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AUSTRALIA

Surface Water Study

Proposed Yeelirrie Development

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ABBREVIATIONS

Abbreviation	Description
AgWA	Agriculture Western Australia
AHD	Australian Height Datum
ALS	Australian Laboratory Services
ANZECC	Australian and New Zealand Environmental and Conversation Council
ANZMEC	Australian and New Zealand Minerals and Energy Council
AR&R	Australian Rainfall & Runoff
ARI	Average Recurrence Interval
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
bgl	below ground level
BND	Bund (Flood Protection)
BoM	Bureau of Meteorology
CER	Consultative Environmental Review
DEM	Digital Elevation Model
DO	Dissolved Oxygen
DoE	Department of Environmental Protection
DoIR	Department of Industry and Resources
DoW	Department of Water
EC	Electrical Conductivity
EIA	Environmental Impact Assessment
EPA	Environmental Protection Authority
EPP	Environmental Protection Policy
ERMP	Environmental Review and Management Programme
GL	Gigalitres (1 billion Litres)
GTSMR	Generalised Tropical Storm Method
ha	Hectares
ha	Hectare (10,000 m^2)
HG	High Grade
HR	Haul Road
IFD	Intensity, Frequency, Duration
km	Kilometre
LG	Low Grade
LOR	Limits of Reporting
m^3/s	Cubic metres per second
MG	Medium Grade
mg/L	milligram per Litre
ML/d	Megalitres per day
mm	millimetre
Mt/a	Million tonnes per annum
N/A	Not available

Abbreviation	Description
NASA	National Aeronautics and Space Administration
NAT	Natural (Area of limited disturbance)
NATA	National Association of Testing Authorities
NOI	Notice of Intent
NWI	National Water Initiative
°C	Degrees Celsius
PER	Public Environmental Review
PHS	Plant and Hardstand
ppm	Parts per million
QA/QC	Quality Assurance and Quality Control
RO	Reverse Osmosis
STRM	Shuttle Radar Topography Mission
SWP	Stormwater Pond
t/a	tonnes per annum
t/a	tonnes per annum
TDS	Total Dissolved Solids
TS	Top Soil
TSFS	Tailings storage facility
UOC	Uranium Oxide Concentrate
US EPA	United States Environmental Protection Agency
VHG	Very High Grade
WAPs	Water Allocation Plans
WD	Waste Dump
WF	Water footprint
WMPs	Water Management Plans
WRC	Water and Rivers Commission
WRS	Western Radiation Services

EXECUTIVE SUMMARY

This report presents the results of hydrological modelling to predict changes between the baseline conditions and the Proposed Development. The results of the analyses indicate the following:

- The baseline flow paths, which are currently split into two parallel paths on both sides of the calcrete rise, would be partially blocked due to the construction of the surface water diversion bund.
- Therefore, a diversion channel would be constructed to transmit the flood event-related water from the northern watercourse, around the minesite and into a combined watercourse along the western and southern perimeters of the surface water diversion bund, which is nearly coincident with the path of the southern watercourse.
- The proposed development would, at least temporarily, alter the baseline hydrology during a severe flood event. However, the modelling predicts that water would not flow within the catchment as a connected watercourse (versus isolated, local flows) unless a storm event in excess of a 20-year ARI occurs.
- The modelling also predicts that for the duration of the mine operation, and up to a 1:1,000-year ARI event, the surface water diversion bund would both:
  - Prevent catchment-related water from flowing into the proposed Project mine site area, and
  - Prevent the water that collects interior of the surface water diversion bund from discharging outside the bund into the natural environment.
- Outside the surface water diversion bund the predicted changes resulting from a range of design flood events include a temporary:
  - Increase in the water depth immediately upstream of the mine,
  - Increase in the velocity of water flowing around the mine area (through the proposed diversion channel and between the minesite and southern valley slope),
  - Decrease in the water depth immediately downstream of the mine area.
- Inside the surface water diversion bund the predicted changes include a temporary increase in water depth at the lowest points within the mine area, which would be managed through a number of stormwater ponds. During extreme cases, the water could be stored within the inactive pits.
- At the completion of operations, the mine infrastructure would be decommissioned and the site would be rehabilitated. The hydrological modelling predicts that the proposed final landform would result in the after-mining surface water environment to be similar to the pre-development (baseline) conditions. However, as a result of the natural topography near the south-eastern corner of the closed landform, a diversion channel will likely be needed to prevent overtopping during an extreme storm event.
- The sensitivity analyses on the models used in this assessment suggest that the predicted outcomes are reasonable.

1 INTRODUCTION

Cameco Australia have commissioned URS to undertake a review and update where appropriate of the Surface Water Study for the Proposed Yeelirrie Development undertaken for BHP Billiton (URS, 2011). The proposed Yeelirrie Project site (the Project) is located east of the Goldfields Highway between Leinster and Wiluna in Western Australia (Figure 1-1).

This report supports the Public Environmental Review (PER) for the proposed Project. The overall objectives of this assessment are to characterise the existing surface water environment; assess potential changes to the surface water environment resulting from the proposed Project Development; identify mitigation and management strategies to minimize potential change.

The key elements of this study are as follows:

- Desktop review of previous surface water studies.
- Characterise the existing surface water environment of the Project.
- Assess the potential changes to the surface water environment resulting from the proposed Project.
- Identify surface water management and mitigation options to minimise the potential change to the surface water environment.
- Prepare a conceptual surface water management plan.
- Use of the findings of groundwater assessments (completed by URS in 2011 and Cameco in 2015) and other relevant studies to understand surface water-groundwater interactions.

2 PROPOSED PROJECT DESCRIPTION

The proposed Yeelirrie Project location is shown on Figure 2-1 and the surface water study area is presented on **Figure 2-2.**

The proposed Yeelirrie Project description, containing information related to the proposed operations and closure, including the key parameters, the mining concepts and schedule, tailings storage, flood protection and surface water management concepts, water demands, and closure, is presented in Section 9.4 of the Cameco document.

3 PHYSICAL ENVIRONMENT

This section describes the physical environment-related elements that were utilized in the surface water assessment.

3.1 Climate

3.1.1 Rainfall

Rainfall is the primary source of surface water within the study area. Based on available data from Bureau of Meteorology (BoM, 2015) Station No. 012090 (1928 to 2015), the average annual rainfall for Yeelirrie Homestead is 238 mm (Table 3-1 and Figure 3-1) with a minimum annual rainfall of 43 mm and a maximum annual rainfall of 507 mm. The rainfall frequency and total annual rainfall is widely variable with a dependability of only 40%. Small quantities of rainfall occur reasonably regularly, with rainfall in May and June being common.

Table 3-1 Long-Term Mean Monthly Rainfall and Evaporation

Month	BoM Mean Monthly (mm)			SILO Mean Monthly (mm)	
	Rainfall (Yeelirrie Homestead)	Evaporation (Wiluna)	Evaporation (Meekatharra Airport)	Rainfall (Yeelirrie)	Evaporation (Yeelirrie)
January	28	341	502	26	421
February	31	266	398	29	328
March	32	242	369	30	303
April	25	168	246	24	209
May	26	115	171	24	132
Jun	23	75	114	25	96
July	17	81	121	17	105
August	13	115	167	12	144
September	4	171	243	4	216
October	10	245	344	7	304
November	10	279	405	8	353
December	20	313	468	17	403
Annual Mean	**238**	**2,410**	**3,548**	**222**	**3,014**
Period of Record	1928-2009	1957-1985	1967-2009	1889-2010	1889-2010

The annual mean number of rain days (> 1 mm) is 31.6, with the highest monthly mean of 3.8 days occurring in June with and the lowest of 1.1 days for September. The highest recorded monthly rainfall of 211 mm was in April 1992 and the highest daily rainfall of 99 mm occurred on 30 March 1931. Mean rainfall intensity in the Yeelirrie area ranges between 7.6 mm and 9.2 mm per rain day. Yeelirrie receives 61% of mean annual rainfall in the summer months from November to April. The remaining 39% of rainfall occurs during winter, generally at low intensity, and usually these events only produce limited runoff.

Summer rains are normally of high intensity, caused by localised thunderstorm activity or much larger weather systems associated with cyclones and tropical lows. Cyclones and their remnant rain-bearing tropical lows are the source of the majority of extreme rainfall events that are likely to generate surface runoff within the Yeelirrie Catchment. BoM data indicate that 13 cyclones passed within 200 km of Yeelirrie Homestead between 1970 and 2000 (Table 3-2) and that the region has an average annual tropical cyclone frequency of between 0.1 and 0.2 (Figure 3-1).

Table 3-2 Historical Cyclones within 200 km of Yeelirrie

Cyclone	Date (year)
Mavis	1971
Trixie (tropical low)	1975
Gertie	1985
Connie	1987
Ilona	1988
Orson	1989
Bobby	1995
Kirsty	1996
Olivia	1996
Rachel	1997
Vance	1999
Elaine	1999
Steve	2000
Emma	2006

3.1.2 Evaporation

In a desert environment such as at Yeelirrie, evaporation can result in significant losses of water from the catchment area.

No evaporation data are recorded at the Yeelirrie BoM station. The mean annual pan evaporation at the two nearest meteorological stations (Wiluna and Meekatharra Airport) is 2,412 mm and 3,548 mm, respectively. Both meteorological stations have limited records from commencement dates in 1957 and 1967. Further, the evaporation data from Wiluna may be unreasonably low due to shaded positioning of the pan. It might be expected that Wiluna and Meekatharra would have similar mean annual pan evaporation potentials of about 3,500 mm.

In the absence of evaporation data at Yeelirrie, long-term (1889-2015) SILO synthetic rainfall and evaporation data were generated for the Yeelirrie Catchment (Table 3-1). Evaporation from a free water surface is estimated using a pan factor of 0.75 to be about 2,260 mm per annum, with monthly rates in the range from 90 mm (winter) to 418 mm (summer).

Mean annual rainfall at Yeelirrie is about 10% of mean annual pan evaporation. Average potential evaporation exceeds average rainfall every month (Table 3-1 and Chart 3-1).

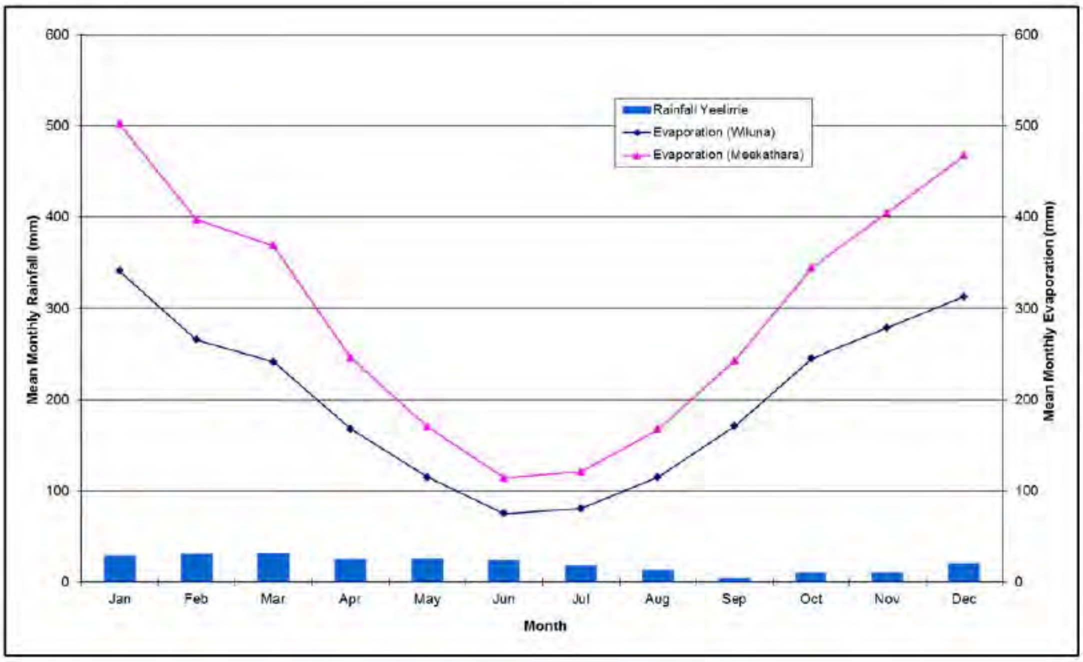

Chart 3-1 Long Term Monthly Rainfall and Evaporation (BoM, 2015)

3.1.3 Climate Trends and Predictions

Warming of the global climate system and changes in rainfall patterns are evident over the past century and since the mid-20th century is interpreted to be linked to increased greenhouse gas concentrations in the atmosphere (CSIRO, 2007). The climate changes are predicted to continue into the foreseeable future (see Figures 3-2 through 3-4). The predicted continued climatic changes would result in changes in related rainfall intensities, which would affect the peak flood flows within the study area.

3.2 Topography

The topographic relief, together with the geology, landforms, soils and vegetation, influences rainfall-related runoff and groundwater recharge. Generally, the study area has a very gentle relief, except in local areas of granite breakaways and sand dunes. The total elevation range within the catchment is approximately 100 metres - from about 480 m AHD in the centre of the catchment near the Yeelirrie Homestead, to a maximum of about 580 m AHD on the granite breakaways, which mark the divide between the catchments (Figure 3-5). The topographic relief along the valley floor of the catchment is very gentle, with total relief within the proposed Project area being on the order of about 20 meters.

3.3 Geology, Landforms and Soils

The geology, landforms and soils, together with the topography and vegetation, influence rainfall-related runoff and groundwater recharge.

Landforms and Soils

Previous mapping of the Yeelirrie region has been completed by the Department of Agriculture (Payne et al, 1998 and Pringle et al, 1994) using a land systems approach to landscape classification. Land systems are described as a natural classification of landscapes based on key biophysical features such as landform, soils, vegetation and drainage attributes.

In 2011, Blandford mapped the proposed Project area into three soil landscapes: Sand Plain, Calcrete System, and Playa System (Figure 3-6). However, in order to support the modelling for this hydrological study, the study area was divided into five catchment units based on their likely or possible relevance to surface water and groundwater regimes within the study area (Figure 3-7). These include:

- Playa
- Calcrete
- Wash Plain
- Sand Plain
- Breakaway.

3.4 Vegetation

In an arid region like Yeelirrie, vegetation effectively mirrors water availability, which in this region is largely controlled by runoff/runon and soil characteristics.

In addition, on the soil types presence of cryptograms (scientific name *cryptogamae*) has been observed. These are non-vascular plants that live on the soil surface. The cryptograms form a crust several millimetres thick on the soil surface. The crust swells on contact with water and acts to bind and seal the soil surface. A study (Verrecchia, 1995) has shown that the presence of cryptograms may:

- Increase surface runoff by reducing infiltration rates, and
- Increase the water retaining capacity of the soil.

The cryptograms reportedly provide similar protection to the soil as weed cover and limit raindrop erosion (Gaskin and Gardner, 2001). The cryptograms were considered during the evaluation of infiltration-related inputs to the baseline characterisation.

3.5 Hydrology

3.5.1 Regional Drainage Characteristics

The proposed Yeelirrie Project is located within the Lake Miranda Catchment (7,560 km^2), which is a closed drainage area for typical rainfall events. Extreme rainfall events may generate sufficient runoff for flood waters to fill Lake Miranda and spill across a low topographic saddle east of Lake Miranda and into Lake Darlot which is part of the larger Lake Carey Catchment (114,000 km^2).

The Lake Carey Catchment is a surface runoff catchment within the Salt Lake Basin (441,000 km^2) of the Western Plateau Division. The Salt Lake Basin is one of the largest river basins in Western Australia. The regional drainage catchments are shown on Figure 3-8.

3.5.2 Catchment Characteristics

There is no known hydrological record for the study area in the form of gauged run-off events and stream flow measurements. There is also no known record of a major flood in the main valley, although sheet-flooding has been observed nearby at the Yeelirrie Homestead.

In April 1973, a reported 125 mm rainfall event resulted in some flooding of the Yeelirrie Homestead and portions of the road to Albion Downs (Blackwell and Cala, 1977).

During the period of 19 to 28 February 1975, a rain-bearing depression associated with Cyclone Trixie resulted in 125 to 130 mm of rainfall at Yeelirrie. No flooding reportedly occurred at Yeelirrie, but runoff in the Sandstone-Pinnacles Valley initiated a flood wave through Lake Raeside, washing out a road and a railway embankment (Binnie, 1978).

The hydrology of the study area has been characterised by several technical reports, predominantly hydrological studies for Yeelirrie feasibility and EIA studies from 1976 to 1982. Reports prepared for these historical studies include:

- Western Mining Corporation Limited, 1978; Draft Environmental Impact Statement and Environmental Review and Management Programme, particularly Appendix III of the report - Evaporation and Flood Estimation.
- Binnie and Partners, 1982; Additional Yeelirrie Flood Level Estimates.
- Kinoco-Stearns Roger (KSR), August 1982; Yeelirrie Uranium Joint Venture – Project Feasibility Study

The Yeelirrie catchment (upstream of the Yeelirrie Playa) drains to the southeast into Lake Miranda (Figure 3-9). Generally, the valleys between the breakaways are broad with very little relief, except towards the western and northern portions of the catchment, where low hills of basement rocks occur, with an average relief of about 40 m. Side valley slopes (0.3% to 0.5%) and longitudinal valley slopes (0.1 to 0.2%) are comparatively gentle, typically increasing to about 1% at the foot of the breakaways.

Surface runoff only occasionally occurs within the Yeelirrie Catchment. Following intense rainfall, sheet runoff may shed from the upper margins of the catchments, flow rapidly to the central drainage line and generate short-lived stream flow. Typically, the stream flow terminates in playas (including clay pans). Water may remain on the larger clay pans and playas for several weeks after large rainfall events (Western Mining Corporation, 1978).

Surface water infiltrates into the ground at a rate dependent on a number of factors including: rainfall intensity, duration, frequency, hydraulic conductivity of the soil and moisture characteristics during and between rainfall events. Typically, the infiltration rate is high where sandy soils are present in areas of low relief and where calcrete, and related “crab holes” are present in low-lying areas where runoff accumulates. Another important aspect is the interaction of surface water and groundwater in low-lying areas that are subjected to inundation and hence prolonged infiltration even if the underlying soils are clayey. Clay pans that are present along the valley floor are examples of this type of accumulation mechanism.

In addition to accumulating clay and silt from the runoff, these areas accumulate salt derived from natural sources within the catchment.

The relationship between surface water and groundwater is often complex because of the wide variety of factors described above in addition to local variations in many of them. The rate and location that surface water recharges groundwater influences the quality of both and the elevation water table across the catchment. Groundwater may influence surface water where the water table is close to or above the ground surface. Evaporative pumping draws salt from the water table and accumulate it at the surface along with salt derived from runoff. Salt lakes such as Lake Miranda and other smaller features in the Albion Downs area are examples of this. Springs resulting from conditions where the water table is above the surface (temporarily or permanently) can affect the surface water quality due to the accumulation of salt and other naturally-occurring solutes around the discharge area. Only one spring – Palm Springs- is known to occur in the region. It is remote (54 km east south east) from the Project site and located to the northeast of the Albion Downs Borefield.

One other surface water feature of potential interest in the Yeelirrie Catchment has been identified. Small rock holes occur on a granitic outcrop to the southwest of Yeelirrie Homestead. These features fill after rainfall and evaporate shortly afterwards. They hold significance to the local aboriginal community.

4 BASELINE SITE INVESTIGATIONS

4.1 Introduction

As part of the surface water study undertaken by URS for BHPB during 2009 -2011 selected site investigations were undertaken to support both the surface water and the groundwater studies (URS, 2011) and the geochemical study (SRK, 2011). The purpose of the field investigations was to characterize the surface water-related conditions within the Yeelirrie Catchment. The site investigations included:

- Reconnaissance survey (March 2009), with a walkover of the Proposed Development footprint and local reaches of the Yeelirrie Catchment.
- Infiltration tests (June 2009 and January 2010).
- Soil sampling (June 2009 and January 2010), with subsequent laboratory testing of collected samples.
- Opportunistic surface water sampling.

4.2 Reconnaissance Survey

During the three-day reconnaissance survey in March 2009, 13 locations of interest were observed, including:

- The upper Yeelirrie Catchment and northeast catchment divide.
- Potential drainage paths, upstream of the Proposed Development Area
- Calcrete deposits within the Proposed Development Area.
- Yeelirrie Playa.
- Other potential drainage paths and recharge areas.

During the reconnaissance, the following observations were noted regarding the local surface water flow:

- There is little evidence of major drainage channels (no defined bed and banks).
- Small-scale, minor braided drainage channels are evident (Plate 4-1).
- Surface runoff is likely to be dominated by overland sheet flow.
- Numerous drainage channels terminate upslope and are disconnected from the downstream drainage system.
- There is little evidence of significant erosion. Accumulations of leaf matter and debris occur between the braided drainage lines and in possible sheet flow areas, indicating flow in excess of the capacity of localised drainage features in these areas (Plate 4-2).
- Drainage features rarely reach the central drainage area (Plate 4-3), usually terminating on sand plain deposits.

Plate 4-1 Braided Drainage Channels South of the Proposed Development Area

Plate 4-2 Debris Accumulation Associated with Sheet Flow

Plate 4-3 Major Drainage Line South of the Minesite (near Mica Well)

Attachment A contains the locations, photographs and detailed descriptions (drainage features, soil, and vegetation) of the inspected sites.

4.3 Infiltration Tests

Infiltration tests were completed in order to support the hydrological modelling. The infiltration tests were completed across the Lake Miranda Catchment, intending to differentiate between the four soil types identified within the five catchment units: wash plain, sand plain, calcrete and playa catchment units (the breakaways were not tested because they consist of granite bedrock and not soil). The results from the infiltration tests were compared with generally accepted guidance values to frame the modelling inputs.

Each infiltration test was completed using a double ring infiltrometer. This method measures the infiltration capacity of the surface layer and consists of an inner and outer steel ring inserted concentrically into the ground with both rings filled with water. Infiltration capacities are calculated by measuring the fall in head in the inner ring over time. The presence of the saturated annulus between the two rings forces the flow from the inner ring to penetrate mainly vertically downwards, thereby reducing the need to account for lateral flow in the soil.

A total of 27 double-ring infiltration tests were conducted in the four soil types, or catchment units, within the Lake Miranda Catchment. The locations are shown on Figure 4-1. A detailed description of the methodology and test results is given in Appendix B.

Table 4-1 presents the summary of the infiltration test results for each of the catchment units. Attachment B provides data and results of the infiltration test programme, including photographs of test sites and test data sheets.

Table 4-1 Infiltration Test Results Summary

Catchment unit	Number of Sites	Number of Tests	Field Infiltration Rate (m/day)	
			Range	Mean
Wash Plain	9	10	3.6 – 7.9	5.8
Sand Plain	11	13	3.6 - 13.7	10.8
Calcrete	2	2	1.1 – 3.6	2.3
Playa/Clay Pan	2	2	0 – 0.3	0.2

Based on the findings of the site investigations, the sand plain catchment unit soils have the highest infiltration rates in the Lake Miranda Catchment; approximately twice those of the wash plain catchment units. Conversely, the playa, clay pan soils have the lowest infiltration rates.

In about 40% of the sand-plain tests, a steady-state infiltration rate did not occur. In these cases, the infiltration rate was observed to decrease as the water level in the double ring infiltrometer declined, so it appears that the infiltration rate is proportional to water head in the higher transmissivity areas of the sand plains, which is expected based on the relatively free-draining characteristics of these soils. Figure 4-2 shows time-series plots of the measured infiltration rates.

4.4 Soil Sampling Programme

As part of the earlier studies undertaken by URS during 2009 -2011 a soil sampling programme was completed in order to characterize the physical and chemical conditions. The field classification of the soils, which were based on the physical conditions, was used to confirm the land system classification that was used in the hydrological modelling. The analytical testing and related results were used for evaluating the surface water and groundwater-related conceptual models.

In total some 55 soil samples were collected from locations focused on characterising the catchment units within the study area. The locations are shown on Figure 4-3. The detailed description of the soil tests and the results are given in Appendix C.

The soil sampling assisted in defining the catchment units which were utilized in the hydrological modelling. Based on these findings the land systems of the study area have been categorised into five units based on their likely or possible relevance to surface water and groundwater regimes within the study area.

4.5 Surface Water Quality Sampling Programme

Opportunistic surface water sampling was completed during two rainfall events that occurred in 2009 and 2010. The analytical testing and related results are described in detail in Appendix D.

The results were used for evaluating the surface water and groundwater-related conceptual models and assisted in understanding the surface water to groundwater-related processes as they relate to both recharge and discharge, which are important in predicting the groundwater-related changes resulting from the proposed development.

Opportunistic sampling was completed during one rainfall event each in 2009 and 2010. Due to logistical challenges related to lack of physical access resulting from isolated flooding during the rainfall events, only six surface water samples were collected.

Two of the samples were collected following approximately 9.2 mm of rainfall at Yeelirrie Station on 24 June 2009. The remaining four samples were collected following approximately 42.6 mm of rainfall over two days at Yeelirrie Station on 21 and 22 March 2010 (Figure 4-4).

For selected parameters indicative surface water sampling results are provided in Table 4-2. Further information on the sampling methodology, sample preservation, analytical schedules adopted for the surface water samples and laboratory analytical results are presented in Appendix D.

Sample location descriptions:

- SW4: Upstream Central Valley Playa Land System
- SW3: Northern Flank – Wash Plain Land System
- SW6: Northern Flank – Downstream Wash Plain Shedding to Yeelirrie Playa
- SW2: Southern Flank – Downstream Breakaway Land System
- SW5: Yeelirrie Playa
- SW1: Outskirts Albion Downs Playa

Table 4-2 Indicative Surface Water Quality

Parameter	Units	SW4	SW3	SW6	SW2	SW5	SW1
Physical Parameters							
TDS	mg/L	23	<5	123	824	16,800	4,130
Selected Ions							
Na	mg/L	1	<1	2	45	119	26
Cl	mg/L	<1	<1	1	61	97	13
SO_4	mg/L	3	<1	2	11	10	2
Total Alkalinity (as $CaCO_3$)	mg/L	5	4	2	27	314	56
Selected Metals (Dissolved)							
Al	mg/L	0.11	0.28	0.04	-	6.28	-
Fe	mg/L	0.07	0.27	<0.05	<0.05	1.43	3.66
Mn	mg/L	0.04	0.014	0.05	-	0.079	-
Zn	mg/L	0.03	<0.005	0.07	<0.005	0.020	0.012
Sr	mg/L	0.01	0.002	0.005	0.022	0.022	0.006
V	mg/L	<0.01	<0.01	<0.01	<0.01	0.080	<0.01

In interpreting the results, there are limited data on the transient salinity concentrations available for surface water. The available surface water quality data, measured in the short-term after rainfall, indicates the surface water is fresh, with relatively low concentrations of chloride, sodium, sulphate and bicarbonate. The measured total dissolved solids (TDS) concentrations range from <23 to 16,800 mg/L. Samples collected from the Yeelirrie Playa and Albion Downs Playa had comparatively high salinities of 16,800 and 4,130 mg/L, respectively.

The measured TDS concentrations, however, are known to include suspended sediments (which is the standard procedure for measurement of TDS). Accordingly, initial baseline surface water stream flow is likely to be inclusive of suspended solids but is expected to be fresh.

The measured chloride concentrations of < 1 to 1 mg/L occur within the upper catchment reaches of watercourses and are coincident with measured comparatively low TDS concentrations. These measurements may reflect both low chloride contents in rainfall and limited dissolution and mobilisation, at the time of sampling, of stored salts either on the surface or in shallow soils.

In the vicinity of the Yeelirrie and Albion Downs Playas, the measured chloride concentrations are indicative of fresh waters, with limited dissolution and transport of salts or evaporation along local flow paths at the time of sampling. The measured chloride concentrations are not aligned with the TDS concentrations.

The available data suggests there is likely to be evaporation concentration processes and dissolution of stored salts that influence the salinity of infiltrates reporting to the water table, which are discussed in more detail later in this report. This information also aided to better understand the relationships between surface water and groundwater, and how the catchment behaves in terms of the conceptual site model, which informed the groundwater numerical models

5 BASELINE HYDROLOGY

5.1 Background

Surface water flow in the study area is typically characterised as short-lived, overland sheet flow and channel flow terminating in clay pans and the Yeelirrie, Albion Downs and Lake Miranda playas. The catchment is inherently dry and arid; there is no permanent surface water.

The characterisation of the baseline surface water flows within the study area is based on:

- The results of a literature review. (Appendix E)
- Use of available topographical data to delineate the local catchments, inform drainage patterns and channel characteristics.
- Development of design rainfall data for selected Average Recurrence Interval (ARI) events based on available regional historical rainfall data and patterns.
- The analysis of available datasets from both historical records and recent site investigations, which include land system information from the Department of Agriculture Western Australia (AgWA, 1994 & 1998); collated topographic and geological catchment data; and observations and results from site investigations.
- The development of a conceptual hydrological model.
- Hydrological modelling to simulate the rainfall-runoff characteristics of the study area for a range of rainfall events.
- Hydraulic modelling to simulate surface water drainage and flow characteristics of the study area for a range of rainfall events.
- Sensitivity analyses to examine the influence of certain model parameters on the model outputs.

5.2 Topography

Topographic contour data for the Lake Miranda Catchment, from the Shuttle Radar Topography Mission (SRTM, 2010), were used in this study. SRTM is an international project led by the National Geospatial-Intelligence Agency and the National Aeronautics and Space Administration (NASA). The SRTM dataset for Australia was sampled at three arc-seconds, which is 1/1200th of a degree of latitude and longitude, or about 90 meters. Contours with a 5-m interval have been interpolated for the Lake Miranda Catchment using the SRTM 90 m contour data.

A LIDAR survey by Fugro Spatial Solutions Pty Ltd was conducted in the Project area. The survey data consists of a ground digital terrain model, 10 m key point model with 0.5 m contours. For the purposes of the surface water study the two sets of topographical data have been merged in ARCGIS and a combined Digital Elevation Model (DEM) was developed.

5.3 Rainfall

Cyclones and tropical lows are the source of the majority of rainfall events that are likely to generate surface runoff within the Yeelirrie Catchment. Rainfall data recorded at the BoM

Meekatharra station, approximately 120 km to the northwest of the Yeelirrie Catchment, and the SILO data for Yeelirrie have been used to characterise cyclonic rainfall. These data provide a comparatively reliable historical record. The pluviograph data for Cyclones Connie, Orson and Trixie, has been used to inform rainfall characteristics for the Lake Miranda Catchment. Table 5-1 summarises the characteristics of the most significant recorded cyclonic events between 1970 and 2010.

Table 5-1 Rainfall Data from Selected Cyclones (BoM and SILO, 2015)

Cyclone	Year	Dates	Duration (hours)	Rainfall (mm)	Estimated ARI (years)
Emma	2006	27/2 to 1/3	72	82.6	1:4
Vincent	2001	11/2 to 13/2	72	51.4	1:2
Kirsty	1996	13/3 to 14/3	48	39.6	1:1
Bobby	1995	25/2 to 27/2	72	85.6	1:3
Orson	1989	23/4 to 24/4	14	29.6	1:2
Connie	1987	20/1 to 22/1	46	90.7	1:5
Trixie	1975	19/2 to 24/2	113	68.4	1:2

The ARI values were estimated using the duration and rainfall data. The ARIs are indicative of the relative significance of the various cyclonic events, and provide a semi-quantitative comparison between the historical events and the modelling predictions, which are described in Section 6.

5.3.1 Design Rainfall

Design rainfalls events have been estimated to support the baseline surface water assessments within the Lake Miranda Catchment. Design rainfall quantities have been estimated for a range of average recurrence intervals (ARI) from 1- to 1,000-year ARI and including the Probable Maximum Precipitation (PMP).

The estimations have been determined for two catchment areas:

- Lake Miranda Catchment of approximately 7,560 km2, that drains to Lake Miranda (Figure 5-1).
- Yeelirrie (Playa) Catchment of 4,640 km2, which is the portion of the Lake Miranda catchment upstream of Yeelirrie Playa (Figure 5-1) comprising of sub-catchments A1-4, B, C and D.

Several different approaches have been used in the design rainfall estimation, depending on the rainfall ARI and duration. The different approaches include:

- Design rainfall for selected 1- to 1,000-year ARIs, estimated using standard Australian Rainfall and Runoff (AR&R, 1987) Intensity-Frequency-Duration data, without the application of Areal Reduction Factors. The design rainfall intensities, as derived from the Intensity-Frequency-Duration curves, are shown in Table 5-2.

- Design rainfalls for selected 5- to 1000-year ARIs, estimated using the WA CRC-FORGE EXTRACT (DoE, 2004) Intensity-Frequency-Duration data, inclusive of the application of Areal Reduction Factors.
- The WA CRC-FORGE EXTRACT employs a regional frequency analysis technique to inform point rainfalls and areal-reduced rainfalls for specified catchment location and surface areas. It calculated Areal Reduction Factors (ARF) for extreme rainfall events (100- and 1,000 year ARI). For the smaller event the ARF values have been extrapolated. The Areal Reduction Factors derived using WA CRC-FORGE EXTRACT are shown in Table 5-3.
- The estimated design rainfalls are point source rainfalls. It is unrealistic to assume that similar rainfall intensities can be maintained over catchment areas greater than 4 km2. As such, for rainfall over catchment areas larger than 4 km2, a reduction is made by applying Areal Reduction Factors (AR&R, 1987). Preferentially, but not in all cases, the Areal Reduction Factors derived from the WA CRC-FORGE EXTRACT have been used to reduce the point source rainfalls as the method is current and specific to Western Australia. The design rainfall for selected ARI events is shown in Table 5-4.

The Intensity-Frequency-Duration and log-normal rainfall intensities used in estimation of design rainfall for the catchment areas were interpreted using the software AUS IFD 2.0 (Appendix F1).

Table 5-2 Intensity-Frequency-Durations for Design Rainfall Events

ARI (year)	Rainfall Duration (hrs)					
	1	6	12	24	48	72
	Rainfall Intensity					
	mm/hr	mm/hr	mm/hr	mm/hr	mm/hr	mm/hr
1	12.5	3.5	2.1	1.3	0.8	0.6
2	16.6	4.7	2.9	1.8	1.1	0.8
5	23.0	7.1	4.5	2.8	1.7	1.2
10	27.0	8.7	5.6	3.5	2.1	1.5
20	32.1	10.7	7.0	4.4	2.7	1.9
50	39.0	13.6	9.0	5.6	3.4	2.5
100	44.4	15.9	10.6	6.7	4.1	3.0
1,000	55.0	20.0	13.3	9.0	5.4	3.8

Table 5-3 Design Rainfall Areal Reduction Factors using WA CRC Forge Extract

Areal Reduction Factors						
ARI (year)	Rainfall Duration (hrs)					
	1	6	12	24	48	72
Yeelirrie (Playa) Catchment						
1	NC	NC	NC	NC	NC	NC
5	0.6	0.7	0.73	0.74	0.78	0.81
20	0.7	0.72	0.75	0.76	0.82	0.84
100	0.8	0.82	0.84	**0.87**	**0.91**	**0.93**
1,000	NC	NC	NC	**0.91**	**0.94**	**0.95**
Lake Miranda Catchment						
20	NC	0.67	0.71	0.73	0.79	0.82
100	NC	0.79	0.81	**0.84**	**0.89**	**0.91**
1,000	NC	NC	NC	**0.89**	**0.93**	**0.94**
Notes						
1	*Highlighted values are direct results from CRC Forge Extract. Non-highlighted values are extrapolated values*					
2	*For selected events the Areal Reduction Factors (ARF) were not calculated (NC) as these are non-critical events and therefore no ARF is required.*					

Based on consolidating the different ranges of design rainfall derived using different methodologies, the total design rainfall depths (for the various ARI and durations) for the Yeelirrie Playa and Lake Miranda Catchment scale hydrological models are summarised in Table 5-4. The methodology for estimating the design rainfall for the Probable Maximum Precipitation (PMP) is described in Appendix F2

Table 5-4 Design Rainfall for Selected ARI

Design Rainfall for Selected ARIs (mm)						
ARI (year)	Rainfall Duration (hrs)					
	1	6	12	24	48	72
Yeelirrie (Playa) Catchment						
1	12.5	20.8	25.2	31.2	37.4	40.3
5	15.6	29.9	39.5	49.7	63.6	71.8
20	22.5	46.2	63.1	79.9	104.8	116.8
100	36.0	78.5	107.0	139.2	177.8	198.8
1,000	NC	NC	NC	197.4	242.9	257.7
PMP	NC	NC	NC	650	860	1,030
Lake Miranda Catchment						
20	20.9	43.0	59.7	76.7	100.9	114.0
100	34.1	75.2	103.0	134.54	173.9	194.6
1,000	NC	NC	NC	193.5	239.4	254.5
PMP	NC	NC	NC	560	740	900
Notes	*For selected events the design rainfall have not been calculated (NC) as these are non-critical events and therefore not required.*					

5.4 Baseline Surface Water Hydrology and Drainage Characterization

Predictive models have been developed to simulate the baseline catchment responses and surface water flow under selected (1-, 5-, 20-, 100-, and 1,000-year ARI) design rainfall scenarios.

The predictive surface water flow models comprise:

- Rainfall-runoff hydrological models, using XPrafts software. These models have been used to simulate catchment responses to selected design or historical rainfall events and generate runoff hydrographs from discrete catchment areas.
- Hydraulic flood models, using MIKE-21 HD software. These models route the flows generated by the hydrological models through the central valley of the catchment and simulate the extents of flooding (water level, water depth and stream flow velocity) for selected ARI events.

The hydrological and hydraulic conceptual modelling methodology, with the various model input and outputs, are summarised in the Chart 5-1.

Calibration of the predictive models has not been possible as surface water flow data are not available for the Lake Miranda Catchment. As such, the conceptual hydrology model is supported by the topographic data, catchment unit classifications and on-site infiltration test results. Further, significant historical rainfall events such as Cyclone Trixie have been simulated using recorded rainfall gauges from regional BoM stations to support the model parameterisation.

In the absence of model calibration, significant effort has been placed on the simulated results of the models to understand the sensitivities to variations in key model parameters.

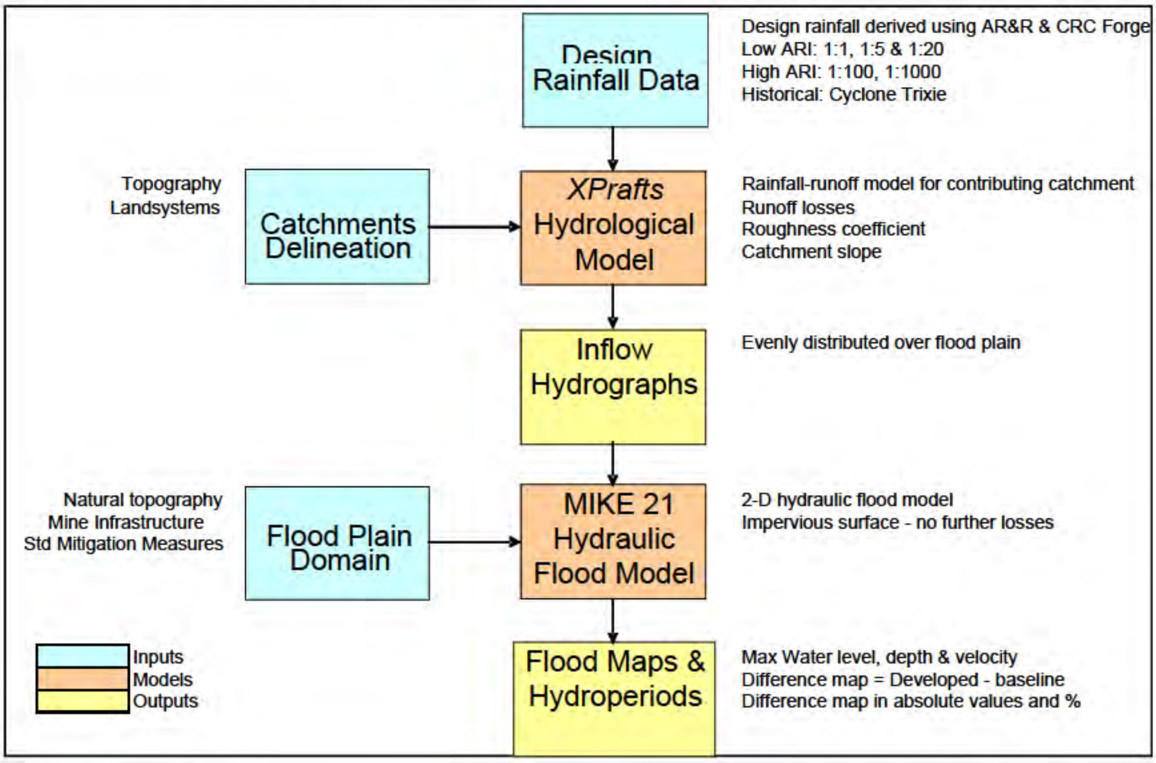

Chart 5-1 Conceptual Approach to Baseline Surface Water Catchment Characterisation

The Lake Miranda Catchment is characterised by granite breakaways at the catchment divides. Surface runoff from the headwaters at the catchment divides typically flows through several catchment units before reaching the valley-floor, including:

- Breakaways
- Wash plains
- Sand plains
- Playa
- Calcrete.

Generally, surface water flow within the catchment occurs as sheet flow. Several drainage lines provide flow in shallow discontinuous channels on the upper catchment slopes. Surface runoff reaching the valley floor flows to the southeast along the axis of the valley floor towards Yeelirrie Playa, Albion Downs Playa and ultimately Lake Miranda.

Of particular relevance to the baseline surface hydrology characterisation are the infiltration characteristics of the soils that form the local catchment units. A large proportion of the surface water from the breakaways may be lost before it reaches the valley floor as it traverses the wash plains and sand plains. The conceptual hydrological model is illustrated on cross-sections (Figure 5-2), showing various hydrological processes, including:

- Channel runoff from the breakaways near the catchment divides.
- Sheet flow on the wash plain and sand plain catchment units. At a local scale on the wash plains, the flows may be concentrated within shallow braided channels.
- On the valley-floor, the runoff is concentrated on the playa catchment units.
- Occurrence of potential recharge zones on the sand plains. In these areas, high infiltration capacities promote infiltration of rainfall and runoff. Infiltrates may be intercepted within the unsaturated profile by evaporation and evapotranspiration.
- Infiltrates that intersect silcrete and ferricrete hard pan beds may be laterally deflected and form temporary perched flow systems.
- Discharge to small clay pans, Yeelirrie Playa, Albion Downs Playa and Lake Miranda.
- Ephemeral recharge from the clay pans and playas. Although the hydrological regime may be dominated by evaporation, there may be episodic recharge to the water table from the clay pans and playas.

Within the Lake Miranda Catchment there may be occasional flooding events from cyclones. During an extreme rainfall event, surface water may overflow from Lake Miranda into the Lake Carey Catchment.

It is evident from the conceptual hydrological model that the catchment units influence runoff. The breakaway, wash plain, sand plain, playa and calcrete catchment units influence the spatial distribution infiltration and other losses within each catchment, the roughness coefficient for surface water flows, temporary interception and storage of runoff and, potential discharge mechanisms. Table 5-5 summarises the proportional occurrence of the catchment units within the Yeelirrie Playa and Lake Miranda Catchments.

An analysis of the areas of the different catchment units shows that the wash plains and sand plains constitute at least 75% of the catchment areas.

Table 5-5 Catchment Unit Areas (AgWA, Pringle et al, 1994 and Payne et al, 1998)

Catchment Unit	Total Area (km^2)	Percentage of Catchment
Yeelirrie (Playa) Catchment		
Breakaway	814	18%
Wash Plain	1,104	24%
Sand Plain	2,518	54%
Playa	146	3%
Calcrete	58	1%
Total	4,640	100%
Lake Miranda Catchment		
Breakaway	1,255	17%
Wash Plain	2,131	28%
Sand Plain	3,634	48%
Playa	280	4%
Calcrete	260	3%
Total	7,560	100%

5.4.1 Rainfall-Runoff Hydrological Model Development

The hydrological modelling utilized XPrafts, which is software developed by XP Software. The software uses the Laurenson non-linear runoff routing procedure to generate surface runoff hydrographs from both historical and design rainfall events. The baseline hydrological simulations include:

- Design flood events: flood events between 1- and 1,000- year ARIs.
- Historical flood events: historical rainfall from cyclones/depressions within 100 km of Yeelirrie Homestead.
- The software uses two loss components to generate rainfall runoff hydrographs:
- Initial loss: This parameter represents the first rainfall that will infiltrate into the soil and not generate runoff.
- Continuing loss: This parameter represents the portion of subsequent rainfall that is lost through evaporation and evapotranspiration and therefore does not contribute to surface water runoff.

