestones, termed the Quobba Aquifer in this report, is considered an aquifer.
- Westphal Clay (aquitard);
- Trealla Limestone, which includes the underlying Carbadia Group and Giralia Calcarenite (aquifer).

The base of the Trealla Limestone, which coincides with the top of the Cretaceous carbonate rocks, is considered to be effectively impermeable.

Table 6: Hydraulic Parameter Values

Hydrogeological Unit	Horizontal Hydraulic Conductivity (m/d)		Vertical Hydraulic Conductivity (m/d)		Specific Yield		Specific Storage (m^{-1})	
	CyMod	Logan‡	CyMod	Logan†	CyMod	Logan*	CyMod	Logan
Upper Ibis Gypsite	2-38	0.004-0.03	0.05-4	NA	0.04-0.1	0.02-0.15	0.001	NA
Texada Halite	50-5,000**	0.01-4.1	2-3,500**	NA	0.27-0.5**	0.27	0.0001	NA
Cygnet Carbonate	NA	8×10^{-6}	NA	NA	NA	NA	NA	NA
Quobba Sands	NA	1.2-2.5	NA	NA	NA	0.18-0.25	NA	NA
Trealla Limestone	NA	0.8-8	NA	NA	NA	0.4-0.8	NA	NA

Note: data for CyMod was sourced from Liquid Earth 2005, data for Logan was sourced from various reports provided by Dampier Salt Ltd. ‡ Horizontal hydraulic conductivity values for Logan were calculated from reported absolute permeability values. † Horizontal and vertical hydraulic conductivities were not distinguished in reports prepared by Logan. ***** Specific yields for Logan are based upon reported porosities. ** The upper value quoted by CyMod for hydraulic conductivity and specific yield relate to areas affected by karst development around brine recovery trenches, based upon test pumping carried out by Rockwater in 1980 and groundwater flow model calibration.

The hydraulic parameter values for the various units are summarised in Table 6. A schematic long-section showing the relative positions of the hydrogeological units is presented in Figure 4.

The hydraulic conductivity values adopted by CyMod and Logan shown in Table 6 vary considerably. However, in viewing the data it should be noted that values provided by CyMod are based upon numerical model calibration and pumping test results reported by Rockwater (1980), while those from Logan are mostly from testing of core samples. It is likely that the values from Cymod are more representative at the lake scale.

Lake MacLeod groundwater systems

The conceptual model recognises a shallow and deeper groundwater system below Lake MacLeod. The shallow system comprises the Ibis Gypsite and Texada Halite aquifers. These are underlain by the low permeability Cygnet Carbonate, which in the area of the salt field restricts flows to the deeper groundwater system comprising the Quobba Aquifer and Trealla Limestone.

Laterally the very high permeability Texada Halite pinches out against the overlying Ibis Gypsite and Cygnet Carbonate. However, the gypsite does on-lap onto the Quobba Aquifer to the north, east and west; and is contiguous with the Boolathanna Formation to the south thereby facilitating lateral flows between the shallow and deep systems along these margins.

The deeper groundwater system extends beyond the footprint of the lake and overlie the Krojon and Toolonga Calcarenites, which are considered to be aquitards and provide a base to the deeper system. The Trealla Limestone outcrops along the coast east of Lake MacLeod and include karst structures that hydraulically link Cygnet Pond to the Indian Ocean.

Groundwater flow regimes

Horizontal groundwater flows in the shallow groundwater system are generally to the south and east from the recharge zones in the vicinity and south of Cygnet and Ibis Ponds towards the regional depressions in the lake surface at the Ralph and Texada Sinks. The contoured brine water level in the Ibis Gypsite and Texada Halite is shown in Appendix A Figure A8. Assuming constant brine densities across the lake, flow directions will be at right-angles to the contour lines. There is also likely to be some lateral groundwater inflows from the lake margins in response to groundwater recharge and the low elevation of the lake bed.

The vertical flow regime is poorly understood with insufficient data on the groundwater levels in the specific hydrogeological units. However, monitoring data collected from bores installed in 2010 and 2011 indicate gradients may be generally upward between the Quobba Aquifer and Texada Halite, although vertical flow directions were reversed during lake flooding in early 2011.

Groundwater recharge

Groundwater recharge to the near surface lake deposits will be from infiltration from brine sheets flowing south from Ibis Pond and from periodic infiltration of brackish to saline water from flood sheets.

The brine sheets extending south of Ibis Pond are formed from marine waters, concentrated by evaporation, overflowing from Cygnet Pond. The majority of the flows report to Ibis Pond to the south, but a proportion flow eastwards directly to Ralph Sink. Further evaporative concentration occurs at Ibis Pond, which overflows southward towards the Texada Sink and again eastwards towards Ralph Sink.

The sizes of the brine sheets are seasonally variable being greater in winter when evaporation rates are low. Their areal extent is strongly influenced by wind direction and strength. This can result in winter brine sheets inundating the lake surface as far as the Ralph and Texada Sinks. Infiltration from the brine sheets is locally enhanced south of the Ibis Pond by karst development at the northern edge of the Texada Halite, where it underlies the outcropping gypsite (in the so called karst field).

Flood sheets form as a result of rainfall runoff from the lake catchment and direct rainfall onto the lake surface. The development and infiltration from flood sheets is highly variable. During wet years when large areas of the lake are inundated infiltration will completely recharge the groundwater system (e.g. 2000 and 2011), i.e. there will be no residual impact from the previous year's brine extraction at the Dampier Salt Ltd operation. However, during dry years (like 2009 and 2010) the development of flood sheets will be minimal and groundwater levels in the gypsite and halite aquifers may still be drawn down from the previous summer's brine pumping.

Lake discharge

The primary outflows from the lake are from:

- evaporation;
- vertical downward flows to the underlying deeper aquifer system, at the Texada and Ralph Sinks.

Mean monthly evaporation rates range from 146 mm in June to 378 mm in January, with mean evaporation exceeding mean rainfall in all months (Section 4.2). Evaporation is also likely to occur from groundwater via capillary action (where groundwater levels lie close to surface).

Regionally, lake groundwater is expected to flow to the deeper groundwater system at the Texada and Ralph Sinks, driven by the high density of the brines. Although unconfirmed it is presumed the brines will eventually discharge westward to the Indian Ocean, via submarine springs and seepages.

As discussed above, vertical groundwater flows away from the sinks are expected to be generally upward. However monitoring data from bores near the Bitterns Storage Area during lake flooding in 2011 indicate downward groundwater losses can periodically occur in response to flooding and the resultant increase in the groundwater head in the Ibis Gypsite and Texada Halite aquifers.

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6.0 FIELD INVESTIGATIONS

A series of field investigations were undertaken as part of the Pre-Feasibility Study to collect additional and better quality data of the conditions on Lake MacLeod. These comprised the following programmes:

- The drilling and construction of monitor bores to measure groundwater conditions within the near surface hydrogeological units, and equipping of bores with pressure transducers/dataloggers to monitor groundwater levels.
- Installation of a pressure transducer/datalogger to monitor water levels in Cygnet Pond.
- Collection of groundwater and surface water monitoring data.
- Measurement of flow rates in the Brine Recovery Trenches, which was unsuccessful.
- Tracer testing around the limits of the Bitterns Storage Area.

The results from the field programmes are discussed below.

6.1 Drilling and Monitor Bore Construction

Drilling and monitor bore construction was carried out at nine locations within the salt field north of Pump Station 3 and south of the Gypsum Ponds; and at nine locations in the vicinity of the crystallisers and Bitterns Storage Area. The bores were installed in two stages in April 2010 and May 2011. Details of the two programmes are presented in separate bore completion reports (Groundwater Resource Management 2010B and Groundwater Resource Management 2011). The second programme was carried out when the lake was flooded following cyclonic rainfall events in late 2010 and early 2011.

The bores installed within the salt field were constructed to monitor groundwater conditions in the Upper Ibis Gypsite (MBG-series bores), Texada Halite (MBH-series bores) and Quobba Sand Aquifer (MBQ-series bores). The salt field bores were all installed during the 2010 programme.

The bores installed in the vicinity of the crystallisers and Bitterns Storage Area were designed to measure groundwater conditions in the Quobba Sand Aquifer, the Texada Halite being absent in this area and the Ibis Gypsite not always present. Three of these bores (MBQ016 to 018), located on the southern perimeter of the Bitterns Storage Area, were installed in 2010. The remaining six bores were installed in 2011 when the lake was flooded. The locations of the monitor bores are shown in Figure 5 and a bore schedule is presented in Appendix C.

Geological and hydrogeological data were collected during drilling; and groundwater samples collected and groundwater levels measured after bore completion. The bores were subsequently equipped with pressure transducers/dataloggers to enable the collection of high resolution water level data.

The results from the programme included the following:

Salt Field Bores

- The thicknesses of the Ibis Gypsite, Texada Halite and Cygnet Carbonate were consistent with historic data ranging from 1 to 2.5 m, 4 to 6 m and 1 to 2 m respectively.

- The lithology of the Ibis Gypsite, Texada Halite and Cygnet Carbonate were consistent with historic data; and the Quobba Sand Aquifer comprised interbedded soft clay, silt and sand, made up of quartz grains, common shell fragments and coral.

- The Ibis Gypsite was dry in all bores at the time of construction in 2010, indicating the water table was below the gypsite and within the Texada Halite.

- Groundwater flow rates of 5 L/s or greater (based upon field measurements during drilling) were observed in the Texada Halite, which is consistent with the high hydraulic conductivities estimated for this unit by CyMod (Table 6).

- No appreciable inflow rates were observed in the Quobba Sand Aquifer, due to the masking effects for the high flows in the halite, i.e. inflows from the Quobba Sand Aquifer were much lower than those from the halite.

- Groundwater levels measured soon after completion indicate generally upward heads (i.e. water levels in the Quobba Sand Aquifer are higher than those in the adjacent Texada Halite bore), indicating groundwater flows are upward through the Cygnet Carbonate.

- Groundwater quality in the Gypsite, Texada Halite and Quobba Sand was hypersaline as would be expected in close proximity to the halite body, with near neutral pH.

Crystalliser/Bitterns Storage Area Bores

- The Texada Halite was not intersected in any of the bores, although uncemented gypsum sand was observed near the lake surface in two of the bores (MBQ019 located at the northern end of the crystallisers and MBQ024 near Pump Station 7), which may represent the Upper Ibis Gypsite. This is consistent with the historic data which shows the halite pinches out north of the crystallisers.

- All bores intersected the Quobba Sand Aquifer which comprised soft clay, silt and sand (some weakly cemented) similar to the material intersected on the Salt Field.

- Groundwater levels in the bores located around the southern end of the Bitterns Storage Area, which were installed in 2010 when the lake was dry, showed artesian pressures (vertical upward flows). The groundwater salinity at the time of bore installation was lower compared to the groundwater in the saltfield bores (Specific Gravity 1.0 and Electrical Conductivity 1,330 mS/m, equivalent to about 8,000 mg/L TDS). This indicates a brackish recharge source at a higher elevation to the lake surface, most likely the Quobba Sand along the Barrier west of the lake. The confining layer is poorly defined in the drilling results, but is likely to comprise clayey shallow deposits on the lake surface.

- Groundwater levels in the bores installed in 2011 (MBQ019 to 024), located on the northern and eastern side of the crystallisers/Bitterns Storage Area (MBQ019 to 021 and 024) showed water levels similar to the surrounding lake flood water levels. The quality of the groundwater was also hypersaline with a Specific Gravity of about 1.2 which is consistent with the feed brine. This suggests movement of brine downward either from the lake water or from brines in the crystallisers and Bitterns Storage Area, i.e. a reverse of the condition observed when the lake was dry.

  Groundwater levels in bores MBQ022 and 023, when they were installed, were close to surface and the quality of the groundwater was higher than in MBQ019 to 021 and 024, with Specific Gravities of 1.032 in MBQ022 the western most bore and 1.129 in MBQ023. This indicates a reduced influence from downward seepage of flood water brines moving westward onto the Barrier, most likely due to continued effects of lower salinity recharge from the Quobba Sands west of the lake.

6.2 Installation of Cygnet Pond Depth Probe

A pressure transducer/datalogger was installed at Cygnet Pond in late-October 2010 to monitor pond water depths. The data shows pond water depth above the sensor were stable at around 0.2 m prior to the flooding of Lake MacLeod in early-2011. After the flood event the water depth increased to a maximum of about 1 m during January 2011, before regressing to approximately the pre-flood depth. During the regression the results show considerable short-term variability, possibly in response to wind action.

A hydrograph showing the Cygnet Pond water depth is shown in Figure 6 and the location of the monitoring station shown in Figure 5.

6.3 Groundwater and Surface Water Monitoring

Groundwater and surface water monitoring for the Pre-Feasibility Study has comprised:

- Monthly measurement of groundwater levels in the accessible monitor bores and downloading of the associated dataloggers.
- Monthly download of Cygnet Pond datalogger (Section 6.2).
- Collection and analyses of groundwater samples from the monitor bores installed during 2010 and 2011 (Section 6.1).

The bores monitored included those installed during the 2010 and 2011 programme and a number of pre-existing bores that have a longer monitoring record. The pre-existing monitor bores were not constructed to measure conditions within individual aquifers, but do provide continuity with earlier modelling studies and are therefore considered useful for model calibration purposes. A schedule of the bores monitored is presented in Appendix C.

The manual groundwater level measurements and logger data were processed following each monitoring run to provide levels relative to Australian Height Datum and compared to help ensure data integrity. The data have been stored within a project database.

The results of the groundwater level monitoring and groundwater quality analyses are discussed in Sections 7.0 and 8.0 respectively.

7.0 ONGOING GROUNDWATER LEVEL MONITORING

Groundwater level monitoring has been on-going since late-2009 at eleven older monitoring bores installed prior to the start of the Pre-Feasibility Study; and from 2010 in the more recently constructed monitoring bores that were installed during the 2010 and 2011 programmes (Section 6.1). Levels were monitored using pressure transducers and dataloggers set to read at hourly intervals. The automated readings were augmented by manual measurements taken when the loggers were downloaded, generally monthly when bores were accessible.

Pressure transducers measure water pressure acting on the sensor. These measurements were converted to water depths, and then water levels relative to Australian Height Datum, using specified water densities. The densities used related to the location of each bore. For bores on the salt field a density of 1,218 kg/m^3 was adopted, which is consistent with the density of the feed brine and hydrochemical analysis for these bores. A density of 1,000 kg/m^3 was used for bores located around the crystallisers/Bitterns Storage Area, where water quality data collected after the 2010 bore installation programme show the presence of brackish water.

Historic groundwater level data are also available for 52 bores dating back to 1988, which include:

- manual water level data collected by Dampier Salt Ltd between 1988 and 2003;
- automated data collected by Liquid Earth Pty Ltd during 2004;
- automated data collected by MWH Australia Pty Ltd (MWH) between 2006 and 2008.

A schedule showing the monitoring and equipping of the bores is presented in Table 8 and the groundwater level hydrographs are presented in Figures 8 to 13. Schedules of the pre-existing and Pre-Feasibility Study monitoring bores are presented in Appendix C and their locations (where known) are shown on Figure 5.

