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Residue Management Area

ENV-RPT-20151014 – Environmental Report
Environmental Evaluation
Yarwun RMA – Expressed Saline Groundwater

Investigation Results and Assessment

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Glossary

µS/cm – micro Siemens per centimetre
ALS – Australian Laboratory Services
ALD – Aldoga
Al – Aluminium
ANZECC – Australian and New Zealand Environment and Conservation Council
ARMCANZ – Agriculture and Resource Management Council of Australia and New Zealand, Canberra, Australia
AS – Australian Standard
BH – Borehole
CSIRO - Commonwealth Scientific and Industrial Research Organisation
DEC - Department of Environment and Conservation
DEHP – Department of Environment and Heritage Protection
DERM – Department of Environment and Resource Management
DO – Dissolved Oxygen
EA - Environmental Approval
EC - Electrical Conductivity
EC_{se} – Average Root Zone Salinity
EE – Environmental Evaluation
Ga – Gallium
Hwy – Highway
K – Potassium
LTMS – Long Term Management Strategy
MB – Monitoring Bore
Mg – Magnesium
mg/L – milligrams per litre
Mo – Molybdenum
Na – Sodium
NTU – Nephelometric Turbidity Units
NZS - New Zealand Standard
pH – pH
QWQG - Queensland Water Quality Guidelines
RMA – Residue Management Area
RTA Yarwun -RioTinto Alcan Yarwun
RTAY – RioTinto Yarwun
SAR – Sodium Absorption Ratio
SS – Suspended Solids
STMS – Short Term Management Strategy
Temp – Temperature
TDS – Total Dissolved Salts
TSS – Topsoil Sample
Turb – Turbidity
Va – Vanadium
VT – Vegetation Transect
WQO – Water Quality Objectives

1. Purpose

The following Environmental Evaluation (EE) presents the results and findings of the Residue Management Area (RMA) groundwater management investigations and ongoing monitoring programme to address the Department of Environment and Heritage Protection (DEHP) Notice to conduct or commission an environmental evaluation, issued on 25 March 2015, referred hereafter as the Notice. The EE seeks to address all requirements outlined in the Notice.

2. Background

RTA Yarwun operates the RMA located North West of Gladstone, which stores residue produced from the refinery located approximately 9 km to the east. RTA Yarwun has been placing residue in the RMA Dam since 2003 and there is approximately 15 million tonnes of residue in the dam.

In late 2013 impacted vegetation was identified in the northern area (including a 7ha area offsite) of the RMA. The impacted area is shown in Figure 1 and hereafter referred to as the site. Further reports and investigations during 2014 identified vegetation stress and death in the area was caused by the expression of "natural" saline groundwater. The Fire Dams (Figure 1) located to the east of the site which captured the expressed saline groundwater on the RMA were also identified as being acidic. By 2014, the centre of the site had become hypersalinated, with localised salinity levels above that of seawater. The hypersalinated area is within a naturally occurring low, seasonally inundated area hereby reffered to as the swamp (Figure 1).

Monitoring over the 2014/2015 wet season indicated that:

- initial releases of hypersalinated swamp waters during rainfall events caused salt scalds in the area between the swamp and the Lily Pond (situated approximately 100m downstream of site, and shown in Figure 1);
- salinity increased significantly as base flow water passed through the swamp; and
- salinity remained low as event water passed through the swamp.

A short term mitigation strategy (STMS) was agreed between stakeholders on the 26 February 2015 which involved the draining of the swamp and the excavation of a drainage system designed to collect and pump (the location of the sump is shown in Figure 1) expressed saline groundwater and base flows back to the RMA for treatment, while allowing event flows to pass through the site. Figure 2 presents the "as constructed" drawing of the STMS which was implemented in full by late March 2015. All water collected in the Fire Dams is also pumped back to the RMA.

In early April 2015, RTA Yarwun submitted "*Short Term Mitigation Strategy, Principles of design, operations strategies and monitoring plan for the short term mitigation strategy*" report to the DEHP to formalise the STMS construction works and outline the ongoing monitoring programme to assess the environmental impact of the expressed groundwater on the site. For the purpose of reporting the monitoring period stated herein refers to the results collected between March and August 2015.

The long term mitigation strategy (LTMS) has been led by GHD. GHD were contracted in December 2014 to prepare a Sampling and Analysis Plan (SAP), oversee investigations, assess results and provide long term mitigation options for the site. The investigations began in March 2015 and were completed on July 2015. GHD's reports are detailed below in Section 4.

3. Review of Previous Reports

RTA Yarwun has submitted the following reports to the DEHP. The key findings have been summarised below:

- Investigation of dead vegetation north of the RTA Yarwun RMA, October 2014;
    - Highly saline groundwater to the north-north-west pre-dated the construction of the RMA Dam,
    - Groundwater between the RMA and Larcom Creek is relatively shallow (less than 5m below the surface), That apart from the high salinity with associated elevated sodium, magnesium, calcium, sulphate and chloride, there are no other constituents of concern;
    - The source of the saline surface water can be determined from comparison to the very distinct signatures of the two potential sources, groundwater and/or decant/pore water seepage from the RMA, and
    - The water in the northern drainage line and the swamp area have the same chemical signature, which is different from the chemical signature of decant from the RMA Dam, but the same chemical composition as the groundwater.
- Groundwater seepage at the Rio Tinto Alcan Yarwun RMA, November 2014;
    - Seepage to the north of the RMA is clearly groundwater related with no influence from water present in the RMA Dam, and
    - It appears that seepage is occurring in response to elevated groundwater pressure in foundation materials beneath the RMA Dam.
- Short Term Mitigation Strategy, March 2015;
    - RTA Yarwun outlined its preferred temporary strategy to mitigate the risks of the expressed groundwater, or storm water contaminated by saline groundwater leaving the site;
    - Plans for a detailed investigation focused on understanding how the groundwater is being pressurised, its pathway to the surface and remedial actions to halt the expression of saline groundwater; and
    - A monitoring plan including, groundwater, surface water, soil, sediment and vegetation monitoring to assess the effectiveness of the STMS and to provide ongoing information on the sites rehabilitation.

4. GHD Groundwater Management Report

GHD were contracted to develop a SAP to investigate, analyse and determine the spatial extent of saline groundwater pressurisation, to provide a concept design of management options to alleviate pressurisation of the northern embankment and off-site downstream of the RMA and an assessment of low-pH water in the Firewater Dams. The GHD provided RTA Yarwun with the following reports;

- Detailing of Groundwater Management Actions Spatial Analysis of Groundwater Pressurisation of the Northern Embankment and Development of Sampling and Analysis Plan, GHD (2015A);
- RTA Yarwun Groundwater Management - Low pH Water Investigation, GHD, (2015B); and

- RTA Yarwun RMA Groundwater Management Actions, Groundwater Conceptualisation and Management Options GHD (2015C).

The GHD reports are presented in Appendices A and B.

5. Assessment Criteria

The sites ephemeral drainage channels drain into Larcom Creek approximately 2km to the north-west of site. Larcom Creek is included in the Curtis Island, Calliope River and Boyne River Basins Environmental Values and Water Quality Objectives (WQOs), under the Environmental Protection Agency (EPA) Water Policy 2009, which lists environmental values by waterway and states the following environmental values are applicable to Larcom Creek;

- Aquatic ecosystems;
- Irrigation Farm supply/use;
- Stock water;
- Aquaculture;
- Human consumer;
- Primary recreation;
- Secondary recreation;
- Visual recreation;
- Drinking water;
- Industrial use; and
- Cultural and spiritual values.

5.1 Surface and Groundwater

For base and event flows, field and laboratory results were assessed against the;

- DEHP, 2009A Schedule 1, EPA Water Policy (2009), Capricorn-Curtis Coast Region Scheduled Environmental Values and WQOs Calliope Fresh Waters Inside State Development Area

Table 1 provides a summary of the assessment values used for base and event flows.

Table 1 Base flow and event WQOs

		DO	Turb	SS	pH
Lowland fresh <150m (s2)[1]	Units	(% sat)	(NTU)	mg/L	
	WQO's	85–110	<50	<10	6.5–8.0

[1]Calliope default lowland rivers in Table 2F DEHP,2009A.

For standing surface water and groundwater water quality results were assessed against the;

- ANZECC/ARMCANZ, 2000. National Water Quality Management Strategy *Australian and New Zealand Guidelines for Fresh and Marine Water Quality (herein as* **NWQMS**);
- DEHP, 2009B. Queensland Water Quality Guidelines *Guideline Values for Central Coast Lowland Streams (*herein as *QWQG)*, and;

- RT HSEC, 2014. *Saline Groundwater Impacts on Vegetation*, Internal Decant Water Signature Values (herein as RTAY).

Table 2 provides a summary of the assessment values used for the EE.

Table 2 Groundwater and Standing Water Assessment Values

	Physico-Chemical		Mass Ratios			Filtered Metals			
	EC	pH	Na:Cl	Mg:Cl	K:Cl	Al	Ga	Mo	V
Units	µS/cm					mg/L	mg/L	mg/L	mg/L
NWQMS		**6.5-8.0**				**0.055**			
QWQG	*1500*[2]	*6.5-8.0*							
RTAY[3]			>0.9	<0.004	>0.02	>1	0.05	0.20	

[2]EC value being the 90th Percentile of EC of rateable Central Coast South sites Table G.4 in Appendix G (DEHP, 2009B)

[3]Decant water physico chemical signatures were identified and presented RT HSEC, 2014

5.2 Flora

Vegetation transect surveying was undertaken in accordance with the Western Australian Department of Environment and Conservation's (DEC) Standard Operating Procedure for Establishing Vegetation Transects (DEC, 2009). The line intercept method was used to assess and monitor groundcover and while plot transects were used to assess and monitor vegetation health.

5.3 Soil Salinity and Sodicity

Assessing soil salinity and sodicity requires the consideration of a number of factors, including soil type, plant salt tolerance, climate and landscape. There are no environmental trigger values for the pH, salinity or sodicity of soils outlined in either the ANZECC/ARMCANZ, 2000 or QWQG, 2009.

The CSIRO, 2003 report titled "*Assessment of physico-chemical changes in dryland saline soils when drained or disturbed for developing management options*" presents indicator values for salinity (using EC and EC_{se}) and sodicity (using pH and SAR). The report also outlines best practise management options post draining of saline areas. Table 3 provides a summary of the soil guideline values, with the expectation that salt tolerant pioneer vegetation (i.e. couch grass) would be able to grow if shallow root zone soils in the sites heavy clay soils do not exceed the guideline values.

Table 3 Indicator values for Saline Soils

	pH	EC	EC_{se}	SAR
Units		µS/cm	µS/cm	
CSIRO	**>8.5**	**>16000**	**>12000**	**>46**

6. Environmental Evaluation Notice Requirement 1 - Southern RMA Groundwater Assessment

GHD, 2015C have assessed, in detail, the sites groundwater levels (north RMA) to determine the extent of groundwater expression (Appendix A). Groundwater levels to the south, east and west were outside the scope of the GHD study. However, to addresses the DEHP Notice Requirement 1 – *Identify all possible groundwater expressions associated with the RMA in addition to the already identified Northern Groundwater Expression and Firewater Dams Expression* groundwater level monitoring data from southern RMA are assessed.

6.1 Schedule and Methodology

Figure 3 illustrates the monitoring bores assessable for the Southern RMA groundwater assessment. The monitoring of the bores is undertaken by the RTA Yarwun Environmental Department as part of the EA monitoring schedule for the RMA. Bore location and details are listed in Table 4 below.

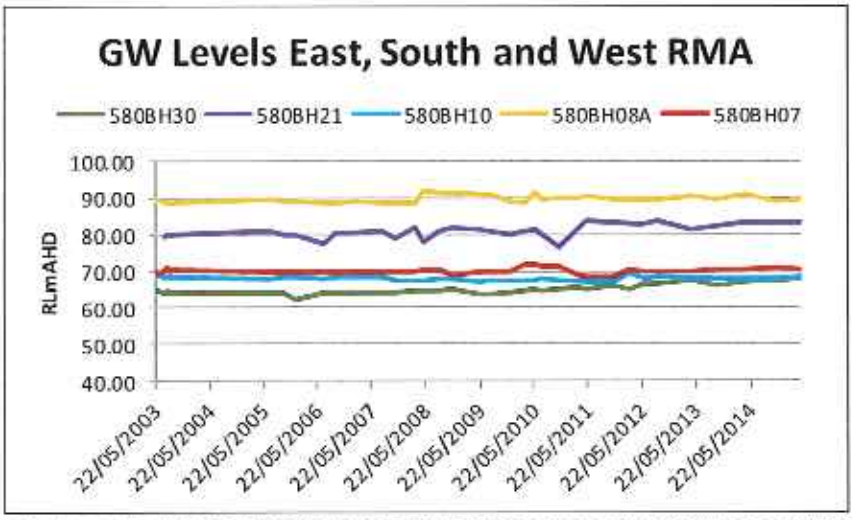
Table 4 Location and surveyed levels of assessable RMA groundwater monitoring bores

	mE	mN	RL Top of Casing	RL Ground Level	Depth of GW from surface 2015
580BH30	305148	7359434	77.88	77.46	9.41
580BH21	305498.8	7358553	96.24	95.87	12.83
580BH10	304001.4	7357884	85.03	84.03	15.70
580BH08A	303226.5	7358452	94.07	93.60	4.08
580BH07	303132.3	7358786	83.55	83.04	12.92

6.2 Results

Graph 1 illustrates the groundwater levels from the southern monitoring bores.

Graph 1 Measured static groundwater levels Southern RMA



No significant change in water levels can be observed in the south and western bores (580BH10, 580BH07 and 580BH08A) over the twelve years of monitoring. A rise in groundwater levels in the eastern bores 580BH30 and 580BH21 can be observed with groundwater rising 3.58m and 2.5m respectively. All groundwater levels however are well below ground level with groundwater depth (below ground level) ranging from 4.08m at 580BH08A to 15.70m at 580BH10.

6.3 Assessment

Based on the monitoring results, there are no other areas (or other areas likely in the near future) of groundwater expression associated with the RMA. Monitoring of all compliance bores in accordance with the EA shall continue and mitigation work undertaken in any future areas assessed as likely to be impacted by groundwater expression.

7. Environmental Evaluation Notice Requirement 2 - Groundwater Expression Source and Extent

GHD, 2015C have assessed the site's groundwater quality and have identified the likely causes and the extent of groundwater expression (Appendix A). The GHD 2015C report addresses the DEHP Notice Requirement 2 – *Identify the source, cause and extent of groundwater expressions associated with the RMA.*

8. Environmental Evaluation Notice Requirement 3 - Groundwater Expression Water Quality

Analysis of the expressed groundwater was undertaken to address the DEHP Notice Requirement 3 – *Identify and characterise all contaminants contained within the groundwater expression water, with reference to Australia and New Zealand Environment Conservation Council and the Queensland Water Quality Guidelines.*

8.1 Schedule and Methodology

Expressed groundwater monitoring on site was undertaken in accordance with Table 5 below at both Fire Dams and the Sump. Figure 4 illustrates the surface water monitoring locations for the site.

Table 5: Expressed Groundwater Monitoring Schedule

Locations	Testing Parameters	Frequency
FD1 and FD2	Field parameters (pH, Temp, DO, EC, Salinity and Turbidity)	Weekly
	Laboratory dissolved metals (Aluminium (Al) Gallium (Ga), Molybdenum (Mo) and Vanadium (V)) and major ions (Sodium (Na), Calcium (Ca) Magnesium (Mg) Potassium (K), Sulphur (S) and Chloride Cl))	Monthly
Sump	Field parameters (pH, Temp, DO, EC, Salinity and Turbidity)	Twice Weekly
	Laboratory (as above)	Monthly

In situ field physico-chemical parameters were measured using a calibrated YSI Pro DSS multi meter. Surface water samples were collected in accordance with the Australian and New Zealand Water Sampling Guidelines AS/NZS 5667.6:1998, guidance on sampling of rivers and streams. Samples were collected in the appropriate containers and labelled, chilled in field before being couriered to ALS's analytical laboratories in Brisbane for testing under Chain of Custody.

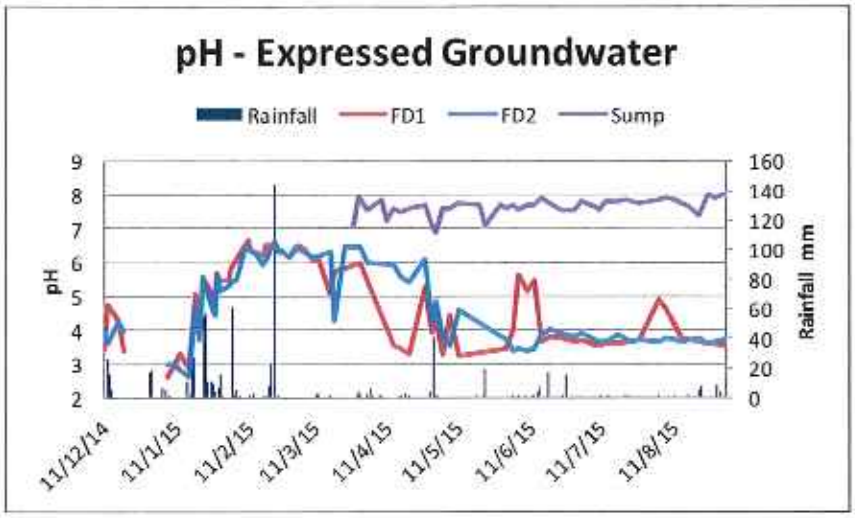
8.2 Results

The GHD, 2015B (Appendix B) memo assesses in detail the Fire Dam's water chemistry to determine the likely source of acidity. Laboratory certificates for surface water are attached in Appendix C. Appendix D presents the tabulated surface water quality results.

8.2.1 Field Results

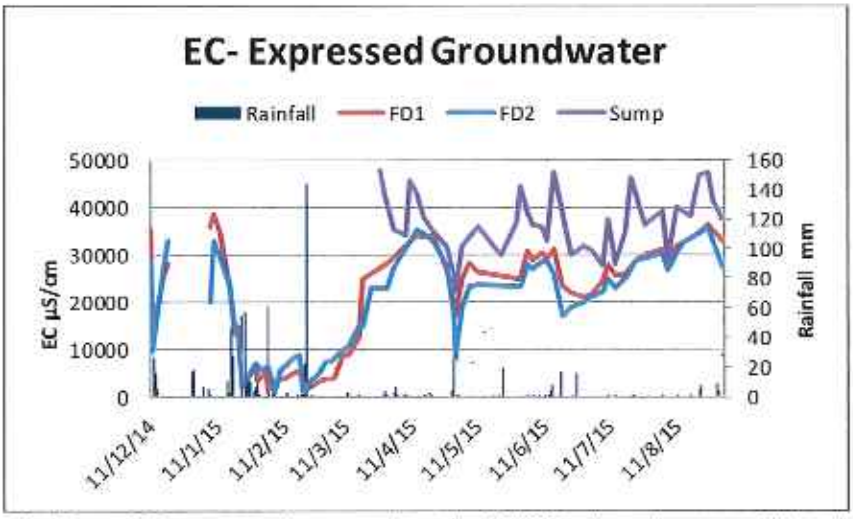
Graphs 2 and 3 illustrate the field monitoring results for pH and EC for the expressed ground water monitoring locations.

Graph 2 pH monitoring results



Sump pH levels have fluctuated within the NWQG and QWQG guideline range. Fire Dam pH levels are below the minimum guideline value of 6.5.

Graph 3 EC monitoring results



The recorded Sump EC concentrations are above the QWQG value with concentrations fluctuating between 20,000 and 50,000 µS/cm over the monitoring period. The initial two peeks in EC on 23 March and 16 April were attributed to the draining of the swamp. Post draining, the fluctuations in EC are attributed to rainfall and temperature.

EC concentrations in both fire dams were above the QWQG value of 1500 µS/cm. Only during and post significant rainfall did EC concentrations fall below the guideline value.

8.2.2 Laboratory Results

Table 6 below presents assessable laboratory results for expressed groundwater.

Table 6 Assessable Laboratory Results for Expressed Groundwater

	Physico-Chemical		Anions		Cations				Mass Ratios			Filtered Metals			
Date	**pH**	**EC**	**Cl**	**S**	**Ca**	**Mg**	**Na**	**K**	**Na:Cl**	**Mg:Cl**	**K:Cl**	**Al**	**Ga**	**Mo**	**Va**
Unit		µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L				mg/L	mg/L	mg/L	mg/L
NWQMS	**6.5-8.0**											**0.055**			
QWQG	*6.5-8.0*	*1500*													
RTAY	6.5 - 8.5	-	-	-	-	-	-	-	>0.9	<0.004	>0.02	1.000	0.05	0.20	
FD1															
9/2/15	**5.68**	*3820*	-	132	-	-	-	-				0.02	<0.001	<0.001	<0.01
27/4/15	**3.67**	*34900*	11200	2940	1080	3290	3770	19	0.34	0.29	0.002	**0.67**	<0.001	<0.001	<0.01
31/5/15	**3.55**	*27100*	8530	2130	405	2130	2910	11	0.34	0.25	0.001	**6.87**	<0.001	<0.001	<0.01
2/7/15	**3.59**	*25400*	8760	1820	308	1800	2660	12	0.30	0.21	0.001	**9.05**	0.002	0.003	<0.01
27/7/15	**3.54**	*33100*	9760	2710	475	2500	3810	14	0.39	0.26	0.001	**10.2**	<0.001	<0.001	<0.02
25/8/15	**3.55**	*36600*	9270	3190	476	1820	3260	14	0.35	0.20	0.002	**10.3**	<0.001	<0.001	<0.02
FD2															
9/2/15	6.75	*5900*	-	246	-	-	-	-	-	-	-	0.02	<0.001	<0.001	<0.01
27/4/15	**6.16**	*36400*	12280	2780	959	3600	3550	20	0.29	0.29	0.002	<0.01	<0.001	<0.001	<0.01
31/5/15	**3.8**	*25100*	8700	1800	577	2560	1960	<10	0.23	0.29	-	**3.77**	<0.001	<0.001	<0.01
2/7/15	**3.74**	*25100*	8880	1300	537	2030	1920	9	0.22	0.23	0.001	**3.79**	0.001	0.002	<0.01
27/7/15	**3.53**	*32500*	9730	2430	681	2830	2660	11	0.27	0.29	0.001	**2.98**	<0.001	<0.001	<0.01
25/8/15	**3.55**	*36600*	9370	2860	726	2230	2620	11	0.28	0.24	0.001	**6.79**	<0.001	<0.001	<0.01
Sump															
27/4/15	7.9	*38200*	12000	2880	887	2160	6200	3	0.52	0.18	0.000	<0.01	<0.001	<0.001	<0.01
31/5/15	7.8	*41600*	12600	3640	719	2140	6780	2	0.54	0.17	0.000	<0.01	<0.001	<0.001	<0.01
2/7/15	7.9	*38400*	13000	3380	788	2140	6790	10	0.52	0.16	0.001	<0.01	<0.001	<0.001	<0.01
27/7/15	7.8	*41200*	11500	3520	761	2090	6690	10	0.58	0.18	0.001	<0.01	<0.001	<0.001	<0.01
25/8/15	8.1	*44700*	11200	3670	814	1680	6870	<10	0.61	0.15	-	<0.01	<0.001	<0.001	<0.01

8.2.2.1 pH

Laboratory pH measurements reflected field pH measurements. Sump pH levels were within the guideline range for pH at all times during the monitoring period. Fire Dams pH levels were below the minimum guideline during the monitoring period with the exception of sampling following significant rainfall events.

8.2.2.2 Salinity

Laboratory EC measurements reflected field EC measurements. EC concentrations for Sump and the Fire Dams were above the guideline value with exception of sampling following significant rainfall events.

8.2.2.3 Surface Water Chemistry

The mass ratios for the sump and fire dams are almost identical to the mass ratios of the monitoring bores directly upstream of the sampling locations MB06 and ALD1A respectively (groundwater mass ratios shown in Table 8). Results indicate that the expressed groundwater at the sump has higher Na:Cl and lower Mg:Cl ratios than the Fire Dams mass ratios.

The expressed groundwater mass ratios are also significantly different to decant water mass ratios, with the expressed groundwater having higher concentrations of Mg, lower concentrations of Na and very low concentrations of K when compared to decant water mass ratios.

Dissolved metal concentrations were below the limit of reporting for the Sump at all times during the monitoring period. As a result of the low pH waters in the Fire Dams significant dissolved Al concentrations and reportable levels of dissolved Ga and Mo were measured. Throughout the monitoring period V measured below the limit of reporting at all locations.

8.3 Assessment

Analysis of the data confirms that the water captured in the Sump is derived from the saline groundwater expressing at the surface and not RMA decant water seepage. The sump water is characterised by significant concentrations of Na and Mg, very low concentrations of K and the absence of signature decant dissolved metals.

GHD have investigated and assessed the source and nature of the acidity of the expressed groundwater captured in the Fire Dams in their July and September 2015 reports. GHD concluded that the acidic expressed groundwater is likely pyritic in origin based on the significant concentrations of sulphur measured in the expressed groundwater. The extent of acidic expressed groundwater appears limited to the area immediately upstream of the Fire Dams indicating that the geological conditions supporting pyritic formation is limited to this area.

The water chemistry of the expressed groundwater that has the potential to cause harm to the receiveing environment are salinity and pH. Post installation of the STMS all expressed groundwater captured in the Sump and in the Fire Dams has been pumped back to the RMA for discharge in accordance with the Environmental Authority (SPDE04134712). Uncontrolled releases to the receiving environment will occur only during significant rain events causing event flow. During these events salinity and pH of the release waters are expected to be of similar quality to the upstream waters entering the site.

9. Environmental Evaluation Notice Requirement 4 – Assessment of the Impacts

Site monitoring was undertaken to delineate, assess and monitor the environmental impacts of the saline groundwater expression on groundwater, surface water, topsoil and vegetation. The environmental values relevant to the site and receiving environment are presented in section 5.

Figure 1 presents a conceptual model for the site, delineating the areas demonstrating high, low and no impact from the expressed groundwater.

Fauna assessment has not be undertaken as:

- The timeframe of the environmental evaluation does not provide enough time to produce any meaningful data,
- The drainage features in the potentially impacted area do not have any interconnected waters, which means it is not possible to apply the either the ANZECC/ARMCANZ, 2000 or the AusRivas methodology.
- It is unlikely that terrestrial fauna would be impacted by overland flow from the site.

9.1 Groundwater Quality

9.1.1 Schedule and Methodology

Figure 5 illustrates the borehole locations selected for the on-going groundwater monitoring programme. Table 7 below outlines the groundwater monitoring schedule undertaken at the selected locations.

Table 7: Groundwater Monitoring Schedule

Locations	Testing Parameters	Frequency
ALD1, ALD2, BH31, BH32 and BH33	WL and field parameters (pH, Temp, DO, EC, Salinity and Turbidity)	Monthly
MB08 and MB09 installed June 2015[4]	Laboratory (dissolved. Al, V, Mo and Ga, major ions)	Quarterly

[4] At the time of reporting only one round of laboratory quantitative assessment and two rounds of qualitative sampling have been undertaken in the MB series boreholes.

The ALD series were installed long before the RMA was built with first monitoring undertaken in 1997. The BH series were installed in 2003 during initial construction and have been monitored as part of the RTA Yarwun Environmental Compliance series from this time forth. The MB series were installed in 2015 as part of the GHD investigation for the purpose of delineating and assessing the extent of the groundwater expression.

Prior to analytical sampling, purging was undertaken using Waterra tubing and pump. All boreholes were purged either three casing volumes or purged twice dry. In situ field physico-chemical parameters were measured using a calibrated YSI Pro DSS multi meter. Samples were collected in accordance with DERM guidelines, chilled in field before being couriered to the analytical ALS laboratories in Brisbane for testing. 2015 ALS test certificates are attached in Appendix E.

9.1.2 Results

Tables 1-7 in Appendix F present all available groundwater monitoring results form the monitoring of the bores since installment. Due to result consistancy over the 10 (BH series) to 18 (ALD series) years of monitoring only the assessable results for the initial and the 2015 laboratory monitoring rounds are presented below in Table 8.

Table 8 Assessable Laboratory Results for Groundwater Quality

	Physico-Chemical		Anions		Cations				Mass Ratios			Filtered Metals			
Date	**EC**	**pH**	**Cl**	**S**	**Ca**	**Mg**	**K**	**Na**	**Na:Cl**	**Mg:Cl**	**K:Cl**	**Al**	**Ga**	**Mo**	**Va**
Units	uS/cm		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L				mg/L	mg/L	mg/L	mg/L
NWQMS		**6.5-8.0**										**0.055**			
QWQG	*1500*	*6.5-8.0*													
RTAY		6.5 - 8.5	-	-	-	-	-	-	>0.9	<0.004	>0.02	>1	0.05	0.20	
ALD1A															
14/10/97	-	7.41	8150	1080	303	574	<1	4610	0.57	0.070	-	0.05	-	0.017	0.06
20/4/15	*30500*	7.08	10300	1530	310	882	5	5610	0.54	0.086	0.0005	0.02	<0.001	0.001	<0.01
21/7/15	*29500*	7.07	7140	1150	320	778	5	4960	0.69	0.109	0.0007	<0.01	<0.001	<0.001	<0.01
ALD2A															
14/10/97	-	-	11100	1260	545	815	30	6050	0.55	0.073	0.0027	<0.05	-	0.012	0.09
17/4/15	*27400*	7.27	8990	956	347	778	9	5130	0.57	0.087	0.0010	<0.01	<0.001	0.002	<0.01
21/7/15	*29500*	7.07	7110	1000	326	710	8	4590	0.65	0.100	0.0011	0.04	<0.002	0.002	<0.01
580BH31															
3/2/03	-	6.93	11200	985	242	869	16	-	-	0.078	0.0014	<0.05	<0.001	0.002	<0.05
17/4/15	*31500*	7.07	-	1040	263	806	-	5950	-	-	-	<0.01	<0.001	0.002	<0.01
21/7/15	*34300*	6.92	8260	1110	268	802	8	5940	0.72	0.097	0.0010	<0.01	<0.001	<0.001	<0.01
580BH32															
3/2/03	-	***8.06***	2360	179	76	174	13	1410	0.60	0.074	0.0055	0.025	-	0.024	<0.05
20/4/15	*16300*	7.46	5430	333	254	477	3	2830	0.52	0.088	0.0006	0.01	<0.001	<0.001	<0.01
21/7/15	*18200*	7.43	4330	361	265	469	2	2760	0.64	0.108	0.0005	<0.01	<0.001	<0.001	<0.01
580BH33															
1/2/03	-	7.52	8350	843	486	746	21	3940	0.47	0.089	0.0025	<0.05	<0.001	0.001	<0.05
21/7/15	*29000*	7.29	7050	1080	580	792	13	4520	0.64	0.112	0.0018	<0.01	<0.001	<0.001	<0.01
MB08															
21/7/15	*29800*	7.38	7120	931	268	659	3	5340	0.75	0.093	0.0004	0.03	<0.001	0.001	<0.001
MB09															
21/7/15	*17000*	7.2	4000	488	320	736	3	2030	0.51	0.184	0.0008	<0.01	<0.001	0.001	<0.001

9.1.2.1.1 *pH*

Laboratory pH measurements reflected field pH measurements. With the exception of 580BH32 (that recorded an initial pH value of 8.06) all monitoring bore pH measurements were within the guideline range for pH at all times during the monitoring period.

9.1.2.1.2 *Salinity*

Laboratory EC measurements reflected field EC measurements. EC was not included in the initial laboratory analysis, however initial major anion results (initial TDS concentrations presented in Appendix E) and ongoing monitoring indicate that the groundwater on site is saline and significantly above the QWQG value.

9.1.2.1.3 *Groundwater Chemistry*

The calculated mass ratios for all bores indicate that the groundwater is dominated by Na and Mg – Cl salts and contains only small concentrations of K – Cl salts. Dissolved metalloid concentrations were below the assessment values for all bores.

9.1.3 Assessment

Monitoring results are consistent with historical results and reconfirms that the site's groundwater is naturally saline and has a chemical signature which is significantly different from decant water. The site's groundwater is characterised by significant concentrations of Mg, very low concentrations of K and the absence of decant signature dissolved metalloids.

9.2 Surface Water

9.2.1 Schedule and Method

Surface water monitoring was undertaken in accordance with Table 9 below. Figure 4 illustrates the surface monitoring locations.

Table 9: Surface Water Monitoring Schedule

	Locations	Testing Parameters	Frequency
Event and Base Flow	Culvert, East Inlet, West Outlet and Lily Pond	Field parameters (pH, Temp, DO, EC, Salinity and Turbidity)	During periods of flow only
Standing Water	Sump and Lily Pond	Field parameters (pH, Temp, DO, EC, Salinity and Turbidity) Laboratory (dissolved. Al, V, Mo and Ga, major ions)	Twice Weekly Monthly
Additional Upstream/Down stream	Larcom Creek Hwy, Aldoga Road Larcom Creek U/S and D/S	Field parameters (pH, Temp, DO, EC, Salinity and Turbidity) Laboratory (dissolved. Al, V, Mo and Ga, major ions)	During periods of flow and monthly Monthly

In situ field physico-chemical parameters were measured using a calibrated YSI Pro DSS multi meter. Surface water samples were collected in accordance with the Australian and New Zealand Water Sampling Guidelines AS/NZS 5667.6:1998, guidance on sampling of rivers and streams. Samples

were collected in the appropriate containers and labelled, chilled in field before being couriered to ALS's analytical laboratories in Brisbane for testing under a Chain of Custody.

9.2.2 Results

9.2.2.1 Flow Monitoring

One event flow (22 January 2015) and one base flow (12 February 2015) were sampled throughout the monitoring period. Laboratory certificates attached in Appendix C with results tabulated in Appendix D.

Table 10 below presents assessable results verses the base flow WQOs for the Calliope River Basin (Lowland fresh <150m (s2)). The WQOs aim to protect the aquatic ecosystem environmental values for the Calliope River Basin.

Table 10 Laboratory Results for Event and Base Flow

Location	Date	pH	EC (µS/cm)	Turbidity (NTU)	SS (mg/L)	DO (% sat field)
WQO's		(6.5–8.0)		<50	<10	85-110
East Inlet (Event)	22/1/15	6.9	127	91.6	56	-
(Base flow)	12/2/15	7.9	1620	7.5	<5	78.4
West Outlet (Event)	22/1/15	6.9	330	92.2	33	-
(Base flow)	12/2/15	7.9	3020	4.8	<5	84.0
Lily Pond (Event)	22/1/15	6.9	351	92.3	41	-
(Base flow)	12/2/15	7.6	5290	3.8	<5	53.6

Results of the 22 January monitoring during the event (112.5mm) indicated that although suspended solids and turbidity were above their respective WQOs level there was no significant change between upstream and downstream levels. pH was with the WQO range at all locations. There is no WQO for EC however a slight rise in EC from 127 to 351µS/cm was observed as water passed through the site.

The 12 February base flow results for pH, Turbidity and TSS are within the objective range when compared to the WQOs. DO results for both the upstream East Inlet and the downstream Lily Pond were below the WQOs range while DO saturation for the West Outlet was within the WQOs DO range.There is no WQO for EC. During base flow conditions EC concentrations rose significantly from 1620 to 5290µS/cm as water passed through the site. To mitigate the significant rise in EC the STMS was designed to capture and pump back (to the RMA) both base flow and expressed saline groundwater from the site

9.2.3 Assessment

Neither event nor base flows through the site (i.e. Culvert to Lily Pond) have been experienced post installation of the STMS. Since construction of the STMS in late March, the three highest rainfall

totals recorded at the sites weather station have been 19.6mm (21-22 May), 16.8mm (17 June) and 16mm (25 June). These rainfall events did result in minor runoff onsite which led to higher pumping frequencies for the duration of the event and through the next 24 hours.

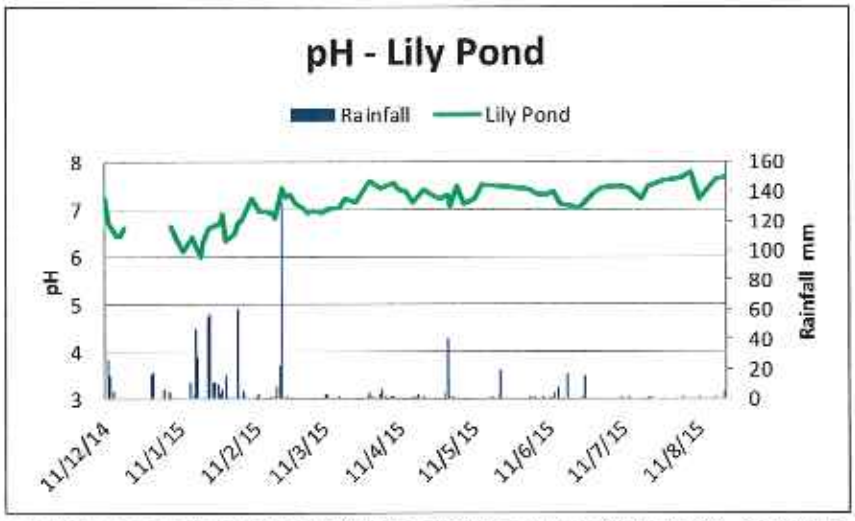
Ongoing monitoring of event and base flows over several wet seasons is required to better assess flow water quality against the WQOs and to assess the effectiveness of both the STMS and the LTMS.

9.2.3.1 Standing Water Monitoring

9.2.3.1.1 Lily Pond

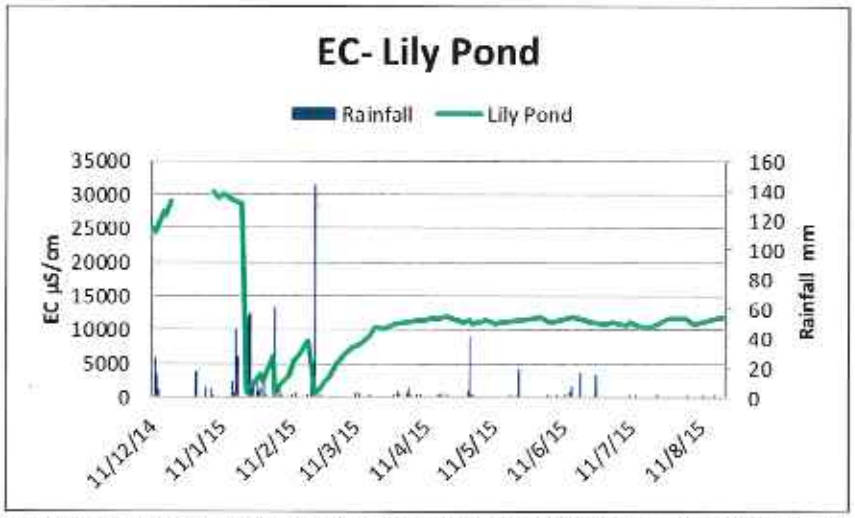
Twice weekly *in situ* monitoring was undertaken at the Lily Pond for field physico chemical parameters. Graph 4 and 5 illustrate pH and EC field monitoring results respectively.

Graph 4 pH monitoring Lily Pond



Field pH levels have generally fluctuated within the guideline values of 6.5 to 8.0. pH levels measured below 6.5 in December 2014 and January 2015 following significant rainfall events.

Graph 5 Electrical Conductivity monitoring Lily Pond



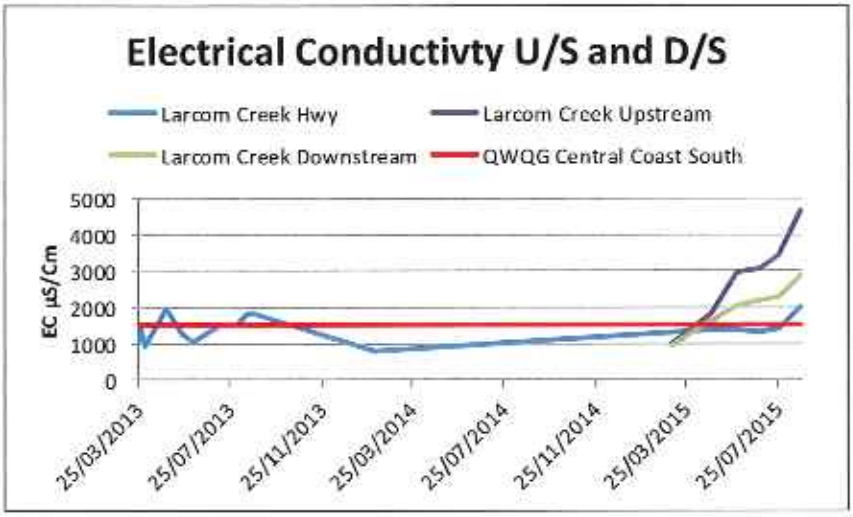
Only during significant rainfall events did EC measure below the QWQG value. EC concentrations have stabilised between 11,000 and 13,000µS/cm since the implementation of the STMS. Prior to the implementation of the STMS EC concentrations were measured as high as 30,000µS/cm.

9.2.3.1.2 ***Larcom Creek***

Monitoring of Larcom Creek Hwy has been undertaken for several years and historic EC results are presented herein for assessment. Larcom Creek Upstream and Larcom Creek Downstream monitoring locations are situated approximately 100m north and 200m south respectively from the sites drainage channel's confluence with Larcom Creek. Neither Larcom Creek nor the sites ephemeral drainage channel flowed during the reporting period.

Graphs 6 below illustrates measured EC for upstream and downstream monitoring locations.

Graph 6 Electrical Conductivity for Larcom Creek Upstream and Downstream



Electrical conductivity at Larcom Creek Hwy has fluctuated close to the guideline value with the highest historic measurement recorded 1956µS/cm on the 1/5/2013. Concentrations in EC for the upstream and downstream locations have risen over the 2015 dry season to above the QWQG value.

9.2.3.1.3 Laboratory Results Standing Water

Surface monitoring locations were sampled monthly for laboratory testing. Laboratory test certificates are presented in Appendix C. Appendix D presents the tabulated results for surface water.

Table 11 below presents assessable results of the monthly laboratory testing.

Table 11 Laboratory Results for Surface Water Monitoring Locations

	Physico-Chemical				Major Cations				Mass Ratios			Filtered Metals			
Date	pH	EC	Cl	S	Ca	Mg	Na	K	Na:Cl	Mg:Cl	K:Cl	Al	Ga	Mo	Va
Unit		µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L				mg/L	mg/L	mg/L	mg/L
NWQMS	6.5-8.0											0.055			
QWQG	*6.5-8.0*	*1500*													
RTAY	6.5 - 8.5								>0.9	<0.004	>0.02	1.000	0.05	0.20	
Lily Pond															
27/4/15	7.4	*12800*	4010	352	296	399	1690	8	0.421	0.100	0.002	<0.01	<0.001	<0.001	<0.01
31/5/15	7.6	*13100*	4150	428	339	566	1880	8	0.453	0.136	0.002	<0.01	<0.001	<0.001	<0.01
2/7/15	7.6	*12900*	4360	365	324	422	1710	7	0.392	0.097	0.002	<0.01	<0.001	<0.001	<0.01
27/7/15	7.6	*13300*	3780	403	350	470	1960	9	0.519	0.124	0.002	<0.01	<0.001	<0.001	<0.01
25/8/15	7.88	*14400*	3700	399	375	428	2010	9	0.543	0.116	0.002	<0.01	<0.001	<0.001	<0.01
Larcom Creek Hwy															
27/4/15	7.8	1350	212	8	75	60	125	2	0.590	0.283	0.009	<0.01	<0.001	<0.001	<0.01
31/5/15	7.8	1450	260	11	76	54	131	2	0.504	0.208	0.008	<0.01	<0.001	<0.001	<0.01
2/7/15	7.9	1470	295	10	78	57	140	2	0.475	0.193	0.007	<0.01	<0.001	<0.001	<0.01
27/7/15	7.7	*1540*	239	12	87	68	157	2	0.657	0.285	0.008	<0.01	<0.001	<0.001	<0.01
25/8/15	7.91	*1540*	223	16	90	68	148	2	0.664	0.305	0.009	<0.01	<0.001	<0.001	<0.01
Larcom Creek U/S															
27/4/15	7.79	*2090*	441	34	83	88	278	2	0.630	0.200	0.005	<0.01	<0.001	<0.001	<0.01
31/5/15	7.79	*3320*	736	103	100	107	405	2	0.550	0.145	0.003	<0.01	<0.001	<0.001	<0.01
2/7/15	7.88	*3570*	879	71	111	105	466	2	0.530	0.119	0.002	<0.01	<0.001	<0.001	<0.01
27/7/15	7.9	*4060*	845	140	129	133	525	2	0.621	0.157	0.002	<0.01	<0.001	<0.001	<0.01
25/8/15	***8.02***	*4660*	876	145	153	162	625	2	0.713	0.185	0.002	<0.01	<0.001	<0.001	<0.01
Larcom Creek D/S															
27/4/15	7.91	*1860*	389	28	68	67	247	2	0.635	0.172	0.005	<0.01	<0.001	<0.001	<0.01
31/5/15	***8.38***	*2180*	480	49	63	68	261	2	0.544	0.142	0.004	<0.01	<0.001	<0.001	<0.01
2/7/15	***8.16***	*2480*	592	48	79	73	315	2	0.532	0.123	0.003	<0.01	<0.001	<0.001	<0.01
27/7/15	***8.11***	*2610*	540	58	90	89	357	2	0.661	0.165	0.004	<0.01	<0.001	<0.001	<0.01
25/8/15	***8.39***	*2870*	545	58	93	102	404	3	0.741	0.187	0.006	<0.01	<0.001	<0.001	<0.01

9.2.3.1.4 *pH*

Laboratory pH measurements reflected field pH measurements. pH values were generally within the QWQG range of 6.5-8.0 at all locations throughout the monitoring period. The only exceptions were Larcom Creek downstream (May through to August) and Larcom Creek upstream (August only) where pH values slightly above 8.0 were recorded during these times.