Two hydrological models have been developed to characterise the Yeelirrie (Playa) and Lake Miranda catchment responses to rainfall, generating rainfall runoff hydrographs based on generalised parameters for each of the hydrological zones (Figure 5-3). For the hydrological modelling, the Lake Miranda Catchment was sub-divided using topographic boundaries based on points of interest including outcrops of the central calcrete catchment unit (Yeelirrie Playa, Albion Down Playa and Lake Miranda). The sub-catchments are shown on Figure 5-3 and include:

- Sub-catchment A – the headwaters, predominantly upstream of the central calcrete catchment units, with further subdivision into the A1, A2, A3 and A4 sun-catchments.
- Sub-catchment B – southern catchment areas that shed to the central calcrete catchment unit.
- Sub-catchment C – straddling the Proposed Development area.
- Sub-catchment D – immediate upstream hinterland to the Yeelirrie Playa.
- Sub-catchment E – local watersheds of the Albion Downs Playa.
- Sub-catchment F – immediate catchment of Lake Miranda.

Table 5-6 Hydrological Sub-catchment and Modelling Zones

Sub-Catchment	Area (km^2)	Percent of Total	Zone	Area (km^2)
A1	867			
A2	925			
A3	383			
A4	274			
B	466			
Upstream of proposed Mine Site	2,915	39%		
C	222		1	3,137
D	1,505		2	1,505
E	664		3	664
F	2,257		4	2,257
Downstream of proposed Mine Site	4,648	61%		
Total	7,563	100%		

Simulated hydrographs are subsequently routed through a network of channels to produce representative cumulative hydrographs at particular discharge points. Figure 5-4 shows schematic diagrams of the hydrological model setup for both the Yeelirrie Playa Catchment and Lake Miranda Catchment models.

Both hydrological models incorporate the same lumped parameters over individual sub-catchment areas. The only difference in the models occurs with the design rainfall inputs, which vary in magnitude and temporal patterns dependent on catchment area (Appendix F Table F-1).

Subsequently, for the purposes of baseline hydrology characterisation and assessment of cumulative flows at a local and regional catchment scale, sub-catchments A through F are rolled-up into four zones. The four zones (Zone 1 to Zone 4, inclusive) as shown on Figure 5-4 include:

- Zone 1: Mine Site, this includes the upper reaches of the Lake Miranda catchment, including sub-catchments A1 through C.
- Zone 2: Yeelirrie Playa, this includes the local contributing sub-catchments between the Mine site and the Yeelirrie Playa.
- Zone 3: Albion Downs Playa, including local contributing sub-catchments between the Yeelirrie Playa and Albion Downs Playa.
- Zone 4 - Lake Miranda, including local sub-catchments contributing to Lake Miranda, downstream of Zone 3.

The Yeelirrie Playa Catchment model is focussed on Zone 1 and Zone 2. The Lake Miranda Catchment model incorporates Zones 1 to 4 and estimates flows on a regional scale, with particular emphasis on:

- Valley-floor flows within the entire catchment.
- Flows potentially leaving the catchment.

The parameters used in the development of the hydrological models are described in detail in Appendix F.

5.4.2 Baseline Stream Flow Hydrographs

5.4.2.1 Simulated Peak Flows – Yeelirrie Playa Catchment Model

Local flows are generated on the playa and calcrete catchment units along the valley floor during 1-year and 5-year ARI rainfall events. Rainfall events less frequent than a 20-year ARI generate flows from the greater catchment. This aspect is linked to the high proportion of sand plain catchment unit in the sub-catchment areas. The sand plain parameterisation has a high initial loss value, requiring rainfall events of significant intensity (for infiltration excess), volume and duration (for saturation excess) to generate runoff.

Table 5-7summarises the simulated peak flows within the discrete sub-catchments and zones of the Yeelirrie Playa Catchment model. Figure 5-5 shows the zone hydrographs generated for selected rainfall ARI events.

The peak flows for the sub-catchments have been simulated based on the catchment characteristics of each discrete sub-catchment. Due to their differences the peak flows at the outlet of the sub-catchment occur at different times after the storm event.

The peak flows for the zones have been simulated based on the catchment characteristics of the entire zone as a single entity. Therefore the peak flows for the zones are not the same as the sum of the peak flows of the sub-catchments.

The mean peak flow in Zone 1 occurs after approximately 14 hours of rainfall. The majority of the hydrograph peaks are within four hours of the mean peak time. Sub-catchment A2 produces the highest simulated peak flows of all sub-catchments. In Zone 2, the mean time to peak flow is approximately 3.5 hours, with flows above 1 m^3/s lasting for approximately five hours.

Table 5-6 Simulated Peak Flows from the Yeelirrie Playa Catchment Model

Sub-Catchment	Simulated Peak Flows (m^3/s)			
	ARI (Years)			
	1	5	20	100
A1	0	0	0	78
A2	0	0	0	101
A3	0	0	0	69
A4	0	0	0.06	47
A4_VF[1]	0.8	2.8	8.1	
B	0	0	0	30
B_VF[1]	0.3	1.2	3.1	
C	0	0	1.5	56
C_VF[1]	0.8	3.0	8.4	
Zone 1	**1.2**	**4.1**	**12.0**	**242**
D	0	0	0	330
D_VF[1]	3.7	12.8	30.3	
Zone 2	**3.7**	**12.8**	**30.3**	**330**
Notes:				
1: Valley Floor sub-catchment areas.				

5.4.2.2 *Simulated Peak Flows - Lake Miranda Catchment Model*

The results from the Lake Miranda Catchment hydrological modelling have shown that only rainfall events less frequent than a 50-year ARI event produce valley floor flows from Zone 1 to Zone 4. Table 5-8 summarises the simulated peak flows generated in each sub-catchment and each zone for selected ARI rainfall event. The surface runoff hydrographs for Zones 1 to 4 are presented on Figure 5-6.

Table 5-7 Simulated Peak Flows from the Lake Miranda Catchment Model

Sub-Catchment	Simulated Peak Flows (m^3/s)	
	ARI (Years)	
	100	1,000

Sub-Catchment	Simulated Peak Flows (m^3/s)	
	ARI (Years)	
	100	1,000
A1	60	370
A2	76	424
A3	52	274
A4	35	178
B	22	208
C	45	166
Zone 1	**172**	**1,080**
D	95	503
Zone 2	**95**	**503**
E	60	320
Zone 3	**60**	**320**
F	136	655
Zone 4	**136**	**655**

5.4.2.3 Simulated Peak Flows - Cyclone Events

Cyclone Connie produced the highest simulated flow of 10 m^3/s for Zone 1, which is slightly greater than the peak flows generated by a 50-year ARI event. Flows above 1 m^3/s generated by Cyclone Connie occur for 6 days, compared to approximately 3.5 days for flows generated by the 1:100 year ARI rainfall event. Flows from Cyclone Connie peak after approximately 28 hours. Rainfall from Cyclone Trixie also generated runoff. Although the rainfall intensity during Cyclone Trixie was not particularly high, the duration of the event (approximately 4.5 days) is likely to have caused wet antecedent soil conditions within Zone 1, which promoted runoff.

Simulations of both Cyclone Trixie and Cyclone Connie generate runoff with peak flows in Zone 2 of 4 m^3/s and 8 m^3/s respectively. The simulated Cyclone Orson did not generate any runoff.

Table 5-9 summarises the simulated peak flows generated by Cyclones Trixie and Connie in each sub-catchment and each zone within the Lake Miranda Catchment model.

Table 5-8 Simulated Cyclone Peak Flows from the Lake Miranda Catchment Model

Sub-Catchment	Simulated Peak Flows (m^3/s)	
	Trixie	Connie
A1	1	3
A2	3	4
A3	2	4
A4	2	4
B	1	0
C	4	5

Sub-Catchment	Simulated Peak Flows (m^3/s)	
	Trixie	Connie
Zone 1	**5**	**10**
D	4	8
Zone 2	**4**	**8**
E	2	5
Zone 3	**2**	**5**
F	6	16
Zone 4	**6**	**16**

5.4.3 Sensitivity Analysis

The parameterisation of the rainfall-runoff hydrological models hosts uncertainty. The uncertainty is common in arid interior catchments, particularly given the nature of the local climate, length of the available rainfall records and absence of gauged stream flow in the Lake Miranda Catchment or nearby catchments.

The sensitivity analyses have been undertaken for the 1:20, 1:100 and 1:1,000 year ARI rainfall events as smaller events only generate localised runoff. A range of sensitivity analyses on selected parameters has been undertaken. These analyses enable the gauging of the potential influences of uncertainty on the simulated baseline catchment responses to rainfall in the models. The parameters used in the sensitivity analyses include:

- Rainfall intensity.
- Initial losses.
- Continuing losses.
- Roughness coefficients.
- Climate Change.

A detailed description of the sensitivity analyses undertaken is presented in Appendix F-3.

Rainfall Intensity

Rainfall intensity is a key input into the hydrological models. Of all sensitivity parameters, the change in rainfall intensity has the largest influence on peak flows and particularly during higher frequency ARI events. Substantial increases in simulated peak flow increases may occur under scenarios of increased rainfall intensity.

The analysis shows that the simulated peak flows are sensitive to the rainfall intensity for a design rainfall event, particularly for events less than 100 year ARI events. The sensitivity for these smaller events is relatively high because the changes in peak discharges for such events are from a relative small base. This sensitivity does indicate the importance of assuming reasonable rainfall intensity rates. The use of the AR&R derived IFD curve and rainfall intensities is therefore a reasonable assumption.

Initial Loss

The sand plain and wash plain catchment units are predominant within the Lake Miranda Catchment and therefore strongly influence the aggregate initial loss values adopted for each sub-catchment. Sensitivity analyses on the initial loss values for sand plain and wash plain catchment units enable an understanding of changes in peak flows of runoff linked to variations of initial loss values.

From the analysis it is evident that changes in initial loss values cause the largest relative change in peak flow. The simulated results indicate that reduced rates of initial losses may cause significant percentage increases of peak flow for the higher frequency events. This relative change diminishes as the ARI increases.

Continuing Loss

Sensitivity analyses of peak flows on both sand plain and wash plain in Zone 1 for selected ARI rainfall events where continuing losses were by varied by 20%.

The highest frequency ARI events show the highest percentage change in peak flow. However, there is considerable change in peak flows for a 1,000-year ARI event, with a 20% decrease in continuing losses producing a 20% increase in peak flow on the sand plain catchment unit. Continuing loss parameters for the sand plain have greater impact than on the wash plain catchment unit. Further, variations to continuing losses have stronger influences than initial losses on peak flows during extreme events. Roughness

Variations in roughness alter the velocity at which surface water flows over a catchment unit and therefore change the shape and the peak value of the hydrograph. The analysis shows that the simulated change in peak flows for selected ARI rainfall events resulting from variation of Manning's n values on the wash plain and sand plain catchment units. For both catchment units, the variations in roughness appear to predominantly influence the 20- and 100-year ARI events.

Climate Change

Australia is expected to experience increased frequency in spells of dry days and an increase in intensity of rainfall (Climate Change in Australia: PMSEIC, 2007). Uncertainty analyses were utilized to determine how potential changes in rainfall intensities caused by climate change may influence simulated peak flows within Zone 1 of the Lake Miranda Catchment.

The results of the analyses suggest that changes in rainfall intensity (ranging from -1% to plus 4%) would result in changes to the simulated peak flows, ranging from a lowest value of -10% for a 20-year ARI event, to a highest value of 44% for a 20-year ARI event, respectively.

5.5 Baseline Flood Characterisation

The baseline hydraulic flood model characterises the surface water flow along the main flow paths of the Lake Miranda Catchment. The model incorporates the predominant flow paths of the Lake Miranda Catchment and routes the runoff generated from the defined sub-catchments to simulate the catchment flood characteristics, including:

- Extents of flooding for selected ARI events.
- Depths of flood water for selected ARI events.

- Natural attenuation of flood waters.
- Flow velocities.
- Potential surface water flows out of the Lake Miranda Catchment.

5.5.1 Development of Hydraulic Models

A two-dimensional flood model, using MIKE-21 HD modelling software, characterised the surface water flows along the main flow paths of the Lake Miranda Catchment. The software is developed by the Danish Hydraulic Institute and forms a comprehensive modelling system that simulates unsteady two-dimensional flow on a flood plain. The hydrodynamic module of the package solves the equation of motion in a two-dimensional plane, with the assumption of a vertically homogeneous fluid under unsteady flow conditions. The implicit finite-difference method of resolution is used with the system of equations solved using the Double Sweep method (Abbott, 1979).

Two discrete hydraulic models have been developed for the following areas:

- The Lake Miranda Catchment Model - Large scale regional model in which the baseline conditions use the natural topography of the valley drainage line represented by 200 m x 200 m cells (Figure 5-7). This grid size enables sufficient areal extent, reasonable run time and adequate resolution of the baseline surface water characteristics of the Lake Miranda Catchment.
- The Yeelirrie Playa Catchment Model – More detailed model of the Yeelirrie Playa catchment area, with the topography represented in 100 m x 100 m cells.(Figure 5-8)

5.5.2 Hydraulic Model Parameterisation

The input parameters are the same for both Lake Miranda Catchment and the Yeelirrie Playa Catchment models.

Hydraulic Resistance

Surface roughness values represent the likely resistance to surface water flows in each catchment unit. The distribution of the different catchment units within the Lake Miranda Catchment and the Yeelirrie Playa Catchment are shown in Figure 5-1.

The hydraulic resistance values used are the inverse of Manning's n surface roughness values used in the hydrological models. Table 5-10 shows the applied hydraulic resistance parameter values for each catchment unit and Figure 5-9 shows the spatial distribution of the resistance values within both model domains, where a low surface roughness means lower hydraulic resistance, expressed by a higher hydraulic resistance parameter.

Table 5-9 Surface Roughness and Hydraulic Resistance Parameters by Catchment unit

Catchment unit	Surface Roughness (Manning's n)	Hydraulic resistance (1/n)
Breakaway	0.045	22.2
Wash Plain	0.11	9.1
Sand Plain	0.07	14.3

Playa	0.02	50.0
Calcrete	0.045	22.2

Hydrographs

For the Lake Miranda Catchment the catchment hydrographs generated by the hydrological model have been applied to the model domain for the 1:100 year, and 1:1000 year ARI flood events.

For the Yeelirrie Playa Catchment the catchment hydrographs have been applied for the 1:1 year, 1:5 year, 1:20 year, 1:100 year, and 1:1000 year ARI flood events.

Evaporation

Both models use a fixed daily evaporation rate of 7 mm (BoM, Wiluna Station) to simulate the flood characteristics within the model boundary.

5.6 Baseline Flood Simulations

5.6.1 Lake Miranda Catchment

5.6.1.1 Flood Water Inundation Areas and Flood Water Depths

Table 5-11 shows the simulated maximum water depths for each of the zones (Figure 5-4) within the Lake Miranda Catchment for selected extreme rainfall events. Flood depths increase along the valley-floor flow path due to the increasing number of contributing catchments. As expected, the maximum predicted flood depth (13 m) occurs in the lowest area of the catchment within Lake Miranda. During the 100 year rainfall event the maximum water depth in Lake Miranda is simulated to be 8.2 m receiving flood waters from the largest cumulative contributing catchment.

Table 5-10 Simulated Maximum Water Depths in the Lake Miranda Catchment

Zone	Simulated Maximum Flood Water Depths (m) ARI Rainfall Event		Cyclonic Rainfall
	100-year	1,000-year	Trixie
1	6	3.5	1.8
2	3.5	4.3	2.6
3	5.5	6.3	2.7
4	8.2	9.4	2.9

Figure 5-10 shows the maximum flood water depths and flood extents within the Lake Miranda Model for selected ARI rainfall events.

Model simulations show that flood water flows from the Lake Miranda Catchment to the downstream Lake Carey Catchment. This occurs following somewhere midway between a 50 yr ARI and 100 year ARI event.

Of particular interest in the Lake Miranda Catchment is the potential attenuation of stream flow and flood water by the Yeelirrie and Albion Downs Playas and by Lake Miranda itself. The model simulations indicate that runoff from events of smaller magnitude than a 20-year ARI would be attenuated by the Yeelirrie Playa. Predicted flows generated by a 50-year ARI event reach and are attenuated by the Albion Downs Playa. Figure 5-10 shows that for the 100- and 1,000-year ARI events, the runoff flows out of Albion Downs Playa to Lake Miranda. The simulated 100-year ARI event generates sufficient runoff volumes to fill Lake Miranda and breakout to the east to flow into the Lake Carey Catchment.

5.6.1.2 Flow Velocities

The simulated regional baseline maximum flow velocities are shown in Figure 5-11, which range up to approximately 1 m/s. Due to the natural attenuation in the catchment area the simulated flow velocities have relatively little variation.

5.6.2 Yeelirrie Playa Catchment

5.6.2.1 Flood Extends and Depths

Table 5-12 shows the simulated peak flood depths in the Yeelirrie Playa Catchment for various rainfall events. The 100-year ARI event provides a simulated maximum flood depth of 3.4 m for Zone 1 and 3.7 m for Zone 2, compared to maximum flood depths of 1.0 m and 1.8 m respectively for a 1-year ARI event.

Table 5-11 Simulated Maximum Flood Water Depths in the Yeelirrie Playa Catchment

Zone	Simulated Maximum Flood Water Depths (m)			
	ARI Rainfall Event			
	1-year	5-year	20-year	100-year
1	0.97	0.99	1.4	3.4
2	1.8	1.8	2.6	3.7

Table 5-13 shows the simulated maximum flood depths on the watercourse reaches immediately upstream and downstream of the proposed Project area and on Yeelirrie Playa. Figure 5-12 shows the Yeelirrie Playa Catchment maximum flood water depths and flood extents for the selected ARI rainfall events. The flood maps for the 1-year and 5-year ARI events show intermittent pooling of surface water as runoff accumulates in local depressions on the valley floor along the main flow paths. During rainfall events of frequency greater than 20-year ARI, there may be only localised pooling of water and no interconnected flows on the predominant watercourses on the valley floor. Stream flows along the main channel and into the Yeelirrie Playa start to occur during the 20-year ARI event (Figure 5-12). The maximum flood depths occur where the stream flow slows and pools in low depressions along the main valley-floor flow paths.

Table 5-12 Simulated Baseline Maximum Flood Water Depths on Selected Watercourse Reaches

Event ARI (yrs)	Simulated Maximum Flood Water Depths (m)		
	Upstream Reaches	Downstream Reaches	Yeelirrie Playa
Yeelirrie Playa Catchment Model			
1	<0.1	<0.1	<0.1
5	0.1 - 0.25	0.25 – 0.5	0.25 – 0.5
20	0.25 – 0.5	0.5 – 0.75	0.5 – 0.75
100	0.75 – 1.0	0.75 - 1.0	0.75 - 1.0
1,000	2.0 – 2.5	1.5 – 2.0	1.5 – 2.0

5.6.2.2 *Flow Velocities*

Table 5-14 shows the simulated baseline maximum flow velocities on watercourse reaches immediately upstream and downstream of the proposed Project area and on Yeelirrie Playa. Figure 5-13 shows the simulated baseline flow velocities in the Yeelirrie Playa Catchment. The attenuation of the surface waters during the 1-year and 5-year ARI events limits the flow velocities.

Table 5-13 Simulated Maximum Flood Water Velocities on Selected Watercourses

Event ARI	Simulated Maximum Baseline Flood Water Velocity (m/s)		
	Upstream Reaches	Downstream Reaches	Yeelirrie Playa
Yeelirrie Playa Catchment Model			
1	0.01 – 0.05	0.01 – 0.05	0.01 – 0.05
5	0.05 – 0.1	0.05 – 0.1	0.05 – 0.1
20	0.05 – 0.1	0.05 – 0.1	0.1 – 0.5
100	0.1 – 0.5	0.1 – 0.5	0.5 – 1.0
1,000	0.5 – 1.0	0.5 – 1.0	0.5 – 1.0

The baseline simulations indicate the stream flow velocities are comparatively low. Intermittent opportunities for pooling of surface water and the low topographical relief of the valley-floor settings typically enable broad shallow flow paths.

5.6.3 *Sensitivity Analysis Simulations*

The flow resistance parameterisation of the different catchment units has been reviewed by sensitivity analyses. Table 5-15 shows the baseline resistance parameterisation of the hydraulic flood models and applied lower-bound and upper-bound sensitivity analyses. The Playa area has been excluded from the sensitivity analysis as this area represents a salt pan which has been allocated the lowest resistance parameter.

A detailed description of the sensitivity analyses undertaken is presented in Appendix G.

Table 5-14 Range of Resistance Parameters Used for the Sensitivity Analysis

Catchment unit	Hydraulic Resistance Parameter (1/n)		
	Lower-Bound	Baseline Parameterisation	Higher-Bound
Breakaways	25.0	22.2	20.0
Wash Plain	14.3	9.1	6.3
Sand Plain	22.2	14.3	9.1
Playa	50.0	50.0	50.0
Calcrete	25.0	22.2	20.0

Note: No sensitivity on Playa area (Lowest resistance parameter allocated)

The sensitivity analyses simulations indicate that there is an insignificant difference in the water depths in the 100-year ARI event when comparing baseline with the lower and upper bound values for resistance. In the 1,000-year ARI simulation, there is a 0.1 m increase and 0.25 m decrease in water depth for the respective lower-bound and upper-bound resistance parameterisation. These changes in simulated water depths mainly occur at the confluences of major drainage lines, suggesting that the resistance values for wash plain catchment unit have the predominant influence on surface water flows.

5.7 Baseline Interactions Between Surface Water and Groundwater

The interaction between surface water and groundwater is a significant function that:

- Distributes water and salt via infiltration to the water table that in some areas support dependent ecologies;
- Determines, along with groundwater hydraulic conditions, whether groundwater will influence surface water;
- Distributes salt and other solutes (including uranium) within the catchment, generally from elevated to low-lying areas; and
- Influences surface water flows down the catchment, and along with local gradients, how runoff accumulates in some areas that promotes recharge.

Complexities in characterising groundwater recharge in arid environments are described in URS (2011). In particular, local variability of processes that contribute to recharge include surface soil infiltration capacities, flood depths, durations and proximity to areas dominated by overland or channelled flow. These complexities along the valley floor (floodway) downstream of the proposed mine site were highlighted by the widely variable chloride/bromide ratios (URS, 2011). To understand how these interactions and inter-dependencies operate in the Project area, the analysis outlined in this section focusses on characterising:

1. observed water table responses to rainfall and flooding,
2. the surface water flux actually reaching the water table (recharge) and its predictability based on recently monitored ARI events,
3. the depth to the water table, groundwater salinity and position within the catchment, and

4. comparing the observed recharge rises to local stratigraphy to determine whether event-based recharges are significant to event-based groundwater flow.

5.7.1 Observed Water Table Reponses to Rainfall

Since early 2010, groundwater levels have been measured at many sites across the Yeelirrie Catchment. In November 2010, automatic data loggers were installed in 12 monitoring bores to record climate-driven fluctuations at the water table, and selectively, in deeper bores lower in the hydrogeological profile. While a number of the loggers malfunctioned, or were lost over time, several continued recording until Cameco reinvigorated the programme in September 2013, and replaced most of the older instruments with new devices. There are now 18 loggers operated by Cameco at Yeelirrie. In addition to the logger data, manual groundwater level readings have also been taken to determine the accuracy of the automatic readings, but also to record changes in additional bores not equipped with loggers.

The results of this monitoring, including manual readings to March 2015 and logger readings to August 2014 are shown on Figures 5-14 to 5-26. The locations of these sites are shown on Figure 5-27 along with the stratigraphy they are screened against. It should be noted that many of the sites are situated near potential GDEs also shown on Figure 5-27. They are mostly positioned along the valley floor with the exception of one site (SB14-2), which is located on the northern flanks of the valley.

Recharge responses to rainfall during the monitoring period in many bores have been noted following six climatic events shown in Table 5.16.

Table 5-16 Recharge Initiating Events November 2010 to March 2015

Rainfall Event Date(s)	72-hour Total (mm)	7-day Total (mm)	1-month Total (mm)	Applicable 72-hour ARI
18 February 2011	144.2	144.2	166.2	1 : 20
12-24 January 2012	5.2 to 30.8	5.5 to 50.6	92.1	1 : 1 to 1 : 5
4-9 May 2013	12 to 19.3	12 to 19.3	42.7	1 : 1
23 January 2014	71.6	29.5 to 72.5	102.0	1 : 1 to 1 : 5
5-17 May 2014	8.8 to 32.8	8.8 to 32.8	54.4	1 : 1
2-7 Mar 2015	16.9 to 58.3	61.3	61.3	1 : 1 to 1 : 10

Unlike surface water runoff studies, recharge to groundwater can occur immediately if there is a shallow water table or there is a direct connection between the runoff and the water table. Recharge may also take some time to manifest in a water table response; most often observed as a rise in the level. Such variability may arise from local runoff infiltration and flood characteristics, as well as the water balance in the unsaturated zone. Runoff infiltration rates are dependent on the point at which the unsaturated zone becomes sufficiently wet to allow flow to the water table. If an area floods, the unsaturated zone is subjected to potential infiltration for a longer time. For this assessment, only the change at the water table has been considered; unsaturated soil moisture and flow processes have not been discretely characterised. To account for such above water table variability, recharge from each event has been considered in terms of rainfall during a 72-hour period, 7-day period and 1-month period (Table 5-16).

Considering the hydrographs on Figures 5-14 to 5-26, recharge responses from the events on 18 February 2011 and 23 January 2014 are distinct. The timing of water table responses from the other events however, suggests that recharge took several months to reach maxima after the initiating event. The approach used to estimate recharge is known as the Water Table Fluctuation method described by Healy and Cook, (2002).

Individual recharge responses to each of the above rainfall events from all of the monitored bores are listed in Appendix H.1. Recharge responses sorted according to each of the ARI events listed in Table 5-16, are itemised for water table intervals in Appendix H.2 and intervals just below the water table in Appendix H.3. Responses re-ordered according to the screened hydrogeological unit and ARI event across the water table are shown in Appendix H.4, and just below the water table in Appendix H.5. The remainder of the responses from bores with deeper screened intervals have not been included in the assessment as their responses are hydraulic in nature rather than a physical increase in storage above the water table.

The observed recharge responses for each ARI event, at and near the water table, are summarised in Appendices H.6.1 and H.6.2. These results are considered indicative given the number of results available for review. In a number of cases, only one or two observations are available for each ARI event per hydrogeological unit. They do, however, provide an insight into recharge responses across similar hydrogeological units. The results suggest that in general, calcrete-based units at and near the water table, recorded smaller rises (0.03m to 0.05m) than alluvial units (0.09m to 0.11m). The results from the weathered (clayey) bedrock at SB14-2 indicate relatively small responses, probably as a result of its more elevated position in the catchment – lower runoff residence time – and greater depth to water.

These rises are considered to be net recharge in terms of the water travelling from the surface to the water table, but as gross recharge when viewed in a water balance context with evapotranspiration losses. As net recharge, they are comparable to the recharge variable used in the project's groundwater flow models. It should also be remembered that recharge estimates derived from these data are only reflective of local conditions around each bore site. Collectively, the available data provide a reasonable first-pass dataset for low-lying areas within the Yeelirrie Catchment. Other areas within the catchment are represented by only one bore – SB14-2.

5.7.2 Predictability of Groundwater Recharge to ARI-based Events and Flooding

The predictability of water table recharge has been estimated from the results in Appendix H.6.1 by considering all available bore records and then a sub-set of the bores located between the proposed mine site and Yeelirrie Playa. For this analysis, results from bores screened below the water table (Appendix H.6.2) were not used where there was a corresponding water table bore available (Appendix H.6.1). This would otherwise duplicate and possibly skew the results. The analysis estimated recharge for:

- all water table event responses across each hydrogeological unit and ARI,

- responses observed in 2014 and 2015 (where the most reliable data are available) from selected bores located between the mine site and Yeelirrie Playa, and
- both rainfall and where relevant flooding for each ARI.

The purpose of these analyses was to see whether recharge can be characterised based on the hydrogeological unit, ARI (or annual rainfall) and flood depths (if any). The results for water table responses are shown in Appendix H.6.3 and summarised in Table 5-17.

Table 5-17 Summary of Recharge Estimates

Water Table Hydrogeological Unit	Regional-based Recharge (Event as Percent of Actual Annual Rainfall)	Estimated Recharge (Percent of Flood Event Depth and Actual Annual Rainfall)
Calcrete	6.6%	5.9%
Transitional Calcrete	2.6%	3.4%
Calcrete Formations (average)	**4.6%**	**4.2%**
Clayey alluvium	1.9%	1.9%
Hardpan / Sandy alluvium	6.9%	5.2%
Sandstone alluvium	3.7%	2.6%
Alluvium Formations (average)	**4.2%**	**3.0%**
Clayey (weathered) Bedrock	**0.7%**	**0.8%**
All Water Table Units (Alluvial - 5.5mbgl to 9.8mbgl; Weathered Bedrock 32mbgl)*	**4.4%**	**3.5%**

Table 5-17 suggests that the rate of recharge is generally highest at calcrete and hardpan / sandy alluvium sites, followed by transitional calcrete and sandy alluvium. The smallest recharge rates were observed in clayey alluvium and weathered (clayey) bedrock. Overall, recharge rates (either on a per event basis +/- flood influences) across alluvial and calcrete units between 3.0% and 4.6% of annual rainfall, compared to only 0.8% on the catchment flanks in weathered bedrock (at SB14-2). This suggests a loose relationship exists between rainfall and the hydrogeological unit at the water table. In the case of SB14-2, the depth to the water table may have also contributed to its result.

Estimated recharge rates as both a water table recharge flux, and as a percentage of annual rainfall for the observed ARI events, are shown in Appendix H.6.4. Similar trends are observed for all hydrogeological units whereby larger fluxes and recharge rates for the 1:5 year event of January 2014 compared to the 1:10 and 1:20 year events of March 2015 and February 2011 respectively. Overall, the recharge flux was greatest in cemented water table formations (calcrete, transitional calcrete and hardpan / sandy alluvium) that occur close to and downstream of the mine site. This suggests that at least for the smaller (lower ARI) events, a reasonable relationship may exist between ARI and recharge rate.

Apparently smaller recharge rates for higher ARI events (1:10 and 1:20) are attributed to the relatively short duration of the events (several days) when compared to the lower ARI events that typically comprise a succession of several smaller events within a relatively short period (several weeks). Intuitively, higher ARI events would normally be expected to yield greater runoff and hence flood-initiated recharge, while lower ARI events would generate less runoff.

The influence of flooding on recharge appears to be well-represented by the monitoring data collected from YYHC0037C. This site is located in an area with hardpan / carbonated hardpan at the water table, and is in close proximity to an area where the water table is between 2m and 4m below the surface (Figure 5-28). It is also close to an area that is predicted to accumulate runoff from events of a 1:5 year ARI or greater (Figure 5-12). Following the event of January 2014 (1:5 year ARI), recharge as a result of rainfall is estimated to be 3.1% (Appendix H.6.3). Incorporating an additional 60mm of flooding (derived from predicted baseline flood maps, Figure 5-12), is estimated the flood-related component is the equivalent to about 0.6% of the recorded annual rainfall. This proportion would be higher following higher ARI events – possibly by an order of magnitude following a 1:20 year ARI event when not only the runoff will be larger, but the extent and duration of the flooding would be larger.

5.7.3 Depth to the water table, groundwater salinity and position within the catchment

The implication of the above discussion is that for low-lying areas in the catchment that are subjected to flooding, especially following higher ARI events, the recharge rate is substantially higher than areas subjected to runoff – infiltration processes alone. Recharge in flood-prone such areas is therefore, considered to be important for maintaining groundwater levels and quality along the valley floor. It should also be recognised that water availability alone does not fully describe the salinity in the groundwater environment. Fluxes of salt from surface water are expected to be important, particularly in areas within or downstream of playa features that accumulate salt during smaller, more frequent (non-flood-generating) events. One such area downstream of the proposed mine site is shown on Figure 5-28.

For recharge, this area appears to be unique based on the following criteria:

- Shallow depth to the water table (Figure 5-28),
- Potential to accumulate runoff following relatively low ARI events (Figure 5-12),
- Significant connection and resultant recharge response at the water table from flooding (Figure 5-16),
- Coincident, and possibly a significant contributor to a steep salinity gradient from the proposed mine site to downstream areas containing groundwater of stock water quality (Figure 5-28),
- Close to potential GDEs (Figure 5-28),
- Downstream of areas (within the proposed mine site) where calcrete formations occur below the water table (Figures 5-29 and 5-30), and
- In an area with hardpan/carbonated hardpan that spans the water table (Figure 5-31).

To varying degrees the above criteria also apply elsewhere:

- Further downstream of the proposed mine site near Yeelirrie Homestead, salinity increases as a result of lower net recharge, greater depth to water, lower potential to accumulate flood water, the presence of former clay pans (possibly containing historical salt) and regional salt accumulation processes towards the valley floor.

- Within the proposed mine site, salt has accumulated over a very long time from surface water runoff to local playa areas, especially within the associated clayey formations. Localised evaporative losses through these clayey formations have promoted long-term salt accumulation at, and near, the surface. In addition to this accumulation process, salt has accumulated in the (upstream) calcrete from regional groundwater and surface water accumulation processes. Since the calcrete becomes unsaturated in the eastern portion of this area, throughflow and downstream salt dispersion is somewhat restricted.
- Upstream of the proposed mine site, salt accumulation occurs at a regional scale due to surface water influxes (flooding), and long-term accumulation in groundwater along the flow path. The presence of a locally shallow water table, outcropping calcrete, GDEs, and evapotranspiration may also be significant long-term salt accumulation contributors.

5.7.4 Event-based (Recharge-driven) Groundwater Flow

Detailed groundwater assessments within the proposed mine site (URS, 2011), concluded that the catchment water balance is closely linked to the fundamentals of hydrology and hydrogeology. The derived interpretations suggested that complex arrangements involving the exchange of water between surface water and groundwater environments as flooding, evaporation, recharge and evapotranspiration. At that time evidence of this exchange represented by recharge fluxes at the water table were not available. This assessment considers not only the timing of recharge fluxes, but also a comparison of the magnitude of these fluctuations with the initiating event expressed as the corresponding 72-hour ARI rainfall total.

The results of earlier field investigations suggest that within the proposed mine site, calcrete is mostly above the water table, (Figure 5-29), and that the thickness of saturated calcrete and transitional calcrete is highly variable (Figure 5-30). Downstream, the water table is spanned by a sequence of hardpan and carbonated hardpan (Figure 5-31). In both cases, the observed rises following recharge events have the potential to increase the effective transmissivity (aquifer thickness x hydraulic conductivity) and the width of the water table flow path.

Recharge-related rises also have the potential to change the hydraulic gradients of the water table; steeper gradients along with increased transmissivity have the potential to increase throughflow. The changes in hydraulic gradient from recharge are, however, linked to the amount of water reaching the water table as well as the drainable porosity (specific yield). Based on the observed responses, rises from larger ARI events in calcrete and hardpan-type formations are typically in the order of 0.03m to 0.05m, but locally as high as 0.1m (Table 5-16). Formations with lower specific yield properties (sandy and clayey alluvium) however, generally have larger recharge rises; typically between 0.09m to 0.11m, but as much as 0.4m to 0.9m.

While the rises and apparent increase in transmissivity suggest an increased throughflow rate after a recharge event, the actual rate will be determined by the hydraulic conductivity of the water table formations along the valley floor. In this case, potential throughflow from calcrete-based formations upstream and within the proposed mine site will be restricted by the transition to hardpan and clayey alluvium beneath the eastern portion of the proposed mine site and downstream areas. While the event-based fluxes have not been estimated throughout the proposed mine site, the observed salinity distributions suggest that salt from the site moves downstream at the water table through less transmissive formations at a limited rate.

The hydrographs shown in Figures 5-14 to 5-26 indicate that the recharge hydroperiod is highly variable (months to years) and that there are also hydraulic responses vertically across the hydrostratigraphy. Groundwater studies across the site (URS, 2011) indicate that salt and at least part of the recharge flux, passes downward as well as laterally away from the water table at the proposed mine site. The observed recessions from recharge rises are likely therefore, to be a function of groundwater movements based on local gradients (vertical and lateral) and formations of relatively low hydraulic conductivity. The recharge rise recessions at the water table, particularly where shallow depths to water exist, may also be controlled by evapotranspiration by groundwater dependent vegetation, or evaporation from superficial clayey alluvium that allows capillary pumping to occur.

While the proportions of each of these controls within, and in close proximity of the proposed mine site are not known, the net result suggests that the following criteria (from most to least significant) control the way event-based groundwater flow occurs:

- Local surface water accumulation (including flood depth) characteristics;
- Infiltration rate and unsaturated hydraulic properties of formations above the water table;
- The hydraulic conductivity and specific yield of formations across the water table;
- Depth to water and connectivity vertically and laterally (downstream) with transmissive formations; and
- Presence of groundwater dependent vegetation, and playa with clayey alluvium spanning the unsaturated interval above the water table.

5.8 Summary of Baseline Hydrology and Drainage

The baseline hydrology can be summarized as follow:

- The Proposed Development is located within the upper zone of the Lake Miranda catchment, which comprises three main zones: upstream of Yeelirrie Playa; between Yeelirrie Playa and Albion Downs Playa; and between Albion Downs Playa and Lake Miranda. Lake Miranda overflows across a low topographic saddle eastward into the larger Lake Carey catchment.
- The catchment setting is inherently dry and arid (low rainfall, high evaporation) with occasional cyclonic events that bring high intensity rainfall. There is no permanent surface water.
- The surface water flow, when it does occasionally occur within the Lake Miranda catchment area, is typically characterised as short-lived, overland sheet flow and channel flow terminating in clay pans and the Yeelirrie, Albion Downs and Lake Miranda Playas.

The baseline hydrology and drainage have been characterized using hydrological models to characterize the rainfall runoff and hydraulic flood models to analyse the surface water drainage characteristics of the Lake Miranda catchment zones. The results of modelling indicate:

- Rainfall events smaller than 1:20 year ARI generate localised sheet flow runoff. No interconnected flows are predicted to occur within the catchment valley.
- Larger rainfall events (1:20 to 1:100 year ARI) generate interconnected runoff in the valley floor throughout the Lake Miranda catchment terminating in the playas.
- Extreme rainfall events (1:100 year ARI and greater) generate runoff throughout the Lake Miranda catchment, with Lake Miranda spilling over into the Lake Carey catchment.

The hydrological models could not be calibrated due to a shortage of observed flow data. Instead, analyses have been undertaken to establish the sensitivity of the results to changes in the input parameters. The results of this analyses provided confidence in the results and the appropriateness of representation of the reasonable worst case scenarios.

6 ENVIRONMENTAL CHANGE ASSESSMENT DURING OPERATIONS

6.1 Introduction

This section of the report presents the results of the hydrological modelling in terms of the changes between the baseline hydrology described in Section 5 and the modelled hydrological conditions resulting from the proposed Project.

The proposed Project is located in the valley floor of the Yeelirrie Playa catchment drainage line, on the confluence of two main drainage lines draining the Yeelirrie Playa catchment upstream of the mine site comprising sub-catchments A1-4, B with a total catchment area of 2,915 km^2. The northern drainage line drains sub-catchments A1-4 (2,449 km^2, 84 % of the upstream catchment area) and the southern drainage line drains sub-catchment B (466 km^2, 16% of the upstream catchment area). In addition, sub-catchment C (222 km^2) drains into the Yeelirrie Playa drainage line along the length of the proposed Project mine site (both north and south) (Figure 6-1).

To prevent the inflow from surface water runoff into the proposed mine site area, the mine site area will be protected from external inflows through the construction of a surface water diversion bund around the active mining area to divert surface water runoff and stream flow around the active mining area during the operations (see Chapter 2, Project Description). The diversion bund, designed to protect against a 1,000-year ARI flood event, is proposed to be constructed in two stages in order to minimize the amount of precipitation and surface water runoff that would collect within the mine area and require management.

The mine stages were used as primary inputs into the hydrological model but simplified based upon the years when similar mine conditions are planned:

- Stage 1: Years 1 to 7 (Figure 6-2)
- Stage 2: Years 7 to 22 (Figure 6-3)

The location of the proposed mine site suggests that the baseline flow paths, which are currently split into two parallel paths on both sides of the calcrete rise, would be partially blocked due to the construction of the surface water diversion bund (Figures 6-2 and 6-3). Therefore, a diversion channel would be required to drain the flood waters from the northern watercourse, around the minesite and into a combined watercourse along the western and southern perimeters of the site protected by a surface water diversion bund. This diverted flow path is nearly coincident with the path of the baseline southern watercourse.

Consequently, the proposed development would, at least temporarily, alter the baseline hydrology during a significant flood event. However, as described in Section 5 under baseline conditions, the surface water modelling suggests that water would not flow within the catchment as a connected watercourse (versus isolated, local flows) unless a storm event in excess of a 20-year ARI would occur.

The modelling also predicts that for the duration of the mine operation, and up to a (hypothetical) 1,000-year ARI event, the surface water diversion bund would both:

- Prevent external catchment surface water from draining into the proposed Project mine site area, and

- Prevent the surface water runoff that collects interior of the surface water diversion bund from discharging uncontrolled outside the bund into the natural environment.

Outside the Diversion Bund

Outside the surface water diversion bund the predicted changes resulting from a (hypothetical) flood event include a temporary:

- Increase in the water depth immediately upstream of the mine due to ponding;
- Increase in the stream flow velocity of water draining around the western and southern perimeter of the mine area (through the proposed diversion channel and between the minesite and southern valley slope),
- Decrease in the baseline water depth and flow volume immediately downstream of the mine area due to retardation of stream flow upstream of the mine site.

This Section 6 will present an assessment of the potential changes external to the mine site and assess the extent of any potential changes to the surface water environment further downstream throughout the Lake Miranda catchment area.

Inside the Diversion Bund

Inside the surface water diversion bund the potential changes include a temporary increase in water depth at the lowest points within the mine area, which would be managed through a number of stormwater ponds. During extreme cases, the water could be temporarily stored within the inactive pits.

After Mine Closure

At the completion of operations, the mine infrastructure would be decommissioned and the site would be rehabilitated. The conceptual mine closure design suggests that the proposed final landform would result in after-mining hydrological conditions similar to the pre-development conditions. The assessment of change to the surface water environment after mine closure is presented in Section 7 of this report.

6.2 Change Assessment Methodology and Model Development

The methodology for the assessment of changes in stream flow hydrology focuses on the use of the hydraulic flood model of the Lake Miranda Catchment to predict the effects of the surface water diversion bund on surface water flows. The simulations are based on 1-, 5-, 20-, 100- and 1,000- year ARI events. During mining, the catchment settings and excavated pits would be inherently dry. Exceptions would occur, however, during and after significant rainfall and runoff events, when the pits would be the lowest elevation landscapes and tend to form sinks. Depending on the average recurrence interval of the rainfall event, significant runoff volumes may be temporarily stored in the pits for extended periods.

The predictive assessments of changes to flood depths, extents and velocity of flow are undertaken at three different scales, with a hydraulic flood model developed for each:

- Regional Scale: Lake Miranda Catchment outside of the surface water diversion bund.

- Local Scale: Yeelirrie Playa Catchment outside of the surface water diversion bund.
- Minesite Scale: Area inside the surface water diversion bund forming the predominant disturbance footprint.

The baseline hydraulic flood model has been adapted to incorporate key elements of the propose Project infrastructure that potentially influence the surface water environment. Subsequently, the model has been applied to simulate the potential changes to the surface water flood hydrology that would be imposed by the proposed Project.

6.2.1 Surface Water Diversion Bund Concepts

The assessment has assumed that the surface water diversion bund would be constructed in two primary stages, as shown on Figures 6-2 and 6-3.

The regional scale change assessment only incorporates the Stage 2 operational setting as it has the largest project foot print and associated surface water diversion bund. This has been assumed as a reasonable worse-case scenario. At this stage the footprint of the bunded minesite is at its maximum, potentially causing the largest change to baseline surface water drainage characteristics.

6.2.2 In-bund Runoff

The proposed staging of the mine site footprint would provide different surface water environments over time as the catchment area inside the surface water diversion bund change and increase. The simulations of surface water flows inside the surface water diversion bunds have been assessed for each of the two stages of mining, aimed at assessing the capacity of the surface water diversion bund to retain mine site surface water runoff within the bund and thereby isolate the mine site runoff from the natural environment outside the bund.

6.2.3 Sensitivity analyses

The hydrological and hydraulic models developed for this study are largely uncalibrated due to the general lack of site-specific hydrological data. In the absence of calibration, sensitivity analyses have been done on critical model parameters to assess the robustness of the models and the sensitivity of the simulated results to variations in selected model parameters.