Table 8: Bore Equipping and Monitoring Schedule

Bore ID	Original Dampier Salt Ltd Manual Monitoring Period		Liquid Earth Automated Monitoring Period		MWH Automated Monitoring Period		Pre-Feasibility Study Automated Monitoring Period	
	Start	End	Start	End	Start	End	Start	End
D01	31/03/88	1/01/03	27/06/04	7/12/04	22/07/06	31/01/08	31/10/09	Ongoing
D02	31/03/88	1/01/03	-	-	-	-	-	-
D03	31/03/88	1/01/03	-	-	-	-	-	-
D03	31/03/88	1/01/03	-	-	-	-	31/10/09	Ongoing
D04	31/03/88	1/01/03	27/06/04	8/12/04	-	-	31/10/09	Ongoing
D05	31/03/88	1/01/03	-	-	-	-	-	-
D06	31/03/88	1/01/03	-	-	-	-	-	-
D07	31/03/88	1/01/03	-	-	-	-	-	-
D08	31/03/88	1/01/03	-	-	-	-	-	-
D09	31/03/88	1/01/03	-	-	-	-	-	-
D10	31/03/88	1/01/03	-	-	-	-	-	-

Bore ID	Original Dampier Salt Ltd Manual Monitoring Period		Liquid Earth Automated Monitoring Period		MWH Automated Monitoring Period		Pre-Feasibility Study Automated Monitoring Period	
	Start	End	Start	End	Start	End	Start	End
D11	31/03/88	1/01/03	-	-	-	-	-	-
D12	31/03/88	1/01/03	27/06/04	7/12/04	-	-	31/10/09	Ongoing
D13	31/03/88	1/01/03	-	-	-	-	-	-
D14	31/03/88	1/01/03	-	-	-	-	-	-
D15	31/03/88	1/01/03	-	-	-	-	-	-
D16	31/03/88	1/01/03	-	-	-	-	-	-
D17	31/03/88	1/01/03	-	-	-	-	-	-
D18	31/03/88	1/01/03	27/06/04	7/12/04	-	-	31/10/09	Ongoing
D19	31/03/88	1/01/03	-	-	-	-	-	-
D20	31/03/88	1/01/03	-	-	-	-	31/10/09	Ongoing
D21	31/03/88	1/01/03	-	-	-	-	-	-
D22	31/03/88	1/01/03	-	-	-	-	-	-
D23	31/03/88	1/01/03	-	-	-	-	-	-
D24	31/03/88	1/01/03	-	-	-	-	-	-
D25	31/03/88	1/01/03	-	-	-	-	-	-
D26	31/03/88	1/01/03	-	-	-	-	-	-
D27	31/03/88	1/01/03	-	-	-	-	-	-
D28	31/03/88	1/01/03	27/06/04	6/12/04	-	-	-	-
D29	31/03/88	1/01/03	-	-	-	-	-	-
D30	31/03/88	1/01/03	-	-	-	-	-	-
D31	31/03/88	1/01/03	27/06/04	7/12/04	-	-	31/10/09	Ongoing
D32	31/03/88	1/01/03	-	-	-	-	-	-
D33	31/03/88	1/01/03	-	-	-	-	-	-
D34	31/03/88	1/01/03	-	-	-	-	31/10/09	Ongoing
D35	31/03/88	1/01/03	27/06/04	8/12/04	-	-	-	-
D36	31/03/88	1/01/03	-	-	-	-	-	-
D37	31/03/88	1/01/03	-	-	-	-	-	-
D38	31/03/88	1/01/03	-	-	-	-	-	-
D39	31/03/88	1/01/03	-	-	-	-	-	-
D40	31/03/88	30/04/92	-	-	-	-	-	-
D41	31/03/88	1/01/03	-	-	-	-	-	-
D42	31/03/88	1/01/03	-	-	-	-	-	-
D43	31/03/88	1/01/03	-	-	-	-	-	-
L15	31/03/88	30/04/92	27/06/04	8/12/04	22/07/06	31/01/08	27/06/04	Ongoing
L1	31/03/88	30/04/92	27/06/04	8/12/04	-	-	-	-
L3	31/05/88	31/05/88	-	-	-	-	-	-
L4	-	-	-	-	-	-	31/10/09	Ongoing
L9	31/03/88	31/01/90	-	-	-	-	31/10/09	Ongoing
L47	31/03/88	30/04/92	-	-	-	-	-	-
L48	31/03/88	31/03/88	-	-	-	-	-	-
TO3	27/06/04	-	27/06/04	8/12/04	-	-	-	-

Bore ID	Original Dampier Salt Ltd Manual Monitoring Period		Liquid Earth Automated Monitoring Period		MWH Automated Monitoring Period		Pre-Feasibility Study Automated Monitoring Period	
	Start	End	Start	End	Start	End	Start	End
MBG001	-	-	-	-	-	-	3/06/10	Ongoing
MBG002	-	-	-	-	-	-	3/06/10	Ongoing
MBG003	-	-	-	-	-	-	3/06/10	Ongoing
MBG004	-	-	-	-	-	-	3/06/10	Ongoing
MBG005	-	-	-	-	-	-	3/06/10	Ongoing
MBG006	-	-	-	-	-	-	3/06/10	Ongoing
MBG007	-	-	-	-	-	-	3/06/10	Ongoing
MBH001	-	-	-	-	-	-	3/06/10	Ongoing
MBH002	-	-	-	-	-	-	3/06/10	Ongoing
MBH003	-	-	-	-	-	-	3/06/10	Ongoing
MBH004	-	-	-	-	-	-	3/06/10	Ongoing
MBH005	-	-	-	-	-	-	3/06/10	Ongoing
MBH006	-	-	-	-	-	-	3/06/10	Ongoing
MBH007	-	-	-	-	-	-	3/06/10	Ongoing
MBQ001	-	-	-	-	-	-	3/06/10	Ongoing
MBQ002	-	-	-	-	-	-	3/06/10	Ongoing
MBQ003	-	-	-	-	-	-	3/06/10	Ongoing
MBQ004	-	-	-	-	-	-	3/06/10	Ongoing
MBQ005	-	-	-	-	-	-	3/06/10	Ongoing
MBQ006	-	-	-	-	-	-	3/06/10	Ongoing
MBQ007	-	-	-	-	-	-	3/06/10	Ongoing
MBQ014B	-	-	-	-	-	-	3/06/10	Ongoing
MBQ015	-	-	-	-	-	-	3/06/10	Ongoing
MBQ016	-	-	-	-	-	-	21/09/10	Ongoing
MBQ017	-	-	-	-	-	-	21/09/10	Ongoing
MBQ018	-	-	-	-	-	-	3/06/10	Ongoing
MBQ019	-	-	-	-	-	-	20/05/11	Ongoing
MBQ020	-	-	-	-	-	-	20/05/11	Ongoing
MBQ021	-	-	-	-	-	-	20/05/11	Ongoing
MBQ022	-	-	-	-	-	-	20/05/11	Ongoing
MBQ023	-	-	-	-	-	-	20/05/11	Ongoing
MBQ024	-	-	-	-	-	-	20/05/11	Ongoing

The hydrographs show the following:

MBG/H/Q001 to 007, and MBQ14a and 015 (Pre-Feasibility Study salt field bores)

- General trends showing gradually declining levels in all three aquifers up until the flood in December 2010, with levels in the Quobba Sand Aquifer commonly higher than those in the overlying halite and gypsite. This shows upward gradients and groundwater flows through the Cygnet Carbonate is the norm.

- Levels in all three aquifers show a response to the lake flood, although the responses in the Ibis Gypsite and Texada Halite are significantly quicker than those seen in the Quobba Sand Aquifer. The delay in the Quobba Sand response is due to the low permeability of the Cygnet Carbonate. During the first few months of flooding the vertical hydraulic gradient is reversed showing downward recharge to all three aquifers.

- A number of anomalous results were also observed, which include the following.

  - The results for MBQ001 show a gradual decline over the monitoring record. It is believed the bore was damaged during construction and is not measuring levels in the Quobba Sand Aquifer.

  - Levels recorded in the Ibis Gypsite and Texada Halite near the northern end of BRT6 (Bores MBG/H004 to 007) commonly show a sudden drop in early-December 2010 of up to about 0.3 m. The largest falls were observed close to the trench. It is noted that Dampier Salt Ltd were cleaning out the northern end of the Brine Recovery Trench system at this time and it is likely the reduction in the groundwater level is due to deepening of the trench. The propagation of the response to MBG/H007, located 1 km west of BRT6, confirms the high permeability of the near surface aquifers.

  - There is a disparity between the manual water level measurements and logger values for MBH001 and MBQ14a collected in December 2011 and January 2012, where measured values are higher. The reason for this disparity is not known but may relate to lowering of the groundwater density at these bores, resulting in an underestimation of the levels calculated from the logger data.

  - There is a rapid decline in the water level recorded in MBH007 in April 2011. The reason for the drop is not known and is not mirrored in the neighbouring gypsite monitoring bore.

MBQ016 to 018 (Pre-Feasibility Study crystalliser/Bitterns Storage Area bores)

- General trends showing gradually declining levels in the Quobba Sand Aquifer up until the flood in December 2010.

- Rapid water level rises were recorded in the aquifer in response to lake flooding, although the rise was less than that recorded in the gypsite and halite in the salt field bores. The smaller water level rise is most likely due to the higher pre-flood water levels around the crystallisers/Bitterns Storage Area, where artesian pressures were measured when the bores were installed in April 2010.

- There is a disparity between the manual water level measurements and the logger values collected from October 2011 onwards for all the bores. However, unlike the MBH001 and MBQ014a, the manual levels are lower than the calculated logger values. This indicates a change in the groundwater density with higher densities after flooding. This is consistent with the water quality results for the crystalliser/Bitterns Storage Area bores that show groundwater salinities were low when the lake was dry and became saline when the lake was flooded (Section 8.0). Interestingly levels calculated from logger data for December 2011 are comparable with the pre-flood levels, however manual measurements are nearly a metre lower.

D-series and L-series bores (historic monitor bores)

- The water level data for the historic bores in some instances extends back to 1988.
- The logger data collected for the Pre-Feasibility Study shows similar trends to those recorded in the Ibis Gypsite and Texada Halite bores installed for the Pre-Feasibility Study for the pre and post-flood period.
- The data collected for the Pre-Feasibility Study is consistent with the historic data collected manually and using loggers, both with respect to trends and absolute values.

Hydrographs for monitoring bores MBQ019 to 024, and D03, D20, D34, L15 and L9 are not presented because no survey data were available for these sites when the data was processed; therefore levels relative to datum could not be calculated.

8.0 HYDROCHEMICAL CHARACTERISATION

Rio Tinto's Technology and Innovations Group were engaged to assess the hydrochemical and geochemical information collected at Lake MacLeod and the surrounding area to investigate:

- the source of the salts in the feed brine;
- the potential flow directions of any seepage leaving the Bitterns Storage Area;
- the dynamics of the lake groundwater system and potential impacts from any expansion of the Lake MacLeod Operation.

The results from the Technology and Innovation Group's assessment are presented in their final report (2011), and summarised below.

The water in Cygnet Pond is consistent with sea water samples collected from the Indian Ocean, apart from the concentrations of calcium and magnesium that are higher and lower in the pond water respectively. This difference in concentration may be attributable to the influence of karst system that provides a pathway from the ocean to the pond, through the Trealla Limestone.

The ratio of magnesium to both bromide and potassium are significantly higher in the samples of the Texada Halite salt (i.e. solids samples of the halite unit) compared to the groundwater collected from halite monitoring bores, although the absolute concentration of magnesium in the halite is much lower than in the surrounding groundwater. This variance suggests the high salinity of the halite groundwater is not primarily a result of halite dissolution, which supports the conclusion that the current operation is harvesting rather than mining salt; and is therefore sustainable.

The ratio of the median concentrations of sodium, chloride, magnesium, calcium, potassium, sulphate and bromide to chloride in the lake groundwater, Indian Ocean water and water collected from the Brine Recovery Trenches have been used to assess the contribution of marine recharge water to the Lake MacLeod Operation feed brine. The assessment identified the following:

- the ratio of sodium and potassium to chloride are similar in water collected from the Brine Recovery Trenches, Texada Halite and Indian Ocean water;
- the ratio of bromide to chloride are similar in water collected from the Brine Recovery Trenches, Ibis Gypsite and Indian Ocean water, but lower than the ratio in the Texada Halite and Quobba Sand Aquifer;
- the ratio of calcium and sulphate to chloride was higher in the seawater, compared to both the groundwater and trench water;
- the ratio of magnesium concentration to chloride is highly variable. This is consistent with the precipitation of gypsum during evaporative concentration of marine water prior to it reaching the Brine Recovery Trenches.

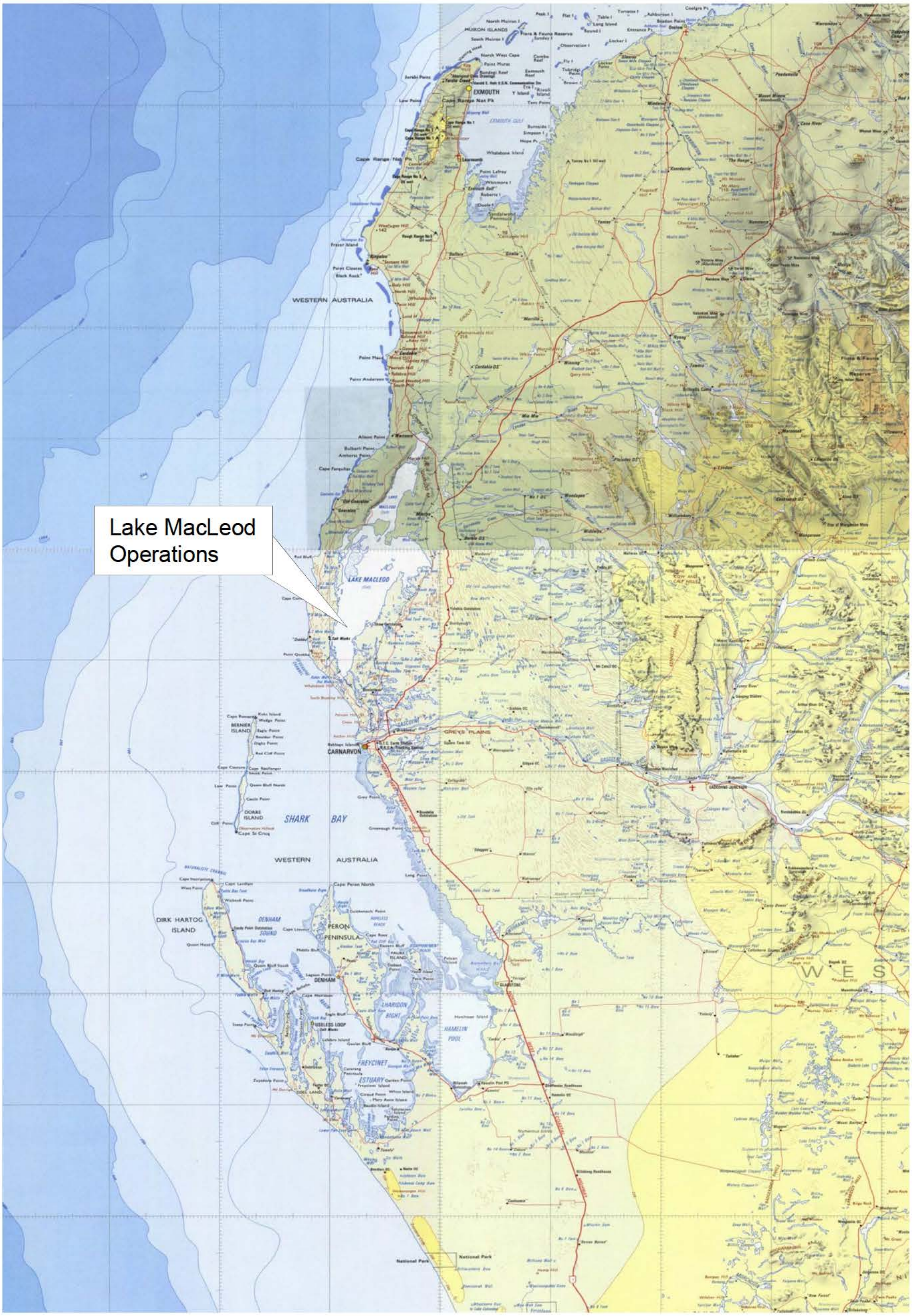
These results indicate the evaporative concentration of marine water recharge is likely to be the primary mechanism in the development of the brines feeding the Brine Recovery Trenches. The lower relative concentrations of calcium and sulphate in the groundwater and Brine Recovery Trench water are consistent with the evaporative concentration of the marine water and the precipitation of gypsum. The reason for the disparity between the relative concentrations of bromine and magnesium in the seawater and groundwater is not known.

The maximum concentration of all ions is similar in the groundwater and Brine Recovery Trench water samples, confirming groundwater is the source of the feed brine. The concentrations also show evaporative concentration has resulted in a loss of about 90% of the water, i.e. the concentration of salts has increased ten-fold. It is likely this concentration mainly occurs when the marine water is at or near surface, i.e. before entering the groundwater system, although some evaporation will occur from the Brine Recovery Trenches. This is consistent with observations of salting in the trenches.

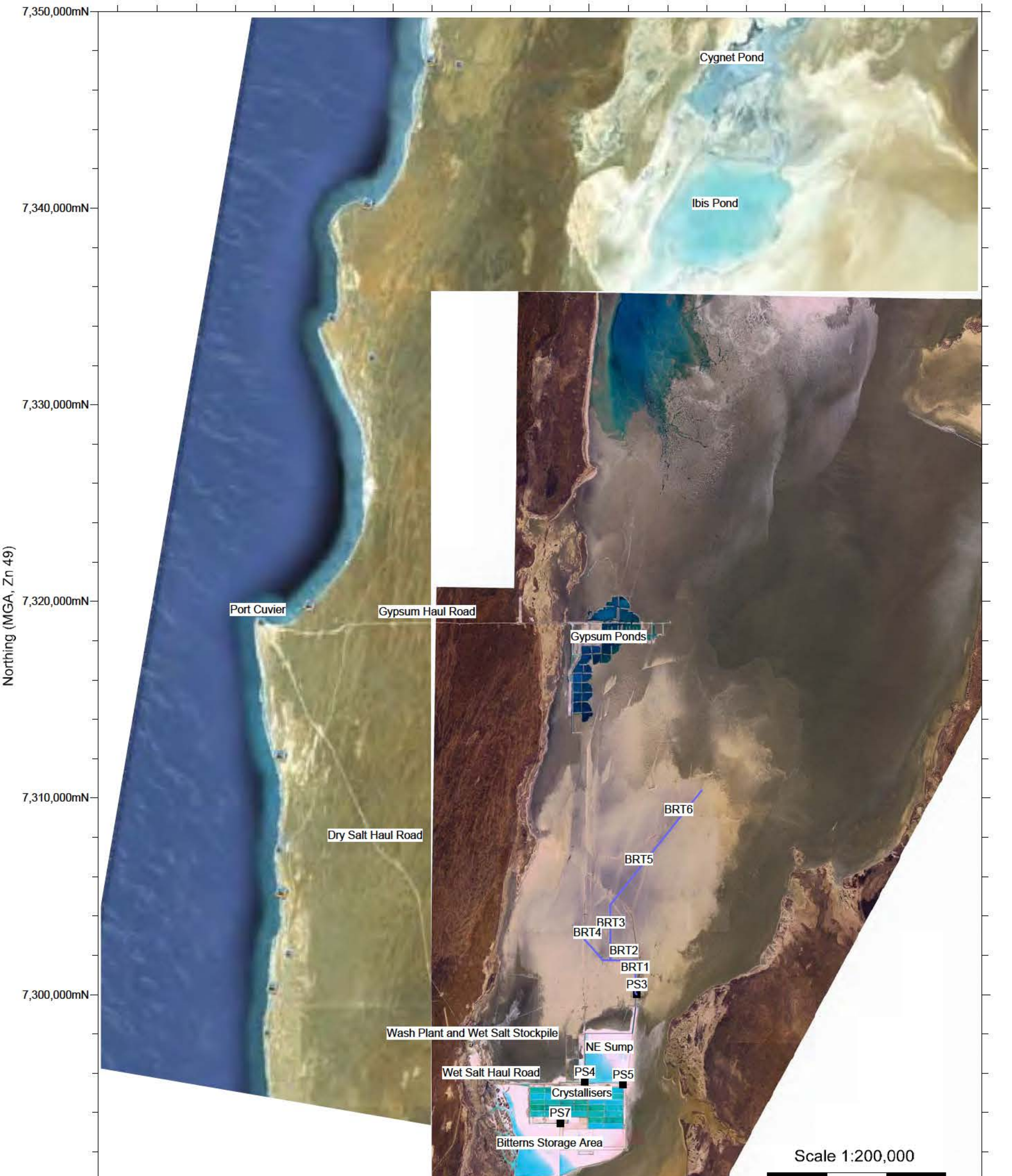
The groundwater samples from bores around the crystallisers/Bitterns Storage Area were collected on two occasions. In April 2010 when the lake was dry and in March 2011 after the lake was flooded. The analyses of the first set of samples show the groundwater around the Bitterns Storage Area is of relatively high quality, low salinity, under normal (i.e. dry) conditions. The results from the second set of samples, however, show high salinity groundwater around the storage, with elevated relative concentrations of magnesium and potassium. This change in hydrochemistry could be the result of brine seepage from the Bitterns Storage Area in response to the presence of high density brines and elevated water levels in the storage (which was also flooded at the time of sampling).