9.2.3.1.5 *Salinity*

Laboratory EC measurements reflected field EC measurements. EC concentrations rose throughout the monitoring period to above the QWQG value in all locations.

Comparing EC concentrations for the Lily Pond and TP3 (situated approximately 100m to the south of the Lily Pond) suggests that they are connected. TP3's shallow aquifer at 1.8m below ground level measured EC concentrations of 16,000µS/cm, only 3,000 to 4,000 µS/cm higher than the Lily Pond's EC concentration during the dry season.

9.2.3.1.6 *Surface Water Chemistry*

The mass ratios of Na:Cl; Mg:Cl and K:Cl for the standing water bodies are consistent with the ratios observed in the groundwater monitoring bores in close vicinity to them. Analysis of the standing water bodies shows significant concentrations of both Mg – Cl salts and very low concentrations of K – Cl salts. The ratios are significantly different to RMA decant water that contains very low concentrations of Mg – Cl salts but relatively high concentration of K – Cl salts.

Dissolved metalloid concentrations were below the limit of reporting for all locations throughout the monitoring period.

9.2.4 Assessment

Ongoing monitoring over the 2015/2016 wet season will continue to assess if the marginally high pH values at Larcom Creek downstream is seasonal (algae the likely cause). The marginally low pH values recorded during rainfall events are expected in upper catchment runoff as pH of pure rain is naturally below 6.0 (EPA, 2004).

Major ion analysis indicates that the standing water bodies are connected with the shallow groundwater which is naturally saline. Standing water chemical signature ratios are consistent with the groundwater signatures and are significantly different to decant water signatures.

Results indicate the increases in EC concentrations in standing water bodies over the 2015 dry season is normal (most likely seasonal) and is caused by both evaporation and the direct recharge by the shallow groundwater.

9.3 Vegetation

9.3.1 Schedule and Methodology

Twelve vegetation transects (VT) were seleceted between the site and Lacorm Creek and surveyed quarterly over the monitoring period. Figure 6 illustrates the locations of the 12 transects. The line intercept method was chosen to assess and monitor groundcover and while plot transects were chosen to assess and monitor tree health.

Where possible transects were situated so that:

- the transect ran perpendicular to the contour;

- when within the site, approximately half of the transect was positioned inside the current impacted areas and half outside;
- when downstream of the site (and where non visible impact is visible) the transect was positioned so that the ephemeral drainage drain is intercepted. So if a change occurs in the future the transect will capture the transition; and
- there were greater than 20 trees present per transect.

Quarterly surveys of the transects consisted of;

- Line intercept method for recording percentage ground cover - starting at the 0m peg moving down the tape record the vegetation cover at each 1m intercept. The categories of grass, dead grass, water, herbs, dead herbs, rock and bare earth were recorded. For the purposes of assessment the indicator cover types are grass, bare earth and litter cover.
- Plot transects for determining tree health - starting at the left hand side at the 0m peg. The plot is divided into subplots that are 10m long and 5m wide. The categories consisted of shrubs less than 1m in height and small (diameter <10cm), medium (diameter 10-30cm), large (diameter <30-50cm) and very large (diameter >50cm) trees. For the purposes of assessment only common names and/or family names are used.

9.3.2 Transect Rational and Description

Table 12 below summarises the rational and quarterly descriptions of the surveyed vegetation transects.

Table 12 Vegetation Transect Rational and Quarterly Descriptions

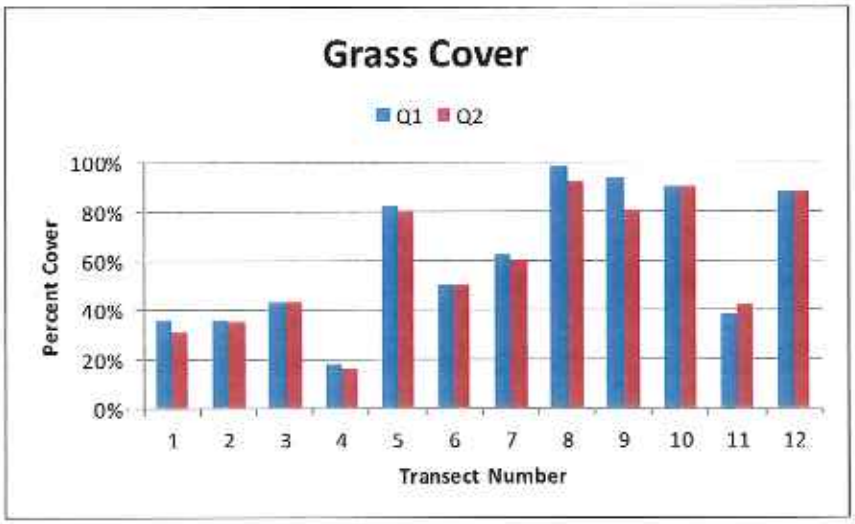
	Length	Bearing	Rationale	1st Quarter Description	2nd Quarter Description
1	100	260	To assess the extent/advancement of groundwater expression outside of the STMS and rehabilitation post LTMS.	Located within the site however no mitigation works could be undertaken in this area due to the Jemena and GAWB infrastructure corridors. Beginning in the centre of the drainage channel the transect bears west past ALD1. Extent of salt scalding is extreme for approximately 75m before a rise in ground level delineates the limit of the saline groundwater expression.	Salt scald observed in new areas of dead grass.
2	100	48	To assess the extent/advancement of groundwater expression, effectiveness of the STMS, rehabilitation post LTMS.	Located within the site. Transect beginning on the western side of the excavated southern drain bears east through the STMS to terminate on higher ground presently unaffected by salt scald.	Grass brown due to the dry/cold winter conditions.
3	100	266	To assess the extent/advancement of groundwater expression, effectiveness of the STMS drainage system and long term rehabilitation.	Located within the site. Transect bears west following the old farmer's fence through the confluence of the excavated east, south and west drains. Salt scalding is extreme for approximately the first 60m before a rise in ground level delineates the limit the saline groundwater expression.	No change
4	50	144	To assess the extent/advancement of groundwater expression, the effectiveness of the STMS, sand blanket system and rehabilitation post LTMS.	Located within the site and bearing south through the eastern drain. Extreme salt scalding for approximately the first 30m before a rise in ground level delineates the limit the saline groundwater expression.	No change
5	50	360	To assess the extent/advancement of groundwater expression, the effectiveness of the installed cut off trench and rehabilitation post LTMS.	Located north-east of the site. Starting at the head of the cut off trench the transect bears north through the upstream ephemeral drainage channel.	No change
6	100	28	To assess the extent/advancement of groundwater expression in the north of the STMS, the effectiveness of the STMS in the southern section of the transect and	Approximately, 2/3 of this transect is located within the site while the remaining 1/3 is located to the north in the impacted area with no mitigation work undertaken. Transect bears north over the farmers track to the northern impacted area. Salt scalding present both south and north of	No change

	Length	Bearing	Rationale	1st Quarter Description	2nd Quarter Description
			rehabilitation post LTMS.	the farmers track	
7	100	312	To assess the extent/advancement of groundwater expression and rehabilitation post LTMS.	Starting to the north of ephemeral drainage channel in the northern impacted area. Salt scalding is extreme for approximately the first 40m. The vegetation for the remaining 60m has been recently effected by fire, and all of the small to medium trees listed as dead in section of the transect can be attributed to fire and not saline groundwater expression.	No change
8	50	30	To assess the extent/advancement of groundwater expression downstream.	Ephemeral drainage channel north-west of site, south of Lily Pond. No evidence of salt scalding from saline groundwater expression, however overland flows with significant EC concentrations have occurred prior to the STMS.	Feral pigs rooting along transect.
9	100	71	To assess the extent/advancement of groundwater expression downstream.	Ephemeral drainage channel at BH33. No evidence of salt scalding from saline groundwater expression or overland flow.	Grass brown due to the dry/cold winter conditions.
10	100	344	To assess the extent/advancement of groundwater expression downstream.	Ephemeral drainage channel between BH33 and ALD2. No evidence of salt scalding from saline groundwater expression or overland flow.	No change
11	50	180	To assess the extent/advancement of groundwater expression downstream.	Ephemeral drainage channel at ALD2. No evidence of salt scalding from saline groundwater expression or overland flow.	No change
12	50	145	To assess the extent/advancement of groundwater expression downstream.	Ephemeral drainage channel at Larcom Creek downstream surface water quality monitoring location. No evidence of salt scalding from saline groundwater expression or overland flow.	No change

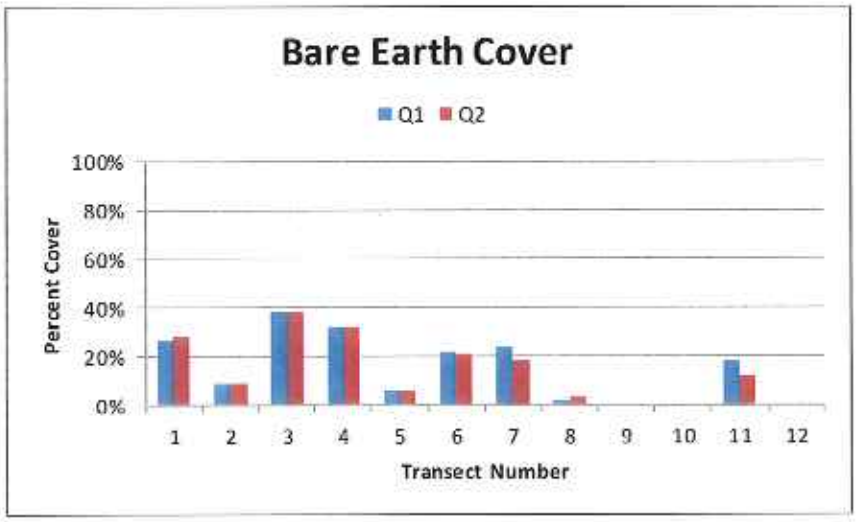
9.3.3 Results

Results for indicator groundcover types are illustrated in Graphs 7-9.

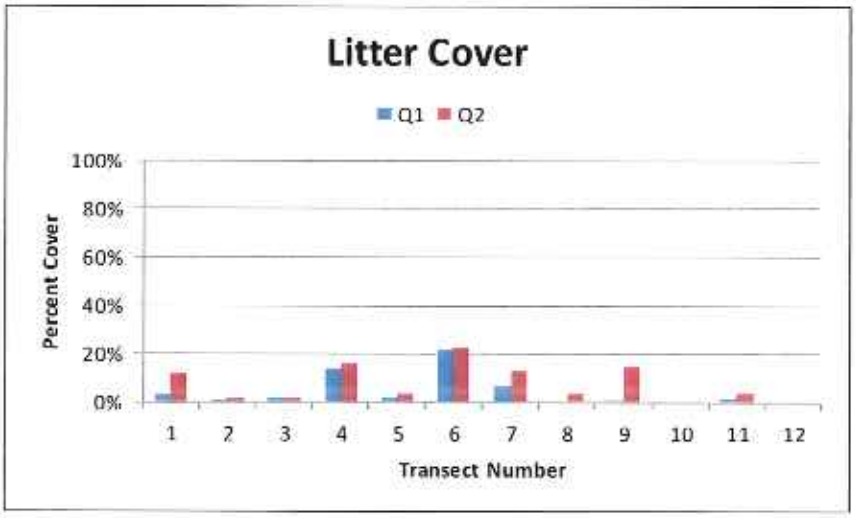
Graph 7 Percentage Grass Cover



Graph 8 Bare Earth Cover



Graph 9 Litter Cover



Between Q1 and Q2 grass cover has decreased in 7 of the 12 transects, however only the VT1 decrease was attributed to the expressed saline groundwater. VT1 is outside the STMS and grass cover die back is continuing in this low lying area (Plate 1).

The dry season is the likely cause of grass cover decreases in VT's 2, 4, 5, 7 and 9 (Plates 2 and 3) while the 6% decrease in grass cover recorded at VT8 was caused by feral pig activity (Plate 4).



Plate 1 – Dead grass at VT1 attributed to the expressed saline groundwater



Plate 2 – VT2 showing dead grass attributed to the dry season



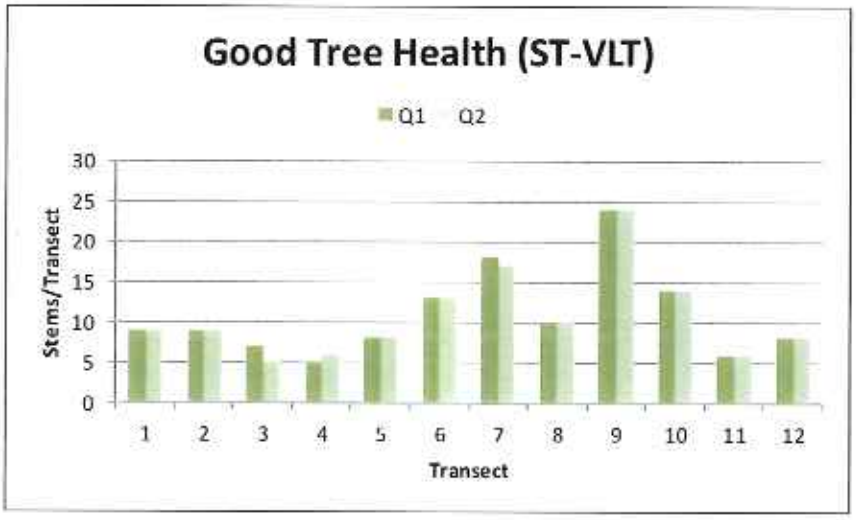
Plate 3 –. VT9 showing dead grass attributed to the dry season



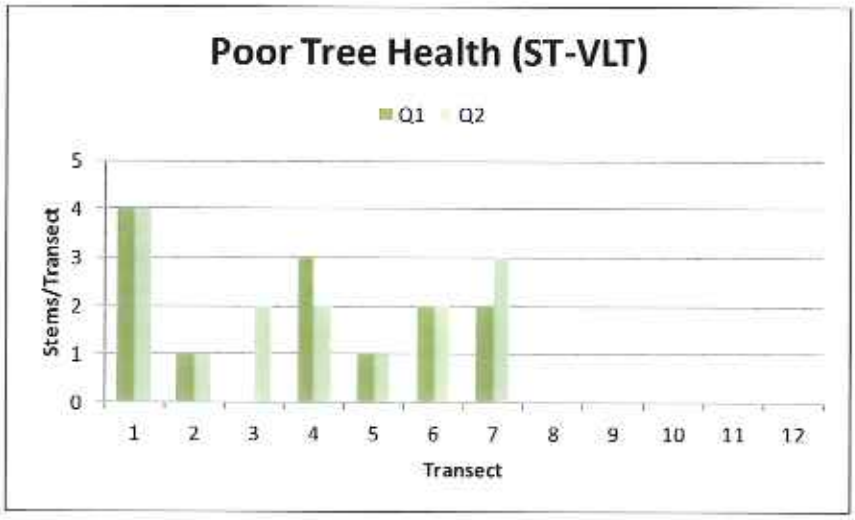
Plate 4 – Increased bare ground at VT 8 caused by feral pigs

The results for vegetation health are illustrated in Graph 10-12.

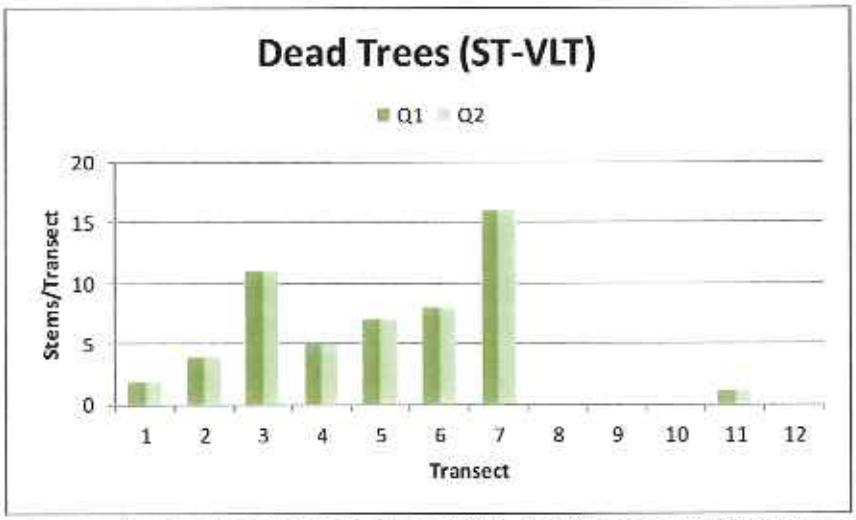
Graph 10 Good Tree Health



Graph 11 Poor Tree Health



Graph 12 Dead Trees



Tree health has remained unchanged in nine of the 12 VT. VT3 (2 trees) and VT7 (1 tree) indicate degenerating tree health while VT4 (1 tree) indicates improving tree health.

9.3.4 Assessment

Both groundcover and tree vegetation within and close to the site are being impacted by the expressed saline groundwater. The cover decreases attributed to the dry season are expected to increase back to original cover percentages in all transects (with the exception VT1) during the 2015/2016 wet season.

To date insuffiecent data has been collected to assess the effectiveness of STMS as both quarterly monitoring events occurred within the 2015 dry season. Ongoing monitoring over several wet seasons is required to monitor the effectiveness of the STMS, the future LTMS and site rehabilitation.

9.4 Soils

9.4.1 Methodology and Schedule

Eight topsoil samples (TSS) located at the vegetation transect 0m pegs were sampled quarterly for laboratory testing. Figure 7 illustrates the topsoil monitoring locations. Sediment sampling was not undertaken as the site and potentially impacted area (between the Lilly Pond and Larcom Creek) did not have connected waters and is ostensibly a flood plain feature. Any impact from the overland flow of contaminated waters from the site would be visible within the soil samples taken from within the flow path of water along the flood plain.

The sampling method comprised of the mixing of three small (approximately 50 grams) topsoil samples within a 1m square plot around the peg. The composite sample was zip locked in a labelled plastic bag, chilled in field before being couriered to ALS's analytical laboratories in Brisbane for testing.

Table 13 presents the topsoil monitoring schedule.

Table 13: Soil Monitoring Schedule

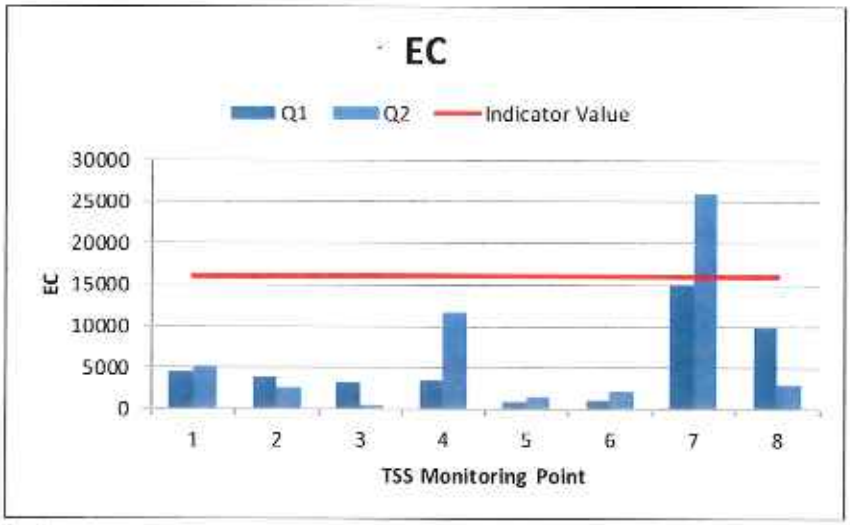
Locations	Testing Parameters	Frequency
TSS 1 – TSS 8	pH, EC, SAR	Quarterly

The topsoil samples were tested qualitatively for pH, EC using the 1:5 soil water paste method and quantitatively tested for the cations; Na, Ca and Mg for the calculation of the Sodium Absorption Ratio (SAR). The average root zone salinity (EC_{se}) was calculated by using the EC (1:5) and a 0.2 leaching fraction for heavy clays.

9.4.2 Results

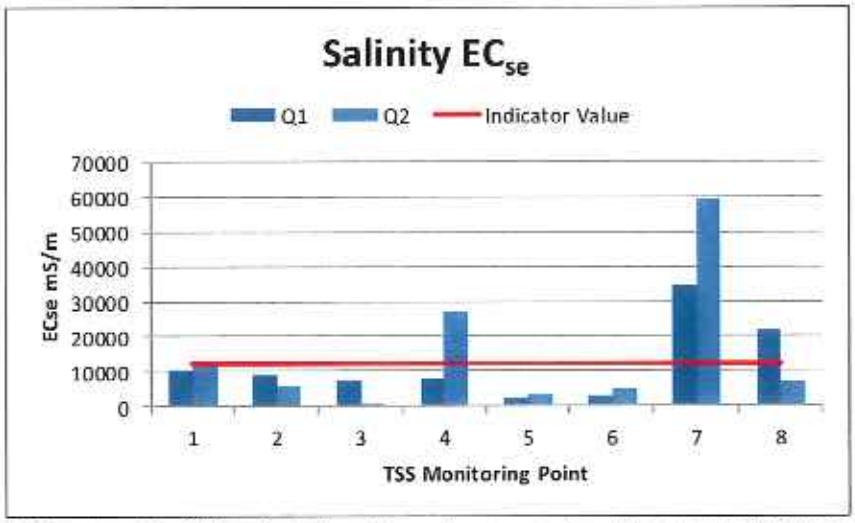
Laboratory test certificates and COC records are presented in Appendix G. Appendix H presents the results of the soil monitoring. Graphs 13 to 16 below illustrate the pH, EC, EC_{se} and SAR results respectively.

Graph 13 Calculated Salinity EC



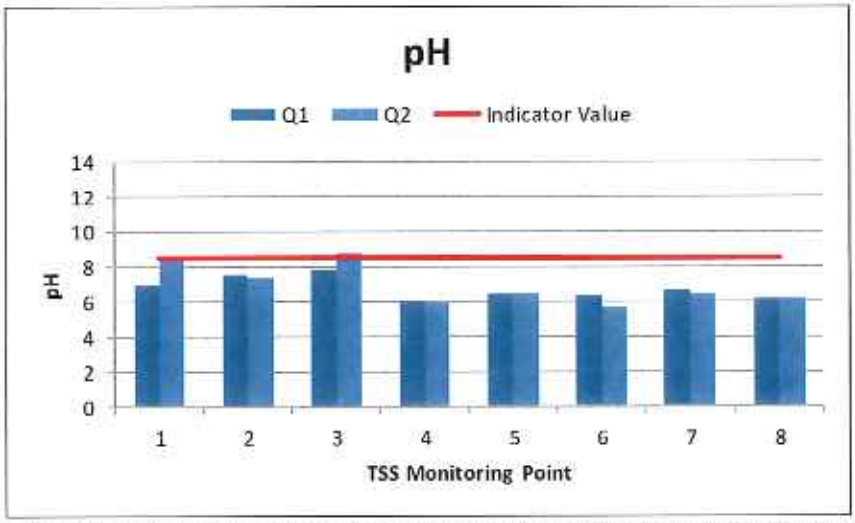
EC values indicate the sites topsoil is saline (>2000µS/cm) with only TSS7 measuring extreme levels of salinity.

Graph 14 Calculated Salinity EC_{se}



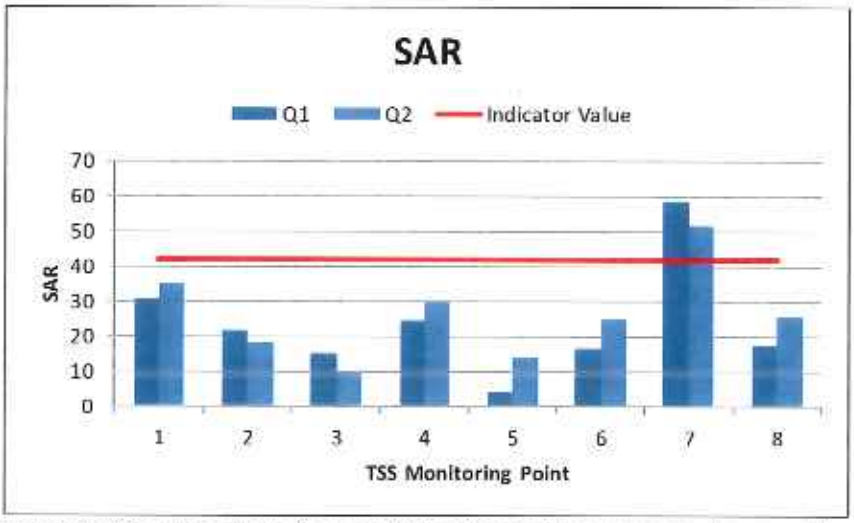
Calculated EC_{se} values for TSS 1, 2, 4, 7 and 8 are close to or above the extreme indicator value average root zone salinity. Significant decreases in ECse values can be observed at monitoring points 2, 3 and 8 between Q1 and Q2 monitoring.

Graph 15 Topsoil pH



The pH results indicate that the topsoil's at TSS 1-3 are neutral to slightly alkaline with pH ranging 6.9-8.7. The remaining monitoring points show slightly acidic soil with pH values ranging from 5.6-6.6.

Graph 16 Sodium Absorption Ratio



Only TSS7 recorded SAR values above the high SAR indicator value. However, because the topsoil's are saline, SAR values are of little assessment value (ANZECC/ARMCANZ, 2000).

9.4.3 Assessment

The sites topsoil's are saline and are very to extremely saline in areas around TSS4 and TSS7 respectively. Calculated EC_{se} values for TSS 1, 2, 4, 7 and 8 indicate high to extreme average root zone salinity in these areas. These results suggest that growth of even salt tolerant vegetation will be limited by salinity in the sites topsoil. Vegetation monitoring at these TSS locations is consistent with the salinity assessment with the absence of vegetation at TSS1, 2, 4, 7 and 8.

pH results indicate that topsoil in the centre of site (historic swamp area) is alkaline, indicating potential sodic soils. Although SAR results cannot be accurately assessed due to the salinity levels it is expected that leaching during subsequent wet seasons (and future applications of gypsum if required in sodic areas) will lower Na concentrations sufficiently to allow for SAR assessment and plant growth.

Ongoing monitoring over several wet seasons is required to monitor the effectiveness of the STMS, LTMS and rehabilitation of the sites soils.

10. Environmental Evaluation Notice Requirement 5 – Environmental Evaluation Assessment Criteria

The DEHP Notice Requirement 5 – *Assessments must be carried out in accordance with the* Australian and New Zealand Guidelines for Marine Water Quality (2000) and AusRivas methodology.

The area immediately north-west of the potentially impacted area does not contain any water courses that could be considered ephemeral streams. There is an undefined drainage path through the flood plain area which allows water to flow into Larcom Creek, approximately 2km north west of the impacted site, during high, sustained rainfall events. However, for the majority of the year the area is dry, with some standing water present in unconnected depressions. While Ausrivas approaches can be used to describe the responses of macroinvertebrate communities in temporary streams (Boulton, 2003), this area could not be classified as a temporary/ephemeral stream and therefore these

methodologies are not applicable. Even if there was a temporary stream in this area, Boulton (2003) stressed that long-term data collection (years) is required in temporary stream health assessment. Only if long-term data collection and analyses of temporary streams is performed at a range of spatial and temporal scales, can a certain degree of confidence be established regarding the normal (or 'healthy') range of variation that occurs within the system.

Larcom Creek would be described as a temporary/ephemeral creek but the risk of stressors/contaminants from the potentially impacted area being transported to Larcom Creek at concentrations that would result in an impact would be very low, given the area would need high, sustained rainfall for any substantive flow from the site to Larcom Creek to occur. Any high, sustained rainfall event would also cause event flows in Larcom Creek. In addition even if there is an expectation of applying an Ausrivas methodology to Larcom Creek it would require many years of data as described above.

RTAY have assessed the area between the impacted area and Larcom Creek based on terrestrial assessment criteria as presented in section 9 of this report.

11. Environmental Evaluation Notice Requirement 6 – Remediation Options

GHD, 2015C have outlined and detailed two remediation options for the site (Appendix A). The GHD report addresses the DEHP Notice Requirement 6 – *Determine and report on all available remediation options, including costs, and detail remedial works required to prevent contaminated water being discharged to the receiving environment. Remediation must ensure protection of the environmental values of the receiving environment.*

12. Environmental Evaluation Notice Requirement 7 – Preferred Remedial Option

DEHP Notice Requirement 7 – *Nominate a preferred solution and provide a timetable for the implementation of the necessary remedial works.*

Option 1 of the GHD, 2015C report is the RTA Yarwun preferred option for the site. Rio Tinto uses a standard methodology for execution of all capital projects. The preferred remediation option will be executed as per this standard methodology which comprises six project Stages, after the definition of the problem (whih this report provides). These project Stages are illustrated below.



A detailed schedule has not been approved by the executive Committee for the commencement of the project as the project scope was unknown prior to the finalisation of the 2016 RioTinto capital cycle. The process of assessing a deveation to the 2016 RioTinto capital to include this project plan is currently underway. Table 14 below presents the anticipated costs associated with preferred option.

Table 14 Preferred Option Indicative Costs

Item	Contractor	Anticipated Costs
RTA Yarwum Project Management	RTA	$185,000
Further Investigations and Modelling	GHD	$150,000
Depressurisation System Design	GHD	$170,000
Drilling Contractor	TBA	$150,000
Pilling Contractor	TBA	$400,000
Manifold and Pump Setup	TBA	$740,000
Collection Trench and Sump	TBA	$190,000
Ongoing Laboratory Monitoring	ALS	$25,000
Total		**$2,070,000**

13. References

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Brown, P. 2014. Groundwater seepage at the RTA Yarwun RMA. Report to RTA Yarwun, 9 October 2014

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RTA Yarwun, 2015, Short Term Mitigation Strategy. Principles of design, operations strategies and monitoring plan for the short term mitigation strategy, Yarwun RMA, RioTinto, Report 20150330. March 2015

GHD,2015A. Detailing of Groundwater Management Actions Spatial Analysis of Groundwater Pressurisation of the Northern Embankment and Development of Sampling and Analysis Plan, February 2015

GHD, 2015B RTA Yarwun Groundwater Management - Low pH Water Investigation Memo, June 2015

GHD, 2015C, RMA Groundwater Management Actions, Groundwater Conceptualisation and Management Options, September 2015

GHD, 2015B. RTA Yarwun Groundwater Management, Low pH Water Investigation, April 2015

EPA, 089/2004. Acid Rain – Why is it a concern, Government of South Australia, March 2004

DEHP, 2009A. Environmental Protection (Water) Policy 2009 Curtis Island, Calliope River and Boyne River Basins, Environmental Values and Water Quality Objectives, November, 2014

DEHP, 2009B. Queensland Water Quality Guideline, Version 3 ISBN 978-0-9806986-0-2, July 2013

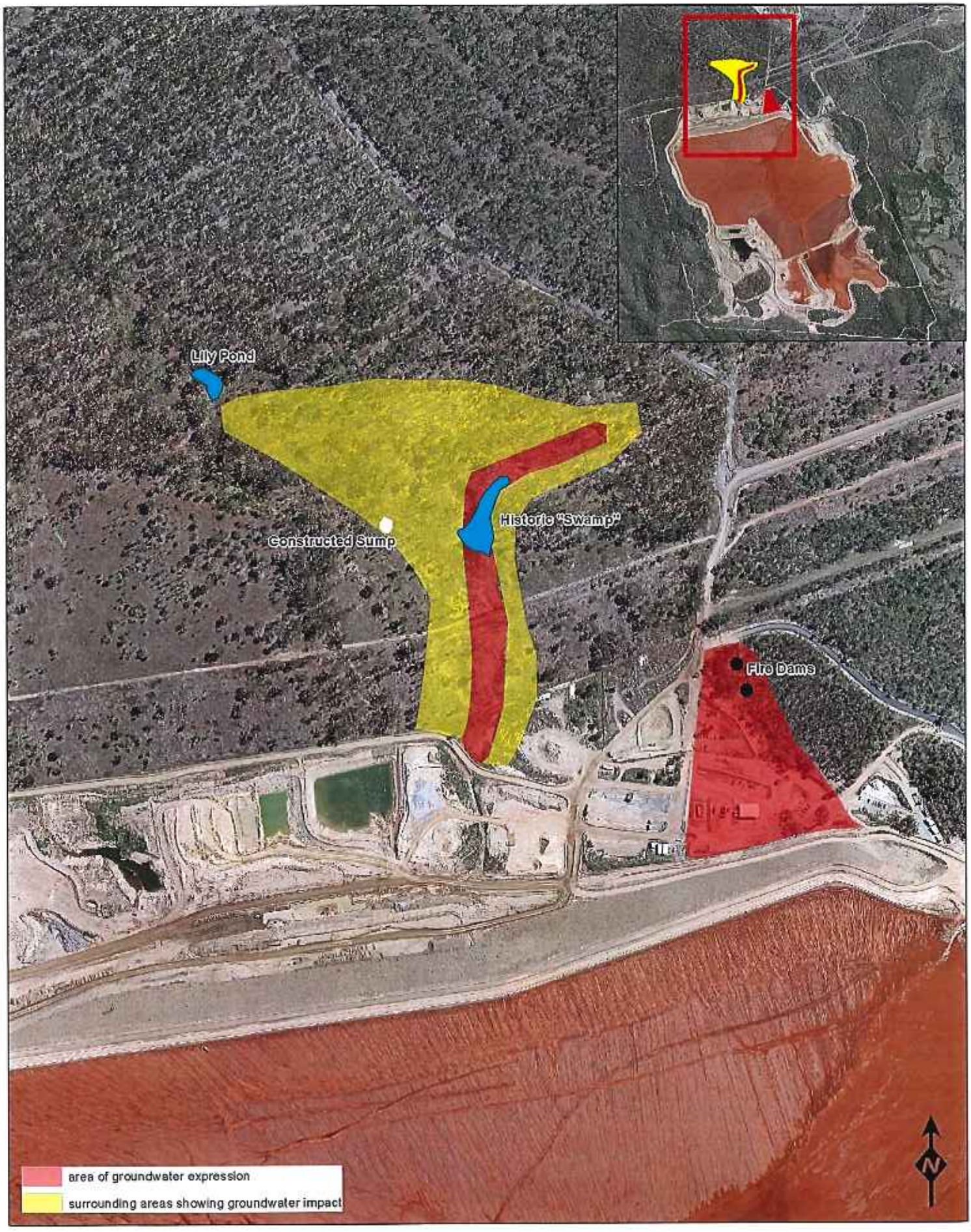
CSIRO, 2003.Land and Water Assessment of physico-chemical changes in dryland saline soils when drained or disturbed for developing management options, Technical Report 2/03, January 2003DEC, 2009. Western Australian Department of Environment and Conservation's, Standard Operating Procedure for Establishing Vegetation Transects, Version 1.0 (June 2009)

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FIGURES

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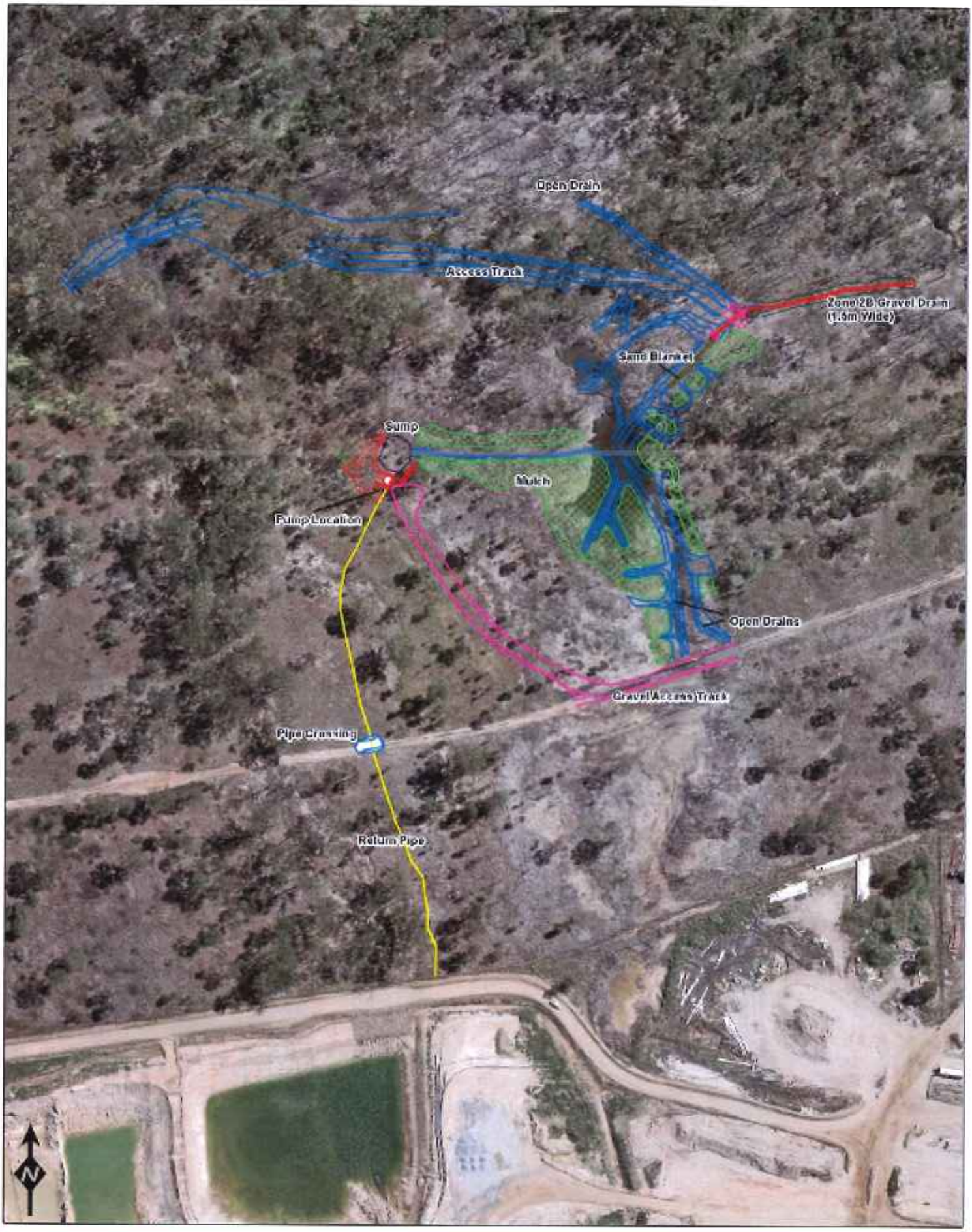
0 25 0 50 100 150
Meters

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994 Grid: MGA Zone 50
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Figure 1- Site Area Showing Region of Groundwater Impact RTA Yarwun RMA - Environmental Evaluation

Map ID: 0111-20151012 - Site Area Showing Region of Groundwater Impact RTA Yarwun RMA-environmental evaluation
Created By: A Cox
Date Issued: 12 Oct 2015

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Figure 2- Northern Drainage Remedial Work
RTA Yarwun RMA - Environmental Evaluation

Map ID: 0110-20150917 - Northern Drainage Remedial Work RTA Yarwun RMA-environmental evaluation
Created By: A Cox
Date Issued: 17 Sep 2015



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Figure 3 - Southern RMA Groundwater Bore Locations
RTA Yarwun RMA - Environmental Evaluation

Map ID: 0114-20150921 - Southern RMA Groundwater Bore Locations RTA Yarwun RMA environmental evaluation
Created By: A Dai
Date Issued: 21 Sep 2015

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110 55 0 110 220 330
Meters

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Figure 4 - Surface Water Locations
RTA Yarwun RMA - Environmental Evaluation

Map ID: 0113-20150921 -Surface Water Locations RTA Yarwun RMA-environmental evaluation
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0 0.5 1 1.5 2
(Miles)

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994 Grid: MGA Zone 50
Image: [illegible]

Figure 5- Site Groundwater Bore Locations
RTA Yarwun RMA - Environmental Evaluation

groundwater bores

Map ID: 0108-20150917 - Site Groundwater bore locations RTA Yarwun RMA environmental evaluation
Created By: A Cox
Date Issued: 17 Sep 2015

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30 15 0 30 60 90
Meters

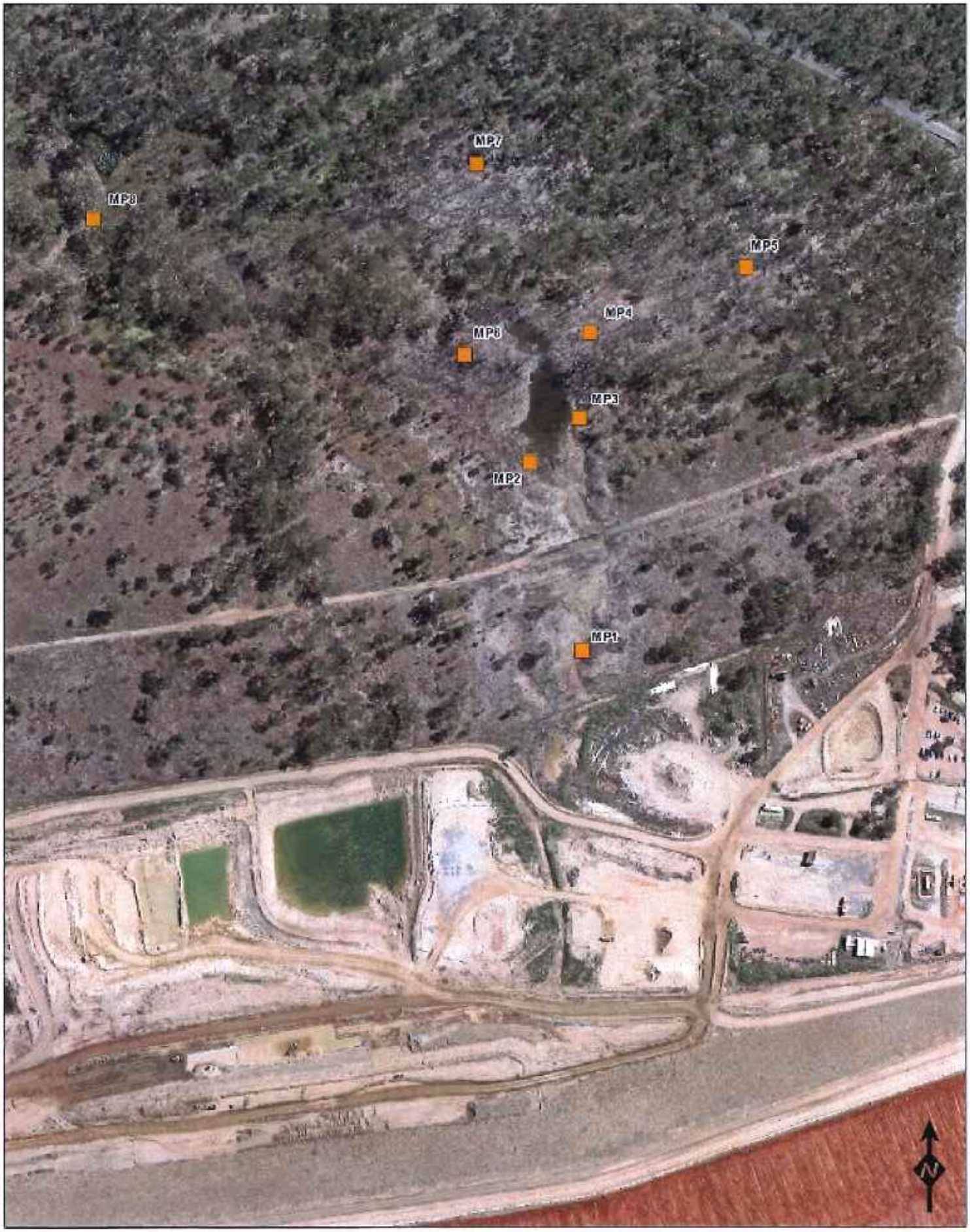
Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994 Grid: MGA Zone 56
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Figure 6 - Vegetation Transect Locations
RTA Yarwun RMA - Environmental Evaluation

Map ID: 0115-20150921 -Vegetation Transect Locations RTA Yarwun RMA-environmental evaluation
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Figure 7 - Topsoil Sample Locations
RTA Yarwun RMA - Environmental Evaluation

Map ID: 0112-20150921 -Topsoil Sample Locations t RTA Yarwun RMA-environmental evaluation
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APPENDICES

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Appendix A– GHD SAP and GW Management Report

Rio Tinto Aluminium Yarwun

Detailing of Groundwater Management Actions

Spatial Analysis of Groundwater Pressurisation of the Northern Embankment and Development of Sampling and Analysis Plan

February 2015

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Appendix A – Northern Embankment Investigation and Monitoring Location Plans

Appendix B – Data Analysis & Time Series Groundwater Elevations

Appendix C –Typical Bore Construction Details/Specification

Appendix D – SAP Proposed Investigation Locations Plan and Summary Table

1. Introduction

GHD Pty Ltd (GHD) was commissioned by Rio Tinto Alcan Yarwun (RTAY) under Contract Number CW2081249 to assist with the development of an improved groundwater management system for the Yarwun Residue Management Area (RMA) site (herein referred to as the site).