The sensitivity analysis for the hydraulic models focussed on two key input parameters: flood hydrology (peak flow hydrographs) and the surface roughness. The sensitivity simulations were undertaken for the following models:

- Regional Lake Miranda hydraulic model (200 m grid): upstream, mid-point and downstream
- Yeelirrie Playa hydraulic model (100 m grid): upstream, mid-point and downstream
- In-bund Mine site hydraulic model (10 m grid)

The sensitivity analyses incorporated variations in peak flow rate and roughness parameters for a range of rainfall events as shown in Appendix G.

The sensitivity analyses suggest that the predicted outcomes are reasonable but will need to be confirmed through the collection of additional surface water flow data, when possible, and modelling refinements.

6.3 Change Assessment Scenarios

The hydraulic flood model has been applied to simulate the surface water characteristics of selected scenarios within the Yeelirrie Playa catchment area. A summary of the selected predictive scenarios is provided in Table 6-1.

Table 6-1 Hydraulic Flood Model Altered Hydrology Predictive Scenarios

Mining Stage	Simulations of Flood Water Depths and Flow Velocity					
	Event Recurrence Interval (Years)					
	1	5	20	Cyclone Trixie	100	1,000
Regional Lake Miranda Catchment Model – Outside of the Surface Water Diversion Bund						
2 – Year 8-22	-	-	√	√	√	√
Yeelirrie Playa Catchment Model - Outside of the Surface Water Diversion Bund						
1 – Year -1-7	√	√	√	-	√	√
2 – Year 8-22	√	√	√	-	√	√

6.4 Simulated Altered Hydrology Outside the proposed Mine Site

The findings of the hydraulic flood model predictive simulations are presented in a suite of maps that characterise:

- Maximum flood water depths.
- Flow velocity.
- Differences (absolute values) between the baseline and Proposed Development-related hydrological simulations.

The assessment of the changed hydrology is focussed on the simulations of the Yeelirrie Playa Catchment model that incorporates the Stage 2 – Year 8-22 surface water diversion bund. These predictive outcomes present the effects of the proposed Project on the surface water hydrology and drainage.

6.4.1 Innundation and Water Depths

The hydraulic flood model simulations indicate the surface water diversion bund impedes surface water flow upstream of the Proposed Development, with consequential changes in flood depths and extents. The presence of the surface water diversion bund attenuates the natural stream flow on the valley floor. Consequently, there is a predicted increase in flood water depths and extents on local reaches of the valley-floor watercourses upstream of the surface water diversion bund.

Conversely, local downstream reaches of the valley-floor watercourses are influenced by reduced flows and consequent reductions in flood water depths. Although the volume of surface water runoff for each ARI event is unlikely to be significantly reduced, the flood peak would be reduced on reaches downstream of the surface water diversion bund. The scales of the predicted changes increase corresponding to the staged enlargement of the surface water diversion bund and in association with the lower frequency ARI events.

6.4.1.1 *Regional Lake Miranda Catchment*

The majority of the Lake Miranda Catchment is located downstream of the proposed Project. As such, the majority of runoff generated within the catchment would not be affected by the surface water diversion bund. The findings of the regional Lake Miranda Catchment for the 1:100 and 1:1,000 year ARI events are outlined on Figure 6-4. These findings are consistent with those of the Yeelirrie Playa Catchment, discussed hereafter.

6.4.1.2 *Yeelirrie Playa Catchment*

A summary of the predictive findings from the hydraulic flood model simulations for the Yeelirrie Playa Catchment is provided in Table 6-2. Included in the summary are predicted maximum flood water depths and depth changes compared to the baseline models for local reaches of the valley floor watercourses upstream and downstream of the surface water diversion bund and also within the Yeelirrie Playa.

Table 6-2 Simulated Flood Water Depths and Differences from Baseline

Event ARI	Simulated Maximum Flood Water Depths (m)			Simulated Maximum Differences from Baseline (m)		
	Upstream Reaches	Downstream Reaches	Yeelirrie Playa	Upstream Reaches	Downstream Reaches	Yeelirrie Playa
Stage 2 – Year 8-22 Yeelirrie Playa Catchment Model						
1	0.1	<0.1	0.5	0.1	-0.1 to 0.1	-0.1 to 0.1
5	0.5	0.25 – 0.5	0.25 – 0.5	0.25	-0.1 to 0.1	-0.1 to 0.1
20	0.5 – 0.75	0.50 – 0.75	0.50 – 0.75	0.5	-0.1 to 0.1	-0.1 to 0.1
100	1.5 – 2.0	1.0 – 1.5	1.0 – 1.5	1.25	0.25 – 0.5	0.25 – 0.5
1,000	4.5 – 5.0	1.5 – 2.0	2.0 – 2.5	2.5	-0.1 to 0.1	-1.0 to -0.1

Figures 6-5 through 6-7 show the predicted flood water depths and extents for the Stage 2 - generated by 1-, 5-, 20-, 100- and 1,000-year ARI events. Also shown are the simulated changes from baseline simulated flood water depths as a result of the proposed Project.

The predictive findings illustrate, particularly for events less frequent than a 20-year ARI, the attenuation of flood water upstream of the surface water diversion bund. For events that might occur at a regular frequency during the operational stages of the Project, the predicted changes to the regional surface water environment, hydrology and drainage characteristics are limited and probably less than the vertical resolution of the model.

For flood events up to and including the 5-year ARI, the predicted differences from baseline range up to 0.25 m on upstream and downstream reaches and the Yeelirrie Playa. Given the high level of variability and irregularity of the flow regime, these predicted differences are probably insignificant and not measureable.

For the 20-year ARI event and other lower frequency more extreme events simulated, the predicted change as expressed in the differences from baseline become evident. During and in the short-term after such events, the following changes to the surface water environment are expected:

- Ponding of surface water runoff upstream (north-east) of the proposed bunded mine site as shown by the increase of the simulated maximum water level at this location.
- The upstream ponding causes an attenuation of the surface water flows downstream of the mine site. As a result the model predicts a relatively small decrease in maximum flood water levels immediately downstream of the mine site. The model results show that this slight decrease in maximum water levels diminishes further along the downstream of the proposed mine site and is not measurable.

The catchment setting is intrinsically dry, with periodic occurrence of temporary, short-term stream flow events and consequently, the potential changes may be reflected in terms of changes in the ARI of the individual events that produce a runoff response. For instance:

- On upstream reaches, the 20-year ARI maximum flood water depths of 0.5 to 0.75 m during the proposed Project operation would probably reflect the occurrence in a baseline setting (in the absence of the proposed Project) of say a 50-year ARI event.
- On the downstream reaches, the differences from baseline tend to be negligible for events of frequency greater than a 20-year ARI. The flow distributions appear to change slightly due to alterations of the upstream watercourses, but typical flood depths are similar to baseline.
- The baseline surface water flow conditions in the Yeelirrie Playa catchment valley are highly variable. The relatively small change in these flow conditions predicted to occur during the less frequent and more severe events are therefore not significant.

6.4.2 Flow Velocities

The simulated attenuation of surface water flows upstream of the proposed mine site due to the construction of the surface water diversion bund causes a slight reduction in the simulated flow rates along the downstream reaches of the valley-floor watercourses.

The simulated maximum flow velocities from the Yeelirrie Playa Catchment hydraulic flood model simulations are summarised in Table 6-3. Included in the summary are predicted maximum flood water velocity and velocity changes compared to the baseline models for local reaches of the valley floor watercourses upstream and downstream of the surface water diversion bund and also within the Yeelirrie Playa.

Figures 6-8 through 6-10 show the predicted maximum flood velocities generated by 1-, 5-, 20, 100- and 1,000-year ARI events. The figures also show difference maps of the simulated changes between baseline flow velocities and the simulated flow velocities during Stage 2 of the proposed Project development.

Table 6-3 Predicted Flow Velocities and Differences from Baseline

Event ARI	Simulated Maximum Flood Water Velocity (m/s)			Simulated Maximum Difference from Baseline (m/s)		
	Upstream Reaches	Downstream Reaches	Yeelirrie Playa	Upstream Reaches	Downstream Reaches	Yeelirrie Playa
Stage 2 – Year 8-22 Yeelirrie Playa Catchment Model						
1	0.01 – 0.05	0.01 – 0.05	0.01 – 0.05	none	none	none
5	0.05 – 0.1	0.05 – 0.1	0.05 – 0.1	none	none	none
20	0.05 – 0.1	0.05 – 0.1	0.1 – 0.5	-0.1 to 0.1	-0.1 to 0.1	-0.1 to 0.1
100	0.1 – 0.5	0.1 – 0.5	0.5 – 1.0	0.3 – 0.4	-0.2 to -0.1	-0.2 to -0.1
1,000	0.5 – 1.0	0.5 – 1.0	0.5 – 1.0	>0.5	-0.5 to -0.2	-0.3 to -0.1

The simulated stream flow velocities along the valley floor are comparatively low (less than 1 m/s), and variable, as a result of the wide and flat valley floor with intermittent attenuation in local depressions, clay pans and playas.

The predictive findings indicate only subtle changes in the predicted stream flow velocities for events of greater frequency than a 20-year ARI. For events that might occur at a regular frequency during the proposed Project operational life, the predicted changes of altered hydrology on the stream flow velocities are limited and probably less than the vertical resolution of the model. Commonly, the predicted differences are linked in part to changes in the flow paths because of the altered hydrology. In the worst case, the predicted increases in velocity occur on upstream reaches, but are limited to about 0.5 m/s.

The simulated differences in stream flow velocity are not considered significant.

6.4.3 Changes to Stream Flow Hydroperiods

The altered hydrology is predicted to change the surface water availability on watercourse reaches upstream and downstream of the surface water diversion bund. In particular, the attenuation of flood waters on upstream reaches of the surface water diversion bund may increase the hydroperiods for stream flow. This aspect has been investigated using the Yeelirrie Playa Catchment hydraulic flood model.

Six sites (locations A to F as shown on Figure 6-11) were selected as points of interest (due to the potential presence of ecological receptors) for assessment:

- Three sites (A, B and C) in different water courses immediately upstream of the Proposed Development, and
- Three sites downstream of the Proposed Development in the main water course of the Yeelirrie Playa. Site D is immediately downstream of the Proposed Development, site E about halfway between the Proposed Development and Yeelirrie Playa and site F is the most downstream site at Yeelirrie Playa.

The Yeelirrie Playa hydraulic model was used to simulate flood depths at these locations. The applied modelling incorporated the Stage 1 and Stage 2 surface water diversion bund for both 20- and 100-year ARI events and takes into account the evaporation losses of 7 mm per day over the simulated period. The hydroperiod simulations have been run for a period of 15 days (360 hrs). The results of the predictive modelling have been compared to the results from the baseline simulations. The comparative findings are summarised in Table 6-4 and on Figures 6-12 through 6-17.

Table 6-4 Simulated Changes in Hydroperiod at Selected Locations

Location	20-year ARI				100-year ARI			
	Change in Hydroperiod (hours)		Change in Depth (m)		Change in Hydroperiod (hours)		Change in Depth (m)	
	Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2
A	none	>200	none	-0.2	>200	>200	0.3 – 0.7	0.3 – 0.9
B	none	>150	none	none	>500	>500	0.7 – 1.3	0.7 – 1.6
C	none	>300	none	0.3	>500	>500	1.0 – 1.6	1.0 -1.8
D	none	none	none	none	-4	3	-0.4	-0.3
E	none	none	none	none	-10	-4	-0.9	-0.6
F	none	none	none	none	NA	none	NA	-0.3

The comparison of the simulated hydrographs for the baseline and Stage 1 and 2 of the Proposed Development at these locations show the following:

- At sites A, B and C, upstream of the surface water diversion bund, the simulated hydroperiods for Stage 1 of the Proposed Development show no significant change from baseline. For Stage 2 of the Proposed Development, with the largest footprint, the simulated hydroperiods have extended by more than 200 hours in a 20 year event and more than 500 hrs during a 100 year event. This indicates that the surface water diversion bund causes backing up of flood waters upstream of the bund, which causes attenuation of flows.
- At sites D, E and F, downstream of the Proposed Development, the simulated hydroperiods for Stage 1 of the Proposed Development show no significant change from baseline. For stage 2 of the Proposed Development the simulated changes in hydroperiods are comparatively minor and probably insignificant.
- Several of the simulated hydrographs show that the tail of the hydrograph has not returned to zero flow within the simulation period. This indicates that the model needs to simulate a longer hydro period to completely drain. However, hydraulic models of this scale and resolution are generally much more suited to simulating the rising limb of the hydrograph than the falling limb. As water levels recede local ponding of water is likely to distort the true drainage period of the model

Cognisant of the regional scale and large cell size of the hydraulic model, the above results should be considered as indicative and not to be interpreted as absolute.

6.4.4 *Changes to Erosion and Sedimentation Characteristics*

The predicted change from baseline conditions to erosion and sedimentation characteristics of the project area and in particular the valley floor and downstream playas is best described by the change in predicted stream flow streamflow velocities along the valley floor upstream and downstream of the proposed Project. As a guide stream flow velocities less than 2 m/s are considered to be non-erosive and, when carrying suspended sediment, would cause sediments to drop out of suspension and cause sedimentation. Conversely, flow velocities greater than 2 m/s are considered erosive and therefore have the potential to pick-up and transport suspended sediments downstream.

The assessment of change to the erosion and sedimentation characteristics of the study area is therefore based on the predictive simulations of the stream flow velocities along the valley floor as discussed above in Section 6.4.2.

Based on the predicted changes in stream flow velocities along the valley floor the following observations and conclusions are made:

- During the more frequent flow event (up to 20 year ARI) the catchment runoff drains to the valley floor with predominantly local ponding in valley depressions. This indicates that there is likely to be local catchment erosion in the local gullies and streams draining into the valley with local sedimentation from these streams in the valley as flow velocities drop. There is little stream flow along the valley floor, which means for these events there is no to little sediment transportation along the valley floor and therefore there is no change in the erosion and sedimentation characteristics as a result of the development of the proposed Project.
- During the less frequent and more extreme events the modelling predicts that there is stream flow along the valley floor and therefore a potential for change in the erosion and sedimentation characteristics as a result of the proposed Project.
- The predicted ponding of surface water flows upstream of the proposed Project caused by the construction of the flood bunds around the mine site, is expected to be a location where during the less frequent and more extreme streamflow events some localised sediment deposition may occur. However, the flow velocities in the valley upstream of the site, even for the more extreme events, are less than 0.5 m/s which indicates there is minimal transport of sediment along the valley floor and therefore sediment deposition upstream of the proposed mine site is considered to be insignificant.
- The deposition of sediments upstream of the proposed Project site means that these sediments no longer are transported further downstream and therefore reduce the natural sedimentation under baseline conditions. However, the limited sediment deposition upstream of the proposed Project means that the overall change to the downstream sediment loads is considered to be very limited.
- The model predictions for the more extreme events indicate that the streamflow velocities along the southern flood protection bund could reach values up to 2 m/s and therefore potentially cause limited localised erosion along this stretch. The eroded sediments in suspension are expected to drop out downstream of the mine site in areas where the stream flow starts to pond or once stream flows are reduced after the event. This could be in the valley floor depressions and playas downstream of the proposed Project site.

To minimize the local change in erosion and sedimentation characteristics some management and mitigation measures are proposed as described in Section 9.

7 CHANGE ASSESSMENT AFTER MINE CLOSURE

7.1 Closure Concepts

Mine closure-related change to the surface water environment modelled conceptually incorporated the following:

- Backfill of the pit area and build-up of the proposed disturbance area of the minesite to a 1:100 year ARI flood level. The area above this level would be shaped to be free draining.
- The northern watercourse would be reinstated by means of a channel along the northern side of the mine backfill area, with a capacity to convey the 1:100 year ARI flood flow without overtopping the site.
- Small areas on the northern upstream side of the surface water diversion bund are filled to ensure hydraulic smoothness.

The conceptual proposed landform after closure is shown on Figures 7-1 and 7-2.

A comparison of the baseline and proposed after-closure landforms, with cross sections, are shown on Figure 7-1. The figure also shows that the backfilled pit area, which is expected to be up to 2-3 m higher than the baseline conditions. It also shows the northern drainage channel being reinstated northeast of the mine site area. The after-closure cross sections are shown on Figures 7-3 through 7-6.

It should be noted that as a result of a combination of the natural topography and the elevations of the after-closure landform, the initial modelling runs showed overtopping of the after-closure landform at this location, even during relatively low ARI events. Therefore, a diversion channel was incorporated into the modelling to allow water to flow around the closed landform, versus over it, during a (hypothetical) extreme event. This channel is shown on Figure 7-5, Cross Section F-F', and Figure 7-6, Cross Sections G-G' and H-H', at about station 1000.

The difference in elevation between the baseline and the proposed conceptual after-closure landforms is shown in Figure 7-3. The conceptual post closure landform shown in Figure 7-3 has been used for all after-closure model simulations.

7.2 Simulated Change to Flood Characteristics

The after-closure simulations aim to assess the change in flood characteristics from baseline caused by the conceptual after-closure landform. The simulations focus on the following:

- Change in flood water depth / levels around the mine site
- Change in flow velocities.

7.2.1 Flood Water Depth and Levels

The flood characteristics of the after-closure landform have been simulated using the Yeelirrie Playa hydraulic model, modified to include the after-closure minesite landform. The simulated maximum water depths and difference from the simulated baseline maximum water depths for the 1:1 and 1:5 year ARI rainfall events are shown in Figure 7-7. The simulations show that:

- For the 1:1 year ARI event there is a small and localised increase in flood water depths around the after-closure minesite and along a 5 km stretch some 10 km downstream from the minesite. Neither is significant.
- For the 1:5 year ARI event there is a small and localised increase in flood water depths around the after-closure minesite.
- The after-closure backfilled pit area would not be subject of inundation for either event.

The simulated maximum water depths and difference from the baseline maximum water depth for the 1:20 and 1:100 year ARI rainfall events are shown in Figure 7-8. The simulations show that:

- For the 1:20 year ARI event there is no significant change from baseline.
- For the 1:100 year ARI event the localised increase in flood water depths around the after-closure minesite appears a little more significant, especially in the watercourse north of the after-closure minesite. However, a significant part of the water depth rise is due to the flow constriction of the flow through the northern water course channel.
- The after-closure backfilled pit area would not be subject of inundation for either event.

The simulated maximum water depths and difference from the baseline maximum water depth for the 1:1000 year ARI and PMP rainfall events are shown in Figures 7-9. The simulation shows that:

- For the 1:1,000 year ARI event the localised increase in flood water depths around the after-closure minesite appears more significant in both the north and south watercourses around the after-closure minesite. However, a significant part of the water depth rise is due to the constriction of the flow through the northern water course channel. This relatively small change to the surface water environment is limited to the immediate vicinity of the after-closure landform. Changes upstream and downstream of the after-closure landform are both small and rare and therefore insignificant
- For the 1:1,000 year ARI event the after-closure backfilled pit area would be subject to inundation for the duration of the event and surface water would potentially infiltrate the closed landform.
- For the PMP event the localised increase in flood water depths around the after-closure minesite appears more significant immediately upstream of the after-closure minesite. A significant part of the water depth rise is due to the constriction of the flow through the site. A predicted flood level change of less than 0.5 m for this ultra-extreme event in a limited area upstream of the minesite is not significant and under such circumstances not measurable. Changes upstream and downstream of the after-closure landform are both small and rare and therefore insignificant
- For the PMP event the after-closure backfilled pit area would be subject to significant inundation for the duration of the event and surface water would potentially infiltrate the closed landform.

7.2.2 Flow Velocity

The simulated maximum flow velocities and difference from the baseline maximum flow velocities for the 1:1 and 1:5 year ARI rainfall events are shown in Figure 7-10. The simulations show that for the 1:1 and 1:5 year ARI event there are small increases in flood water flow velocities. These are not considered significant. The identified changes are well within the resolution of the model at this scale.

The simulated maximum flow velocities and difference from from the baseline maximum flow velocities for the 1:20 and 1:100 year ARI rainfall events are shown in Figures 7-11. The simulations show that:

- For the 1:20 year ARI event there would be small, insignificant changes from baseline.
- For the 1:100 year ARI event there would be small and localised decreases in flood water flow velocities around the post-closure minesite. This would give rise to a marginal increase in sediment deposition, seepage of surface water into the groundwater and the slower flow will give rise to increased evaporation losses. The increase in potential losses from the stream flow would marginally reduce the flood flow volumes downstream of the after-closure minesite.

The simulated maximum flow velocities and difference from the baseline maximum flow velocities for the 1:1,000 year ARI and PMP rainfall events are shown in Figure 7-12. The simulations show that:

- For the 1:1,000 year ARI event the changes in flow velocities across the valley water course both upstream and downstream of the after-closure minesite are less significant than for the 1:100 year ARI event. The significantly larger volume of water for the 1:1,000 year event is simulated to be less affected and obstructed by the after-closure minesite land form.
- The simulated flow velocities in the water course channels around the after-closure landform are less than 1.0 m/s. This indicates that even in this extreme event there would not be any significant erosion in the water courses along the after-landform.
- The simulated flow velocities of the flood waters over the closed landform are less than 0.5 m/s. this indicates that although the final landform is inundated with flood water flowing over the top, the flow velocities are not high enough to cause any significant erosion of the landform cover..
- For the PMP event the changes in flow velocities across the valley water course both upstream and downstream of the after-closure minesite are less significant than for the 1:100 year ARI event. The significantly larger volume of water for the 1:1,000 year event is simulated to be less affected and obstructed by the after-closure minesite land form.
- The simulated flow velocities in the water course channels around the after-closure landform are less than 1.0 m/s. This indicates that even in this extreme event there would not be any significant erosion in the water courses along the after-landform.
- The simulated flow velocities of the flood waters over the closed landform are less than 0.5 m/s. this indicates that although the final landform is inundated with flood water flowing over the top, the flow velocities are not high enough to cause any significant erosion of the landform cover.

7.3 Change to Erosion and Sedimentation Characteristics

For the smaller events, up to and including the 1:20 year ARI, the changes in flow velocities are insignificant from baseline. As a result the change to baseline erosion and sedimentation characteristics are insignificant.

- For extreme events up to 1:100 year ARI. (Figure 7-11) there would be small and localised decreases in flood water flow velocities around the post-closure minesite of less than 0.2 m/s. This relatively small change in velocities is not increasing the erosion characteristics as the flow velocities are still well below the 2/ms threshold for erosion.
- For the very extreme events to 1:1,000 year ARI (Figure 7-12) the changes in flow velocities across the valley water course both upstream and downstream of the after-closure minesite are less significant than for the 1:100 year ARI event. Therefore no changes to the erosion and sediment characteristics are expected.
- For ultra-extreme PMP event (Figure 7-12) the changes in flow velocities across the valley water course both upstream and downstream of the after-closure minesite are less significant than for the 1:100 year ARI event. Therefore no changes to the erosion and sediment characteristics are expected.

8 INTERACTION OF SURFACE WATER AND GROUNDWATER

As described in Section 5.7, the water table environment (levels and quality) is closely linked to the occurrence of surface water and a number of processes that variously link the two. Water table elevations are supported by the rate that surface water infiltrates to groundwater and prevailing hydraulic conditions of underlying aquifers. Similarly, the salinities of groundwater and surface water are linked to rates of exchange during wet and dry periods, the depth to the water table, and position within the catchment.

Project-related changes that may influence how surface water and groundwater interact include:

- Changes to the water table elevation (from mine dewatering) in areas containing GDEs;
- Surface water diversion and related influences on recharge from changes to the way surface water accumulates (floods) both upstream and downstream;
- Releases of storm-water from the mine site that may increase the rate that salt (and other solutes) accumulate in groundwater downstream, and
- Changes to flooding (and recharge) due to an altered landform after closure.

Under baseline conditions, an area located downstream of the mine site has been identified as being important to maintaining downstream water table depths, salinity, and supporting potential GDEs (Section 5.7.3). Observed event-based groundwater recharge rises along the valley floor increase the potential flow rate through normally unsaturated highly transmissive calcrete and hardpan-type aquifers. Event-based recharge and flows are controlled by a range of criteria:

- Local surface water accumulation (flood depth and duration) characteristics,
- Infiltration rate and hydraulic properties of formations above the water table,
- The hydraulic conductivity and specific yield of formations across the water table,
- Depth to water and connectivity vertically and laterally (downstream) with transmissive formations,
- Presence of playa with clayey alluvium spanning the unsaturated interval above the water table.

Changes to these baseline conditions may influence groundwater availability to GDEs and downstream groundwater quality. These changes may be initiated by surface water diversions, runoff containment structures (flood-protection bund and stormwater ponds), and drawdown from groundwater abstraction.

8.1 Changes to Surface Water and Groundwater Availability to GDEs

During the operational phase, groundwater will be abstracted from the water table to dewater the mine, and from other aquifers to provide the project with a make-up water supply. At its peak (Year 19), drawdown from this abstraction will extend beneath the floor of the Yeelirrie Valley and to a lesser degree towards the flanks. The relationships between the predicted drawdown, potential GDEs, and depth to the baseline water table are shown on Figures 8-1 (Year 19) and Figure 8-2 (time plots at selected downstream sites).

Within the cone of depression that develops at the water table from abstraction, groundwater will be drawn laterally towards the mine and both laterally and vertically towards the deeper water supply bores. During this time, recharge from rainfall and flooding will continue to occur except where surface disturbance (open pits, waste dumps, flood bunds etc.) reduces infiltration capacity, diverts runoff, or prevents flooding. Given that the baseline water table is at least 2m to 3m below the surface across the proposed mine site, drawdown from groundwater abstraction is expected to have no impact on the rate of recharge or its contribution to GDEs. The recharge potential to soil moisture that will also be supporting this vegetation will continue unless disturbed. Drawdown-related impacts on GDEs have been assessed elsewhere in URS (2011) and Cameco (2015).

8.2 The Influence of Altered Hydrology on Recharge during the Operational Phase

During the operational phase, surface water will be diverted around the mine using a series of flood bunds and diversion drains (Figure 6-3). The correlation of the maximum predicted drawdown from groundwater abstraction with flood depth changes due to altered hydrology is shown on Figure 8-3.

Following smaller, more frequent rainfall events, recharge is primarily a function of the rainfall total rather than flood depth. As the ARI increases, recharge is interpreted to be increasingly driven by flood depth and duration (Section 5.7.2). The implication of this relationship is that:

- For low ARI events, i.e. up to about a 1:5 Year ARI event, flood depths and groundwater recharge outside of the disturbance footprint is expected to remain largely unaltered (Figure 6-10). Within the disturbance footprint, recharge may be less in areas occupied by pit, TSFs, haul roads, ROM pads, stockpiles and storage dams. This reduced recharge is not expected to manifest in a significant change at the water table as it will be within the drawdown cone from mine dewatering.
- For larger events, i.e. greater than a 1:20 Year ARI event, hydrological changes to flood depth and duration from the project have the potential to increasingly affect the recharge rate. Based on the available groundwater monitoring data and predicted flood depths, recharge is expected to increase slightly along the south-western side of the proposed mine site since this is where surface water will be diverted, i.e. greater flood depths (Figure 6-11). Increases are also expected in areas immediately upstream of the site, where surface water will tend to pond due to the presence of the diversion bunds around the proposed mine. The effect of these increases on the water table will be negated by drawdown from mine dewatering while that footprint remains. Downstream however, the recharge flux related to flooding is not expected to change for events of up to about a 1:20 Year ARI.
- For an extreme event (1:100 Year ARI or larger), maximum flood depths in downstream areas may decrease slightly, resulting in a slightly smaller recharge flux (water table rise) at the water table. In upstream areas the reverse is expected. Based on the recharge trend with ARI shown in Appendix H.6.4, the actual downstream recharge flux would be significantly larger than the observed 1:10 year ARI rise at YYHC0037C (17% annual rainfall, or 0.42m). The net change associated with the peak flood depth difference is likely to be indistinguishable from natural variability. It is also worth noting that this effect would also be occurring within an area where the water table may have been lowered by between 1m and 2m (Figure 8-3). Recharge within the cone of depression would tend to increase the availability of low salinity soil moisture to local vegetation in place of brackish

or saline groundwater. For context, the likelihood of an event of this magnitude actually occurring at that time is minimal (<1%). Irrespective of this, the component of incidental rainfall-related recharge on soil moisture should remain unaffected both upstream and downstream.

8.3 Changes to Groundwater Quality due to Stormwater Releases

In the baseline environment, the ambient groundwater quality is a result of rates of recharge from rainfall, flooding, and discharge from evapotranspiration, groundwater throughflow, and solute accumulations from the sources and dispersals at the sinks. During the initial baseline study (URS, 2011), quality sampling determined that groundwater in the Yeelirrie Catchment was within stock water criteria with respect to salinity. The baseline quality did however, exceed the guidelines with respect to concentrations of sodium, sulphate, dissolved metals, bromine, iron and uranium, radon (222), and radiological activities of radium (226 and 228) and lead (210). Concentrations and activities of these components were spatially complex suggesting that project-related changes would also be difficult to reconcile.

Based on the proposed conceptual flood bund design, the mine site would be isolated from external flood water.. It is possible however, that during the operational phase, Cameco may need to release stormwater in order to maintain a safe operating environment and internal storage capacities for large follow-up events. Should this be required, the released water would need to be of sufficient quality to avoid making surface water available to animals that was not at least of stock water quality, and to minimise the accumulation of solutes in groundwater along the valley floor.

For context, a composite map has been prepared using mapped solute concentration distributions downstream of the proposed mine site (Figure 8-4). It is apparent from this map that groundwater downstream of the proposed mine site within the 1:100 year ARI floodplain is not of stock water quality. Stormwater releases from the site would not, therefore, significantly reduce the availability of stock-quality groundwater. Releases during an event larger than 1:100 year ARI would be significantly diluted by local flood waters, and recharge-related loadings to groundwater outside this floodplain would be minimal. Receding floodwaters carrying any mine-sourced loadings would be concentrated along the valley floor within the non-stock quality area.

8.4 Changes to Surface Water due to Impacts on Groundwater Levels and Quality

As described in Section 5.7 and URS (2011), surface water flow rates within the Yeelirrie Catchment are independent of groundwater based on their being no known surface water baseflows, and that groundwater is consistently well below the surface. The only known occurrence of groundwater actively discharging to the surface is at Palm Springs that is remote from the influence of the proposed Yeelirrie Project.

At its shallowest, the observed water table has remained at least 3.7m below the surface close to the mine site (YYHC0037C) and 1.0m at the Yeelirrie Playa (YYHC0059B) – including the largest observed recharge rises following a 1:10 year ARI event in March 2015. It is conceivable however, that the water table may rise close to the surface following an extreme rainfall event (of 1:100 ARI or more), and based on the available data, it may take a number of years to recover to its normal depth.

Under baseline conditions, the quality of surface water in the Yeelirrie Catchment is only likely to be influenced by groundwater at locations where it discharges either directly (by springs), or indirectly (by capillary-rise, or evaporative pumping).

Although present within the broader catchment, Palm Springs is not expected to be influenced by the proposed project. While ephemeral springs related to the presence of shallow hardpan layers in the catchment have been postulated based on soil and vegetation mapping, such surface discharges have not yet been observed. While their influence may be related to locally perched water supporting shallow-rooted vegetation species on the flanks of the catchment, their occurrence or longevity are not expected to be influenced by the water table elevation, or by drawdown from groundwater abstraction.

Groundwater influences on surface water quality are therefore expected to be restricted to playa where salt accumulates from evaporating saline groundwater during dry periods. The playa in the mine area is expected to be consumed by mining operations. Such natural accumulations of salt and downstream discharges (during events greater than 1:20 ARI) will therefore, no longer occur. Salt loadings and the salinity of downstream groundwater may decrease as a result. The same may true for solutes that would normally accumulate (by precipitation and geochemical binding), would then disperse into the groundwater downstream. Significant solute re-concentration would not occur until such groundwater reached the Yeelirrie Playa, which represents the next site for large-scaled evaporative pumping (and solute accumulation).

One other project-specific influence that groundwater may have on surface water is associated with reinjection activities with the first four years of the mine life. Reinjection into calcrete formations at the western end of the proposed mine site is proposed to manage excess water produced by mine dewatering while the demand from ore processing is relatively small. To influence surface water, the reinjected groundwater needs to discharge to the surface, or rise sufficiently, to allow evaporative pumping to accumulate solutes. To understand the risks, the depth to the water table while reinjection takes place has been estimated by the groundwater flow model (Cameco, 2015). The depth to water at distances of 50m and 250m to the northwest of the proposed site have been calculated (Figure 8-5). Given the calcrete is highly transmissive, the mounding gradient around the site is relatively flat. The closest the mound approaches the surface during the four-year period is 4.3m at 50m distance. Surface water is, therefore, not expected to be influenced by the proposed groundwater discharges.

8.5 Alterations to recharge due to an altered landform after closure

During the closure and post-closure phases, surface water will be diverted around the final (mounded) landform (Figure 7-1). Relationships between residual drawdown and altered hydrology after closure are shown on Figure 8-6. Changes to groundwater recharge are predicted to be minor and linked to the elevation of the final land surface and infiltration rate of the TSF covers within the proposed mine site. Residual groundwater level and quality changes are not expected to influence surface water levels or quality as they should remain well-below the surface. Changes to surface water flood depths alongside the mine site are also expected to be minor and virtually indistinguishable from baseline until an extreme event (greater than 1:100 year ARI).

Downstream of the proposed mine site, changes to surface water flooding are predicted to diminish as flows along the northern and southern sides of the final landform merge. In this downstream area, groundwater recharge and resultant levels and quality are expected to remain similar to baseline conditions As described above, the absence of the playa within the proposed mine site may reduce the salt loadings reporting to this area. Since the final landform is expected to comprise benign waste rock and top soil, the actual quality of groundwater in this area will probably be influenced more by regional throughflow and mixing with seepage from the TSF cells within the (then) former mine site. Such changes are assessed in URS (2011) and Cameco (2015). As with the mine site area groundwater is not expected to discharge to or affect surface water quality since the depth to the water table should remain largely unchanged.

9 SURFACE WATER MANAGEMENT AND CHANGE MITIGATION

9.1 Proposed Mitigation and Management Measures Outside the Flood Protection Bund

9.1.1 Development stages

The proposed Project would be developed in two stages chiefly to minimize the development foot print and disturbance area, as well as minimize the volume of surface water runoff inside the bund that requires management. The conceptual layout of the two proposed mine site stages is given in Figures 6-2 and 6-3.

9.1.2 Flood Protection Bunds

9.1.2.1 Development Stage 1

The proposed Project operational footprint foe the first stage of development is shown on Figure 6-2. Surface water runoff from the northern slope will be drained in two directions at the metallurgical plant. Surface water shed to the west would be diverted into the southern diversion channel. Surface water shed to the east would be drained by the eastern stormwater drain.

The eastern surface water diversion bund wraps around the metallurgical plant and stockpiles located north of the proposed pit. Surface water shed to the east would flow down the eastern slope to the eastern limits of the proposed mine site draining into a sedimentation basin before draining into the natural (undisturbed) valley floor watercourses immediately downstream of the proposed mine site.

The western diversion bund protects the proposed mine site from surface water inflow from the Northern drainage channel. The conceptual design of the bund provides for flood protection up to a 1:1,000 year ARI event.

The southern diversion bund protects the proposed mine site from surface water inflow from the southern drainage channel and direct surface water runoff from the area immediately south of the mine site and any stream flow from upstream of the mine. The conceptual design of the bund provides for flood protection up to a 1:1,000 year ARI event. .

9.1.2.2 Development Stage 2

This subsequent stage of the proposed development is an extension of the project operational footprint for operational years 8 to 22 shown in Figure 6-3.

The western diversion bund is moved further upstream (westward) protects the proposed mine site from surface water inflow from the southern drainage channel and direct surface water runoff from the area immediately south of the mine site. to provide a drainage connection from the Northern water course to the Southern water course. Following significant rainfall events, this channel will convey streamflow from the Northern drainage line around the mine site into the Southern drainage line.

9.1.3 Diversion channels

9.1.3.1 *Development Stage 1*

On the valley floor, the watercourses within the playa catchment unit are naturally partitioned by outcrops of calcrete that are several metres above the playa topography (Figure 6-1).

Western Diversion Channel

The conceptual design provides for a diversion channel located to the west of development stage 1 of the Proposed Project.(Figure 6-2). To reduce excessive ponding following large rainfall events which would have mine safety risks and to mitigate the environmental impact from changes to the flow characteristics (upstream ponding; downstream flow reduction), the proposed Project will include the provision of a shallow streamflow diversion channel. Following significant rainfall events, this channel will convey streamflow from the Northern drainage line around the mine site into the Southern drainage line. This is expected to reduce the potential for ponding water upstream (west) of the mine site and reduce the associated risks to mining operations.

The diversion channel traverses the calcrete to divert stream flow from the northern watercourses to the southern watercourse. The western diversion channels would be excavated through the outcrops of calcrete, with elevations up to 501 m AHD, thus linking the northern and southern watercourses. The conceptual design would provide for a 100 m wide channel with an invert level of 497.0 m AHD.

Southern Diversion Channel

The conceptual design provides for a diversion channel located to the south of development stage 1 of the Proposed Project. (Figure 6-2). To reduce excessive ponding upstream of the mine and drain runoff along the southern perimeter of the mine following large rainfall events, the proposed Project will include the provision of a shallow streamflow diversion channel. Following significant rainfall events, this channel will convey streamflow from the Southern drainage line (combined with the stream flow from the Northern drainage line) around the mine site, through a sediment basin immediately downstream of the proposed mine site before draining into the natural (undisturbed) valley floor watercourse immediately downstream of the proposed mine site. This is expected to reduce the potential for ponding water upstream (south-west) of the mine site and reduce the associated risks to mining operations.

The conceptually proposed channel bed levels of the diversion channels have been selected to be close to the valley floor level, in order to optimize their drainage capacity and, therefore, cause minimum ponding of water upstream of the surface water diversion bund and minimize change to the surface water environment both upstream and downstream of the proposed Project.

9.1.3.2 *Development Stage 2*

Western Diversion Channel

The conceptual design provides for a diversion channel located to the west of development stage 2 of the Proposed Project. (Figure 6-3). To reduce excessive ponding following large rainfall events which would have mine safety risks and to mitigate the environmental impact from changes to the flow characteristics (upstream ponding; downstream flow reduction), the proposed Project will include the provision of a shallow streamflow diversion channel.

The diversion channel traverses the calcrete to divert stream flow from the northern watercourses to the southern watercourse. The western diversion channels would be excavated through the outcrops of calcrete, with elevations up to 501 m AHD, thus linking the northern and southern watercourses. The conceptual design would provide for a 100 m wide channel with an invert level of 496.5 m AHD, which would drain into the extended southern diversion channel.

Southern Diversion Channel

The conceptual design provides for a diversion channel located to the south of development stage 2 of the Proposed Project. (Figure 6-3). For this stage of the development the southern diversion channel would be extended further upstream (westward) along the southern surface water diversion bund to drain the combined flow from the northern water course, via the western diversion channel, and the southern water course.

9.1.4 Sedimentation Basins

To manage and mitigate the potential sediment in the diversion channels, the conceptual project description allows for the construction of sedimentation basins at the downstream (eastern) ends of the diversion channel. These basins will slow down the surface water flows in the diversion channels thereby dropping out the suspended sediments before discharging into the surface water environment downstream.

9.2 Proposed Mitigation and Management Measures Inside the Flood Protection Bund (Mine Site)

9.2.1 Simulated Altered Hydrology Inside of Surface Water Diversion Bund

The objectives of the in-bund hydrological assessment are to:

- Assess the fate of surface water runoff within the mine site area during the operational stages as outlined on Figure 6-2 and 6-3;
- Assess the locations and conceptual design capacities of the minesite stormwater ponds; and
- Evaluate the capacity of the minesite to contain in-bund surface water runoff, without the release of excess surface water to the environment outside the surface water diversion bund.

9.2.2 Stormwater Ponds

The outcomes from the predictive simulations have been applied to determine conceptual design locations and storage capacities for stormwater ponds within each of the seven sub-catchments. Conceptual design locations of the stormwater ponds have been determined based on the surface water drainage points as simulated by the in-bund hydraulic model.

Figures 6-2 through 6-3 show the estimated locations of the ponds. The surface areas are not to scale.

The total minesite areas for each of the proposed development stages are shown in Table 9-1.

Table 9-1 Estimated Areas for Minesite Stages

In-bund Mine Site	Stage 1 (ha)	Stage 2 (ha)
Disturbed	1,360	1,530
Un-disturbed	440	930
Total	1,800	2,460

The conceptual design of the stormwater pond capacities required for each of the minesite areas depends on the design rainfall event to be captured before (hypothetical) spillage of excess water occurs. The estimated stormwater pond capacities for the minesite sub-catchments to contain water associated with 1:20, 1:100 and 1:1,000 year ARI rainfall events are shown in Table 9-2. The required total surface areas have been estimated assuming an average pond depth of 3 m.

Table 9-2 Estimated Stormwater Pond Capacities for Minesite Stages

Minesite Sub-catchment	Total Stormwater Pond Capacity (m^3)		
	Design Rainfall Event		
	20(year ARI)	100 (year ARI)	1,000 (year ARI)
Stage 1	850,000 (28 ha)	1,830,000 (61 ha)	2,830,000 (94 ha)
Stage 2	1,165,000 (39 ha)	2,500,000 (83 ha)	3,870,000 (129 ha)

The above pond sizes have the capacity to contain the stormwater runoff of the minesite for the specified design event excluding the direct rainfall on the pit and TSF areas. It is therefore feasible to contain the storm water runoff from the minesite within the boundaries of the flood protection bund.

If, however, the rainfall event exceeds the design capacity of the stormwater pond, the pond would overflow and the excess water would flow to the lowest point on the minesite, which would likely be the inactive pits. The capacity of the minesite to contain this excess stormwater is assessed as follows.

The conceptual design for the stormwater pond capacity should accommodate the adequate storage capacity to store the first 25 mm of runoff as a minimum. Any capacity over that will proved a buffer for having to divert additional stormwater runoff into the inactive pits. The design of the stormwater pond capacity would have to way up the operational capacity with the cost associated with the construction of stormwater ponds.

9.2.3 *Capacity of Minesite to Contain In-bund Surface Water Runoff*

The in-bund hydrological and hydraulic assessment has been undertaken to determine the capacity of the minesite to contain the surface water runoff inside the bund without the need to discharge excess water outside the bund. The assessment has been undertaken for a range of rainfall events to evaluate a reasonable worst case scenario:

- Stage 2 of the proposed Project has the largest in-bund foot print and therefore the largest runoff for any of the events simulated.
- The stormwater ponds are assumed to have a conceptual design capacity for a 20 year ARI event and protective bunds around the pits.
- The 1:20, 1:100 and 1:1,000 year ARI rainfall events have been assessed.

The indicative results of the assessment show the following:

- For the 1:1 and 1:5 year ARI events, the minesite would experience some localised flooding, but generally the stormwater ponds would have sufficient capacity to store the runoff from the minesite.
- For the 1:20 year ARI event, the minesite would experience temporary flooding of the low lying parts of the minesite as the runoff drains towards the stormwater ponds. The active and inactive pits would contain the runoff from direct rainfall, and depending on the design criteria for the pit bunds, additional surface water runoff from the rest of the minesite would drain into the pits. The minesite would be able to store the runoff from such event without discharge outside the bund, provided the flood protection bund at the far eastern and most downstream end of the minesite is more than 1.5 m high above ground level.
- For the 1:100 year ARI events, the minesite would experience flooding of the low lying areas of the minesite. Assuming the conceptual design criteria for the stormwater infrastructure is set for a 1:20 year ARI event, the stormwater ponds would not have capacity to contain the runoff and are expected to overflow. Water levels are also expected to exceed the pit bund levels, and therefore all excess runoff inside the minesite would drain into the pits. The minesite would be able to store the runoff from such event without discharge outside the bund, provided the flood protection bund at the far eastern and most downstream end of the minesite is more than 2 m high.
- For the 1:1,000 year ARI events, the minesite would experience flooding of the low lying areas of the minesite. Assuming the conceptual design criteria for the stormwater infrastructure is set for a 1:20 year ARI event, the stormwater ponds would not have capacity to contain the runoff and are expected to overflow. Water levels are expected to exceed the pit bund levels, and therefore all excess runoff inside the minesite would drain into the pits. The minesite is able to store the runoff from such event without discharge outside the bund, provided the flood protection bund at the far eastern and most downstream end of the minesite is about 3 m high.

This assessment indicates that, providing that the far eastern section of the flood protection bund is of sufficient height and engineered to not only keep flood waters out but also to keep flood waters in, the minesite is able to contain the in-bund stormwater runoff for a 1:1,000 year ARI rainfall event.