The hydrochemical characterisation has identified evaporative concentration of marine water recharge as the likely dominant mechanism in the development of the Lake MacLeod Operation feed brines. However, expansion of the operation may cause a reduction in the travel times between the Northern Ponds and the Brine Recovery Trenches. This could result in insufficient time for evaporative concentration to occur and thereby adversely affect the quality of the feed brine. Options to increase the sodium chloride content of the feed brine include:

- Dissolution of the halite aquifer or abstraction of connate brines;
- Water leaking upward from the tertiary aquifer into the halite;
- Mining of the Texada halite; and/or
- Pumping additional seawater into the lake.



Lake Macleod PFS (J090028R07)	**LOCATION PLAN**	GROUNDWATER RESOURCE MANAGEMENT
Dampier Salt Ltd		
RG | Jan 12 | **FIGURE 1**		



Google Earth imagery used

Lake Macleod PFS (J090028R07)			GENERAL SITE PLAN	GROUNDWATER RESOURCE MANAGEMENT
Dampier Salt Ltd				
RG	Mar 12	FIGURE 2		

Z:/Jobs2009/J090028_DSLLakeMacLeod/figures/surfer/J090028R07_GeneralSitePlan_Fig2.srf

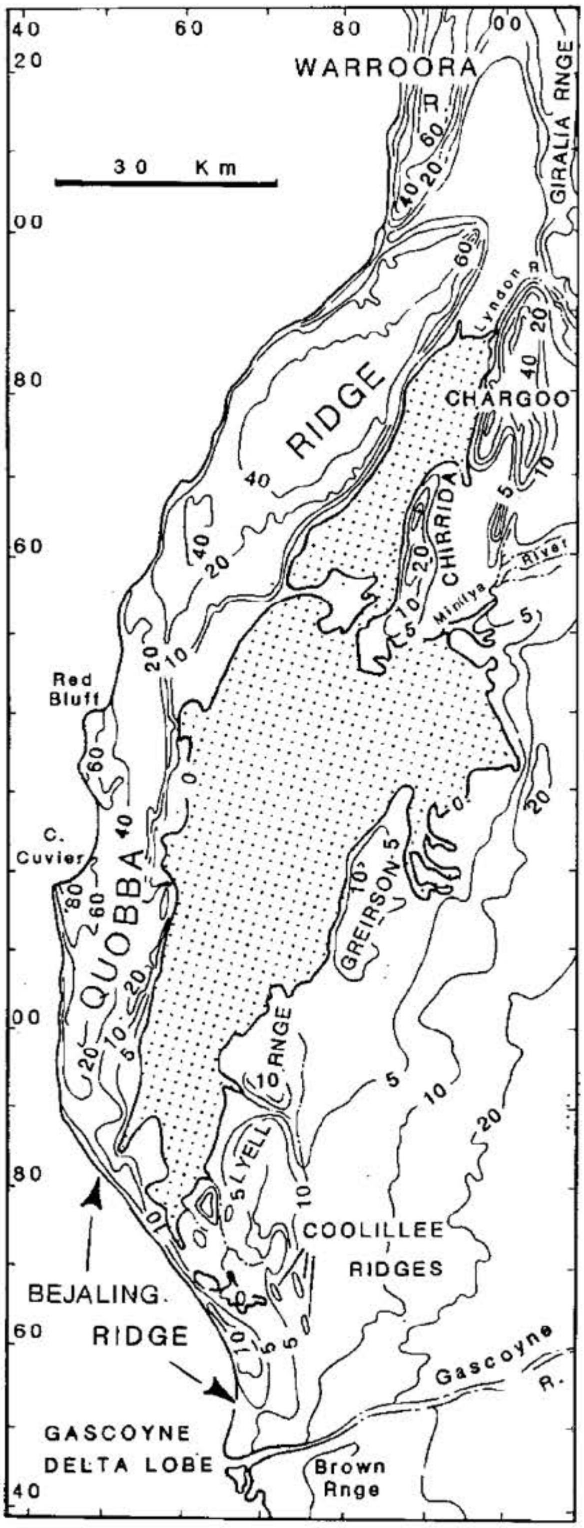
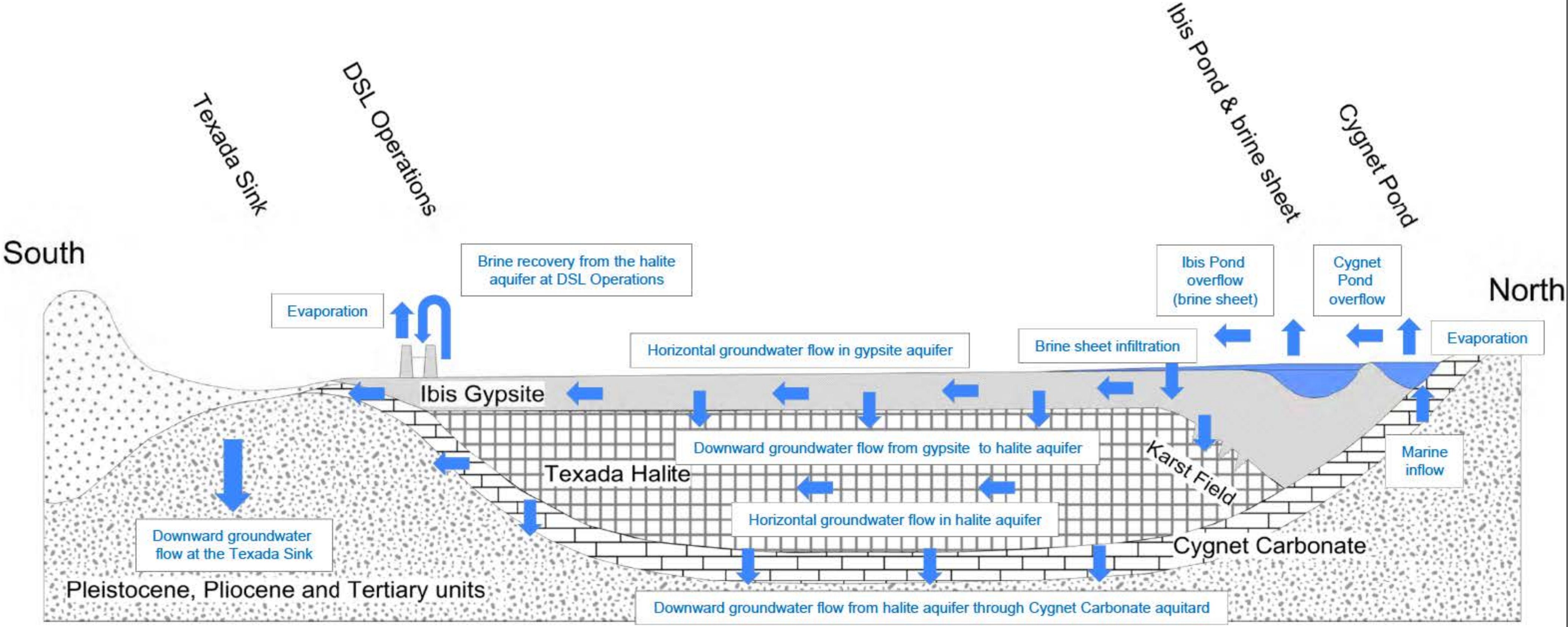


Figure 2. Generalized contour map illustrating topography of MacLeod region; contours are 5, 10, 20, 40, 60 and 80m. The area stippled lies between sealevel and -4.3m. The main geomorphic features are named. Bejaling Ridge (Holocene), Quobba Ridge and Warroora Ridge (Pleistocene) comprise the barrier. The northern levee of the Gascoyne River forms the natural southern boundary of the hinterland province and drainage is northwest to MacLeod Basin.

Figure sourced from Logan 1985.

Lake Macleod PFS (J090028R07)			LAKE MACLEOD GEOMORPHOLOGY	GROUNDWATER RESOURCE MANAGEMENT
Dampier Salt Ltd				
RG	Jan 12	**FIGURE 3**		

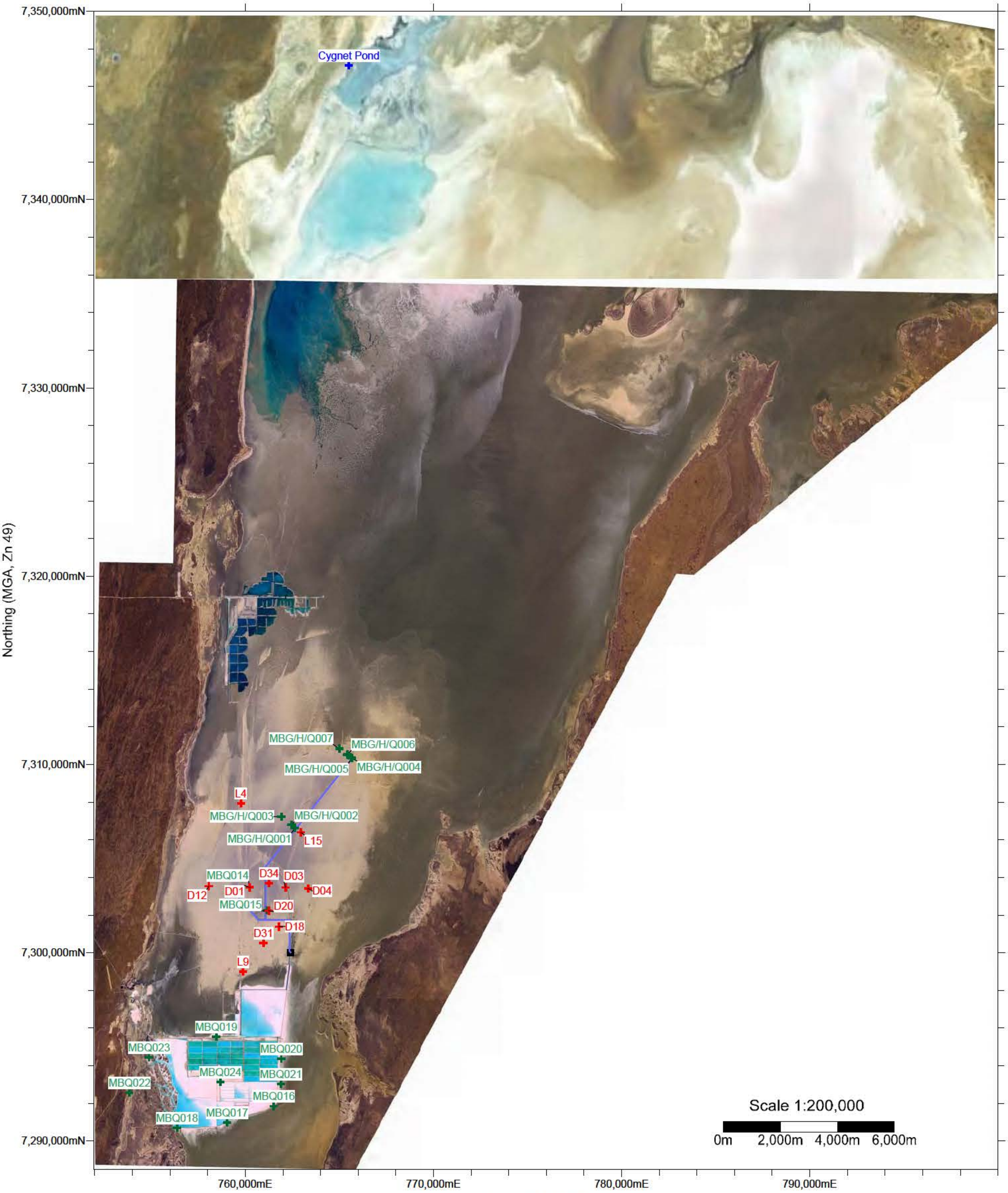


Note: conceptual water balance does not show flows to Ralph Sink or periodic infiltration from flood sheets

Lake Macleod PFS (J090028R07)		
Dampier Salt Ltd		
TN	Mar 12	**FIGURE 4**

SCHEMATIC HYDROGEOLOGICAL LONG-SECTION

GROUNDWATER RESOURCE MANAGEMENT



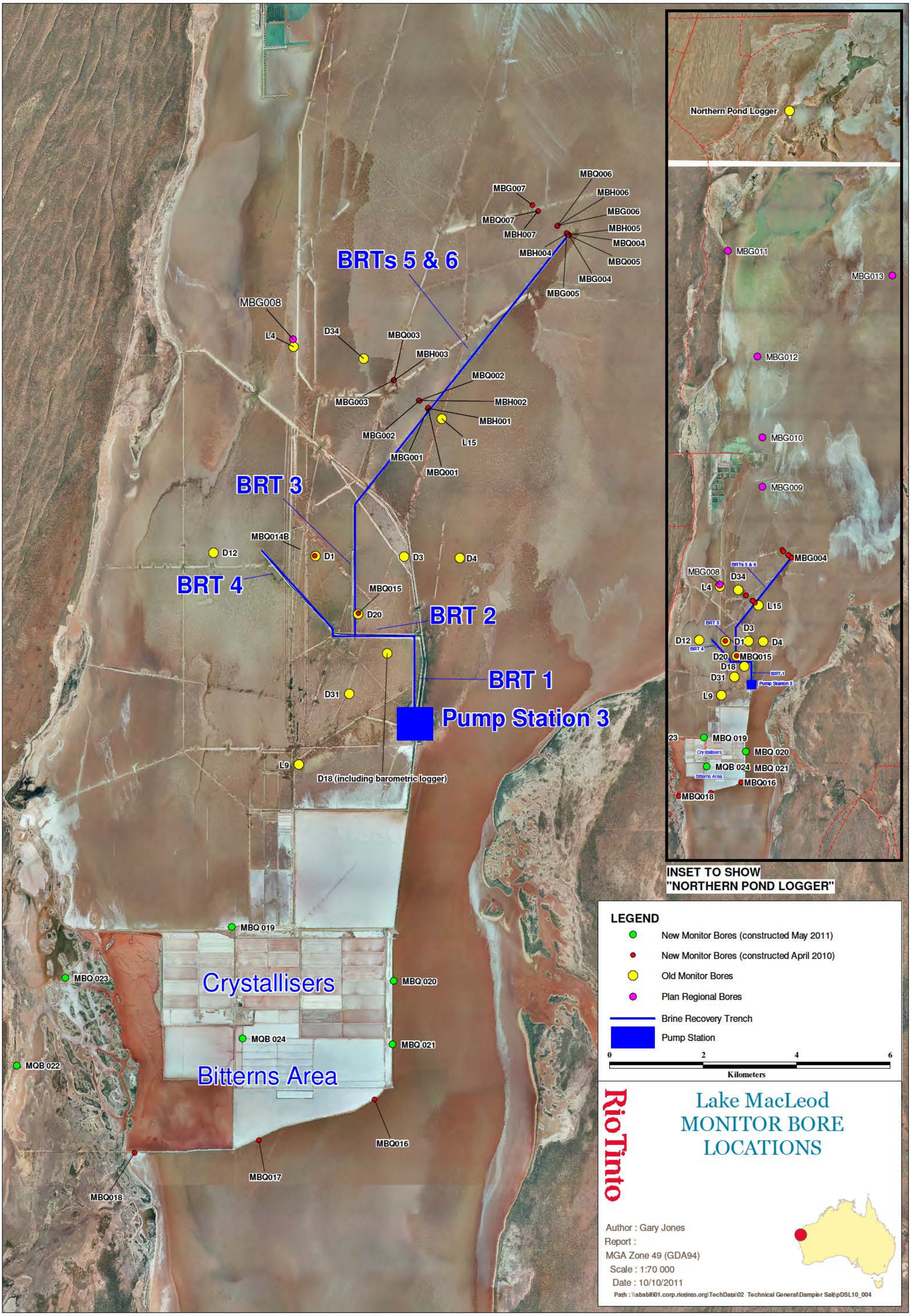
Google Earth imagery used

Legend

- New Monitor Bores Location
- Old Monitor Bores Location
- Pond Monitoring Station
- BRT
- PS3

Lake Macleod PFS (J090028R07)	**MONITOR BORE LOCATIONS**	GROUNDWATER RESOURCE MANAGEMENT
Dampier Salt Ltd		
TN · Mar 12 · **FIGURE 5**		