The purpose of this commission is to assist RTAY in the characterisation and conceptualisation of groundwater mounding to enable a plan to be developed to alleviate the observed pressurised groundwater and to investigate low pH waters within a fire water dam at the RMA. To achieve this, the work has been divided into three tasks as follows:

- Task 1 – Spatial analysis of groundwater pressurisation and development of field investigations
- Task 2 – Concept design of management options to alleviate pressurisation of the Northern Embankment and off-site downstream of the RMA
- Task 3 – Assessment of low-pH water in the Firewater Dam.

This report details Task 1. The outcome of Task 1 is the development of a Sampling and Analysis Plan (SAP, Section 3 onwards), which is to be implemented by RTAY in order to collect additional data in support of completion of Task 2 and Task 3.

1.1 Background

The Rio Tinto Alcan Yarwun (RTAY) alumina Refinery in Gladstone utilise a Residue Management Area (RMA) to store bauxite residue as a by-product of their refining operations. The site is located approximately 11 km west of the refinery and approximately 5 km south west of Yarwun. It occupies a natural valley that trends approximately south – north and is bounded by ridge lines to the east and west. The southern boundary and part of the eastern and western extents of the RMA are bounded by natural watersheds with constructed earth and rock-fill embankments and at the northern boundary, by the main Northern Embankment.

The northern embankment contains a drainage blanket, constructed below the downstream shoulder of the embankment and extends beyond the embankment toe. Pumps are used to extract water from two sumps intercepting the drainage blanket which is discharged back into the RMA, as part of the management of pore water pressures in the drainage blanket. Groundwater seepage was first noted in the vicinity of the western toe in 2008. Pressurised groundwater beneath the drainage blanket was relieved in this area by the installation of a series of pressure relief bores in 2011. Groundwater investigations (pre-construction and during operation) have also ascertained that the natural underlying groundwater is highly saline and in the vicinity of the toe is not associated or impacted with decant seepage from the RMA.

In 2013, surface water ponding and dead vegetation was then observed by RTAY adjacent to and north of the northern boundary of the RMA with salt scalding and additional seepage areas further identified, including within the north and north western areas of the RMA down gradient of the main embankment.

Recent studies undertaken by RTAY in 2014 identified that the low lying area located downgradient and adjacent to RMA northern embankment has been impacted by salinity and is considered to be associated with the progressive mounding of underlying naturally saline groundwater within the foundation materials beneath the RMA. Low pH waters were also identified within a firewater dam present to the northeast of the RMA that also requires further investigation. This receives possible seepage from subsurface fracture flow and/or surface water from the adjacent hillside and eastern end of the northern embankment. Desktop studies,

including inspections and groundwater and surface water sampling and analysis also provided further confirmation using chemical signatures of the disconnect between the RMA decant compared to ponded surface waters, fire dam waters and groundwater.

As part of the previous RTAY studies, a number of recommendations in relation to monitoring of the RMA embankments and the observed seepage were presented, including but not limited to the following:

- The spatial extent of groundwater pressurisation needs to be ascertained
- Alleviation of groundwater mounding
- Need to maintain monitoring network accessibility and continuity
- The low pH waters in the fire dam likely due to precipitation of iron hydroxide, groundwater required to be tested along with dam waters
- Relationship of groundwater in the area to north of RMA boundary with that to east needs to be clarified.

1.2 Purpose of this report

The purpose of this report is to provide RTAY with a SAP to provide information in support of completion of Task 2 (concept design of management options to alleviate pressurisation of the Northern Embankment and off-site downstream of the RMA) and Task 3 (assessment of low-pH water in the Firewater Dam).

1.3 Scope and limitations

As per Section 4.3(a)(i) and 4.3(a)(ii) of the RTAY Contract for Consultancy Services document, the Task 1 scope of work, as detailed in GHD's *Request for Tender* submission (Contract number WS 441745638), is for the following:

- Literature and data review and summary, including a gap analysis
- Spatial analysis of groundwater pressurisation at the RMA
- Complete a site investigation location plan, including:
  - Identification of existing bores that require inspection to determine suitability for on-going monitoring.
  - Location of new bores, test pits and surface water monitoring points.
- Provide investigation specifications including:
  - Investigation location target strata and depths,
  - Soils and surface water sampling requirements (frequency of sampling)
  - Bore construction, development, sampling and aquifer testing requirements
  - Water level instrumentation installation and monitoring requirements,
  - Laboratory analytical schedule, monitoring program (frequency),
  - Remediation of boreholes and handling of water / soil samples during the monitoring process.
- Recommendations for on-going monitoring, any required future works and remediation.

Environmental impacts related to saline groundwater, groundwater level changes, and assessment of these impacts (i.e. soil, water, ecological, human health, and receiving environment) are outside the scope of this report.

This report 'Detailing of Groundwater Management Actions, Spatial Analysis of Groundwater Pressurisation of the Northern Embankment and Development of Sampling and Analysis Plan' has been prepared by GHD for Rio Tinto Aluminium Yarwun and may only be used and relied on by Rio Tinto Aluminium Yarwun for the purpose agreed between GHD and the Rio Tinto Aluminium Yarwun as set out in Section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than Rio Tinto Aluminium Yarwun arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described throughout this report. GHD disclaims liability arising from any of the assumptions being incorrect.

2. Desktop review

2.1 Literature review

Table 1 lists the reports that have been reviewed as part of this assessment. The following sections briefly summarise pertinent information from each report.

Table 1 Reviewed reports

Date	Author	Title
July 2014	GHD	Residue Management Area (Area 580) Quarterly inspection and monitoring
July 2014	P Richter	RTAY internal memo - Groundwater rise and treatment investigation options
July 2014	P Richter	RTAY internal document - Root cause investigation scope of work, elevated groundwater observations
October 2014	D Parry	RTAY report - Investigation of dead vegetation north of the RTA Yarwun RMA
9 October 2014	P Brown	RTAY report - Groundwater seepage at the Rio Tinto Alcan Yarwun RMA
February 2012	GHD	Yarwun RMA Stage 2 development geotechnical investigation interpretive report
May 2012	GHD	Hydrogeological investigation for Yarwun, RMA Stage 2 development interpretive report

2.1.1 (GHD) Quarterly inspection report July 2014

Quarterly inspection of the northern embankment was undertaken in July 2014 and is reported in *Residue Management Area (area 580) Quarterly Integrity – Inspection and Monitoring July 2014* (GHD October 2014).

A number of the northern embankment vibrating wire piezometers appear to be recording erroneous water level data, detailed as follows (for locations refer to Appendix A):

- Chainage MC01 380 – VWP01A (records a water level approximately 10 m higher than historic data for the decommissioned CBH 0001)
- Chainage MC01 620 - vibrating wire piezometer installed in standpipe CBH0007 and in CBH0008 however the standpipes can be dipped manually.
- Chainage MC01 755 – VWP03A (recorded water levels approximately 37 m higher than historic data for CBH 0009 (standpipe no longer in use))
- Chainage MC01 755 - VWP03B (recorded water levels approximately 10 m higher than historic data for CBH 0010 (standpipe no longer in use) and inconsistent with levels recorded beneath the toe berm (CBH0011, CBH0012, SPP01, SPP02).
- Chainage MC01 985 – vibrating wire piezometer installed in standpipe CBH0015 (foundation) however the standpipe can be dipped manually.

- Chainage MC01 985 – vibrating wire piezometer installed in standpipe CBH0016 (foundation) however the standpipe can be dipped manually.

An action plan has been drafted by GHD and detailed to RTAY for repair/replacement of faulty instrumentation and/or monitoring bores.

2.1.2 (RTAY internal memorandum) Draft options to address risks and actions reported 17/7/2014

This memo details options for consideration for managing rising groundwater levels within the Northern Embankment and are summarised below:

1. Surface water interception and observational approach
   - monitor the size and location of seepage areas for changes over time
   - direct 'clean' water away from impacted catchment areas
   - direct contaminated runoff to the firewater dam
   - install measureable flow pumping system from firewater dam to transfer to larger capacity runoff control point
   - undertake a site investigation to measure hydrogeological info such as hydrostatic pressures, ground conditions and chemical nature
   - check existing monitoring and subsoil systems
   - Identify triggers for further action
   - define action plan as a result of triggers being reached.
2. Groundwater interception

- 2a) groundwater spears
  - undertake a desktop study and site investigation to install interception wells to lower the regional groundwater table (define depth, spacing and extent).
  - set up spear collection system and transfer for liquid treatment (to RMA A580).

Other options are also noted, but are on hold until Options 1 and 2a are implemented and observed for effectiveness.

Possible causes for the rise in groundwater levels are also noted in the memo, as follows:

- Mounding – earth surcharge from tailings on existing groundwater profile in subgrade beneath RMA
- Seepage from the RMA – with specific flow paths such as foundations, abutments, embankment
- Alternative source eg. artesian, localised charging
- Heavy earthworks activity
- Pressurisation due to elevated levels of subsoil drainage.

Possible causes for low pH water:

- Natural material reacting with groundwater
- Groundwater is naturally low in pH
- Waste material illegally dumped in contact with groundwater
- Acid spill in past in contact with groundwater
- Other causes.

2.1.3 (RTAY internal document) Root cause investigation scope of work – elevated groundwater observations 17/7/2014

In July 2014 it was observed that a number of wet patches or free water were appearing downstream of the toe of the embankment and the abutment of the northern embankment.

Stage 1 of the root cause investigation scope of work to assess the likely cause of the elevated groundwater levels at the Northern Embankment has been completed. It included a desktop study of monitoring data, previous geotechnical and hydrogeological investigations data, hydrogeological modelling, construction and operational activities and methodology.

Stages 2 to 4 of the scope of work are summarised as follows:

- Stage 2a - site investigations
- Stage 2b - concept modelling
- Stage 3 - root cause analysis
- Stage 4 - action plan, based on the root cause analysis.

2.1.4 (RTAY) Groundwater seepage at the Rio Tinto Alcan Yarwun RMA, 9 October 2014

In July 2014 groundwater seepage was observed down-gradient of the eastern side of the Northern Embankment. This report details Stage 1 of the root cause investigation scope of work (site visit and desktop study) undertaken.

The site visit and subsequent desktop study determined that the seepage is groundwater related and not the result of water from the RMA, with a clear groundwater chemical signature. It was concluded that the seepage is occurring in response to elevated groundwater pressure in natural foundation materials beneath the RMA.

To assess and monitor the seepage a number of recommendations were made, including:

- Determine the spatial extent of the groundwater pressurisation
- Alleviate the groundwater mounding
- All monitoring locations are to be accessible and provide reliable data
- Formulate an action and prioritisation plan for repair and/or replacement of monitoring installations and setting of trigger levels
- The low pH of the observed seepage in the firewater dam is likely due to precipitation of iron hydroxide. Groundwater in the vicinity of the dam should be tested to confirm
- Establish a relationship with elevated groundwater levels to the north of the RMA property with that of the elevated levels in the Northern Embankment.

Outcomes of the site visit and desktop study are detailed in the following paragraphs.

In relation to seepage:

- 2008 – Seepage in the vicinity of the north wall was first noted in 2008. To combat this this seepage a number of depressurisation bores were installed. Analysis of water taken from installed piezometers indicates that the pressurised water was groundwater and not seepage from the RMA.
- 2013 – Dead vegetation and standing water was observed just to the north of the northern boundary of the RMA. The area shows evidence of salt scalding that has progressed from 2012 to 2014. Samples have shown to be highly saline and the chemical composition indicates a groundwater signature, not from the RMA.

- Later in 2013 – areas of iron staining appeared in the RMA construction car park.
- July 2014 – more seepage was noted in the construction car park and adjacent areas, including south of the construction area, sides of the haul roads at the foot of the northern wall, and seepage flow into the two dams (RMA_GW1 and firewater) to the north of the construction area.

Chemical signatures of water from toe drains, various piezometers and the Firewater dam were compared with the signatures from seawater and decant water. All seepage, piezometer and dam water samples were found to be groundwater and not seepage from the RMA. The chemical typing was done by comparing potassium-to-chloride ratios, magnesium-to-chloride ratios and trace metals gallium and molybdenum.

It was found that the K/Cl ratio of the decant water was similar to seawater (as seawater is used to neutralise the red mud), but exhibited a much lower ratio in all surface and groundwater samples. The Mg/Cl ratio was also useful for chemical matching as decant water tends to precipitate magnesium as hydrotalcite, therefore has a very low concentrations, whereas the surface water and groundwater samples exhibited much higher ratios.

Geophysical survey was undertaken of the site. Imaging of the survey data clearly shows the outline of the RMA, which contains highly saline water. It also clearly shows the NNW trending fault beneath the RMA. The fault is associated with a high conductivity and is likely the result of long established dryland salinity phenomena.

Recharge is generally low in the lowlands that are underlain by saline groundwater. At the margins of the RMA in the upland areas of thin soil cover, the recharge is much greater. Thus there appears to be potential for increased groundwater flow at the eastern and the western extremities of the northern wall of the RMA. This may potentially contribute with zones of elevated groundwater pressure that have occurred at these locations. A conceptual model was developed.

The observed elevated water and seepage north of the Northern Embankment appears related to water groundwater and not water within the RMA. The chemical signature of the elevated water and seepage closely resembles that of groundwater in the vicinity that occurs due to dryland salinity. The seepage results from groundwater under pressure in the vicinity of the eastern end of the northern embankment similar to the situation that occurred at the western end in 2008.

All seepage occurring north of the construction area is directed to the RMA_GW1 dam, which subsequently flows into the Firewater dam. Analysis on water from the dams has indicated a groundwater chemical signature, with elevated magnesium concentration and low potassium concentration and non-detectable concentrations of gallium and molybdenum.

There is potential for sub-surface flow to continue towards the surface water and salt scalding that has been observed o the north of the RMA northern boundary. The salt scalding and elevated groundwater north of the boundary may be related to a more generic condition of high groundwater north of the RMA and not solely to the elevated groundwater and seepage that has been noted to the eastern end of the northern embankment. The chemical signature of the surface water north of the boundary if similar to that observed at monitoring well ALD1 (even prior to development of the RMA).

Low pH of the dam water is thought to be caused by iron precipitation from emerging groundwater seepage. Iron staining is present in RMA_GW1 dam around the margins. Staining is not evident in the vicinity of the Firewater dam since the majority of the iron is likely to have been lost by the time water has flowed to the firewater dam. Iron staining was observed at a number of seepage points.

Reported recommendations:

- Install additional monitoring points to the eastern side of the northern embankment
- Additional assessment be undertaken to determine whether groundwater beneath the eastern end of the northern embankment is under pressure and whether installation of depressurisation bores will alleviate the groundwater mounding. Spatial extend needs to be determined.
- Groundwater and surface water samples should be taken from the firewater dam and analysed for the full suite including species of iron and organic acid content. A bore should be installed upstream of the two dams and sampled.

2.1.5 (RTAY) Investigation of dead vegetation north of the RTA Yarwun RMA, October 2014

Impact on vegetation immediately to the north of the RMA northern boundary was first identified in October 2013 and reported in January 2014.

Previous studies undertaken at the site have identified that the groundwater beneath and to the north of the RMA is saline and groundwater levels varied from 30 m bgl in upland areas and 5 m bgl between Larcom Creek and the RMA. Airborne geophysical survey conducted in 2010 mapped out the high salinity areas, which tended to correspond with the NNW fault running from the north of the RMA to south of the RMA. Groundwater samples confirmed the salinity. EC values of the groundwater prior to commissioning of the RMA range from 28,700 (BH31, October 2005) to 9,100 (BH32, October 2005). Over eight years the salinity in the bores has increased.

The decant water is characterised as:

- elevated sodium relative to seawater due to caustic used in the Bayer process
- depleted magnesium as a result of the formation of hydrotalcite (Al-Mg layered double hydroxide) precipitated in the seawater neutralisation process
- Elevated concentration of dissolved aluminium, gallium and molybdenum due to incomplete removal during the neutralisation process.

The surface water quality is characterised by:

- surface water in the drainage channel and swamp north-north-west of the RMA is saline, exhibiting elevated sodium, magnesium, calcium, sulfate and chloride. Comparison of the surface water with decant water and groundwater indicates that surface water is nearly identical to that of the groundwater and significantly different to the decant water. Groundwater samples show no contamination from decant water.

In conclusion, the results of the baseline studies showed that groundwater beneath and the NNW of the RMA are naturally highly saline. Groundwater in the area (between RMA and Larcom Creek) is naturally high (less than 5 m bgl). The groundwater has a distinct signature with high salinity, but low concentrations of potassium and dissolved metals

The surface water from the northern drainage line and swamp area has the same signature as the groundwater.

The death of the vegetation of a result of salt scalding from the rising saline groundwater in the area north of the RMA. There is no evidence that there is any seepage of RMA decant into the groundwater.

2.1.6 (GHD) Yarwun RMA Stage 2 development geotechnical investigation interpretive report

The geology ground model for the northern embankment area defines three general geological profiles across the valley floor (where chainages are for control line MCJ01):

- Eastern and Western extents of the valley floor (Chainage 0 to Chainage 550, and Chainage 950 to chainage 1200) comprise a thin layer of colluvium interfingered with alluvium overlying weathered and fractured Rockhampton Group bedrock with localised artesian groundwater conditions on the western flank;
- Between Chainage 720 to Chainage 950, typically 4 m (up to 7 m) depth of alluvium and occasional colluvium mixture overlying an undefined depth of the fissured clay sequence; and
- Between Chainage 550 to Chainage 720, typical 4 m depth of alluvium and occasional colluvium mixture overlying weathered and fractured Rockhampton Group bedrock and some fissured clay.

2.1.7 (GHD) Hydrogeological investigation for Yarwun, RMA Stage 2 development interpretive report

Key points in relation to groundwater flows and groundwater quality are outlined below.

Interpretation of the piezometric surface shows groundwater flow beneath and in the vicinity of the northern embankment is predominantly towards the north east and north west, i.e. inward towards the valley floor and the toe drain sumps. Across the central area of the embankment between ~CH 550 and ~CH 850 (chainages are for control line MCJ01), groundwater flow is towards the north beneath the embankment and further downstream of the toe groundwater flow is towards the south (i.e. back towards the toe drain sumps).

Groundwater quality analysis results for the monitoring bores installed as part of the hydrogeological investigation (580-BH and 580-MB series bores) are consistent with the interpretation of major ion chemistry (i.e. sodium-potassium-chloride type groundwater) and concentrations for previously tested locations along the toe of the northern embankment (CBH 20, CBH24, CBH25, CBH0007, CBH0011, CBH0015) reported in a GHD Memorandum (May 2011). This memorandum also concluded that no evidence of a significant decant seepage component in groundwater at the toe of the northern embankment was identified.

2.2 Data review

The data for existing boreholes and monitoring that has been reviewed as part of this assessment considered relevant to the assessment of elevated groundwater pressures and planning for their management is outlined in Table 2. Plans showing historic investigation locations are included in Appendix A.

Table 2 Summary of reviewed borehole data

Data and description	Data period	Source
Groundwater levels Northern embankment monitoring network (data for 19 monitoring points) as part of the RMA annual inspection. Includes monitoring locations on the embankment and at the toe, but excludes all downstream locations except for 580-BH-2003, 580-BH-2007 and 580-MB-2004. Excludes erroneous data suspected for three vibrating wire piezometers (refer section 2.1.1)	October 2014	Field data, GHD October 2014
Groundwater monitoring network Northern embankment area (embankment crest, toe, downstream area) (39 monitoring points, approximately 10 of unknown operational status), Aldoga property (off-site) to the north of the northern boundary of the RMA (5 monitoring points, operational status unknown) for background and compliance monitoring, RMA background monitoring bores to south east and south west of embankment (4 monitoring points, operational status not known)	2006 to 2014	RMA quarterly monitoring report, GHD July 2014
Groundwater quality Northern embankment groundwater monitoring network. Data for selected monitoring bores with discontinuous records, includes field parameters, major ions, alkalinity, dissolved metals. Interpretation of major ion chemistry for groundwater samples collected in 2011 indicated sodium-potassium-chloride type groundwater downstream of the embankment toe (GHD May 2012)	2001 to 2011	RMA Stage 2 hydrogeological investigation interpretive report, GHD May 2012
Aquifer permeability test results Western end of northern embankment only: 13 standpipes at the toe and downstream of the embankment, west of chainage MC01 850 3 standpipes beneath embankment crest (chainage MC01 755 and 985), 1 standpipe at toe (chainage MC985) 3 standpipes at the embankment toe and 2 south of crest, west of chainage MC01 850 Hydraulic conductivity (K) values typically fall in the order of 1×10^{-06} to 1×10^{-07} m/s predominantly for fractured weathered bedrock	March 2011 2008 2003	Results summarised in RMA Stage 2 hydrogeological investigation factual report, GHD August 2011

Data and description	Data period	Source
Geotechnical investigation boreholes and test pits Northern embankment area. Historic investigation locations predominantly located beneath and downstream (southern areas) of the northern embankment for geotechnical purposes	2000 to 2011	RMA Stage 2 development geotechnical investigation factual report, GHD August 2011
Selected geology ground model sections Interpreted geological ground model sections through the northern embankment area (east/west and north/south trending) based on borehole and test pit data. Sections indicate the subsurface of the eastern area downstream of the embankment predominantly comprises alluvial deposits underlain by fractured weathered bedrock which is bounded by fissured clay to the west	2011	RMA Stage 2 development geotechnical investigation interpretive report, GHD February 2012

2.3 Data gaps

The following gaps have been identified and have been used to inform the development of the SAP.

Operational status of monitoring bores

- The operational status of the off-site groundwater monitoring bores located on the Aldoga property is not currently known to GHD.
- The operational status of RMA background groundwater monitoring bores located outside of the area of the northern embankment (i.e. 580-BH-05, 580-MB-2005 and 580-BH-30 to the east that could assist in delineating groundwater pressures across the northern embankment is not currently known to GHD.
- The operational status of a number of monitoring bores to the north of the northern embankment toe is not known to GHD.
- Current and historic groundwater level data for three of the vibrating wire piezometers located on the crest of the northern embankment is considered erroneous. An action plan has been drafted by GHD and detailed to RTAY for repair/replacement of faulty instrumentation and/or monitoring bores as part of the Quarterly Integrity Inspection and Monitoring reporting (GHD July 2014).
- A large clay borrow pit has been excavated in the near vicinity of the four pairs of monitoring bores (PI1, PI2, PI3 and PI4), installed within clay dominated materials and underlying bedrock, located downstream of the toe at the western end of the embankment. Some of these of these monitoring bores are currently inaccessible (Pi3) and their operational status unknown. There is potential for the pit to influence the groundwater levels at these monitoring locations however this cannot currently be confirmed as there are no recent data for these monitoring bores.

Groundwater levels/pressures

- Whilst the current monitoring network in the eastern half of the northern embankment includes four monitoring bores downstream of the toe (580-MB-2004, 580-BH-2003, 580-BH-2006 and 580-BH-2007), there is no on site monitoring in the area to the north and east of 580-BH-2003 and 580-BH-2007 until the site boundary at 580-MB-2004. There are considered currently insufficient groundwater monitoring points/investigation locations throughout the eastern half of the northern embankment downstream area in the vicinity (i.e. up gradient and down gradient) of the dead vegetation and the salt scalds/seepages identified to:
  - delineate groundwater pressures for development of groundwater contours and interpretation of flow directions in this area
  - to confirm the direction of groundwater flow (i.e. upwards or downwards) between the fractured bedrock and overlying alluvial deposits, as there are no paired monitoring bores currently monitoring this strata in this area
  - to confirm the predominant groundwater flow pathway(s) (i.e. whether alluvial deposits and/or fractured bedrock) in this area
- Groundwater levels can be monitored just inside the northern boundary of the RMA site down gradient of the northern embankment at standpipe piezometers 580-MB-2001 and 580-MB-2004 however the monitoring is located at the western and eastern ends of the embankment area respectively. There is currently no monitoring therefore to confirm shallow groundwater levels in the central part of the site boundary or in the vicinity of the up gradient edge of the dead vegetation.
- The most recent groundwater level data collected for a discrete time period from the northern embankment monitoring network were collected in October 2014 as part of the RMA annual inspection. The dataset does not therefore include any of the off-site bores, monitoring bores located downstream of the embankment toe with the exception of 580-BH-2003, 580-BH-2007 and 580-MB-2004 or monitoring bores outside of the northern embankment area to the east and west. The October 2014 dataset is not therefore considered sufficient to develop groundwater contours or to interpret groundwater flow directions for the northern embankment area. Prior to October 2014, groundwater level contour development and flow direction interpretation was prepared for 2011 groundwater level data (GHD May 2012).

Aquifer permeability

- No aquifer permeability testing (slug testing) has previously been conducted in the standpipes located downstream of the embankment toe in the vicinity of the central or eastern areas of the northern embankment.

Toe drain, drainage blanket and connection to foundation

- A seepage area has been observed by RTAY at the embankment toe to east of the nearest monitoring bores (CBH0003 and CBH0004) where monitoring data indicate that the drainage blanket remains dry. There are currently no monitoring bores or previous shallow investigation locations in the vicinity of this seepage area to assess groundwater pressures, relationship between groundwater levels in the foundation and the drainage blanket, groundwater gradients or potential pathways.
- No data have been identified for monitoring the response of groundwater levels in the foundation beneath the drainage blanket and within the drainage blanket for a known period of continuous pumping of the current toe drain sumps. Based on the available data an estimate of the extent of the cone of depression in the drainage blanket and

underlying foundation in relation to extraction of water from the toe drain sump cannot be made nor an assessment of the response of this extraction on groundwater levels beneath and in the downstream area of the embankment.

Water quality

- Investigations conducted in 2008, 2011 and 2013 (refer Section 2.1.4, 2.1.5 and 2.1.7) which involved the sampling of selected monitoring locations (groundwater and/or surface water) at the toe and downstream of the toe of the northern embankment did not find evidence of decant in groundwater or surface water. Groundwater beneath the crest of the northern embankment (i.e. up gradient of previously sampled locations for decant in groundwater) has not however, previously been analysed for evidence of the presence or absence of decant.

2.4 Data analysis

October 2014 groundwater equivalent depths to groundwater in relation to ground surface (based on survey for the monitoring bores) are shown on Figure 3 of Appendix B and the elevations and interpreted groundwater level contours for the embankment foundation bedrock and downstream bedrock shown on Figure 4 of Appendix B . The plan and invert elevation of the toe drain collection pipe for the 2011 capacity increase design (GHD drawing 41-23944-C013) is also shown.

Interpretation of the groundwater elevations for October 2014 (Figure 4 Appendix B) indicates that groundwater flow in the bedrock is predominantly towards the north east and north west, i.e. inward towards the valley floor, and that groundwater flow beneath the central part of the embankment is towards the north. At the western end of the northern embankment the in the vicinity of monitoring bores CH 950A, CBH19 and CBH17 a relatively steep hydraulic gradient is interpreted across the embankment to the toe in comparison to the northern embankment area as a whole. This suggests a region of lower transmissivity in this area either by virtue of a thinner aquifer and/or an area of lower hydraulic conductivity. Overall, the interpreted groundwater flow directions for the October 2014 data are consistent with those reported for 2011 water level data, in the *Hydrogeological investigation for Yarwun, RMA Stage 2 development interpretive report* (GHD May 2012).

The groundwater elevations for the central area of the northern embankment (CH585 series and CH720 series bores) indicate an upward gradient between the foundation bedrock and the overlying drainage blanket, upstream of the 2012/2013 downstream drainage blanket extension. The groundwater levels in the foundation and drainage blanket for the CH720 bores (around 59 m AHD) are up to around 1 m above the as built survey RL for the top of the drainage blanket (58.079 m RL, as built survey dated 20 April 2012 provided to GHD by RTAY) of the 2012/2013 downstream drainage blanket extension. Given the groundwater elevation at the adjacent monitoring points to the east and west is also around 58 to 59 m AHD the drainage blanket in the central are of the northern embankment is indicated to be more than fully saturated and hence under pressure. The October 2014 groundwater elevations in this area are consistent with historic data collected since completion of the 2012/2013 drainage blanket extension (refer to the time series charts included in Appendix B, reported in the RMA 2014 Annual Dam Safety Inspection report, GHD November 2014).

Comparison of the interpreted groundwater elevation contours to the toe drain collection pipe invert indicates the drainage blanket currently holds water between around chainage MC01 420 in the east to MC01 1080 in the west.

Groundwater elevation contours cannot be developed for much of the downstream area of the northern embankment due to the limited extent of the October 2014 dataset. Where data are available the following is indicated:

- At the western end of the northern embankment comparison of the interpreted elevation contours (Figure 4) to ground surface and depths to water (Figure 3, Appendix B) downstream of the toe and drainage blanket indicate groundwater levels typically within around 2 m below ground surface. At the western end upstream of the drainage blanket collection pipe these data indicate an area of artesian foundation bedrock groundwater pressures in the vicinity of CBH19 (water pressure of around 1.7 m above ground surface). The October 2014 groundwater elevations in this area are consistent with historic data collected since completion of the 2012/2013 drainage blanket extension (refer to the time series charts included in Appendix B).
- At the eastern end of the northern embankment within the downstream area of the toe comparison of the interpreted elevation contours (Figure 3, Appendix B) to ground surface and depths to water (Figure 4, Appendix B) indicate a piezometric surface between around 2 and 4 m below ground surface.

3. Sampling and Analysis Plan

The SAP is designed to obtain additional data in order to develop a better understanding of the spatial extent of groundwater mounding and determine the likely cause. From there, options for reducing the pressurisation and subsequent issues can be developed.

To develop a concept design for management of pressurised groundwater, including assessing the potential extent of saline intrusion (soil, water and groundwater) at the site, a baseline Sampling and Analysis Plan (SAP) has been prepared. The SAP may be altered slightly during the site inspection, screening (i.e. geophysical), borehole and test pit investigation works. This includes where salinity/contaminant indicators, subsurface conditions and groundwater depths are observed that may indicate the need for greater or lesser sampling or a requirement for additional monitoring locations (e.g. vertical groundwater gradients, confining layers). It is expected groundwater sampling will extend to greater depths than what is required for assessment of locations for salinity and suitability for implementing remedial actions and management (i.e. inception trench), with a number of the sampling locations having both geological, soil assessment and groundwater analysis undertaken at the same location.

Potential soil salinity, surface and groundwater quality is proposed to be broadly characterised using insitu sampling and laboratory analysis to determine current conditions and future remedial or management options with groundwater physical properties being evaluated from installed boreholes and physical testing (slug tests).

The use of geophysical screening of the near surface is also proposed to be completed to provide a broad means of evaluating the near surface extent of salinity across the area of interest.

3.1 Objectives of the SAP

The objective of the SAP is to collect sufficient data to:

- Characterise the hydrogeological regime of the northern embankment area for the development of management options for alleviating groundwater pressures in the east of the northern embankment area and off-site downstream of the RMA site boundary
- Investigate the occurrence of low pH water in the firewater dam (FD2) and GW1 (FD1)dam

The data obtained will be used to delineate the extent of groundwater pressurisation, to develop a conceptual hydrogeological model and to support the investigation and development of concept design options for management of the groundwater pressurisation. Information obtained during this investigation may also provide data for the integration of groundwater, stormwater and other management initiatives of RMA operations.

3.2 SAP outline

This SAP includes the following:

RMA

- Inspection and assessment of serviceability of existing (on site) groundwater bores located downgradient of the embankment and nearby monitoring bores located to the east, south east and south west of the northern embankment
- Monitoring of existing and proposed groundwater monitoring points within and in the near vicinity of the Northern embankment

- Installation of groundwater bores and excavation of test pits, detailed field observations, sample collection, permeability testing, logging of the geological profile
- Installation of a groundwater bore immediately upgradient of the fire water dam
- Collection of representative soil, surface and groundwater samples for characterisation and chemical analysis
- Documentation of field observations to evaluate trends and changes over time

North of the RMA (Aldoga)

- Inspection and assessment of serviceability of existing (off site) groundwater bores (5 locations)
- Monitoring of existing and proposed off site groundwater monitoring points
- Selection of suitable sampling site in Larcom creek upstream and downstream of the RMA discharge and overland flow path
- Ponded areas within former creek channel immediately north of RMA boundary at sites previously sampled by RTAY
- Installation of groundwater bores and excavation of test pits, detailed field observations, sample collection, permeability testing, logging of the geological profile
- Collection of representative soil, surface and groundwater samples for characterisation and chemical analysis

3.3 Legislative compliance

The SAP has been prepared based on the following legislation, guidelines and standards, which are considered the most relevant to this project:

Legislation

- The EP Act, 1994.
- EA Permit Number SPDE04134712

Australian Standards

- AS4482.1:2005 Guide to the Sampling and Investigation of Potentially Contaminated Soil – Non-volatile and Semi-volatile Compounds
- AS 5667.1:1998 Water Quality – Sampling Part 1: Guidance on the Design of Sampling Programs, Sampling Techniques and the Preservation and Handling of Samples
- Standards Australia AS/NZ, Australian/New Zealand Standard 1998, AS 5667.11:1998 Water Quality – Sampling Part 11: Guidance on Sampling of Groundwater
- AS1726-1990 Geotechnical Site Investigation

Guidelines for water quality and sampling

- Australian and New Zealand Environment and Conservation Council/Agriculture and Resource Management Council of Australia and New Zealand (ANZECC/ARMCANZ) 2000. *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*
- Department of Environment Resource Management (2009). *Monitoring and Sampling Manual 2009 Version 2*

Guidelines for groundwater well installation

- National Uniform Drillers Licensing Committee, 2012, *Minimum Construction Requirements for Water Bores in Australia,* Edition 3

3.4 Assessment criteria

The proposed approach to assessment of the data collected by the SAP is to review the collected data with regard to the current site conditions and against available historic data.

4. SAP - Site assessment program and methodology

4.1 Site assessment program development

The soil salinity, surface water and shallow groundwater investigations are proposed to be undertaken concurrently. The following has been taken into consideration in the development of the site assessment program:

- Information obtained from previous site inspections and identification of areas of concern
- Review of documents and data, data gaps identified from review of documents
- Geology and hydrogeology of the site
- Location of potential sources of surface expression of groundwater (seepage), migratory pathways and expected distribution of elevated groundwater
- Evaluation of potential management options for elevated groundwater pressures

4.2 Monitoring, sampling and investigation locations

This section summarises the proposed monitoring, sampling and investigation locations and rationale for their selection.

Figure 5 in Appendix D shows the approximate locations of the existing groundwater monitoring locations and the proposed boreholes and test pits included in the SAP. As part of a separate scope of work to this SAP, RTAY is in the process of replacing a number of Northern Embankment crest VWPs with standpipes and these locations are shown on Figure 6 in Appendix D. The table in Appendix D provides the rationale for the selection of each location.

Table 3 summarises the types of testing and sampling in each area (RMA and off-site downstream of the RMA).

Table 3 Summary of monitoring, sampling and investigation locations

Monitoring/investigation type	Location	Monitoring/testing regime
Surface water	Larcom Creek	Water quality (upstream and downstream of confluence with Aldoga)
	Firewater dam (FD2)	Water quality
	RMA-GW1 dam (FD1)	Water quality
	Ponded water (UGFD1various))	Water quality at surface seepage points, channel leading to Firewater Dam, within and downstream of off-site dead vegetation/impacted area
	RMA and off-site downstream (Aldoga)	Inspection of selected bores to confirm suitability for monitoring Groundwater levels and quality

Monitoring/investigation type	Location	Monitoring/testing regime
		Aquifer permeability testing
Groundwater - existing bores	RMA and off-site downstream (Aldoga)	Soil sampling for salinity analysis Geological and geotechnical logging Groundwater levels and quality Aquifer permeability testing
Groundwater - proposed bores	RMA and off-site downstream (Aldoga)	In near surface deposits - groundwater inflow estimates, identification water bearing and confining horizons Geological and geotechnical logging Soil sampling for salinity analysis and grading
Proposed test pits	RMA site and Aldoga site	In areas previously not investigated in geotech investigations, near surface deposits, wet and seepage zones, dead vegetation and ponded areas - Geological and geotechnical logging Soil sampling for salinity analysis and grading

4.2.1 Rational for monitoring bore locations

RMA and Aldoga property

Proposed new monitoring bore locations were selected based on data required to assess the groundwater pressurisation and in consideration of the locations of the dead vegetation and seepages observed, the existing infrastructure and the current monitoring network at the RMA site. Existing groundwater monitoring points for the Northern Embankment are also included in the SAP. The existing monitoring network lies to the north, east and west of the northern embankment. Some of the existing monitoring bores will require inspection for their serviceability prior to inclusion. If any of the existing monitoring bores are not considered to be operational but are considered essential to the monitoring program, replacement of the bore may be required.

The groundwater monitoring locations were selected to:

- Support spatial assessment of the groundwater regime and aquifer permeability at the eastern end of the downstream area (on site and off site) of the northern embankment and possible influence of the RMA tailings on groundwater
- Provide additional monitoring points to better delineate groundwater levels and flows across the northern embankment area as a whole
- Assess the feasibility of the potential management option of pressure relief bores at the eastern end of the embankment
- Assess the potential influence of the Aldoga creek line intersecting the RMA site

- Enable monitoring of groundwater quality in order to identify facies (water types), possible preferential groundwater flow pathways and potential discharge areas to ground surface as seepage

Once the embankment VWP replacement standpipes have been commissioned they will form part of the on-going monitoring network, specifically for the assessment of any decant leakage from the RMA beneath and/or through the northern embankment and to confirm water levels beneath and within the embankment.

Fire water dam

The groundwater monitoring location was selected to:

- Asses groundwater levels and quality up gradient of the firewater dam (being a potential source of water supply to the dam) to assist in the investigation of the low pH water in the fire water dam.

4.2.2 Rational for test pit locations

RMA and Aldoga property

Test pits have been located to:

- Assess the near surface geological and hydrogeological regime across the eastern half of the northern embankment area in areas up gradient of, within and down gradient of the observed areas of salt scalding and surface expression of groundwater
- Assess shallow sub-surface characteristics (geotechnical and hydrogeological) in the central part of the downstream area (on-site) and at the northern boundary of the RMA site to assist with evaluation of an interception trench as a potential management option
- Enable collection of soil samples across the eastern downstream area of the northern embankment to assess the soil salinity profile in areas up gradient of, within and down gradient of the observed areas of salt scalding and surface expression of groundwater

4.2.3 Rational for surface water sampling locations

RMA and Aldoga property

Surface water sampling locations have been selected to:

- Be consistent with the two locations sampled by RTAY (drainage channel and swamp) as part of the *Investigation of dead vegetation north of the RTA Yarwun RMA* (RTAY, October 2014)
- Confirm quality of receiving surface water in Larcom Creek, upstream and downstream of the confluence with Aldoga Creek for comparison to other surface water samples collected
- Confirm quality of water (if present) in Aldoga Creek upstream and downstream of the area of dead vegetation

Fire water dam

To assist in the investigation of the low pH water in the fire water dam, surface water sampling locations have been selected for the fire water dam (FD2), the RMA-GW1 dam (FD1) and any ponded water in the channel leading to the dams (USFD1).

4.3 Investigation approach and sampling

4.3.1 Contractor requirements

A licensed (Queensland registered) drilling contractor must be subcontracted to undertake the drilling and installation of bores, under the supervision of a geologist/hydrogeologist. Test pits must also be undertaken by a licenced heavy plant operator and excavated using an excavator suitable to be able to achieve penetration up to 5 m below ground and into weathered rock. Test pit excavation must also be completed under the supervision of a geologist/hydrogeologist or environmental engineer.

Drilling method

The drilling contractor selected should, consider to allow the adoption of a number of drilling methods, including triple tube core (i.e. sonic), rotary hammer etc. at the site (the driller should have available a number of techniques at his disposal). The use of a sonic head is considered to provide a number of benefits for drilling, casing off and isolating as well as obtaining samples through the profile within the embankments and within the alluvium and upper weathered sediments. Where possible, by sonic or other methods, it should allow continuous core sampling to be completed that will provide relatively undisturbed borehole samples that can be extracted from the drilled profile. Consideration should also be made of the core integrity with regard to the various methods adopted to allow various levels of interpretation/ accurate recording of the profile, where required.

As Gladstone, Meta-sediments have often been identified as being problematic to drill and core, and any estimate of drilling rates should consider the fractured nature of the bedrock and that with nested wells, coring of the adjacent bore may not be required. Depending on the location, access and drill pad construction may also be required to be undertaken prior to establishment. Where a deep and a shallow bore are proposed at one location, the deep borehole should be drilled first in order to plan the required depth and standpipe construction details for the shallow bore.

Field observation records

Observations of seepage and surface expression (salt scalds/affected vegetation) should be collated into an inventory, to enable evaluation of trends and changes in the future. The following records should be kept and updated as per any ongoing monitoring:

- Type of observation (e.g. salt scald, damp area, surface ponding, affected vegetation)
- Location identifier
- GPS of the location
- Photograph of the observation, including maintaining the same orientation over time
- Date and time of the observation
- Estimate the area of impact
- Note any iron staining, precipitation, films etc.
- Electronic records in an excel sheet or similar

Surveying of key impacted areas

Surveying the extents of stressed vegetation, ponded areas, overland flow paths and significant seepage and surface expression should also be undertaken with each area given an identifier and central location, to enable quantitative evaluation of changes over time. The survey data

may be limited to hand held GPS and "tracks" taken of perimeters along with photo surveys taken from the same point in N,S,E and W directions.

4.3.2 Inspections of existing monitoring bores

All existing monitoring bores are to be inspected and assessed for suitability for on-going monitoring. For all existing bores the following must be investigated and noted:

- Positively identify the bore and GPS the location
- Inspect the casing and monument for integrity
- Gauge the base of the bore with a dipper and record the water level
- Undertake repairs if required, including installing protection markers

4.3.3 Soil sampling

While the boreholes are being drilled and test pits excavated it is considered prudent to take soil samples for analysis to profile soil salinity. Salinity sampling through the soil profile, particularly in areas where groundwater has not been encountered at shallow depths, may provide an indication if lateral migration is occurring from other areas.

For boreholes and test pits located in salt scaled areas sampling of the soil will be undertaken throughout the profile and submitted for laboratory testing. Sampling of boreholes and test pits will be executed as follows:

- Soil samples will be collected at the ground surface, at near surface (i.e. between 0 m and 0.25 m), at 0.5 m, at 1.0 m and then every subsequent metre depending on ground conditions intercepted and any salinity indicators identified.
- Up to three soil samples may be submitted for chemical analysis from each of the exploratory boreholes and test pit locations. In key areas where seepage and scalding is identified, soil samples will be analysed for salinity parameters with an average of one soil sample per sampling location. Other samples will be kept on hold at the laboratory if additional analysis is required based on results.

4.3.4 Installation and development of groundwater bores

An appropriately qualified and Queensland licenced driller must be subcontracted to undertake the installation of groundwater monitoring bores. The drilling and installation must be supervised by a geologist/hydrogeologist. All monitoring bores are to be installed in accordance with the National Uniform Drillers Licensing Council (NUDLC) Minimum Construction Requirement for Water Bores in Australia, 2012.

Monitoring bore design

Borehole depth may vary to the proposed target depth, depending upon observations made during drilling and logging. The supervising geologist/hydrogeologist is to determine the final termination depth based on the geotechnical logging of the hole. Termination of the borehole will occur when sufficient data has been gathered from the profile (i.e. target formation reached, groundwater intercepted etc.). The proposed depth and required information from each investigation location is detailed in the SAP table, Appendix D.

Appendix C provides a general specification and a standard drawing for the installation and design of a monitoring bore and does not take into account site-specific hydrogeological conditions or drilling method adopted. Bore installation supervision and final design are to be completed by a site Hydrogeologist after an assessment of sub-surface conditions and

hydrogeological characteristic are known, therefore modifications to the standard design may be required.