The minesite can contain the stormwater runoff within the flood protection bund without the physical requirement to discharge excess stormwater outside the flood protection bund. This means that the minesite has the potential to be a no-discharge minesite. However, depending on the development stage of the mine, there are likely to be operational requirements to manage and discharge excess water.

9.3 Surface Water Management Plan

A conceptual surface water management plan (SWMP) is presented in Appendix H. It should be noted that a SWMP is a live document that should be updated periodically to reflect changes to the design of infrastructure, the operational policies or any other changes material to the management and monitoring of surface water in the Project area.

10 SUMMARY AND CONCLUSION

This report presents an assessment of the anticipated change to the baseline surface water environment as a result of the proposed development of the Yeelirrie Project during operation and after closure. The change has been assessed through the development of hydrological and hydraulic models used to predict changes between the baseline conditions and the proposed Project during the main stages of the project life. The results of the analyses indicate the following:

- The baseline flow paths, which are currently split into two parallel paths on both sides of the calcrete rise, would be partially blocked due to the construction of the surface water diversion bund.
- Therefore, a diversion channel would be constructed to transmit the flood event-related water from the northern watercourse, around the minesite and into a combined watercourse along the western and southern perimeters of the surface water diversion bund, which is nearly coincident with the path of the southern watercourse.
- The proposed development would, at least temporarily, alter the baseline hydrology during a (hypothetical) flood event. However, the modelling predicts that water would not flow within the catchment as a connected watercourse (versus isolated, local flows) unless a storm event in excess of a 20-year ARI would occur.
- The modelling also predicts that for the duration of the mine operation, and up to a (hypothetical) 1,000-year ARI event, the surface water diversion bund would both:
    - Prevent catchment runoff from flowing into the proposed Project area, and
    - Prevent the water that collects interior of the surface water diversion bund from discharging outside the bund into the natural environment.
- Outside the surface water diversion bund the predicted changes resulting from a (hypothetical) flood event include a temporary:
    - Increase in the water depth immediately upstream of the mine,
    - Increase in the velocity of water flowing around the mine area (through the proposed diversion channel and between the minesite and southern valley slope),
    - Decrease in the water depth immediately downstream of the mine area.
- Inside the surface water diversion bund the predicted changes include a temporary increase in water depth at the lowest points within the mine area, which would be managed through a number of stormwater ponds. During extreme cases, the water could be stored within the inactive pits.
- At the completion of operations, the mine infrastructure would be decommissioned and the site would be rehabilitated. The hydrological modelling predicts that the proposed final landform would result in after mine closure hydrological conditions that are similar to the pre-development (baseline) conditions. However, as a result of the natural topography near the south-eastern corner of the closed landform, a diversion channel will likely be needed to prevent overtopping of the final land form during an extreme storm event.
- analyses suggest that the predicted outcomes are reasonable.

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12 LIMITATIONS

12.1 Geotechnical & Hydro Geological Report

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of Cameco Australia and only those third parties who have been authorised in writing by URS to rely on the report.

It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the contract dated 24/02/2015.

The methodology adopted and sources of information used by URS are outlined in this the Report.

Where this report indicates that information has been provided to URS by third parties, URS has made no independent verification of this information unless required as part of the agreed scope of work. URS assumes no liability for any inaccuracies in or omissions to that information.

This Report was prepared between [24/02/2015] and [15/04/2015].The information in this report is considered to be accurate at the date of issue and is in accordance with conditions at the site at the dates sampled. Opinions and recommendations presented herein apply to the site existing at the time of our investigation and cannot necessarily apply to site changes of which URS is not aware and has not had the opportunity to evaluate. This document and the information contained herein should only be regarded as validly representing the site conditions at the time of the investigation unless otherwise explicitly stated in a preceding section of this report. URS disclaims responsibility for any changes that may have occurred after this time.

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

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

Where conditions encountered at the site are subsequently found to differ significantly from those anticipated in this report, URS must be notified of any such findings and be provided with an opportunity to review the recommendations of this report.

Whilst to the best of our knowledge information contained in this report is accurate at the date of issue, subsurface conditions, including groundwater levels can change in a limited time.

Therefore this document and the information contained herein should only be regarded as valid at the time of the investigation unless otherwise explicitly stated in this report.

Except as required by law, no third party may use or rely on, this Report unless otherwise agreed by URS in writing. Where such agreement is provided, URS will provide a letter of reliance to the agreed third party in the form required by URS.

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URS does not represent that this Report is suitable for use by any third party.

Except as specifically stated in this section, URS does not authorise the use of this Report by any third party.

It is the responsibility of third parties to independently make inquiries or seek advice in relation to their particular requirements and proposed use of the relevant property.

Any estimates of potential costs which have been provided are presented as estimates only as at the date of the Report. Any cost estimates that have been provided may therefore vary from actual costs at the time of expenditure.

FIGURES

Cameco URS	Project **Surface Water Study, Proposed Yeelirrie Project**	Title Proposed Yeelirrie Project Location
Drawn: RNM	Approved: BW	Date: 7/04/2015
Job No.: 42908794	File No.: 42908794-SW-001.mxd	Figure: 1-1 — Rev. A — A4

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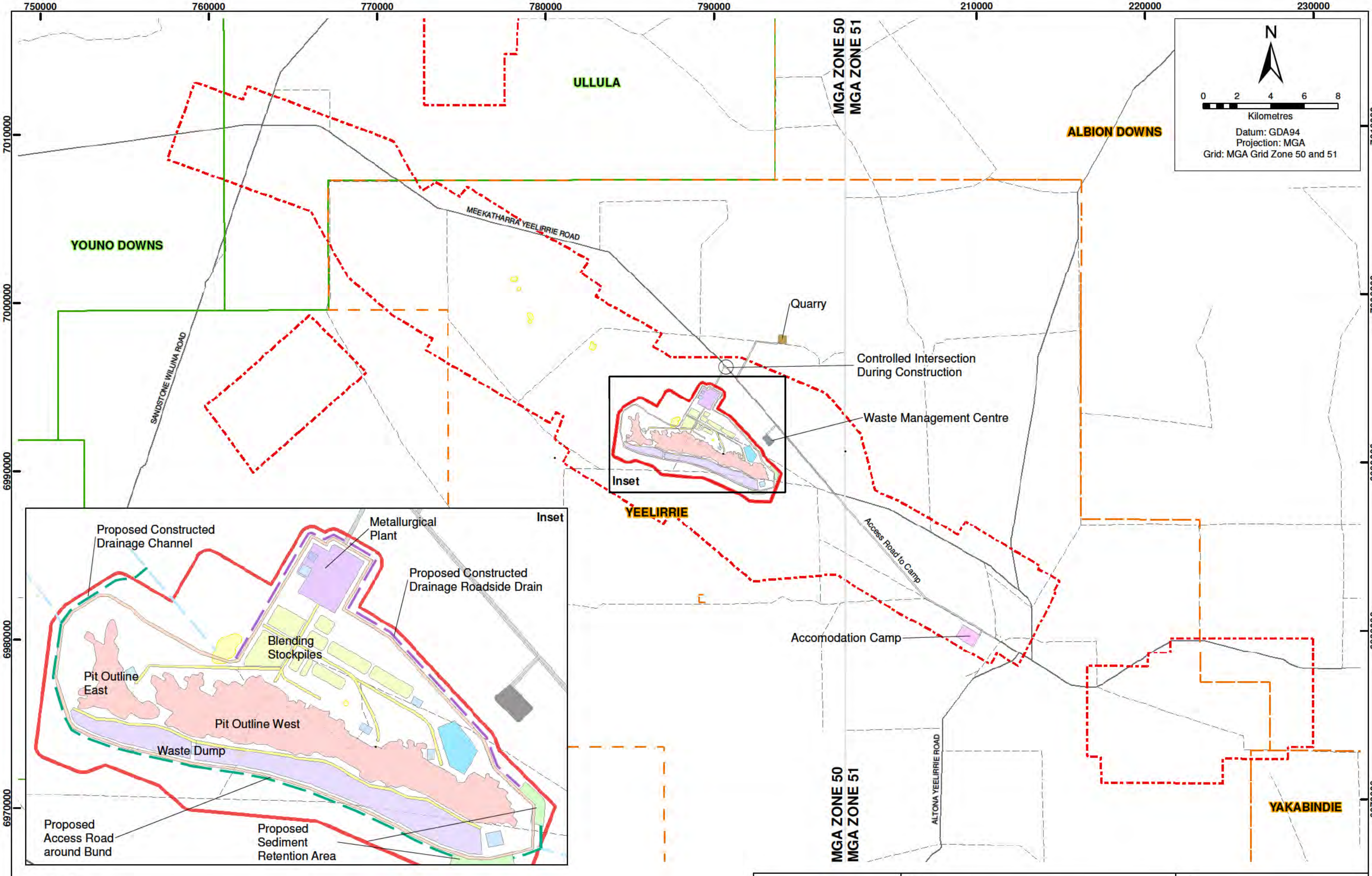

Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: Proposed Yeelirrie Project Area and Layout	
	Drawn: RNM	Approved: BW	Date: 5/06/2015	Figure: 2-1	Rev. A
	Job No.: 42908794	File No.: 42908794-SW-002.mxd			A3

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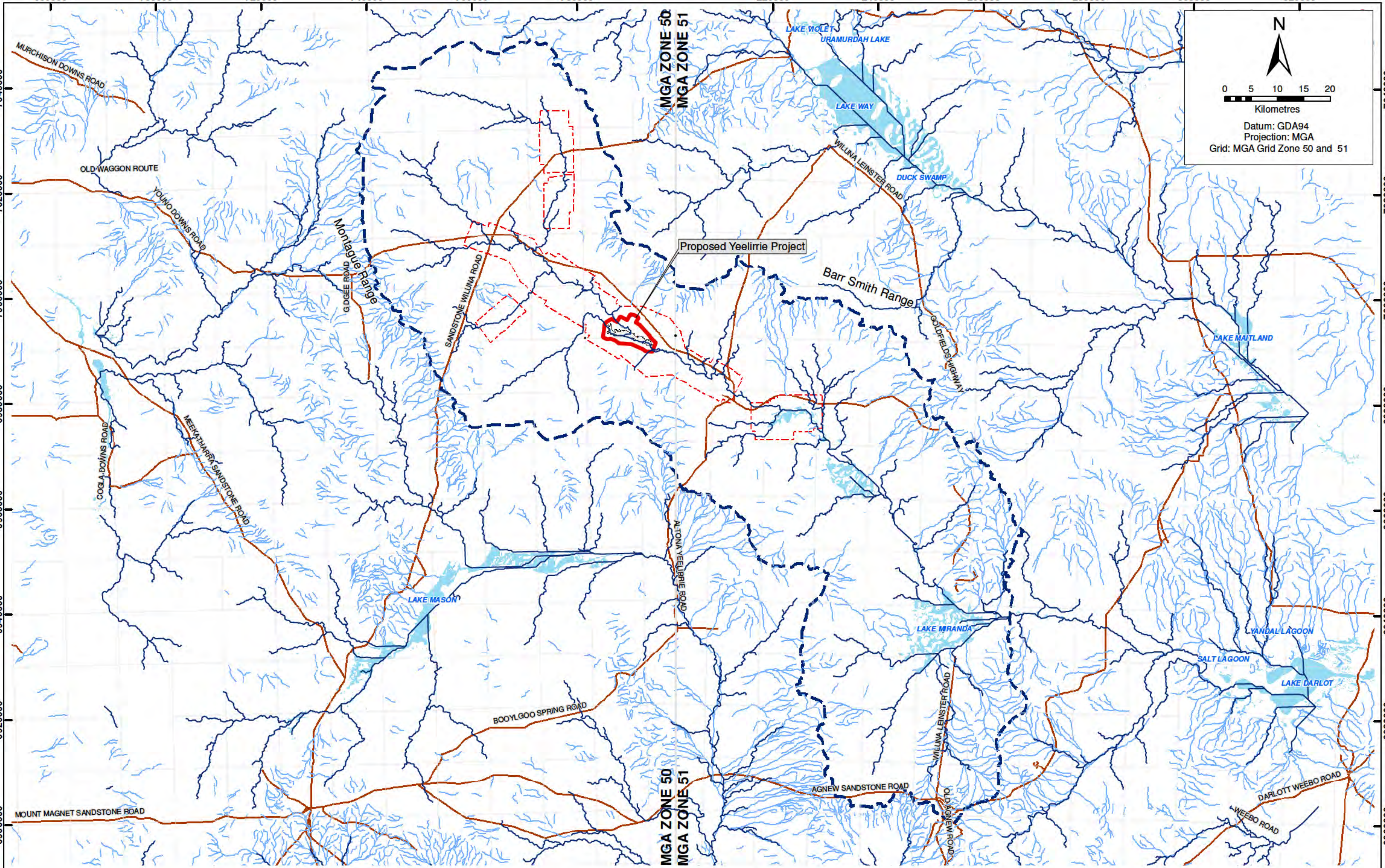

Legend

- Key Flowpaths
- Watercourses
- Roads
- Development Envelope
- Ministerial Temporary Reserve TR70/6899
- Lake Miranda Catchment
- Pit Outline

Cameco

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Project	Title
Surface Water Study, Proposed Yeelirrie Project	Proposed Yeelirrie Project Area and Layout

Drawn: RNM	Approved: BW	Date: 9/04/2015	Figure: 2-2	Rev. A
Job No.: 42908794	File No.: 42908794-SW-003.mxd			A3

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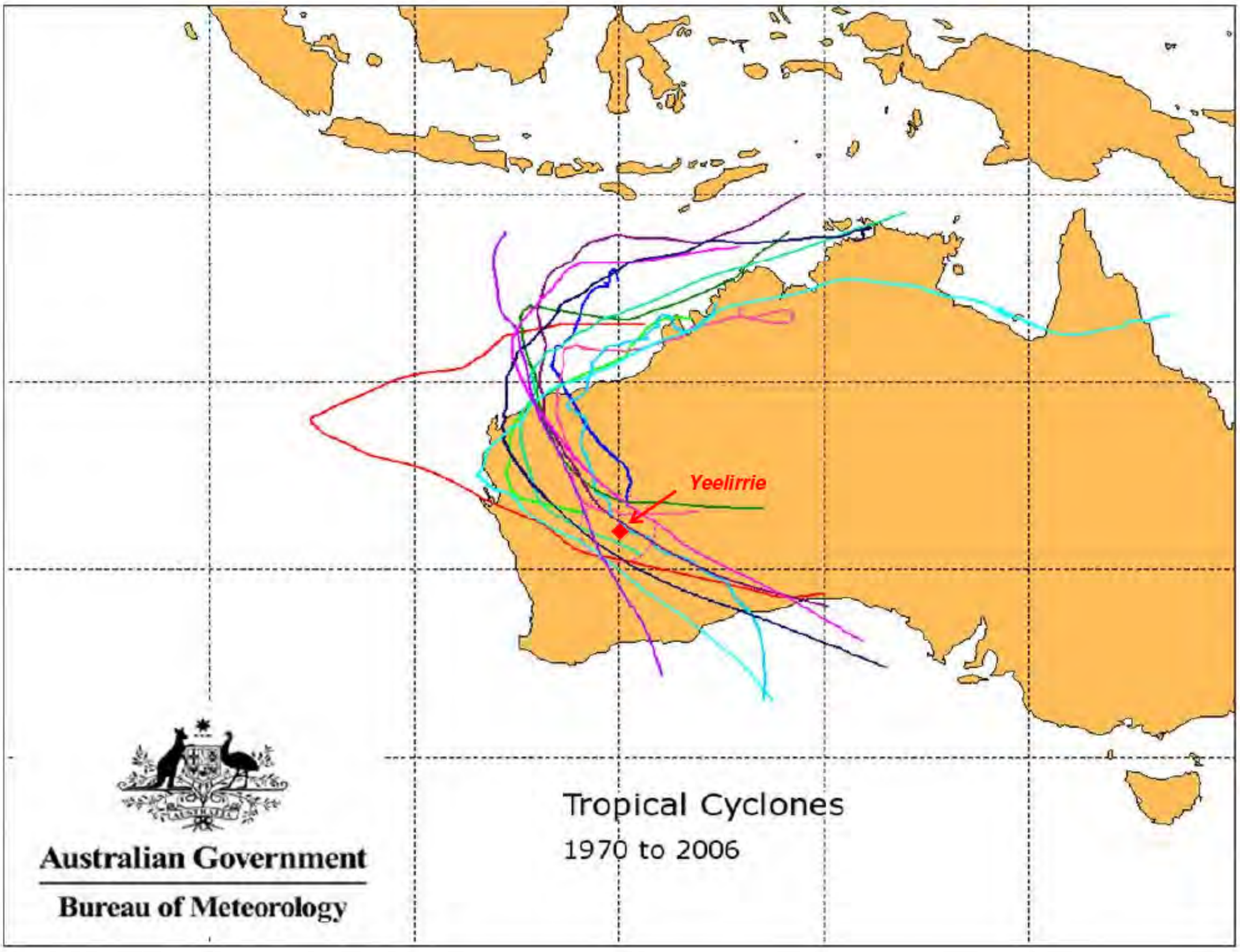

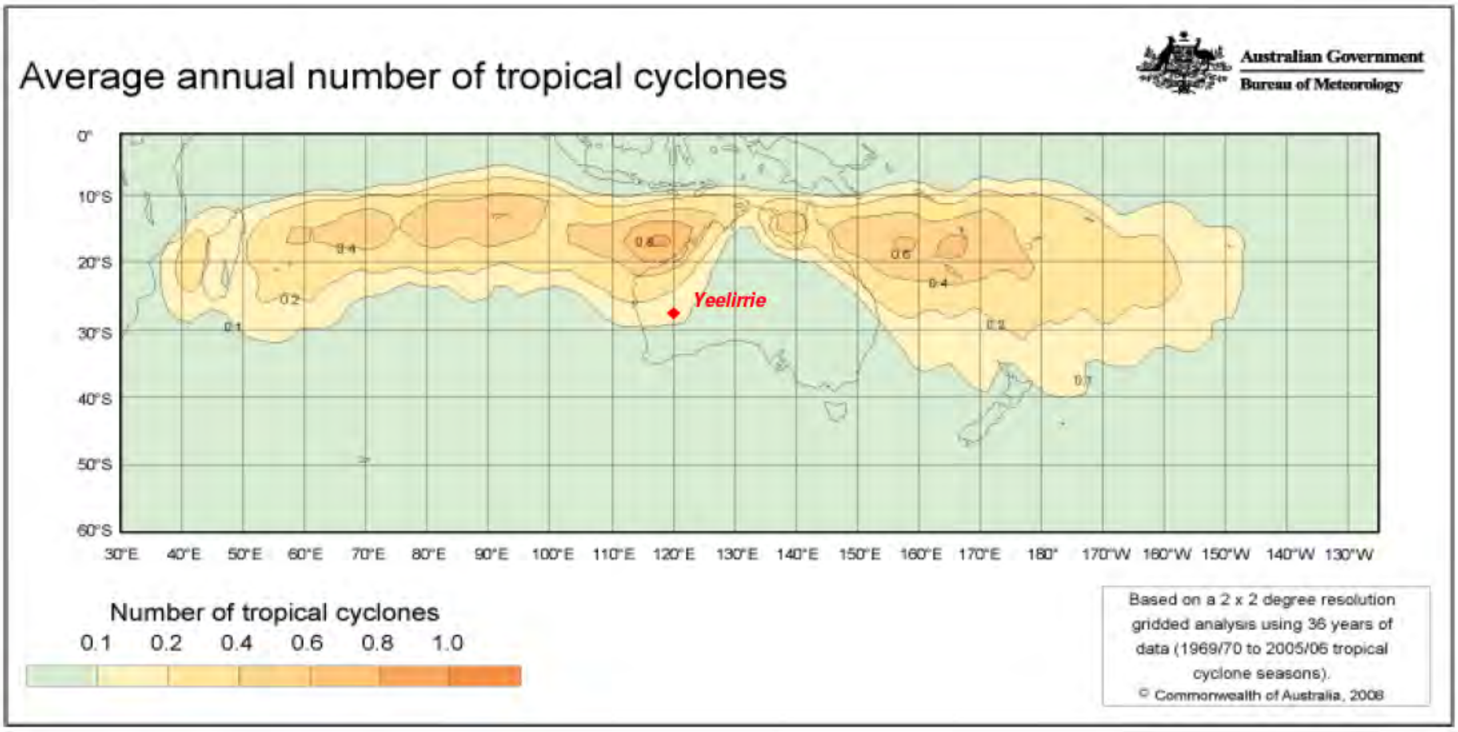

after Bureau of Meteorology, 2010

Cameco	Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: Cyclone Tracks and Frequency (1970 to 2006)	
URS	Drawn: SH/RNM	Approved: BW	Date: 1/04/2015	Figure: 3-1	Rev. A
	Job No. 42908794	File No. 42908794-SW-100.xls			A4

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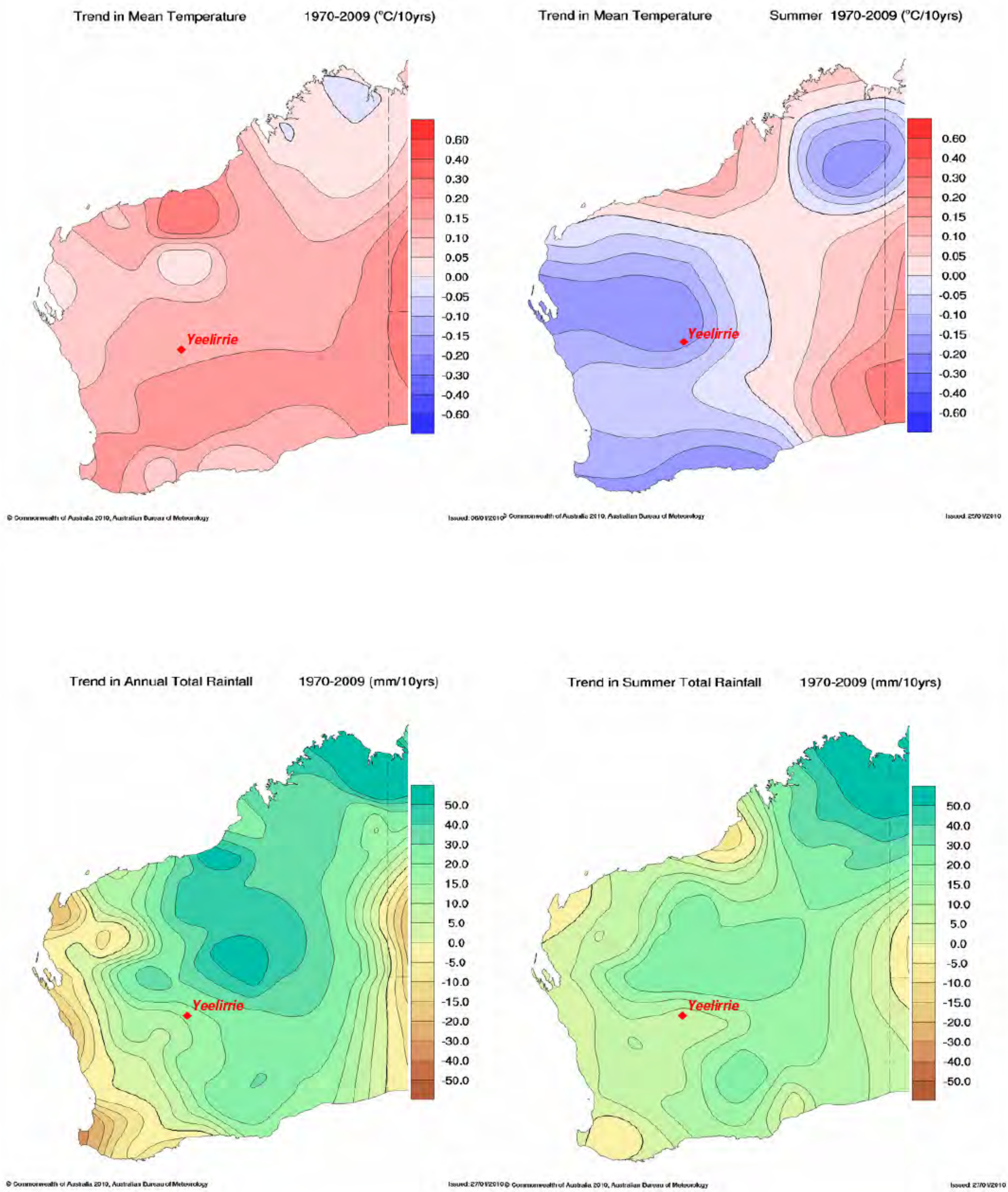

after Bureau of Meteorology, 2010

Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: Climate Change Temperature and Rainfall Trends (1970 to 2009)	
	Drawn: SH / RNM	Approved: BW	Date: 10/04/2015	Figure: 3-2	Rev. A
	Job No. 42908794	File No. 42908794-SW-102.xls			A4

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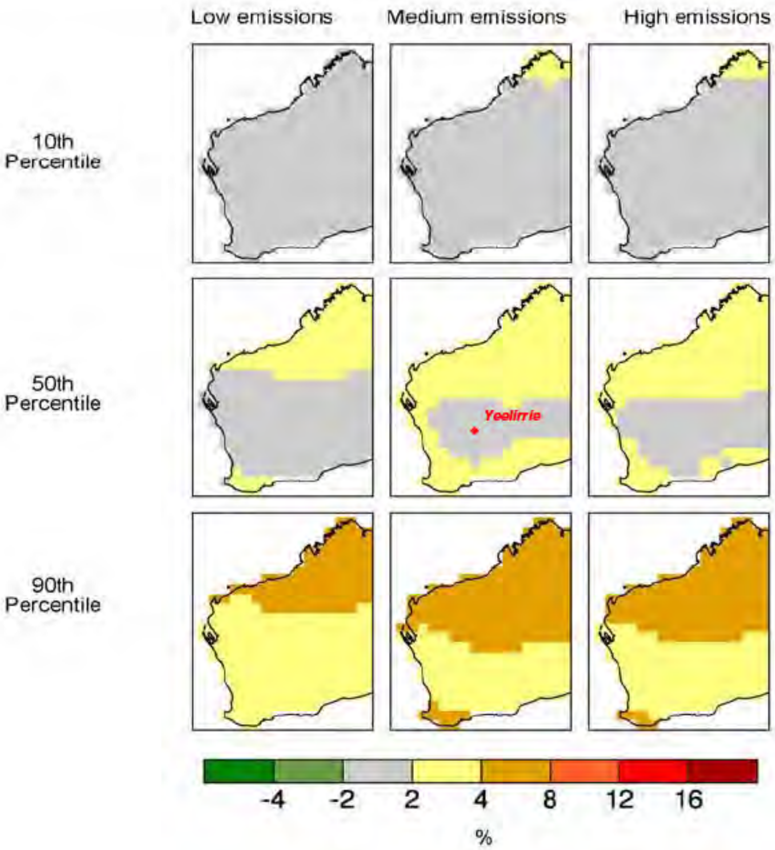
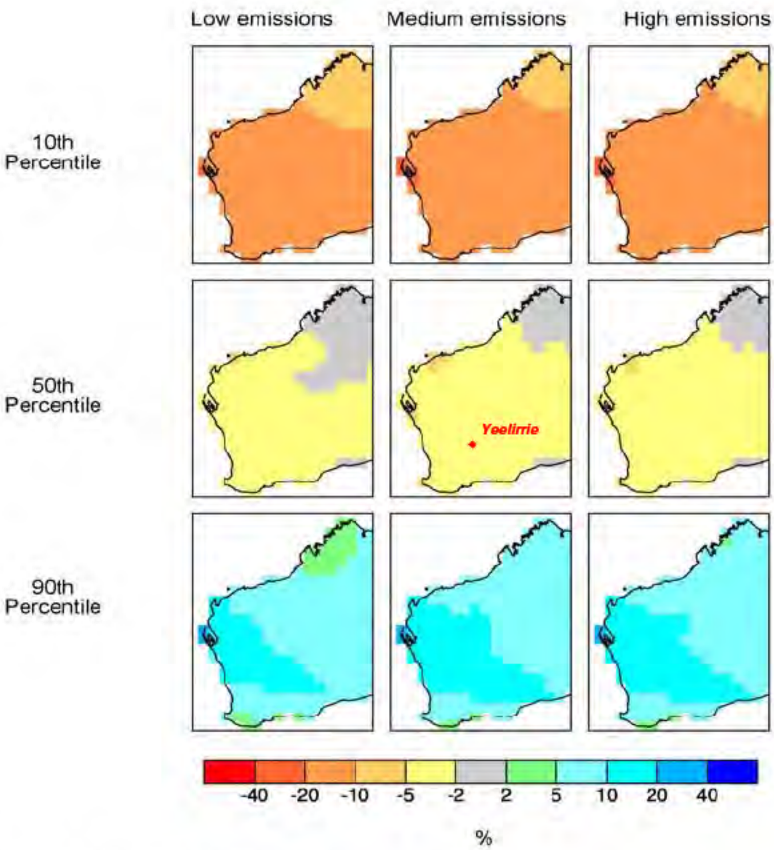


Predicted change in 2030 Annual Evapotranspiration compared to the 1980 to 1999 period



Predicted change in 2030 Summer Rainfall compared to the 1980 to 1999 period

after www.climatechangeinaustralia.gov.au

Cameco	Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: Predicted Changes to Annual Evapotranspiration and Summer Rainfall (2030)
URS	Drawn: SH/RNM	Approved: BW	Date: 10/04/2015	Figure: 3-3 — Rev. A
	Job No. 42908794	File No. 42908794-SW-103.xls		A4

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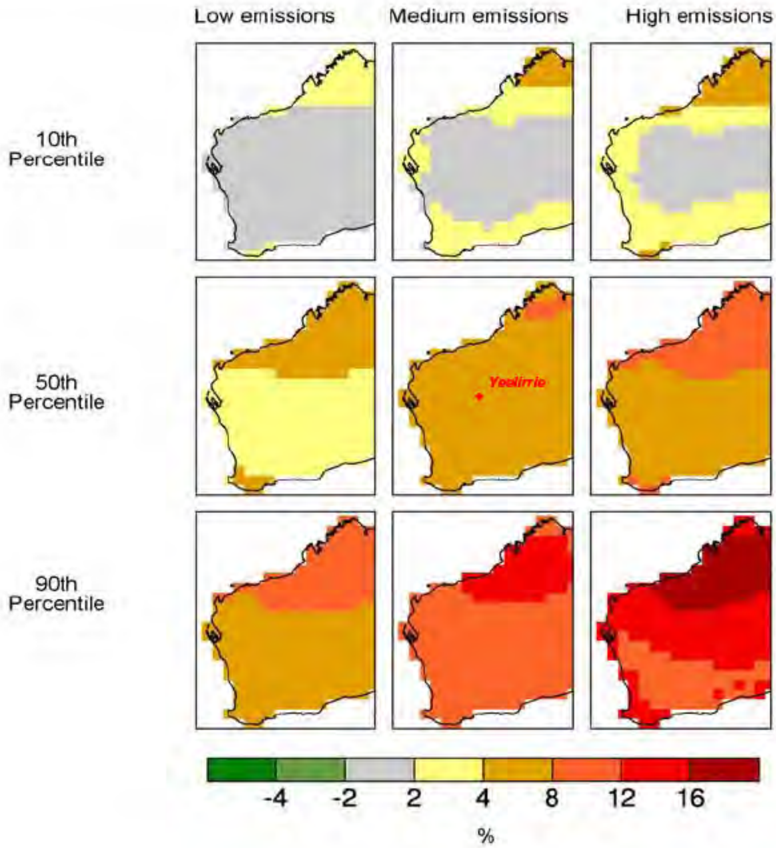
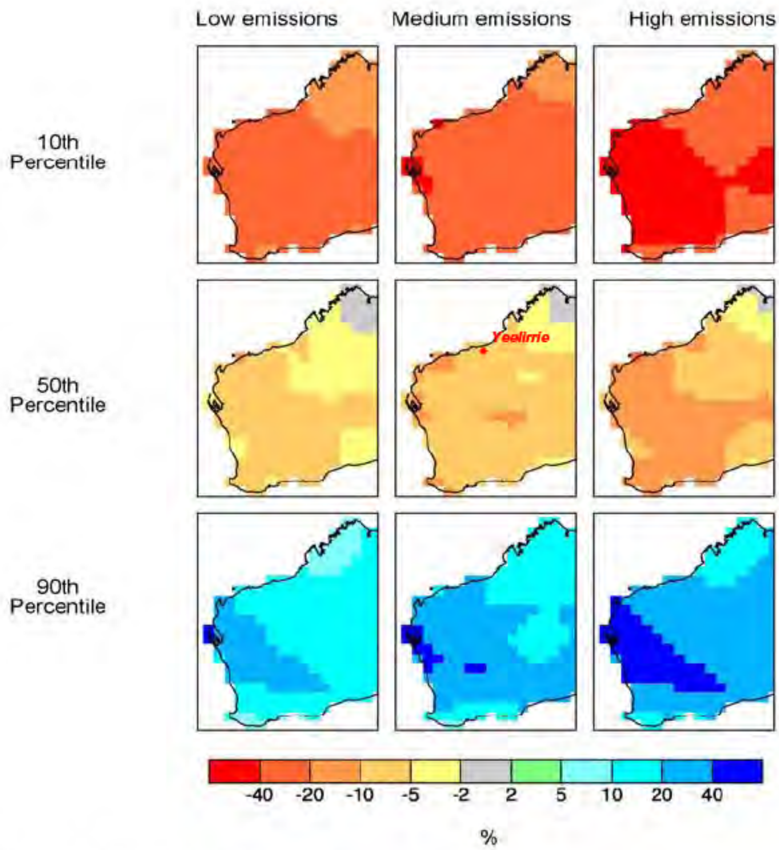


Predicted change in 2070 Annual Evapotranspiration compared to the 1980 to 1999 period



Predicted change in 2070 Summer Rainfall compared to the 1980 to 1999 period

after www.climatechangeinaustralia.gov.au

Cameco	Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: Predicted Changes to Annual Evapotranspiration and Summer Rainfall (2070)		
URS	Drawn: SH/RNM	Approved: BW	Date: 10/04/2015	Figure: 3-4		Rev. A
	Job No. 42908794	File No. 42908794-SW-104.xls				A4

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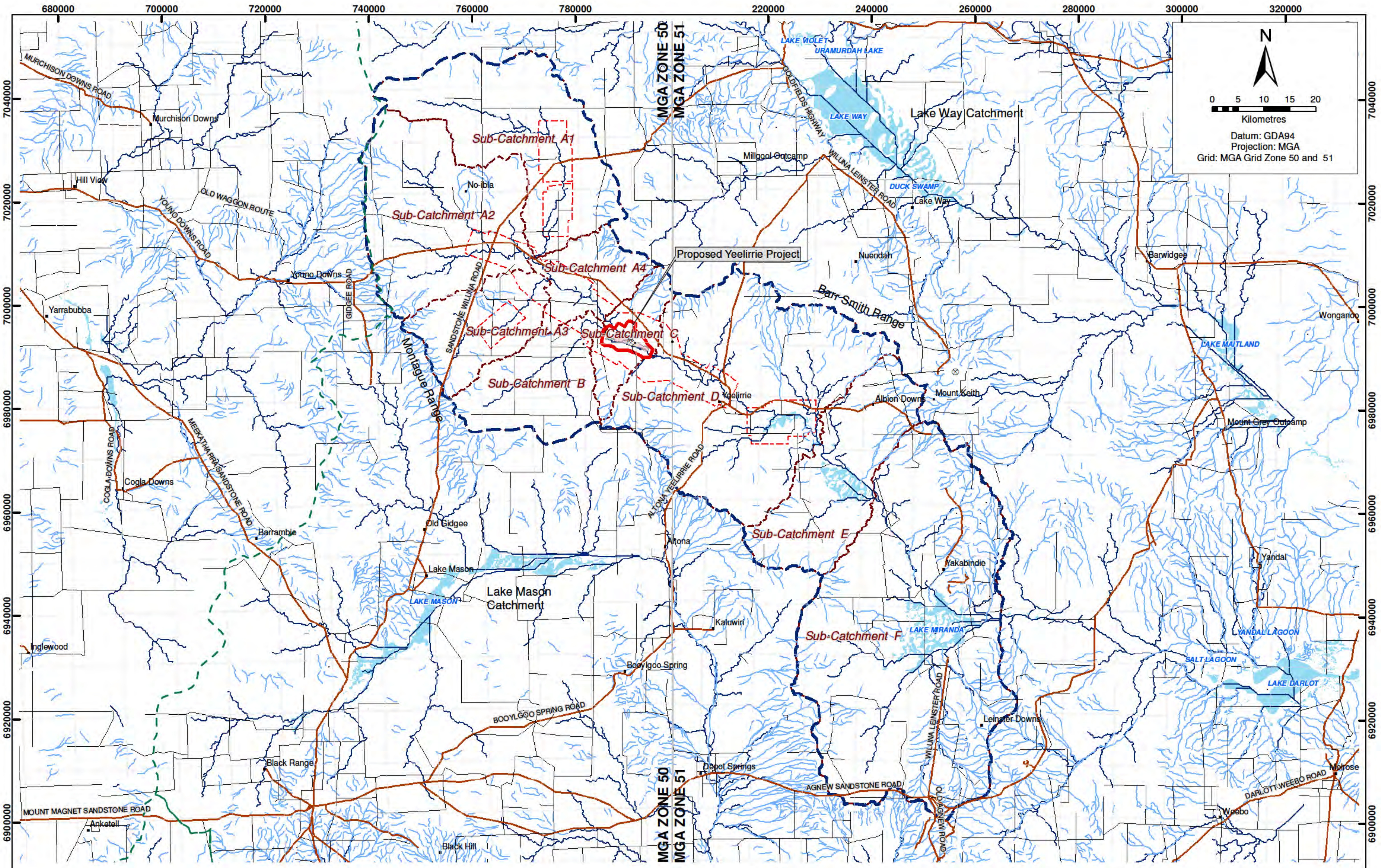

Legend

- · Locations
- ▪ Homesteads
- Roads
- Watercourses
- Ministerial Temporary Reserve TR70/6899
- Lake Miranda Sub-Catchments
- Surface Water Study Area (Yeelirrie Catchment)

Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**		Title: Topography of Lake Miranda Catchment
	Drawn: RNM	Approved: BW	Date: 7/05/2015
	Job No.: 42908794	File No.: 42908794-SW-006.mxd	Figure: 3-5 · Rev. A · A3

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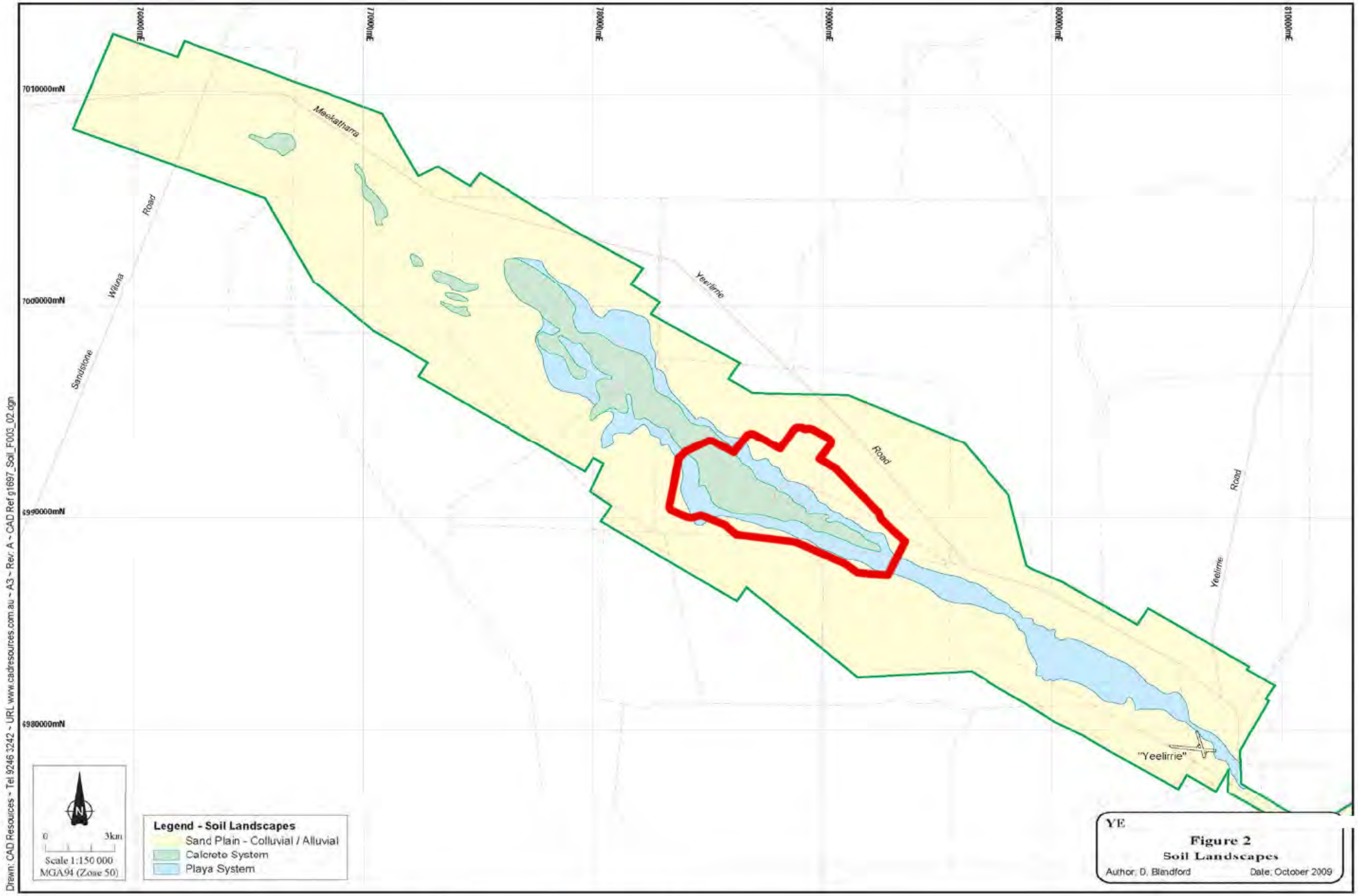

Cameco URS	Project: Surface Water Study, Proposed Yeelirrie Project			Title: Soil Landscapes	
	Drawn: RM/RNM	Approved: BW	Date: 10/04/2015	Figure: 3-6	Rev. A
	Job No. 42908794	File No. 42908794-SW-105.xls			A4

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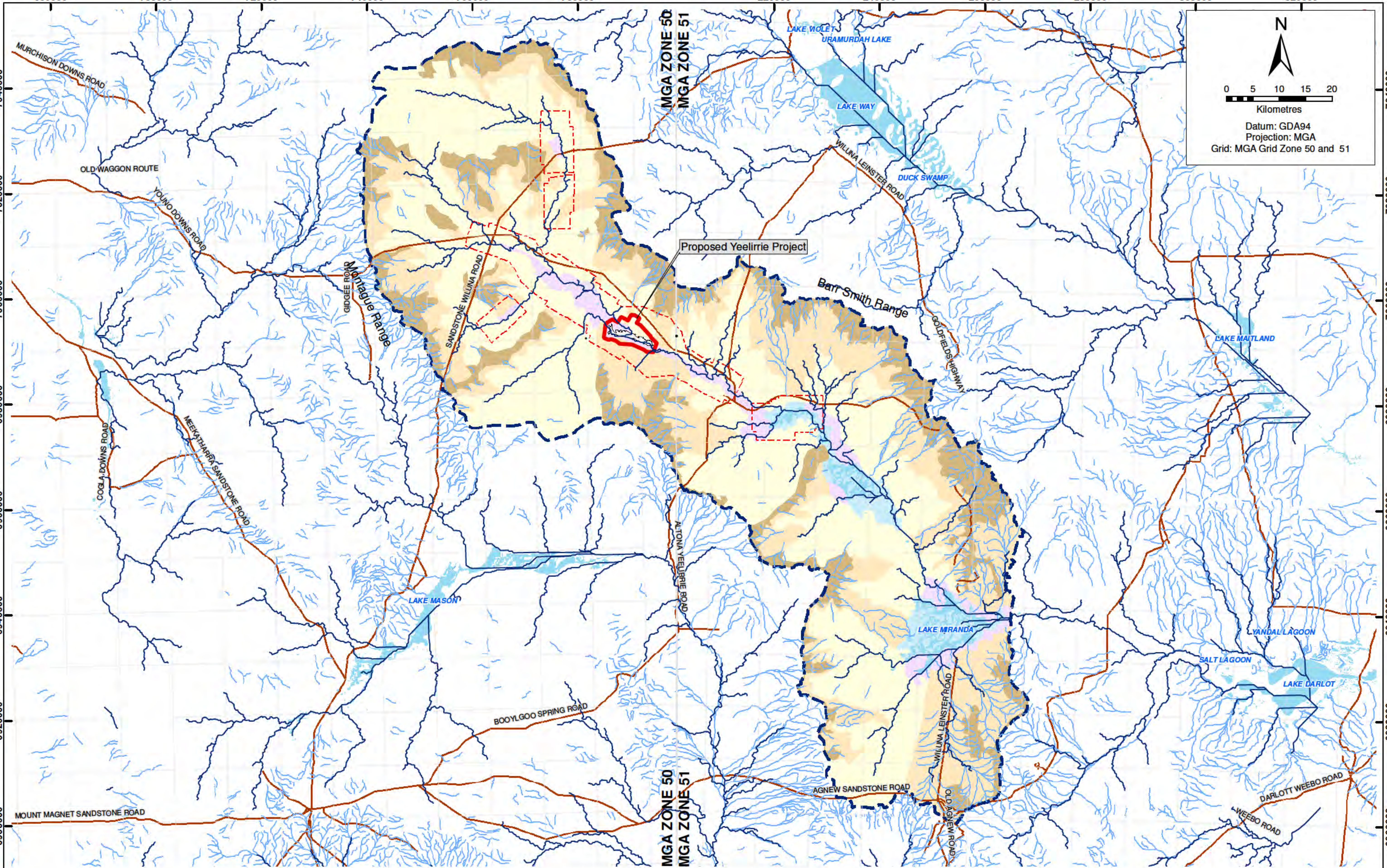