Z:/Jobs2009/J090028_DSI.LakeMacLeod/figures/surfer/J090028R07_MonitoringStationLocationPlan_Fig5.srf



Lake MacLeod
MONITOR BORE
LOCATIONS
RioTinto
BRTs 5 & 6
BRT 3
BRT 4
BRT 2
BRT 1
Pump Station 3
Crystallisers
Bitterns Area
MBG007
MBQ006
MBH006
MBG006
MBQ007
MBH005
MBH007
MBQ004
MBH004
MBQ005
MBG004
MBG005
MBG008
L4
D34
MBQ003
MBH003
MBQ002
MBG003
MBH002
MBH001
MBG002
L15
MBG001
MBQ001
MBQ014B
D12
D1
D3
D4
MBQ015
D20
D31
L9
D18 (including barometric logger)
MBQ 019
MBQ 023
MBQ 020
MQB 024
MBQ 021
MQB 022
MBQ016
MBQ017
MBQ018
Northern Pond Logger
MBG011
MBG013
MBG012
MBG010
MBG009
INSET TO SHOW
"NORTHERN POND LOGGER"
LEGEND
New Monitor Bores (constructed May 2011)
New Monitor Bores (constructed April 2010)
Old Monitor Bores
Plan Regional Bores
Brine Recovery Trench
Pump Station
0 2 4 6
Kilometers
Author : Gary Jones
Report :
MGA Zone 49 (GDA94)
Scale : 1:70 000
Date : 10/10/2011
Path : \\sbsbfil01.corp.riotinto.org\TechData\02 Technical General\Dampier Salt\pDSL10_004

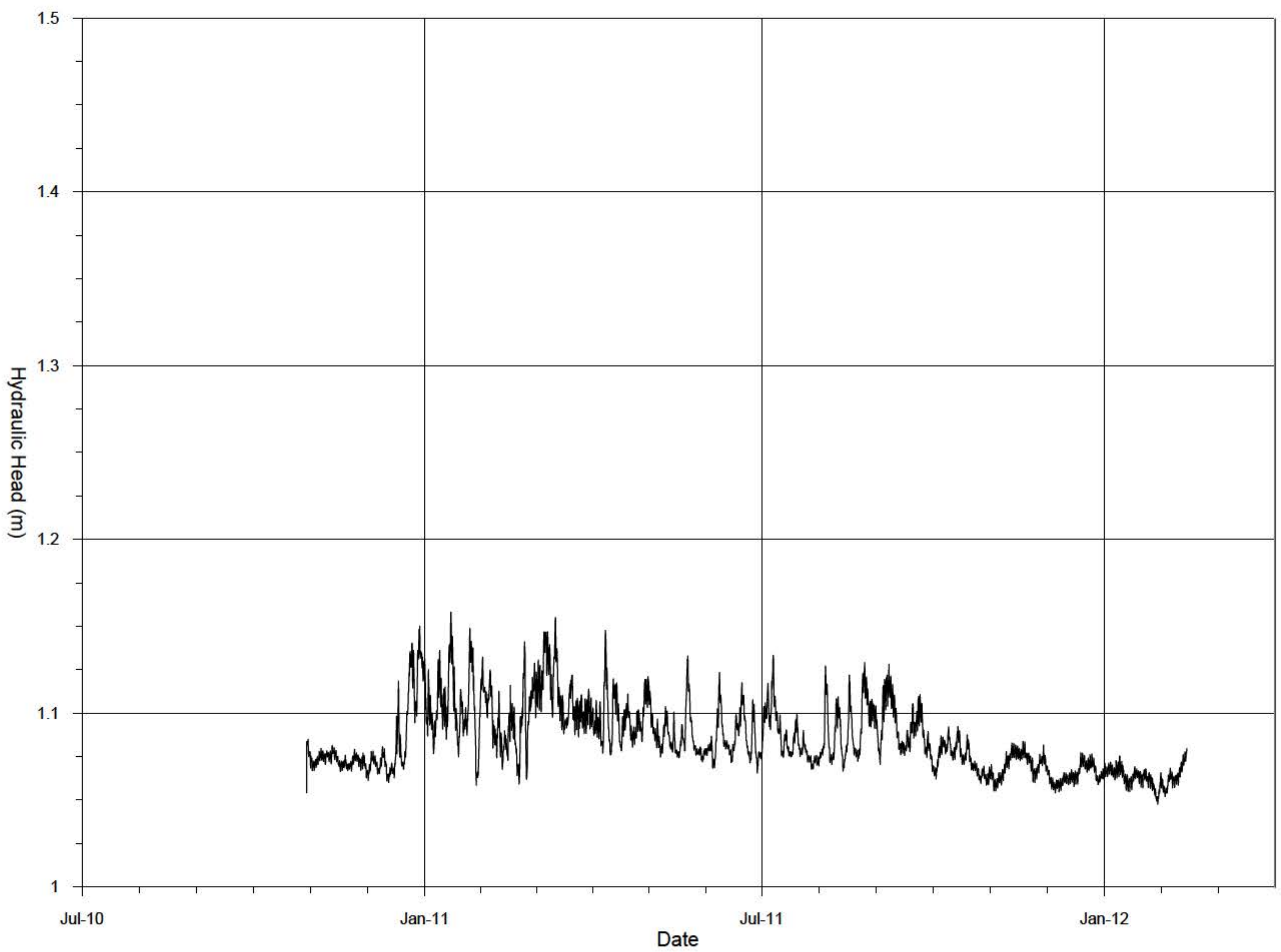
Lake Macleod PFS (J09028R07)

Dampier Salt Ltd

TN | Mar 12 | **FIGURE 6**

CYNGET POND WATER LEVEL HYDROGRAPH

GROUNDWATER RESOURCE MANAGEMENT



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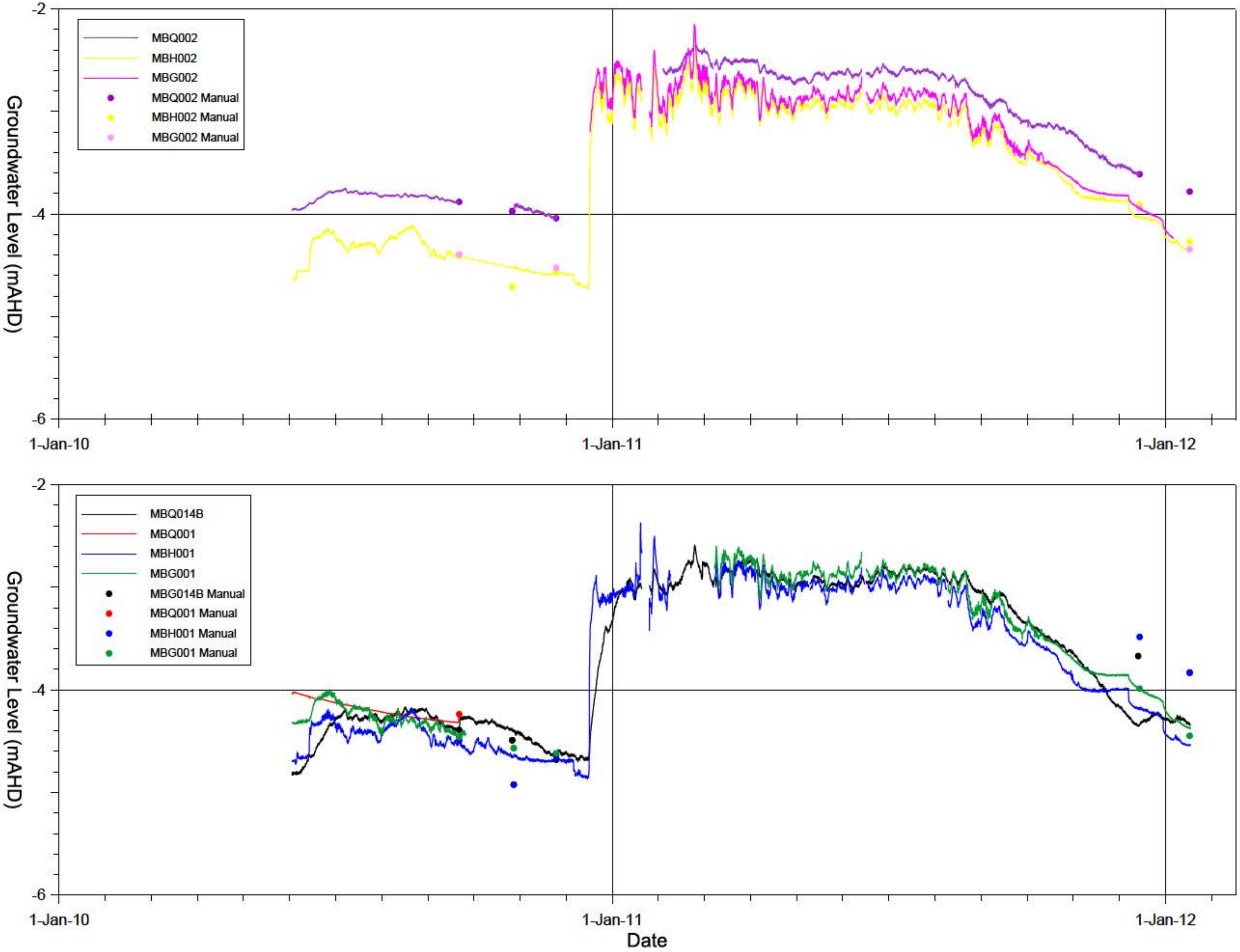
- Breakthrough at Dye Tracing Location
- No Breakthrough at Dye Tracing Location

Figure source from Umwelt 2011

Lake Macleod PFS (J090028R07)			**TRACER TESTING LOCATION PLAN**	GROUNDWATER RESOURCE MANAGEMENT
Dampier Salt Ltd				
TN	Mar 12	**FIGURE 7**		

FILE:\\J090028_DSLLakeMacLeod\figures\powerpoint\J090028R07PowerPointA4Port.ppt



Lake Macleod PFS (J090028R07)

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Feb 12

FIGURE 8

GROUNDWATER LEVELS CALCULATED FROM LOGGER DATA MB001, 2 & 14

GROUNDWATER RESOURCE MANAGEMENT

G:\Jobs2009\J090028_DSLLakeMacLeod\figures\grapher\MonitoringDataReview\LoggerData1b.grf

LLake Macleod PFS (J09028R07)

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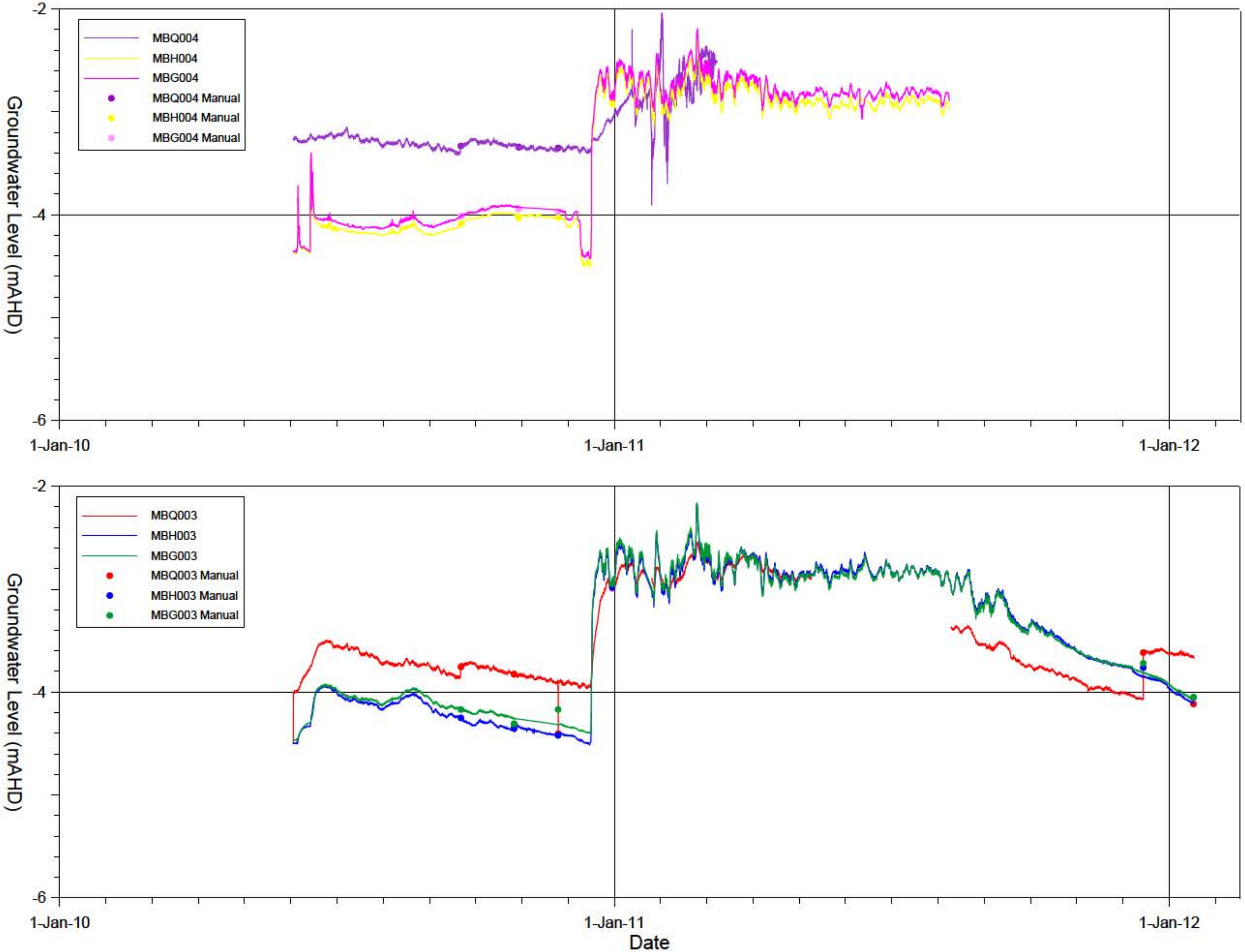
Feb 12

FIGURE 9

GROUNDWATER LEVELS CALCULATED FROM LOGGER DATA MB003 & 4

GROUNDWATER RESOURCE MANAGEMENT



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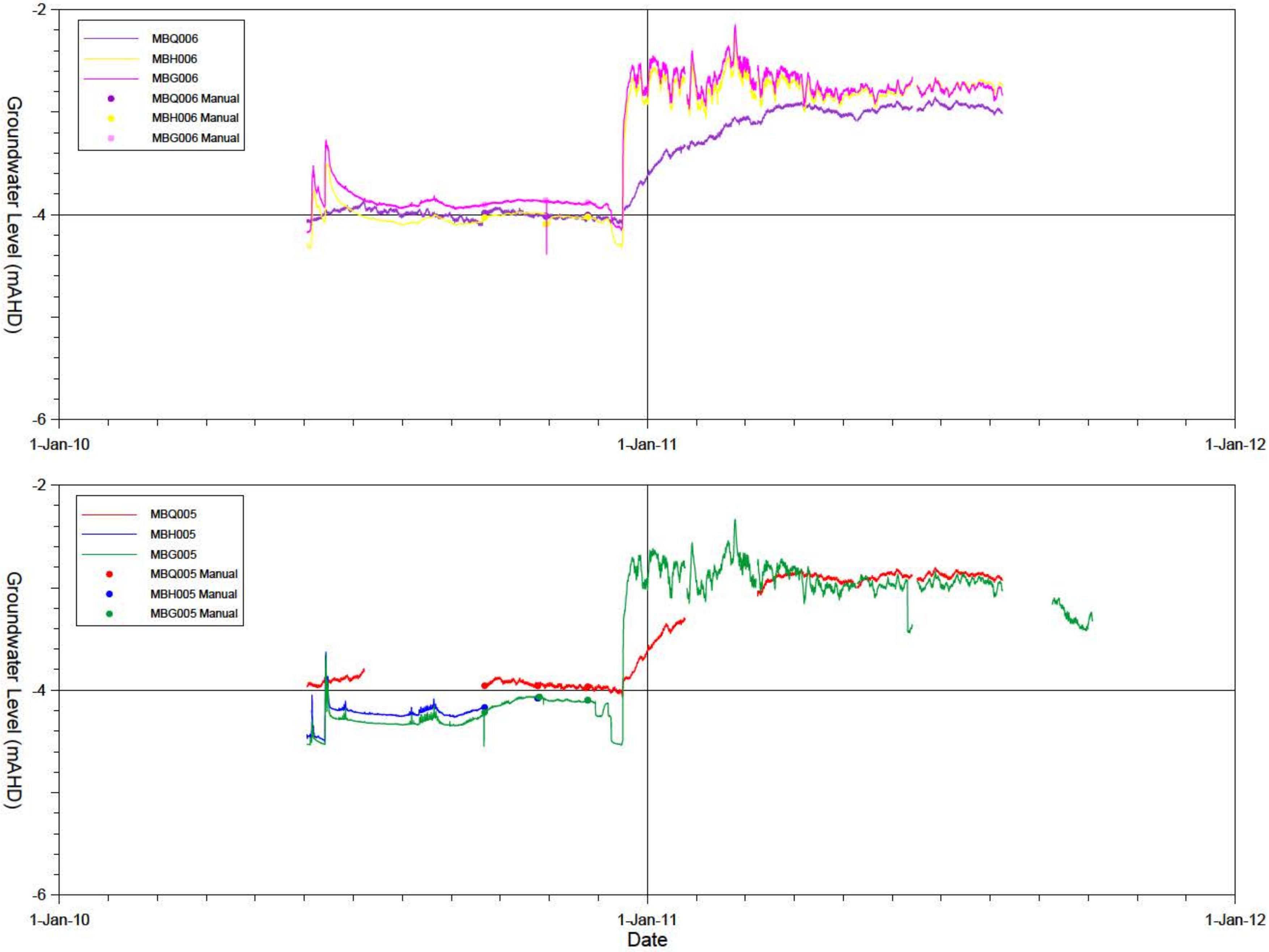