Drilling and installation

The following approach to drilling and groundwater bore installation is required and must be read in conjunction with the supplementary information provided in Appendix C:

- Accurate records must be kept of lithology, termination depth, intersected groundwater, indications of seepage/saline intrusion, and depth of any soil samples taken. The lithology will be logged in accordance with the Unified Soil Classification System (USCS).
- The borehole will be drilled with a minimum diameter of 150 mm (to provide sufficient clearance for placement and thickness of filter pack).
- The bores will be constructed with thread-jointed, Class 18, 50 mm ID uPVC acid washed casing. A 1.0 m to 3.0 m machine-slotted, 0.4 mm-aperture screened section is to be placed at the bottom of the bore/placed to screen the strata to be monitored.
- The screened section of the casing will be positioned between 5 and 10 m below the water table (allowing for seasonal groundwater level fluctuation). The bore should target shallow groundwater that is generally intersected up to 15 m below ground level.
- Prior to installation of the standpipe ensure that the depth to the top of the screen will be a minimum of 4 m below ground surface, i.e. sufficient to allow for a minimum of 2 m thickness of bentonite cement grout from ground surface to ensure good seal.
- The bore annulus will be backfilled with washed and graded filter pack (2 mm silica sand) to between 0.5 and 1.0 m above the screened interval. A minimum 1.0 m bentonite seal ("1/4 inch" coated bentonite pellets) will be placed on top of the filter pack. The bentonite pellets will require a minimum of 0.5 hours to hydrate prior to grouting of the bore. The remainder of the bore annulus will be sealed to ground surface with a bentonite-cement grout (made with 3 to 5% bentonite powder).
- GPS the location of the bore. A mark will be made at the top of the casing sticking up above ground level to indicate where water level and survey measurements are to be taken from. The bores will require later differential survey with a vertical accuracy to +/- 1.0 mm.
- Where nested bores are required targeting two depths (i.e. to evaluate vertical groundwater gradients), individual boreholes will be drilled adjacent to each other (with approximately 3 m separation).
- Bores will be completed at the surface with stick-up PVC monuments using a PVC push on cap, bedded in concrete. The internal bore casing will be fitted with a push on plastic top cap or J-plug / torque plug. All bores will have high visibility marker post installed (2.0 m in height) adjacent to the bore. Bore identifier details attached to a label will be affixed to the bore monument.

Bore development

The bores are to be developed prior to monitoring to remove borehole smear and formation fines present in the filter pack surrounding the screen. Development should be via airlifting until for a minimum of one hour and until less than 1 cm^3 of fines are present in 10 litres of water removed from the bore,. If a bore is slow to recharge, the most effective way to develop will be to use Waterra tubing (high density poly ethylene, fitted with a footvalve) with a surge block attached. Development should be conducted no less than 24 hours after completion of grouting to ensure that the cement has set.

Monitoring equipment installation (option)

Selected groundwater monitoring bores (approximately 10 existing and new bores) recommended to be fitted with a Solinst M30 water level logger suspended with a Kevlar or similar cable to at least 2 m below the predicted lowest water level fluctuation. A single Solinst Barro-logger is also required to be deployed in one of the monitoring bores in the middle of the site.

The loggers will be set to record once per day. All the loggers should be set to record at the same time each day. Following the installation of the logger the date, time and SWL should be recorded. Where loggers are located in close proximity to the toe drain sumps, the recording interval may be shortened to evaluate the response to pumping in the bores.

When purchasing the loggers, additional equipment that should be supplied includes connection cables, software programs, calibration certificates and a manual for their operation.

Selected groundwater monitoring bores (existing and new) can be fitted with a 25 mm diameter dedicated "Waterra" sampling hose fitted with a footvalve for sampling. For one off sampling, disposable bailers and/or a 12 v submersible pump may be used, with any logging equipment removed beforehand.

Groundwater disposal

Groundwater extracted during the development and purging process will be managed and disposed of on-site in accordance with RTAY requirements as required. Groundwater left over from the purging, development and sampling of the groundwater bores will be at this stage, discharged to ground. If required, this water will be collected and stored in drums on-site, and depending on quality, may be later discharged to ground or the RMA (with RTAY appropriate approval). If required, off-site disposal of the waste water may have to be arranged.

4.3.5 Groundwater sampling

Existing bores, after inspection and confirmation of their suitability, are to be included in the monitoring program for quality and/or water level data.

Groundwater sampling will be undertaken using the following methodology:

- Groundwater sampling will not take place prior to stabilisation of the water level post-bore development.
- One groundwater sample round will be initially undertaken for the SAP.
- Prior to sampling, the bore will be gauged to determine depth of bore and groundwater level utilising an electronic probe. Monument stick-up and datum to ground will also be recorded. Where required, resurvey of the bores will be also undertaken.
- All bores will be purged dry, at least twice, using the dedicated sampling equipment (waterra or bailer) at a rate of approximately 1.5 L/min. Field water quality parameters (dissolved oxygen (DO), pH, oxidation/reduction potential (Eh), electrical conductivity (EC) and temperature) will be recorded during the purging process, to assess water quality and to ensure the bore has been adequately purged. A flow cell should be utilised to minimise oxidation during sampling.
- Samples are to be collected at a flow rate of approximately 0.5 L/min, filtered to <0.45 µm (metals only), placed in laboratory-supplied containers with preservatives appropriate to the required analytes and cooled on ice for storage and transport to the analytical laboratories.

- Groundwater samples will be collected, preserved and stored in accordance with the DERM Sampling Guidelines and laboratory requirements for the analysis requested.
- Sample documentation, including chain of custody documentation, sample receipt information, certified analytical results and laboratory quality control documentation are to be included in the deliverables schedule (see Section 7).
- Decontamination of sampling equipment will be undertaken prior to and between each sampling event. The decontamination process will consist of thoroughly cleaning the equipment in a phosphate free detergent solution, followed by two rinses in potable water. To comply with guideline protocols, pH, EC, DO and temperature will be determined by field measurements using a calibrated portable field meter (i.e. TPS FLMV 90).

4.3.6 Permeability testing

Borehole permeability testing is proposed to provide information on the hydraulic conductivity of the aquifer for proposed conceptual groundwater modelling.

Designated bores will be selected for permeability testing (one rising and one falling head test) using a solid slug or pneumatic slug to displace the water and a solinst level logger to record the test data. The data should show adequate displacement of the water column followed by a consistent recovery curve. Slug testing and recording of levels shall be undertaken until at least 90% recovery of aquifer to pre-testing levels occurs. If not, the test should be repeated.

Testing is to be completed post- development when water levels have stabilised, prior to sampling, or after sufficient time since sampling has occurred allowing for water level stabilisation to occur. Preferably, using a suitable software package, aquifer permeability's shall be determined and provided along with water levels, to allow an estimation of flow to be determined.

4.3.7 Test pits

Test pits are required to provide geological, geotechnical and hydrogeological information as well as a visual indication of possible groundwater inflows, confining layers and indicators of seepage, including rates of ingress and groundwater depth.

Accurate geotechnical logging and comments relating to trench stability and construction issues should be recorded to provide information for future design of groundwater pressure relief management options and provide contractors with relevant information.

The depths of test pits may vary from the proposed depth depending upon observations made during excavation. The supervising geologist/hydrogeologist is to determine the final termination depth based on geotechnical logging of the test pit. Termination of the test pit will occur when sufficient data has been gathered from the profile (i.e. target formation reached, groundwater intercepted etc.). The proposed depth and required information from each investigation location is detailed in the SAP table, Appendix D.

Where seepage is apparent into an excavation principally from a conductive layer, a field estimate of inflow rates is to be undertaken along with water level data. Where it can be undertaken safely and a representative sample can be obtained, water ingress is to be sampled and assessed for field physical parameters (pH, DO, redox, conductivity, temperature, salinity) and if required, for later laboratory analysis.

General

The Contractor shall excavate test pits vertically to a depth of 4 m (or refusal in hard weathered rock), unless otherwise instructed.

Material excavated from test pits shall be safely stockpiled in the order of excavation adjacent to the pits, i.e. each type of material shall be stored in different stockpiles. For excavations on sloping ground the material shall be properly protected in such a manner that it does not fall or wash downhill or in any way enter surface water drainage systems, prior to reinstatement. The Contractor shall also take all necessary measures to prevent the ingress of surface water into the excavations. Each soil stockpile shall be reinstated into the test pit in the order that it was excavated, and compacted to a similar density to that of insitu material.

Logging and photography of each test pit shall not be carried out until the termination depth has been achieved.

Test pitting, logging and sampling

Test pits shall be to 4.0 m deep or refusal and have lateral dimensions to suit the space at the pit location (nominally 1.0 m wide by 3.0 m long). The excavator used must also have a variety of buckets/ground breaking tools to suit the excavation of soft soils to competent bedrock.

The Contractor shall ensure that the excavations are kept free from surface water, where possible so that the base of each excavation shall be clearly visible during logging and taking photographs.

Each test pit shall be logged and photographed using a reference board. Photographs shall be taken such that shadows do not obstruct the view off the test pit walls and floor. Each face and the base shall be photographed. Each photograph shall identify the face of the excavation and shall contain a natural scale (i.e. use of a tape measure or measuring staff to the base of the test pit). These photos shall be included in the Field Work Report submitted. During test pit excavations records of the variability of strata in faces, stability of test pit faces (any collapses, sloughing/fretting, undercutting), ease of excavation (subjective – very easy, easy, difficult, hard, as well as recording how much time each strata takes to excavate), type of horizons (shape and dimensions) and records of the type of machine used to excavate the pit and the type and width of bucket used (e.g. 600 mm wide toothed bucket) should be taken and reported on the associated test pit log. In addition, measurements of the height of spoil (above or below existing ground level) on completion of backfilling of the test pits should also be recorded and reported on test pit logs. It will also be expected that the logs shall identify/differentiate between main soil groups (e.g. fill, alluvium, residual soils) and rock types and their associated stratigraphy.

One small bag of disturbed sample shall be taken in all test pits at surface (between 0.0 m and 0.25 m), at 0.5 m, at 1.0 m and then at subsequent 1.0 m intervals to the base of the test pit or at every major change in lithology. The disturbed samples shall be representative of the composition of the soil exposed and sufficient material (approximately 500 g) shall be taken to fill the sample bags. Each sample is to be placed into an airtight snap lock plastic bag and shall be labelled with the test pit ID and the depth at which the sample was taken.

Backfilling and reinstatement

Test pits shall be backfilled as soon as practical possible after sampling and logging, in the order of excavation. The material used to backfill test pits shall be compacted until original ground level is restored. The ground surface shall be restored to its condition prior to the excavation. Any excess spoil will be required to compacted and placed within the pit dimensions and a record of the height above original ground level should be measured and recorded on the test pit logs.

4.4 Fieldwork preparation

Prior to the commencement of works on site, as a minimum the following tasks are to be completed, (including any additional RTAY requirements):

- Preparation of Job Safety and Environment Assessment (JSEA). This will identify foreseeable hazards associated with site works, and address control measures to be adopted to minimise/eliminate the hazard.
- Obtaining relevant site approvals (including on adjacent land), complete inductions and training as required, to undertake the works.
- Identify vehicle and walking access tracks to the investigation locations, considering that the monitoring points will be routinely visited. Undertake ground improvements, where required to facilitate improved access, considering wet weather conditions.
- Assessment of underground services, utilising Dial Before You Dig, site plans, survey data and information supplied by RTAY.
- Engaging a professional services locator to identify potential sampling locations;
- On-ground marking of the monitoring bore and test pit locations (paint and peg, recording the site details).
- Marking on the ground the location of key services and exclusion zones. Ensure all field personnel are aware of the services located at the site.

4.5 Laboratory analysis program

4.5.1 Analytical laboratory

RTAY will subcontract all primary laboratory analytical services to their preferred National Association of Testing Authorities (NATA) lab, Australian Laboratory Services (ALS). The analysis of duplicate samples for quality control purposes will also be undertaken by ALS. As the sampling parameters to be assessed are typical routine analysis and part of an initial investigation, no secondary laboratory is considered to be required for analysis of split samples (inter-laboratory duplicate samples). Duplicate samples will be analysed at a rate of one in every ten primary samples.

Rinsate sampling has not been scheduled at this stage, but if required by RTAY, these can be allocated for each batch of samples submitted to the lab for analysis and will be analysed for heavy metals/metaloids. No trip blank samples are considered to be required due to the expected absence of volatiles.

As with the soil samples, groundwater inter-laboratory samples will be analysed at a rate of one in every ten primary samples. As dedicated groundwater sampling equipment is proposed, no rinsate blanks are proposed to be undertaken.

4.5.2 Soil sample analysis

Soil samples will be collected, preserved and stored in accordance with established protocols. Table 4 lists the proposed analytical program for soil samples.

Table 4 Laboratory analytical schedule for soil samples

Analysis parameter	Frequency of testing	Treatment of sample
Physicochemical Electrical conductivity, pH (1:5 soil water)	All surface and selected subsurface samples to be analysed.	Samples should be in zip-lock bags and positively identified with sampling location ID and depth of sample. Deliver to laboratory the following day post-sampling.
Major ions Soluble ions (Na, Mg, K, Ca, SO_4, Cl, Cation exchange capacity (CEC),	All surface and selected subsurface samples to be analysed.	Samples should be in zip-lock bags and positively identified with sampling location ID and depth of sample.
Optional additional Suites. Carbonate and bicarbonate, Exchangeable CEC, Exchangeable sodium percent (ESP), SAR	Surface and subsurface soil samples to be analysed, where soil health assessment is required.	Samples should be in zip-lock bags and positively identified with sampling location ID and depth of sample.

Note:
Pending initial laboratory results for soil investigation locations, additional analysis may be required if further salinity delineation or if further soil characterisation is required.

4.5.3 Surface water sample analysis

All surface water samples will be submitted to the laboratory within required holding times and scheduled for the analytes listed in Table 5.

Table 5 Laboratory analytical schedule for surface water samples

Analysis parameter	Frequency of testing	Treatment of sample
Physicochemical Electrical conductivity, total dissolved solids, total suspended solids, pH	All surface water samples	Samples to be collected in laboratory supplied containers. Samples are to be chilled in the field and during transport to laboratory. Holding times for pH are 6 hours therefore it is unfeasible to have samples delivered within this holding time. Field pH should always be taken to compare with the laboratory results. EC and TDS have holding times of 7 days
Major ions Na, Mg, K, Ca, SO_4, Cl,	All surface water samples	Holding time is 7 days.

Analysis parameter	Frequency of testing	Treatment of sample
carbonate and bicarbonate (alkalinity), fluoride		
Metals/metalloids Total and dissolved: Al, Ga, V, Mo, As, Cd, Cr, Cu, Pb, Ni, Zn, Mn	All surface water samples	
Metals/metalloids Speciated iron dissolved (ferrous and ferric)	Additional analytes for the firewater dam	Ferrous iron holding time is 7 days
Minor ions NH4, NO3, NO2, PO4, total P, Total N, Total organic carbon	Additional analytes for the firewater dam	Holding time is 2 days for Nitrates, Nitrites.

4.5.4 Groundwater sample analysis

All groundwater samples will be submitted to the laboratory within required holding times and scheduled for the analytes listed in Table 6.

Table 6 Laboratory analytical schedule for groundwater samples

Analysis parameter	Frequency of testing	Treatment of sample
Physicochemical Electrical conductivity, total dissolved solids, pH	All groundwater samples	Samples to be collected in laboratory supplied containers. Samples are to be chilled in the field and during transport to laboratory. Holding times for pH are 6 hours therefore it is unfeasible to have samples delivered within this holding time. Field pH should always be taken to compare with the laboratory results. EC and TDS have holding times of 7 days
Major ions Na, Mg, K, Ca, SO_4, Cl, carbonate and bicarbonate (alkalinity), fluoride	All groundwater samples	Holding time is 7 days.
Metals/metalloids Total and dissolved: Al, Ga, V, Mo, As, Cd, Cr, Cu, Pb, Ni, Zn, Mn	All groundwater samples	

Metals/metalloids	Fire water dam bore	Ferrous iron holding time is 7 days
Dissolved spectated iron (ferrous and ferric)		

4.6 Quality Control and Quality Assurance Procedures

4.6.1 Relevant Guidelines and Standards

A QA/QC program is to be implemented in general accordance with the DoE (1998), the NEPM (2011) and the AS 4482.1-2005.

4.6.2 Sample Quality Control and Assurance

Quality Control Sampling

These are samples additional to those taken from marked sampling points to indicate the quality of the sampling program. This will include, but not be limited to:

- Collection and testing of blind duplicate samples (one duplicate for every 10 samples).

Blind duplicate and split groundwater samples will be analysed for the key analytes only.

Collection and testing of inter-laboratory (or split) duplicate samples, rinsate samples; and laboratory supplied field (trip) blanks is not proposed as part of this assessment.

Sample Handling and Preservation

Samples will be collected in pre-cleaned laboratory supplied bottles and jars with Teflon lined lids using a new pair of Nitrile disposable gloves for each sample.

Samples will be placed immediately in chilled eskies upon collection. Samples will be dispatched to the designated laboratories on a one to two day basis to ensure that all samples remain chilled and analysis is completed within designated holding times.

All sample consignments will be accompanied by appropriately completed chain of custody documentation

Decontamination Protocols

Decontamination protocols consistent with the methods recommended by the AS4482.1-2005 will be complied with throughout the soil and groundwater sampling program to reduce the risk of cross contamination between samples and sample locations.

All relevant sampling equipment where required, will be decontaminated between samples and sample locations using a phosphate free detergent (e.g. 'Decon 90') and final rinse with deionised water. Tubing and disposable bailers used for sampling groundwater will be dedicated for each well.

Chain of Custody

This is the process which details the links in the transfer of samples between the time of collection and arrival at the laboratory. Sample custody procedures provide a system for documentation of all information related to sample collection and handling to achieve the objectives.

Field data sheets and chain of custody forms will be used as the primary documentation to ensure that relevant information for each sample is properly recorded. All chain of custody forms shall be included in the final report.

Calibration of Field Instruments

All field instruments used will be calibrated and demonstrated to meet the calibration specifications prior to use. All calibration data (off site and on site calibration) shall be recorded and included in final reporting.

4.7 Laboratory QA/QC procedures

Under their NATA certification, the laboratories are also required to undertake their own internal QA/QC procedures including matrix spikes / recoveries, internal duplicates, control blanks and reagent blanks.

The results of the laboratory QA/QC program will be required to be reviewed to make an assessment of the validity of the analytical results and ensure that the laboratory QA/QC program meets the requirements of the NEPM (1999). A Data Quality Report will be produced to assess the site procedures and quality of the data against pre-defined data quality objectives. In accordance with the project brief, the laboratory data will be assessed against the following data quality objectives:

- Accuracy: demonstrated by laboratory spikes in the range of 75-125% recovery;
- Precision: demonstrated by internal laboratory duplicates and field splits and duplicates with less than +/- 50% relative percentage difference (RPD);
- Method blanks less than the laboratory reporting limit; and
- A minimum completeness of greater than or equal to 95%.

Where these objectives are not met, an explanation will need to be provided as to the likely cause of the data issue and where relevant, data-qualifiers will be included on the results tables to indicate the nature of the non-conformance. Any non-conformances will also be required to be investigated to ensure that potential causative factors are identified and remedied.

5. SAP - Additional optional investigations

5.1 Geophysics (terrestrial EM)

As part of a preliminary screening tool to identify approximate extents of saline groundwater seepage and impacted areas, geophysical survey methods are proposed to allow refinement of intrusive sampling locations.

To assist in assessing the presence and extent of dryland salinity, a geophysical survey is to be conducted downstream of the northern embankment filter blanket and within the adjacent Aldoga site as part of the sampling and analysis plan (SAP). This can be completed to support the assessment of remediation/management options and to allow targeting of potential saline mounding at the surface. The results of the survey can be used for the following:

- Determining the likely extent and location of the salinity downstream of the RMA.
- Further targeting the location of boreholes and test pits undertaken as part of the SAP.
- Identifying areas for the placement of future remediation works, including possible ground water capture / interception.
- Provide a baseline survey for the assessment of the effectiveness of any future remediation by repeat surveys.

5.1.1 Geophysical survey method

It is expected that the areas of salinity will be more conductive than the unaffected ground/ground water. To measure this contrast in conductivity a terrestrial electromagnetic (EM) survey will be undertaken using the GEM2 multi-frequency electromagnetic sensor.

The advantages of undertaking a GEM2 survey are:

- In reasonably clear ground GEM2 surveys can be conducted quickly (15 – 20 km of line data can be collected a day).
- By simultaneously measuring multiple frequencies the depth of investigation of the GEM2 is ideal for mapping shallow groundwater and salinity.
- The GEM2 is responsive to conductive targets such as areas of high salinity.
- By identifying targets it reduces the amount of intrusive investigation.

The limitations of an EM survey are:

- Highly conductive soils (e.g. wet clays and filter blanket at the toe of the dam) restrict the depth of investigation and may not provide for sufficient contrast to confidently identify likely salinity
- EM surveys can be strongly impacted by cultural features such as power lines, fences and buildings. The EM signal produced by these cultural features can mask the features of interest. As much of the site proposed to be investigated is open ground, this is considered to be minimal.

5.1.2 Geophysical data collection and processing (GEM2)

Based on the site terrain, the data is to be acquired on foot by a two person crew using the GEM2 instrument linked to a differential GPS (i.e. Trimble Pro XRS real-time satellite differential

GPS) with an lateral accuracy: better than ±1 m and vertical accuracy: ±3 m).. Data is to be collected in a grid pattern with lines spaced approximately 5 m apart with the GEM2 held at approximately 1 m above the ground.

The GEM2 instrument simultaneously measures in-phase (I) and quadrature (Q) electromagnetic signals at 5 frequencies, chosen to avoid local electrical noise and provide for an appropriate depth of investigation. From previous experience the In-phase and quadrature signal components will be measured for the following frequencies: 1875 Hz, 4225 Hz, 9825 Hz, 14625 Hz, and 34825 Hz.

GEM2 data processing

The following products will be required to be produced at the end of the GEM2 survey:

- Apparent conductivity maps of the data from the quadrature EM signal, similar to data from conventional EM systems, but multi-frequency and with multiple depths of penetration.
- In-phase EM signal maps (which is susceptible to ferrous and non-ferrous metals) again similar to conventional EM systems, but multi-frequency and with multiple depths of penetration.
- DTM data; and
- A report detailing likely salinity zones and where potential targets for further investigation can be determined.

6. SAP - Health and Safety and Environmental Management

6.1 Job Safety and Environment Assessment Plan

The contractor and/or consultant will be required to prepare a project specific Job Health, Safety and Environment Plan (HSE) or equivalent, to be provided to RTAY for review, in addition to their own requirements for the works. The HSE will describe the health, safety and environment processes to be applied to this project for the activities under RTAY or designated proponent's control. It may include management responsibilities, consultation and communication protocols, risk management, including a summary of relevant site activities and specific job-related tasks; a hazard register that identifies all foreseeable hazards, ranks risks and provides risk management measures for each identified hazard; and, procedures for monitoring and / or implementing remedial actions to manage all project based risks. Managing training, incident reporting, documentation and record management for the project will also need to be detailed.

All staff that undertake field activities are required to undertake RTAY inductions and appropriate training. Also field staff and contractors will be made aware of the contents of the HSE plans prior to commencing work on this site.

In undertaking the works, RTAY will monitor staff and subcontractors so that all persons engaged in the works will have read and understood the HSE Plan and acknowledged in writing their willingness to comply will all requirements and procedures outlined within.

6.2 Excavation Controls

Test pit excavations, where undertaken are to be completed to RTAYs requirements and controlled so that they are safe. Excavations will be compliant with workplace health and safety legislation and standards.

6.3 Reinstatement of Investigation Locations

Procedures for the reinstatement of investigation locations will be conducted in accordance with RTAYs requirements. This will include the following as a minimum:

- Finishing of monitoring wells with stick up monuments, bentonite/cement grouted only;
- Collection of all excess drill cuttings and storage on site (dependent on RTAYs requirements); and
- Reinstatement of test pits with excavated material. Material excavated from the bottom of the test pit will be replaced back into the test pit excavation first to approximately maintain the vertical soil profile that was present prior to excavation.
- Compaction of the test pits is preferred to be undertaken using a sheep's foot roller/ suitable compactor to reduce the potential to increase permeability and preferential flow paths (aim to achieve a similar level of consolidation as undisturbed material).

7. SAP Deliverables

The following deliverables are required following execution of the SAP:

- Scope of work
- Description of the work and methodology of the work undertaken
- Collation of the data collected during the current phase of the works
- Geotechnical logs of test pits and boreholes
- Sampling procedures equipment and details, types (composite/ discrete) , chain of custody documentation, Quality Assurance procedures
- Daily/weekly report on investigations, including daily weather conditions, general observations, areas of concern or possible further investigation locations to be considered along with works undertaken
- Written record of drilling and installation noting any issues during installation (such as hole collapse), undertaken by driller and site geologist/hydrologist) along with geological log, sketch of the proposed installation
- Record of the actual monitoring bore construction installation including: depth to bottom of borehole, depth to base of screen, depth to top of screen, depth to top of filter pack, depth to top of bentonite, PVC stick-up
- Surveyed locations of monitoring bores (easting, northing, ground elevation, top of casing elevation)
- GPS locations of test pits and surface water monitoring points
- Scans of all field notes (drilling, test pitting and water sampling/monitoring)
- Site photographs with details (including area, time, subject and orientation) recorded during the investigation (digital)
- Laboratory results (hard copy, lab excel and ESDAT files, COCs)
- Tabulated field water quality results (excel)
- Logger installation details (including depth to water at installation)
- Tabulated water level data (dip and raw and corrected logger data) in excel including measurement of bore depth and monument stick up, depth to groundwater, level in mAHD (including where repeat monitoring is undertaken)
- Aquifer testing analysis results reported as hydraulic conductivity. Raw pressure and water level electronic data files, pre and post-test manual water level data for quality control purposes
- Additional monitoring data including northern embankment groundwater monitoring, toe drain pumping and details on operations that may affect or influence the SAP outcomes
- Additional assessments that may be undertaken at the site, including soil salinity, stormwater, or other relevant investigation report

8. References

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- GHD Pty Ltd (2013b), Yarwun Residue Management Area – 2013 Annual Dam Safety Inspection, Rev 1, November 2013. GHD document reference 41/25896/452913.
- GHD Pty Ltd (2014), Yarwun Residue Management Area – 2014 Capacity Increase, Detailed Design, Rev 1, March 2014. GHD document reference 41/27017/456088.
- GHD Pty Ltd (2015), Yarwun Residue Management Area – 2015 Capacity Increase, Detailed Design, Rev 0, October 2014. GHD document reference 41/27837/460389.

Appendices

Appendix A – Northern Embankment Investigation and Monitoring Location Plans

Figure 1 – Historic investigation locations (northern embankment area)

Figure 2 – Groundwater monitoring plan (northern embankment)

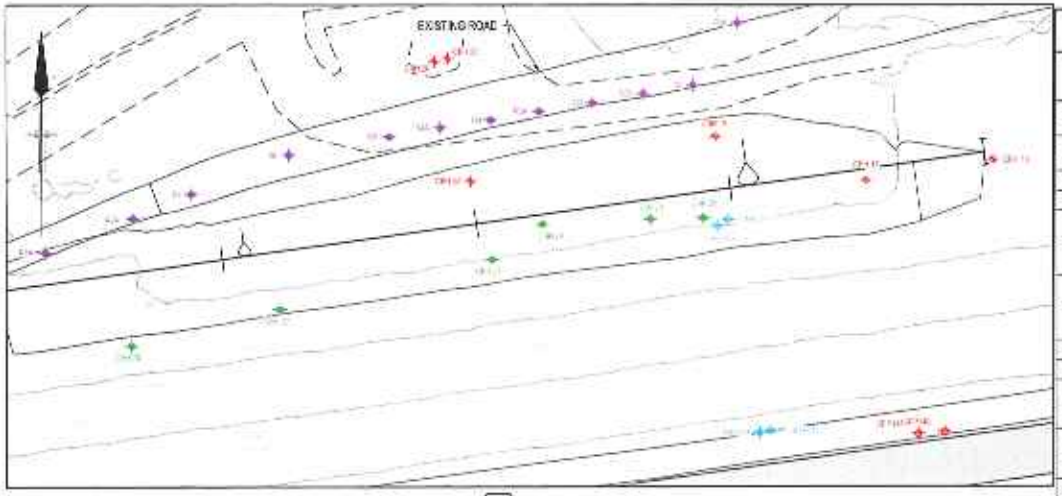


RIO TINTO ALCAN
YARWUN RMA GROUNDWATER MANAGEMENT ACTIONS
PREVIOUS GEOTECHNICAL INVESTIGATIONS AT RTAY RMA SITE

Job Number 41-28523
Revision A
Date JAN 2015

Figure 01

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PIEZOMETER AND BOREHOLE SETOUT TABLE

POINT	EASTING	NORTHING	SURFACE RL (02 OCT 2013 SURVEY)
DSH 0001	304640.350	7359999.505	DECOMMISSIONED (30 NOV 2012)
DSH 0002	304399.671	7359995.667	DECOMMISSIONED (30 NOV 2012)
DSH 0003	304022.672	7359999.452	69.95
DSH 0004	303937.111	7359998.964	69.87
DSH 0005	303816.352	7359997.408	BURIED/NOT FOUND (2 OCT 2013) (ASSUMED DECOMMISSIONED)
DSH 0006	303816.597	7359987.269	BURIED/NOT FOUND (2 OCT 2013) (ASSUMED DECOMMISSIONED)
DSH 0007	303828.631	7359944.974	61.83
DSH 0008	303806.978	7359943.659	61.83
DSH 0009	303676.233	7359885.709	62.09 (ASSUMED DECOMMISSIONED)
DSH 0010	303674.252	7359885.203	62.04 (ASSUMED DECOMMISSIONED)
DSH 0011	303997.272	7359925.467	65.16
DSH 0012	303994.853	7359926.408	65.15
DSH 0013	303463.661	7359943.309	61.27
DSH 0014	303460.552	7359942.781	61.26
DSH 0015	303444.443	7359864.402	64.32

PIEZOMETER AND BOREHOLE SETOUT TABLE

POINT	EASTING	NORTHING	SURFACE RL (02 OCT 2013 SURVEY)
CBH 0216	303442.231	7359883.291	64.67
CBH 0217	303471.972	7359881.582	64.54
CBH 0218	303488.072	7359885.582	65.33
CBH 0219	303441.972	7359930.482	61.62
CBH 0220	303425.572	7359884.682	64.39^
CBH 0221	303398.472	7359878.582	64.03^
CBH 0222	303357.072	7359880.582	66.29^
CBH 0223	303384.272	7359881.782	62.46
CBH 0224	303326.072	7359858.882	67.74^
CBH 0225	303389.300	7359819.700	62.68
CBH 0226	303367.300	7359810.100	62.60
CBH 0227	303368.400	7359828.900	62.25
CBH 0228	303374.510	7359819.400	62.50
CBH 0229	303406.272	7359883.467	"
CBH 0230	303426.272	7359884.467	"
686E	303805.572	7359943.867	61.44
PI 1	303450.200	7359867.000	66.40
P 2	303395.700	7359895.000	66.15
P 3	303333.200	7359892.000	62.50
P 4	303370.300	7360044.000	66.95
VWP01-A	304041.332	7359888.974	62.015^^
VWP01-B	304041.332	7359888.974	62.015^^
VWP02-A	303816.035	7359892.951	61.974^^
VWP02-B	303816.035	7359892.951	61.974^^

PIEZOMETER AND BOREHOLE SETOUT TABLE

POINT	EASTING	NORTHING	SURFACE R. (02 OCT 2013 SURVEY)
VWP23-A	303559.968	7359870.933	61.349^^
VWP23-B	303559.968	7359870.933	61.349^^
SPP01	303575.443	7359917.207	65.289^^
SPP02	303575.175	7359920.177	65.25^^

^ CONVERTED TO PRESSURE RELIEF WELLS
^^ SURVEY, GOLDINGS DECEMBER 2013

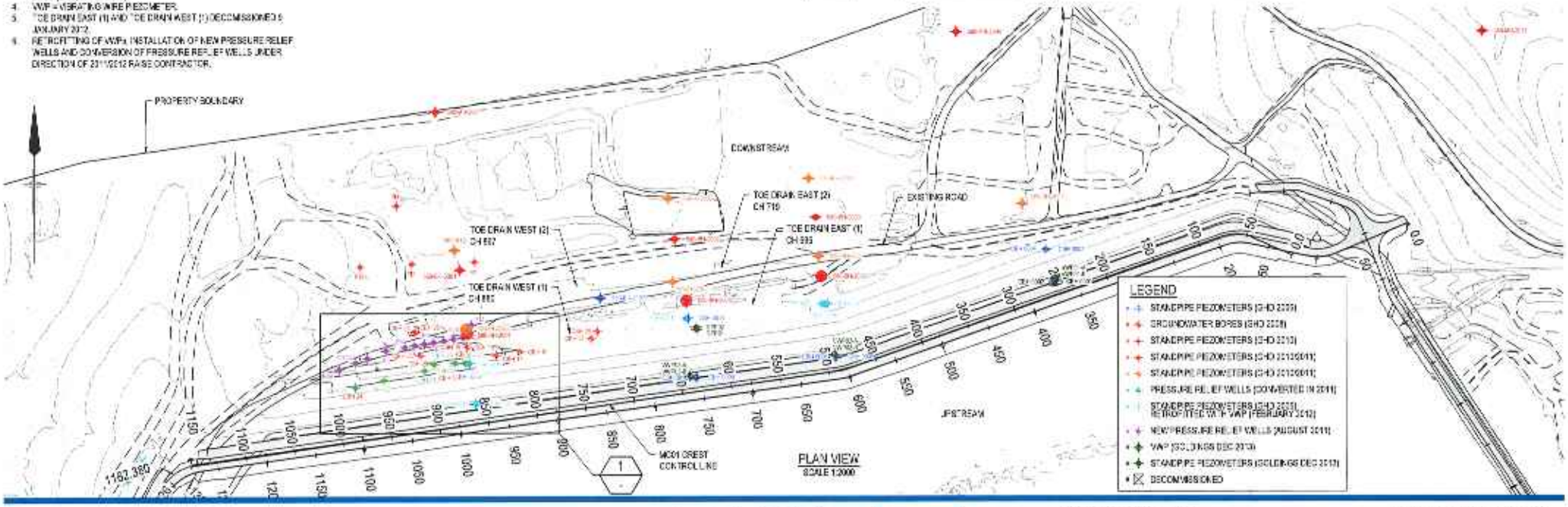
NEW PRESSURE RELIEF BORES SETOUT TABLE

POINT	EASTING	NORTHING	SURFACE RL (OCT 2011 SURVEY)
R1A	303446.0	7359932.7	59.22
R2	303437.6	7359910.4	59.53
R2A	303427.0	7359938.8	59.78
R3	303418.0	7359937.0	59.68
R3A	303407.6	7359935.4	60.48
R4	303398.2	7359933.7	60.88
R4A	303388.4	7359932.2	63.91
R5	303378.4	7359931.4	61.33
R6	303368.0	7359929.0	61.88
R7	303358.0	7359888.3	62.44
R7A	303328.0	7359884.5	63.01
R8A	303311.0	7359877.8	64.15

GENERAL NOTES:

1. SURFACE PROFILE BASED ON LIDAR SURVEY DATED 02 OCTOBER 2013
2. ALL CO-ORDINATES ARE TO MGA94 - ZONE 56
3. PIEZOMETER AND BOREHOLE LOCATIONS ARE BASED ON PIEZOMETER LOGS (2008, 2009 & 2010).
4. VWP = VIBRATING WIRE PIEZOMETER.
5. "TOE DRAIN EAST (1) AND "TOE DRAIN WEST (1) DECOMMISSIONED 5 JANUARY 2012.
6. RETROFITTING OF VWPs, INSTALLATION OF NEW PRESSURE RELIEF WELLS AND CONVERSION OF PRESSURE RELIEF WELLS UNDER DIRECTION OF 2011/2012 RAISE CONTRACTOR.

1 DETAIL
SCALE 1 : 500



PLAN VIEW
SCALE 1:2000

SCALE 1:500 AT ORIGINAL SIZE

SCALE 1:2000 AT ORIGINAL SIZE

RIO TINTO ALCAN
YARWUN RMA GROUNDWATER MANAGEMENT ACTIONS

YARWUN RMA EXISTING PIEZOMETER MONITORING PLAN

Job Number 41-28523
Revision A
Date JAN 2015

Figure 02

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Appendix B – Data Analysis & Time Series
Groundwater Elevations

Figure 3 – Depth to groundwater October 2014

Figure 4 – Groundwater elevations October 2014

Northern Embankment groundwater levels charts (from Residue Management Area (area 580) Quarterly Integrity – Inspection and Monitoring July 2014 (GHD October 2014)



0 20 40 60 80 100m
SCALE 1:2000 AT ORIGINAL SIZE

RIO TINTO ALCAN
YARWUN RMA GROUNDWATER MANAGEMENT ACTIONS

DEPTH TO GROUNDWATER OCTOBER 2014 WATER LEVELS

Job Number 41-28523
Revision A
Date JAN 2015

Figure 03

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PLAN VIEW
SCALE 1:2000

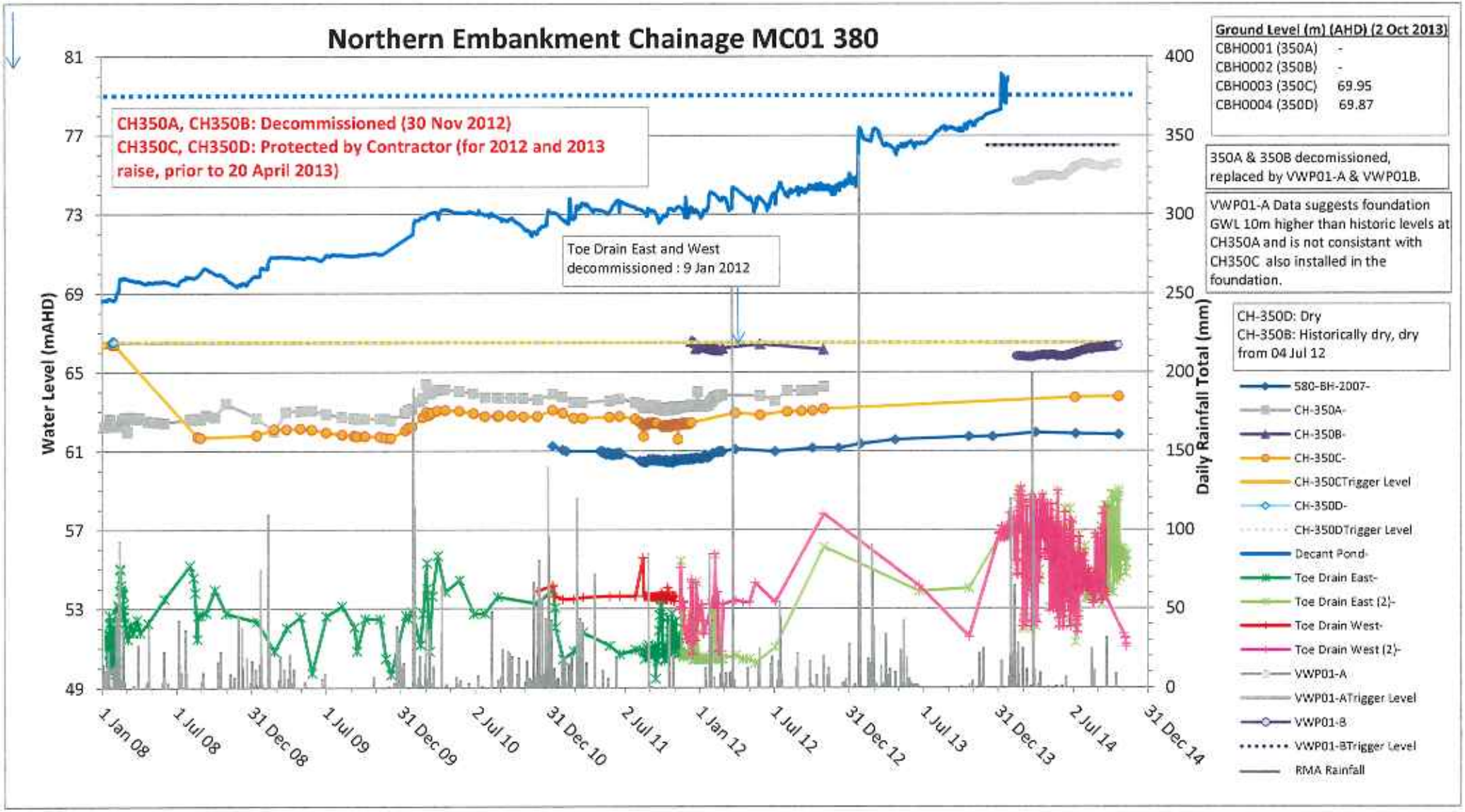
0 20 40 60 80 100m
SCALE 1:2000 AT ORIGINAL SIZE

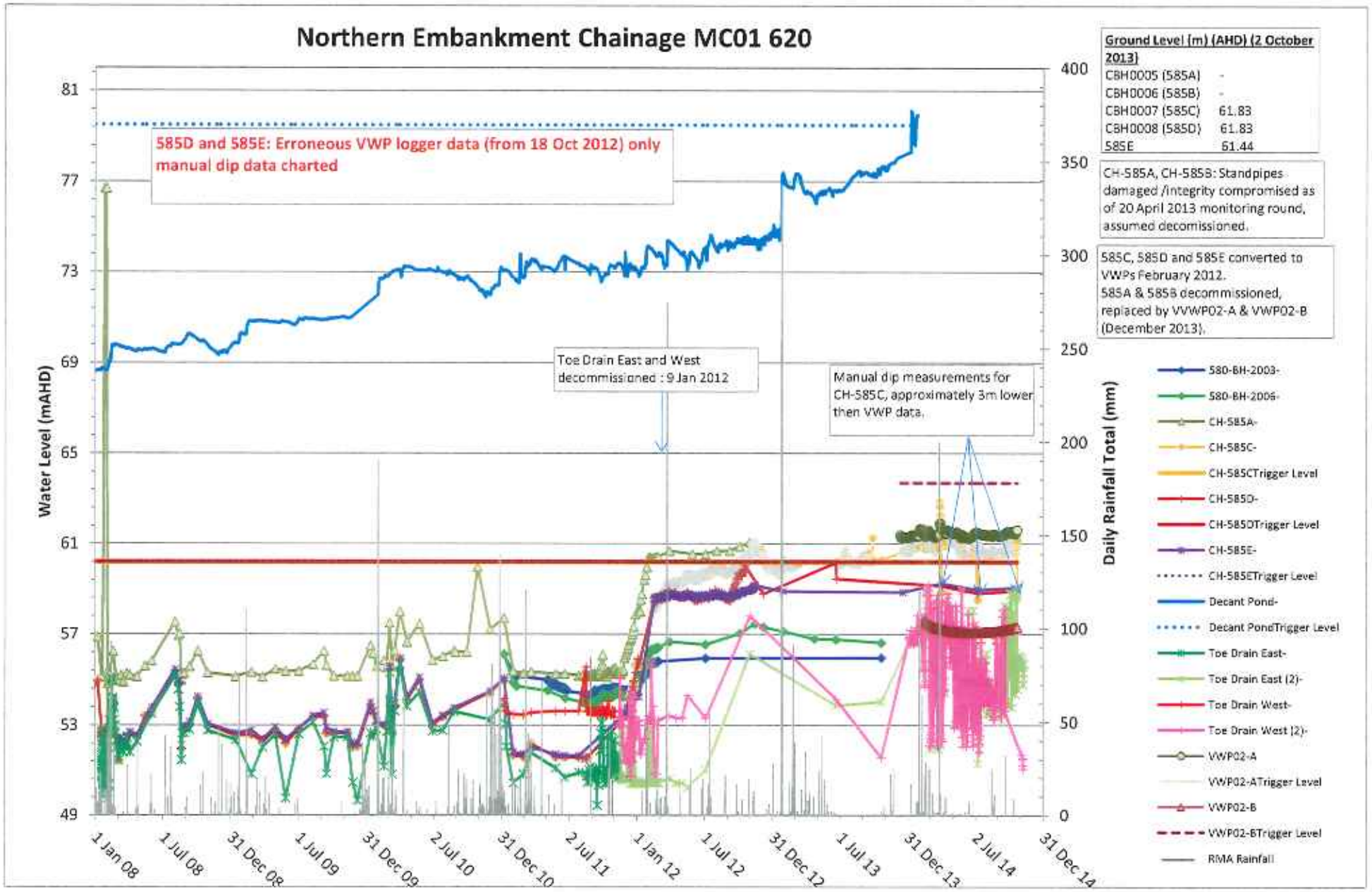
GHD

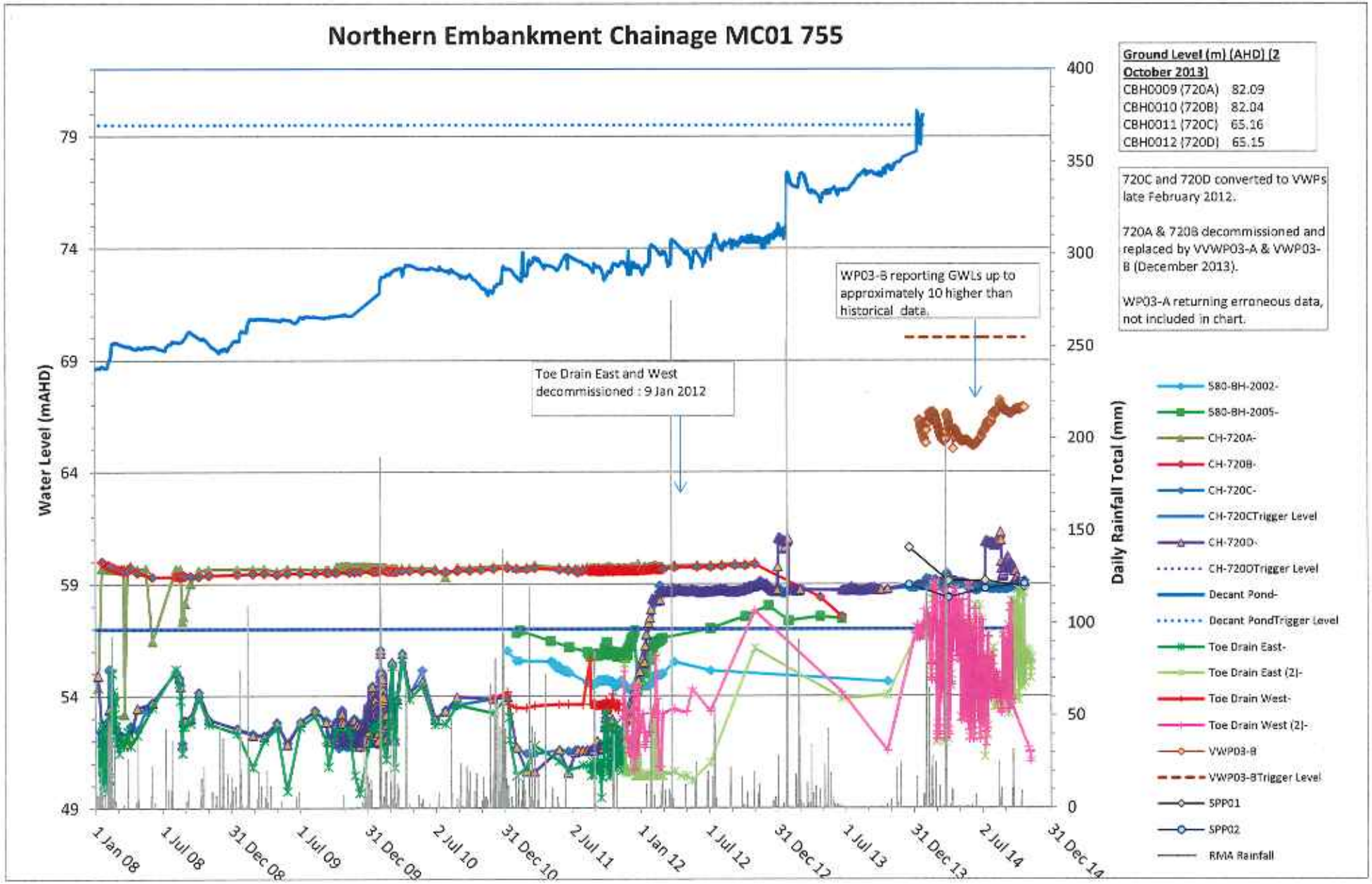
RIO TINTO ALCAN
YARWUN RMA GROUNDWATER MANAGEMENT ACTIONS
GROUNDWATER ELEVATION
OCTOBER 2014 WATER LEVELS