Legend

- Key Flowpaths
- Watercourses
- Roads
- Development Envelope
- Ministerial Temporary Reserve TR70/6899
- Lake Miranda Catchment
- Pit Outline

Catchment Units

- Playa
- Calcrete
- Wash Plain
- Sand Plain
- Breakaway

Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**		Title: Catchment Units
	Drawn: RNM	Approved: BW	Date: 8/04/2015
	Job No.: 42908794	File No.: 42908794-SW-007.mxd	Figure: 3-7
			Rev. A / A3

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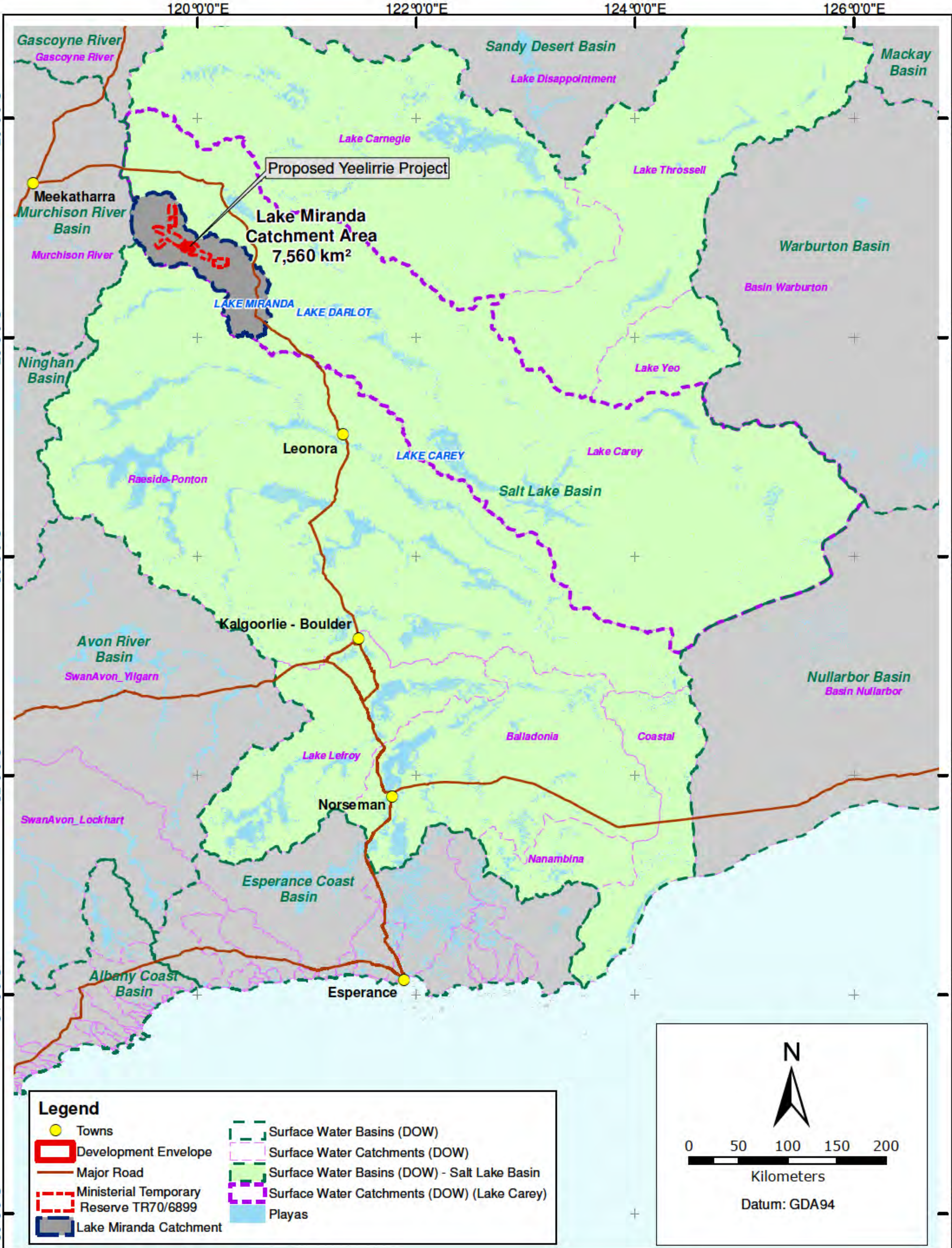

Cameco	Project: Surface Water Study, Proposed Yeelirrie Project		Title: Regional Drainage Basins	
URS	Drawn: RNM	Approved: BW	Date: 10/04/2015	Figure: 3-8	Rev. A
	Job No.: 42908794	File No.: 42908794-SW-008.mxd			A4

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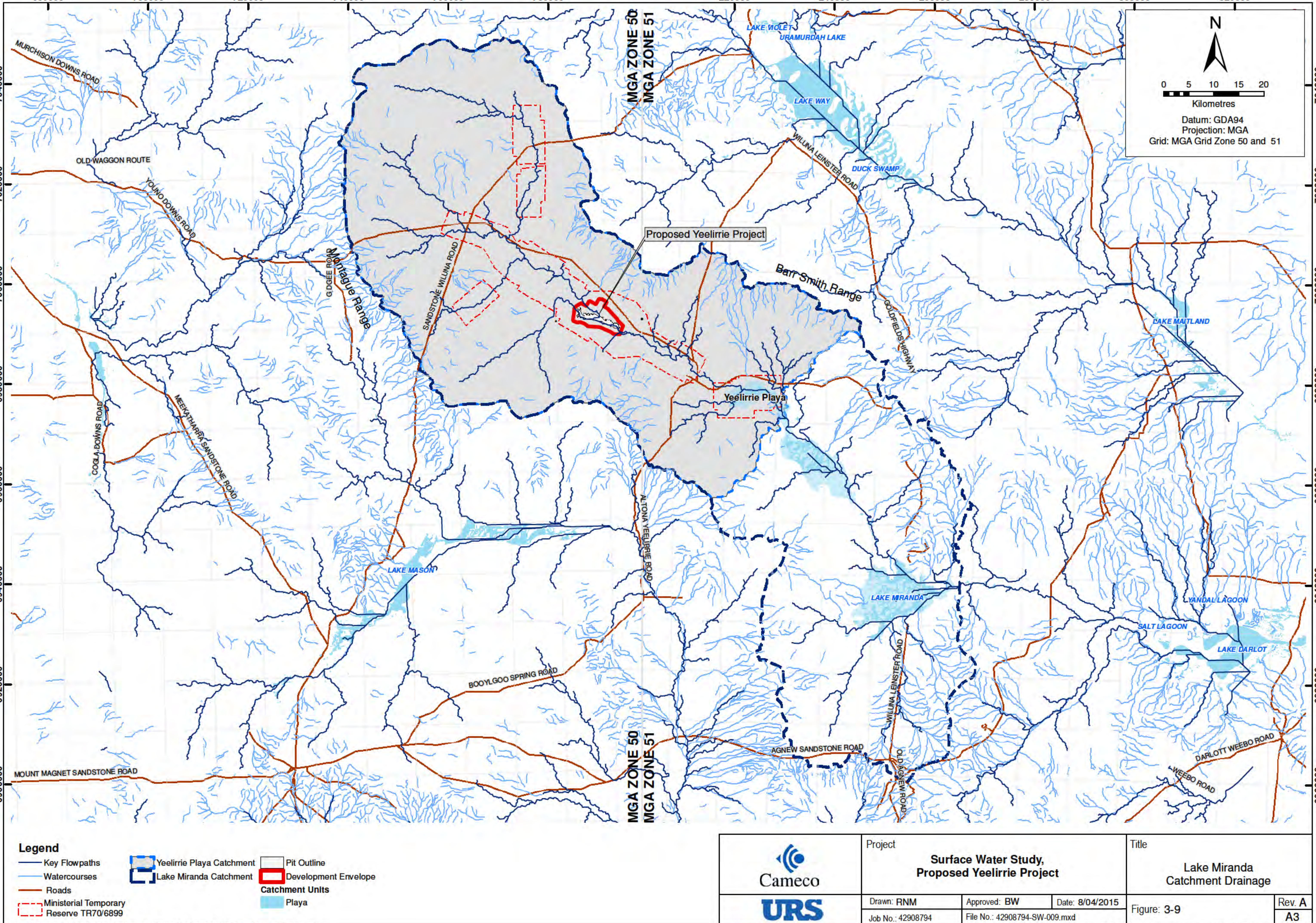

Cameco

URS

Project	Title
Surface Water Study, Proposed Yeelirrie Project	Lake Miranda Catchment Drainage

Drawn: RNM	Approved: BW	Date: 8/04/2015	Figure: 3-9	Rev. A
Job No.: 42908794	File No.: 42908794-SW-009.mxd			A3

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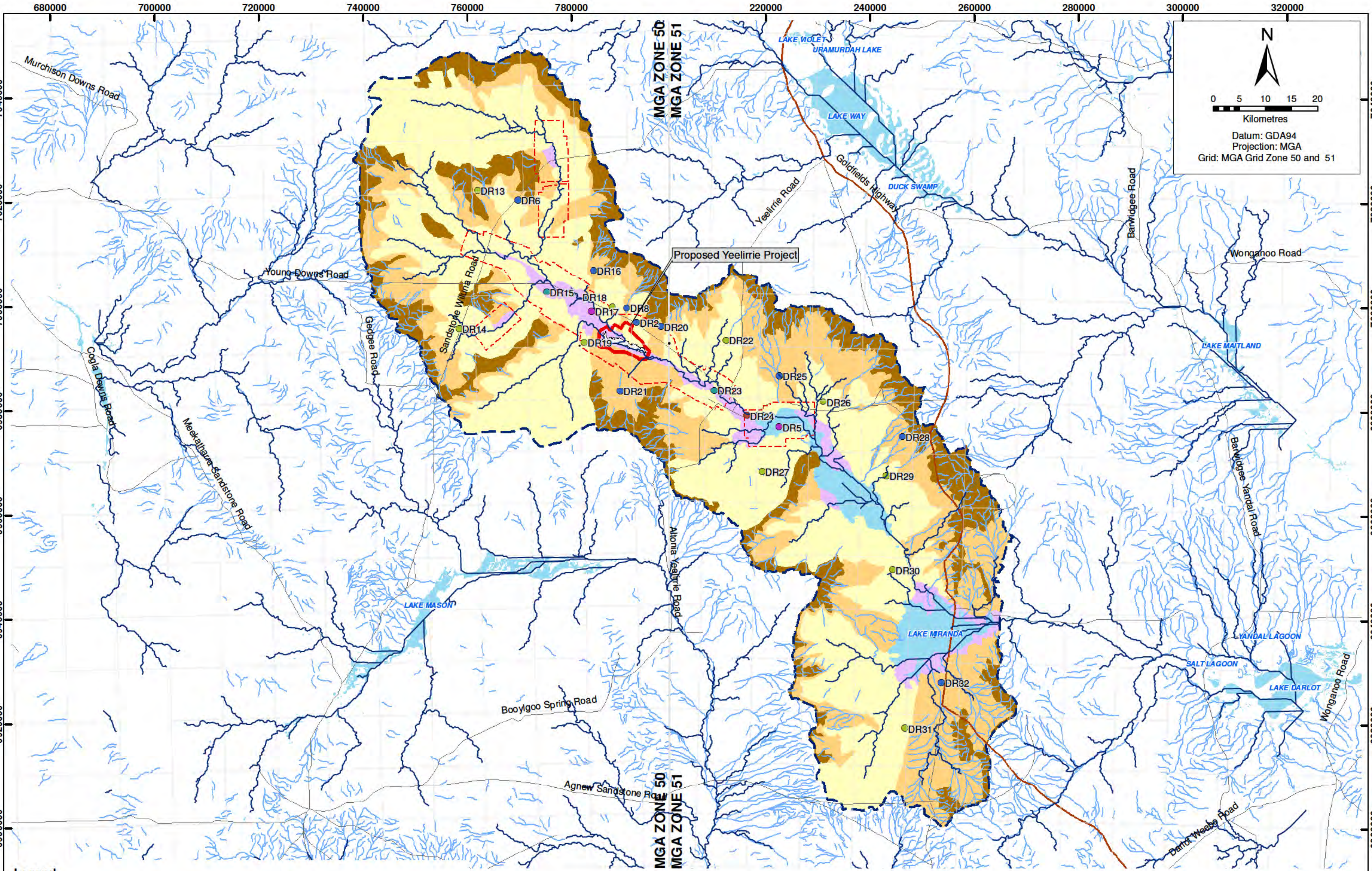

Cameco / URS	Project: Surface Water Study, Proposed Yeelirrie Project		Title: Infiltration Test Locations	
	Drawn: RNM	Approved: BW	Date: 8/04/2015	Figure: 4-1	Rev. A
	Job No.: 42908794	File No.: 42908794-SW-011.mxd		A3

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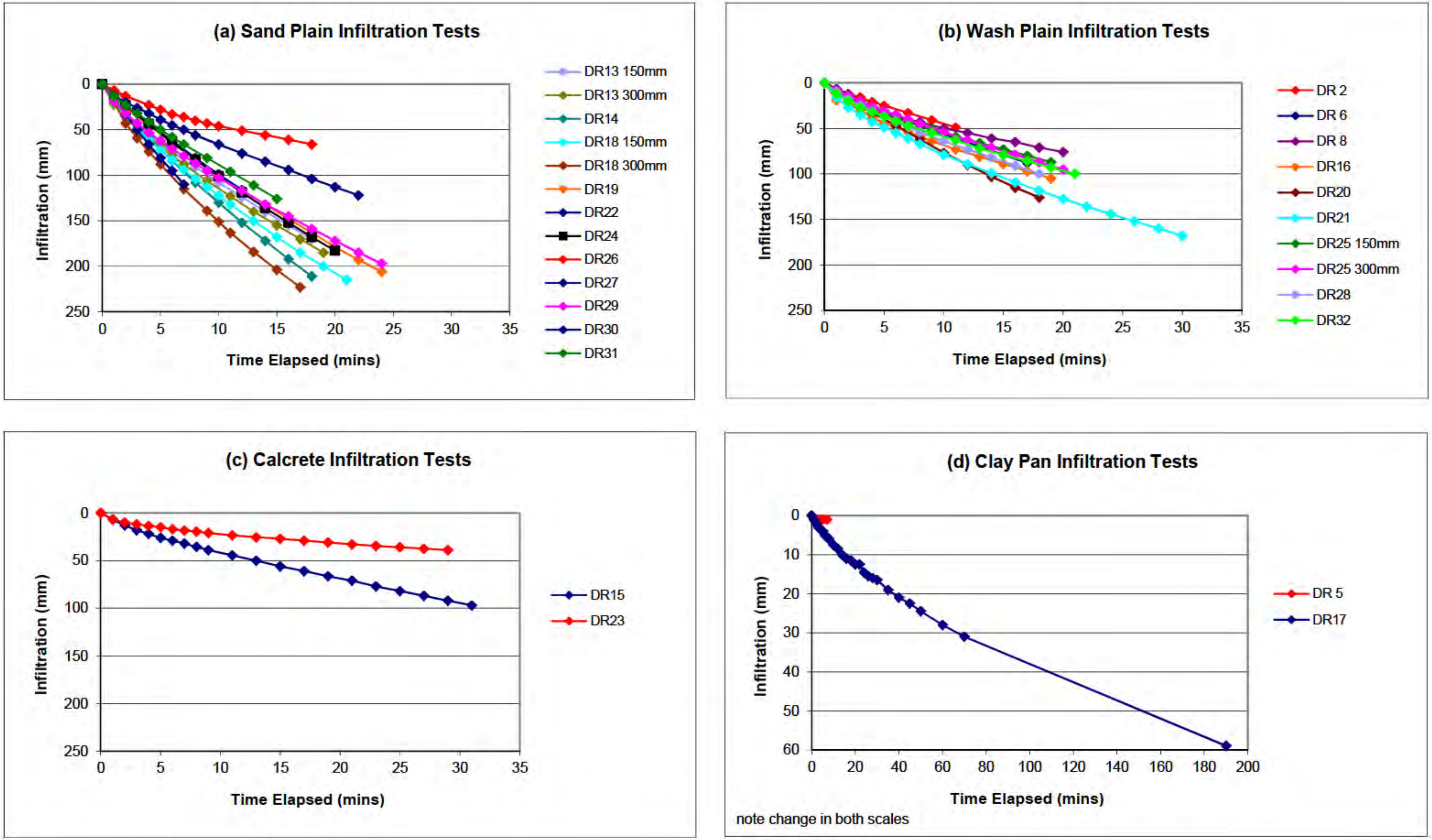
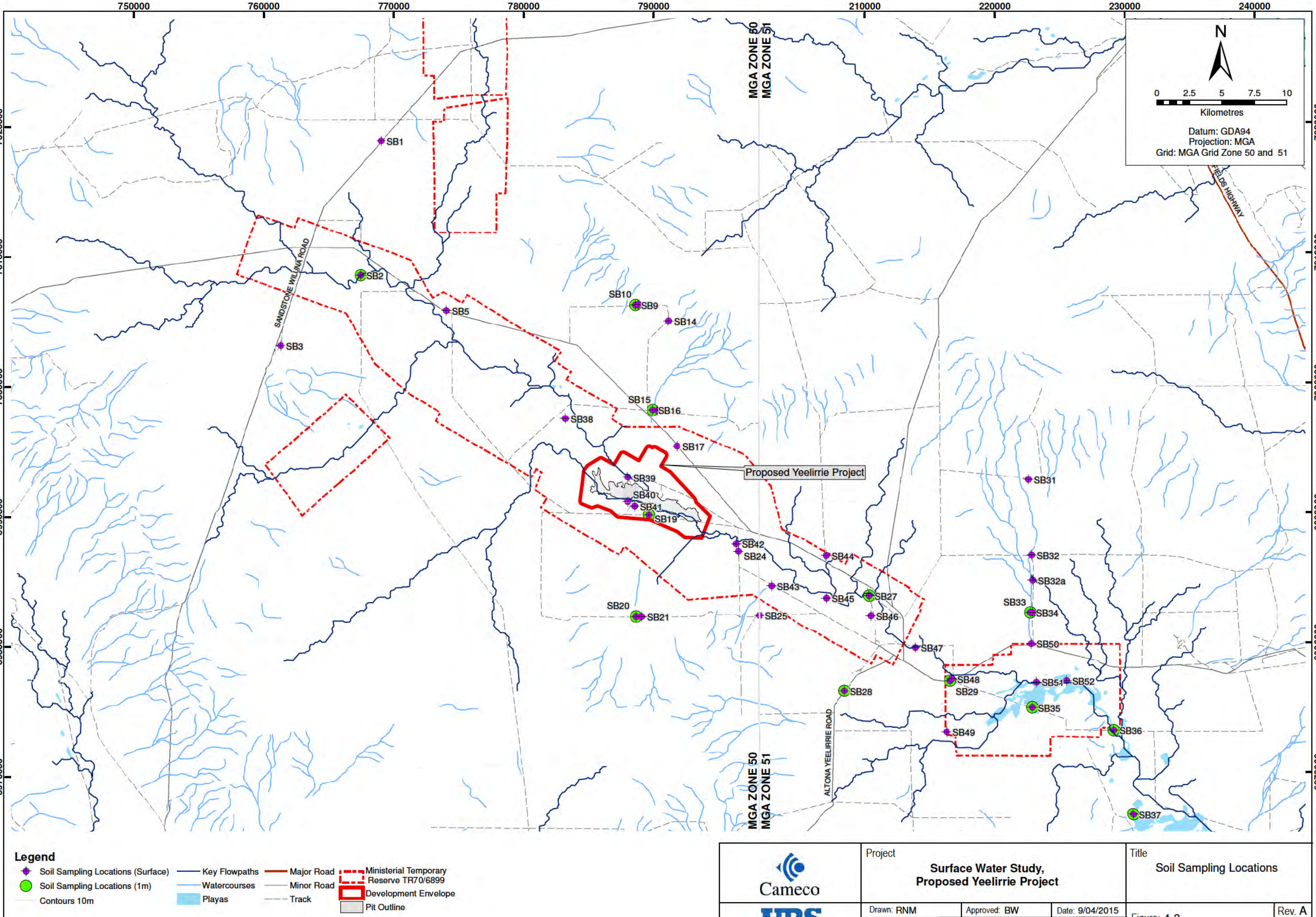


Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**				Title: Infiltration Test Results	
	Drawn: LW/RNM	Approved: BW	Date: 10/04/2015		Figure: 4-2	Rev. A
	Job No. 42908794	File No. 42908794-SW-106.xls				A4



Cameco

URS

Project: **Surface Water Study, Proposed Yeelirrie Project**

Title: Soil Sampling Locations

Drawn: RNM	Approved: BW	Date: 9/04/2015	Figure: 4-3	Rev. A
Job No.: 42908794	File No.: 42908794-SW-012.mxd			A3

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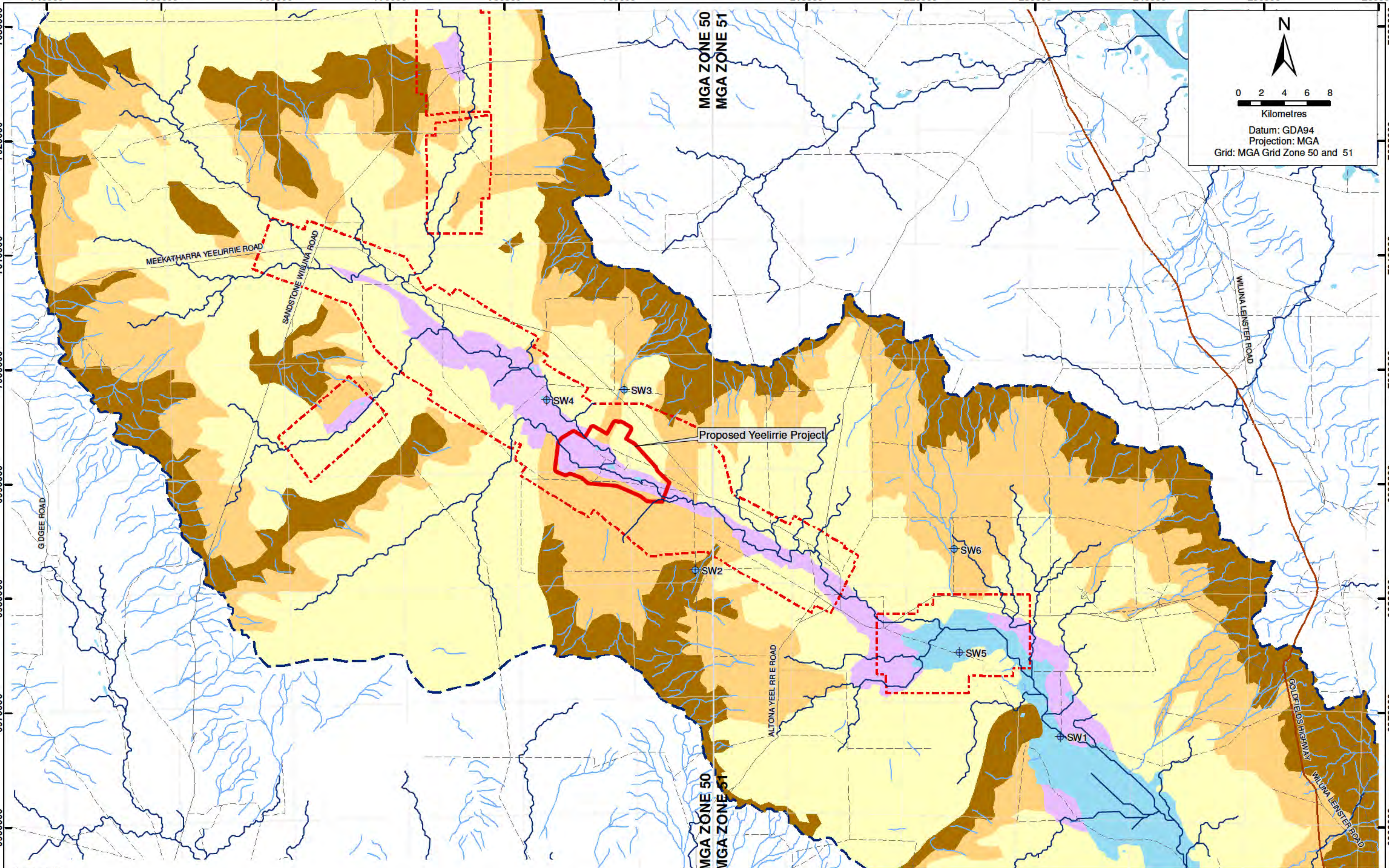

Legend

- Surface Water Sampling Locations
- Development Envelope
- Ministerial Temporary Reserve TR70/6899
- Key Flowpaths
- Watercourses
- Lakes
- Lake Miranda Catchment

Simplified Interpolated Land Systems - Soil Landscapes

- Playa
- Calcrete
- Wash Plain
- Sand Plain
- Breakaway

Cameco	Project: **Surface Water Study, Proposed Yeelirrie Project**		Title: Surface Water Sampling Locations
URS	Drawn: RNM	Approved: BW	Date: 9/04/2015
	Job No.: 42908794	File No.: 42908794-SW-013.mxd	Figure: 4-4
			Rev. A
			A3

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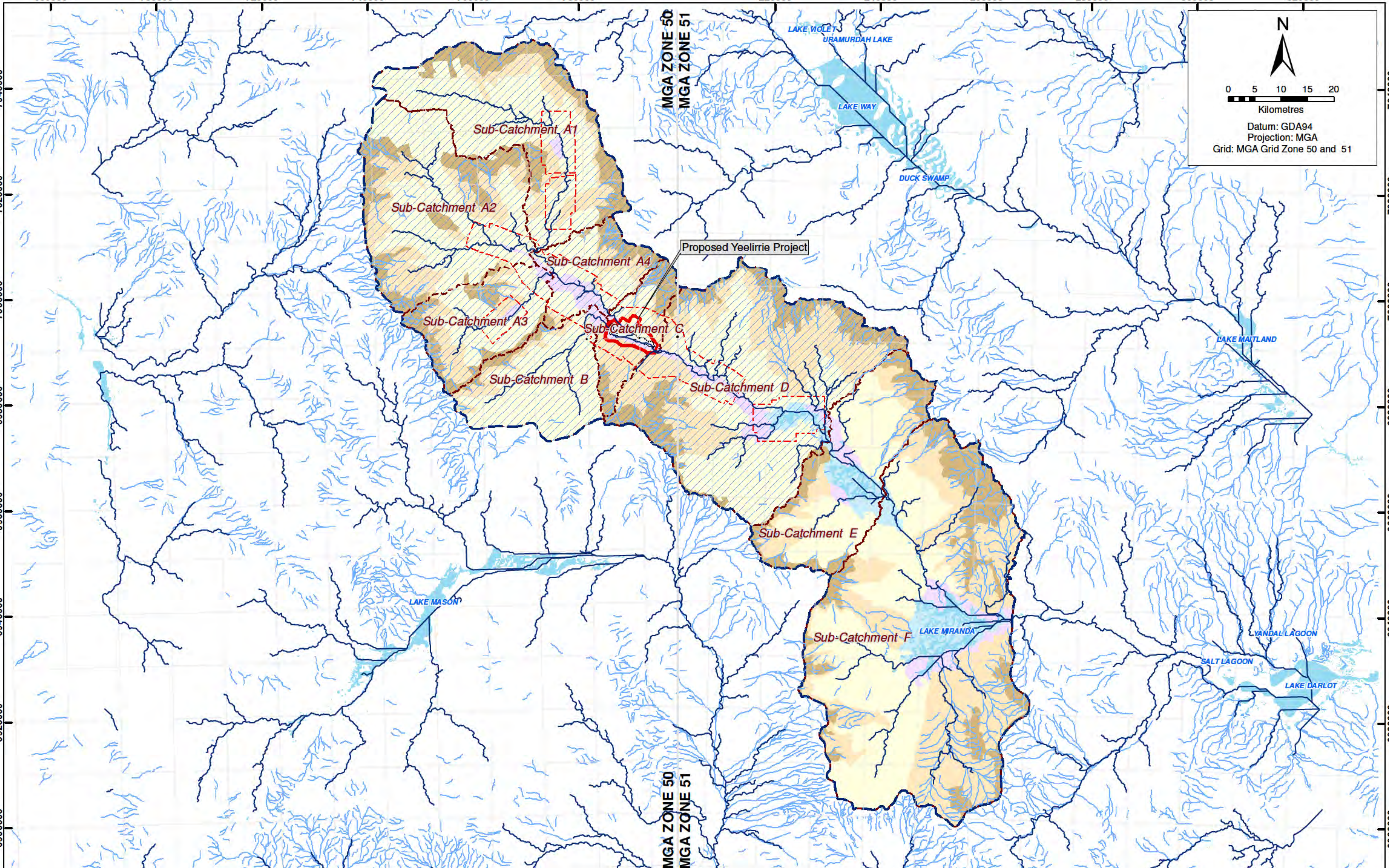

Legend

- Key Flowpaths
- Watercourses
- Ministerial Temporary Reserve TR70/6899
- Development Envelope
- Yeelirrie Playa Catchment
- Lake Miranda Catchment
- Lake Miranda Sub-Catchments
- Pit Outline

Catchment Units

- Playa
- Calcrete
- Wash Plain
- Sand Plain
- Breakaway

Cameco

URS

Project: **Surface Water Study, Proposed Yeelirrie Project**

Title: Lake Miranda Catchment and Sub-Catchments

Drawn: RNM | Approved: BW | Date: 9/04/2015

Job No.: 42908794 | File No.: 42908794-SW-014.mxd

Figure: 5-1 | Rev. A | A3

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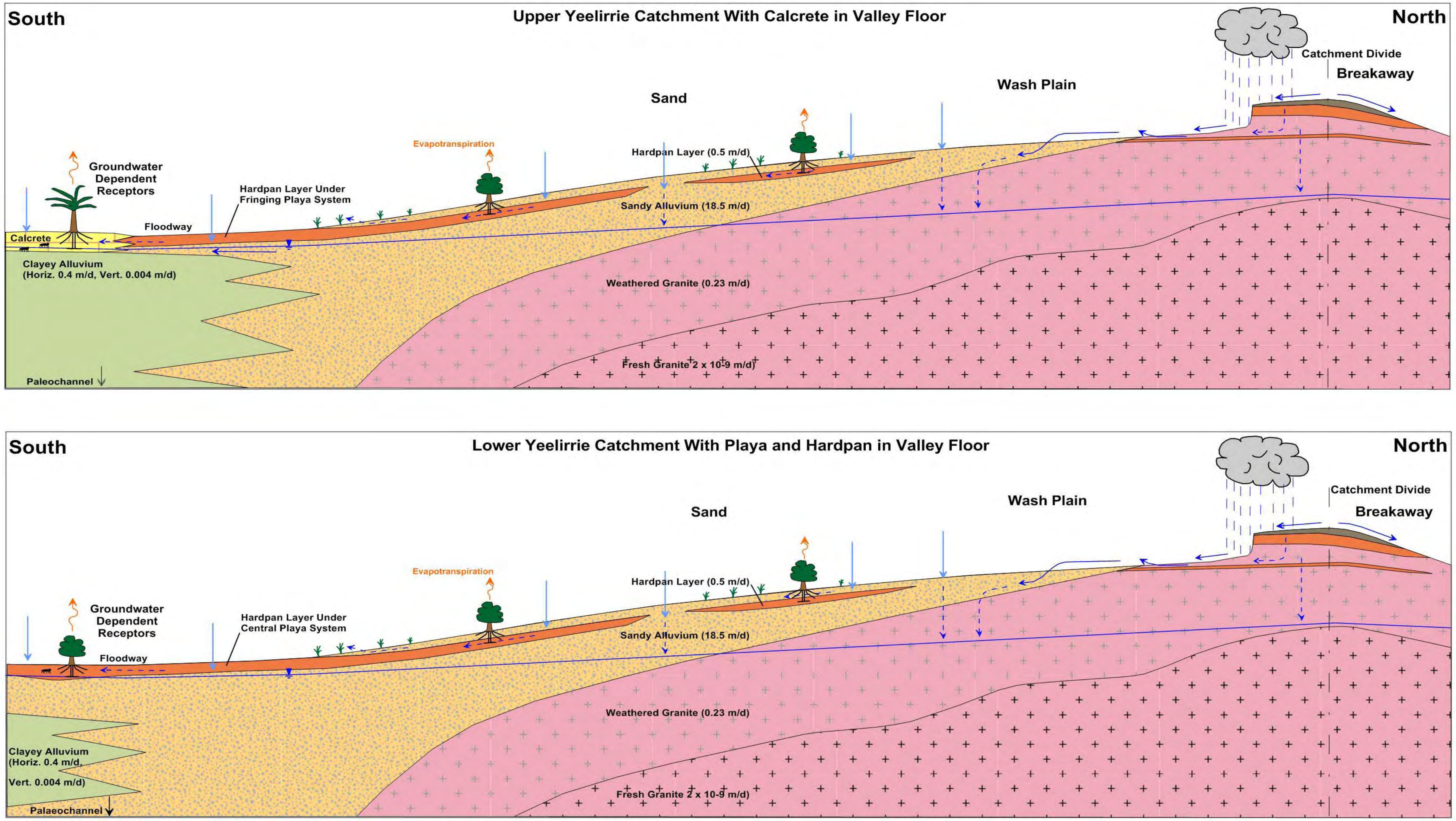
Cross-Sectional Views Looking West



Not to Scale
Vertical proportions exagerated

Conceptual Surface Water Infiltration and Perched Groundwater Relationships

Cameco	Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: Conceptual Hydrological Model (Cross-section)
URS	Drawn: TH/BE	Approved: BW	Date: 10/04/2015	Figure: 5-2 — Rev. A
	Job No. 42908794	File No. 42908794-SW-107.xls		A3

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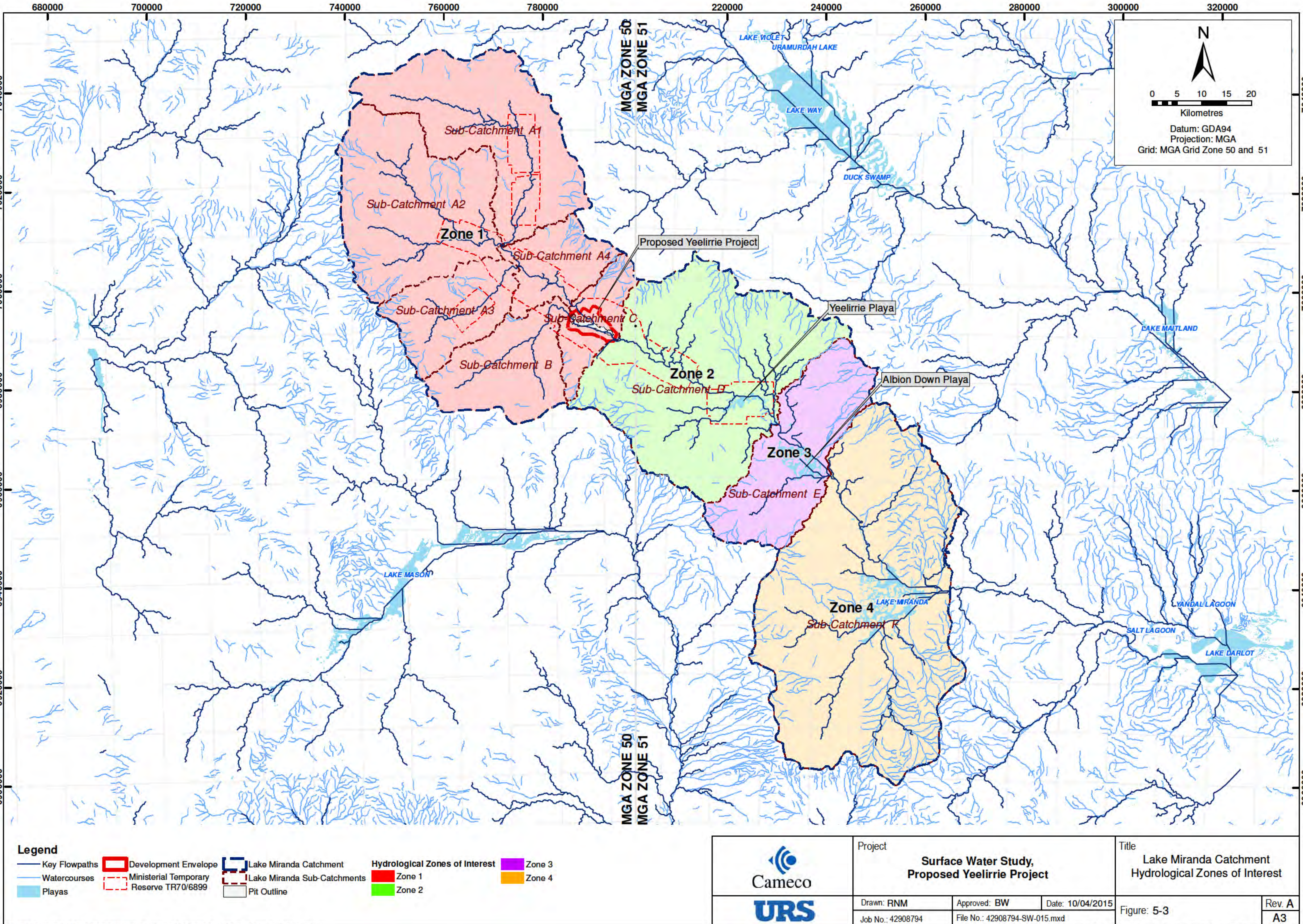

Cameco

URS

Project: **Surface Water Study, Proposed Yeelirrie Project**

Title: Lake Miranda Catchment Hydrological Zones of Interest

Drawn: RNM	Approved: BW	Date: 10/04/2015	Figure: 5-3
Job No.: 42908794	File No.: 42908794-SW-015.mxd		Rev. A
			A3

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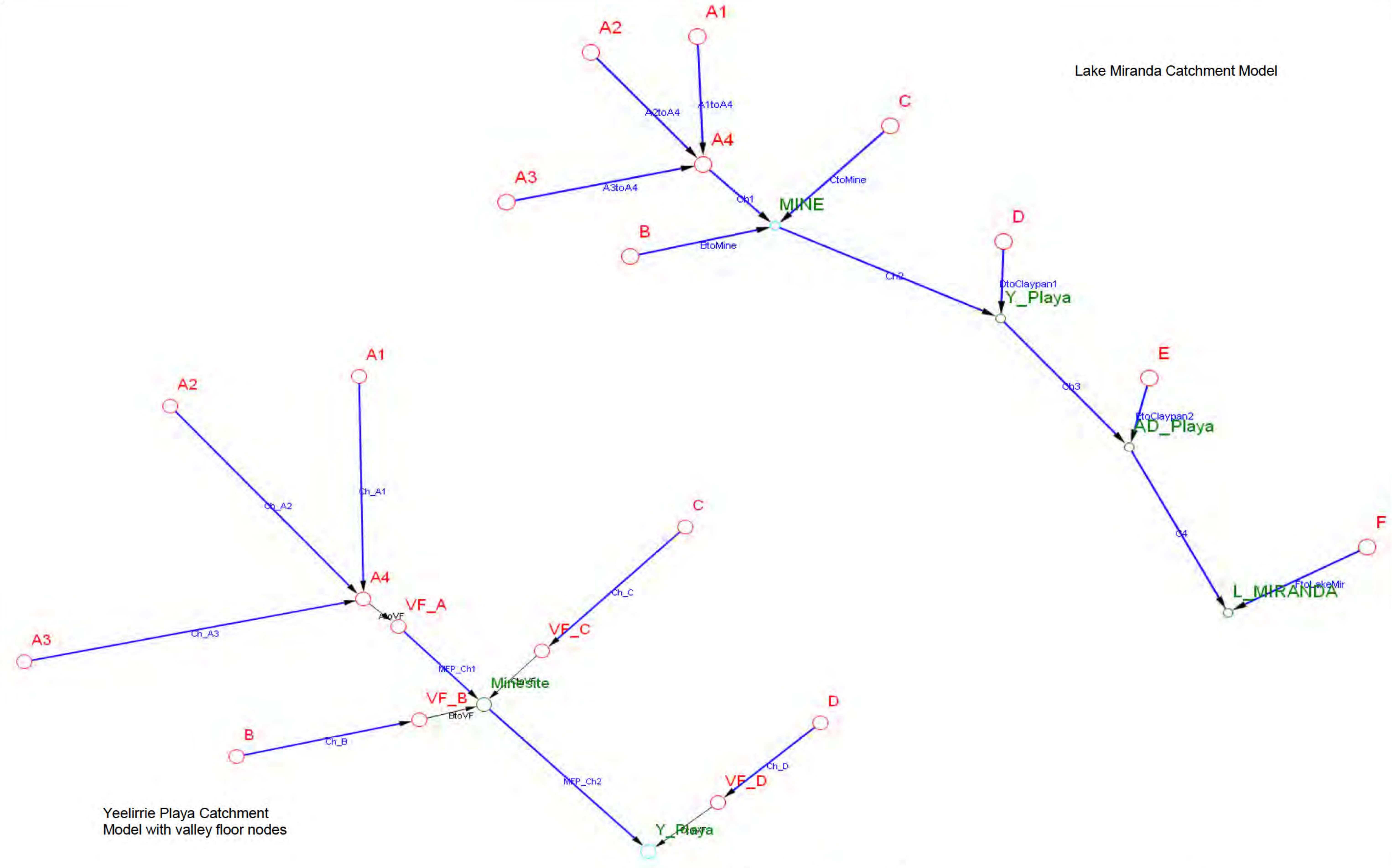

Cameco URS	Project: **Surface Water Study, Proposed Yeelirrie Project**	Title: Hydrological Model XPrafts Schematic Diagrams
	Drawn: LW/BE · Approved: BW · Date: 1/04/2015 Job No. 42908794 · File No. 42908794-SW-108.xls	Figure: 5-4 · Rev. A · A3