Lake Macleod PFS (J090028R07)

Dampier Salt Ltd

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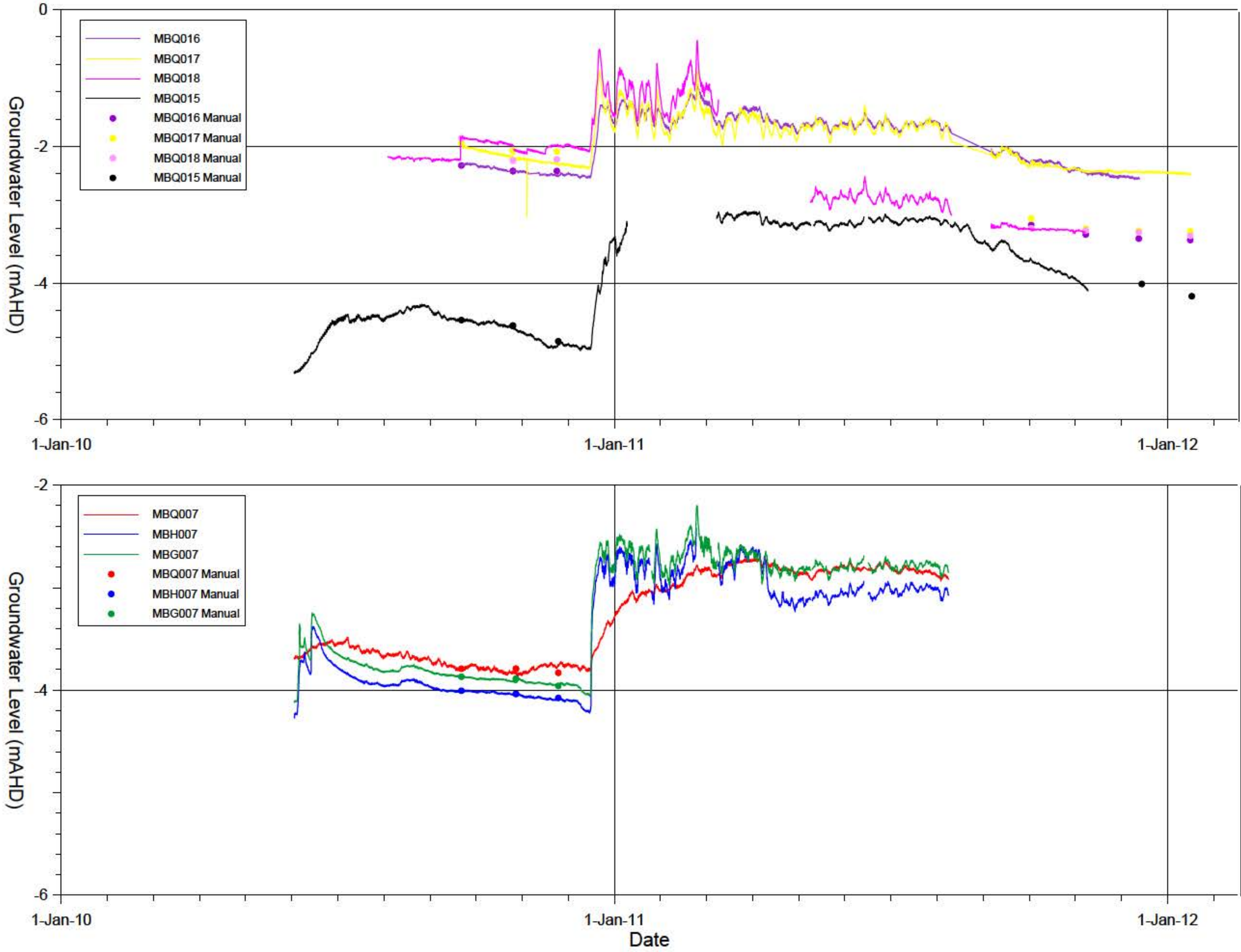
Feb 12

FIGURE 10

GROUNDWATER LEVELS CALCULATED FROM LOGGER DATA MB005 & 6

GROUNDWATER RESOURCE MANAGEMENT

G:\Jobs2009\J090028_DSLakeMacleod\figures\grapher\MonitoringDataReview\LoggerData3b.grf



Lake Macleod PFS (J090028R07)

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Feb 12

FIGURE 11

GROUNDWATER LEVELS CALCULATED FROM LOGGER DATA MB007, 16, 17 & 18

GROUNDWATER RESOURCE MANAGEMENT

G:\Jobs2009\J090028_DS\LakeMacleod\figures\grapher\MonitoringDataReview\LoggerData4b.grf

G:\Jobs2009\J090028_DS\LakeMacleod\figures\grapher\MonitoringDataReview\LoggerData5b.grf

Lake Macleod PFS (J090028R07)

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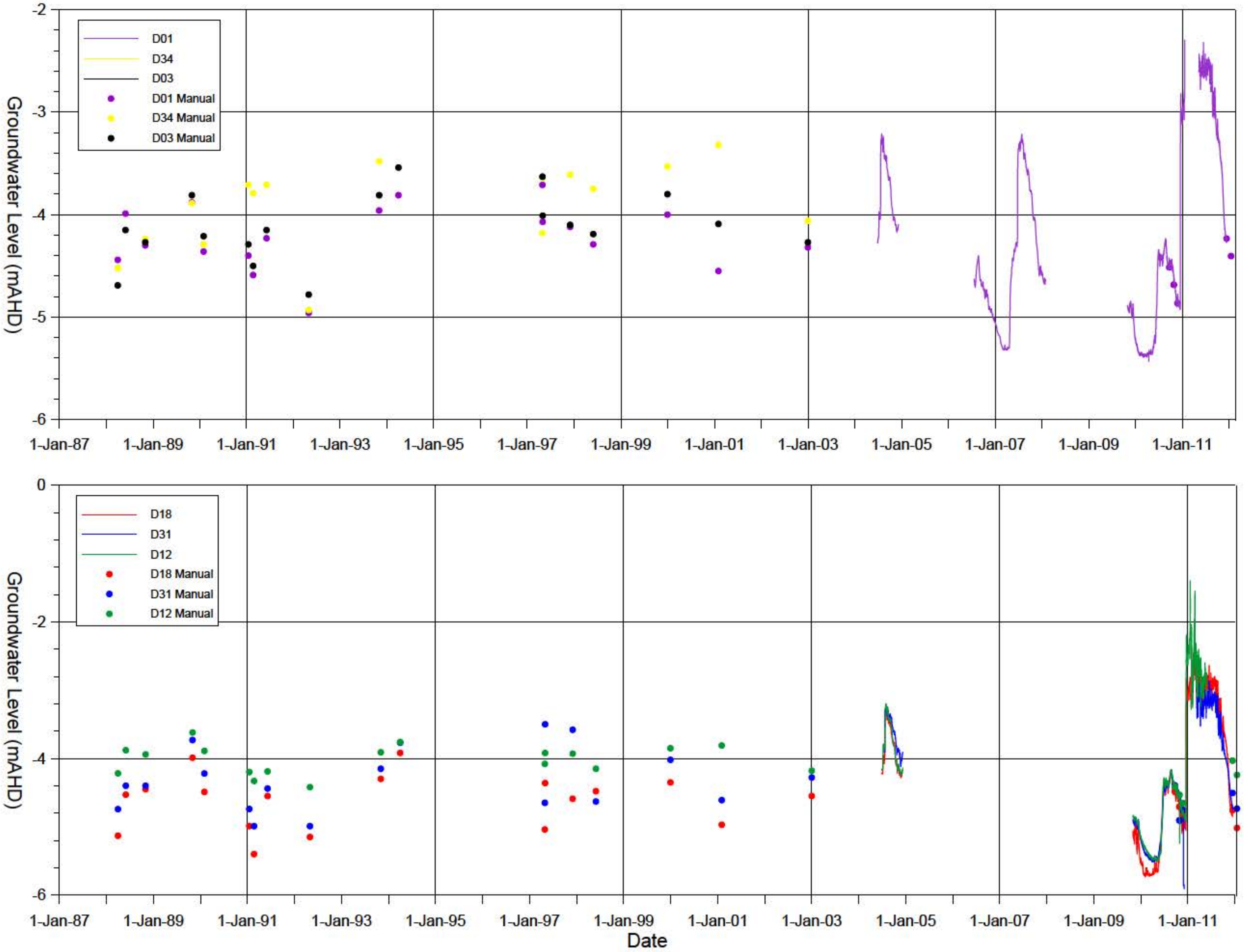
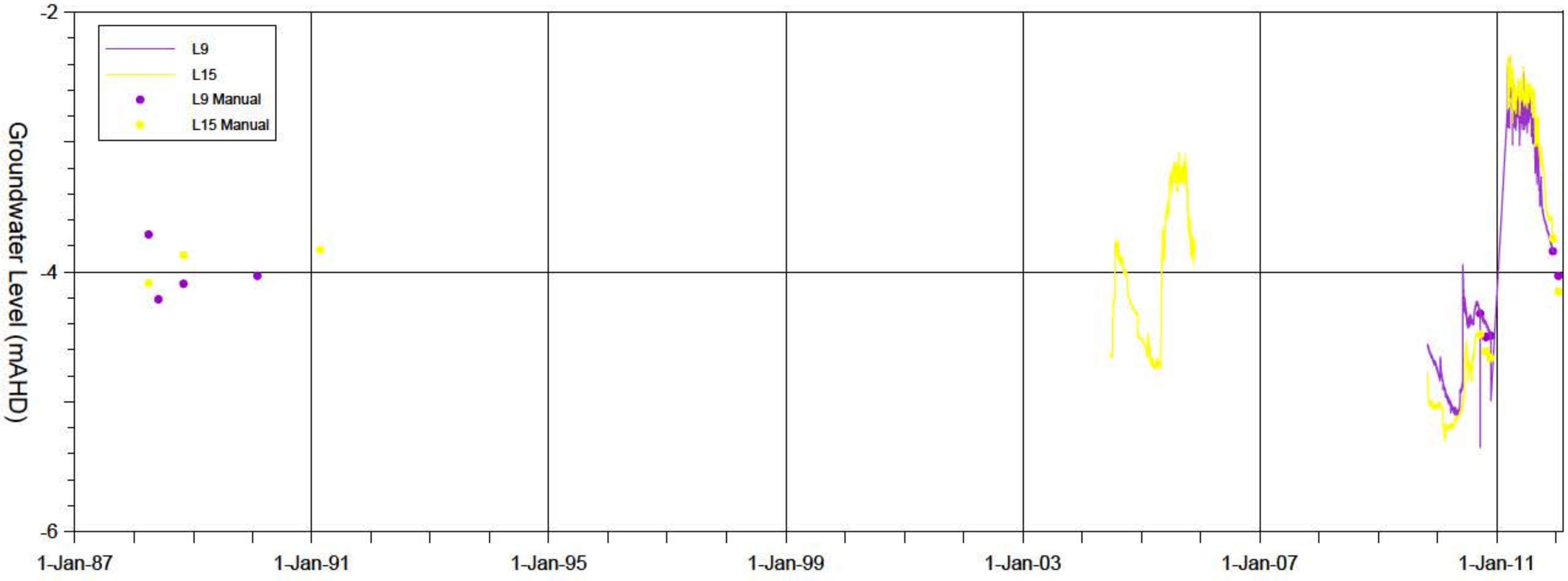
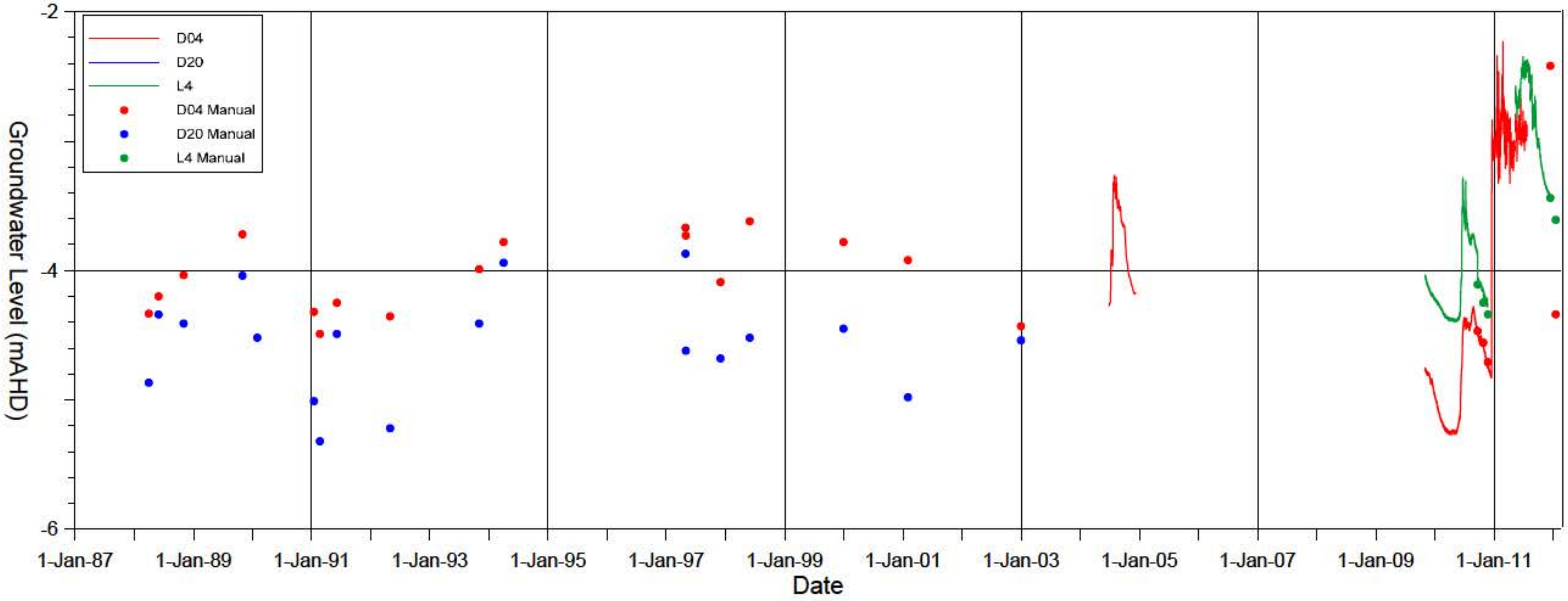
FIGURE 12

GROUNDWATER LEVELS CALCULATED FROM LOGGER DATA D18, D31, D12, D01, D34 &D03

GROUNDWATER RESOURCE MANAGEMENT







Lake Macleod PFS (J090028R07)

Dampier Salt Ltd

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Feb 12

FIGURE 13

GROUNDWATER LEVELS CALCULATED FROM LOGGER DATA D04, D20, L4, L9 & L15

GROUNDWATER RESOURCE MANAGEMENT

G:\Jobs2009\J090028_DS\LakeMacleod\figures\grapher\MonitoringDataReview\LoggerData6b.grf

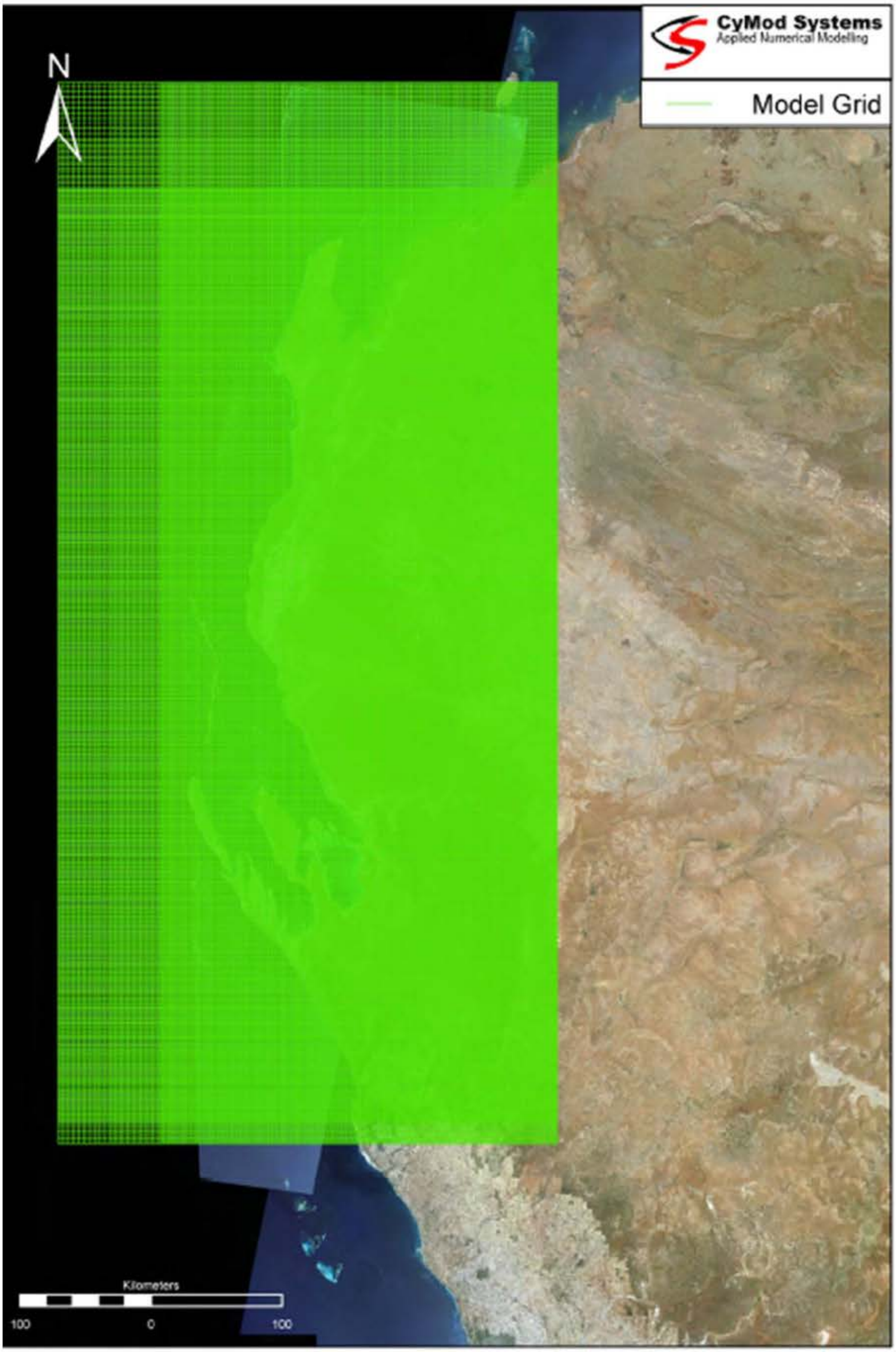


Figure source from CyMod 2012C

Lake Macleod PFS (J090028R07)			BIRDRONG AQUIFER MODEL GRID	GROUNDWATER RESOURCE MANAGEMENT
Dampier Salt Ltd				
TN	Mar 12	FIGURE 14		