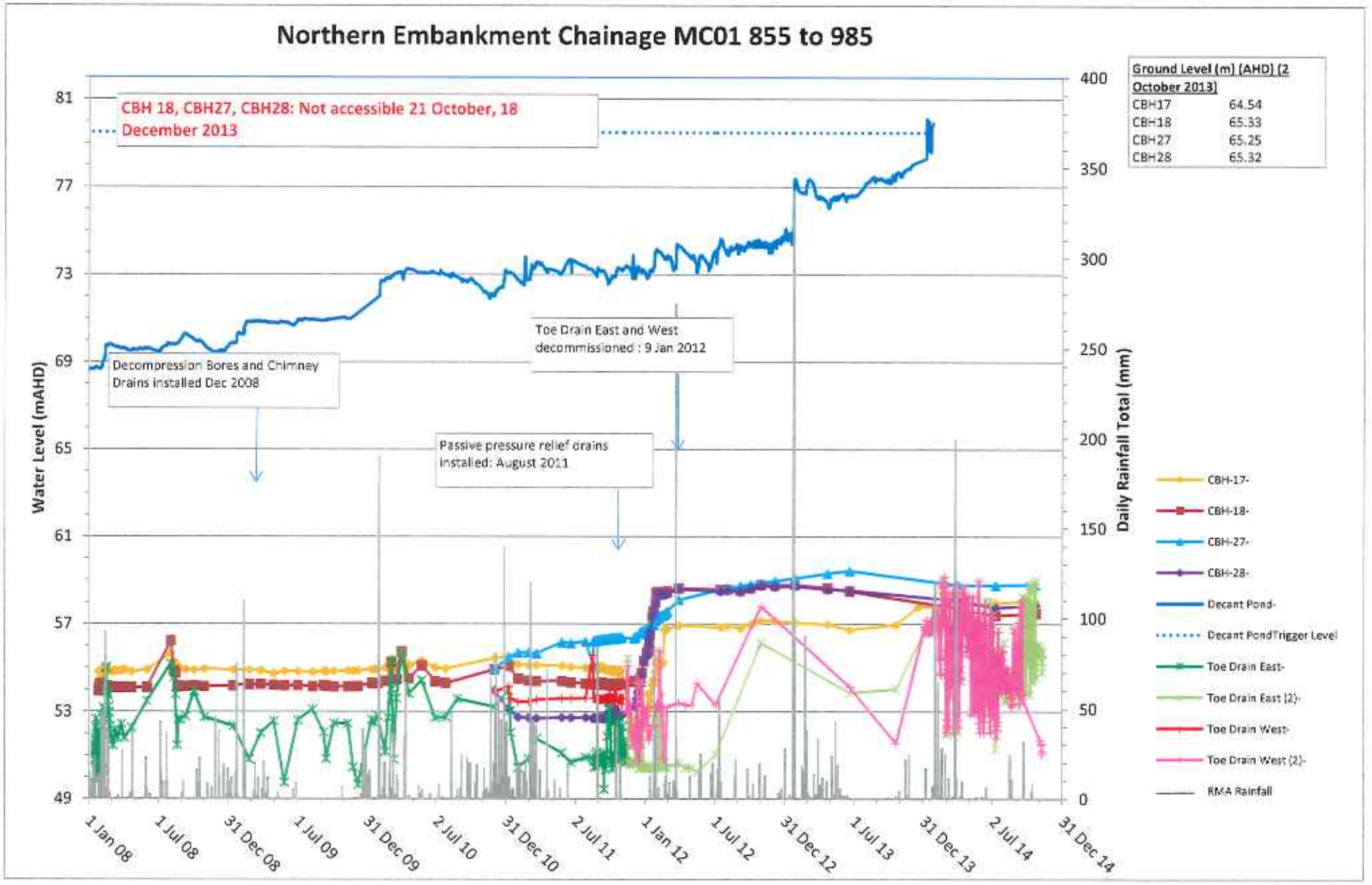
Job Number 41-28523
Revision A
Date JAN 2015
Figure 04

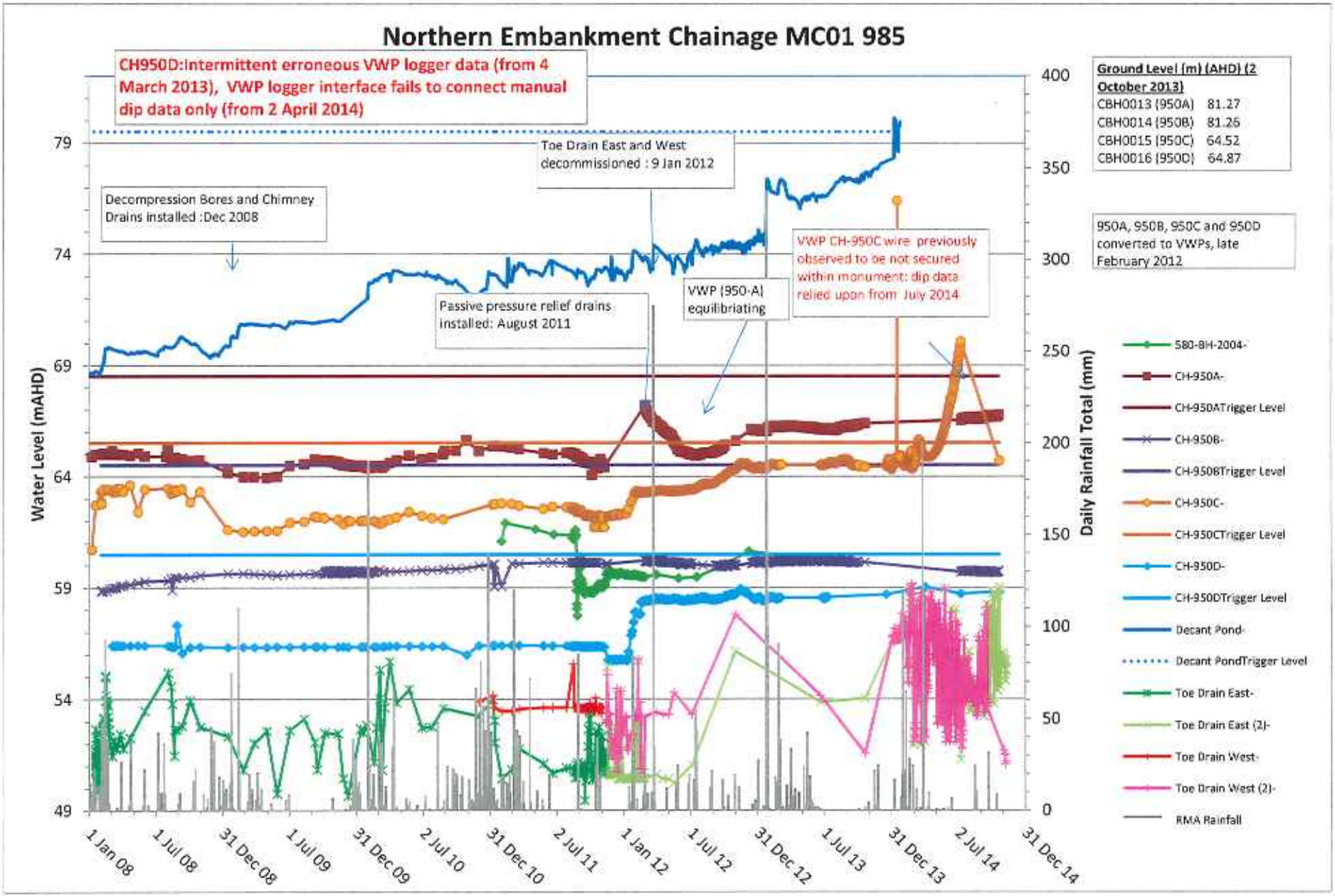
146 Arn St Brisbane QLD 4000 Australia T 61 7 3316 3000 F 61 7 3316 3333 E brmail@ghd.com W www.ghd.com

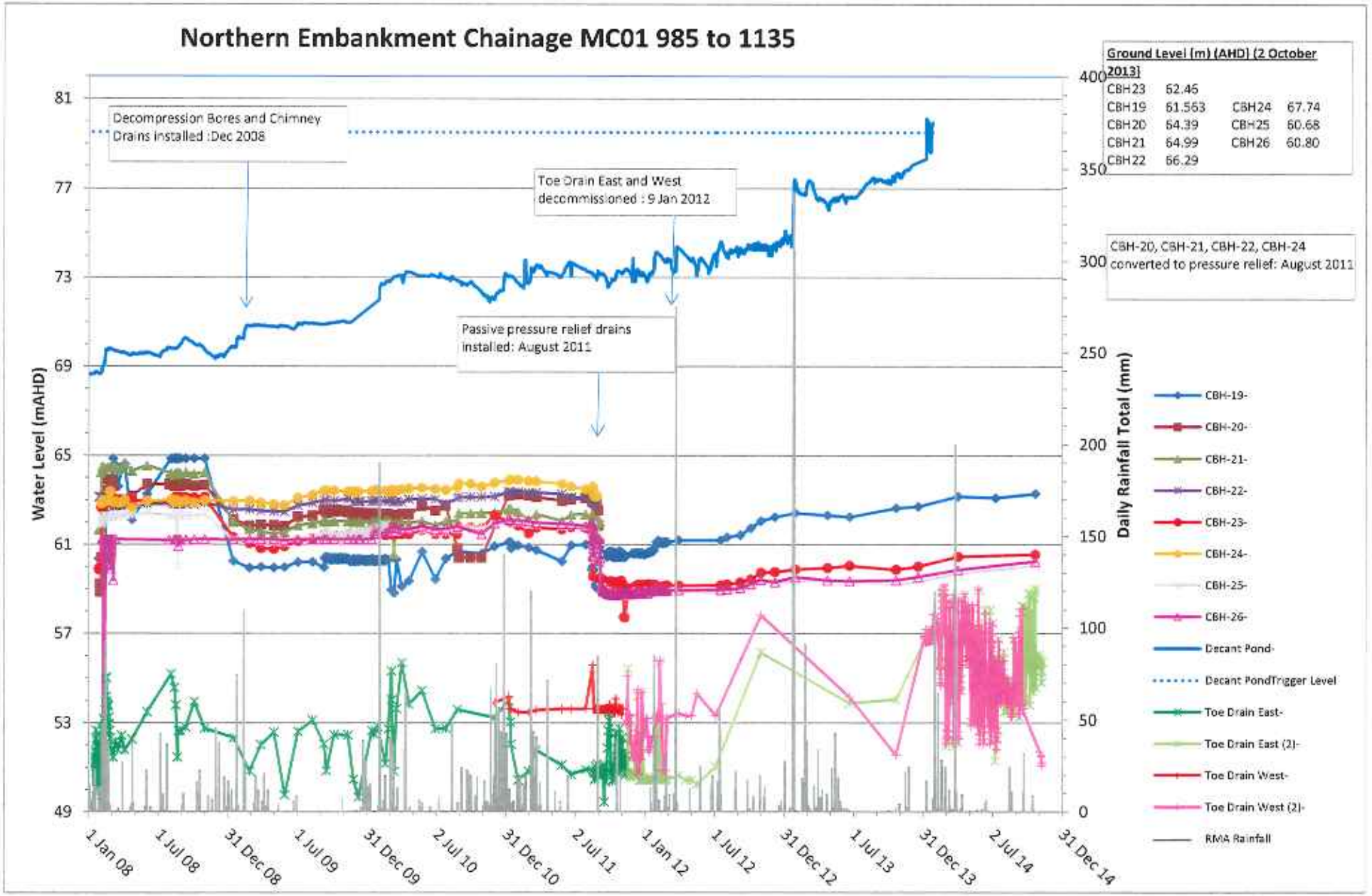

Northern Embankment Chainage MC01 380
CH350A, CH350B: Decommissioned (30 Nov 2012)
CH350C, CH350D: Protected by Contractor (for 2012 and 2013 raise, prior to 20 April 2013)
Toe Drain East and West decommissioned : 9 Jan 2012
Ground Level (m) (AHD) (2 Oct 2013)
CBH0001 (350A) -
CBH0002 (350B) -
CBH0003 (350C) 69.95
CBH0004 (350D) 69.87
350A & 350B decomissioned, replaced by VWP01-A & VWP01B.
VWP01-A Data suggests foundation GWL 10m higher than historic levels at CH350A and is not consistant with CH350C also installed in the foundation.
CH-350D: Dry
CH-350B: Historically dry, dry from 04 Jul 12
Water Level (mAHD)
Daily Rainfall Total (mm)
81
77
73
69
65
61
57
53
49
400
350
300
250
200
150
100
50
0
1 Jan 08
1 Jul 08
31 Dec 08
1 Jul 09
31 Dec 09
2 Jul 10
31 Dec 10
2 Jul 11
1 Jan 12
1 Jul 12
31 Dec 12
1 Jul 13
31 Dec 13
2 Jul 14
31 Dec 14
580-BH-2007-
CH-350A-
CH-350B-
CH-350C-
CH-350CTrigger Level
CH-350D-
CH-350DTrigger Level
Decant Pond-
Toe Drain East-
Toe Drain East (2)-
Toe Drain West-
Toe Drain West (2)-
VWP01-A
VWP01-ATrigger Level
VWP01-B
VWP01-BTrigger Level
RMA Rainfall


Northern Embankment Chainage MC01 620
Water Level (mAHD)
Daily Rainfall Total (mm)
81
77
73
69
65
61
57
53
49
400
350
300
250
200
150
100
50
0
1 Jan 08
1 Jul 08
31 Dec 08
1 Jul 09
31 Dec 09
2 Jul 10
31 Dec 10
2 Jul 11
1 Jan 12
1 Jul 12
31 Dec 12
1 Jul 13
31 Dec 13
2 Jul 14
31 Dec 14
585D and 585E: Erroneous VWP logger data (from 18 Oct 2012) only manual dip data charted
Toe Drain East and West decommissioned : 9 Jan 2012
Manual dip measurements for CH-585C, approximately 3m lower then VWP data.
Ground Level (m) (AHD) (2 October 2013)
CBH0005 (585A) -
CBH0006 (585B) -
CBH0007 (585C) 61.83
CBH0008 (585D) 61.83
585E 61.44
CH-585A, CH-585B: Standpipes damaged /integrity compromised as of 20 April 2013 monitoring round, assumed decomissioned.
585C, 585D and 585E converted to VWPs February 2012.
585A & 585B decommissioned, replaced by VWP02-A & VWP02-B (December 2013).
580-BH-2003-
580-BH-2006-
CH-585A-
CH-585C-
CH-585CTrigger Level
CH-585D-
CH-585DTrigger Level
CH-585E-
CH-585ETrigger Level
Decant Pond-
Decant PondTrigger Level
Toe Drain East-
Toe Drain East (2)-
Toe Drain West-
Toe Drain West (2)-
VWP02-A
VWP02-ATrigger Level
VWP02-B
VWP02-BTrigger Level
RMA Rainfall


Northern Embankment Chainage MC01 755
Water Level (mAHD)
Daily Rainfall Total (mm)
79
74
69
64
59
54
49
400
350
300
250
200
150
100
50
0
1 Jan 08
1 Jul 08
31 Dec 08
1 Jul 09
31 Dec 09
2 Jul 10
31 Dec 10
2 Jul 11
1 Jan 12
1 Jul 12
31 Dec 12
1 Jul 13
31 Dec 13
2 Jul 14
31 Dec 14
Ground Level (m) (AHD) (2 October 2013)
CBH0009 (720A) 82.09
CBH0010 (720B) 82.04
CBH0011 (720C) 65.16
CBH0012 (720D) 65.15
720C and 720D converted to VWPs late February 2012.
720A & 720B decommissioned and replaced by VWWP03-A & VWP03-B (December 2013).
WP03-A returning erroneous data, not included in chart.
WP03-B reporting GWLs up to approximately 10 higher than historical data.
Toe Drain East and West decommissioned : 9 Jan 2012
S80-BH-2002-
S80-BH-2005-
CH-720A-
CH-720B-
CH-720C-
CH-720CTrigger Level
CH-720D-
CH-720DTrigger Level
Decant Pond-
Decant PondTrigger Level
Toe Drain East-
Toe Drain East (2)-
Toe Drain West-
Toe Drain West (2)-
VWP03-B
VWP03-BTrigger Level
SPP01
SPP02
RMA Rainfall


Northern Embankment Chainage MC01 855 to 985
CBH 18, CBH27, CBH28: Not accessible 21 October, 18 December 2013
Decompression Bores and Chimney Drains installed Dec 2008
Toe Drain East and West decommissioned : 9 Jan 2012
Passive pressure relief drains installed: August 2011
Ground Level (m) (AHD) (2 October 2013)
CBH17 64.54
CBH18 65.33
CBH27 65.25
CBH28 65.32
Water Level (mAHD)
Daily Rainfall Total (mm)
81
77
73
69
65
61
57
53
49
400
350
300
250
200
150
100
50
0
1 Jan 08
1 Jul 08
31 Dec 08
1 Jul 09
31 Dec 09
2 Jul 10
31 Dec 10
2 Jul 11
1 Jan 12
1 Jul 12
31 Dec 12
1 Jul 13
31 Dec 13
2 Jul 14
31 Dec 14
CBH-17-
CBH-18-
CBH-27-
CBH-28-
Decant Pond-
Decant PondTrigger Level
Toe Drain East-
Toe Drain East (2)-
Toe Drain West-
Toe Drain West (2)-
RMA Rainfall


Northern Embankment Chainage MC01 985
CH950D:Intermittent erroneous VWP logger data (from 4 March 2013), VWP logger interface fails to connect manual dip data only (from 2 April 2014)
Toe Drain East and West decommissioned : 9 Jan 2012
Decompression Bores and Chimney Drains installed :Dec 2008
Passive pressure relief drains installed: August 2011
VWP (950-A) equilibriating
VWP CH-950C wire previously observed to be not secured within monument: dip data relied upon from July 2014
950A, 950B, 950C and 950D converted to VWPs, late February 2012
Ground Level (m) (AHD) (2 October 2013)
CBH0013 (950A) 81.27
CBH0014 (950B) 81.26
CBH0015 (950C) 64.52
CBH0016 (950D) 64.87
Water Level (mAHD)
Daily Rainfall Total (mm)
79
74
69
64
59
54
49
400
350
300
250
200
150
100
50
0
1 Jan 08
1 Jul 08
31 Dec 08
1 Jul 09
31 Dec 09
2 Jul 10
31 Dec 10
2 Jul 11
1 Jan 12
1 Jul 12
31 Dec 12
1 Jul 13
31 Dec 13
2 Jul 14
31 Dec 14
580-BH-2004-
CH-950A-
CH-950ATrigger Level
CH-950B-
CH-950BTrigger Level
CH-950C-
CH-950CTrigger Level
CH-950D-
CH-950DTrigger Level
Decant Pond-
Decant PondTrigger Level
Toe Drain East-
Toe Drain East (2)-
Toe Drain West-
Toe Drain West (2)-
RMA Rainfall


Northern Embankment Chainage MC01 985 to 1135
Ground Level (m) (AHD) (2 October 2013)
CBH23 52.45
CBH19 61.563
CBH24 67.74
CBH20 64.39
CBH25 60.68
CBH21 64.99
CBH26 60.80
CBH22 66.29
Decompression Bores and Chimney Drains installed :Dec 2008
Toe Drain East and West decommissioned : 9 Jan 2012
Passive pressure relief drains installed: August 2011
CBH-20, CBH-21, CBH-22, CBH-24 converted to pressure relief: August 2011
Water Level (mAHD)
Daily Rainfall Total (mm)
81
77
73
69
65
61
57
53
49
400
350
300
250
200
150
100
50
0
1 Jan 08
1 Jul 08
31 Dec 08
1 Jul 09
31 Dec 09
2 Jul 10
31 Dec 10
2 Jul 11
1 Jan 12
1 Jul 12
31 Dec 12
1 Jul 13
31 Dec 13
2 Jul 14
31 Dec 14
CBH-19-
CBH-20-
CBH-21-
CBH-22-
CBH-23-
CBH-24-
CBH-25-
CBH-26-
Decant Pond-
Decant PondTrigger Level
Toe Drain East-
Toe Drain East (2)-
Toe Drain West-
Toe Drain West (2)-
RMA Rainfall

Appendix C –Typical Bore Construction Details/Specification

1. Specification for Monitoring Bore Design

1.1 Standpipe piezometer installation materials

- Drilled borehole of 150 mm diameter (to provide a good thickness of filter pack to minimise fines entering the monitoring bore).
- Installation of a 50 mm internal diameter uPVC standpipe piezometer.
- The PVC should be: class 18, screw threaded, acid washed and the screened section should be machine slotted (aperture 0.4-0.5 mm).
- Plastic centralisers (as a minimum, placed at the base of the screen and top of the screen and every 3 m).
- Push on plastic end cap.
- Push on plastic top cap or J - plug / Torquer plug.
- Filter pack – 2 mm washed and graded silica sand.
- Bentonite pellets – "1/4 inch" coated pellets.
- Bentonite - cement grout (made with minimum 3% and a maximum of 10% bentonite powder).
- Lockable flush-mounted well cover or monument well cover (this depends on individual requirements) - cemented into place (quick set cement works well for this).
- A weighted tape for measuring installation of filter pack etc.

1.2 Drilling/Installation Fluids

Ideally the boreholes, where possible, will be drilled using a sonic rig (and hence no drilling fluids required and minimal water use). The drilling contractor selected should have available a number of techniques at his disposal, including triple tube core, rotary hammer etc. at the site. The use of a sonic head is considered to provide a number of benefits for drilling, casing off and isolating as well as obtaining samples through the profile within the embankments and within the alluvium and upper weathered sediments. Where possible, by sonic or other methods, it should allow continuous core sampling to be completed that will provide relatively undisturbed borehole samples that can be extracted from the drilled profile. Consideration should also be made of the core integrity with regard to the various methods adopted to allow various levels of interpretation/ accurate recording of the profile, where required.

- Licenced Queensland driller to undertake drilling.
  - No hydrocarbons, no solvents / glues on any installation materials / equipment put down the borehole.
  - Only use vegetable based lubricants / grease etc.

1.3 Typical Installation

- Drill bore hole to target depth, to be confirmed by onsite geologist/hydrologist at the time of drilling the borehole (generally between 5 and 10 m below the water table). If drilling a nested bore, drill the

deep borehole first so that subsurface conditions in shallow bore are anticipated and target depth of shallow borehole planned.

- Where nested bores are required targeting two depths (i.e. clay core and foundation), individual bores will be located adjacent to each other (approx. 3 m separation).
- Continuous sampling of profile to enable logging and determination of target depth and formation.
- Prior to installation of the standpipe ensure that the depth to the top of the screen will be a minimum of 4 m below ground surface, i.e. sufficient to allow for a minimum of 2 m thickness of bentonite cement grout from ground surface to ensure good seal.
- Install 1 to 3 m of screen from the base of the borehole (with centralisers) dependant on onsite geologist/hydrologist requirements.
- Filter pack to 0.5 - 1 m above the top of the screen (drillers should have a weighted tape for checking depths).
- 1 m seal of bentonite pellets (add sufficient water to hydrate if above groundwater table) - leave a minimum 0.5 hour to swell before grouting. A real-time test to confirm hydration rate shall also be performed to verify hydration time required.
- Backfill with bentonite-cement grout mix to ground surface.
- Install monument, ensure top of pvc casing and bore cap can be easily accessed and that lid of monument closes properly.
- GPS the location.

1.4 Written Record of Drilling and Installation (undertaken by driller and site geologist/hydrologist)

- Geological log.
- Sketch of the proposed installation (depth to base of screen, depth to top of screen, depth to top of filter pack, depth to top of bentonite etc).
- Sketch / record the actual installation including: depth to base of screen, depth to top of screen, depth to top of filter pack, depth to top of bentonite etc., note any issues during installation (such as hole collapse).

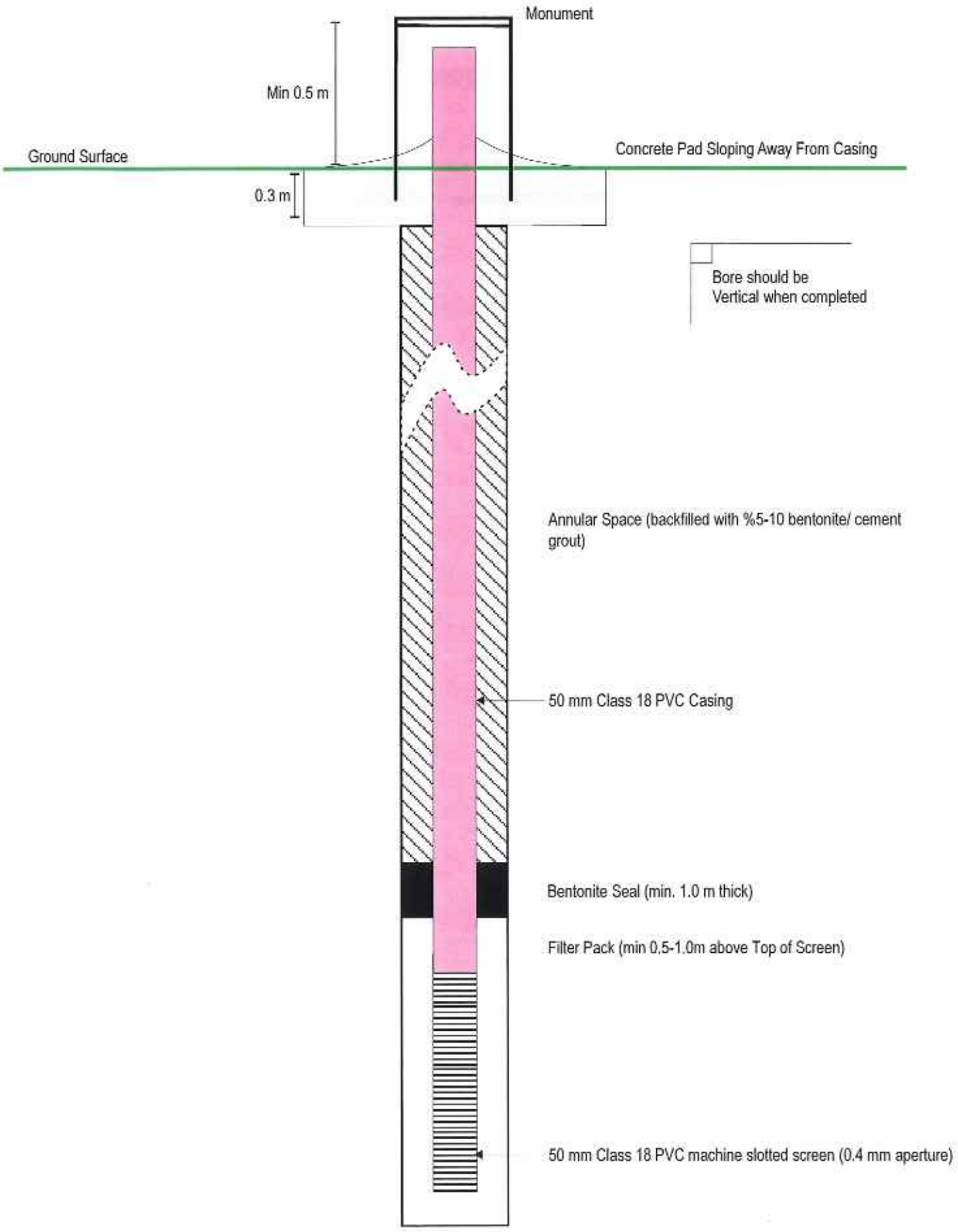
1.5 Bore Development

- The bores need to be developed before they can be used to monitor groundwater (i.e. remove fines present in the groundwater from the monitoring bore and the filter pack surrounding the screen).
- Development should be via airlifting until <1 cm^3 of fines are present in 10 litres of water removed from the borehole, or continue for 1 hour (whichever occurs first).
- If bores are slow to recharge the most effective way to develop them will be to use Waterra tubing (high density, fitted with a footvalve) with a surge block attached.
- Development should be conducted > 24 hours after completion of installation (grouted) to ensure grout seal has set.

1.6 Standard Drawing

The following is a standard drawing for design of a monitoring bore and does not take into account site specific hydrogeological conditions. Bores installation supervision and final design are to be completed by a site Hydrogeologist after an assessment of sub-surface conditions and hydrogeological characteristic are known, therefore modifications to the standard design may be required.

All monitoring bores should be installed in accordance with the National Uniform Drillers Licensing Council (NUDLC) *Minimum Construction Requirement for Water Bores in Australia, 2012.*

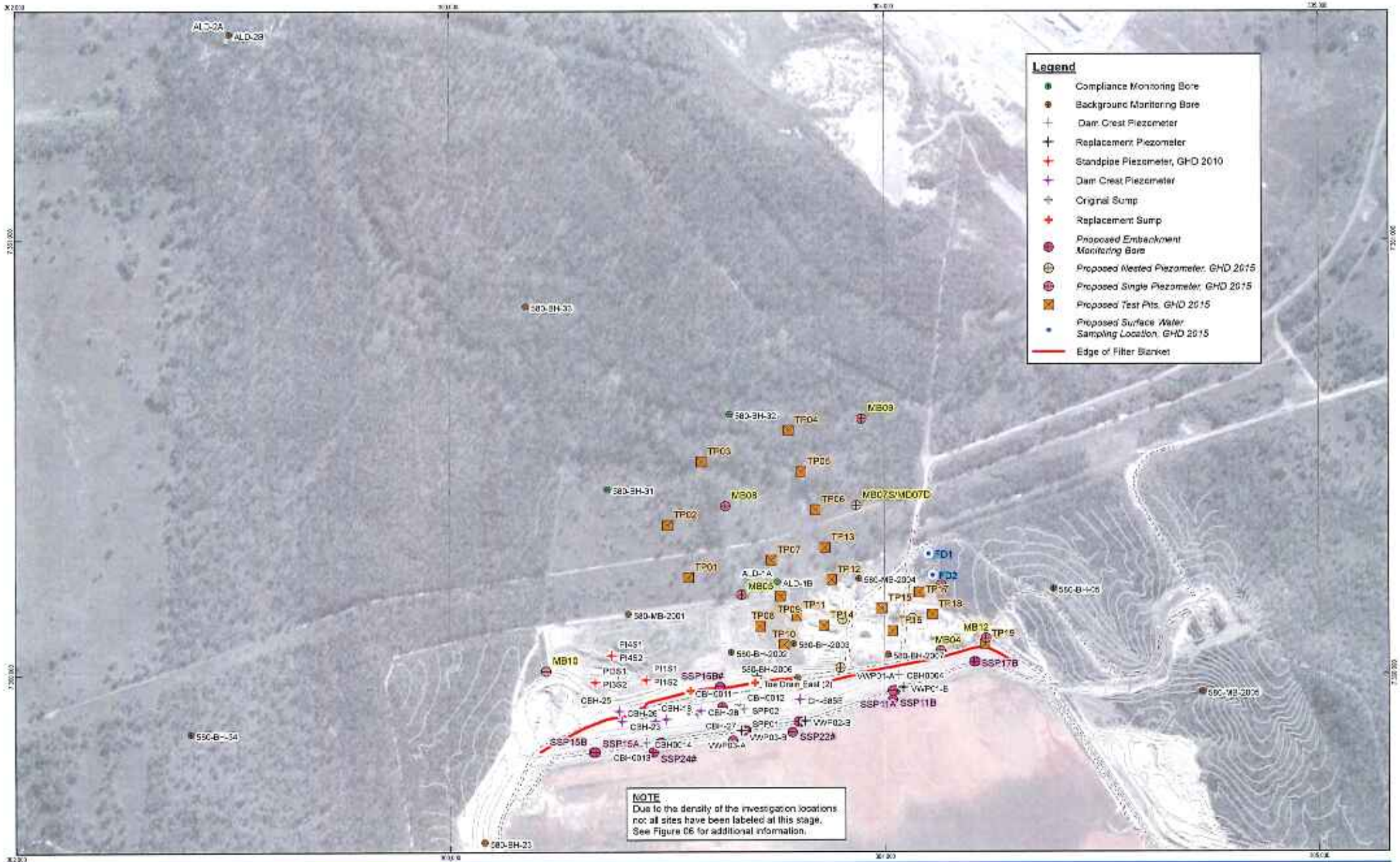

Monument
Min 0.5 m
Ground Surface
Concrete Pad Sloping Away From Casing
0.3 m
Bore should be
Vertical when completed
Annular Space (backfilled with %5-10 bentonite/ cement grout)
50 mm Class 18 PVC Casing
Bentonite Seal (min. 1.0 m thick)
Filter Pack (min 0.5-1.0m above Top of Screen)
50 mm Class 18 PVC machine slotted screen (0.4 mm aperture)

Appendix D – SAP Proposed Investigation Locations Plan and Summary Table

Figure 5 –Investigation Locations (northern embankment and near vicinity)

Figure 6 – Investigation Locations (northern embankment)

SAP Summary Table



1:8,000 (at A3)

0 80 160 240 320 400

Metres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

RIO TINTO ALCAN
Yarwun RMA Groundwater Management Actions

Job Number 41-28523
Revision A
Date 25 Feb 2015

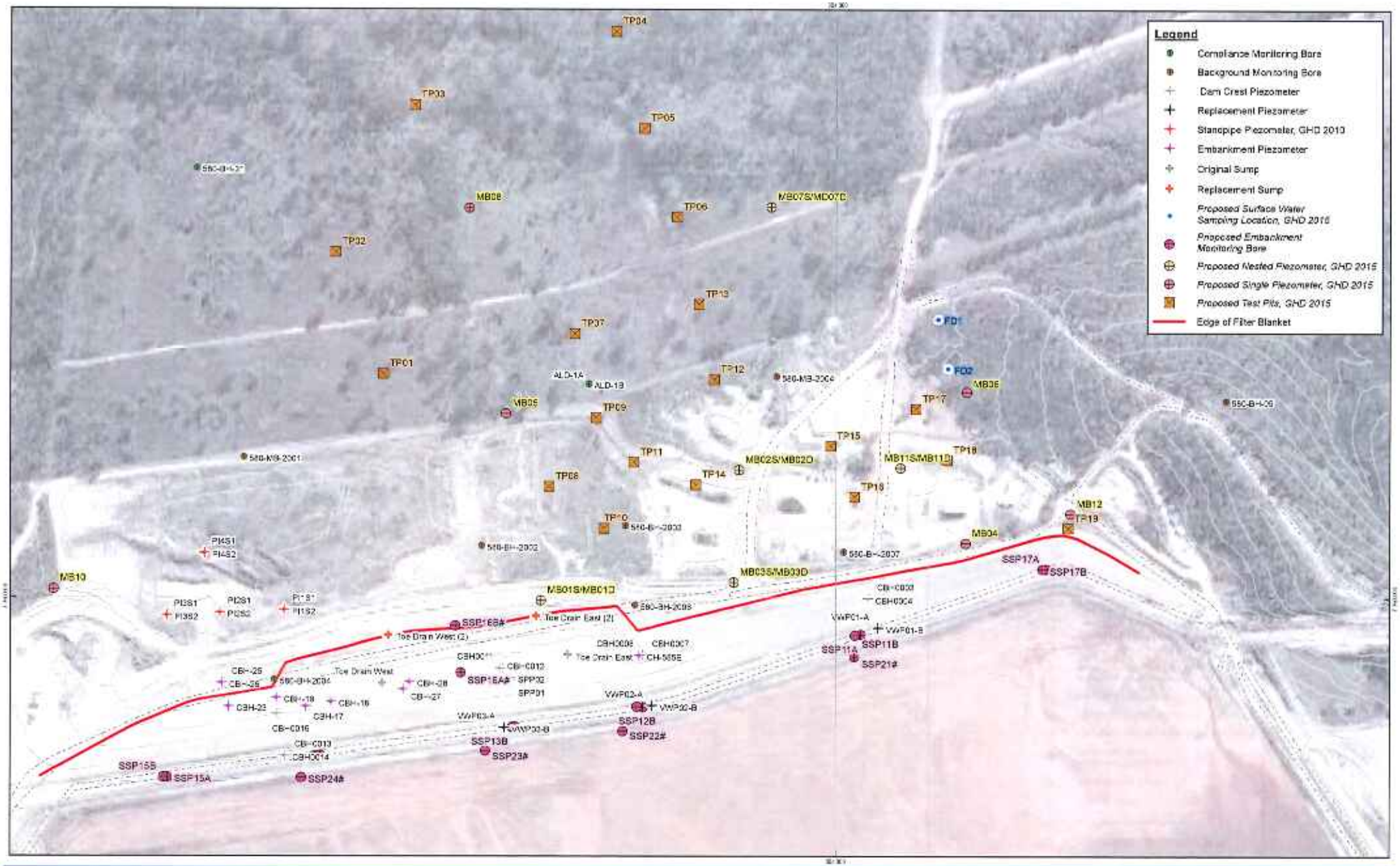
Investigation Locations

Figure 05

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Data source: Data Custodian, Data Set Name/Title, Version/Date, Creation

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1:3,500 [at A3]

0 50 100 200

Metres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

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RIO TINTO ALCAN
Yarwun RMA Groundwater
Management Actions

Job Number 41-28523
Revision A
Date 25 Feb 2015

Investigation Locations

Figure 06

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GHD - SAP Summary Table
27 February 2015

Location	Identifier/ grid position	Purpose (presure delineation = P, fire dam = FD, management options = M)	Operational status (Existing =E, new =N, U = unknown)	Data Objective (G = GW elevation, SG=slug tests, Q= water quality, R= remedial ,S= Soil health, DP depressurisation)	Monitoring Type (Test Pit, GW bore, surface water)	Sample Type (water/ soil/ geotech)	Approx Depth Borehole/ test pit (m)	No. Water Samples Initial (estimate)	No. SOIL Samples Initial (estimate)	No. Samples Ongoing per annum (estimate)	Rational for location of proposed new monitoring bore/test pit
RMA: Groundwater monitoring of embankment and toe											
Toe Drain	Toe Drain East (2)	M	E	GW, DP	GW	W				1	
Toe Drain	Toe Drain West (2)	M	E	GW, DP	GW	W					
Toe	CBH-17	P	E	GW	GW						
Toe	CBH-18	P	E	GW	GW						
Toe	CBH-19	P	E	GW	GW						
Toe	CBH-23	P	E	GW	GW						
Toe	CBH-25	P	E	GW	GW						
Toe	CBH-26	P	E	GW	GW						
Toe	CBH-27	P	E	GW	GW						
Toe	CBH-28	P	E	GW	GW						
East end at toe (foundation)	CH-350C/CBH03	P	E	GW	GW						
East end at toe (filter)	CH-350D/CBH04	P	E	GW (dry)	GW						
Toe (foundation)	CH-585C/CBH007	P	E	GW	GW						
Toe (filter)	CH-585D/CBH008	P	E	GW	GW						
Toe	CH-585E	P	E	GW	GW						
Toe (foundation)	CH-720C/CBH011	P	E	GW	GW						
Toe (filter)	CH-720D/CBH012	P	E	GW	GW						
Toe (foundation)	CH-950A/CBH013	P	E	GW	GW						
Toe (core)	CH-950B/CBH014	P	E	GW	GW						
Toe (foundation)	CH-950C/CBH015	P	E	GW	GW						
Toe (filter)	CH-950D/CBH016	P	E	GW	GW						
Toe berm	SPP01	P	E	GW	GW						
Toe berm	SPP02	P	E	GW	GW						
crest	VWP01-A	P	E	GW	GW						
crest	VWP01-B	P	E	GW	GW						
crest	VWP02-A	P	E	GW	GW						
crest	VWP02-B	P	E	GW	GW						
crest	VWP03-A	P	E	GW	GW						
crest	VWP03-B	P	E	GW	GW						
Proposed New crest bores (10) and toe berm (2)	various	P	U	GW, Q	GW	W				12	As part of embankment monitoring points. Water level data used in mapping GW contours, sampling demonstrate that decant not impacting groundwater (as closest to upstream, may be first to detect RMA seepage)

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RMA: Groundwater monitoring north of embankment toe											
north of CBH019	580BH2004	P	E	GW	GW						
Northwest border	580MB2001	P	E	GW, Q	GW	W		1			
North East near boundry	580MB2004	P, FD	E	GW, SG, Q	GW						
North of embankment centre	580BH2003	P	E	GW, SG, Q	GW						
North of embankment centre haul Rd	580BH2006	P	E	GW	GW						
North of toe	580BH2007	P	E	GW, SG, Q	GW	W		1			580-BH2007 currently monitored with embankment bores.
North of embankment centre haul Rd	580BH2005	P	U (destroyed)	GW	GW						
North of embankment centre haul Rd	580BH2002	P	E	GW	GW						
Adj/vicinity western clay pit	PI1S	P	E	GW	GW						
Adj/vicinity western clay pit	PI1D	P	E	GW	GW						
Adj/vicinity western clay pit	PI2S	P	E	GW	GW						
Adj/vicinity western clay pit	PI2D	P	E	GW	GW						
Adj/vicinity western clay pit	PI3S	P	E	GW	GW						
Adj/vicinity western clay pit	PI3D	P	E	GW	GW						
Adj/vicinity western clay pit	PI4S	P	E	GW	GW						
Adj/vicinity western clay pit	PI4D	P	E	GW	GW						

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RMA: New monitoring bores											
Adjacent to toe drain East 2 sump - deep	MB01D	P, DP	N	GW, SG, Q	GW	W, S	15	1			Adjacent to toe drain East (2) sump. Nested bore pair measuring the foundation pressure below the filter blanket to allow evaluation of performace and sensitivity of pumping of sump to be undertaken, to identify if any localised mounding due to the downgradient lower permeability clays and potential flow around this deposit (borrow area). Evaluate option of need for installation of depressurisation bores to intersect the overlying blanket. Deep bore to evaluate vertical gradient with MB01S.
Adjacent to toe drain East 2 sump - shallow	MB01S	P	N	GW, SG, Q	GW	W, S	7	1	4		Adjacent to toe drain East (2) sump. Nested bore pair measuring the filter blanket to allow evaluation of performace and sensitivity of pumping of sump to be undertaken (outside cone of pump influence). Shallow bore to evaluate vertical gradient with MB01D.
north east of 580BH2007- deep	MB02D	P	N	GW, SG, Q	GW	W, S	15	1			Located in an area with limited groundwater monitoring allowing triangulation between existing bore (580BH2003) and proposed bore (fire water dam BH1) to the west and east respectively. Located west of the ephemeral creek channel, and in an area adjacent and slightly downgradient where some seepage has been observed. Deep bore to evaluate vertical gradient with MB02S.
north east of 580BH2007 - Shallow	MB02S	P	N	GW, SG, Q	GW	W, S	7	1	4		Located in an area with limited groundwater monitoring allowing triangulation between existing bore (580BH2003) and proposed bore (fire water dam BH1) to the west and east respectively. Located west of the ephemeral creek channel, and in an area adjacent and slightly downgradient where some seepage has been observed. Shallow bore to evaluate vertical gradient with MB02D.