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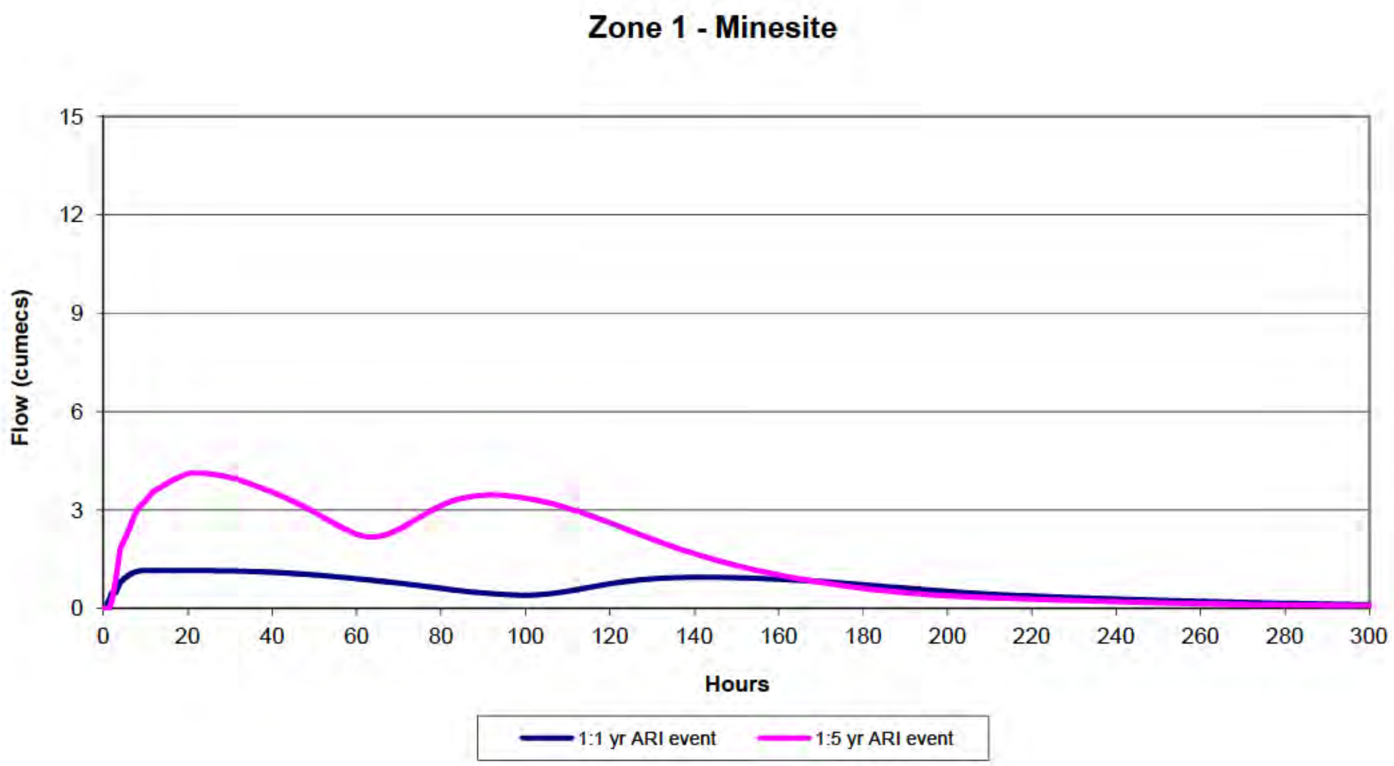

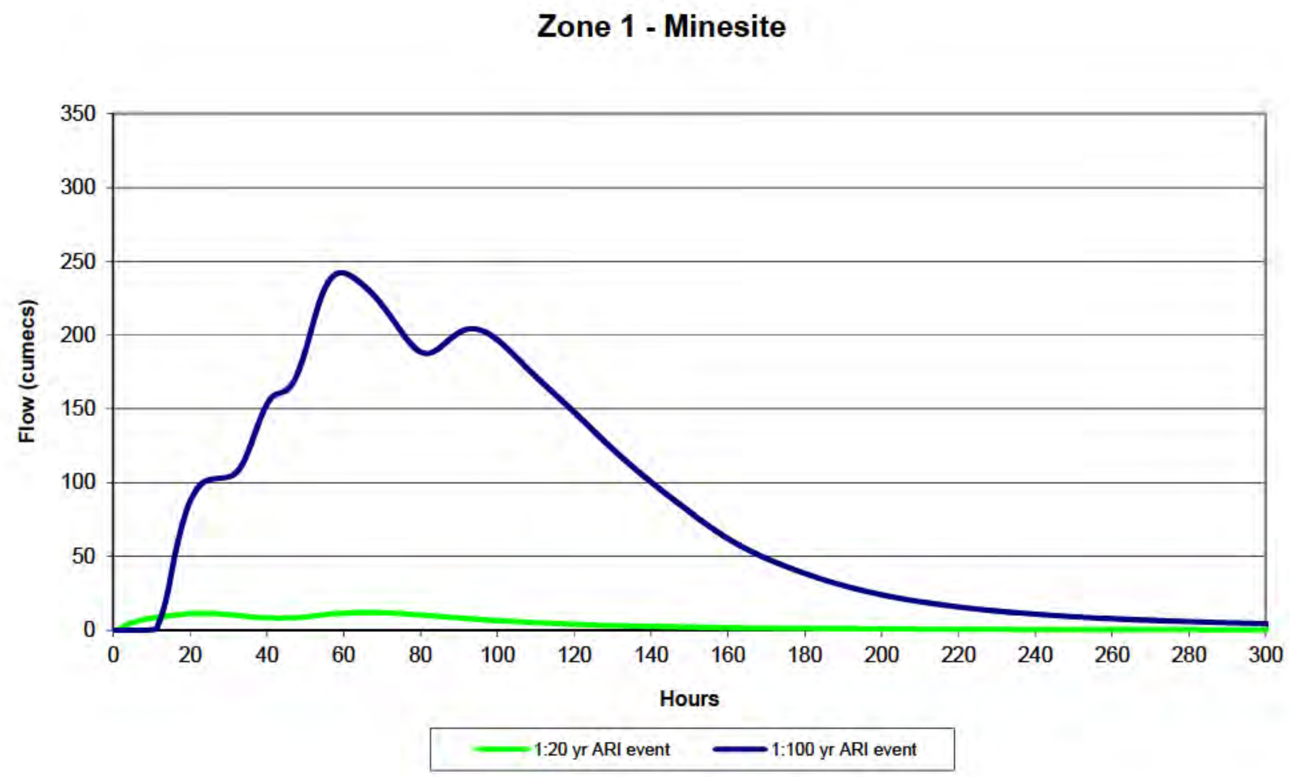

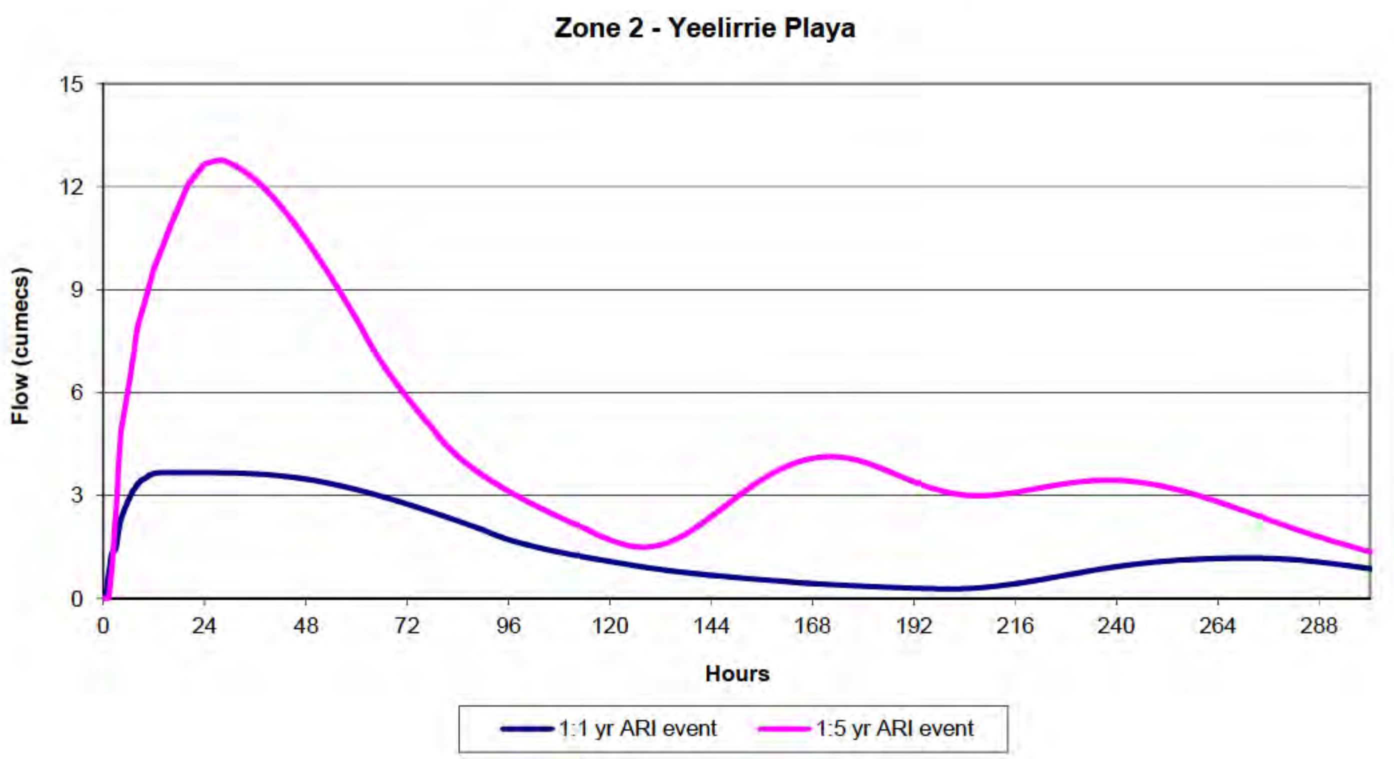

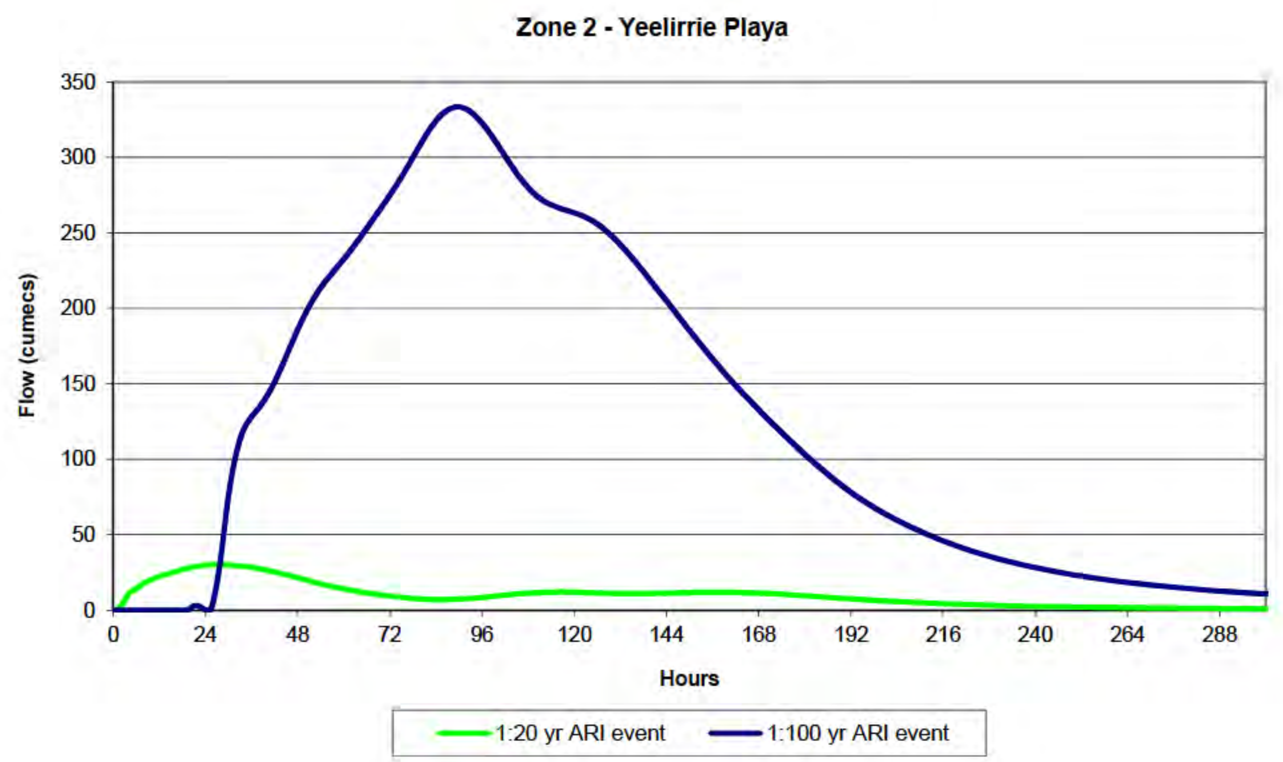

Cameco	Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: Yeelirrie Playa Hydrological Model Hydrographs - Zones 1 and 2
URS	Drawn: LW/RNM	Approved: BW	Date: 1/04/2015	Figure: 5-5 / Rev. A
	Job No. 42908794	File No. 42908794-SW-110.xls		A3

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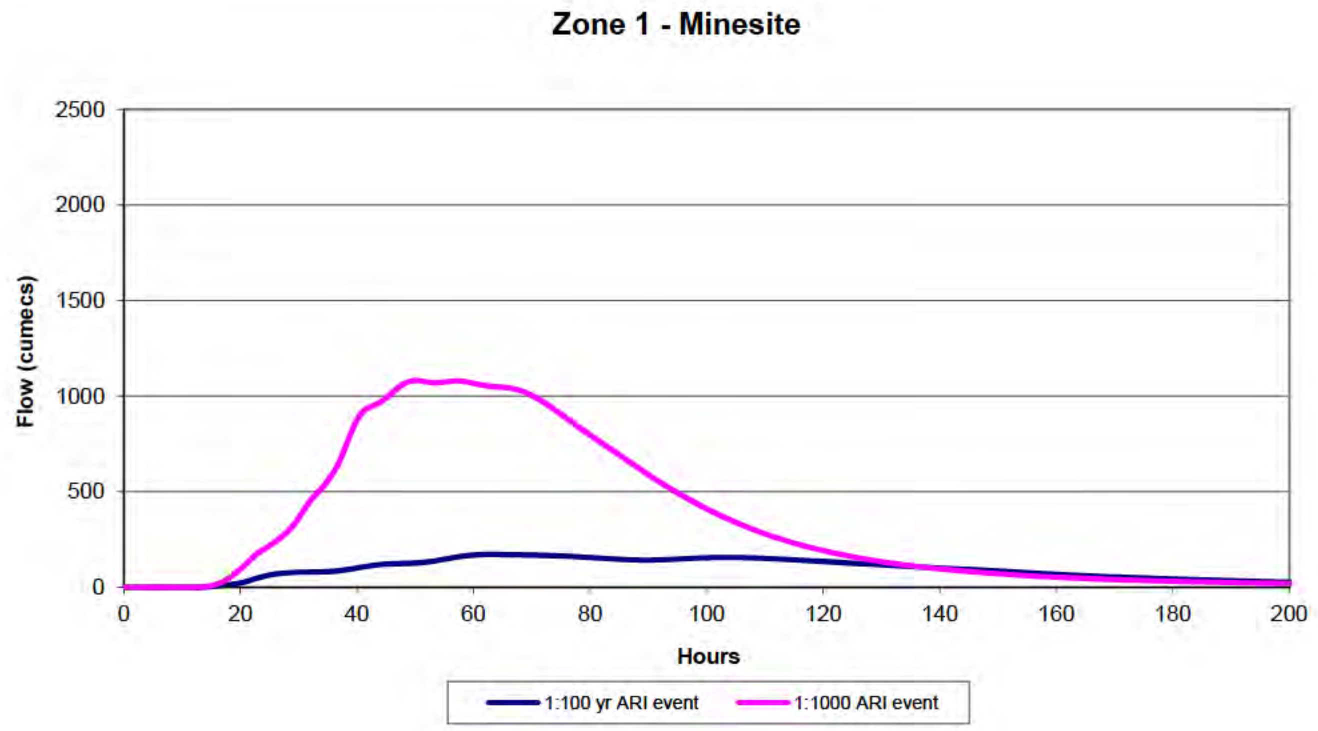

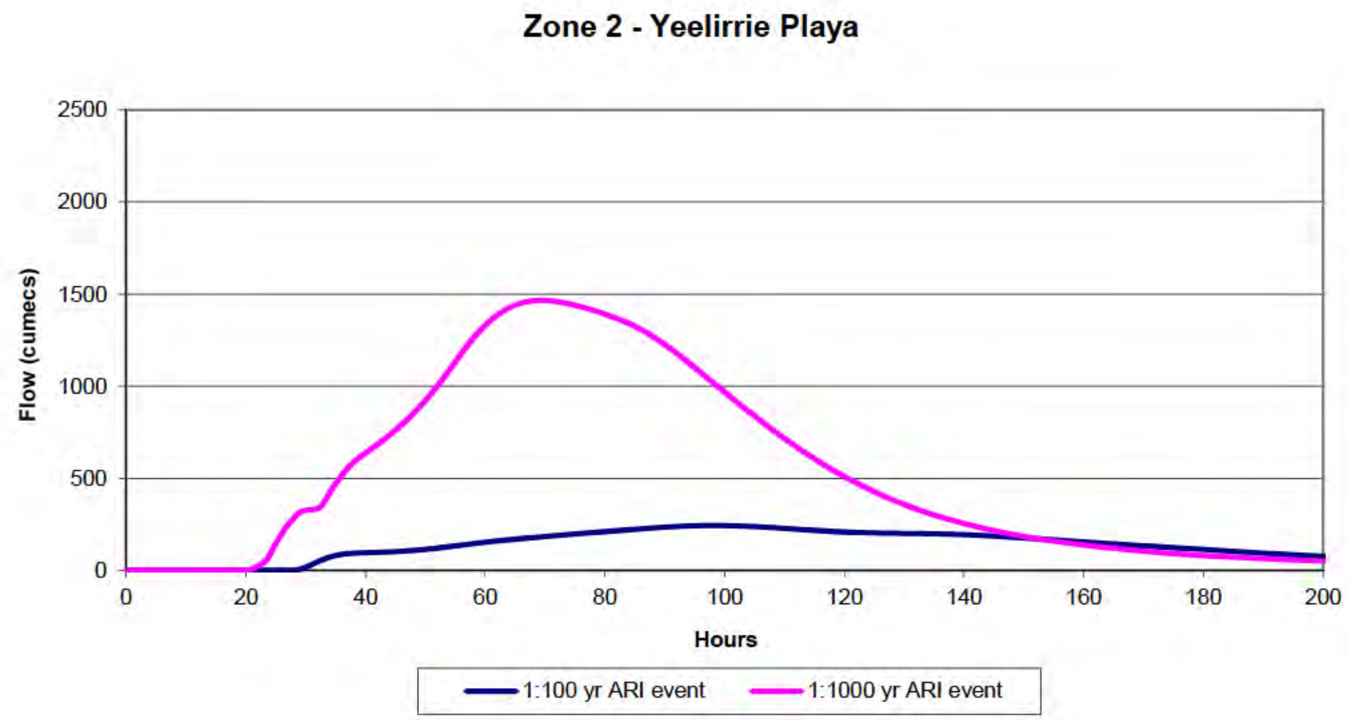

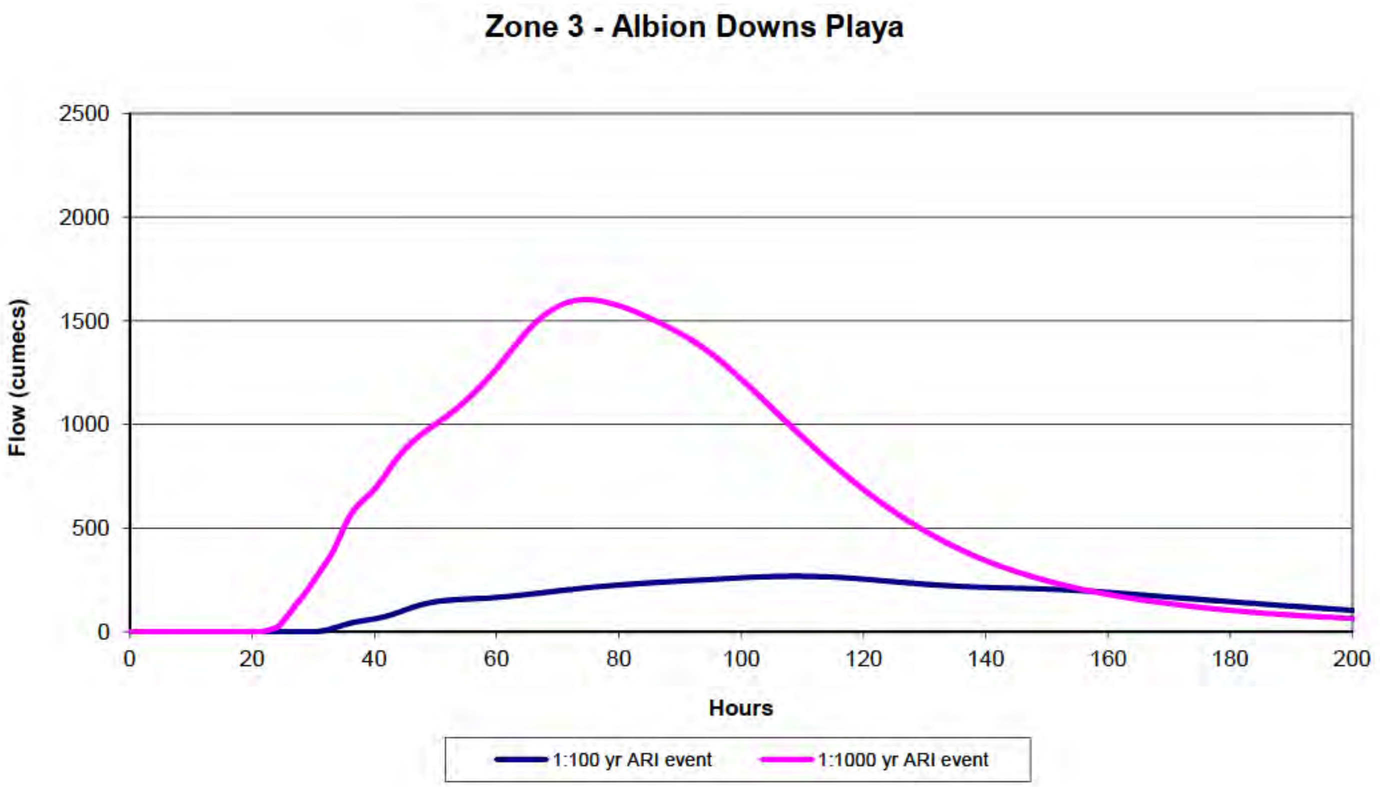

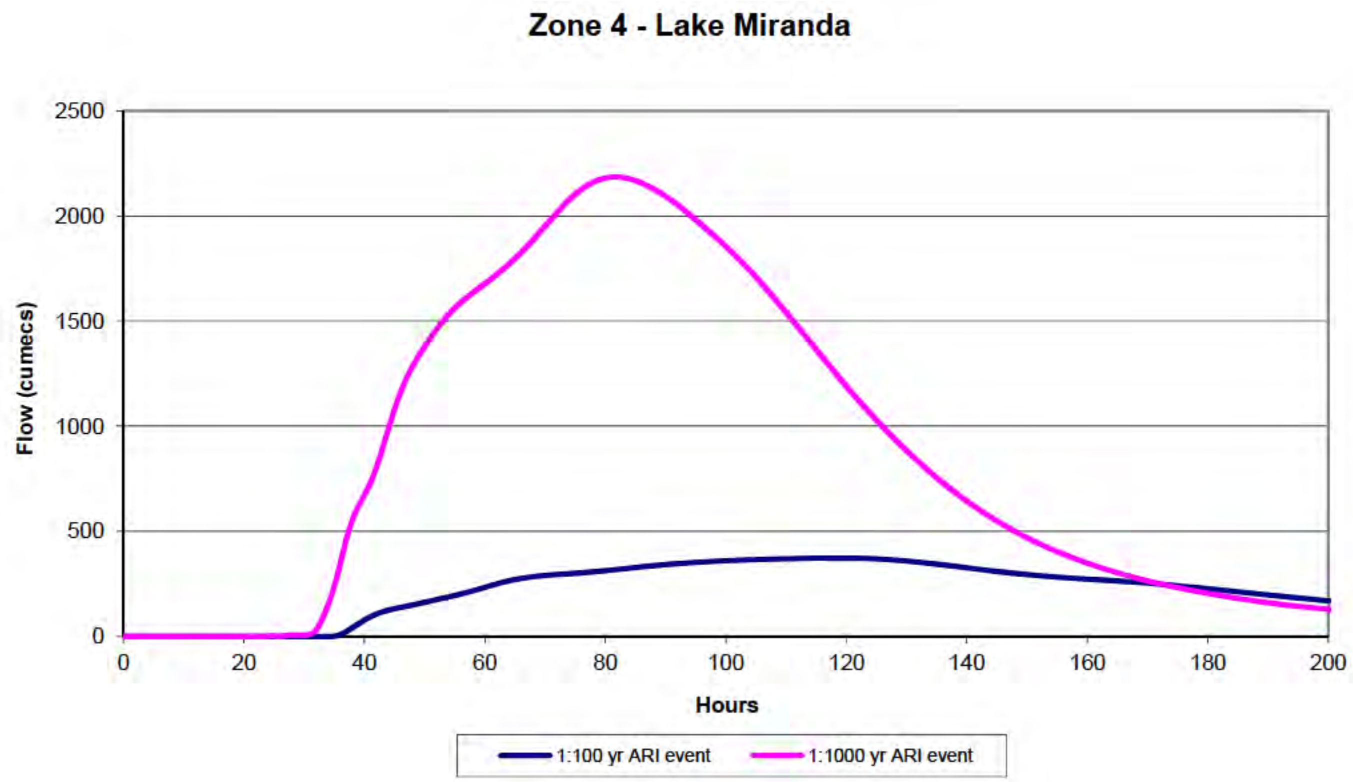

Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Development**			Title: Lake Miranda Hydrological Model Hydrographs - Zones 1 to 4
	Drawn: LW/BE	Approved: IGB	Date: 1/04/2015	Figure: 5-6 — Rev. B
	Job No. 42908794	File No. 42908794-SW-109.xls		A3

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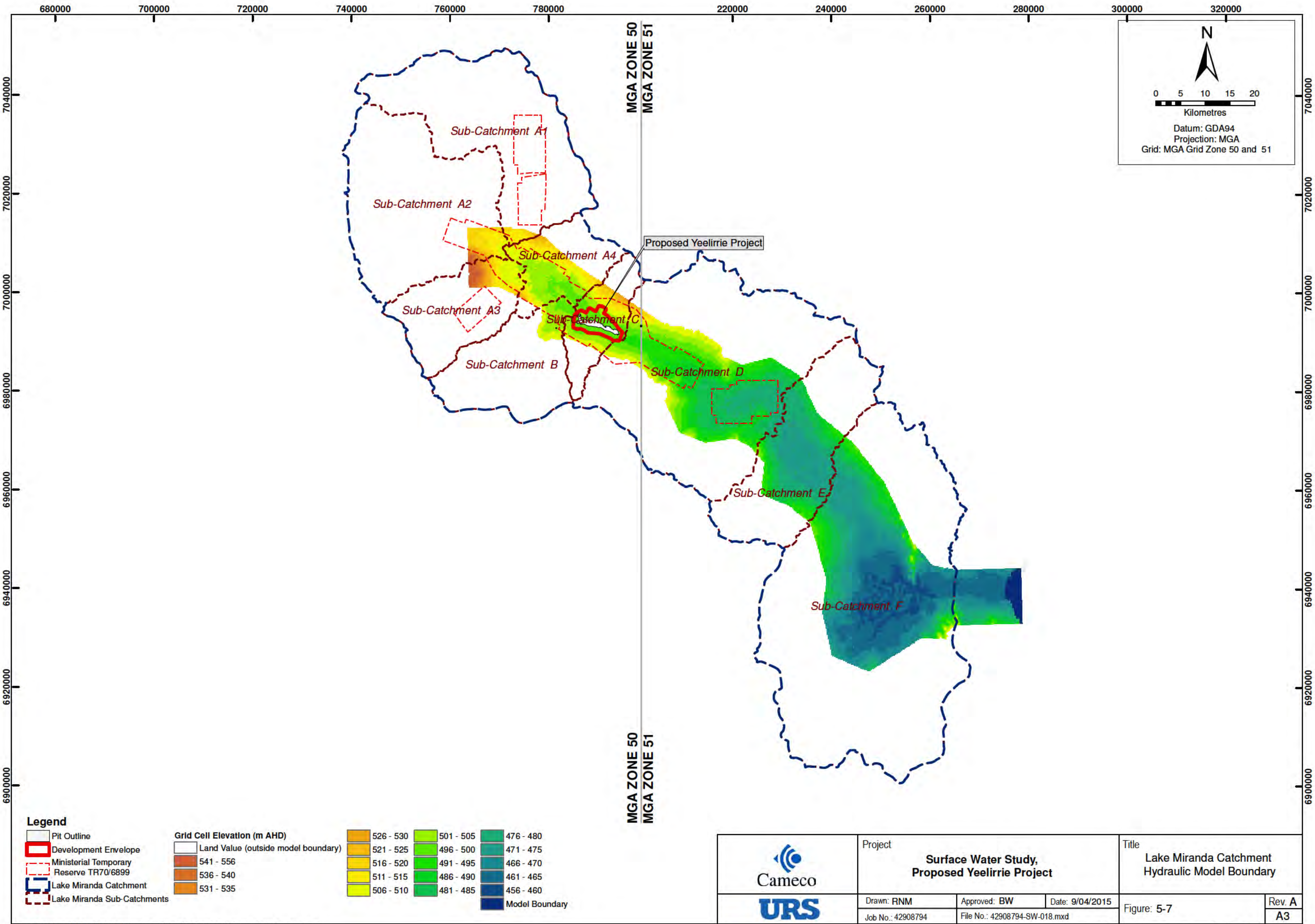

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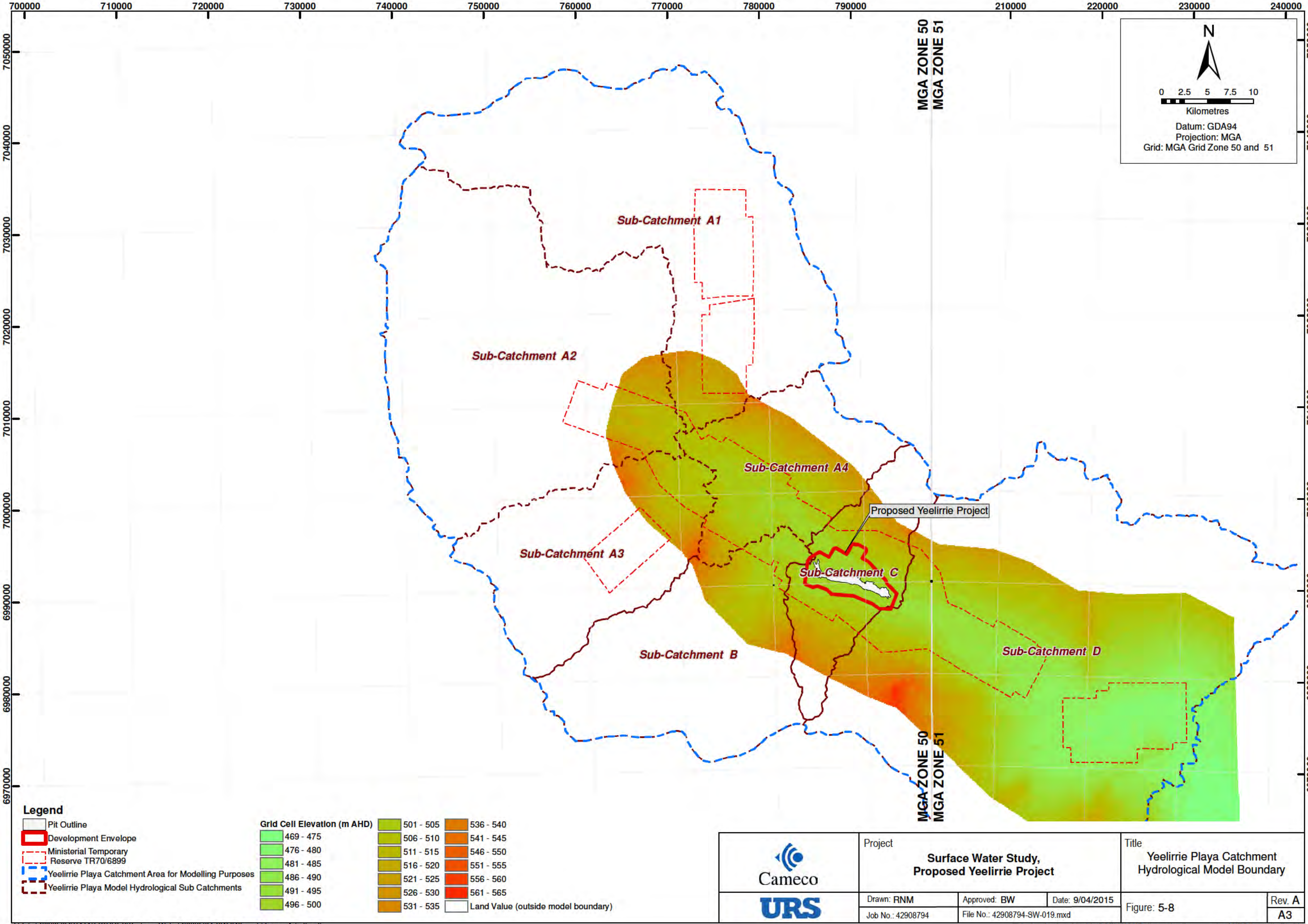

Cameco / URS	Project: Surface Water Study, Proposed Yeelirrie Project	Title: Yeelirrie Playa Catchment Hydrological Model Boundary
Drawn: RNM; Job No.: 42908794	Approved: BW; Date: 9/04/2015; File No.: 42908794-SW-019.mxd	Figure: 5-8; Rev. A; A3

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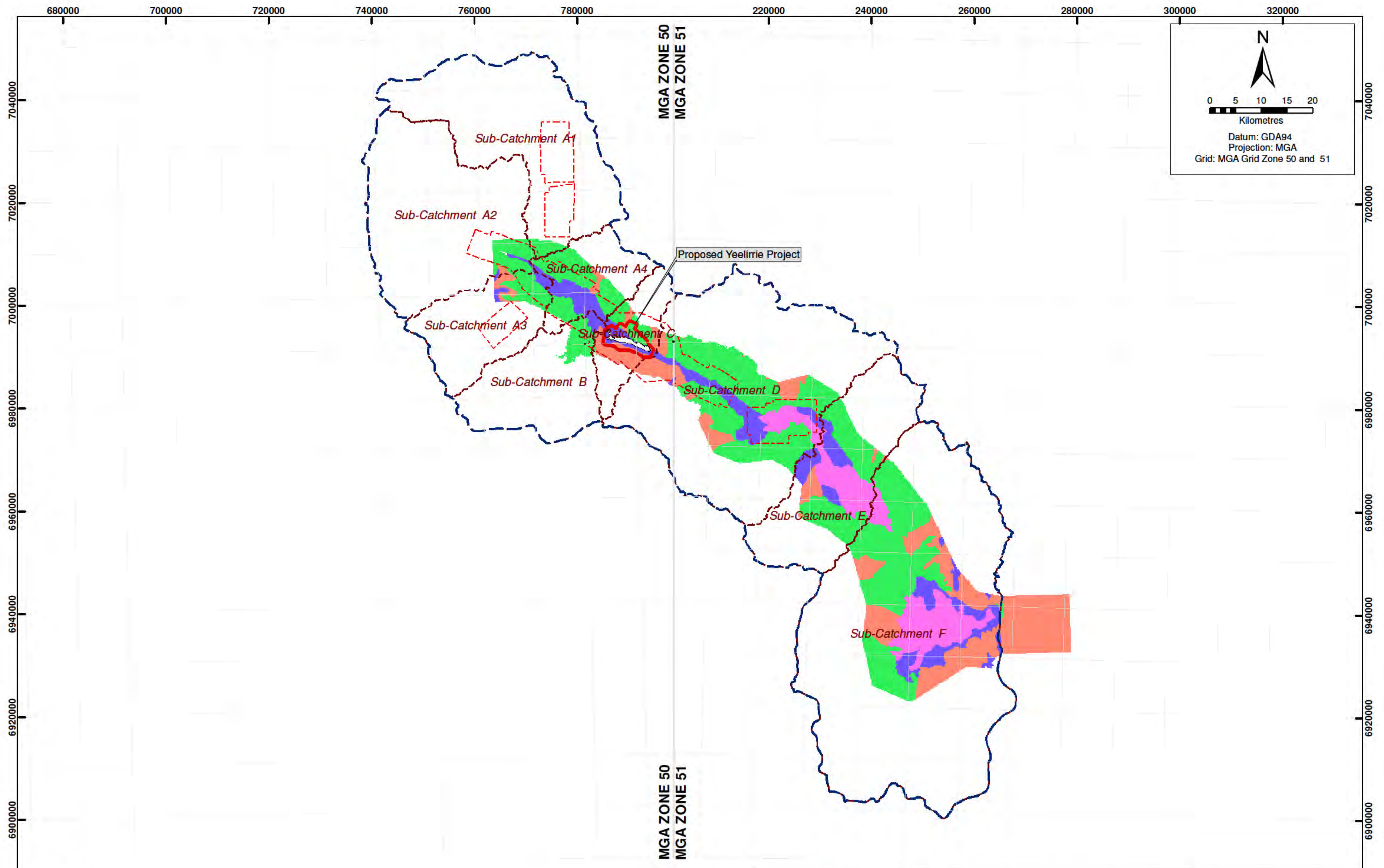

Cameco

URS

Project: **Surface Water Study, Proposed Yeelirrie Project**

Title: Hydraulic Model Resistance Values

Drawn: RNM	Approved: BW	Date: 10/04/2015	Figure: 5-9	Rev. A
Job No.: 42908794	File No.: 42908794-SW-020.mxd			A3

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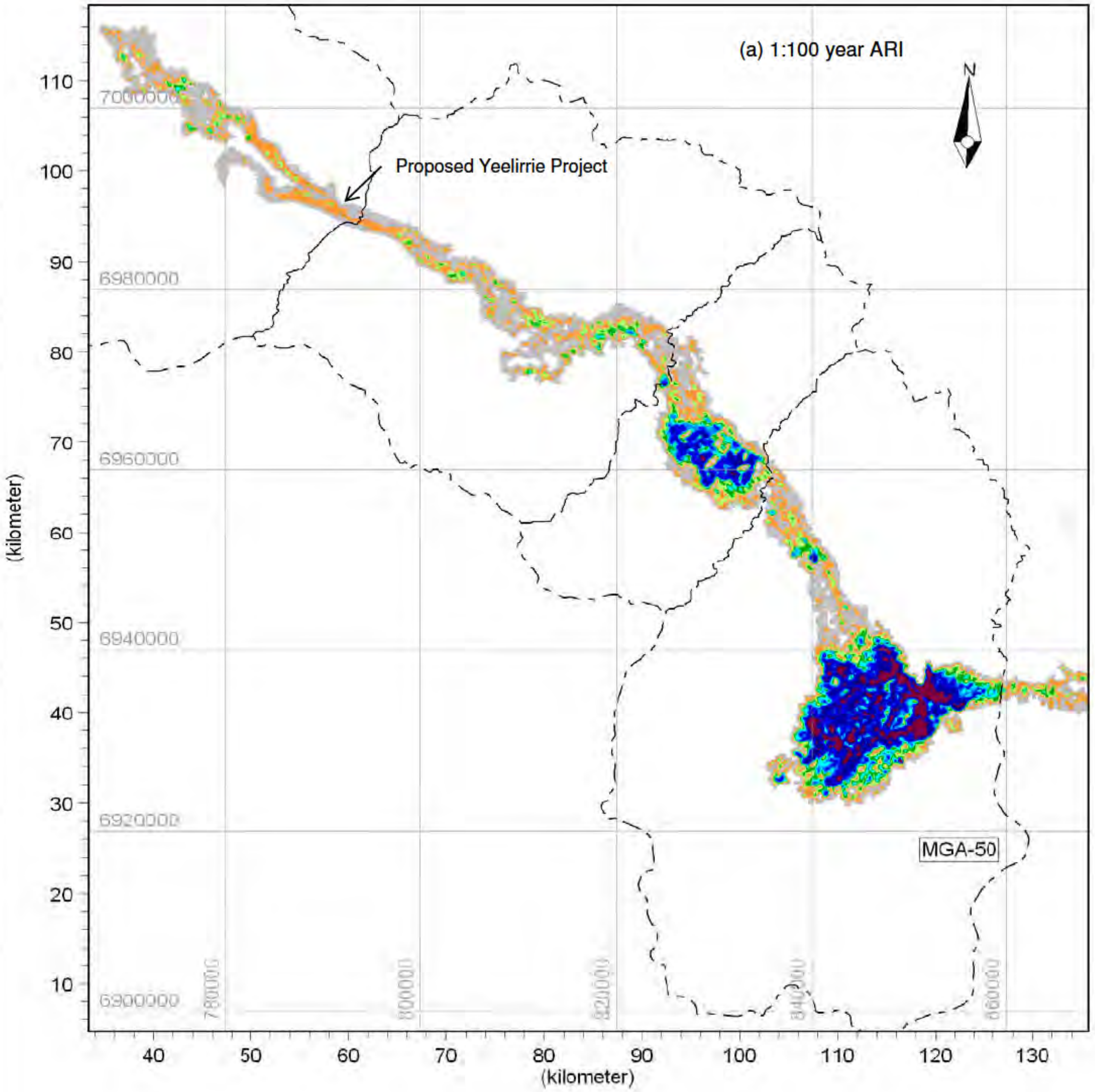

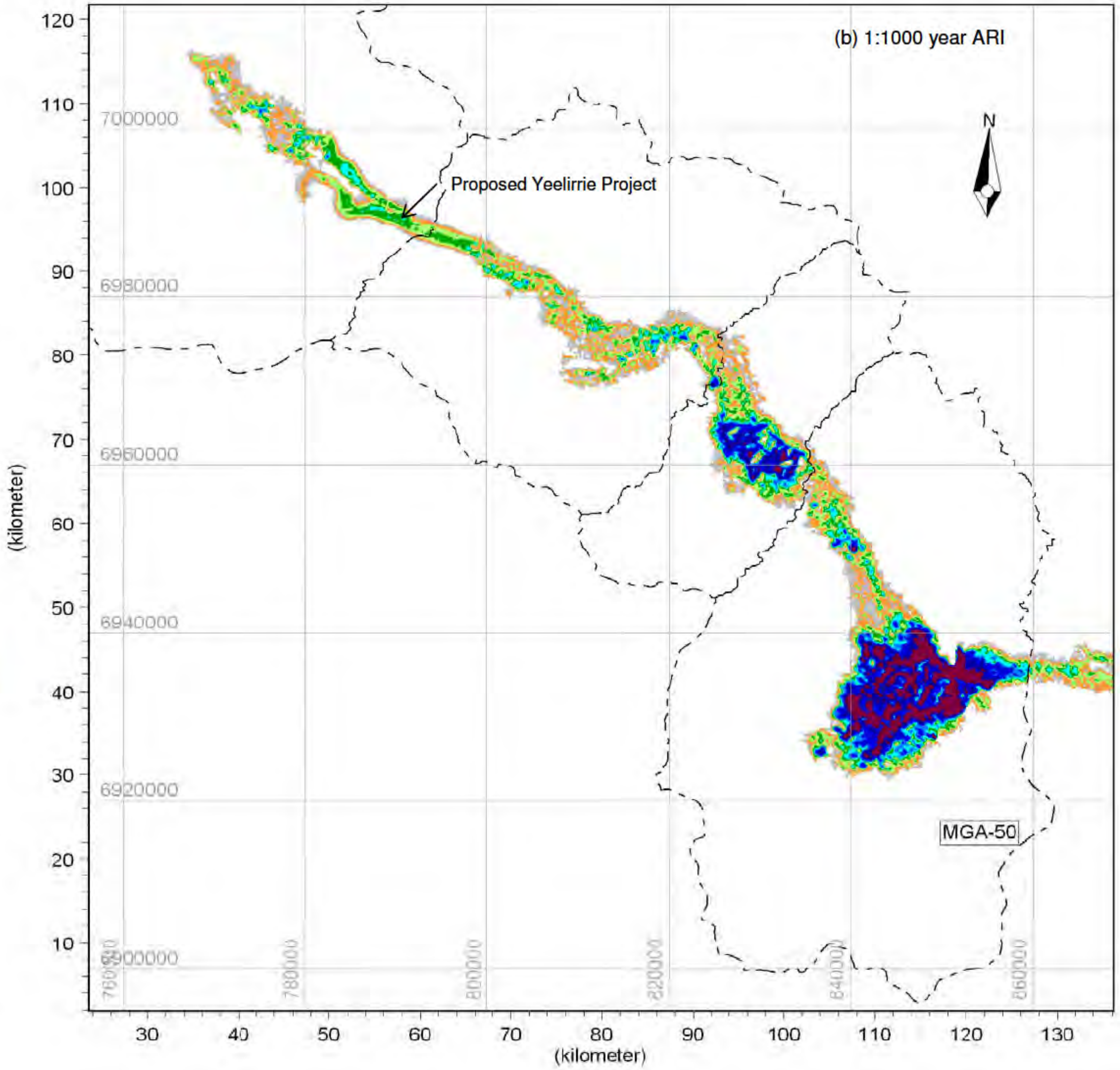

LEGEND

Max Water Depth (m)