Z:\Jobs2009\J090028_DSLLakeMacLeod\figures\powerpoint\J090028R07_BirdrongAquiferModelGrid_Fig14

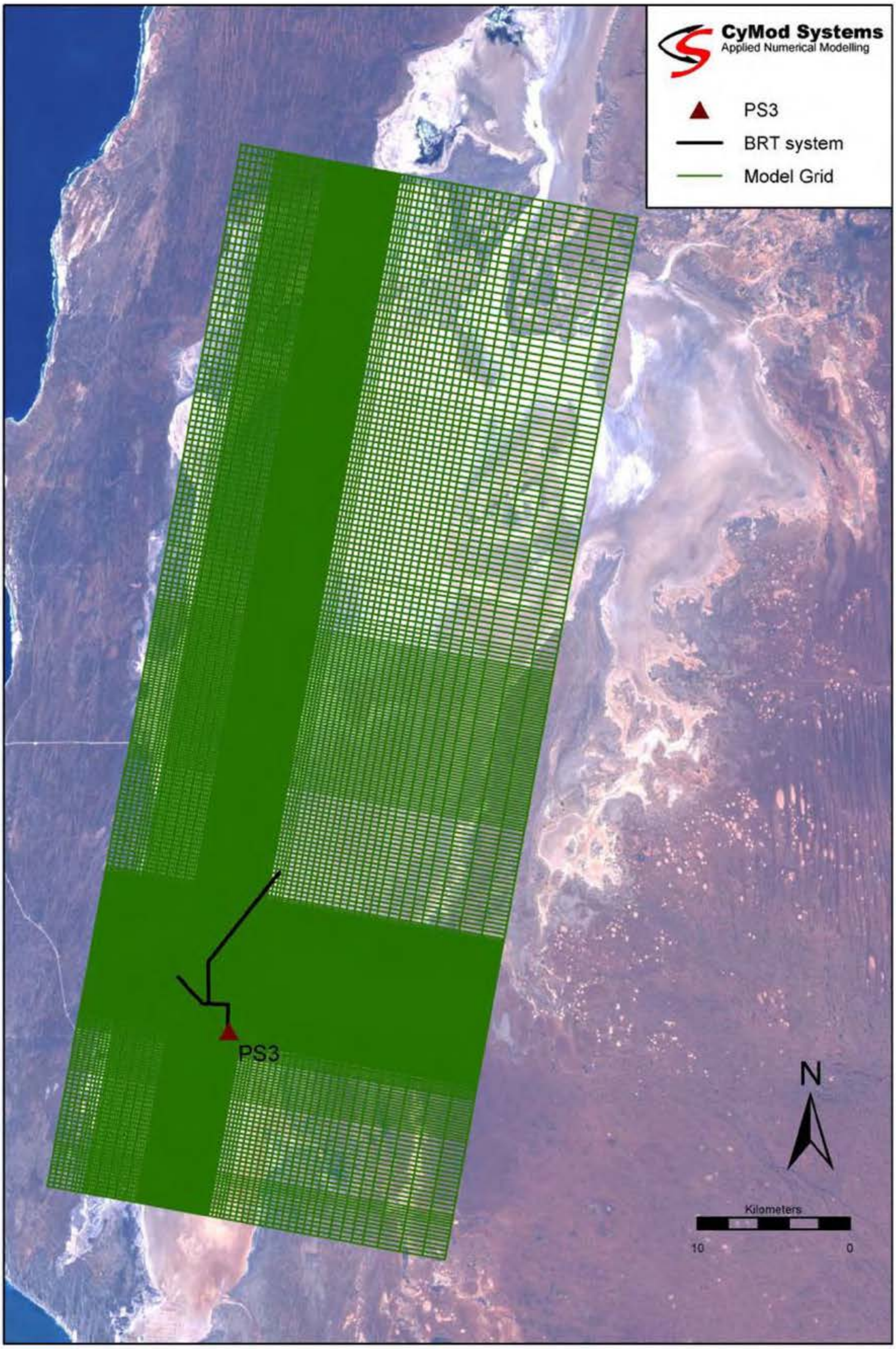


Figure source from CyMod 2012B

Lake Macleod PFS (J090028R07)			LAKE MACLEOD MODEL GRID	GROUNDWATER RESOURCE MANAGEMENT
Dampier Salt Ltd				
TN	Mar 12	**FIGURE 15**		

Z:\Jobs2009\J090028_DSLLakeMacLeod\figures\powerpoint\J090028R07_LakeMacleodModelGrid_Fig15

Lake Macleod PFS (J090028R07)

Dampier Salt Ltd

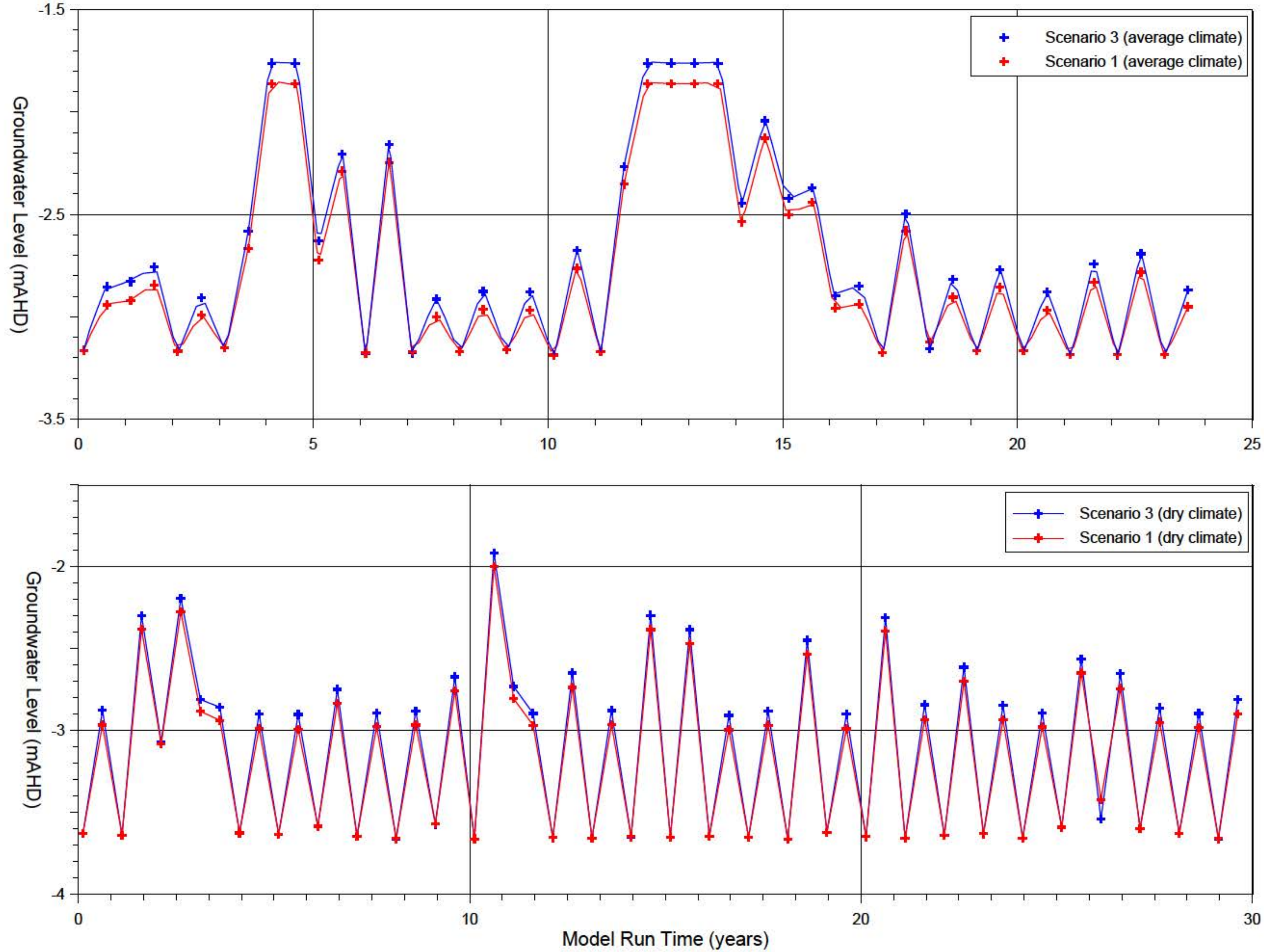
TN

Feb 12

FIGURE 16

GROUNDWATER LEVELS CALCULATED FROM LOGGER DATA MB001, 2 & 14

GROUNDWATER RESOURCE MANAGEMENT



G:\Jobs2009\J090028_DS\LakeMacleod\figures\grapher\J090028R07Grapher\F16.grf

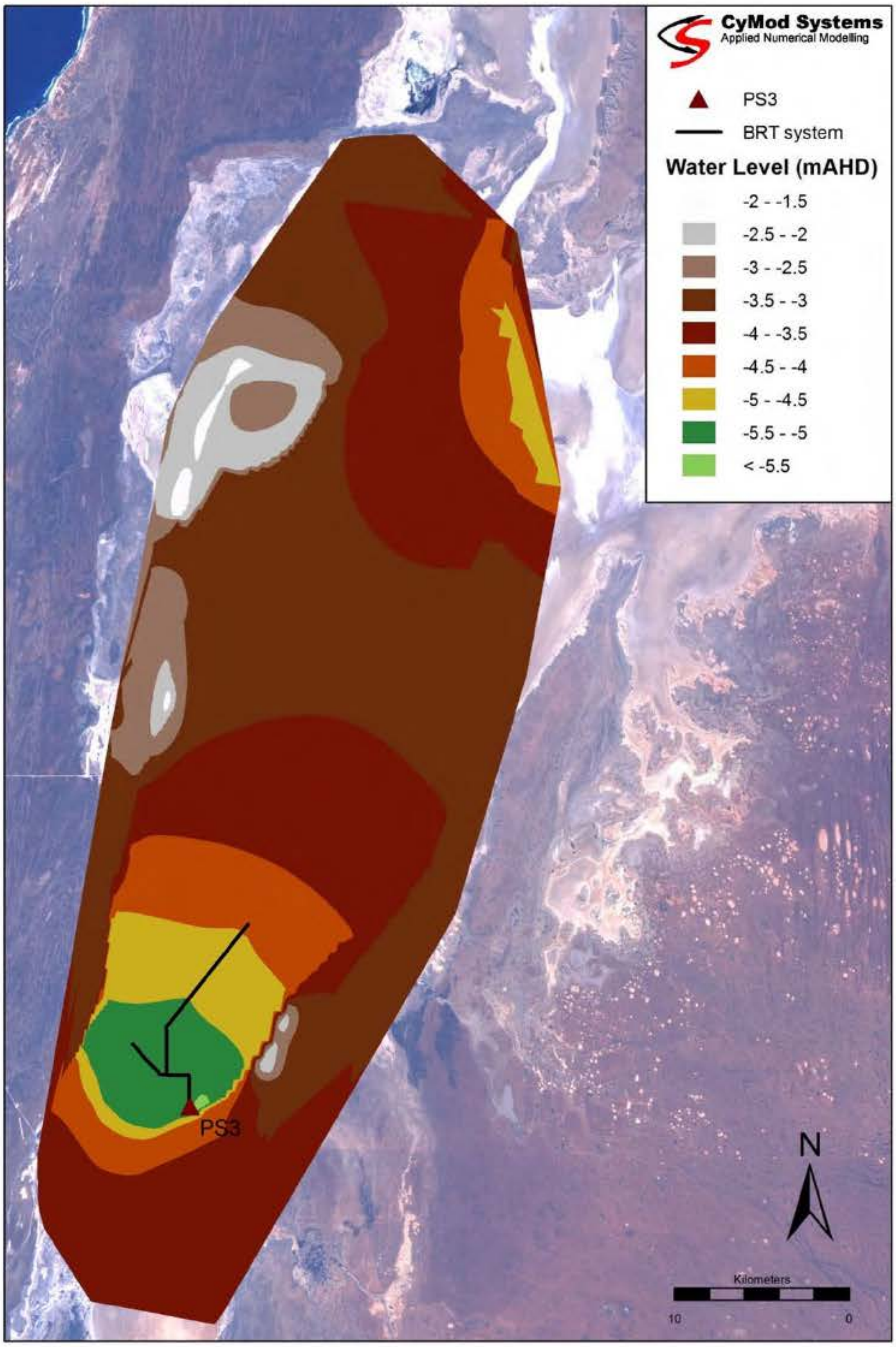


Figure source from CyMod 2012B

Lake Macleod PFS (J090028R07)		
Dampier Salt Ltd		
RG	Feb 12	**FIGURE 17**

SIMULATED HALITE AQUIFER WATER LEVELS SCENARIO 1

GROUNDWATER RESOURCE MANAGEMENT

FILE:\\J090028_DSLLakeMacLeod\figures\powerpoint\J090028R07PowerPointA4Port.ppt

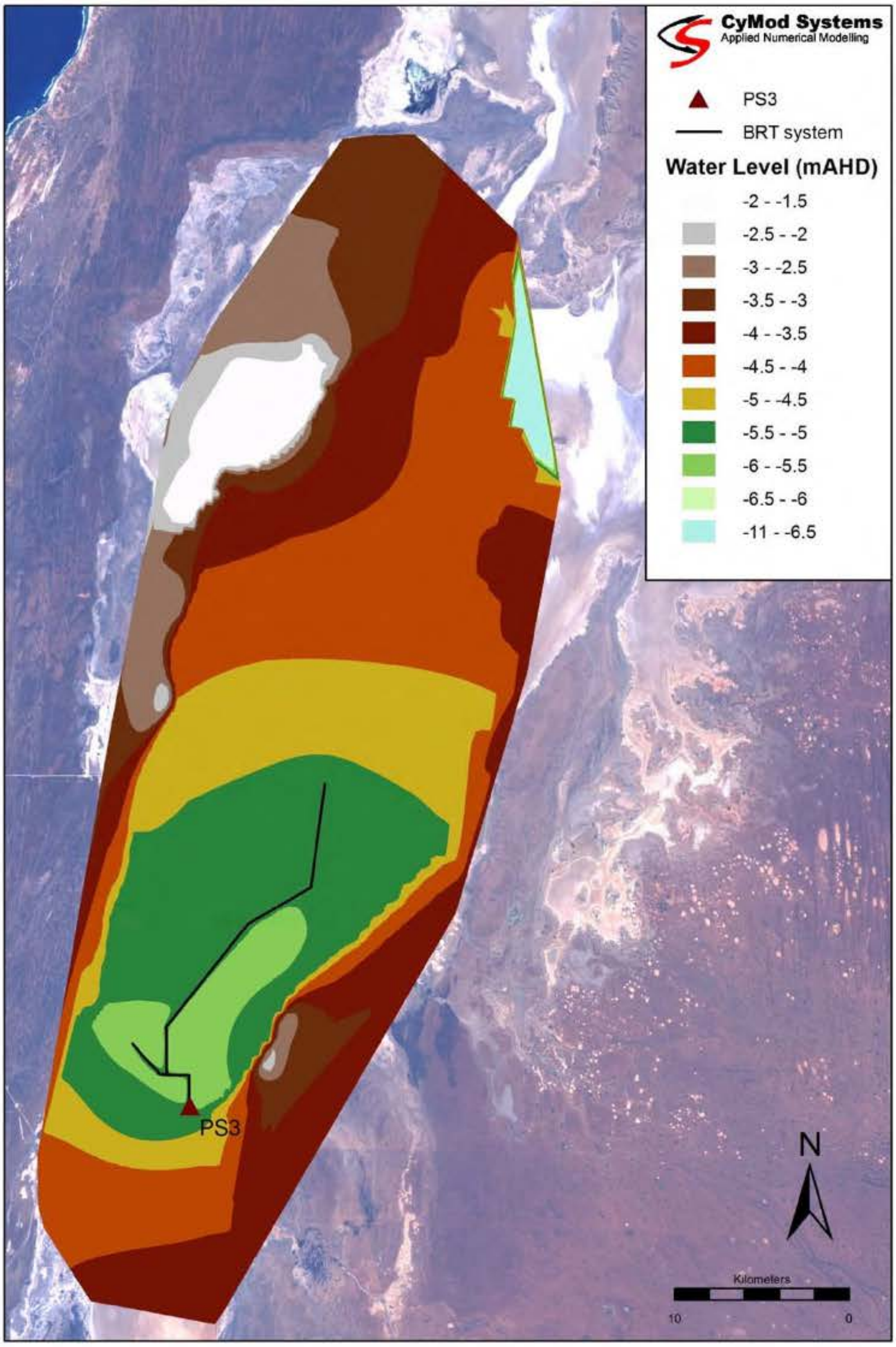


Figure source from CyMod 2012B

Lake Macleod PFS (J090028R07)			SIMULATED HALITE AQUIFER WATER LEVELS SCENARIO 3	GROUNDWATER RESOURCE MANAGEMENT
Dampier Salt Ltd				
RG	Feb 12	**FIGURE 18**		