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West of 580BH2007	MB3D	P, DP	N	GW, SG, Q	GW	W, S	20	1			Nested Bore Pair. Central location parallel to the north Emb and DS of toe between two existing bores 580BH2007 and 580BH2006, upgradient of observed saline impacted area, downgradient of the filter, in foundation. To provide GW level data and allow correlation with filter blanket levels monitored upgradient. Evaluate presence/absence of clay lense, shallow sand layer (potential pathway) and connection to drainage blanket. Evaluate depressurisation options.
West of 580BH2007	MB3S	P, DP	N	GW, SG, Q	GW	W, S	10	1	4		Nested Bore Pair. Central location parallel to the north Emb and DS of toe between two existing bores 580BH2007 and 580BH2006, upgradient of observed saline impacted area, downgradient of the filter, in foundation. To provide GW level data and allow correlation with filter blanket levels monitored upgradient. Evaluate presence/absence of clay lense, shallow sand layer (potential pathway) and connection to drainage blanket. Evaluate depressurisation options.
At the eastern end of toe of the embankment	MB4	P, DP	N	GW, SG, Q	GW	W, S	10	1	4		To evaluate groundwater levels in foundation below the filter blanket, contouring of GW, evaluation of conectivity between the filter and GW and/or if deeper flow is contributing to downgradient recharge and possibly expressing downgradient . Evaluate feasability of depressurisation option in this area.

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North boundry adj to clay pit by old creek	MB5	P	N	GW, SG, Q	GW	W, S	15	1	4		Located in an area east of the fissured clay formation (and potential near surface aquitard), and near former creek channel to evaluate groundwater levels and if any localised mounding or prefererential flow paths may exist that are not fully intercepted by the toe drain. Shallow bore to evaluate potential mounding and conectivity between lower strata monitored by deeper bore.
30 m up gradient of fire dam	MB6	P,FD	N	GW, Q	GW	W, S	20	1	4	1	Aproximatley 30 m upgradient of the fire dam adjacent to an stormwater excavated channel, to evaluate the depth of groundwater in the area and specifically the potential for shallow fracture zones where seepage above permanent GW may be occurring. This will allow determination of GW levels and sampling may provide an indication of a source of acidity (Fe) and/or a disconect between overlying seepage. Will also provide GW level data from the east for contouring.
West of clay pit	MB10	P	N	GW, Q	GW	W, S	15	1	4		Located in arrenite that bounds clay (borrow pit) to east to evaluate groundwater levels and possible short circuit/flow path that may be present. Evaluate the effectiveness of the existing depressurisation bores and filter downstream of the western end of the toe. Replaces the PI1 to PI4 monitoring bores located in/around the clay pit.
Eastern end of embankment, north of toe, downgradient of filter blanket (north east of 580BH007 and NW of proposed MB04)	MB11S	P	N	GW, Q, SG	GW	W, S	10	1	3		Nested bore, shallow. Located north of toe of embankment inbetween TP16 and TP18, and observed surface seepage areas. To look at underlying groundwater levels in area where wet areas observed in vicinity and to determine if any vertical gradients are present.
Eastern end of embankment, north of toe, downgradient of filter blanket (north east of 580BH007 and NW of proposed MB04)	MB11D	P	N	GW, Q, SG	GW	W, S	25	1			Nested bore, deep. Located north of toe of embankment inbetween TP16 and TP18, and observed surface seepage areas. To look at underlying groundwater levels in area where wet areas observed in vicinity and to determine if any vertical gradients are present.

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Eastern end of embankment at toe, downgradient of filter blanket (adjacent to TP19 and roadway)	MB12	P	N	GW, Q	GW	W, S	15	1			Located adjacent to toe of embankment near TP19, where GW was not encountered to 4 m. To look at underlying groundwater and upgradient filter blanket effectiveness as well as groundwater levels and possible short circuit/flow path that may be present.
RMA: Surface water monitoring											
Fire dam 1 (lower)	FD1	FD	E	Q	S	W		1		1	
US pond Fire Dam 2 with iron	FD2	FD	E	Q	S	W		1		1	
US gully from Fire Dam 2	USFD1	FD	E	Q	S	W		1		1	
RMA: New test pits											
North of site boundary and clay pit	TP1	M	N	S, DP	TP	G,S	4		4		To characterise shallow groundwater conditions (confining layers, depth to groundwater, any inflows to pit (i.e. lateral/vertical) and source (alluvim/bedrock)). To evaluate existing salt concentrations through the shallow soil profile.
North of 580BH2002	TP8	M	N	S, DP	TP	G,S	4		4		To characterise shallow groundwater conditions (confining layers, depth to groundwater, any inflows to pit (i.e. lateral/vertical) and source (alluvim/bedrock)). To evaluate existing salt concentrations through the shallow soil profile.
South side of site boundry, west of ALD1	TP9	M	N	S, DP	TP	G,S	4		4		Close to southern extent of dead vegetation. To evaluate feasibility of drainage trench management option (geology and geotechnical profile). To characterise shallow groundwater conditions (confining layers, depth to groundwater, any inflows to pit (i.e. lateral/vertical) and source of inflows (alluvim/bedrock)). To evaluate existing salt concentrations through the shallow soil profile.
West side of creek, west of 580BH2003	TP10	M	N	S, DP	TP	G,S	4		4		Within area of fissured clay. To characterise shallow groundwater conditions (confining layers, depth to groundwater, any inflows to pit (i.e. lateral/vertical) and source (alluvim/bedrock)). To evaluate existing salt concentrations through the shallow soil profile.

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Upgradient of centre of dead vegetation, north of 5808H2003	TP11	M	N	S, DP	TP	G,S	4		4		To characterise shallow groundwater conditions (confining layers, depth to groundwater, any inflows to pit (i.e. lateral/vertical) and source of inflows(alluvim/bedrock)). To evaluate existing salt concentrations through the shallow soil profile.
South side of site boundary, east of ALD1	TP12	M	N	S, DP	TP	G,S	4		4		Close to southern extent of dead vegetation. To evaluate feasibility of drainage trench management option (geology and geotechnical profile). To characterise shallow groundwater conditions (confining layers, depth to groundwater, any inflows to pit (i.e. lateral/vertical) and source of inflows (alluvim/bedrock)). To evaluate existing salt concentrations through the shallow soil profile.
Upgradient of centre of dead vegetation, north of 5808H2003	TP14	M	N	S, DP	TP	G,S	4		4		To evaluate feasibility of drainage trench management option (geology and geotechnical profile) through central area of site. To characterise shallow groundwater conditions (confining layers, depth to groundwater, any inflows to pit (i.e. lateral/vertical) and source (alluvim/bedrock)). To evaluate existing salt concentrations through the shallow soil profile.
In area of salt/moisture car park north east of CBH03	TP15	M	N	S, DP	TP	G,S	4		4		Located in area between proposed monitoring bores, in vicinity of salt/moisture. To evaluate feasibility of drainage trench management option (geology and geotechnical profile) through central area of site. To assist in characterisation of shallow groundwater conditions (confining layers, depth to groundwater, any inflows to pit (i.e. lateral/vertical) and source (alluvim/bedrock)). To evaluate existing salt concentrations through the shallow soil profile.
In area of salt/moisture car park north east of CBH03	TP16	M	N	S, DP	TP	G,S	4		4		Located in area between proposed monitoring bores, in vicinity of salt/moisture. To characterise shallow groundwater conditions (confining layers, depth to groundwater, any inflows to pit (i.e. lateral/vertical) and likely source(s) of inflows (alluvim/bedrock)). To evaluate existing salt concentrations through the shallow soil profile.

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In area of salt/moisture car park north east of CBH03	TP17	M	N	S, DP	TP	G,S	4		4		Located in area between proposed monitoring bores, in vicinity of salt/moisture. To evaluate feasibility of drainage trench management option (geology and geotechnical profile) through central area of site. To assist in characterisation of shallow groundwater conditions (confining layers, depth to groundwater, any inflows to pit (i.e. lateral/vertical) and source (alluvim/bedrock)). To evaluate existing salt concentrations through the shallow soil profile.
In area of salt/moisture car park north CBH03	TP18	M	N	S, DP	TP	G,S	4		4		Located in area between proposed monitoring bores, in vicinity of salt/moisture. To characterise shallow groundwater conditions (confining layers, depth to groundwater, any inflows to pit (i.e. lateral/vertical) and likely source(s) of inflows (alluvim/bedrock)). To evaluate existing salt concentrations through the shallow soil profile.
In area of salt/moisture, eastern end of embankment	TP19	M	N	S, DP	TP	G,S	4		4		Located to evaluate likely source of salt/moisture at surface close to toe of embankment (depth of pit may be constrained by close proximity to embankment). To characterise shallow groundwater conditions (confining layers, depth to groundwater, any inflows to pit (i.e. lateral/vertical) and likely source(s) of inflows (alluvim/bedrock)). To evaluate existing salt concentrations through the shallow soil profile.

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RMA: Compliance monitoring bores/other bores											
East of embankment, thickner road	5808H5	P	E	GW	GW						
East site boundary, near east embankment	5808H30	P	E	GW	GW						
West site boundary	5808H07	P	E	GW	GW						
Aldoga: Surface water monitoring											
Larcom Creek US	W1		N	w	S	W		1		2	
Larcom Creek DS	W2		N	w	S	W		1		2	
Ponded area former creek channel (prev sampled RTAY)	North Swamp		E	W	S	W		1		2	
Ponded area former creek channel (prev sampled RTAY)	North Swamp 2		E	w	S	W		1		2	

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Aldoga: Groundwater monitoring											
North adj to boundry	ALD1A		E	GW, Q, SG	GW	W		1		1	shallow and deep bores may be connected
North adj to boundry	ALD1B		U	GW, Q, SG	GW	W		1		1	
NW of ALD1, LHS creek	SBOBH31		E	GW, Q	GW	W		1		1	
North of ALD1, RHS creek	SBOBH32		E	GW, Q, SG	GW	W		1		1	
North of 32	SBOBH33		U	GW, Q	GW	W		1		1	
North, near Larcom Ck	ALD2A		U	GW, Q	GW	W		1		1	
North, near Larcom Ck	ALD2B		U	GW, Q	GW	W		1		1	
Aldoga: New groundwater monitoring											
NW of RMA gate near pipeline	MB7S	P	N	GW, Q	GW	W, S	7	1	4	1	Located NW of RMA gate and east of impacted vegetation to evaluate GW levels, vertical flow gradients and if potential for further expression to occur
NW of RMA gate near pipeline	MB7D	P	N	GW, Q	GW	W, S	15	1	4	1	Located NW of RMA gate and east of impacted vegetation to evaluate GW levels, vertical flow gradients and if potential for further expression to occur
NW of dead vegetation area	MB8	P	N	GW, Q	GW	W, S	15	1	4	1	Located west of impacted vegetation and adjacent to a creek channel to evaluate GW levels, flow gradients and if potential for further expression to occur
Northeast of BH32, and scaled area	MB9	P	N	GW, Q	GW	W, S	15	1	4	1	Located north east of impacted vegetation to evaluate GW levels, flow gradients and if potential for further expression to occur

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Aldoga: Test pits											
Western extent	TP2	M	N	S, R	TP	G,S	4		4		
North west extent	TP3	M	N	S, R	TP	G,S	4		4		
Northern extent	TP4	M	N	S, R	TP	G,S	4		4		
Eastern extent	TP5	M	N	S, R	TP	G,S	4		4		
Central part of dead vegetation	TP6	M	N	S, R	TP	G,S	4		4		
North of site boundary, west of ALD1	TP7	M	N	S, R	TP	G,S	4		4		
North of site boundary, east of ALD1	TP13	M	N	S, R	TP	G,S	4		4		
Aldoga and RMA: Geophysics											
Terrestrial electromagnetic survey across eastern area of RMA and Aldoga, downstream of northern embankment											To delineate the likely extent and location of near surface salinity downstream of the RMA embankment, to assist in targetting of investigation locations, to provide a baseline survey against which to measure the effectiveness of any future remediation
RMA Decant Pond											
Decant pond	Decant	P, M	-	Q	SW	W	-				

GHD

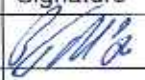
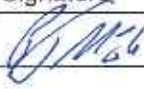
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RTA Yarwun

RMA Groundwater Management Actions
Groundwater Conceptualisation and Management Options

October 2015

WATER | ENERGY & RESOURCES | ENVIRONMENT | PROPERTY & BUILDINGS | TRANSPORTATION

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1. Introduction

1.1 Introduction

GHD Pty Ltd (GHD) was commissioned by RTA Yarwun Pty Ltd (RTA Yarwun) under Contract Number CW2081249 to:

- Assess, characterise and conceptualise the groundwater pressurisation in the vicinity of the Residue Management Area (RMA) Northern Embankment
- Develop concept management options to alleviate the observed pressurised groundwater
- Investigate low pH waters within the Firewater Dam north of the RMA

To achieve this, the work was divided into three tasks as follows:

- Task 1 – Spatial analysis of groundwater pressurisation and development of field investigations and a Sampling and Analysis Plan (SAP)
- Task 2 – Concept design of management options to alleviate groundwater pressurisation in the vicinity of the Northern Embankment and off-site downstream of the RMA
- Task 3 – Assessment of low-pH water in the Firewater Dam.

This report details Task 2 and uses data collected from the SAP developed by GHD (GHD 2015[a]) as part of Task 1 and actioned by RTA Yarwun. Task 3 has been completed and issued to RTA Yarwun as a technical note (GHD 2015[b]).

1.2 Background to this report

In 2013, surface water ponding and vegetation die-off was observed by RTA Yarwun operations personnel adjacent to and to the north of the northern boundary of the RMA, with salt scalding and seepage areas identified within the RMA site to the north of the Northern Embankment at the eastern end.

Recent studies undertaken by RTA Yarwun in 2014 (October 2014[a] and October 2014[b]) identified that the areas to the north of and adjacent to the RMA Northern Embankment impacted by salinity were considered to be associated with the progressive mounding of underlying naturally saline groundwater within the foundation materials beneath the RMA.

1.3 Purpose of this report

The purpose of this report is to characterise and conceptualise the groundwater pressurisation in the vicinity of the eastern end of the Northern Embankment and to provide concept-level management options to alleviate the elevated groundwater pressures.

1.4 Scope and limitations

As per Section 4.3(b) of the RTA Yarwun Contract for Consultancy Services document, the Task 2 scope of work as detailed in GHD's *Request for Tender* submission (Contract number WS 441745638) is for the following:

- Analysis of data collected by RTA Yarwun detailed by the SAP (GHD 2015[a]) and reported by RTA Yarwun (2015[a], 2015[b], 2015[c]).
- Hydrogeological conceptualisation in the vicinity of the groundwater pressurisation.
- Simplified analytical modelling to determine (orders of magnitude) groundwater flows.

- Options analysis detailing a conceptual depressurisation system to alleviate the observed groundwater mound at: (1) the east of the Northern Embankment; and (2) off-site downstream of the Northern Embankment.
- Order of Magnitude (OoM) quantities analysis for each option.
- Costing and outcome analysis of options.
- Recommendations for future groundwater monitoring for RTA Yarwun to continue to monitor and implement.

Environmental impacts related to saline groundwater, groundwater level changes, and assessment of these impacts (i.e. soil, water, ecological, human health, and receiving environment) and assessment of embankment stability are outside the scope of this report.

This report: 'RMA Groundwater Management Actions, Groundwater Conceptualisation and Management Options' has been prepared by GHD for RTA Yarwun and may only be used and relied on by RTA Yarwun for the purpose agreed between GHD and the RTA Yarwun as set out in Section 1.3 of this report.

GHD otherwise disclaims responsibility to any person other than RTA Yarwun arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by RTA Yarwun and others who provided information to GHD, which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

2. Data analysis

2.1 Introduction

This section presents assessment and analysis of data collected by RTA Yarwun as part of the SAP for the downstream area of the Northern Embankment. Selected historic data (groundwater levels and hydraulic conductivity) have also been reviewed in support of the assessment. The following information has been used in the data assessment:

- Data collected by the SAP:
  - Results of the test pitting (TP1 to TP20) and pit seepage inflow analysis (Memo Test Pit Investigation – RMA Groundwater Management, RTA Yarwun 2015[a])
  - Results of the groundwater monitoring bore installation (MB series and SPP series monitoring bores) and groundwater monitoring (MB series, for groundwater levels and quality (Memo Borehole Investigation – RMA Groundwater Management, RTA Yarwun 2015[b])
  - Results of the slug testing on selected monitoring bores (Memo Slug Test Investigation – RMA Groundwater Management, RTA Yarwun 2015[c])
- Historic data:
  - Groundwater level time-series data for environmental monitoring bores to July 2015 (provided by RTA Yarwun)
  - Estimated hydraulic conductivity values (GHD 2012)
- Locations of seepage as observed during implementation of the SAP and as reported by RTA Yarwun (October 2014[a] and October 2014[b])

A plan of the investigation locations (Figure 1) and copies of the investigation memorandums for the data collected by the SAP are included in Appendix A.

2.2 Groundwater levels and flows

2.2.1 Test pits

Review of the test pit logs indicate the presence of shallow groundwater that was typically encountered between around 1 and 2.8 m below ground surface. This groundwater is typically associated with a gravelly clay and clayey gravel layer, overlain and underlain by a variable thickness of clay and silty clay. Free water in the form of seepage to the pit was not observed in test pits where clay and extremely weathered bedrock (clay-dominated) was encountered, located at the eastern end of the downstream area of the embankment (TP15, TP16, TP17). Whilst these three test pits are located in close proximity to areas with evidence of surface expression of seepage, groundwater was not encountered, which indicates the presence of discrete flow pathways to ground surface allowing groundwater to reach the surface within the affected seepage areas.

2.2.2 Groundwater monitoring bores

Maps of the groundwater elevations (June and July 2015), inferred groundwater elevation contours and an approximation of the areas where the groundwater pressure is above ground surface and within 1 m of ground surface are included in Figure 2 and Figure 3 of Appendix A. The groundwater contours were developed using the Kriging method of interpolation (with GMS software).

Review of the borehole logs, water strikes and groundwater levels indicates that groundwater in natural ground is typically under confined conditions (i.e. is held under pressure beneath an overlying lower permeability layer) which is consistent with previous interpretations across the Northern Embankment area (GHD 2012). Monitoring bores MB07S and MB07D to the north of the RMA boundary did not, however, encounter a significant confining layer.

Depth to groundwater is at least 6 m below ground level at MB11S. Throughout the monitoring bore investigation, moist ground was typically encountered during drilling of the boreholes however significant water strikes (wet ground) were infrequent (only identified in MB07S, MB07D, MB08, MB09). These observations are consistent with typically discrete, relatively low-permeability fracture flow pathways within bedrock.

Groundwater pressures in bedrock are indicated to be above ground surface at the eastern end of the Northern Embankment, within an area extending towards the north-north east beyond the RMA boundary from the embankment. Groundwater pressures are indicated to be at least 3 m above ground level at MB04S, MB04D and MB06. The identified areas of seepage (both on-site and off-site) fall within the areas where groundwater pressures are indicated to be above ground surface. The areas of seepage are relatively small in comparison to the aerial extent of groundwater pressures above ground surface, which indicates the presence of discrete groundwater flow pathways to ground surface rather than a diffuse network of pathways to the surface across the wider area.

Comparison of the calculated groundwater elevations for the shallow (bore identifier ending in 'S') and deep (bore identifier ending in 'D') monitoring bore pairs show a slight downward vertical gradient from the shallow to deeper groundwater ranging from less than 0.1 m (MB02S and MB02D) to around 0.5 m (MB03S and MB03D).

The interpreted groundwater flow direction through bedrock at the far eastern end of the Northern Embankment is broadly from the south east towards the north west, with a predominantly westerly component of flow in the vicinity of the embankment toe and downstream area at the eastern end. Flow through bedrock beneath central parts of the embankment is typically from south to north and south east to north west, and flow beneath the western part of the embankment is typically from the south west towards the north east. These interpreted groundwater flow directions are consistent with the valley feature within which the RMA site (and off-site area to the north) is located.

2.2.3 Trends in groundwater levels

Groundwater elevation time-series data for RTA Yarwun environmental monitoring bores (data provided by RTA Yarwun) located to the north of the toe of the Northern Embankment are included in Appendix B.

Increasing groundwater level trends, which commenced around early 2007, are apparent at 580-BH-2005, ALD1A, ALD1B, 580-BH-31 and 580-BH-32. ALD2A and ALD2B do not have sufficient data points to comment on groundwater level trends. As an indication of the magnitude of change, the calculated difference in water level between early 2007 and mid-2015 data is provided in Appendix B. The greatest calculated increase in groundwater level (10.1 m) is at 580-BH-2005 located to the north east of the eastern end of the Northern Embankment, followed by 580-BH-32 (8.2 m) located off-site to the north of the RMA boundary.

No significant increasing trends in groundwater levels have however been reported for the nearby long term embankment monitoring bores (CBH01, CBH02, CBH03) or for monitoring bores to the north of the embankment (580-BH-2007 and 580-MB-2004) (GHD 2014).

2.2.4 Toe drain and drainage blanket

Monitoring bore CBH04 located towards the eastern end of the northern embankment and reported to be installed within the drainage blanket (to 64.6 mAHD) was dry in June/July 2015. This is a continuation of the historic trend for this bore. Whilst the groundwater elevation is below the invert of the drainage blanket at this location (at CBH03) and hence the blanket might be expected to be dry, groundwater pressures to the east (up-slope along the blanket) are up to around 3.5 m above the invert of the drainage blanket toe. This indicates the drainage blanket to the east of CBH04 is not connected, or has very limited connectivity to the underlying water bearing bedrock strata. That the drainage blanket is dry to the east of CBH04 is supported by observation of the HDPE pipe and associated filter material being not saturated with water, which was uncovered at the eastern end of the embankment during construction of the haul road (refer to Figure 1 of Appendix A for location).

Groundwater level data for the embankment monitoring bores indicate that from some point west of CBH04 (between CBH04 and CBH08) the drainage blanket becomes fully saturated with preferential flow from east to west towards the toe drain (east) sump. Of note is the elevated groundwater level at CBH19 at the western end of the embankment, which is thought to be due to a lack of connectivity with the drainage blanket in the immediate vicinity of CBH19.

The estimated rate of inflow to the toe drain (east) sump (July 2015) is around 2 L/s (around 7.22 m^3/hour) (information provided to GHD by RTA Yarwun). No cumulative data on inflow rates or monitoring of changes to inflows over time are available.

2.3 Groundwater quality

The groundwater field quality monitoring results and laboratory analysis certificates are included in Memo Borehole Investigation – RMA Groundwater Management (RTA Yarwun 2015[b]) (Appendix A).

A Piper plot of the major ion chemistry for the tested monitoring bores in 2015 is shown in Diagram 2-1.

The major ion chemistry of the on-site (580-BH-2003, 580-MB-2004 and 580-BH-2007 sampled in 2014 by RTA Yarwun) and off-site monitoring bores downstream of the embankment is of a sodium-potassium-chloride dominated type and is consistent with historic data reported in GHD 2012 for on-site monitoring bores downstream of the embankment. The major ion chemistry at MB06 (adjacent to the Firewater Dam in the east and up slope from the downstream area) is of a magnesium-chloride dominated type. This difference in chemistry may be due to a difference in lithology and/or the origin of the groundwater.

Based on the EC of the sampled groundwater bores (laboratory EC of 10,100 to 39,100 µS/cm) and of the shallow seepage inflow to the test pits (field EC of 14,500 to 39,900 µS/cm) the groundwater is considered saline. The range of EC is consistent with historical site data collected in mid-2011 for the downstream area of the northern embankment (reported in GHD 2011[a]).

The groundwater pH is near neutral and consistent across the off-site and on-site monitored groundwater bores, ranging from 6.3 to 7.3 pH (field) and from 6.7 to 7.5 pH (laboratory).

Review of the groundwater and toe drain sump analysis results for concentrations of dissolved gallium, molybdenum, vanadium and aluminium (refer to Appendix A for laboratory results) indicate dissolved concentrations are typically less than the laboratory limit of reporting (LoR). In some instances dissolved concentrations are just above the LoR, however significantly lower than typical concentrations in decant. A more detailed analysis of the chemistry data should be completed to confirm the absence of the decant signature in these most recent groundwater quality data. Previous detailed analysis of groundwater samples collected during the operation

of the RMA did not indicate the presence of a decant signature in groundwater (refer to RTA Yarwun 2014[b] and GHD 2011[b]).

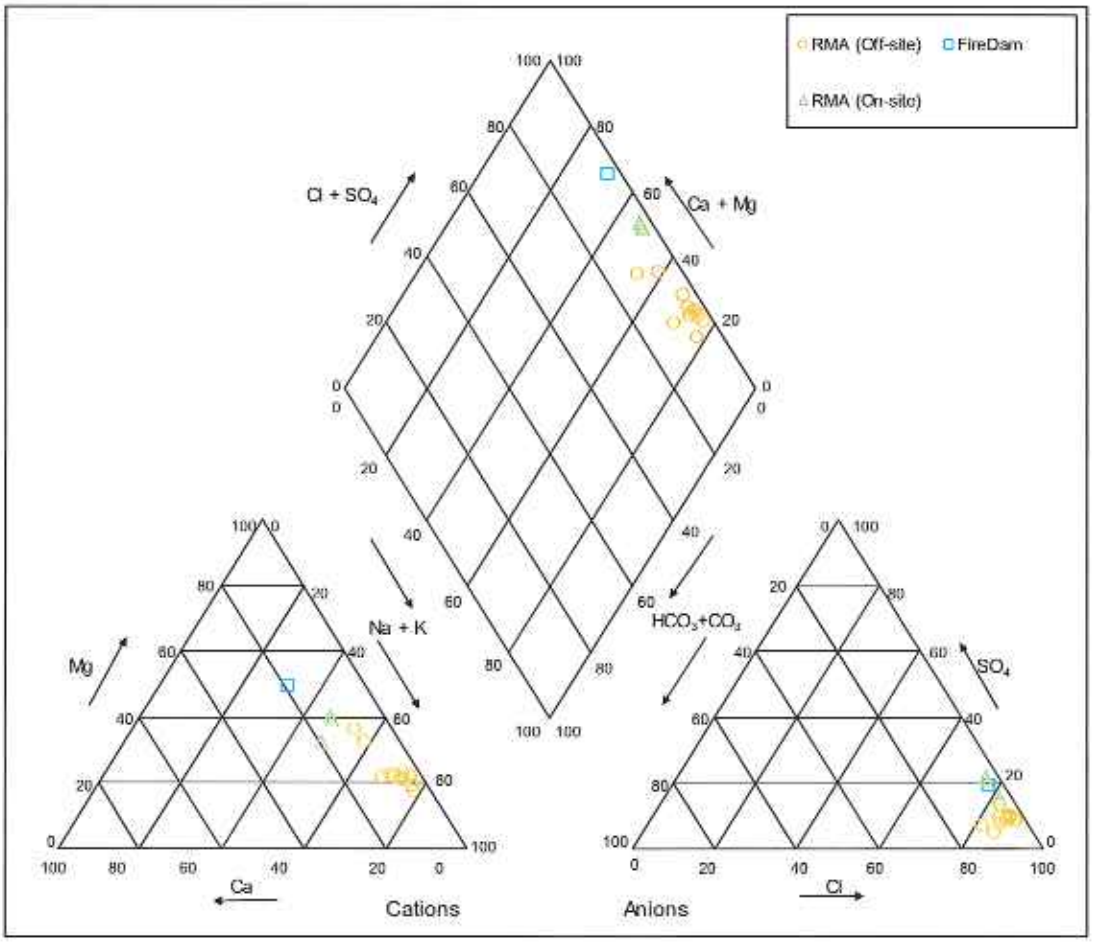


Diagram 2-1 Piper plot

2.4 Estimated hydraulic conductivity

2.4.1 Slug testing

Slug testing was conducted on selected monitoring bores in the eastern half of the Northern Embankment area (test locations are shown in Figure 1 of Appendix A).

Hydraulic conductivity was estimated for the tested horizons (falling and rising head tests) using the Bouwer-Rice (1976), Hvorslev (1951) and Springer-Gelhar (1991) analytical solutions, analysed using AQTESOLV software (HydroSOLVE Inc). The results are summarised in Appendix B. The median estimated hydraulic conductivity ranges from 4.2 x 10^{-8} m/s (MB03S) to 9.7 x 10^{-5} m/s (580-MB-2004) with an overall median of 8.7 x 10^{-7} m/s and is consistent with historical data for the vicinity of the Northern Embankment.

Estimated hydraulic conductivity values are plotted by test interval depth and grouped by selected chainage intervals (control line MC01) in Diagram 2-2. Test results from this investigation along with historic test results for the vicinity of the Northern Embankment are plotted. No trends in hydraulic conductivity with depth or by chainage interval (i.e. east to west across the embankment) are indicated.

2.4.2 Test pit inflows

The inflow rate of shallow groundwater (within 2.5 m of ground surface) into the test pits was used to estimate hydraulic conductivity of shallow water-bearing horizons. A table summarising the estimated hydraulic conductivity values calculated using the Somerville (1986) analytical solution for a rising head in a test pit is included in Appendix B. The estimated hydraulic conductivity values range from 3.5×10^{-8} to 1.1×10^{-6} m/s and are consistent with the values estimated for the slug tests (at depths greater than 3 m below ground level).

Estimated hydraulic conductivity values are plotted by seepage inflow depth for the test pits in Diagram 2-2 and indicate the hydraulic conductivities of near surface strata to the north of the RMA boundary fall within the mid to high end of the estimated range whereas the strata within the boundary of the RMA fall within the mid to lower end of the estimated range. However, this may be influenced by the small number of test pit sites in comparison to the number of monitoring bores slug tested.

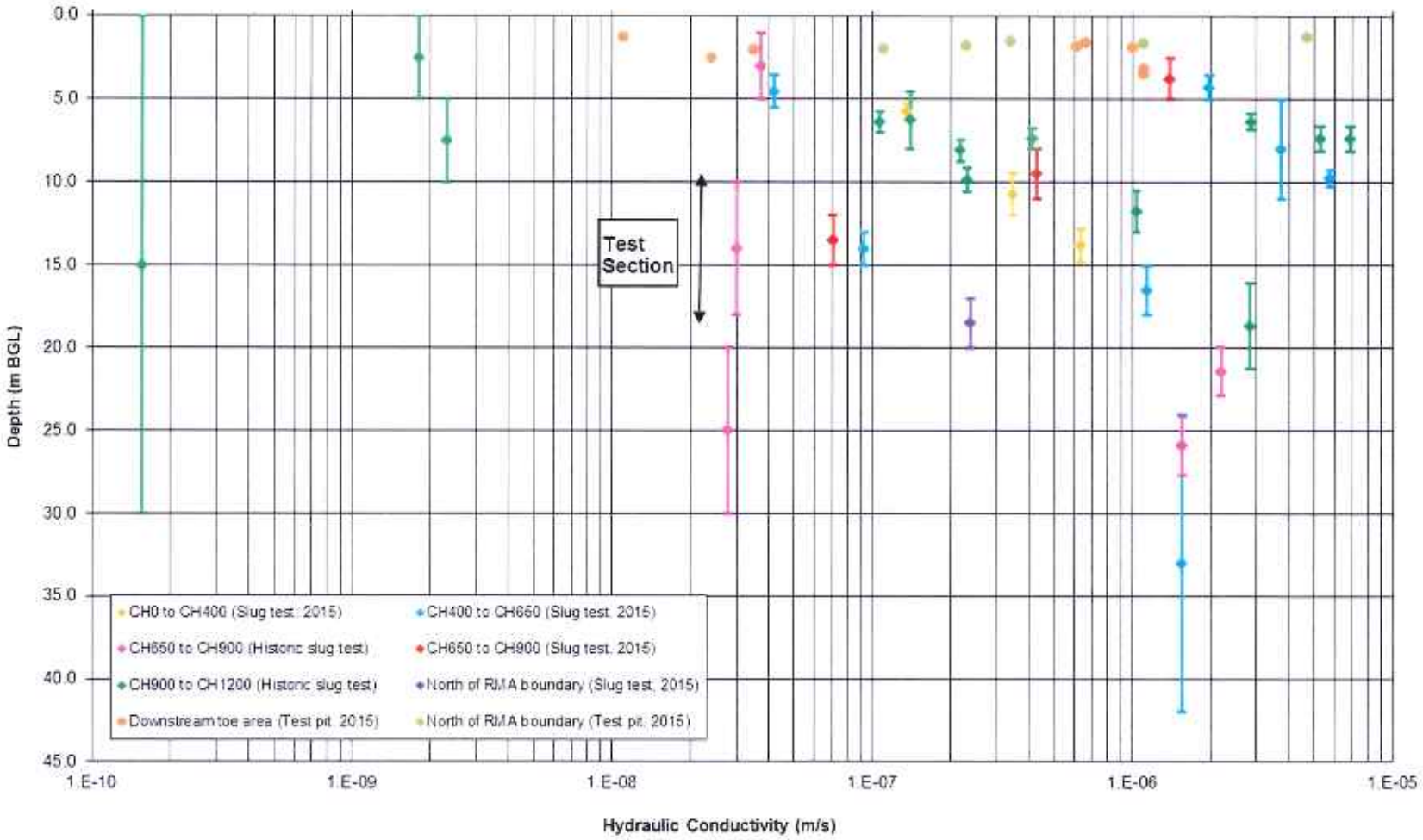


Diagram 2-2 Estimated hydraulic conductivity values from boreholes and test pits

3. Hydrogeological conceptual model

This section presents the hydrogeological conceptual model developed for the eastern end of the Northern Embankment, based on the findings of the data analysis (Section 2) and drawing on our hydrogeological understanding of the site gained from previous reports and investigations.

A plan-view of the conceptual model (Figure 4), a plan identifying the conceptual section lines (Figure 5) and three annotated conceptual cross sections (Figure A, Figure B and Figure C) are included in Appendix C.

3.1 Conceptual model

Groundwater elevations are highest beneath the eastern end of the Northern Embankment and at the embankment toe and fall towards the west and north. Consequently, the direction of groundwater flow is interpreted as being broadly from the south east towards the north west across the eastern end of the site and in the off-site area to the north. The main cause of the elevated groundwater levels is thought to be associated with compression of the natural ground underlying the tailings due to increased downward pressure from the tailings, resulting in increased pore pressure within the strata and subsequent mounding of groundwater along the fringes of the tailings residue including downstream. It is likely the mounding effects are compounded by the position of the dam in the floor of the valley whereby reduced pore spaces (due to compression) beneath the mud residue limit the movement of groundwater flow from the topographic high in the east, resulting in increased pressures beneath, adjacent to and downstream of the dam.

Another potential contribution to the high groundwater levels at the eastern end of the Northern Embankment is localised recharge from the infiltration of pore water held in the tailings to the underlying strata. However, there is no evidence that this is occurring at present given that no signature of decant in groundwater has so far been identified and that the major ion chemistry of groundwater sampled in 2015 (RTA Yarwun 2015[b]) in the vicinity of the Northern Embankment continues to be similar to historic data.

Whilst there is potential for localised recharge of groundwater as a result of seepage from the unlined Pocket decant (in place since 2013, located adjacent to the eastern side of the residue storage area) and through the base of the unlined decant chute from the thickener (the "Falls", which have operated regularly since the RMA became operational) to the underlying strata it is not considered to be the primary cause of elevated groundwater levels given:

- Surface expression of groundwater was identified on-site prior to commissioning of the Pocket decant.
- Near surface joints and fractures beneath the Falls are likely to have been sealed with residue over time, thus limiting infiltration to the underlying strata.

From ground surface, a low-permeability confining layer in the vicinity of the eastern end of the embankment appears to extend across the toe and on-site downstream area, being in the order of 10 m thick. At the toe of the embankment in this area, groundwater cannot move freely to the drainage blanket due to a lack of connectivity between the water-bearing strata and the drainage blanket due to the low permeability layer resulting in groundwater pressures above ground surface. Further to the west along the embankment toe, the water-bearing strata are in connection with the drainage blanket and maintaining groundwater levels below ground surface. The water in the drainage blanket moves west and north, towards the toe drain sump (east) from where it is returned to the RMA.

On-site within areas where groundwater pressure is above ground surface, groundwater can, however move upwards through discrete pathways within the confining layer, such as interconnected fractures, to ground surface where it expresses as seepage, salt-scalded areas and potentially as seepage to the Firewater Dam.

Off-site to the north, the confining layer appears to be much thinner (in the order of 1 to 2 m) and in some areas is absent (MB07S and MB07D). Groundwater moves from the south east and discharges to ground surface where the groundwater pressure/water table along a line trending approximately perpendicular to the direction of groundwater flow is above ground surface. The discharged water ponds on the low-permeability ground, in the low-lying areas to the west of the seepage line. At present, the off-site drainage installed by RTA Yarwun intercepts expressed groundwater in the vicinity of the seepage area and directs it to a sump from where the water is pumped out and pumped back to the RMA for treatment and discharge in accordance with the Environmental Authority (SPDE04134712).

4. Groundwater management options analysis

4.1 Management options

This section provides concept-level management options to alleviate the groundwater pressures observed at the eastern end of the Northern Embankment, at the toe and within the area to the north of the embankment (on-site and off-site). The options have been developed based on the hydrogeological conceptual model and in consideration of the following:

- A desired outcome of a reduction in groundwater levels both on-site and off-site in the area of the eastern end of the Northern Embankment, with a sufficient decrease in groundwater level to stop the occurrence of seepage.
- Low capital cost.
- Minimisation in the use of high maintenance equipment.
- Design of an approach that can be staged to enable implementation of groundwater management in consideration of managing costs.
- Design of a pressure relief system that can either be entirely separate from the existing drainage blanket/toe drain sump collection system or tied into it.

The two management options that have been developed are illustrated in plan-view in Figure 6 of Appendix D. Option 1 provides a concept for on-site management and Option 2 a concept for off-site management.

A staged approach to implementation of any management option is recommended, where monitoring and performance of the effectiveness of the system form the basis for the implementation of additional management measures.

4.1.1 Option 1: On-site depressurisation bores

The presence of a relatively thick (in the order of 10 m), low permeability layer extending from ground surface in the vicinity of the eastern end of the Northern Embankment means that construction of a trench (or trenches) to facilitate lowering of the groundwater pressure is not a practicable solution for on-site management. Previous artesian conditions experienced in the vicinity of the toe of the western end of the Northern Embankment was managed by the installation of pressure relief bores (installed in 2008 and 2011) connected to the embankment toe drainage blanket.

A concept using depressurisation bores has therefore been developed to relieve groundwater pressure on-site at the eastern end.

Option 1 is designed to alleviate elevated groundwater pressures close to the Northern Embankment, adjacent to the seepage close to the embankment toe and is located up-gradient of all of the other observed seepages, on the basis that alleviation of groundwater pressure up-gradient will result in lowering of groundwater levels down-gradient of the installed management option. In addition, there is potential to enhance the stability of the embankment through a reduction in the groundwater pressure in the vicinity of the embankment toe.

Option 1 is outlined as follows:

- Installation of an initial line of depressurisation bores running parallel to the toe of the Northern Embankment at the eastern end, in the vicinity of the toe (i.e. targeting of the elevated groundwater pressures close to the 'source'). A nominal target drawdown of

10 m in the depressurisation bores (i.e. around 7 m below ground surface) has been selected as the starting point for the basis of the concept design and the preliminary analytical modelling (refer to Section 4.2).

- Connection of each depressurisation bore to a single in-ground sump using a siphon system to move the water from each bore, discharging below water level in the collection sump using a combination of gravity and pressure. The collected groundwater is pumped out from the sump to an appropriate location (to be determined by RTA Yarwun), keeping the level as low as possible but above the siphon outlet to prevent air inflow and loss of suction. Management of the water level in the sump enables a gradient between the water level in the borehole and the water level in the sump to be maintained and hence continued operation of the closed system.
- Construction of each depressurisation bore similar to a large diameter standpipe piezometer (to enable a pump to be retro-fitted if needed):
  - A slotted PVC screen surrounded by a filter pack between 10 and 20 m below ground surface (based on review of the borehole logs) through the water bearing strata.
  - Plain PVC casing from 10 m below ground to ground surface, through the low permeability layer, with a sealed and fully grouted annular space between the casing and borehole.
  - A suction riser, nominally 32 mm uPVC or thick-walled HDPE extending from the base of the bore, such that it is always submerged, discharging to the siphon main.
- Additional lines of depressurisation bores and collection sumps could be added, if monitoring of the initial system indicated additional pressure relief is required (for example, location of an additional line to the east of the toe berm and/or in the vicinity of the Firewater Dam and/or close to the northern site boundary, as shown on Figure 6 of Appendix D) in order to stop the off-site seepage. Additional depressurisation bores to the east of the toe berm and/or in the vicinity of the Firewater Dam would likely need to be deeper than at the toe of the embankment given the higher ground surface elevations and potentially greater depth to groundwater.

An illustration of a concept depressurisation bore is included in SK010, Appendix D.

4.1.2 Option 2: Off-site depressurisation bores and collection trench

An alternative management option is to address the elevated groundwater pressures by means of a system installed to the north of the RMA boundary (off-site). The siting of such a system would alleviate the groundwater pressures down-gradient, and in the vicinity of the off-site seepage more rapidly than Option 1, but would not, however, address the on-site elevated groundwater levels or seepage.

Option 2 is outlined as follows:

- As per Option 1, installation of a line of depressurisation bores trending approximately perpendicular to the direction of groundwater flow (i.e. trending north north-east to south south-west) using a siphon system to move the water from each bore to a single collection sump from where the water is removed from the depressurisation system to an appropriate location (to be determined by RTA Yarwun).
- Construction of each depressurisation bore similar to a large diameter standpipe piezometer (to enable a pump to be retro-fitted if needed):
  - A slotted PVC screen surrounded by a filter pack between 5 and 15 m below ground surface (based on review of the borehole logs) through the water bearing strata.

- Plain PVC casing from 5 m below ground to ground surface, through the low permeability layer and upper most water bearing horizon, with a sealed and fully grouted annular space between the casing and borehole. Plain casing of 5 m should be sufficient to ensure a good seal between the water bearing strata and ground surface.

  A suction riser, nominally 32 mm uPVC or thick-walled HDPE extending from the base of the bore, such that it is always submerged, discharging to the siphon main.

- As the lower permeability confining layer appears to be relatively thin in the off-site area, a collection trench could be installed close to the discharge of the seepage in support of the depressurisation bores and may reduce the number of depressurisation bores required:
  - Collection trench up to 4 m depth to capture and further reduce groundwater levels immediately up gradient of the main seepage area. Trench fitted with collection drain at base with sump and riser, and backfilled with gravel.

4.1.3 Option evaluation and preferred option

Option 1 On-site depressurisation bores

Advantages of Option 1 include:

- Located on the RMA site, therefore easy access for installation, monitoring and maintenance.
- Targeting of the elevated pressures close to the toe at the eastern end of the northern embankment for pressure alleviation measures provides an opportunity for:
  - A reduction in groundwater pressures and seepage in the vicinity of the toe of the Northern Embankment (eastern end)
  - A reduction in groundwater pressures and seepage across the broader eastern downstream area (on-site and off-site)
- Targets the areas of significant elevated pressures.
- It is a separate collection system to the existing drainage blanket and toe drain sump system, therefore can be managed separately.
- Scope for augmentation of the pressure relief system through the addition of extra bores / lines of bores placed appropriately.
- Scope for the installation of pumps in the depressurisation bores, if needed.
- Installation of each line or collection of depressurisation bores can be staged, so that the effectiveness of the initial set of bores can be monitored and the collected information and data inform the need for and design of any additional pressure alleviation.
- Potential to enhance the stability of the Northern Embankment at the eastern end through a reduction in groundwater pressure in the close vicinity of the embankment, and bearing in mind future embankment raises.