- Above 5.0
- 4.0 - 5.0
- 3.0 - 4.0
- 2.5 - 3.0
- 2.0 - 2.5
- 1.5 - 2.0
- 1.0 - 1.5
- 0.5 - 1.0
- 0.0 - 0.5

Cameco URS	Project: **Surface Water Study, Proposed Yeelirrie Project**		Title: Regional Baseline Flood Maps Maximum Water Depths	
	Drawn: RN<	Approved: BW	Date: 1/04/2015	
	Job No. 42908794	File No. 42908794-SW-111.xls	Figure: 5-10	Rev. A A3

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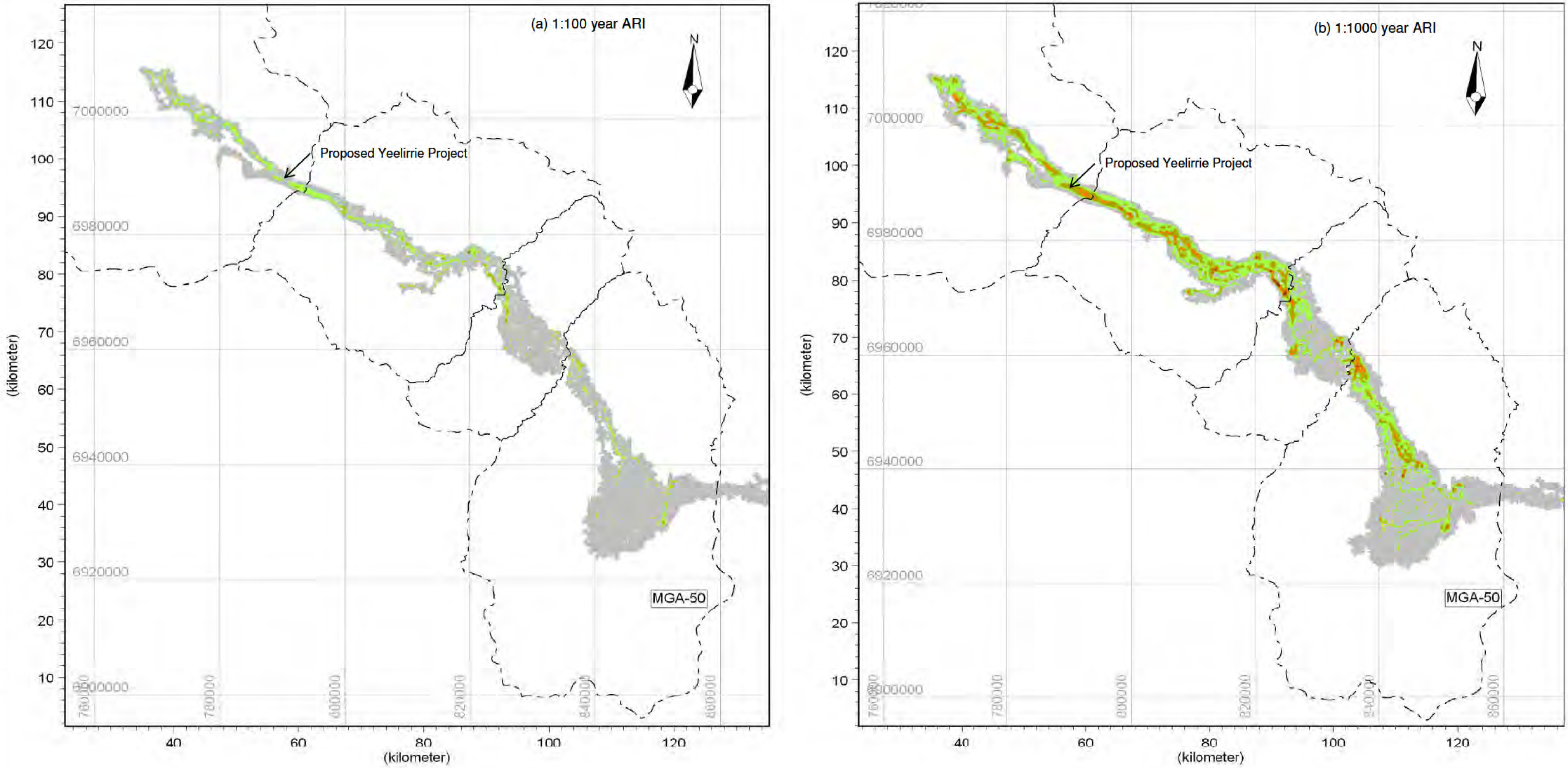

LEGEND

Maximum Velocity (m/s)

- Above 2.0
- 1.0 - 2.0
- 0.8 - 1.0
- 0.6 - 0.8
- 0.4 - 0.6
- 0.2 - 0.4
- Below 0.2

Cameco / URS	Project: Surface Water Study, Proposed Yeelirrie Project		Title: Regional Baseline Flood Maps Maximum Flow Velocity	
	Drawn: RNM	Approved: BW	Date: 1/04/2015	Figure: 5-11 / Rev. A
	Job No. 42908794	File No. 42908794-SW-111.xls		A3

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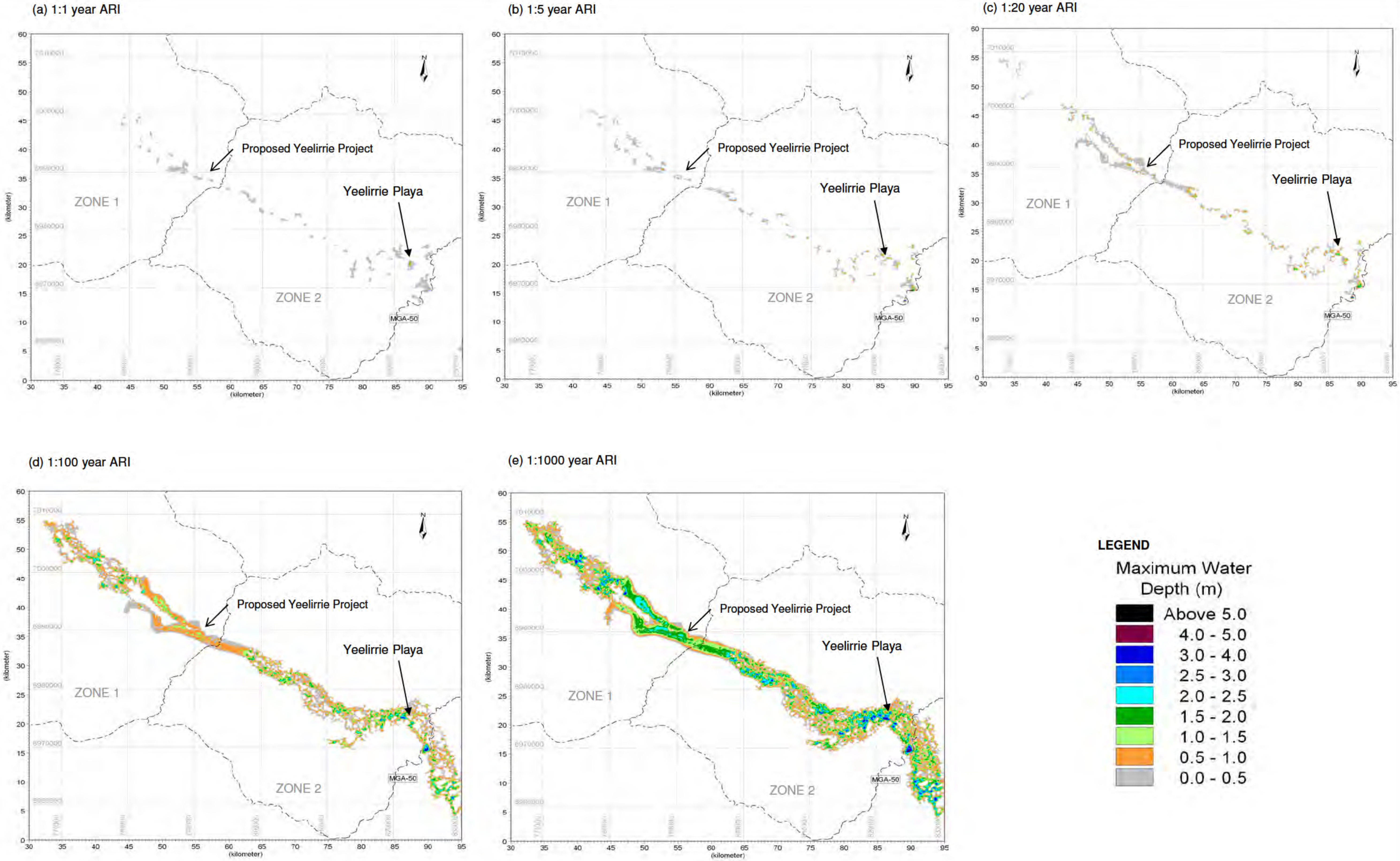

Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**	Title: Yeelirrie Playa Baseline Flood Maps Maximum Water Depth
	Drawn: RNM — Approved: BW — Date: 1/04/2015	Figure: 5-12 — Rev. A
	Job No. 42908794 — File No. 42908794-SW-111.xls	A3

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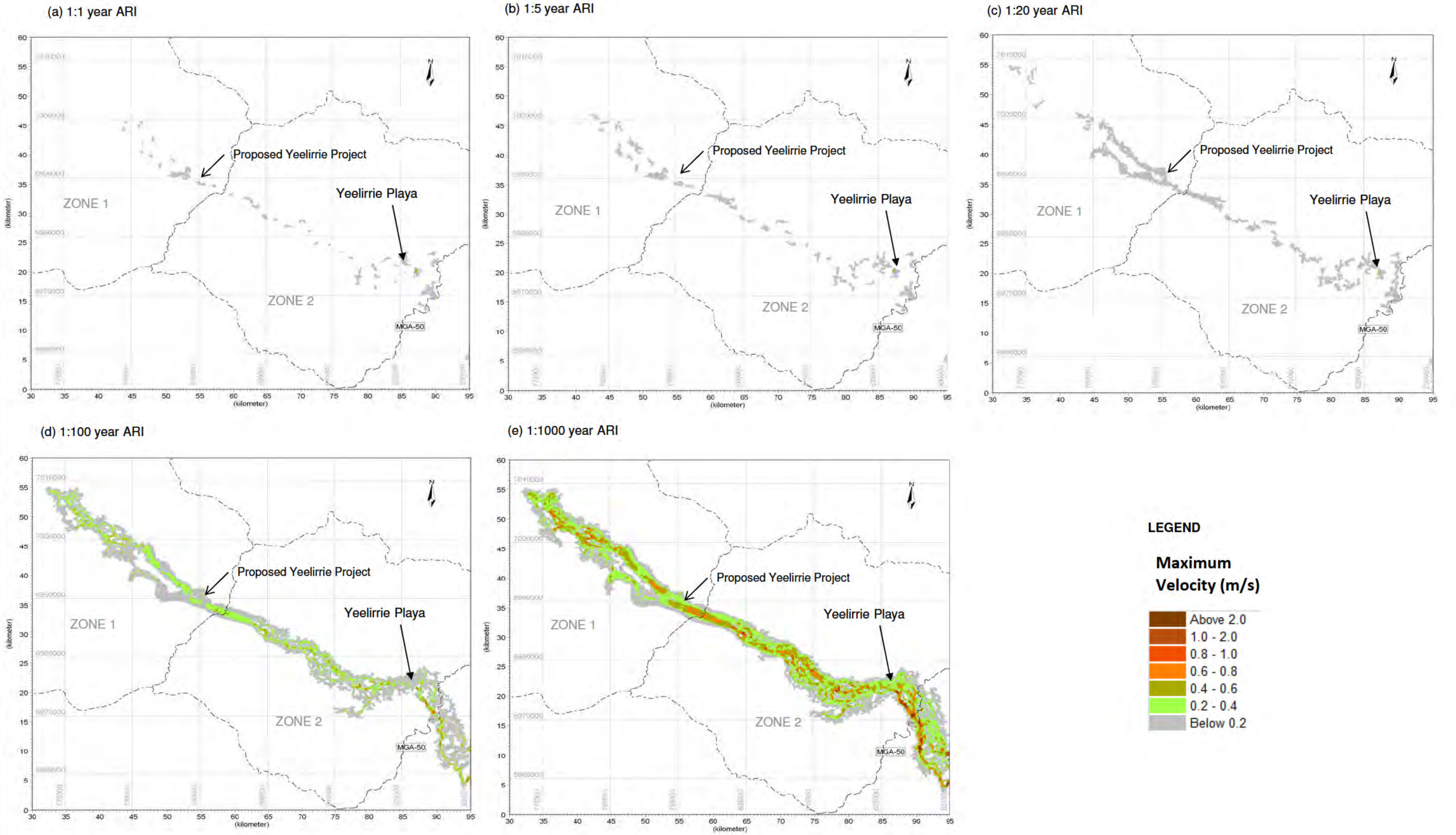
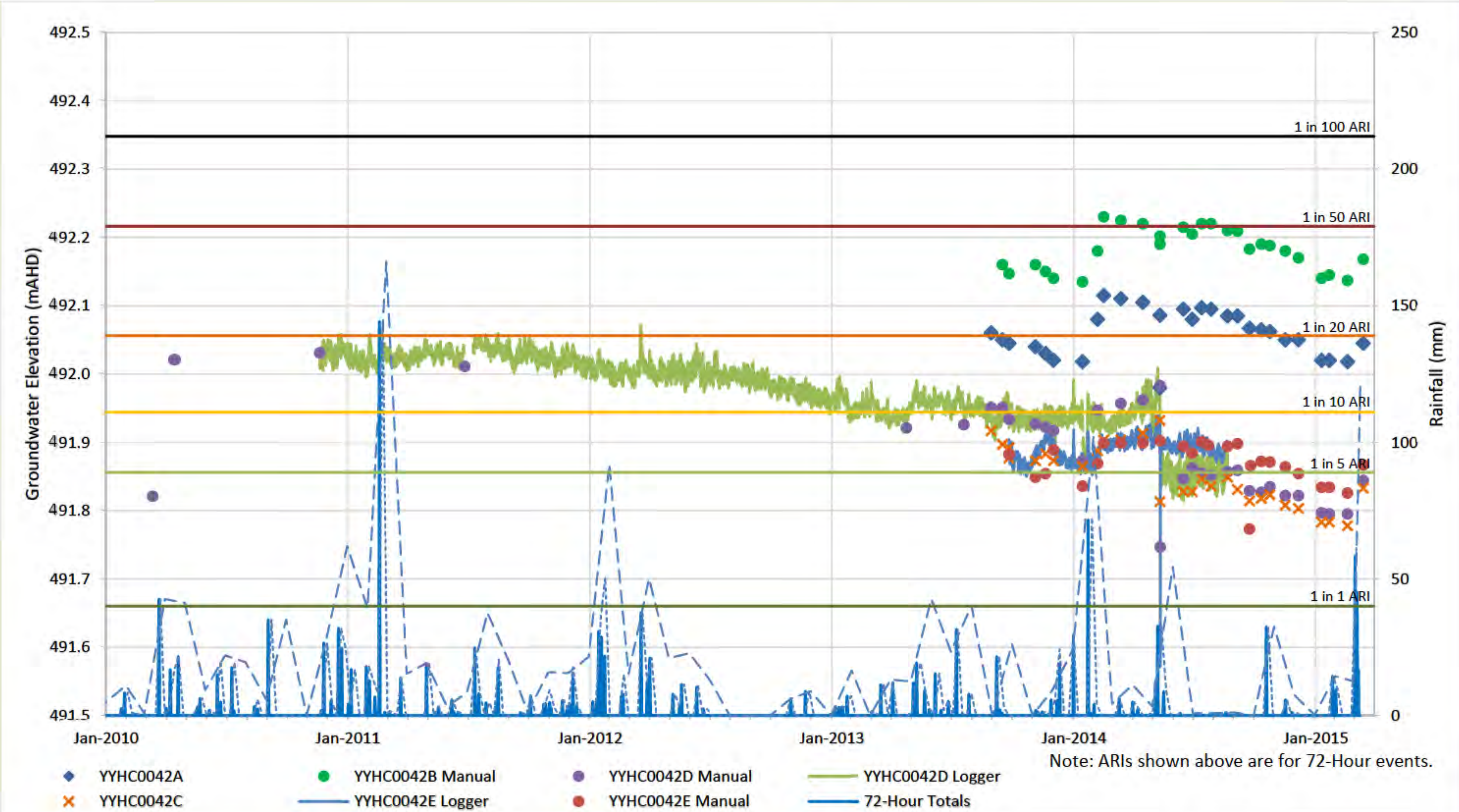


	Project:		Title:
Cameco / URS	Surface Water Study, Proposed Yeelirrie Project		Yeelirrie Playa Baseline Flood Maps Maximum Flow Velocity
	Drawn: RNM	Approved: BW / Date: 10/04/2015	Figure: 5-13 / Rev. A
	Job No. 42908794	File No. 42908794-SW-111.xls	A3



Source: Data sourced from Cameco Australia (2015)

Cameco URS	Project: **Surface Water Study, Proposed Yeelirrie Project**				Title: HYDROGRAPHS AND RAINFALL PLOT FOR BORES YYHC0042B, YYHC0042D and YYHC0042E	
	Drawn: RM/RNM	Approved: RW	Date: 10/04/2015		Figure: 5-14	Rev. A
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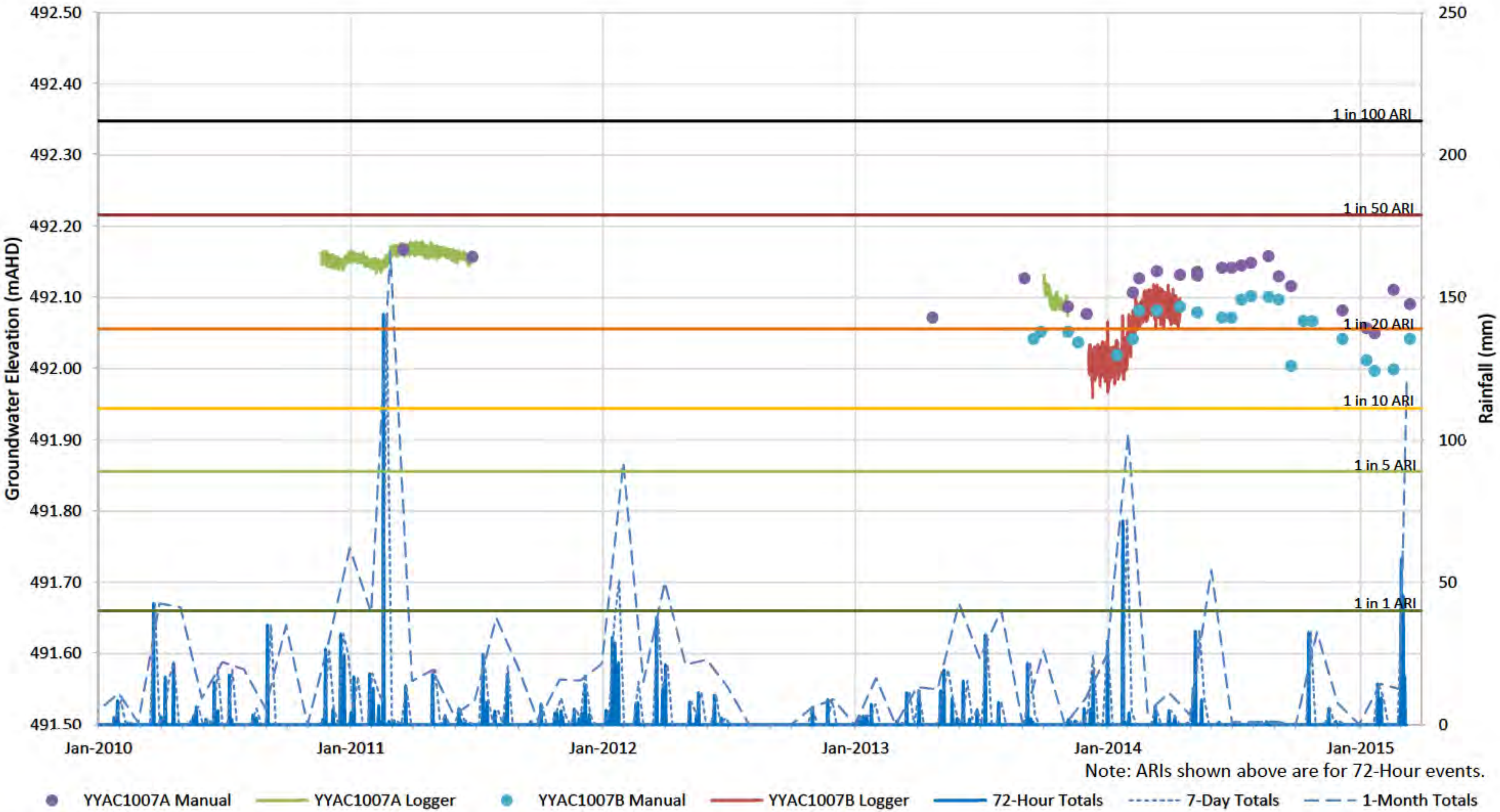
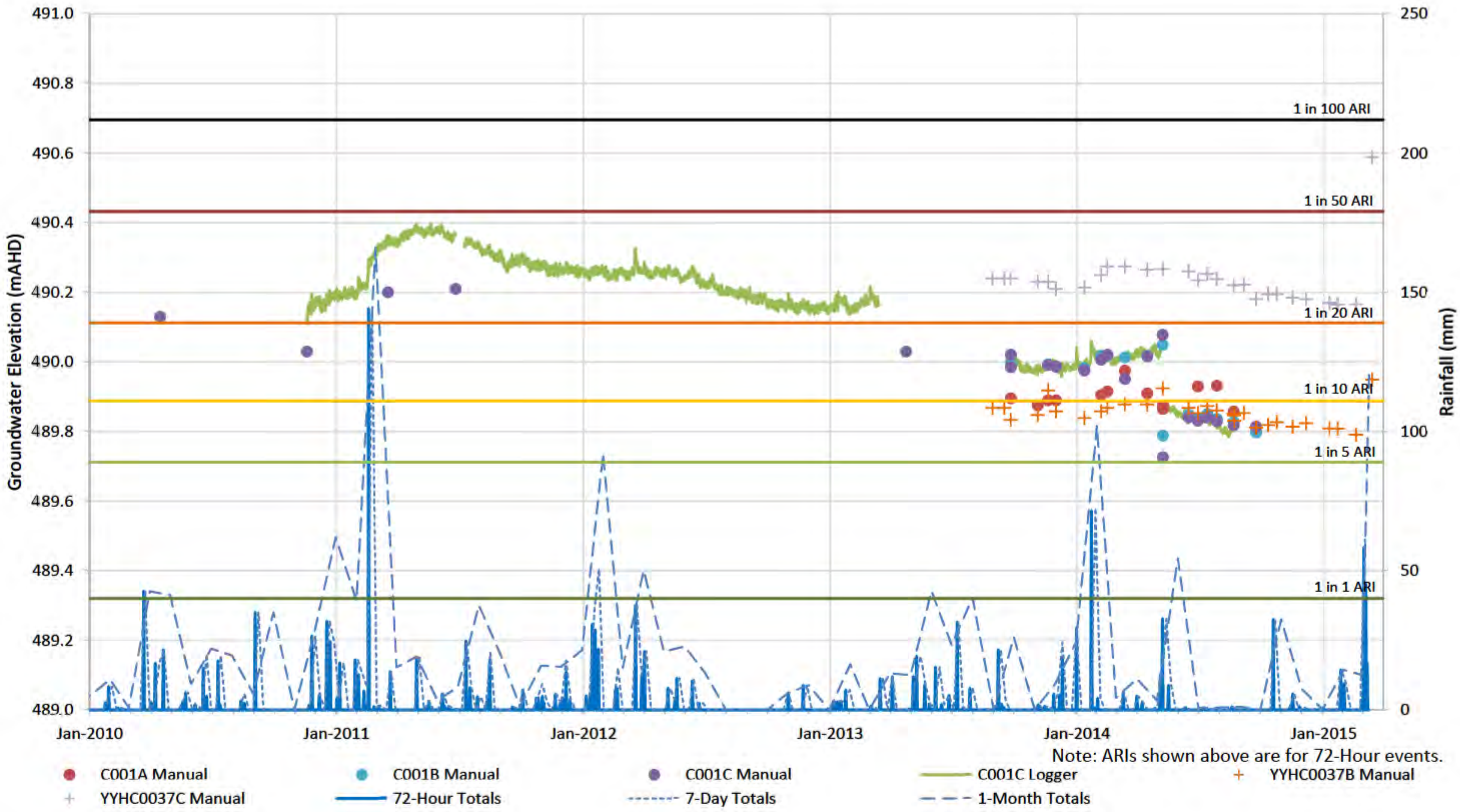


Source: Data sourced from Cameco Australia (2015)

Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**				Title: HYDROGRAPHS AND RAINFALL PLOT FOR BORES YYAC1007A, and YYAC1007B	
	Drawn: RM/RNM	Approved: RW	Date: 10/04/2015		Figure: 5-15	Rev. A
	Job No. 42908794	File No. 42908794-SW-114.xls				A4



Source: Data sourced from Cameco Australia (2015)

Cameco URS	Project: **Surface Water Study, Proposed Yeelirrie Project**				Title: HYDROGRAPHS AND RAINFALL PLOT FOR BORES C001A, C001B, C001C, YYHC0037B and YYHC0037C	
	Drawn: RM/RNM	Approved: RW	Date: 10/04/2015		Figure: 5-16	Rev. A
	Job No. 42908794	File No. 42908794-SW-116.xls				A4

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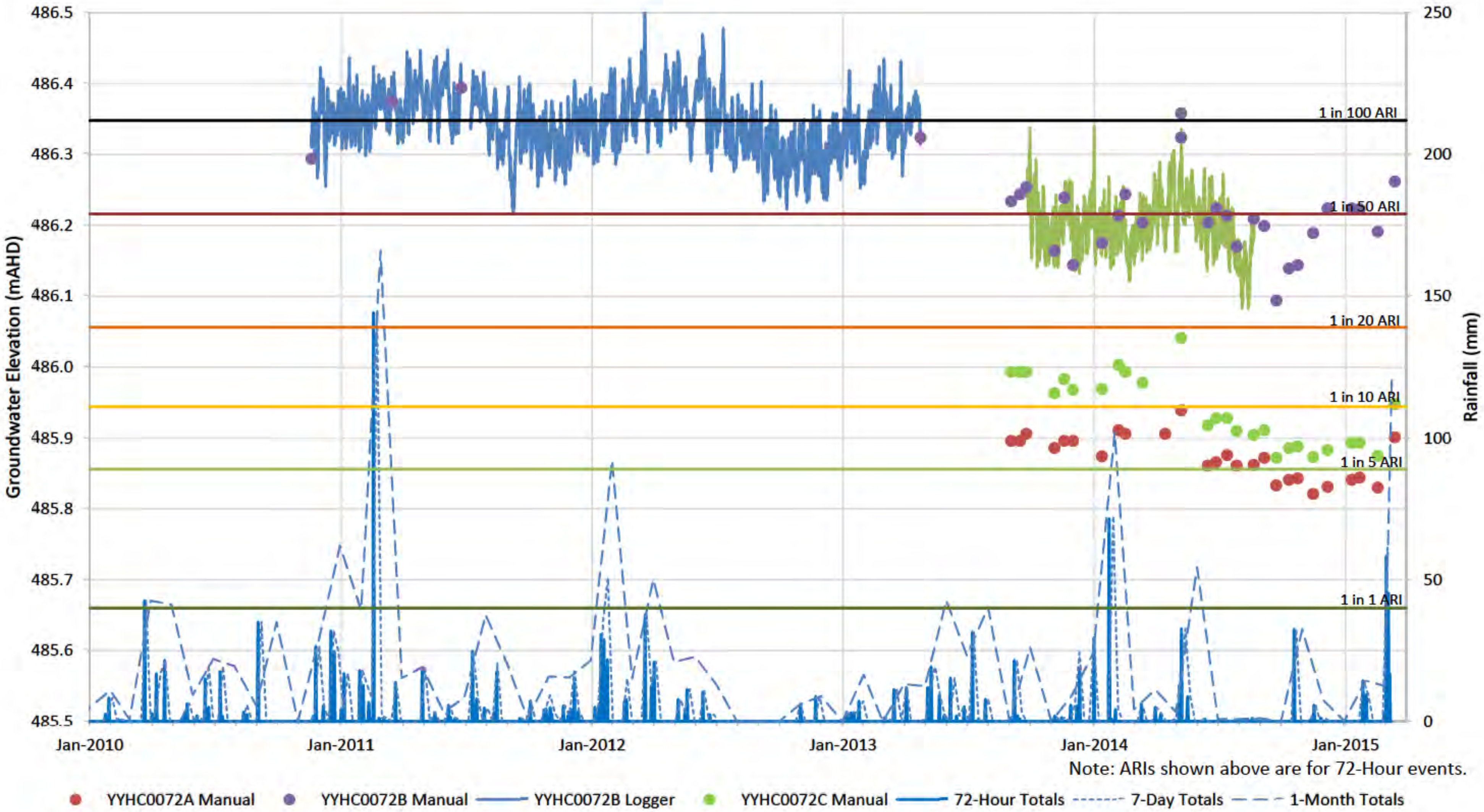

Source: Data sourced from Cameco Australia (2015)

Cameco URS	Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: HYDROGRAPHS AND RAINFALL PLOT FOR BORES YYHC0072A, YYHC0072B and YYHC0072C	
	Drawn: RM/RNM	Approved: RW	Date: 10/04/2015	Figure: 5-17	Rev. A
	Job No. 42908794	File No. 42908794-SW-117.xls			A4

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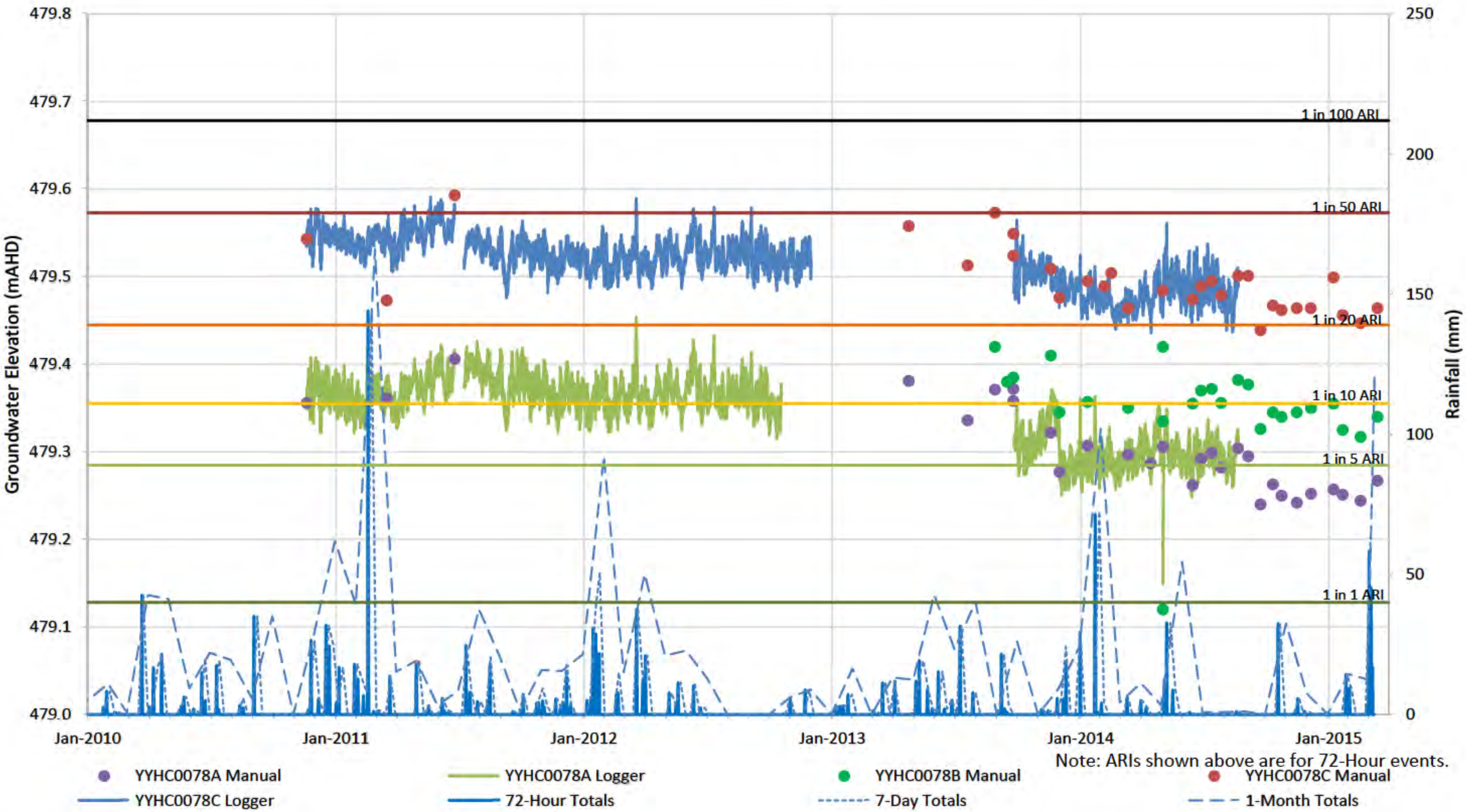

Source: Data sourced from Cameco Australia (2015)

Cameco URS	Project: **Surface Water Study, Proposed Yeelirrie Project**				Title: HYDROGRAPHS AND RAINFALL PLOT FOR BORES YYHC0078A, YYHC0078B, and YYHC0078C	
	Drawn: RM/RNM	Approved: RW	Date: 10/04/2015		Figure: 5-18	Rev. A
	Job No. 42908794	File No. 42908794-SW-118.xls				A4

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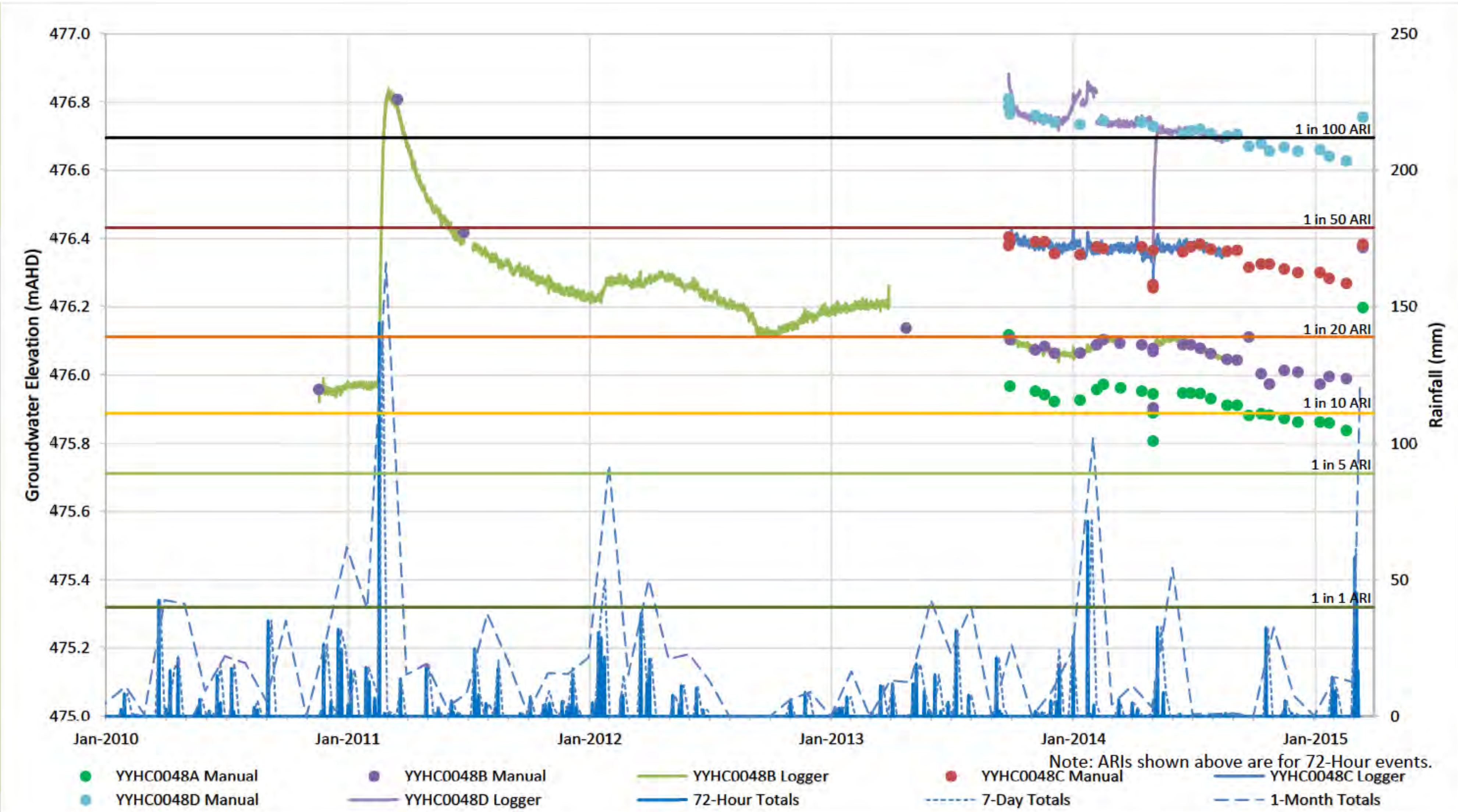

Source: Data sourced from Cameco Australia (2015)

Cameco URS	Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: HYDROGRAPHS AND RAINFALL PLOT FOR BORES YYHC0048A, YYHC0048B, YYHC0048C, and YYHC0078D	
	Drawn: RM/RNM	Approved: RW	Date: 10/04/2015	Figure: 5-19	Rev. A
	Job No. 42908794	File No. 42908794-SW-119.xls			A4

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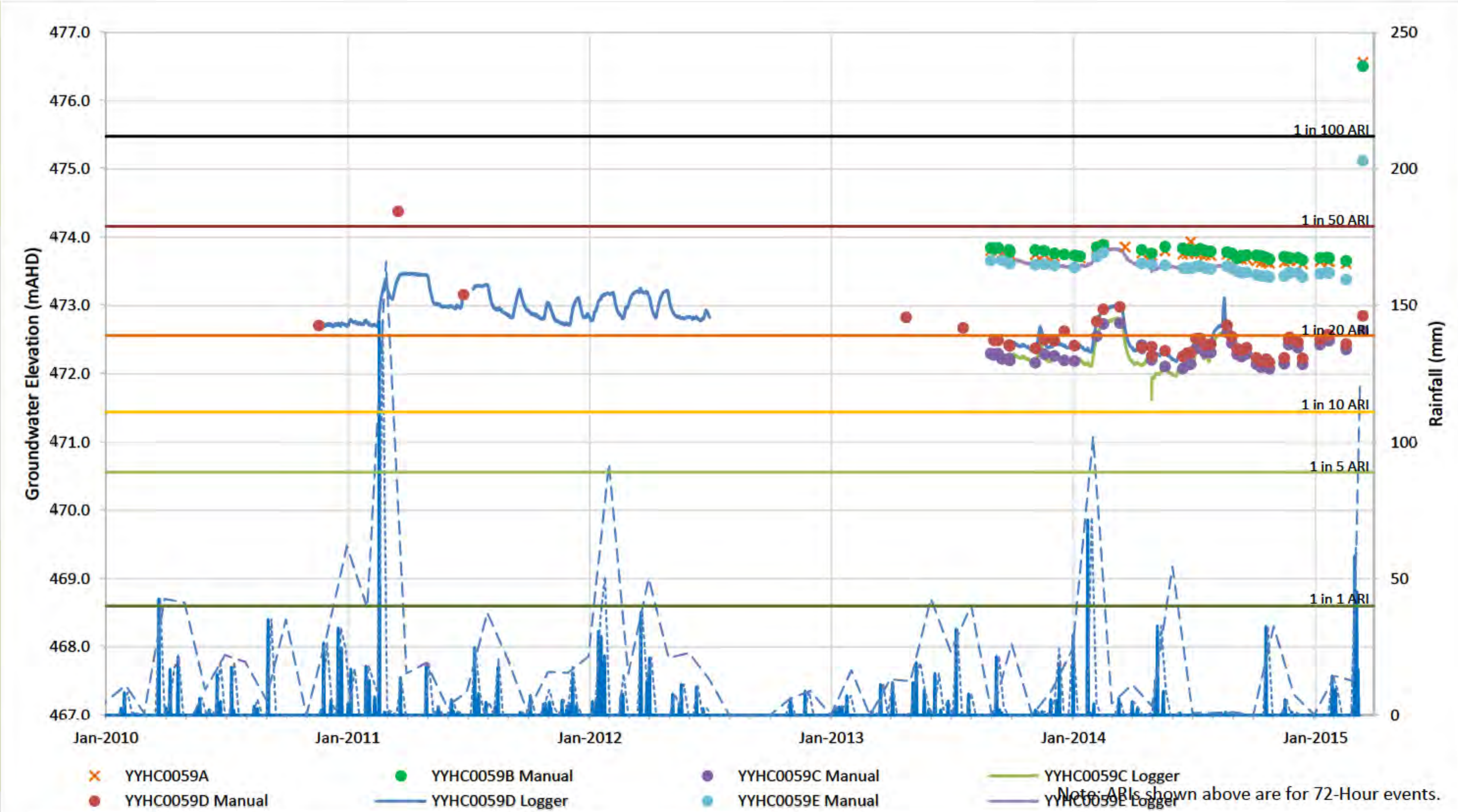

Source: Data sourced from Cameco Australia (2015)

Cameco

URS

Project:	Title:
Surface Water Study, Proposed Yeelirrie Project	HYDROGRAPHS AND RAINFALL PLOT FOR BORES YYHC0059B, YYHC0059C, YYHC0059D, and YYHC0059E

Drawn:	RM/RNM	Approved:	RW	Date:	10/04/2015	Figure:	5-20	Rev. A
Job No.	42908794	File No.	42908794-SW-120.xls					A4

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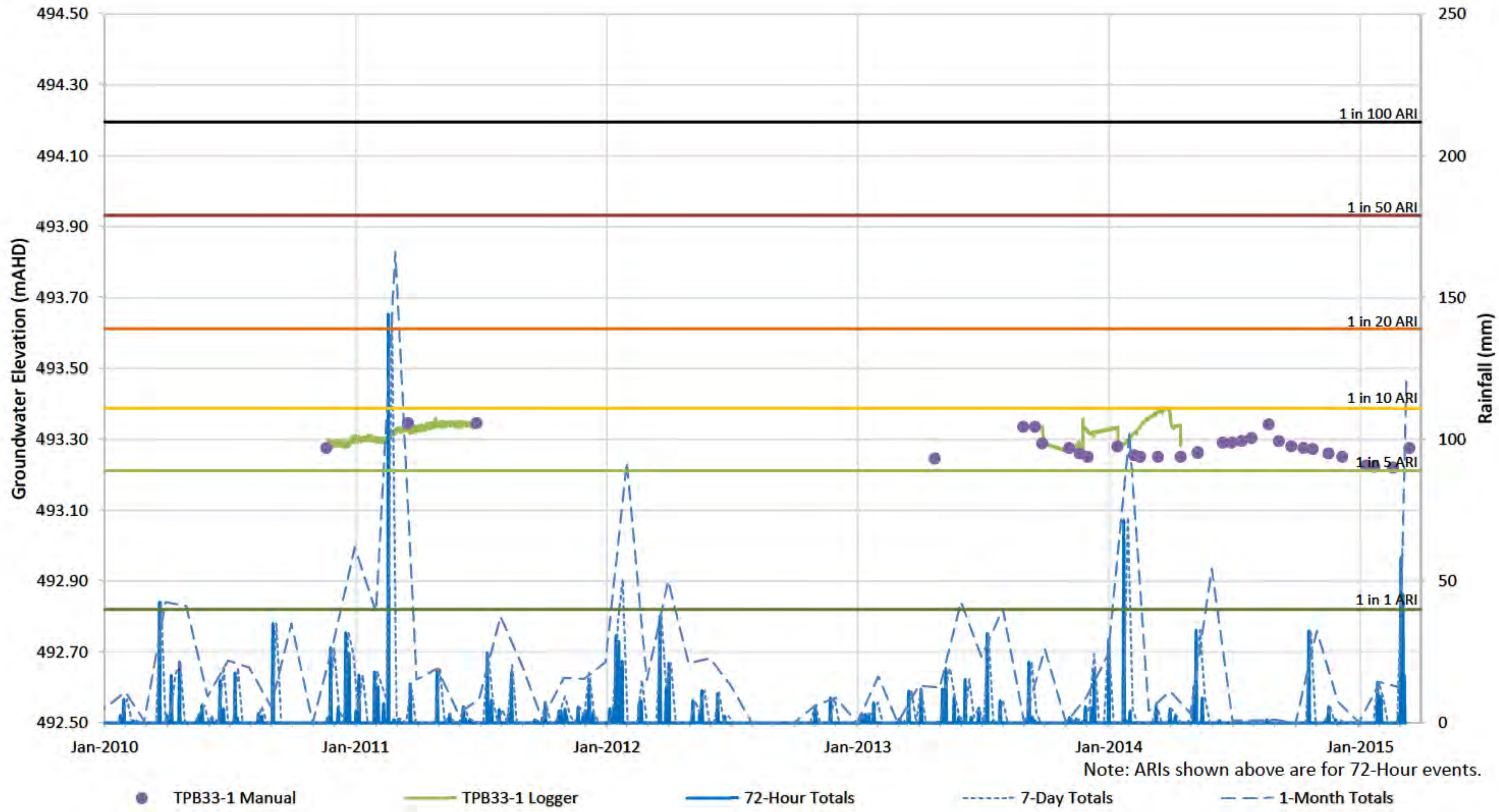