FILE:\\J090028_DSLLakeMacLeod\figures\powerpoint\J090028R07PowerPointA4Port.ppt

APPENDIX A

Figures of the Lake MacLeod Morphology and Stratigraphy

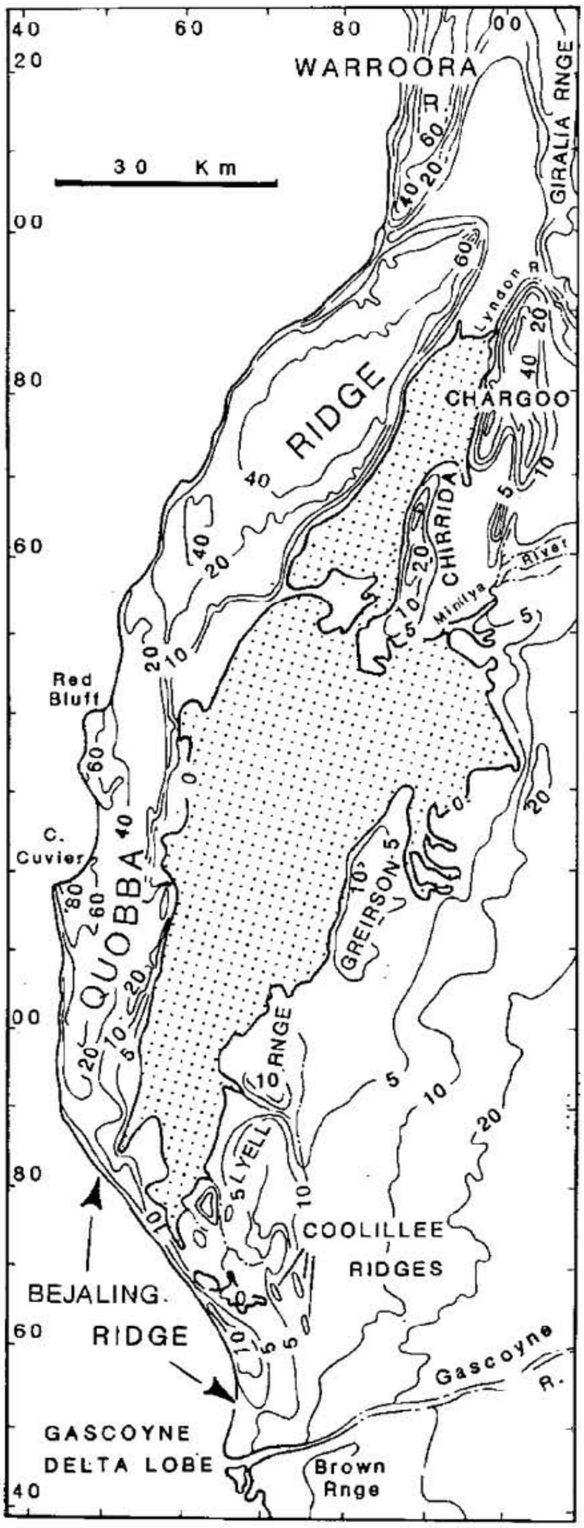


Figure 2. Generalized contour map illustrating topography of MacLeod region; contours are 5, 10, 20, 40, 60 and 80m. The area stippled lies between sealevel and -4.3m. The main geomorphic features are named. Bejaling Ridge (Holocene), Quobba Ridge and Warroora Ridge (Pleistocene) comprise the barrier. The northern levee of the Gascoyne River forms the natural southern boundary of the hinterland province and drainage is northwest to MacLeod Basin.

Figure sourced from Logan 1985.

Lake Macleod PFS (J090028R07)		
Dampier Salt Ltd		
RG	Jan 12	**FIGURE A1**

GENERAL AREA CONTOUR PLAN

GROUNDWATER RESOURCE MANAGEMENT

FILE:\\J090028_DSLLakeMacLeod\figures\powerpoint\J090028R07PowerPointA4Port.ppt

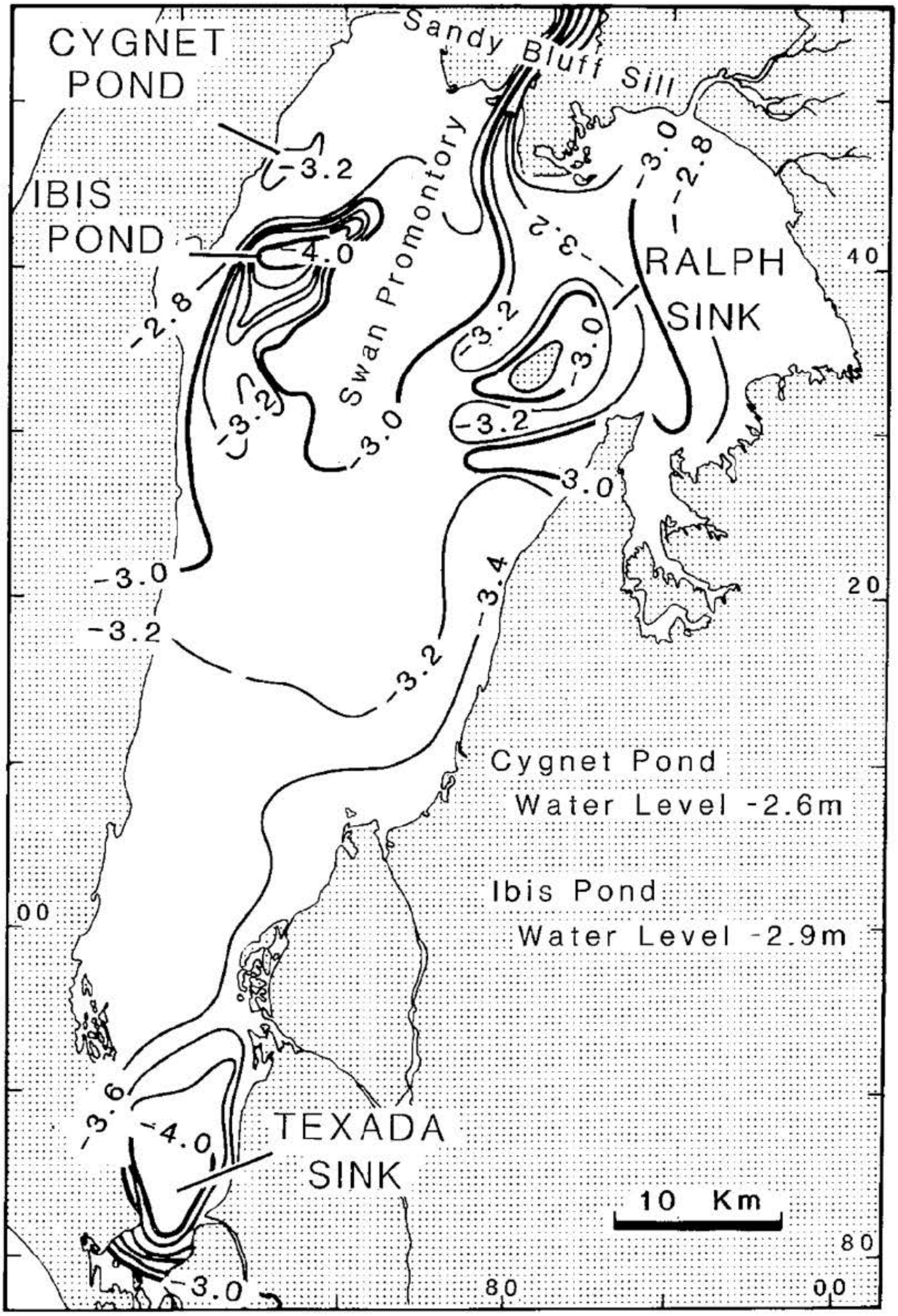


Figure 13. Contour map showing topographic configuration of the lake bed; figures are meters below mean sealevel. High level depressions are sites of permanent marine brine ponds, Cygnet and Ibis. Ralph Sink and Texada Sill sink are sites for ephemeral pond development. Chirrida Bay to the north (not shown)is above -3m.

Figure sourced from Logan 1985.

Lake Macleod PFS (J090028R07)			**LAKE SURFACE CONTOUR PLAN**	GROUNDWATER RESOURCE MANAGEMENT
Dampier Salt Ltd				
RG	Jan 12	**FIGURE A2**		

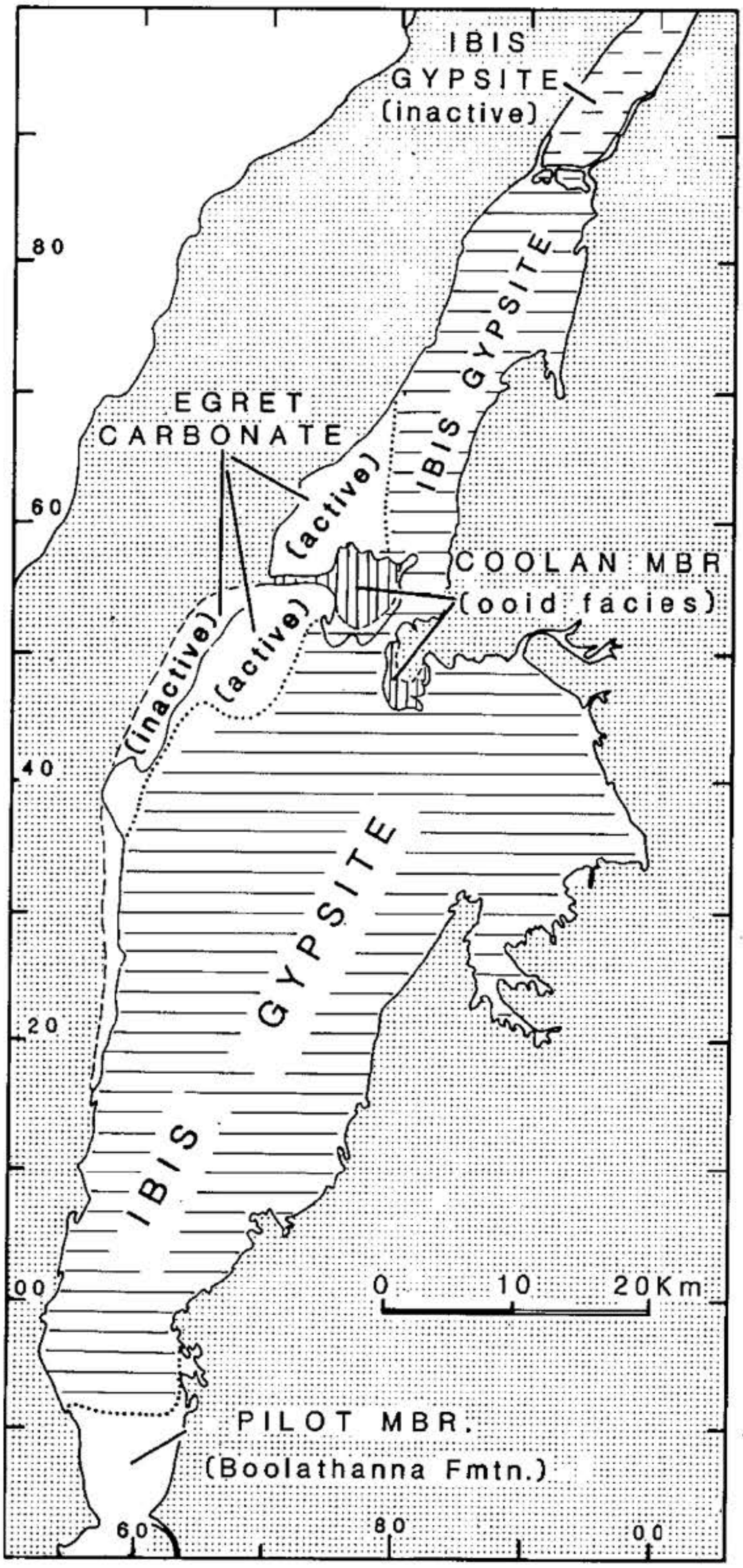


Figure 14. Map showing outcrop pattern of MacLeod Evaporite members. Areas in which sedimentation is active are differentiated from those where deposition has ceased.

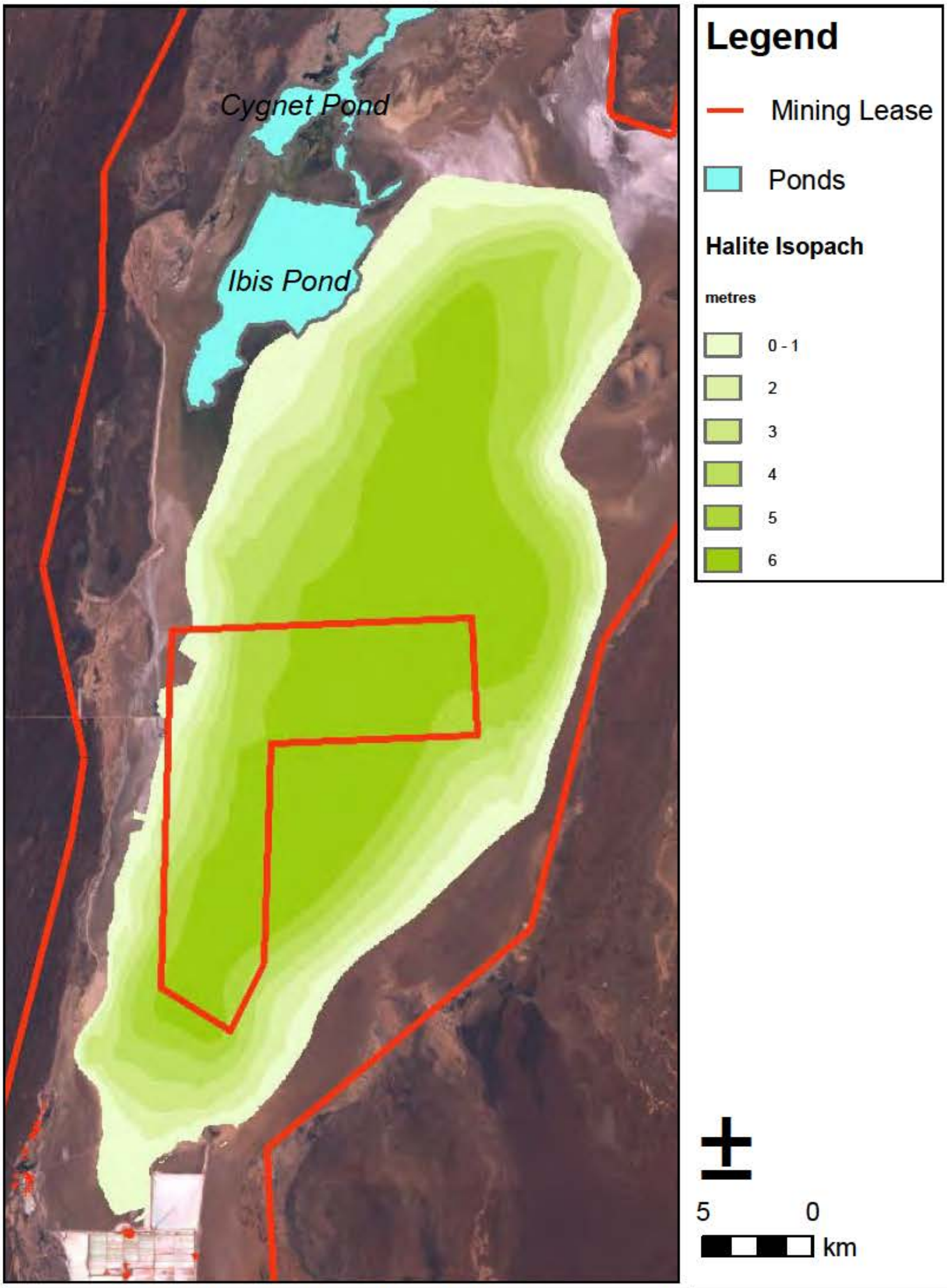
Figure sourced from B.W. Logan and M. Lewis 1983.