Disadvantages of Option 1 include:

- Pressure relief measures are located up to around 400 m up-gradient of the off-site seepage area, therefore the benefits of reduced groundwater levels on the off-site seepage would likely be realised later in comparison to implementation of Option 2.
- Whilst no evidence of a decant signature in groundwater has been identified so far, if it is occurring (as a result of seepage of pore water [decant] held within the mud residue of

the RMA dam through the dam floor) then there is potential to draw in groundwater with a decant signature to the depressurisation bores.

Option 2 Off-site depressurisation bores and collection trench

Advantages of Option 2 include:

- Pressure relief measures (depressurisation bores) located around 200 m up-gradient of the off-site seepage area, therefore the benefits of reduced groundwater levels on the off-site seepage should be realised sooner in comparison to implementation of Option 1.
- Depth of depressurisation bore anticipated to be up to around 15 m and potential for reduction in the number of depressurisation bores required if combined with the construction of a trench collection system, therefore potential cost savings in relation to construction.
- Supplements the existing off-site seepage management system which manages the seepage discharge at the end point, with a system that manages the groundwater levels up gradient of the end point thereby limiting the potential for development of more seepage areas up gradient of the main seepage area into the future.

Disadvantages of Option 2 include:

- Does not address the on-site elevated groundwater pressures or the on-site seepage issues, only addresses off-site seepage. On-site groundwater issues are likely therefore to continue and potentially worsen with future dam raises.
- Located on state-owned land, therefore potentially difficult access for installation, monitoring and maintenance now and into the future.
- Could require purchase of land in the future.
- Potential for new seepage points to develop up-gradient of off-site depressurisation bores (which could develop either on or off-site).

Preferred option

Based on the evaluation of advantages and disadvantages for both concept management options, Option 1 is considered the most appropriate option to take forward.

4.2 Analytical solution modelling for Option 1

An in-house model (developed in excel) has been used to estimate a preliminary spacing of depressurisation boreholes and borehole diameter for Option 1, the preferred concept option. The solution also provides an estimate of the lateral and vertical extent of the cone of depression with time and distance, after the start of pumping (depressurisation).

The model uses the Theis (1935) analytical solution for a pumping test in a confined aquifer to estimate groundwater level drawdown at any radial distance from the pumped borehole. In this case the pumped borehole of the Theis solution is represented by a depressurisation borehole. A line of pumped boreholes were used in the model to represent a line of depressurisation bores at the toe of the Northern Embankment and observation bores used to obtain the modelled drawdown at specific locations. For the estimated aquifer transmissivity (0.35 m^2/day) and borehole diameter selected (0.2 m), bore spacings of 10 m, 15 m and 20 m were tested along with various depressurisation bore flow rates (including 0.01, 0.02, 0.05 and 0.1 L/s) to identify a preliminary bore spacing for Option 1.

The input parameters that give a modelled water level drawdown in the order of 10 m in the borehole with a drawdown in between each borehole of around 7 m are outlined in Table 4-1. Further information on the modelling undertaken is provided in Appendix D.

The results of the analytical modelling (Appendix D) indicate the following in relation to a line of depressurisation bores at the toe of the Northern Embankment under the Option 1 concept:

- A preliminary depressurisation bore spacing of around 20 m, reaching the maximum allowable drawdown (set at 10 m) after around 60 days.
- After around 60 days groundwater level drawdown at MB11D (around 100 m down-gradient of the depressurisation bores) of the order of 1.5 m, at MB06 (around 150 m down-gradient of the depressurisation bores) of the order of 0.5 m and minimal drawdown of <0.05 m at 580-MB-2004 (around 310 m down-gradient of the depressurisation bores).
- Whilst the maximum allowable drawdown at the depressurisation bores is reached after around 60 days, the cone of depression will continue to expand after this time and hence down-gradient groundwater levels would be anticipated to continue to reduce for some time after.
- The rate of discharge from the depressurisation bores is anticipated to be low (modelled at 0.02 L/s from each bore), given the relatively low hydraulic conductivity of the water bearing strata (in the order of 4×10^{-7} m/s) in the area.

Based on these preliminary modelling results, an additional line (or lines) of depressurisation bores may also need to be located close to the northern boundary of the RMA (on-site) to reduce off-site groundwater levels and subsequent cessation of groundwater discharge to surface. The need for an additional line (or lines) of depressurisation bores will be evaluated by the measured reduction in groundwater levels at monitoring bores located down gradient of the depressurisation bores.

Table 4-1 Input parameters for analytical modelling

Input parameter	Unit	Value	Justification
Horizontal hydraulic conductivity, K	m/day m/s	0.035 4.1×10^{-7}	Average of values estimated for MB11D, MB12, and 580-BH-2007 (bores closest to the proposed area for depressurisation)
Aquifer thickness	m/day	10	Equal to the screen length for each depressurisation bore
Transmissivity, T	m^2/day	0.35	Calculated (K*aquifer thickness)
Pumping bore radius	m	0.2	Can be easily drilled using air percussion method of drilling
Depressurisation bore spacing	m	20	Arrived at through iteration, to model a total drawdown in the depressurisation bore of around 10 m (i.e. lower the groundwater to around 7 m below ground level) and a drawdown in between the bores of around 8 m (i.e. lower the ground water to around 5 m below ground level)
Flow rate from one depressurisation bore	L/s	0.02	Arrived at through iteration, to model a total drawdown in the depressurisation bore of around 10 m (i.e. lower the groundwater to around 7 m below ground level) and a drawdown in between the bores of around 8 m (i.e. lower the ground water to around 5 m below ground level)
Number of depressurisation bores	No.	10	For modelling purposes only, representing a line at the toe of the northern embankment

5. Conclusions and Recommendations

5.1 Conclusion

The elevated groundwater levels at the eastern end of the Northern Embankment are likely to be due to a combination of the following:

- Compression of the natural ground underlying the tailings, resulting in increased pore pressure within the strata and subsequent mounding of groundwater along the fringes of the RMA dam.
- The location of the RMA dam in the valley floor, potentially limiting the movement of groundwater from the topographic high in the east resulting in increased pressures in the vicinity of the dam.
- No decant signature in groundwater has been detected to date, however there is potential for localised recharge of groundwater as a result of seepage of pore water from within the bauxite residue to underlying strata, from the unlined Pocket decant and the unlined decant chute (the Falls). Given the absence of decant signature in groundwater to date, these mechanisms are considered to be secondary in their contribution to the elevated groundwater levels observed.
- Lack of connectivity between the drainage blanket and underlying water bearing strata at the eastern end of the Northern Embankment.

The groundwater is saline (in the order of 20,000 to 40,000 µS/cm) and predominantly held within variably fractured, extremely weathered siltstone, sandstone/arenite with some conglomerate in places, and moves via interconnected fracture flow pathways, broadly flowing from the south east towards the north west across the eastern end of the Northern Embankment. The presence of discrete fracture flow pathways through the low permeability confining layer is thought to enable the groundwater, with a pressure head above ground surface, to discharge as seepage and salt scalds at ground surface.

5.2 Recommendations

The preferred option for management and alleviation of the elevated groundwater levels at the eastern end of the Northern Embankment is the installation of a number of depressurisation bores (Option 1) up-stream of the seepage areas to reduce off-site groundwater levels and groundwater levels in the vicinity of and downstream of the toe of the embankment.

5.2.1 Recommended further actions

The following items are recommended to provide additional information in support of furthering the concept-level design for Option 1 for alleviation of the observed on-site and off-site groundwater pressures in the vicinity of the eastern end of the Northern Embankment area:

- Installation of a groundwater monitoring bore to the north of the Pocket decant and Falls (to be located in the vicinity of the base of the Falls on the northern side, at 15 to 20 m depth) to confirm the groundwater pressure in this area, to enable refinement of groundwater contours and flow directions in this area and to confirm the absence of decant signature in groundwater.
- Conduct small-scale pumping or bail-down and recovery tests on the existing standpipe piezometers in the vicinity of the eastern end of the Northern Embankment to gain a general understanding of the order of yield and drawdown that might be realised in a depressurisation bore.

- Update the existing 3D numerical groundwater flow model for the RMA or develop a local scale 3D groundwater flow model to:
  - Support the design of a pressure relief system.
  - Predict the potential effectiveness of a pressure relief system (for example changes in groundwater levels over time, spatial changes in groundwater levels and flow directions, predictions of pressure reductions in seepage areas for a given pressure relief design).
  - Predict potential effects of a pressure relief system on migration of decant in groundwater using a flow and solute transport numerical modelling code such as MODFLOW-SURFACT (Hydrogeologic, 1996).
- Improve existing monitoring system of the Northern Embankment toe drain system to incorporate continuous monitoring of sump water levels, sump inflows and discharge outflow.
- Conduct a detailed analysis of the groundwater quality results obtained by the SAP to confirm the absence of the decant signature in groundwater, including:
  - Comparison of results (particularly signature metals, EC and pH) to decant, baseline and historic quality data
  - Major ion chemistry analysis with comparison to baseline and historic data
  - Comparison of ratios (such as Na:Cl, K:Cl and Mg:Cl) in groundwater, decant and seawater.

5.2.2 Recommended monitoring

The following are recommended in relation to groundwater monitoring into the future:

- Continue to monitor groundwater levels across the Northern Embankment area (on-site and off-site), and review for increasing trends and spatial variations such as mounding in other areas.
- Monitor groundwater quality in the new standpipes installed beneath the Northern Embankment and the Eastern Embankment (SPP series bores) and the standpipe recommended for installation to the north of the Pocket decant and Falls. Review the results for early detection of decant signatures in groundwater.
- Continuously monitor the Northern Embankment toe drain system sump water levels, sump inflows and discharge outflow (rates and cumulative volume) to provide a better understanding of the volume of water being moved through the system and variation through time.

The following general recommendation is also made:

- Ensure any exposed ground/bedrock is adequately sealed with compacted low permeability material prior to placement of decant or residue mud.

6. References

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RTA Yarwun 2014(b). Investigation of dead vegetation north of the RTA Yarwun RMA, October 2014

RTA Yarwun 2015(a), Memo Test Pit Investigation – RMA Groundwater Management, 15 July 2015

RTA Yarwun 2015(b), Memo Borehole Investigation – RMA Groundwater Management, 26 July 2015

RTA Yarwun 2015(c), Memo Slug Test Investigation – RMA Groundwater Management, 23 July 2015

Appendices

Appendix A – Data and Data Analysis

Memo Test Pit Investigation – RMA Groundwater Management (RTA Yarwun 2015[a])

Memo Borehole Investigation – RMA Groundwater Management (RTA Yarwun 2015[b])

Memo Slug Test Investigation – RMA Groundwater Management (RTA Yarwun 2015[c])

Figure 1 Investigation Location Plan

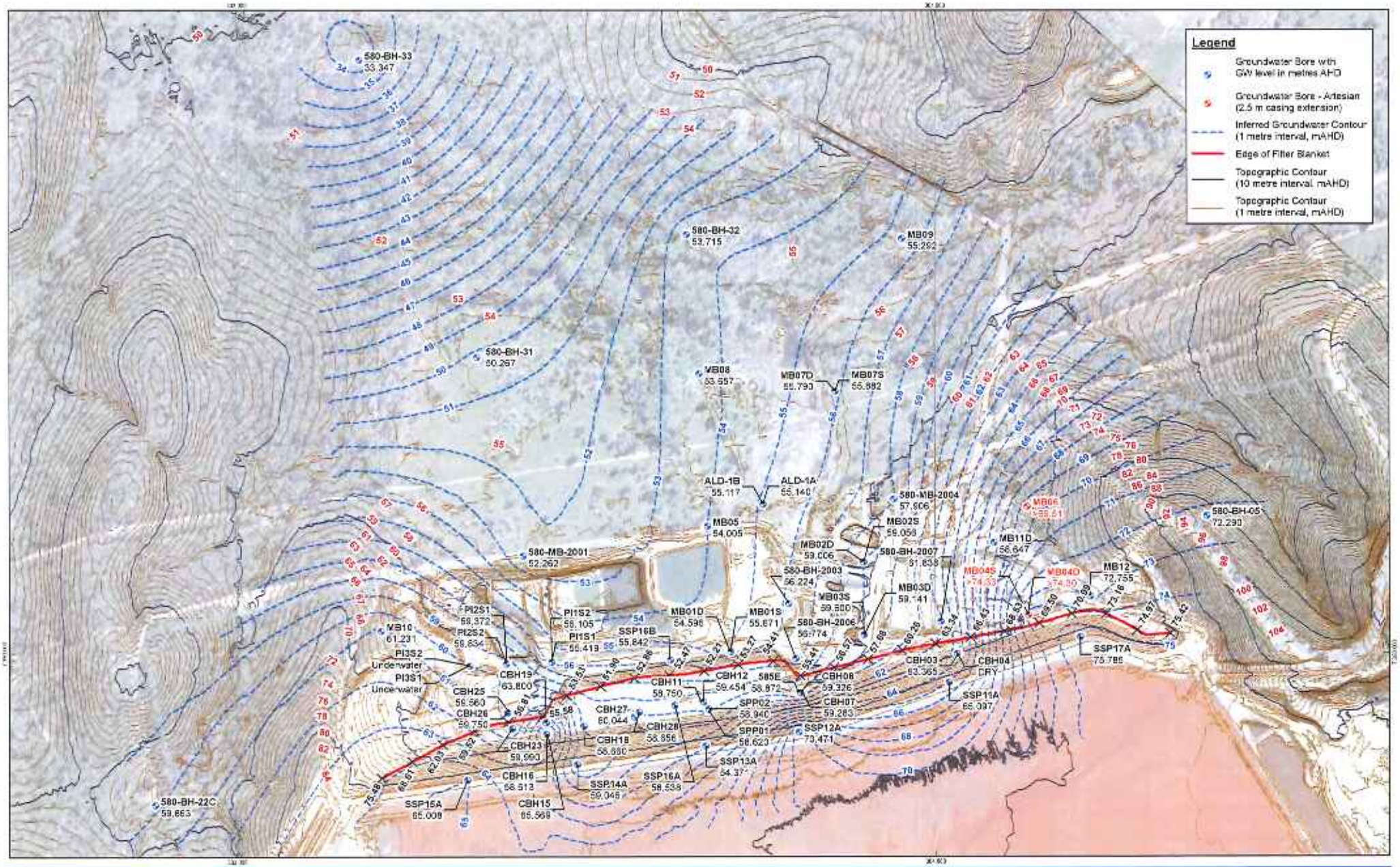
Figure 2 Inferred Groundwater Contouring

Figure 3 Groundwater Levels Compared to Ground Surface



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0 50 100 200 300

Metres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

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NOTES

- Topographic Contours are processed from Lidar data captured February 2013 and January 2015
- Groundwater levels measured in June and July 2015.

RTA Yarwun
Yarwun RMA Groundwater Management Actions

Job Number	41-28523
Revision	B
Date	01 Oct 2015

Inferred Groundwater Contouring

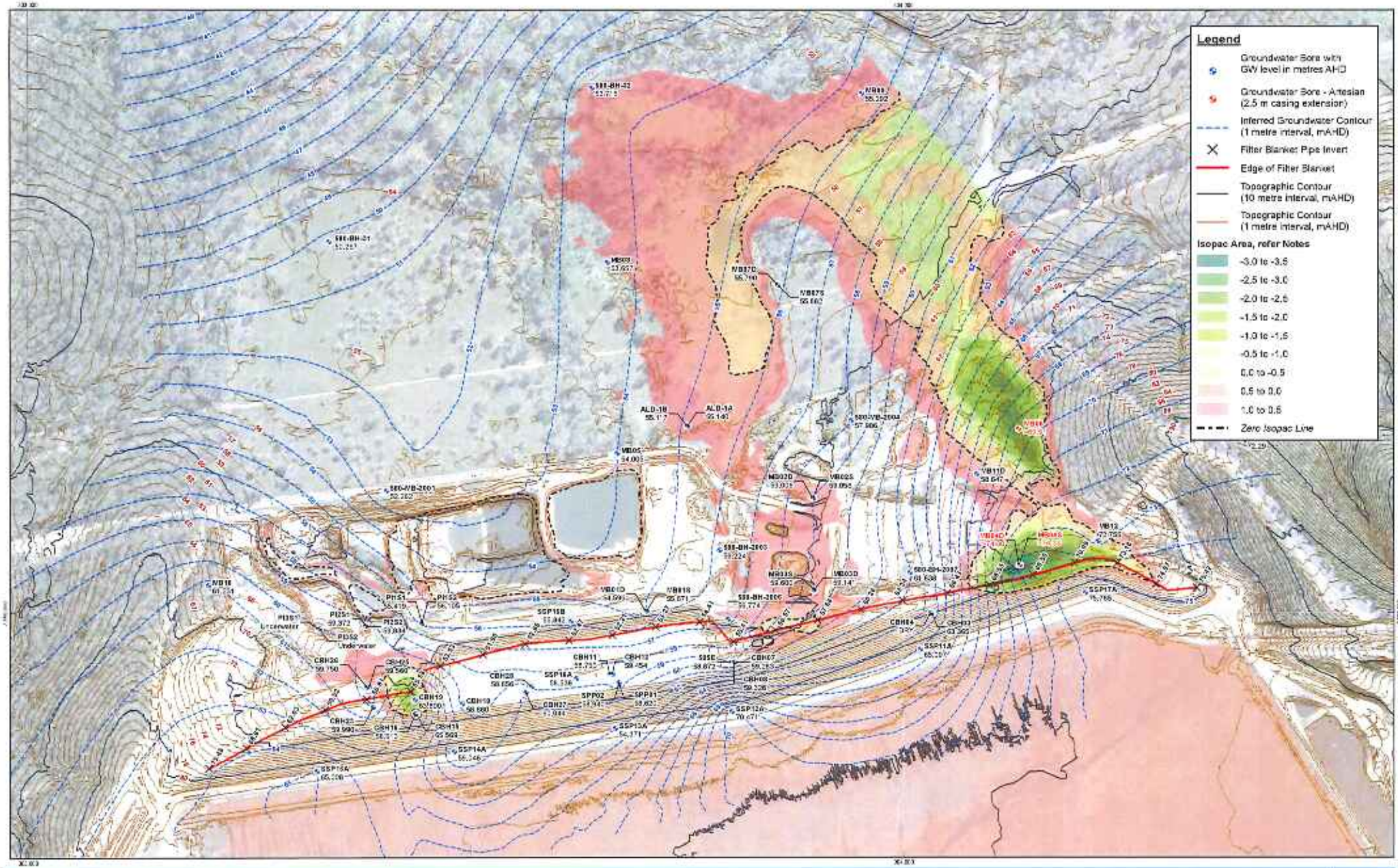
Figure 2

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Metres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

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NOTES

- Topographic Contours are processed from Lidar data captured February 2013 and January 2015
- Groundwater levels measured June and July 2015.
- Isopac Area generated Topographic surface minus the Groundwater surface.

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Yarwun RMA Groundwater
Management Actions

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Groundwater Levels Compared to Ground Surface Figure 3

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Data source: RTA - lidar data (Feb 2015 and Jan 2015); GE aerial imagery (May 2014); Creation: LAS

STRIDE Cherie

From: RITCHIE Pamela
Sent: Monday, 15 February 2016 4:19 PM
To: WALSH Sacha; MULLER Laura; STRIDE Cherie
Cc: BAKER Tony; DELANEY Kate; RITCHIE Pamela
Subject: ACTION REQUIRED: Return of FA's to the Directorate

Good afternoon,

To begin the process of transferring all Financial Assurances to Brisbane we are going to return all CaCQC FA's to the Directorate.

PREPARATION

First you will need to ensure that the FA's you hold are recorded correctly in the DDG's FA register see the link below,

http://team:6002/ehp/esr/CR/D/Finance%20and%20Assets%20documents/January%20FA%20register.xlsx

TRANSPORTATION

Once you are certain that the details in the register are correct,

Securely pack the FA's into an envelope, clearly mark the envelope with the Directorates address (in case it gets misplaced)

Attention: Sacha Walsh
PO Box 413
Rockhampton 4700

and have the CDM's bring them to the next ELM that is to be held in Emerald on 2-3rd March 2016.

All FA's are to be handed to Sacha Walsh, for her to return them to the Directorate.

Please confirm via email to sacha.walsh@ehp.qld.gov.au that the CDM has been given the FA's to deliver.

If you have any questions relating to this request please contact me directly.

Thanks, Pamela

Queensland Government

Pamela Ritchie
Project Support Officer
Directorate – Business Support | Coal & Central Qld Compliance
Department of Environment and Heritage Protection

P 07 4837 3304
209 Bolsover St Rockhampton 4700
PO Box 413 Rockhampton 4700

Appendix B – Data Analysis Tables and Charts

Chart - Groundwater level time series for environmental monitoring bores

Table – Change in groundwater level for environmental monitoring bores

Table – Estimated hydraulic conductivity values from slug tests

Table – Mean estimated hydraulic conductivity values from slug tests

Table – Estimated hydraulic conductivity values from seepage to test pits

Charts – Slug test analysis

Appendix C – Conceptual Model

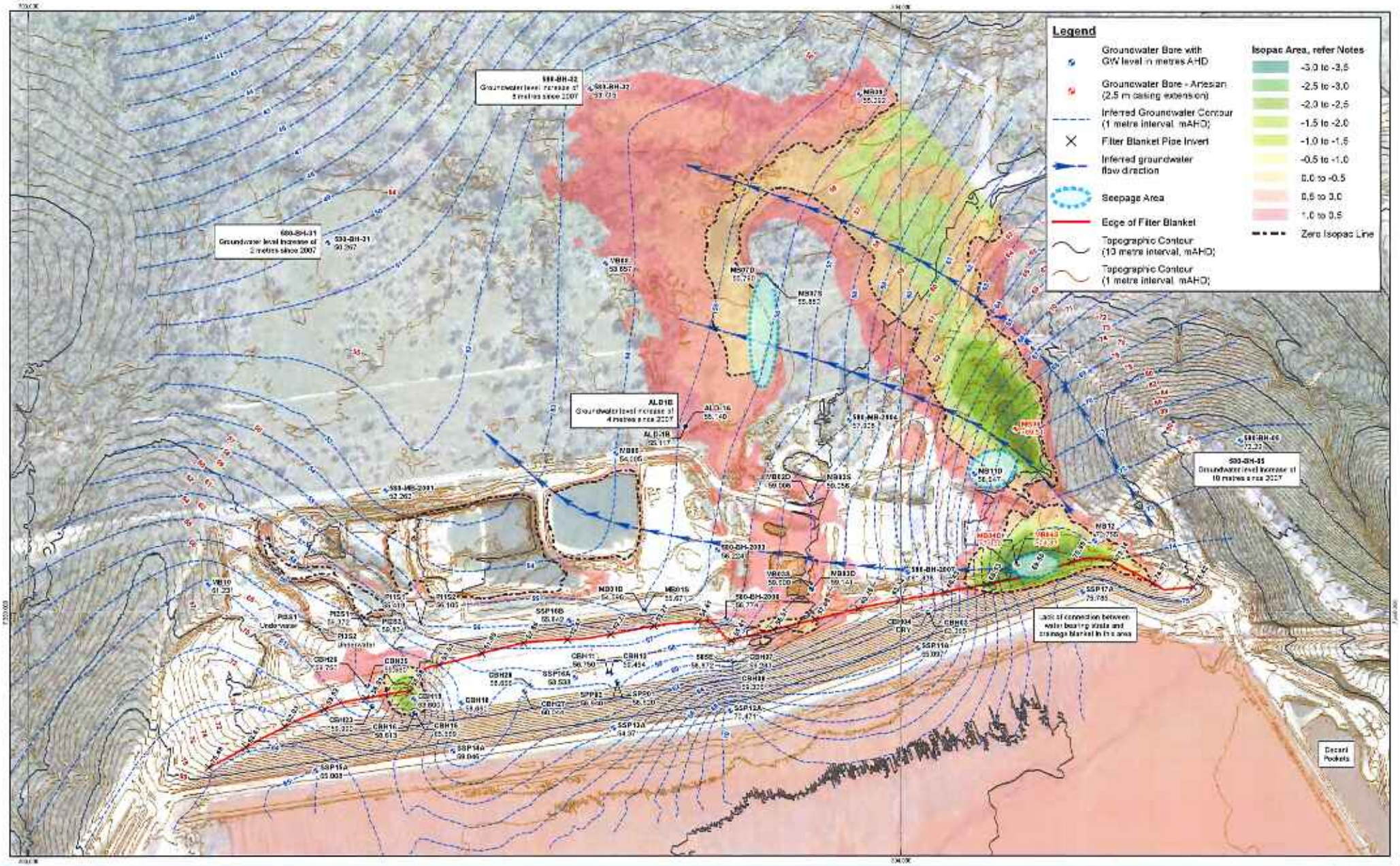
Figure 4 - Hydrogeological conceptual model plan

Figure 5 - Section line plan

Figure A – Conceptual cross section (Section A)

Figure B – Conceptual cross section (Section B)

Figure C - Conceptual cross section (Section C)



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Metres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

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NOTES

- Topographic Contours are processed from Lidar data captured February 2013 and January 2015
- Groundwater levels measured June and July 2015.
- Isopac Area generated Topographic surface minus the Groundwater surface.

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Revision B
Date 01 Oct 2015

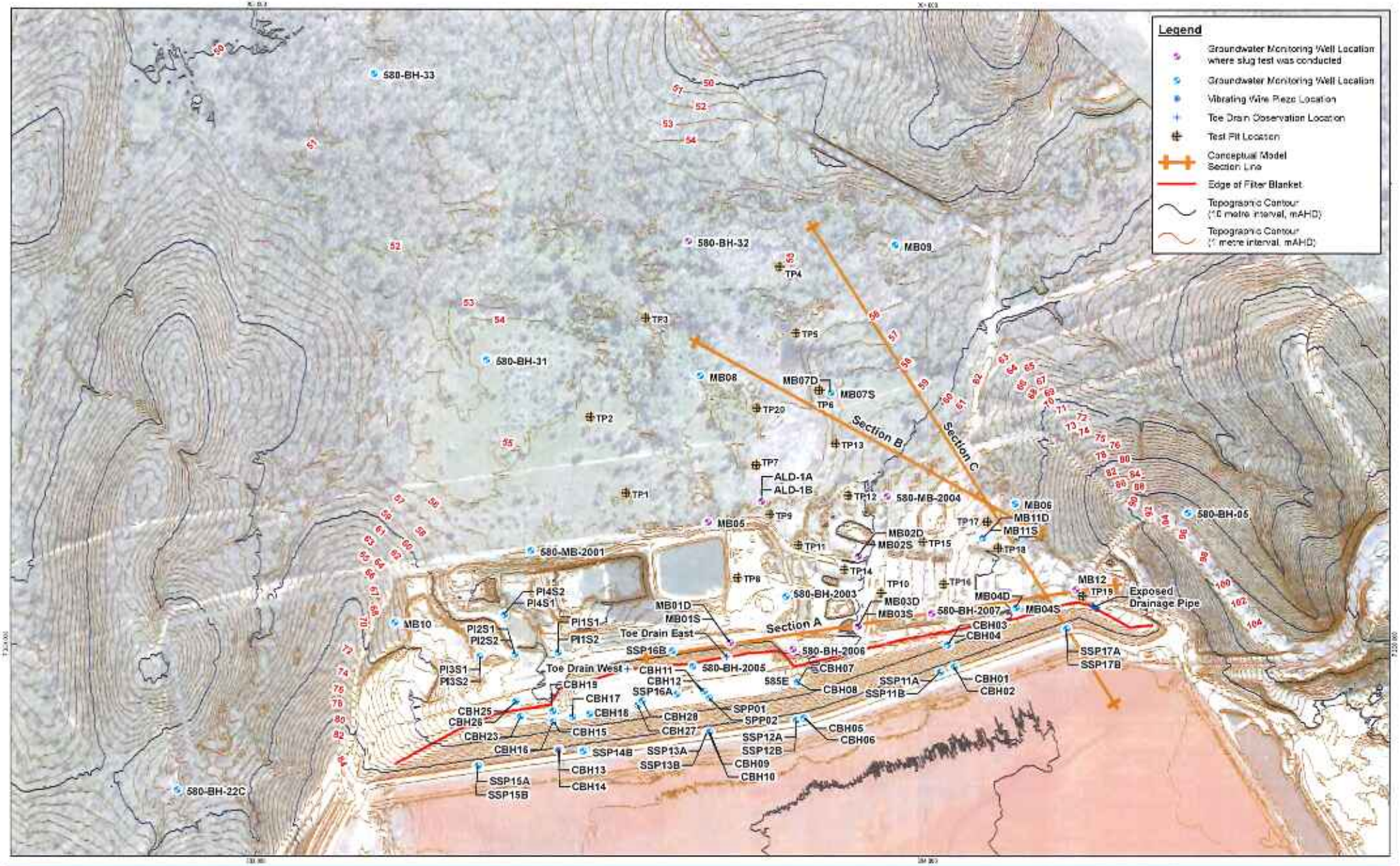
Hydrogeological Conceptual Model

Figure 4

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Metres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

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NOTES

- Topographic Contours are processed from Lidar data captured February 2013 and January 2015

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Yarwun RMA Groundwater Management Actions

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Conceptual Section Lines

Figure 5

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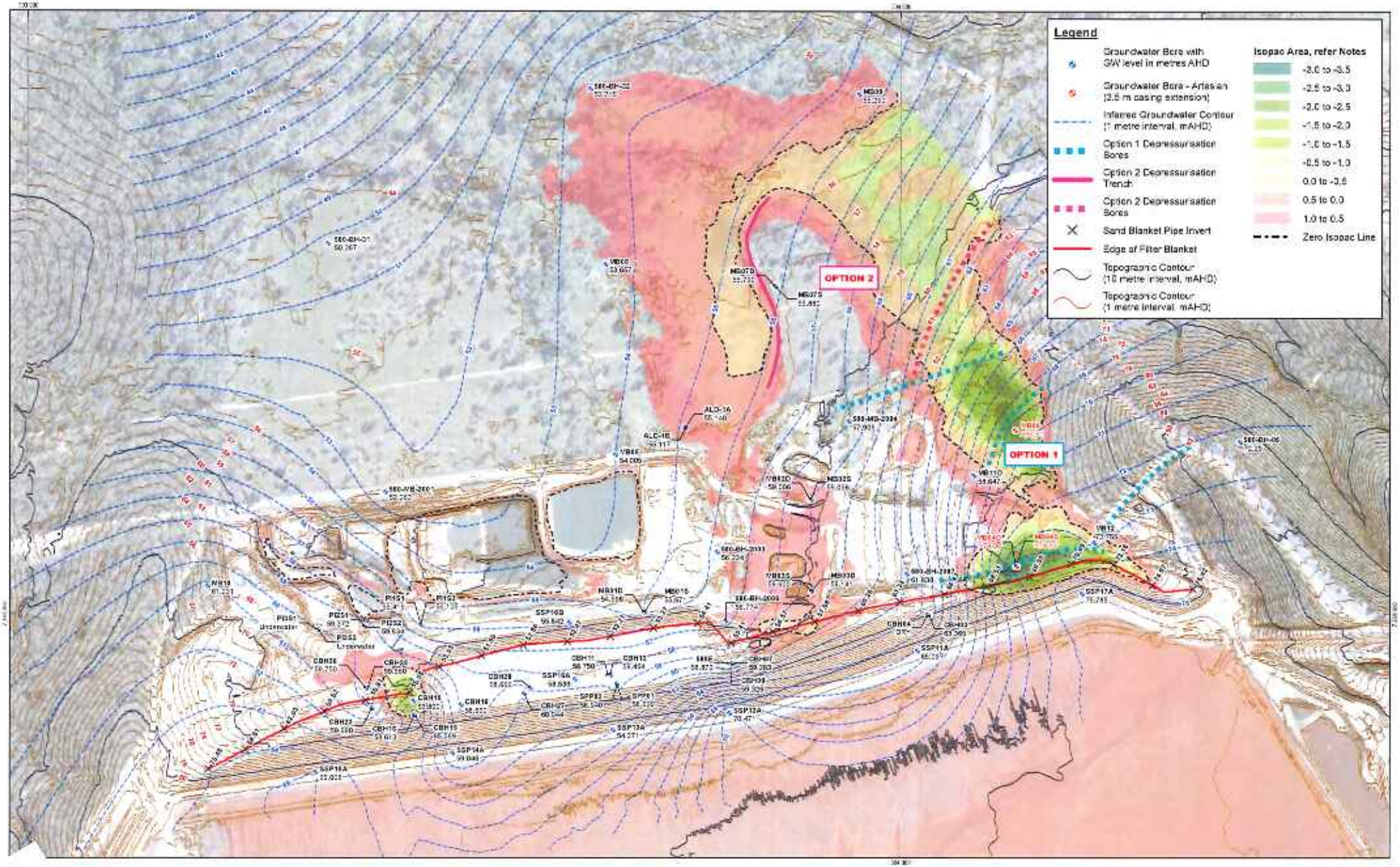
Data source: RTA: Lidar data (Feb 2013 and Jan 2015); GE: aerial imagery (May 2014); Creation: JVo

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Appendix D – Groundwater Management Options Analysis

Figure 6 – Concept groundwater management options

Summary of analytical modelling input data and results



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100 0 100 200

Metres

Universal Transverse Mercator
(a) Datum: GDA 1994
(b) 1994 MGA Zone 56

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GHD

NOTES

- Topographic Contours are processed from Lidar data captured February 2013 and January 2015
- Groundwater levels measured June and July 2015.
- Isopac Area generated Topographic surface minus the Groundwater surface.

RTA Yarwun
Yarwun RMA Groundwater Management Actions

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Concept Groundwater Management Options

Figure 6

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Data Source: Aerial Photography (Nov 2013 and Jan 2015); GIS: (wms: imagery (Nov 2014). Created: jac

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22 April 2015

Luke Craig
Rio Tinto Alcan Yarwun
PO Box 1479
Gladstone
QLD 4680

Our ref: 41/28523
465654
Your ref:

Dear Luke

RTA Yarwun Groundwater Management
Low pH Water Investigation

1 Introduction

GHD Pty Ltd (GHD) was commissioned by Rio Tinto Alcan Yarwun (RTAY) under Contract Number CW2081249 to assist with the development of an improved groundwater management system for the Yarwun Residue Management Area (RMA), herein referred to as the site.

The purpose of this commission is to assist RTAY in the characterisation and conceptualisation of groundwater mounding to enable a plan to be developed to alleviate the observed pressurised groundwater and to investigate low pH waters within a Firewater dam at the RMA. To achieve this, the work has been divided into three tasks as follows:

- Task 1 – Spatial analysis of groundwater pressurisation and development of field investigations
- Task 2 – Concept design of management options to alleviate pressurisation of the Northern Embankment and off-site downstream of the RMA
- Task 3 – Assessment of low-pH water in the Firewater Dam.

This letter report details Task 3 (assessment of low-pH water in the Firewater Dam). The Sampling and Analysis Plan (SAP) for the low-pH water assessment is included in GHD report *Spatial Analysis of Groundwater Pressurisation of the Northern Embankment and Development of Sampling and Analysis Plan*.

The following points summarise the scope of Task 3, as detailed in this letter report:

- Literature review (Section 2)
- Site inspection, sample collection and laboratory analysis (Section 3 and Section 4)
- Hydrogeochemical assessment and modelling (Section 5)
- Conclusions and recommendations for ongoing sampling and a monitoring program (SAP) (Section 6 and Section 7).

2 Literature review

The following sections provide a summary of the pertinent information regarding the low pH water identified by RTAY in the firewater dam.

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T 61 7 3316 3000 **F** 61 7 3316 3333 **E** brsmail@ghd.com **W** www.ghd.com

2.1 (RTAY internal memorandum) Draft options to address risks and actions reported 17/7/2014

This memo details options for consideration for managing rising groundwater levels within the Northern Embankment and briefly presents possible causes for the low pH water.

Possible causes for low pH water identified include:

- Natural material reacting with groundwater
- Groundwater is naturally low in pH
- Waste material illegally dumped in contact with groundwater
- Acid spill in past in contact with groundwater
- Other causes.

2.2 (RTAY) Groundwater seepage at the Rio Tinto Alcan Yarwun RMA, 9 October 2014

In July 2014 groundwater seepage was observed down-gradient of the eastern side of the Northern Embankment. This report details Stage 1 of the root cause investigation scope of work (site visit and desktop study) undertaken. The relevant points from the report in relation to the firewater dams (identified as 'firewater dam' and 'RMA_GW1', where 'RMA_GW1' is located upstream of 'firewater dam' in the RTAY report) are summarised below.

Summary of field observations in relation to the firewater dams:

- July 2014 – seepage flow was observed into the two dams that were present to the north of the construction area (RMA_GW1 and firewater dam). Seepage was also noted in the adjacent construction car park, an area to the south of the construction car park and on the sides of the haul road at the foot of the north wall.
- A red tinge was observed around the RMA_GW1 dam, but no similar tinge was observed around the firewater dam, located down-gradient.

Surface water samples were collected from the two dams (RMA_GW1 and firewater dam respectively) for laboratory analysis. Dam water sample analysis indicated a groundwater chemical signature with elevated magnesium and low potassium concentrations and non-detectable concentrations of gallium and molybdenum. These chemical signatures of water from RMA_GW1 and the firewater dam were compared with the signatures from seawater and decant water from the RMA residue dam. Groundwater sampling and analysis of two existing bores located in the vicinity was also used for comparison purposes. The dam water samples were found to be generally representative of groundwater and not seepage from the RMA. The chemical typing was done by comparing potassium-to-chloride ratios, magnesium-to-chloride ratios and trace metals gallium and molybdenum.

The low pH of the dam water (3.4 pH measured in the firewater dam and 3.2 pH measured in RMA_GW1) is thought to be caused by iron oxidisation and precipitation from emerging groundwater seepage. At the time of the inspection, iron staining was present in RMA_GW1 dam around the margins but staining was not evident in the vicinity of the firewater dam, considered to be because the majority of the iron is likely to have been lost through precipitation by the time water has flowed to the firewater dam. Iron staining was also observed at a number of up-gradient seepage points.

Reported recommendation:

- Groundwater and surface water samples should be taken from the firewater dam and analysed for the full suite including species of iron and organic acid content. A bore should be installed upstream of the two dams and sampled.

3 GHD site inspection and sample collection

Prior to the field work being undertaken, GHD developed a Job Safety and Environmental Analysis plan (JSEA) and liaised with RMA staff prior to undertaking the site visit. On meeting the RMA representative on site, who accompanied GHD staff at all times, the safety plans and job briefing was undertaken with a group toolbox assessment also completed along with a Cat 3 Contractor Authority to Work Permit. This was issued and reauthorised for the following day of site work. The site inspection and groundwater/surface water sampling was undertaken by an environmental engineer from GHD, undertaken in accordance with GHD Practice Manual, 2000, Contaminated Sites Environmental Procedures.

3.1 Site inspection

A site inspection of the two firewater dams, surrounding area and the monitoring bore 580MB2004 was undertaken by GHD, accompanied by RMA Operations, on 9 and 10 February 2015. In relation to the inspection and reporting, GHD herein, refer to the downstream firewater dam as Firewater Dam 1 (FD1) and refer to the upstream area of ponded water as Firewater Dam 2 (FD2), as shown on Figure 1 (previously reported as the firewater dam and RMA_GW1 dam respectively, in RTAY October 2014 *'Groundwater seepage at the Rio Tinto Alcan Yarwun RMA'*).

The inspection was conducted to:

- Document and photograph site features, inspect the firewater dams and surrounds for signs of staining, low pH, seepage zones, inflow channels, nearby landform and vegetation, and comparison to information gathered during the previous investigations.
- Identification of sampling sites, testing water for physical parameters, collection of surface water, seepage, groundwater and soil samples for field testing and laboratory analysis to inform the geochemical assessment.
- Identify a suitable location for an up gradient groundwater monitoring bore to be installed, in order to confirm the depth to groundwater in the vicinity of the firewater dams and the up gradient groundwater quality.



Figure 1 Sampling location plan

3.2 Field observations

A summary of the key field observations made during the site inspection are detailed below with photographs of key observations shown in Table 1.

The week previously, heavy rainfall had been experienced at the site with the soils surrounding the dams being moist but firm. Both the dams, connected by overland flow, are located in semi-open bushland with limited grass cover, with juvenile to mature trees surrounding the area and present on a hillside to the east. The dams appear to have been constructed within natural low points near the base of the hillside with limited excavation occurring and no embankment walls, based on the spoil observed in the area.

Firewater Dam 1

- The Firewater Dam 1, located down-gradient of the upper dam, receives inflow principally from the up-gradient Firewater Dam 2, via overland flow across a poorly defined channel interconnecting the two dams. Some minor stormwater contributions are also received from the higher ground to the east. The dam is generally triangular in shape, being approximately 20 m across, 0.5 m deep and having a standing water level at approximately 64.1 m AHD at the time of inspection. A low point in the north western corner acts as a spill point, where the discharge flows for a short section of bush prior to discharging into a table drain and pipe under the thickener plant access road. The dam has a water level marker installed and it was noted from observations that it would spill from approximately 64.2 m elevation. At the time of the inspection the water within the dam was clear with isolated areas near the edges having green grass growing in the water. Aquaticorganisms were noted to be present and the bottom and side batters of the dam contained abundant leaf litter. A small pad for vehicle access was also present in the northeast with a flexible hose lying on the surface.

Firewater Dam 2

- Firewater Dam 2, being up-gradient, receives stormwater flow from a portion of the RMA access road via a table drain, overland flow from the east and principally from an excavated V drain (inflow channel) that runs parallel to the access road which captures flow from the adjacent hillside to the east. The oval dam is approximately 22 m long, 0.6 m deep and based on a water level survey post, the level was at 65.150 m AHD and just below where it would spill into Firewater Dam 1. The dam edge can be accessed from the roadside with a parking area present adjacent on the western side being constructed of earth fill, with the remainder being surrounded by bush. The water within the dam appeared clear with trace floating detritus/scum and apparent isolated areas of iron flock present on the bottom, principally in the western portion. Some emergent reeds were also present in the centre, being brown and dead, possibly prior to the recent rainfall.

Inflow Channel

- The V drain directs stormwater captured from hillside overland flow into Firewater Dam 2 via a level section of soil to discharge in the southeaster corner. The drain, excavated within shallow topsoil and underlying extremely weathered bedrock was orientated in a north-easterly orientation, with excavated depth ranging from approximately 0.3 to 1.5 m below ground level and up to 0.5 m wide at the base. The bed of the drain appeared undulating with isolated pockets of ponded water present in low points, up to 0.3 m deep. Located approximately 35 m up from the dam, a water sample was collected within a 3 m reach of water with a surface soil sample also retrieved from adjacent topsoil (0.0-0.15 m depth). No flocks or indication of any iron staining were apparent within the ponded water body, but along the walls of the V drain, evidence of seepage was observed. Immediately

downstream of this, a 3 m long, 40 mm diameter piece of wire rope was present in the bottom of the drain, being rusted and having red soil staining adjacent.

Monitoring Bore 580MB2004

- An existing groundwater monitoring bore, 580MB2004, located approximately 150 m west of the fire dams and screened in highly weathered argillite was sampled as part of the investigation. It is considered to be representative of groundwater, down gradient of the dams. Static water level (SWL) recorded prior to sampling was 3.332 m from top of standpipe, being approximately 2.7 m below ground level. This equates to an RL of 58.153 m AHD. Some trace organics as particulates were observed in the bore purge water, although a cap was present on the bore casing prior to sampling.

Proposed Monitoring Bore MB06

- During the site inspection, a suitable location was investigated for a proposed groundwater monitoring bore to be installed, up-gradient from Firewater Dam 2. This bore may be able to further evaluate if there is a relationship between groundwater quality and potential inflows into the fire dam. The proposed location, shown as MB06 on Figure 1, was positioned approximately 20 m south, up-gradient and adjacent to the V drain that flows into Firewater Dam 2.

Photographs taken during the investigation are provided below in Table 1.

Table 1 Photographs of key observations

Item	Photograph	Details
1		View of the RMA access road and table drain that discharges into the upper Firewater Dam 2.

Item	Photograph	Details
2		View of the road table drain into the Firewater Dam 2 with seepage evident in the walls of the drain.
3		View of the Firewater Dam 2, looking up gradient with the level marker in the foreground and trace scum present in the vicinity on the water surface. A V drain present along the toe of the hillside discharges into the dam to the left of the table drain and vehicle pad, shown in the background.
4		View of the overland flow path from the upstream Firewater Dam 2 to the lower Firewater Dam 1 present in the background.