Lake Macleod PFS (J090028R07)		
Dampier Salt Ltd		
RG	Jan 12	**FIGURE A3**

IBIS GYPSITE AREA OF OUTCROP

GROUNDWATER RESOURCE MANAGEMENT

FILE:\\J090028_DSLLakeMacLeod\figures\powerpoint\J090028R07PowerPointA4Port.ppt



Dampier Salt Limited **Sustainability Assessment Lake Macleod**

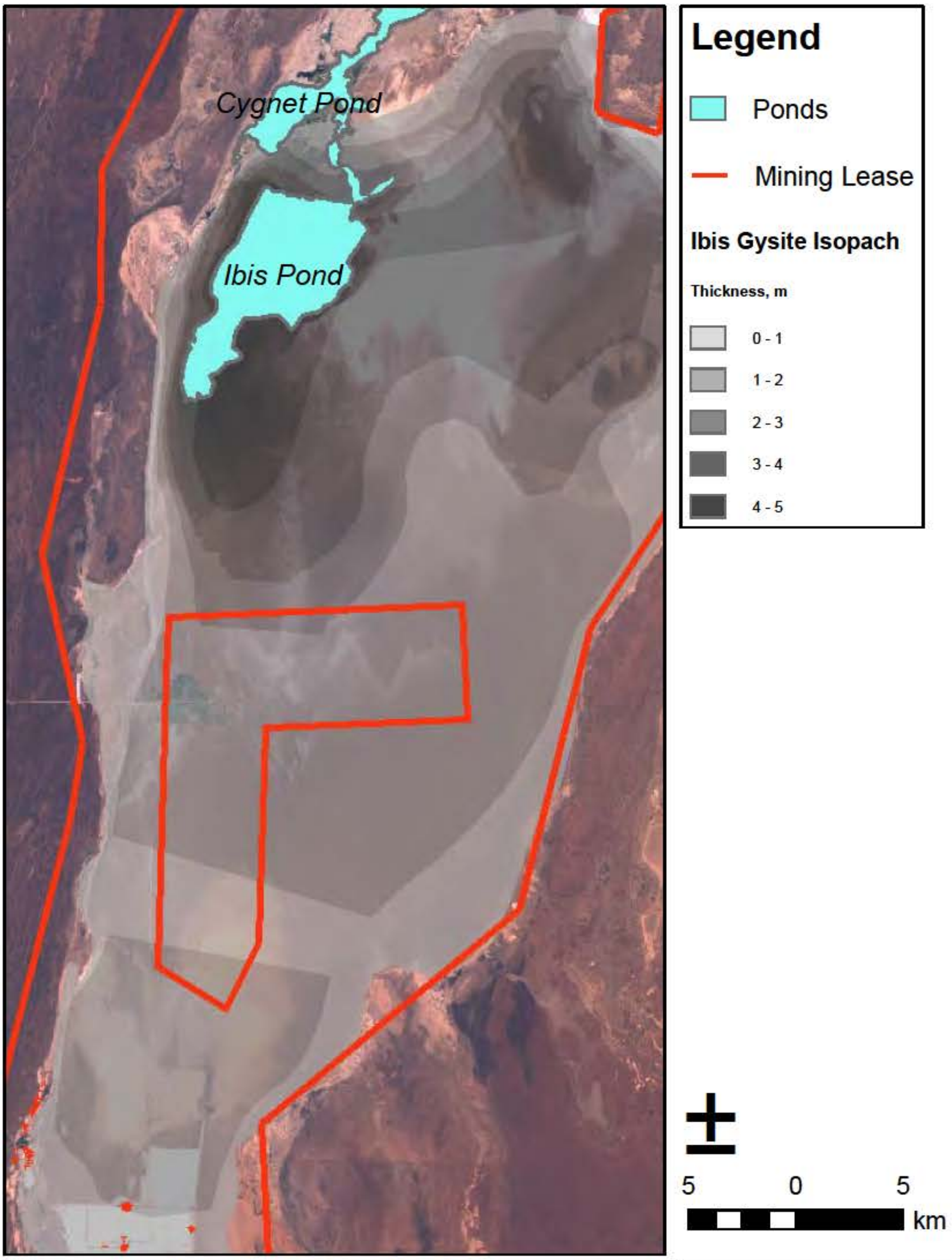
CyMod Systems
Applied Numerical Modelling

Figure sourced from Liquid Earth 2005

Lake Macleod PFS (J090028R07)			**TEXADA HALITE ISOPACH CONTOUR PLAN**
Dampier Salt Ltd			
RG	Jan 12	**FIGURE A4**	

GROUNDWATER RESOURCE MANAGEMENT

FILE:\\J090028_DSLLakeMacLeod\figures\powerpoint\J090028R07PowerPointA4Port.ppt



Dampier Salt Limited **Sustainability Assessment Lake Macleod**

CyMod Systems
Applied Numerical Modelling

Figure sourced from Liquid Earth 2005

Lake Macleod PFS (J090028R07)		
Dampier Salt Ltd		
RG	Jan 12	**FIGURE A5**

IBIS GYPSITE ISOPACH CONTOUR PLAN

GROUNDWATER RESOURCE MANAGEMENT

FILE:\\J090028_DSLLakeMacLeod\figures\powerpoint\J090028R07PowerPointA4Port.ppt

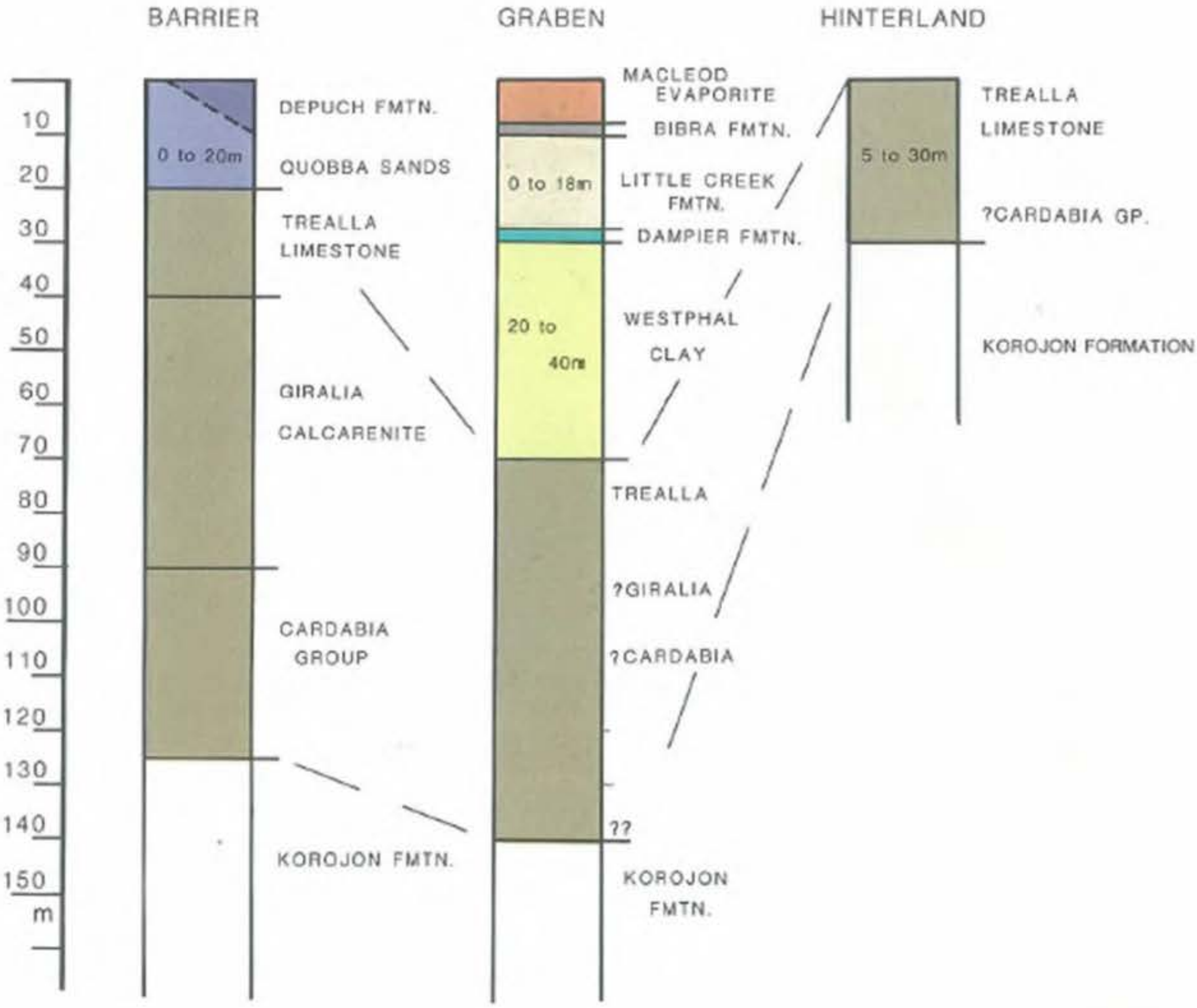


Figure 33. *Stratigraphic sections for Quobba barrier, MacLeoa graben, and hinterland province based on well data.*

Figure sourced from Logan 1987.

Lake Macleod PFS (J090028R07)			STRATIGRAPHY OF THE BARRIER, GRABEN AND HINTERLAND	GROUNDWATER RESOURCE MANAGEMENT
Dampier Salt Ltd				
RG	Jan 12	**FIGURE A6**		

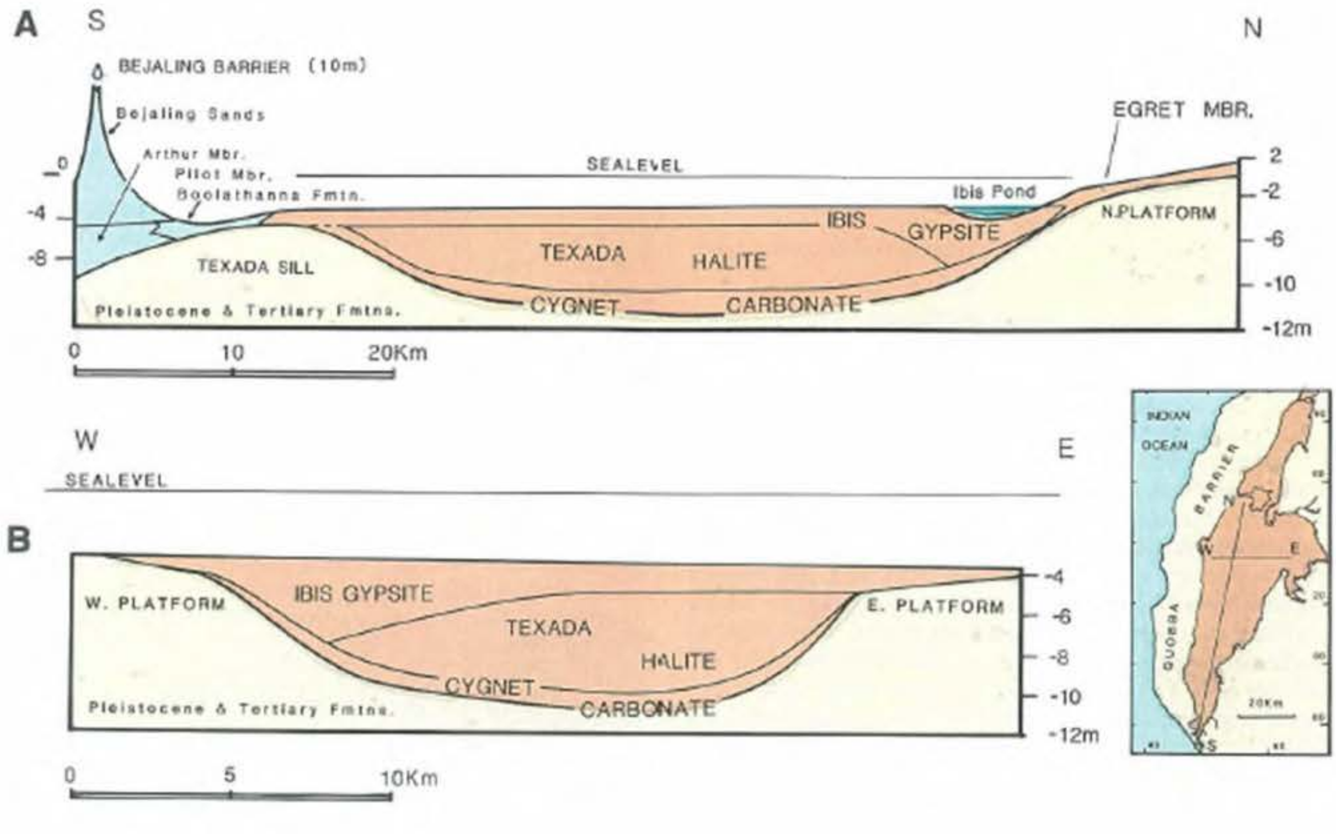


Figure 37. (a) Cross section, south to north from the Texada sill, showing stratigraphic relations in the MacLeod Evaporite and relation to other features. The basin floor slopes from north to south. Pilot Member, Boolathanna Formation, is a transitional unit of marine to evaporite pond facies; Arthur Member, Boolathanna Formation, is a marine sand. (b) Stratigraphic cross section, west–east, sequence in the central basin area; the Cygnet Carbonate wedges out at −5 m to −3.5 m.

Figure sourced from Logan 1987.

Lake Macleod PFS (J090028R07)		
Dampier Salt Ltd		
RG	Jan 12	**FIGURE A7**

LAKE MACLEOD SCHEMATIC SECTIONS

GROUNDWATER RESOURCE MANAGEMENT

FILE:\\J090028_DSLLakeMacLeod\figures\powerpoint\J090028R07PowerPointA4Port.ppt

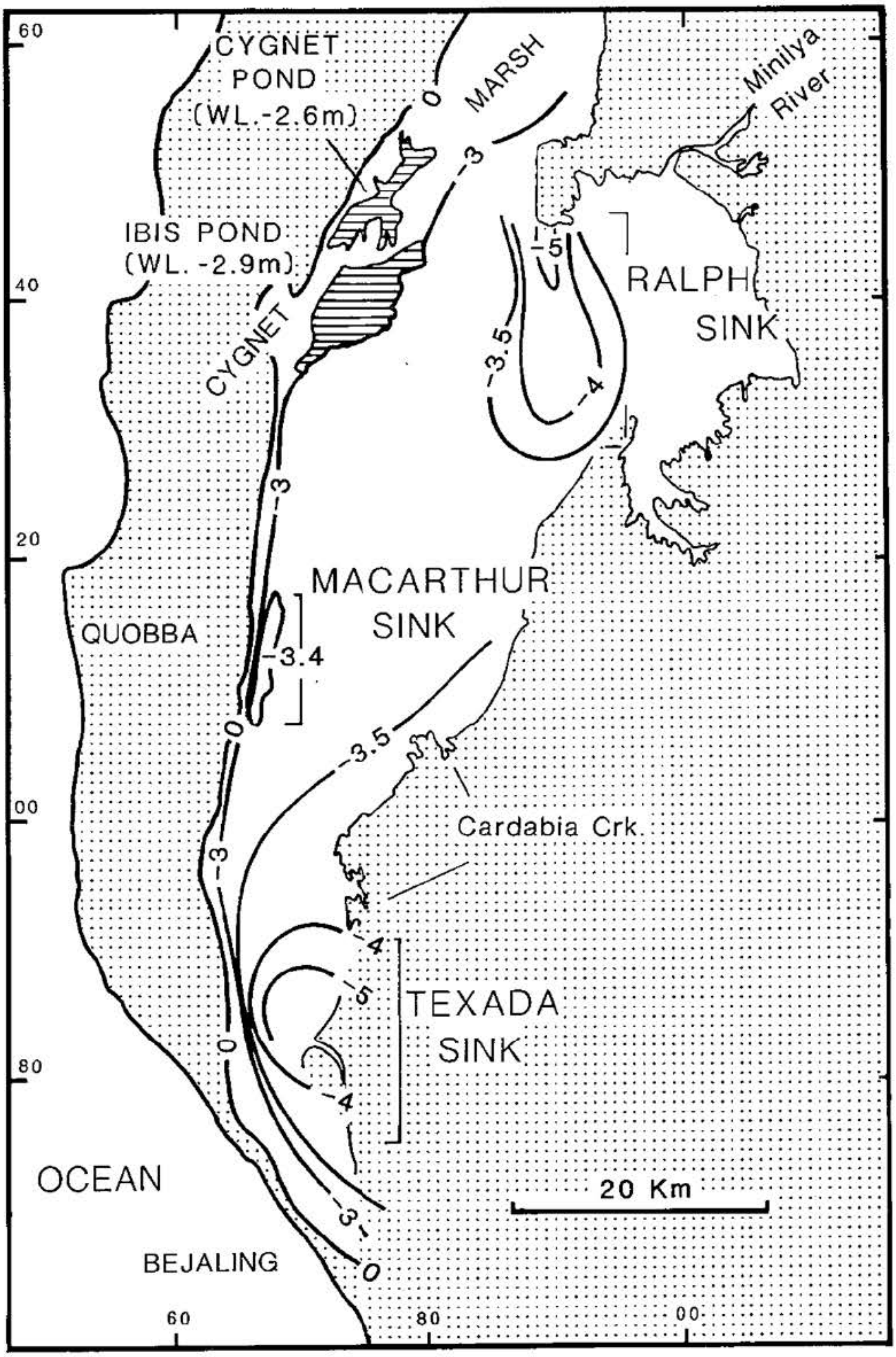


Figure 19. Generalized map of basinal brine surface (piezometric surface) during summer (peak evaporation), based on data from summer 1979, 80, 81, 82 and 85. Generalized contours for brine sinks are shown.

Figure sourced from Logan 1985.

Lake Macleod PFS (J090028R07)			BRINE LEVEL IN HOLOCENE AQUIFERS	GROUNDWATER RESOURCE MANAGEMENT
Dampier Salt Ltd				
RG	Jan 12	**FIGURE A8**		