Item	Photograph	Details
5		Firewater Dam 1, looking north, with the overflow discharge point to the left rear and a vehicle access pad to the right rear. The damp section in the foreground is where the overflow from Firewater Dam 2 enters this area.
6		View of the V drain that has been excavated along the toe of the hillside which directs runoff into Firewater Dam 2. The depth of cut for this drain varies across its length, with isolated areas of water ponding generally associated with low points along the invert.

Item	Photograph	Details
7		The V drain, where a water sample (FD1 US) was taken from a reach of the drain where water was ponding. A shallow soil sample was also sourced from the adjacent soils.
8		Iron stained soils and a 3 m length of wire rope present in the V drain, immediately down-gradient and isolated from the ponded area where water sampling was undertaken in the drain.

Item	Photograph	Details
9		View of a section of the wire rope and the V drain walls indicating clay infilled joints within highly weathered bedrock.
10		The upper catchment and southern section of the V drain with grass cover and a less defined channel present.

4 Sampling and analysis

Within the fire dams, field water quality parameters; dissolved oxygen (DO), pH, oxidation/reduction potential (Eh), electrical conductivity (EC), and temperature were measured at the sampling point and directly opposite within the dams to evaluate variance across the water body. Physical parameters were also taken from an area of ponded water within the V drain and from the groundwater bore that was sampled, to assess water quality and to ensure the bore had been adequately purged. Turbidity readings were also taken within the dams.

Water samples were collected directly from the water body and placed into the laboratory supplied containers, with the groundwater sample being collected using a dedicated Waterra hose and foot valve. Prior to sampling, the bore was purged dry.

A soil sample, taken within topsoils directly adjacent to the V drain water sample, was characterised as a clayey silt, observed to be typical of soils in the area surrounding the dam.

Three surface water samples, one groundwater sample and one soil sample were collected for laboratory analysis and/or field testing, as detailed in Table 2.

Table 2 Summary of field sampling and analytical parameters

Sample location (sample ID)	Sample type	Analysis
Ponded water within Firewater Dam 1 (FD1)	Surface water	Field parameters (pH, electrical conductivity, temperature, dissolved oxygen, salinity, redox) with turbidity taken in dams only.
Ponded water within Firewater Dam 2 (FD2)		Laboratory analysis:
Ponded water in V drain channel, upstream of wire rope and upstream of Firewater Dam 2 (US FD1)		Physicals - pH, electrical conductivity, total dissolved solids, suspended solids, dissolved organic carbon, total organic carbon
		Major ions – calcium, magnesium, sodium, potassium, chloride, sulfate, Alkalinity (carbonate, bicarbonate), hardness, fluoride
		Total and dissolved metals – aluminium, arsenic, cadmium, chromium, copper, gallium, lead, manganese, molybdenum, nickel, vanadium, zinc
		Iron (ferrous and ferric)
		Nutrients – ammonia, nitrate as N, nitrite as N, nitrite + nitrate as N (NOx), reactive phosphorus
Downgradient monitoring bore 580-MB-2004 (incorectly labelled as 580-BH 2004 in laboratory certificates)	Groundwater	As for surface water
Soil adjacent to V drain, upstream of Firewater Dam 2 (US FD1)	Soil	Laboratory analysis:
		Physicals - pH, electrical conductivity, moisture content
		Major cations - calcium, magnesium, sodium, potassium
		Total metals - aluminium, arsenic, cadmium, chromium, copper, gallium, lead, manganese, molybdenum, nickel, vanadium, zinc

5 Soil and water analytical results and hydrogeochemical assessment

5.1 Field water quality results

Field water quality parameters are presented in Table 3 with the field data sheets in Attachment 1.

Table 3 Physico-Chemical Field Parameters

Location	Physical Parameters						
	Temp (°C)	DO (% sat)	pH	EC (uS/cm)	Salinity (ppm/mg/L)	ORP (mV KCl/AgCl)	Turbidity (NTU)
FD1 south	30.3	53.2	6.3	4273	2522	71.4	5.6
FD1 west	30.3	52.4	6.3	4218	2489	79.8	4.7
FD2 west	30.7	88.1	6.40	6730	3939	26.9	4.1
FD2 north	30.3	50.3	6.39	6584	3887	74.2	4.0
US FD1	22.5	42.4	4.8	7788	4829	235.5	
580MB2004	24.8	12.6	6.42	37075	24180	-111	

Electrical conductivity

Electrical conductivity values within the dams ranged from 4,218 uS/cm (FD1 south) to 6,730 uS/cm (FD2 north) and indicated the up-gradient Fire Dam 2 were slightly higher and similar to the sample taken from the up-gradient V drain (US FD1). The down-gradient groundwater bore reported a conductivity an order of magnitude higher at 37,075 uS/cm.

pH and oxidation reduction potential(Er/Eh)

Field pH data indicate that the dam waters were near neutral and all above pH 6.0 with the V drain being acidic, at pH 4.8. The dam water pH is significantly less acidic than previously measured by RTAY (refer to Section 2.2) and is likely to be due to inflow of water following recent rainfall and/or buffering of the acidic waters by the fresh influx of water.

Er values in the dam, measured using a saturated KCl/AgCl (TPS IJ64) electrode, ranged from 26.9 (FD2 west) to 79.8 (FD1 west). These are equivalent to standard hydrogen electrode Eh values of +225.9 to +278.8, using the probe correction factor of +199. The corresponding corrected Eh values in the V drain were 434.5 with the groundwater sample being at 88.

The pH and Eh conditions have a significant effect on the solubility and speciation of solutes and provide information in regard to what chemical processes may be occurring in the water system. Iron speciation and mobility in particular is affected by changes in pH and Eh.

Dissolved oxygen

Dissolved oxygen (DO) concentrations in the dams would be considered consistent with ponded water containing organics (leaf litter) that recently had received rainfall and the groundwater concentrations were typical for groundwater at the site.

Temperature

Temperatures in the dams ranged from 30.3 °C to 30.7 °C, compared to the V drain at 22.5 °C which was similar to the groundwater at 24.8 °C.

5.2 Laboratory analysis

One sediment and four water samples collected, as described in Table 2, were analysed for a range of inorganic and organic anolytes. The laboratory certificates for the analysis are included in Attachment 2 along with Chain of Custody documentation.

5.3 Soil sample results

Sample analysis of soil sample (USFD1) taken adjacent to the V drain and its water sample location are discussed below.

pH and electrical conductivity

The soil pH was reported at 6.4 pH, being similar to the Fire dam water readings which were all less acidic than the V drain water pH. The conductivity was reported at 31 uS/cm, which indicates it is not saline and is significantly lower conductivity than waters within the dams.

Soluble cations

The major soluble cation concentrations were reported at <10, <10, 20 and 10 mg/kg for calcium, magnesium, sodium and potassium respectively.

Metals

Soil metal concentrations are presented in Table 4.

Table 4 Soil Metals Analysis USFD1

Heavy metal	Concentration mg/kg soil
Aluminium	14,900
Arsenic	6
Cadmium	<1
Chromium	6
Copper	43
Gallium	<0.1
Manganese	409
Lead	9
Molybdenum	<2
Nickel	2
Vanadium	156
Zinc	62

The concentrations of metals were all within acceptable guidelines and typical for soils in the area, based on the previous assessments reviewed. No direct comparison was undertaken between the metals in soil and the concentrations reported the water samples.

5.4 Water sample results and hydrogeochemical assessment

Sample analysis of water from the dams (FD1, FD2), the V drain (USFD1) and the groundwater sample (580BH2004) are discussed below as part of the hydrogeochemical assessment. The quality of the laboratory analysis results was assessed and found to be acceptable, including the charge balance errors.

5.4.1 Major ions and general water quality

The field and laboratory analysis results indicate the groundwater and fire dam water have near neutral to slightly acidic pH, while the water sample collected from the drain had acidic pH. The groundwater sample showed reducing conditions, while the fire dam and drain water were under oxidising conditions.

Due the instability of pH and ORP, the field measurements were used in the hydrogeochemical assessment as they were considered to better represent the environmental conditions at the site.

Salinity

The Total Dissolved Solids (TDS) data suggest that groundwater is highly saline (32,000 mg/L at 580MB2004), while the dam water is slightly brackish (~2300 to ~3800 mg/L) and the drain water brackish (~6000 mg/L). This suggests that the drain is receiving discharge of saline water from either groundwater base-flow and / or some surface feature that produces saline leachate.

Chloride

Chloride concentrations show a strong relationship to TDS (refer to Figure 2). Chloride generally behaves conservatively in solution and is not subject to attenuation by sorption or precipitation unless strongly reducing conditions prevail. It is therefore a good reference for ion ratio analysis.

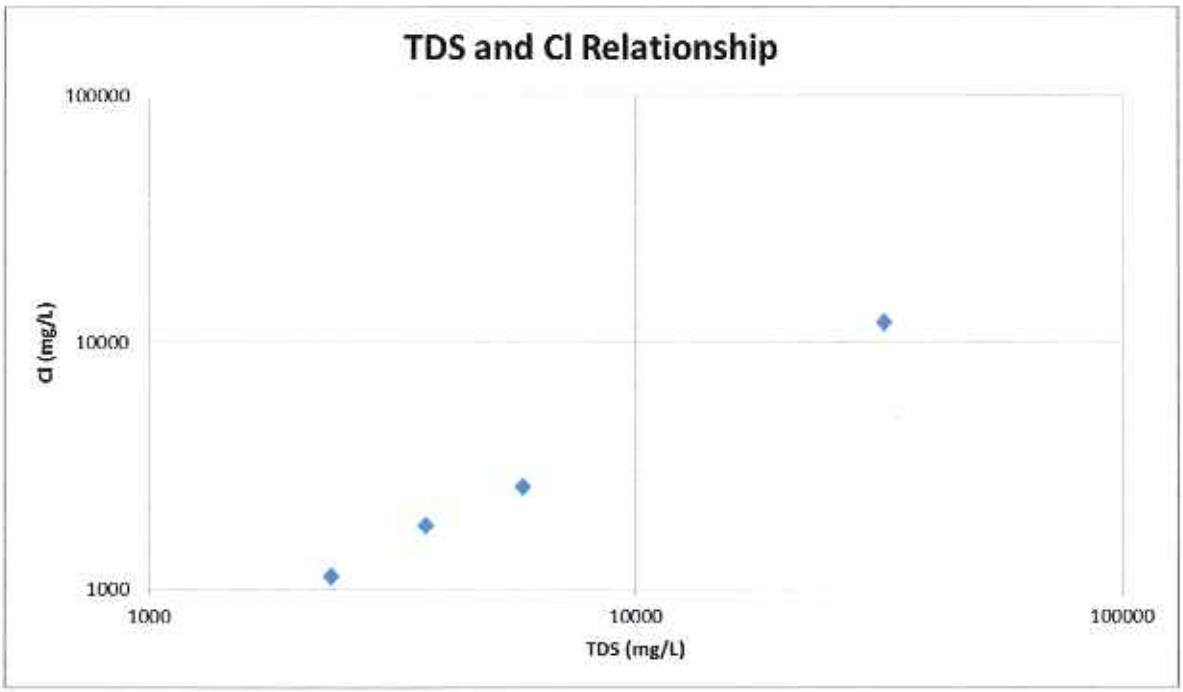


Figure 2 TDS and Chloride relationship for analytical results

Major ion ratios

Major cations (Ca, Mg, Na and K) and anions (Cl, HCO_3 and SO_4) comprise the majority of the TDS and their relative proportion within the TDS provides a good indication of the general hydrogeochemical characteristics of water samples. Figure 3 shows Stiff plots that graphically represent the major ion characteristics of the four water samples analysed. All four samples show sodium, magnesium chloride character, which suggests a linkage between the samples.

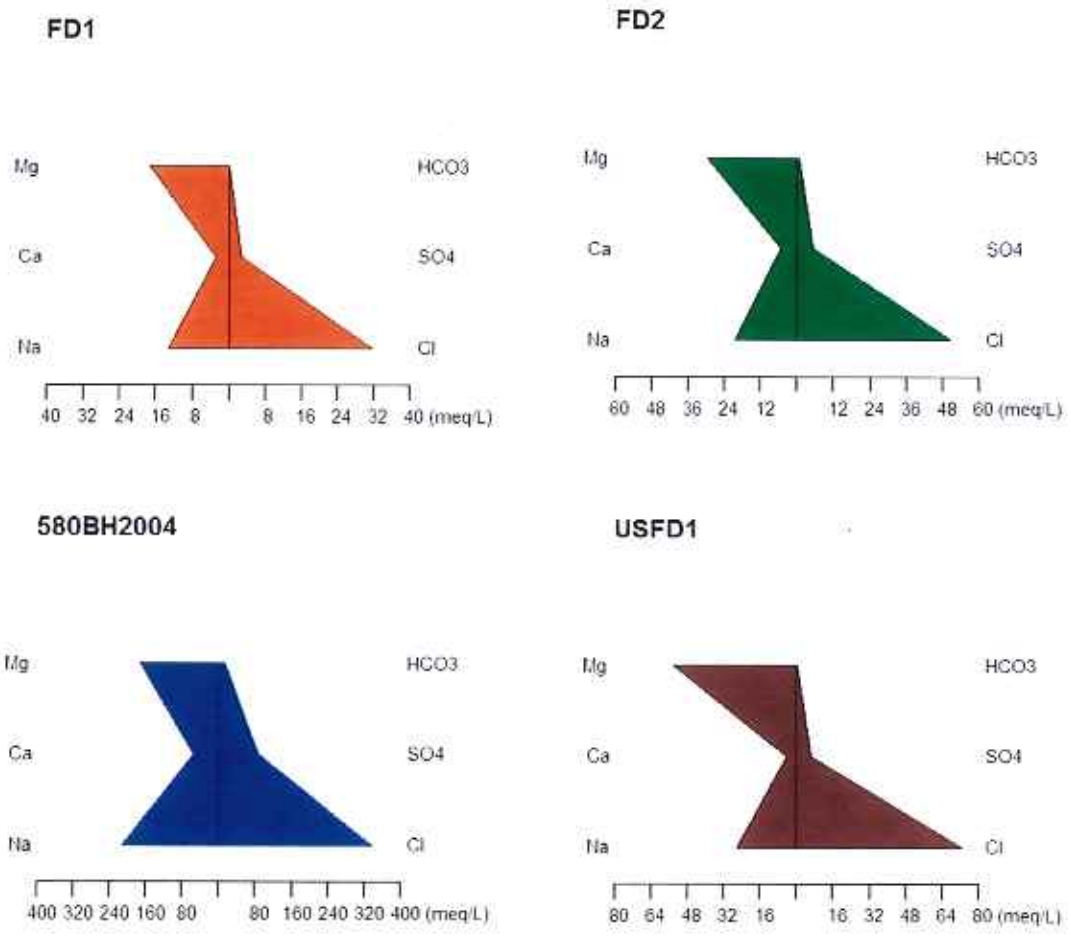


Figure 3 Stiff plots for water samples

The Piper plot (Figure 4) shows that the groundwater has sodium dominant over magnesium and while chloride dominant, has a relatively higher sulfate proportion than the fire dam and drain water samples. The fire dam and drain water samples show magnesium dominance over sodium and are strongly chloride type waters, with low relative sulfate and no bicarbonate.

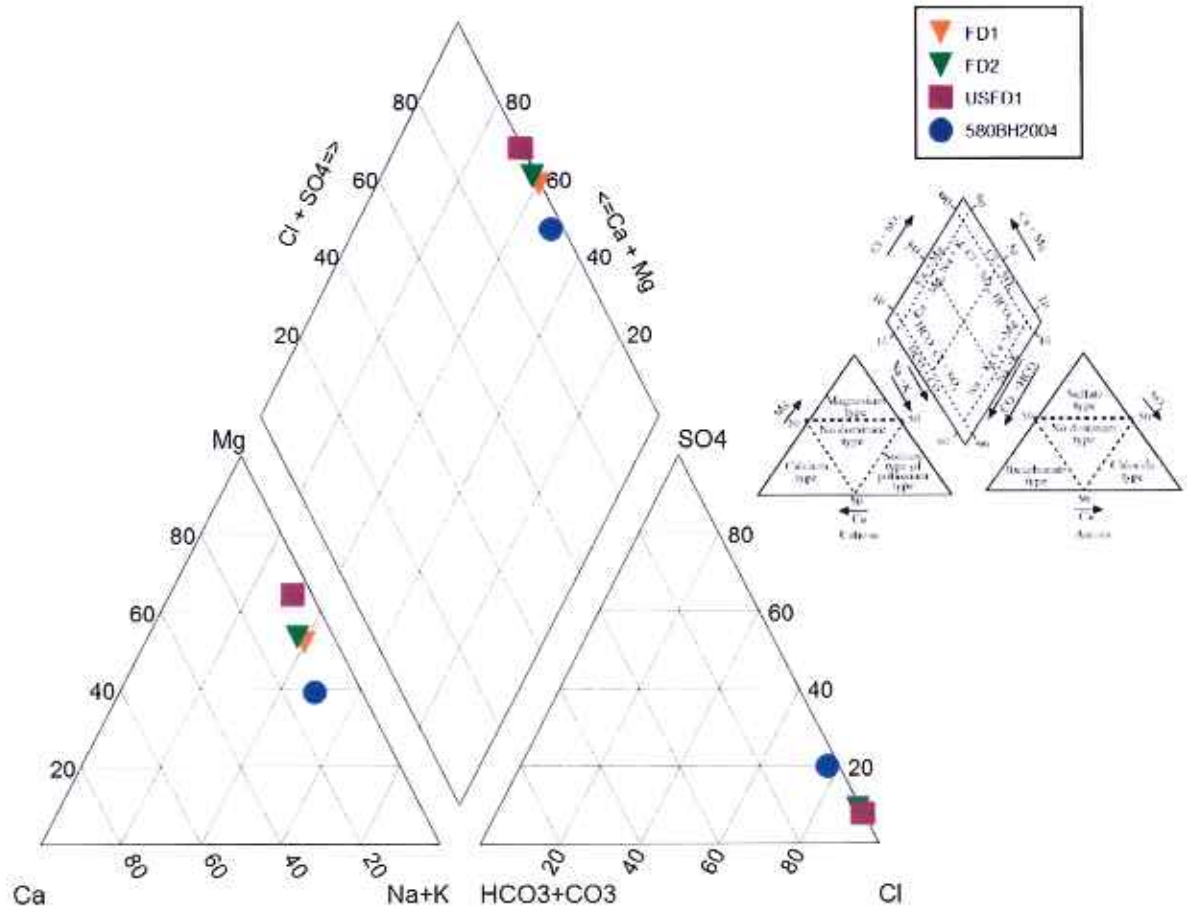


Figure 4 Piper plot

The spatial assessment of major ion data is summarised on Figure 5.

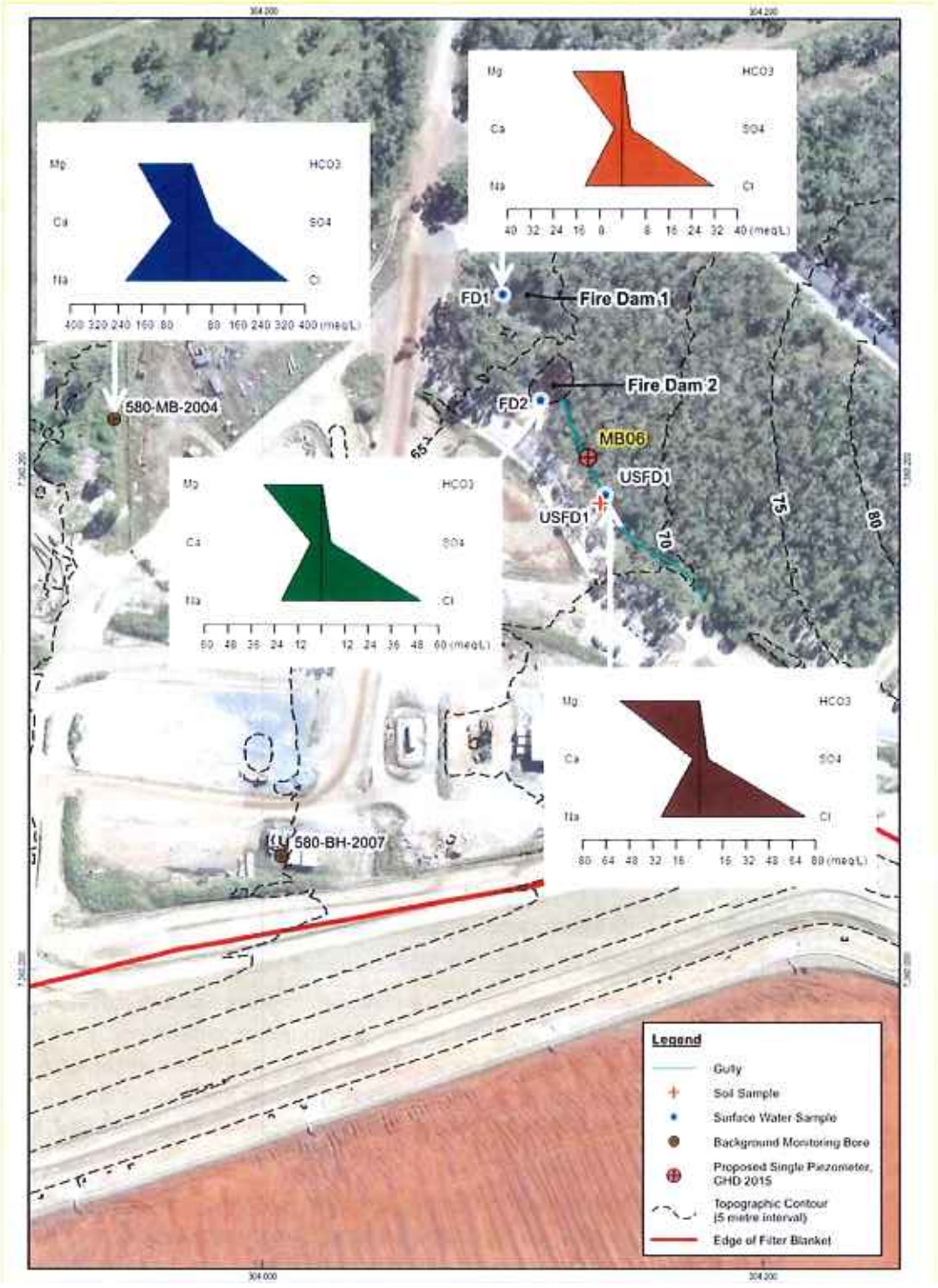


Figure 5 Stiff plots

The water sample analytical data as used to assess the major ion ratios on an equivalent weight basis and results are presented in Table 5.

Table 5 Major ion ratios

Location	Na/Cl	Ca/HCO_3	Na/Ca	Cl/SO_4	Fe/Cl*	HCO_3/SO_4	Ca/SO_4	K/Cl	Mg/Cl	Na+Mg/Cl
580BH2004	0.63	1.00	16.18	15.41	0.45	0.60	0.60	0.004	0.13	0.76
FD1	0.42	8.42	19.63	45.98	16.15	0.12	0.98	0.004	0.14	0.56
FD2	0.40	2.77	16.13	39.65	4.23	0.36	0.99	0.003	0.15	0.55
USFD1	0.35	12.63	25.61	46.48	14.71	0.05	0.64	0.001	0.19	0.54

*** Fe multiplied by 100000**

Assessment of the major ion ratios shown in Table 5 suggested the following:

- Groundwater had a higher sodium to chloride ratio than the fire dam and drain water samples, with all samples showing excess chloride over sodium.
- Groundwater had a significantly lower calcium to bicarbonate ratio than the fire dam and drain water samples, suggesting that water in the fire dams and drain was derived through water in contact with different mineral suite and / or different hydrogeochemical environment than the groundwater.
- The drain water shows a significantly higher sodium to calcium ratio than the fire dam and groundwater water, suggesting that the water sample collected in the drain at the time of the field work was subject to different hydrogeochemical conditions and / or weathering processes than the processes responsible for the water character of the fire dams.
- The fire dam and drain water samples have a significantly higher chloride to sulfate ratio than the groundwater, suggesting that sulfide oxidation through groundwater discharge is not likely to be a significant process in accounting for the low pH in the drain sample and observed acidification in the fire dams. Acidification through sulfide oxidation leads to a decrease in chloride to sulfate ratio between the groundwater and surface water as the surface water is enriched in sulfate with respect to chloride.
- The fire dam and drain water show significantly higher iron to chloride ratios when compared to groundwater, suggesting that the surface water samples have a relatively higher iron concentration when compared to chloride than the groundwater. This is unusual, given that iron is generally more soluble under reducing conditions present in groundwater compared to oxidised surface water.
- Assessment of the bicarbonate and calcium to sulfate ratios suggests that the fire dam waters have buffered any acidification processes. Both fire dam samples show higher ratios in both pairs when compared to the drain water sample.
- The remaining ratios are relatively similar between the samples and provide limited additional information on the potential hydrogeochemical processes likely to be responsible for the observed acidification.

5.4.2 Total organic carbon (TOC) and dissolved organic carbon (DOC)

Total and dissolved organic carbon concentrations where the same within the samples, which were reported at 3, 13, 10 and 8 mg/L for 580MB2004, FD1, FD2 and USFD1 respectively. This indicates that the organic carbon was entirely present in the dissolved form.

5.4.3 Nutrients (minor ions)

NO_x (Nitrate and Nitrite as N)

Nitrate and nitrate concentrations all were reported below the laboratory limit of reporting (LOR) of 0.01 mg/L, except for USFD1, which reported a concentration of nitrate of 0.02 mg/L.

Ammonia (NH_3)

Total ammonia concentrations for 580MB2004, FD1, FD2 and USFD1 were 0.06, 0.04, 0.04 and 0.10 mg/L respectively.

Reactive phosphorus

Concentrations of reactive phosphorus were all below the LOR of 0.01 mg/L.

5.4.4 Metals

Analyses (total and dissolved) undertaken for key and signature (decant water) metals are presented below where concentrations were reported above the level of detection for the particular laboratory analysis undertaken (LOR). No comparison to specific guideline values has been undertaken.

Surface water samples analyses indicated a chemical signature with elevated magnesium and low potassium concentrations and non-detectable concentrations of gallium and molybdenum, which was also reported for the groundwater sample. The dam water samples were again found to be generally representative of groundwater and not seepage from the RMA, based on comparison with signature metals and previous results reviewed as part of this assessment.

Aluminium

Concentrations of total aluminium were reported at 0.14, 0.14, 0.26 and 1.34 mg/L for 580BH2004, FD1, FD2 and USFD1 respectively, with dissolved concentrations at 0.2, 0.2, 0.2 and 1.44 mg/L. Aluminium solubility is influenced by pH, with lowest solubility around pH 6.5.

Arsenic

Arsenic concentrations were below LOR except in FD2 and USFD1 where total Arsenic was at 0.1, and 0.2 mg/L respectively.

Copper

Copper concentrations (total and dissolved) were 0.013, 0.002 and 0.002 for 580BH2004, FD1 and FD2 with USFD1 reporting a total and dissolved concentration of 0.004 and 0.009 mg/L respectively.

Manganese

Manganese concentrations were marginally higher in the total samples at 0.027, 1.4, 1.17 and 1.76 mg/L for 580BH2004, FD1, FD2 and USFD1 with dissolved concentrations being at 0.019, 1.26, 1.15 and 1.83 mg/L respectively.

Nickel

Total Nickel concentrations were 0.004, 0.003 and 0.007 in FD1, FD2 and USFD1 with dissolved concentrations at 0.003, 0.002 and 0.007 mg/L respectively.

Zinc

Total Zinc concentrations were 0.006, 0.006 and 0.031 in FD1, FD2 and USFD1 respectively with dissolved concentrations reported above LOR in USFD1 at 0.022 mg/L.

Iron (ferrous and ferric)

Total and dissolved iron concentrations showed that the majority of the iron was in the form of dissolved ferrous iron, with the highest dissolved ferrous iron concentration measured in the Vdrain sample. The dissolved iron concentration in the Vdrain water sample was an order of magnitude greater than that measured in the groundwater sample. Based on the Eh and pH conditions at the sampling locations the potential speciation of iron under equilibrium conditions can be assessed using the standard temperature and pressure iron stability diagram (Figure 6). This analysis suggested:

- The groundwater sample plotted in the ferrous iron equilibrium field, suggesting that iron is stable in a readily soluble Fe^{2+} form, but was adjacent to the stability field for insoluble pyrite (FeS_2). The relatively low dissolved iron concentration in groundwater suggests that true Eh may have been slightly lower than that measured in the field and that groundwater actually falls in the solid FeS_2 field.
- The drain sample plotted near the ferrous iron and ferric hydroxide equilibrium lines suggesting that the iron present in the drain water, possibly in part from groundwater seepage, is in the ferrous field and may be subject to oxidation and precipitation as a hydroxide mineral.
- The fire dam samples plotted in the ferric hydroxide ($Fe(OH)_3$) solid field, near the dissolved ferrous iron line, suggesting that the soluble ferrous iron may be subject to oxidation and precipitation as iron hydroxides in the aerobic fire dams.

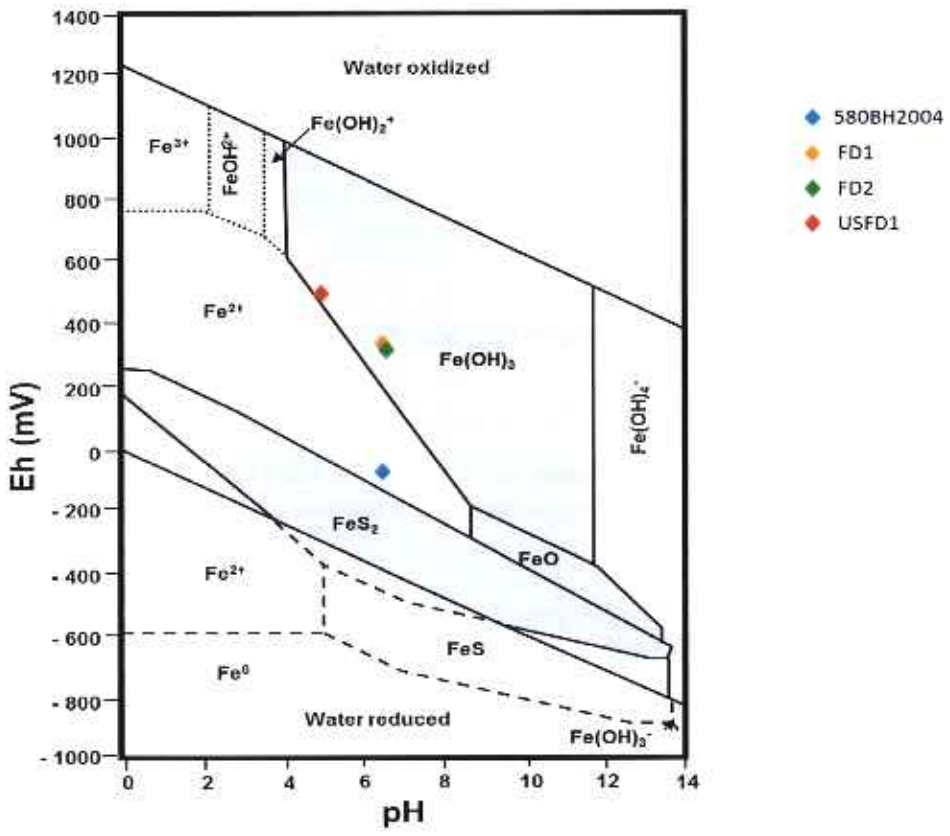


Figure 6 Iron stability diagram

5.5 Potential hydrogeochemical processes

The key focus of the hydrogeochemical assessment was to identify the potential processes responsible for the observed acidification of the fire dam waters. The assessment considered the concentration, ion ratio and process information to assess the potential mechanisms that lead to generation of acid.

5.5.1 General acid generation processes

A number of factors, including parent material, climate, vegetation and management and their interaction, control whether a soil and / or water has a neutral, acidic or alkaline reaction. There are a number of processes in soils and sediments that can generate or consume protons (H^+ ions) and therefore affect pH. These processes interact with the local climate, parent material, and microorganisms over time to determine soil and / or water pH. Water flow through the system is an important variable as it removes weathering products and supplies protons for exchange reactions. Some of the important processes that either generate or consume protons are listed below. Protons that are generated by these processes interact with the soil exchange complex and the solid phase. Thus, primary minerals, clay and organic matter content and percolation are important aspects of soil pH regulation.

5.5.2 Important processes generating or consuming protons

Evaluation of some of the important processes that generate or consume protons in the context of the Firewater Dams is provided below and indicates that 'pyrite congruent dissolution' is a potential process for generation of the observed acidification at the site.

Biological breakdown of proteins

Proteins →Proteoses →Peptones →Polypeptides →Amino acids →NH_3

$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$

This process increases rather than decreases pH and is therefore not considered to result in the observed acidification of the fire dam water.

Nitrification

$NH_4^+ + 1\ ½\ O_2 \rightarrow NO_2^- + 2H^+ + H_2O$,

$NO_2^- + ½\ O_2 \rightarrow NO_3^{2-}$

This process causes acidification but was considered unlikely to contribute to the observed acidification of the fire dams because while ammonia was present in measurable concentrations in all four samples tested, no nitrite or nitrate was detected in the samples. This suggests this process is not a significant contributor to the observed acidification.

Denitrification

$H_2O + NO_3^{2-} + 2e^- + NO_2^- + 2OH^-$, $2H_2O + NO_{2-} + 3e^- \rightarrow ½\ N_2 + 4OH^-$

$1½\ H_2O + NO_2^- + 2e- \rightarrow ½\ N_2O + 3OH^-$

This process increases, rather than decreases pH and is therefore not considers to result in the observed acidification of the fire dam water.

Oxidative metabolism

Enzymatically available organic matter + $O_2 \rightarrow CO_2 + H_2O$

$H_2O + CO_2 \rightarrow H_2CO_3$

$H_2CO_3 \rightarrow H^+ + HCO_3^-$

This process is likely to occur with decay of organic matter in the drain and fire dam system but is generally considered minor and often offset by buffering. If this process were significant, then all surface water systems would be acidic. This process of acidification is ubiquitous in the environment but slow and responsible for most of the long term mineral weathering that occurs in the near surface environment.

Other electron acceptors for microbiological respiration

$2H_2O + MnO_2 + 2e^- \rightarrow Mn^{2+} + 4OH^-$

$Fe(OH)_3 + e^- \rightarrow Fe^{2+} + 3OH^-$

$6H_2O + SO_4^{2-} + 8e^- \rightarrow H_2S + 10OH^-$

This process increases, rather than decreases pH and is therefore not considers to result in the observed acidification of the fire dam water.

Addition of sulfur

$H_2O + S^o + 1\ ½\ O_2 \rightarrow SO_4^{2-} + 2H^+$

This process is a significant generator of acid but generally only occurs to any significant degree in active volcanic regions or geological deposits rich in sulfur directly derived from these activities. This process was not considered to be a significant contributor to the observed fire dam acidification due re geological setting of the site.

Ion uptake

$Root + K^+ \rightarrow K(Root) + H^+$

$Root + NO_3^{2-} \rightarrow Root\ (NO_3^{2-}) + OH^-$

This process of acidification is ubiquitous in the environment but slow and responsible for most of the long term mineral weathering that occurs in the near surface environment.

Congruent dissolution of the mineral Anorthite and fate of products

$Ca\ Al_2\ Si_2O_{8(s)} \rightarrow Ca^{2+} + 2Al^{3+} + 2SiO_4^{4-}$

Ca^{2+} - hydrated solution ion (exchangeable)

$2Al^{3+} + 6H_2O \rightarrow 2Al(OH)_{3(s)} + 6H^+$

$2\ SiO_4^{4-} + 8H_2O \rightarrow 2H_4SiO_4 + 8OH^-$

$2OH^- + 2CO_2 \rightarrow 2HCO_3^-$

This process increases, rather than decreases pH and is therefore not considered to result in the observed acidification of the fire dam water. Anorthite is a rare compositional variety of plagioclase that can occur in mafic igneous rock. It also occurs in granulite facies metamorphic rocks, in metamorphosed carbonate rocks and corundum deposits. Anorthite is generally rarer in surficial rocks than at depth due to its high weathering potential. Therefore concurrent dissolution of Anorthite was not considered a significant progress occurring in the environmental setting of the site.

Faylite congruent dissolution and fate of products

$Fe_2SiO_4 + 4H_2O \rightarrow 2Fe^{2+} + H_4SiO_4 + 4OH^-$

$2Fe^{2+} + 0.5O_2 + 5H_2O \rightarrow 2Fe(OH)_{3(s)} + 4H^+$

This process increases, and can decrease pH and but was not considered to result in the observed acidification of the fire dam water. Faylite is the iron-rich end-member of the olivine solid-solution mineral

series and is generally associated with acidic or alkaline igneous rocks. Therefore concurrent dissolution of faylite was not considered a significant progress occurring in the environmental setting of the site.

Pyrite congruent dissolution

$FeS_{2(s)} + 3.75O_2 + 3.5H_2O \rightarrow Fe(OH)_{3(s)} + 4H^+ + 2SO_4^{2-}$

This process can lead to significant generation of acid and is commonly associated with a wide range of geological domains and is commonly associated with acidification processes. Pyrite oxidation and the associated auxiliary processes are a potential process responsible for generation of acid at the site.

The net result of weathering and buffering reactions along with the attendant climate, produce either acid or basic soils. In each of these soil types there are unique reactions.

6 Summary and conclusions

Based upon the document review, site inspections, sampling and analysis of the two firewater dams, an up-gradient drain and nearby groundwater bore, the following summary and conclusions are provided below.

- Two firewater dams, considered to be partially excavated within natural ground, having no embankments and of limited size and volume (less than 200 kL combined) are present near the entrance to the RMA site. The dams are interconnected via an overland flow path and receive stormwater contributions principally from an undeveloped catchment containing trees, with the remainder being from a table drain associated with an unsealed road that accesses the RMA car park and facilities.
- Previous studies have indicated that low pH waters observed principally within the upper Firewater Dam 2 may be due to the precipitation of iron hydroxide. Previous Fire Dam and groundwater sampling of two adjacent bores by RTAY (refer to Section 2.2) demonstrated that the chemical signatures were similar and not representative of decant water from within the RMA. Elevated salinity within groundwater was also considered to be naturally occurring, based on historical pre-RMA construction sampling.
- Given the phreatic surface of groundwater in the down-gradient bore was around 58.2 m AHD at the time of the inspection and based on groundwater contouring of groundwater levels collected in October 2014 (refer to Attachment 3), it is estimated that the water table (if unconfined) would be at around 62.0 m AHD in the area of the fire dams. With the base RL of the lowest dam being approximately 63.6 m AHD, it is considered that there is unlikely to be a direct interconnection between groundwater and dam water, based on the difference in levels and that saline groundwater may be present in fractured bedrock at greater depths.
- From previous groundwater, surface water and toe drain monitoring, it is considered that there is a very limited potential for any site-derived contamination to impact the dams or their sub catchment, including an absence of evidence from recent monitoring or observations that any decant or residue is interacting with the dams.
- Analysis of a soil sample taken up-gradient of the fire dams indicated a near neutral pH, with low salinity and metal concentrations typical for the site and general area.
- A review of the water sample characteristics indicates that 'pyrite congruent dissolution' (i.e. oxidation of pyrite and subsequent generation of acid) is a potential process (refer to Section 5.5.1) for the observed acidification in the dams.
- There is an apparent linkage between the groundwater and surface water samples given the similarities in major ion chemistry (Figure 3), although differences are apparent in major ion ratios.

Based on the major ion ratios groundwater exhibits a higher sodium to chloride ratio than the surface water samples. Also the calcium to bicarbonate ratios suggest that the dam surface waters may be in contact with a different mineral suite and / or different hydrogeochemical environment than the groundwater. This is also similar for the V drain water, which appears to be subject to different hydrogeochemical conditions and / or weathering processes than that of the fire dams, based on the sodium to calcium ratios.

- Based on the chloride to sulfate ratios, sulfide oxidation through groundwater discharge is not likely to be a significant process in accounting for the low pH in the drain sample and observed acidification in the fire dams, but the surface waters show significantly higher iron to chloride ratios when compared to groundwater, suggesting that the surface water samples have a relatively higher iron concentration when compared to chloride than the groundwater.
- During the assessment the pH measured within the dams was near neutral and it appears that the fire dam waters have buffered any acidification processes, potentially as a result of an influx of rainwater and run-off prior to sampling. Whereas the drain water sample was acidic and whose ability to buffer may be limited.
- Iron analysis within the water samples indicated the majority of the measured dissolved concentration was due to the presence of dissolved ferrous iron, with the highest dissolved ferrous iron concentration measured in the drain sample. Based on the Eh and pH conditions at the sampling locations and using the iron stability diagram, the analyses suggested that the iron present in groundwater, dam and drain waters may be from distinctive processes, including the oxidation of pyrite present in the anaerobic saturated zone, the ferrous species in the V drain may be subject to oxidation and precipitation as a hydroxide mineral and in the fire dams, and ferrous iron may be subject to oxidation and precipitation as iron hydroxides.
- It is considered that low pH conditions that have been experienced in the fire dams are from natural processes and appear to be exacerbated by near surface seepage, dry periods where no flushing/influx of fresh water occurs and where a number of processes, principally iron redox reactions, may influence and lower the pH of waters entering the dams over time. Observations within the upstream V drain and from table drain cuttings indicate that some near surface seepage is occurring within the extremely weathered rock, possibly from rainfall infiltration which is entering the dams as baseflow. Increased salinity and low pH within the dams is also considered to be intensified as a result of evaporation during drier periods. During rainfall, significant increases in runoff and associated soil water interactions are expected to occur, providing additional buffering capacity, dilution and further mechanisms for pH regulation.
- Although historically, low pH readings have been reported within the Firewater dams, the stored volume is considered to be relatively small. It also has to be considered that the potential for environmental impact from Firewater Dam releases after rainfall would be limited and of short duration. During rainfall events, the dams are considered to have a small flow contribution to the receiving environment with significant flows from the catchment flowing into the system prior to discharging at the downstream offsite release point and the main catchment area (Larcom Creek being over 0.5 km away, via overland flow).

7 Recommendations and SAP

Based on the information presented in this letter report, the following are recommended to provide further information as part of evaluating further management and /or remediation measures that may be required.

- RMA continue to monitor dam water levels and water quality and undertake regular site inspections.

- Maintain adequate freeboard and where low pH is observed, suitable management options may include undertake dosing with agricultural lime (pH 6.0-8.5) and/or removal of the water by sucker truck for potential reuse or disposal into the RMA.
- Although direct groundwater interaction and discharge into the dam is unlikely to be occurring, consider installing an up-gradient groundwater monitoring bore (MB06 proposed), which will help to confirm depth to groundwater, flow pathways and flow direction in the area and allow further assessment of potential groundwater interactions, if present.
- If the dams are to remain in use, develop a formal monitoring and reporting program including evaluating potential risks associated with dam release of low pH waters along with appropriate release limits and triggers for management to occur.

Recommendations for ongoing surface and groundwater monitoring are detailed below in Table 6 and Table 7.

This monitoring would need to be reviewed as part of any dam management that may be undertaken.

Table 6 Proposed monitoring, sampling and analysis

Sample location (sample ID)	Sample type	Analysis
Ponded water within Firewater Dam 1 (FD1) Ponded water within Firewater Dam 2 (FD2) Ponded water in V drain channel (US FD1)	Surface water	Weekly: • Water levels measured to datum and field inspections noting water quality observations such as presence of staining, flocks (dams only). • Field parameters (pH, electrical conductivity, temperature, dissolved oxygen, salinity, redox) with turbidity taken in dams only. Twice Yearly (for 1 year and when pH falls below 5.5 pH) Laboratory analysis: • Physicals - pH, electrical conductivity, total dissolved solids, suspended solids. Major ions – calcium, magnesium, sodium, potassium, chloride, sulfate, Alkalinity (carbonate, bicarbonate), hardness, fluoride • Iron (ferrous and ferric)
Downgradient monitoring bore 580-MB-2004 (incorectly labelled as 580-BH 2004 in laboratory certificates). Use MB06 once installed	Groundwater	Monthly: • Static water levels 6 monthly (for 1 year, then biannually) • pH, EC, DO, Eh/Er, Temp (in Field) • Laboratory analysis as per water sample

Table 7 Recommended ongoing reviews and reporting

Task	Frequency	Outline	Timing
Review of surface water inspections and monitoring results	Weekly	Review and implement management actions as required including: • Implement additional monitoring including contingency planning for rainfall events. • pH adjustment (using fine agricultural lime) • pumping out dams and appropriate reuse / disposal on site Review data for trends, against 'action criteria' etc. If exceedances, then follow RTAY reporting procedure.	Completed by end of week of monitoring period
Review of surface water sampling results	Quarterly	Update monitoring requirements in line with management actions undertaken.	Completed within one week of receipt of all results
Review of groundwater sampling and monitoring results	6 monthly	Review data for trends, against 'action criteria' etc.	Completed within one week of receipt of all results

Sincerely
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