Source: Data sourced from Cameco Australia (2015)

Cameco URS	Project: **Surface Water Study, Proposed Yeelirrie Project**				Title: HYDROGRAPHS AND RAINFALL PLOT FOR BORE TPB33-1	
	Drawn: RM/RNM	Approved: RW	Date: 10/04/2015		Figure: 5-21	Rev. A
	Job No. 42908794	File No. 42908794-SW-121.xls				A4

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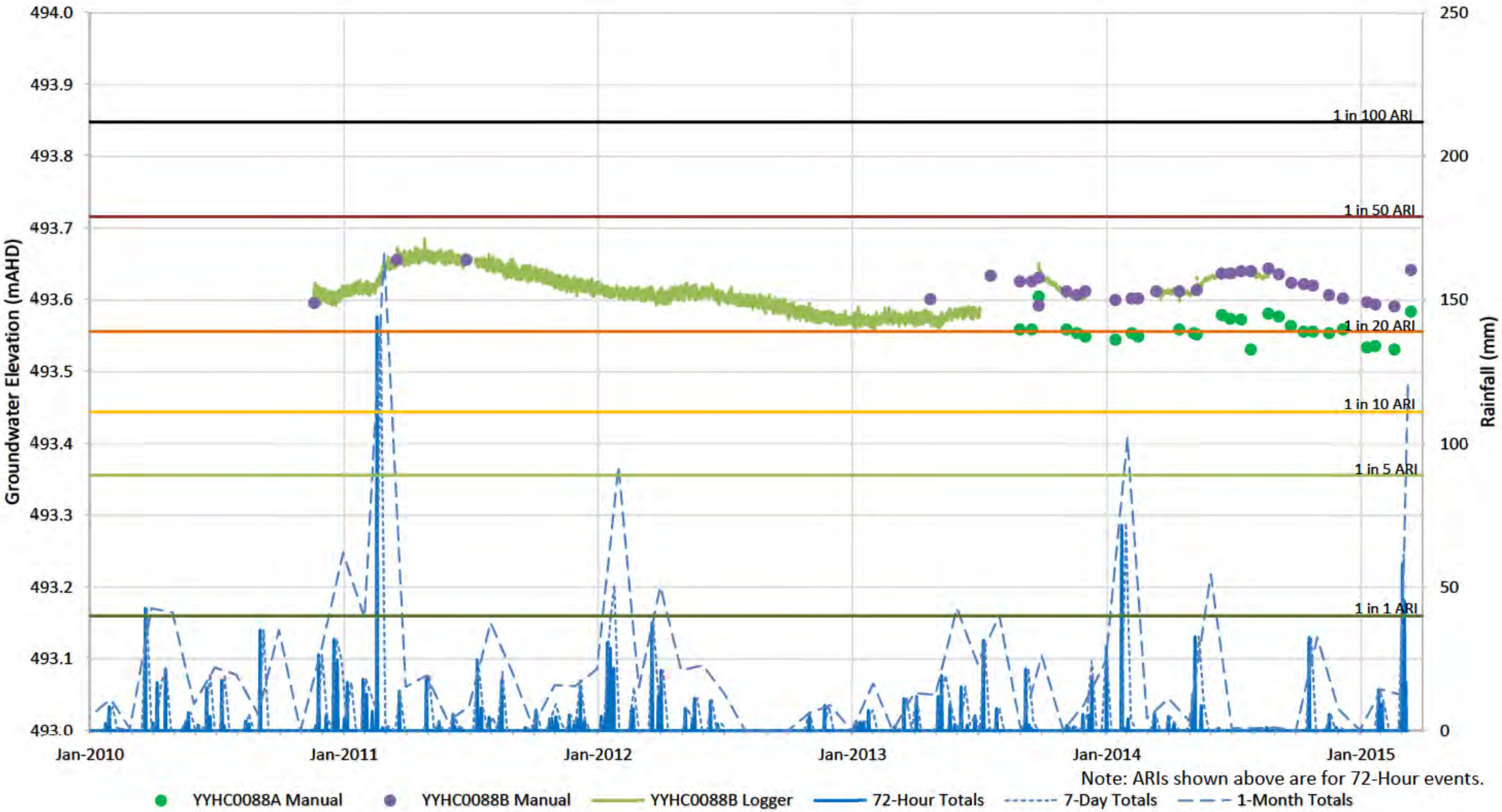

Source: Data sourced from Cameco Australia (2015)

Cameco

URS

Project:						Title:	
Surface Water Study, Proposed Yeelirrie Project						HYDROGRAPHS AND RAINFALL PLOT FOR BORES YYHC0088A and YYHC0088B	
Drawn:	RM/RNM	Approved:	RW	Date:	10/04/2015	Figure: 5-22	Rev. A
Job No.	42908794	File No.	42908794-SW-122.xls				A4

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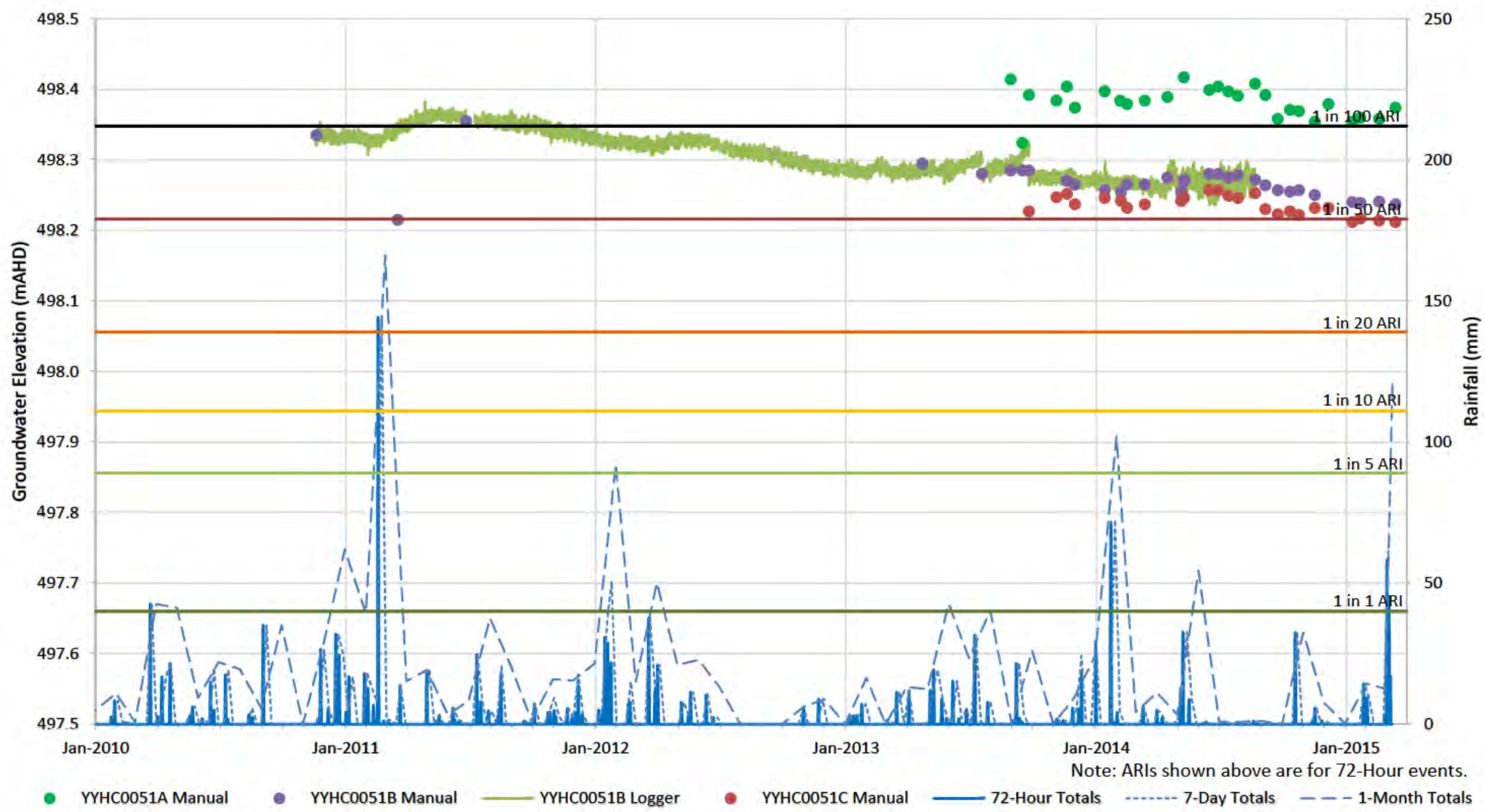

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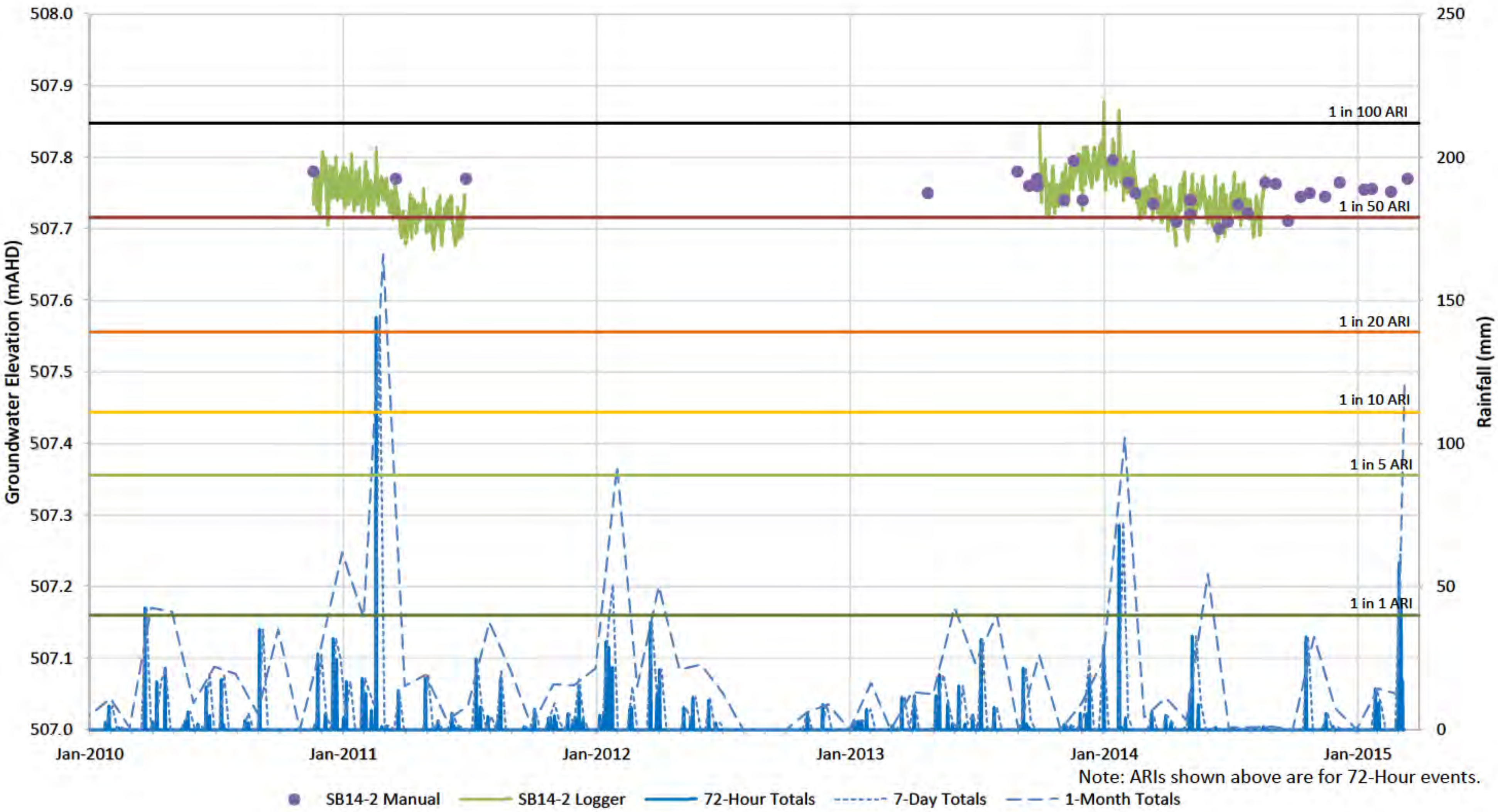
	Drawn: RM/RNM	Approved: RW		Date: 10/04/2015	Figure: 5-23	Rev. A
	Job No. 42908794	File No. 42908794-SW-123.xls				A4



Source: Data sourced from Cameco Australia (2015)

Cameco

URS

Project:

Surface Water Study, Proposed Yeelirrie Project

Title:

HYDROGRAPHS AND RAINFALL PLOT FOR BORE SB14/2

Drawn:	RM/RNM	Approved:	RW	Date:	10/04/2015	Figure: 5-24	Rev. A
Job No.	42908794	File No.	42908794-SW-124.xls				A4

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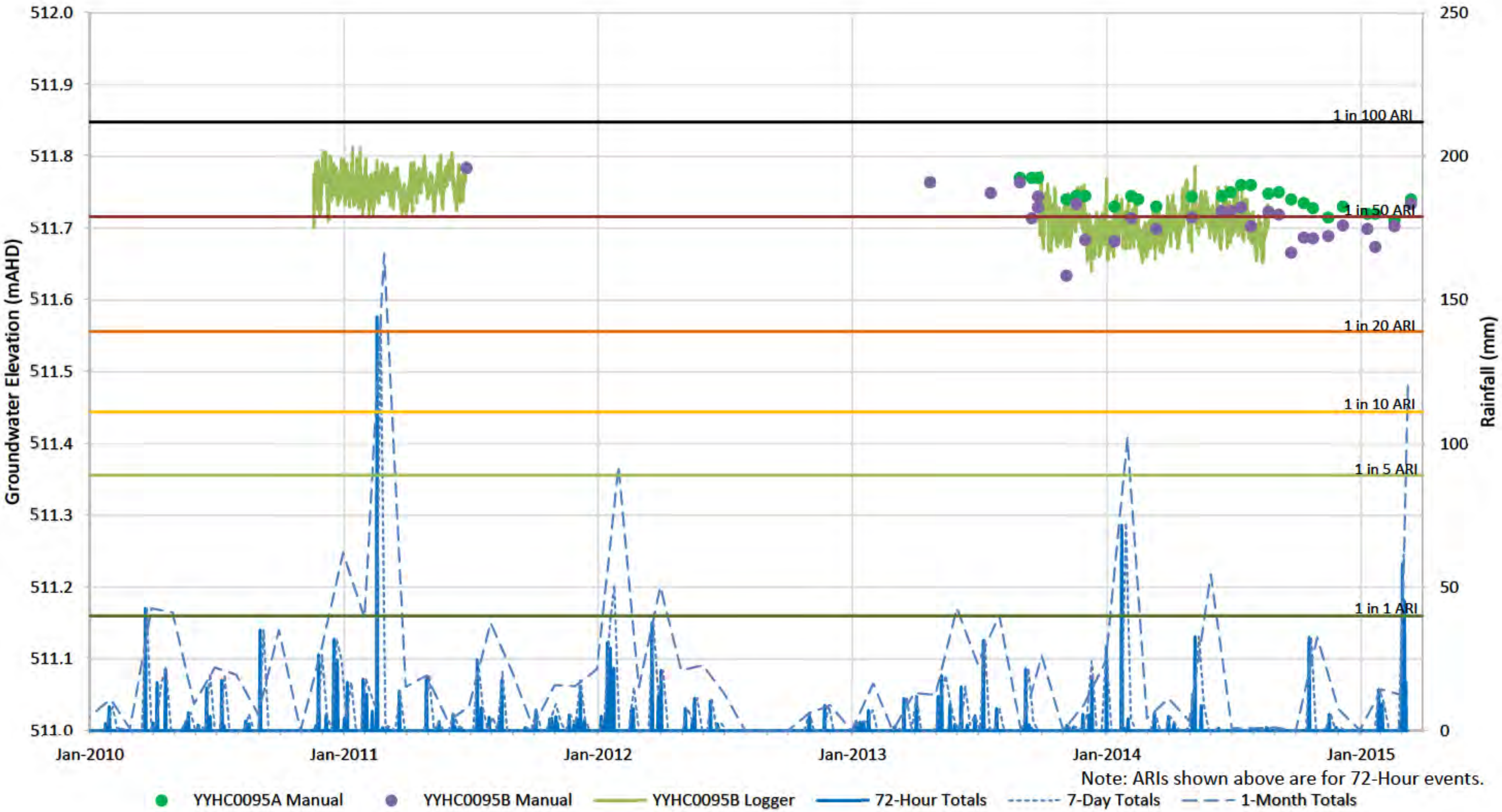

Source: Data sourced from Cameco Australia (2015)

Cameco

URS

Project: **Surface Water Study, Proposed Yeelirrie Project**				Title: HYDROGRAPHS AND RAINFALL PLOT FOR BORES YYHC0095A AND YYHC0095B	
Drawn: RM/RNM	Approved: RW	Date: 10/04/2015		Figure: 5-25	Rev. A
Job No. 42908794	File No. 42908794-SW-125.xls				A4

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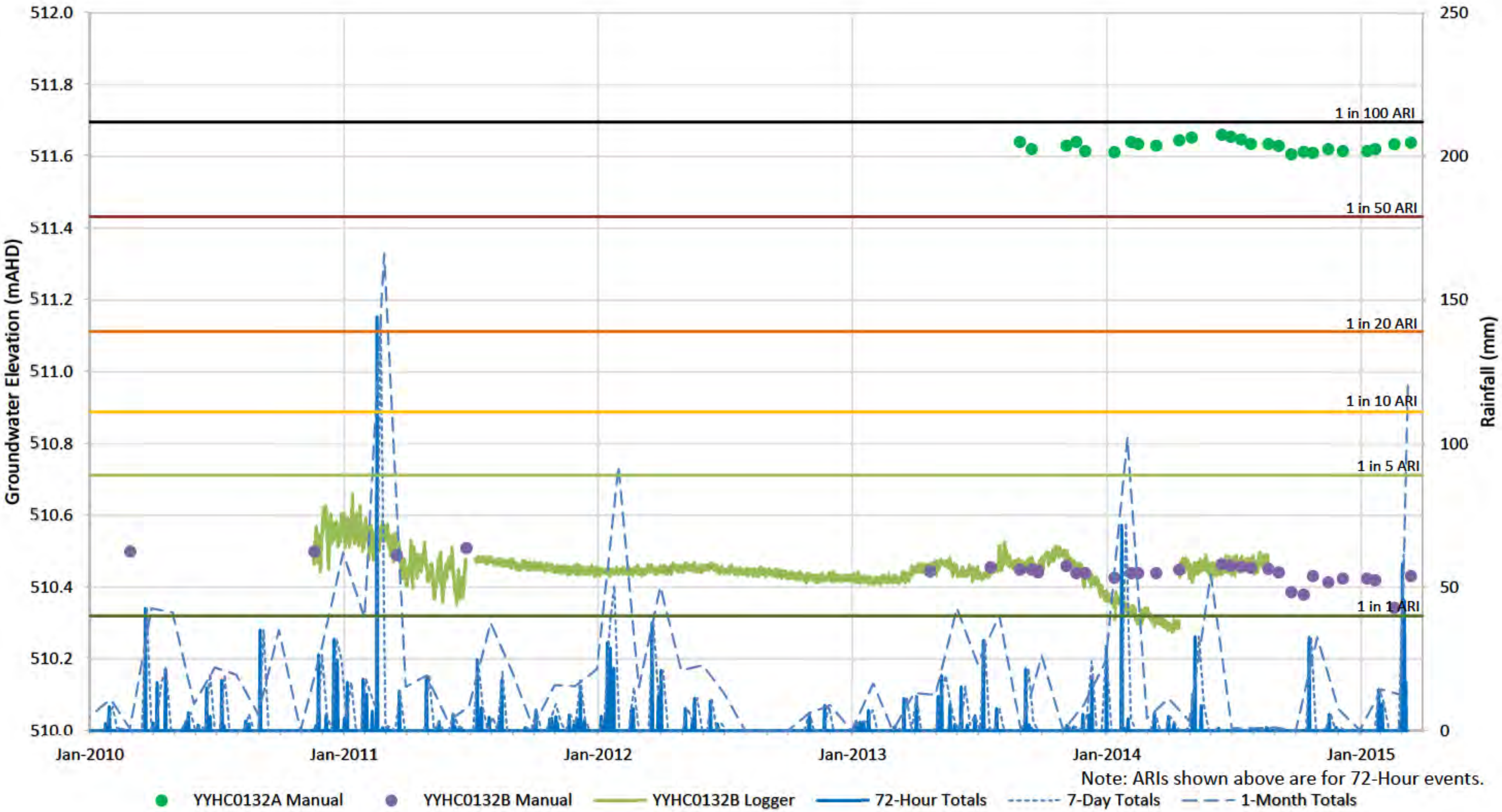

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Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: HYDROGRAPHS AND RAINFALL PLOT FOR BORES YYHC0132A and YYHC0132B	
	Drawn: RM/RNM	Approved: RW	Date: 10/04/2015	Figure: 5-26	Rev. A
	Job No. 42908794	File No. 42908794-SW-126.xls			A4

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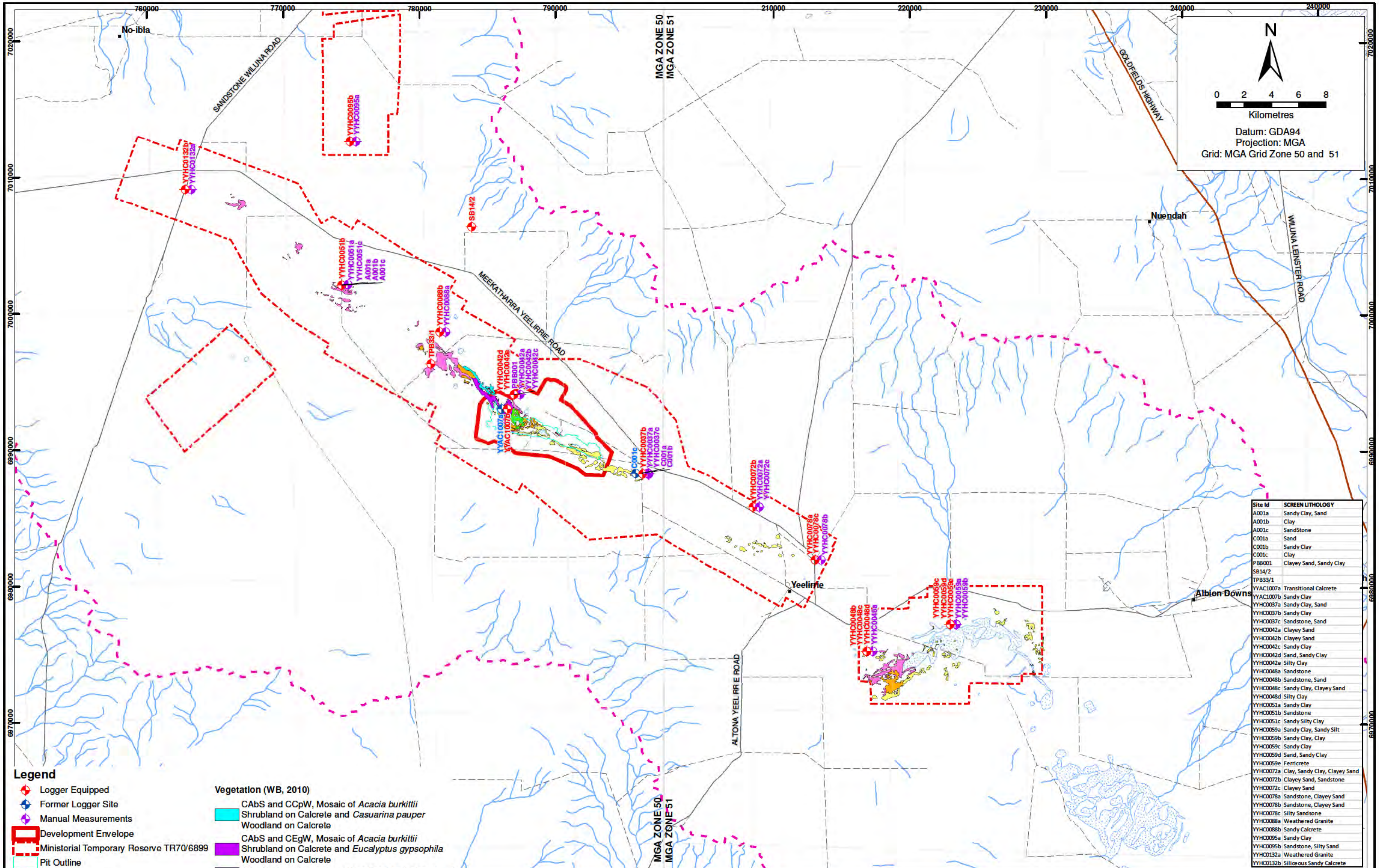

Site Id	SCREEN LITHOLOGY
A001a	Sandy Clay, Sand
A001b	Clay
A001c	SandStone
C001a	Sand
C001b	Sandy Clay
C001c	Clay
PBB001	Clayey Sand, Sandy Clay
SB14/2	
TPB33/1	
YYAC1007a	Transitional Calcrete
YYAC1007b	Sandy Clay
YYHC0037a	Sandy Clay, Sand
YYHC0037b	Sandy Clay
YYHC0037c	Sandstone, Sand
YYHC0042a	Clayey Sand
YYHC0042b	Clayey Sand
YYHC0042c	Sandy Clay
YYHC0042d	Sand, Sandy Clay
YYHC0042e	Silty Clay
YYHC0048a	Sandstone
YYHC0048b	Sandstone, Sand
YYHC0048c	Sandy Clay, Clayey Sand
YYHC0048d	Silty Clay
YYHC0051a	Sandy Clay
YYHC0051b	Sandstone
YYHC0051c	Sandy Silty Clay
YYHC0059a	Sandy Clay, Sandy Silt
YYHC0059b	Sandy Clay, Clay
YYHC0059c	Sandy Clay
YYHC0059d	Sand, Sandy Clay
YYHC0059e	Ferricrete
YYHC0072a	Clay, Sandy Clay, Clayey Sand
YYHC0072b	Clayey Sand, Sandstone
YYHC0072c	Clayey Sand
YYHC0078a	Sandstone, Clayey Sand
YYHC0078b	Sandstone, Clayey Sand
YYHC0078c	Silty Sandsone
YYHC0088a	Weathered Granite
YYHC0088b	Sandy Calcrete
YYHC0095a	Sandy Clay
YYHC0095b	Sandstone, Silty Sand
YYHC0132a	Weathered Granite
YYHC0132b	Siliceous Sandy Calcrete

Legend

- Logger Equipped
- Former Logger Site
- Manual Measurements
- Development Envelope
- Ministerial Temporary Reserve TR70/6899
- Pit Outline
- Yeelirrie Catchment
- Homesteads
- Major Road
- Minor Road
- Track
- Minor Watercourses
- Non-Perennial Lake

Vegetation (WB, 2010)

- CAbS and CCpW, Mosaic of *Acacia burkittii* Shrubland on Calcrete and *Casuarina pauper* Woodland on Calcrete
- CAbS and CEgW, Mosaic of *Acacia burkittii* Shrubland on Calcrete and *Eucalyptus gypsophila* Woodland on Calcrete
- CCpW, *Casuarina pauper* Woodland on Calcrete
- CEgW, *Eucalyptus gypsophila* Woodland on Calcrete
- CErG and CAbS and CEgW, Mosaic of *Eragrostis* sp. Grassland on Calcrete and *Acacia burkittii* Shrubland on Calcrete and *Eucalyptus gypsophila* Woodland on Calcrete
- CMxS, *Melaleuca xerophila* Shrubland on Calcrete

Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**		Title: Groundwater Monitoring Locations
	Drawn: RNM	Approved: RW	Date: 14/04/2015
	Job No.: 42908794	File No.: 42908794-SW-025.mxd	Figure: 5-27
			Rev. A
			A3

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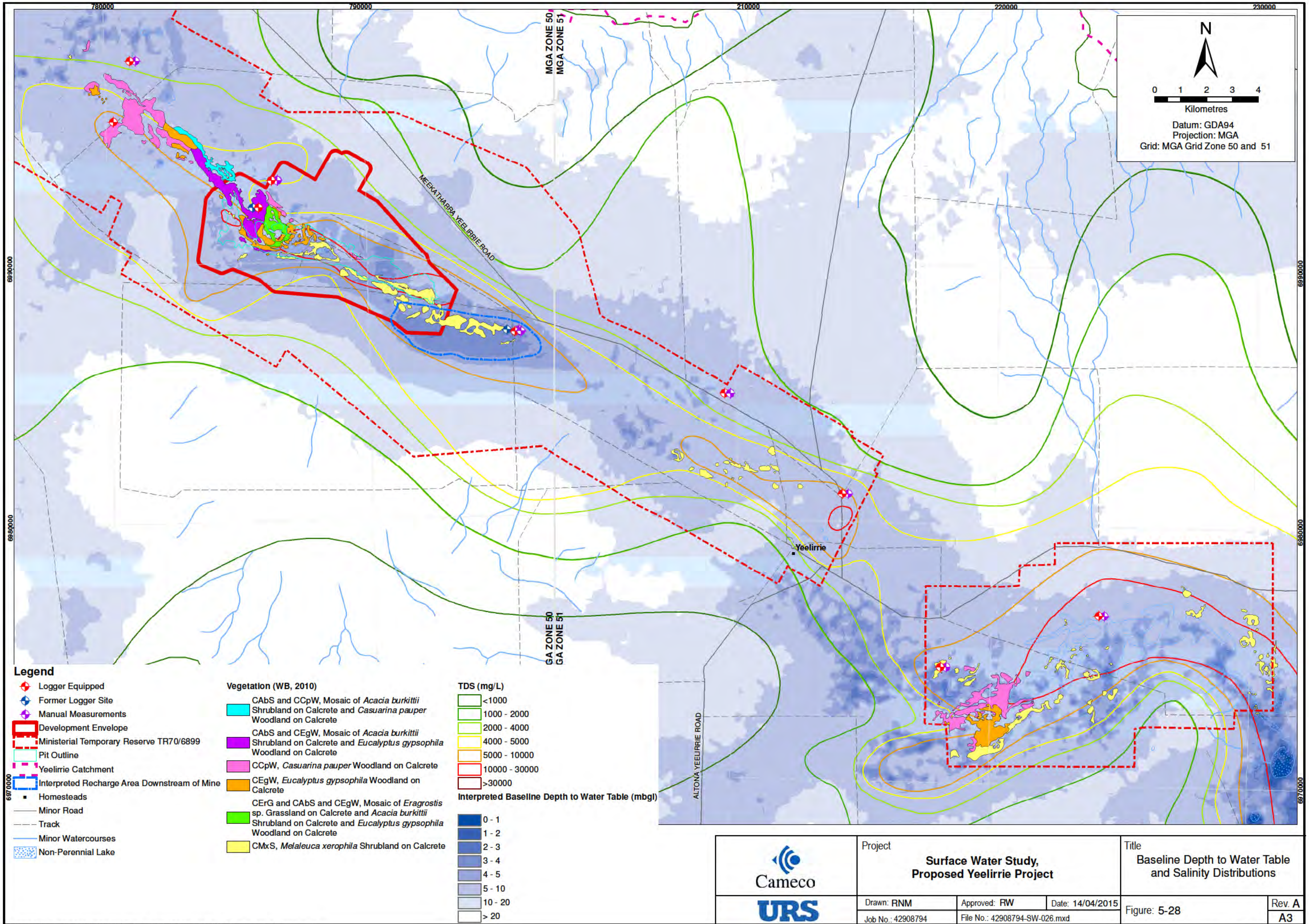

Title: Baseline Depth to Water Table and Salinity Distributions

Figure: 5-28

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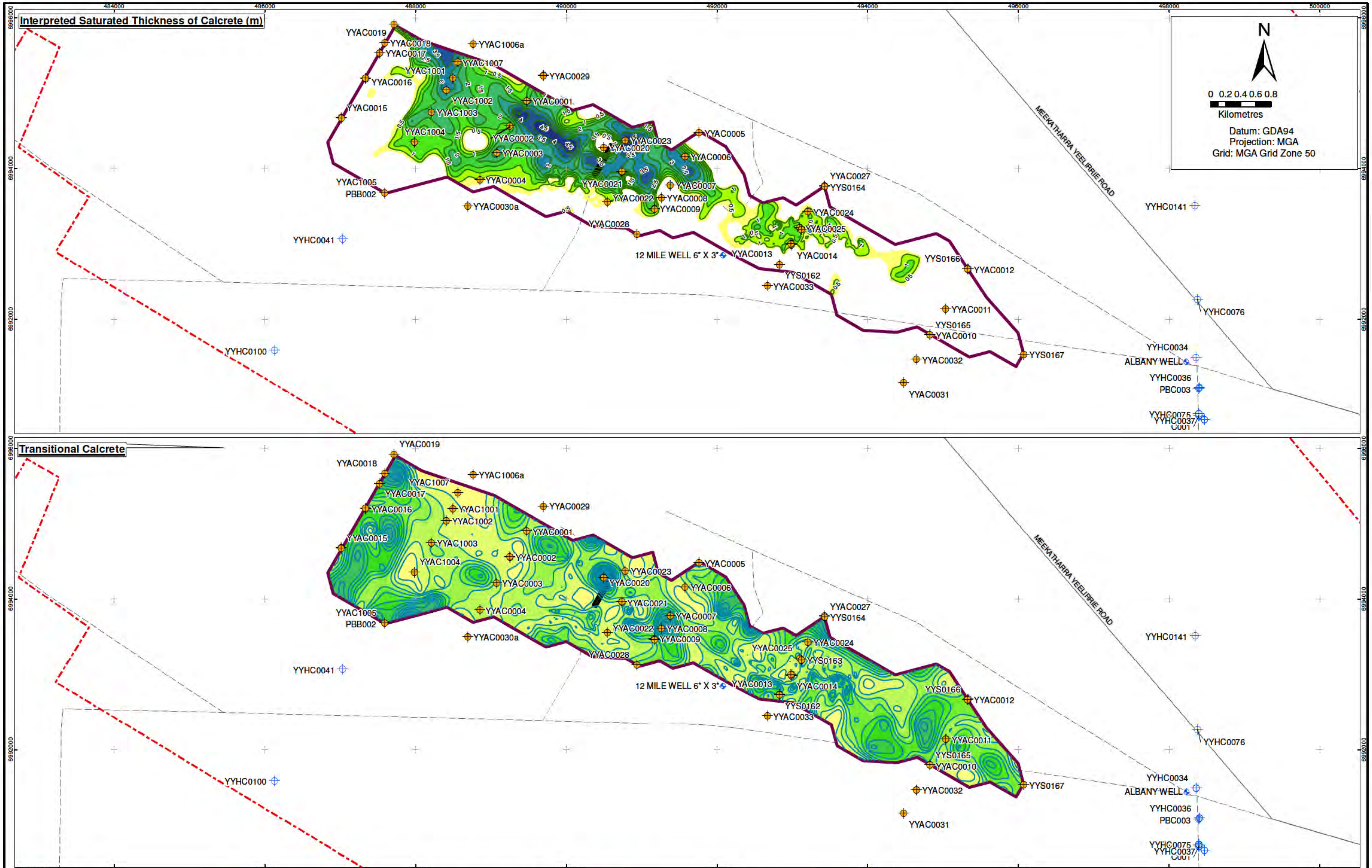

Legend

- Model Domain
- Slot1 Location
- Ministerial Temporary Reserve TR70/6899
- Infill Wells (URS)
- Regional Wells (URS)
- Pastoral Bores/Wells and Other
- Saturated Thickness Contours (m)

Interpreted Saturated Thickness of Calcrete (m)

- < 0.001
- 0.001 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 - 5

Roads (GA, 2007)

- Minor Road
- Track

Cameco

URS

Project	**Surface Water Study, Proposed Yeelirrie Project**	Title	Extent of Saturated Calcrete and Transitional Calcrete in the Proposed Mine Area
Drawn: RNM	Approved: RW	Date: 14/04/2015	Figure: 5-29
Job No.: 42908794	File No.: 42908794-SW-027.mxd		Rev. A
			A3

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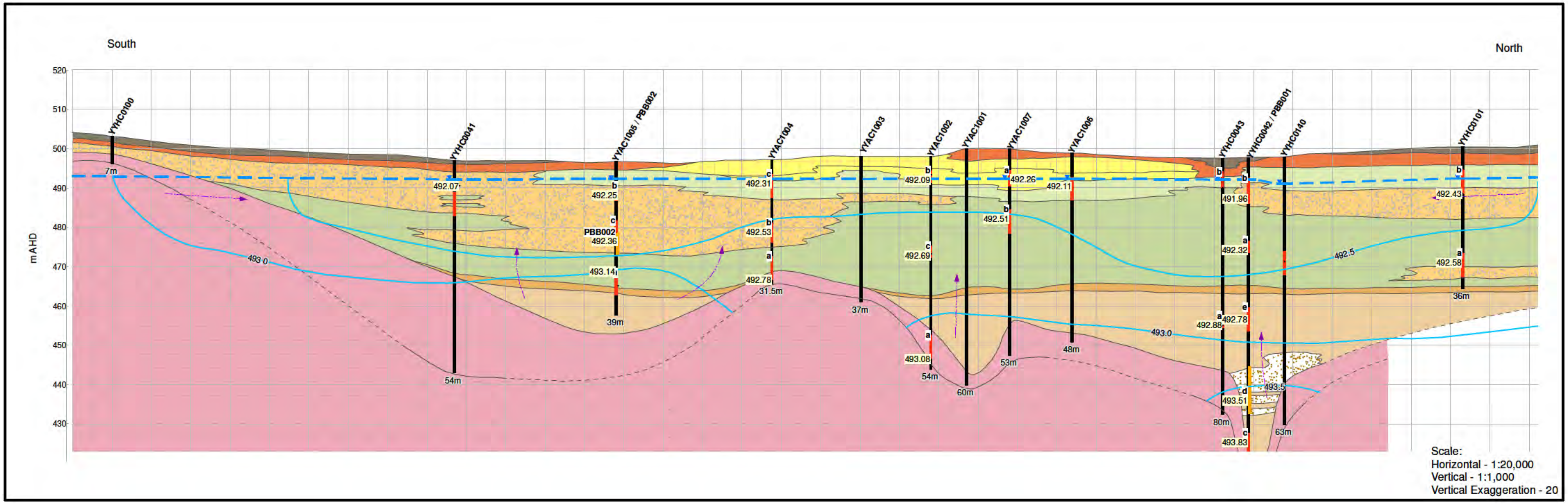

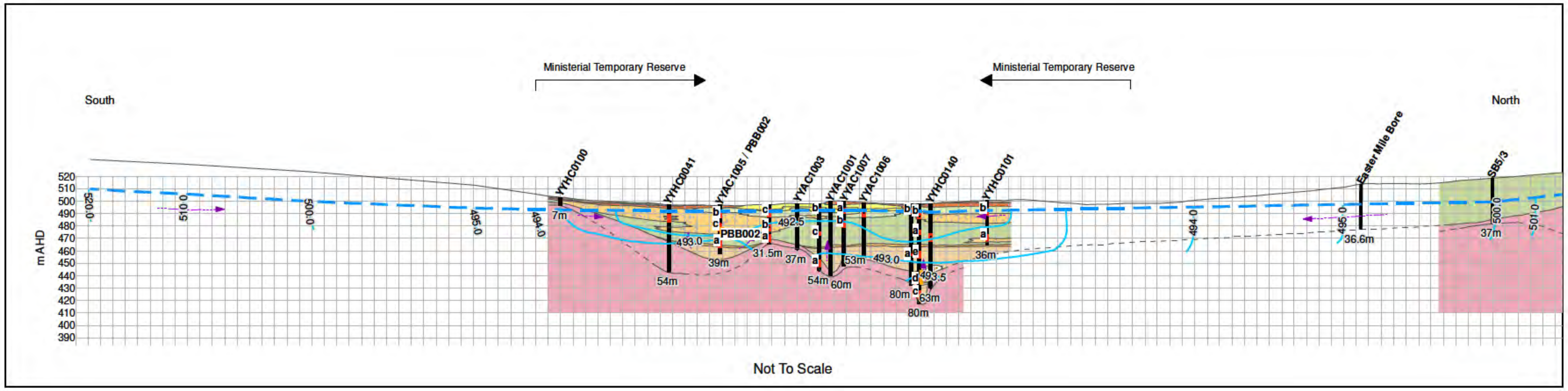

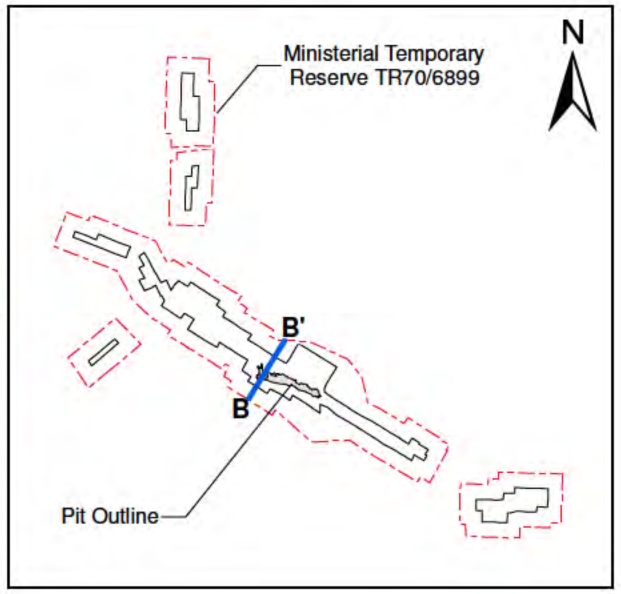

Legend

- Fresh Water Head Contours
- Interpreted Groundwater Flow Lines
- Well
- Inferred Boundary
- Lithological Boundary
- Groundwater Level (Typically for Shallowest Screened Interval)
- 499.40 Monitoring Well Slotted Interval and measured fresh-water head (mAHD)
- Production Well or Multipiezometer Slotted Interval

Quaternary/Recent

- Loam (Superficial Soil / Alluvium)
- Hardpan / Carbonated Hardpan
- Calcrete (Including Porcellanous & Earthy)
- Transitional Calcrete (Including Porcellarous & Earthy)
- Carbonated Clay Quartz
- Sandy Alluvium, Silty Sand, Silty Sandstone
- Clayey Alluvium,Silty Clay, Sandy Clay, Clayey Sand (Incl Clay Quartz)

Early-Tertiary

- Ferricrete / Dessicated Clay (Tertiary Unconformity Marker Bed)
- Palaeochannel Clay (Perkolilli Shale) Upper & Lower Section
- Dark Grey Clay (Carbonaceous Marker Bed)
- Mid-Palaeochannel Sand (Lower Section)
- Basal-Palaeochannel Sand (Wollubar Sandstone)

Archaean

- Weathered Granite
- Granite (Fresh)

Cameco / URS	Project: Surface Water Study, Proposed Yeelirrie Project	Title: Interpreted Stratigraphy and Groundwater Levels - Traverse B (2009)
Drawn: RNM	Approved: RW	Date: 14/04/2015
Job No.: 42908794	File No.: 42908794-SW-028.mxd	Figure: 5-30
Rev. A	A3	

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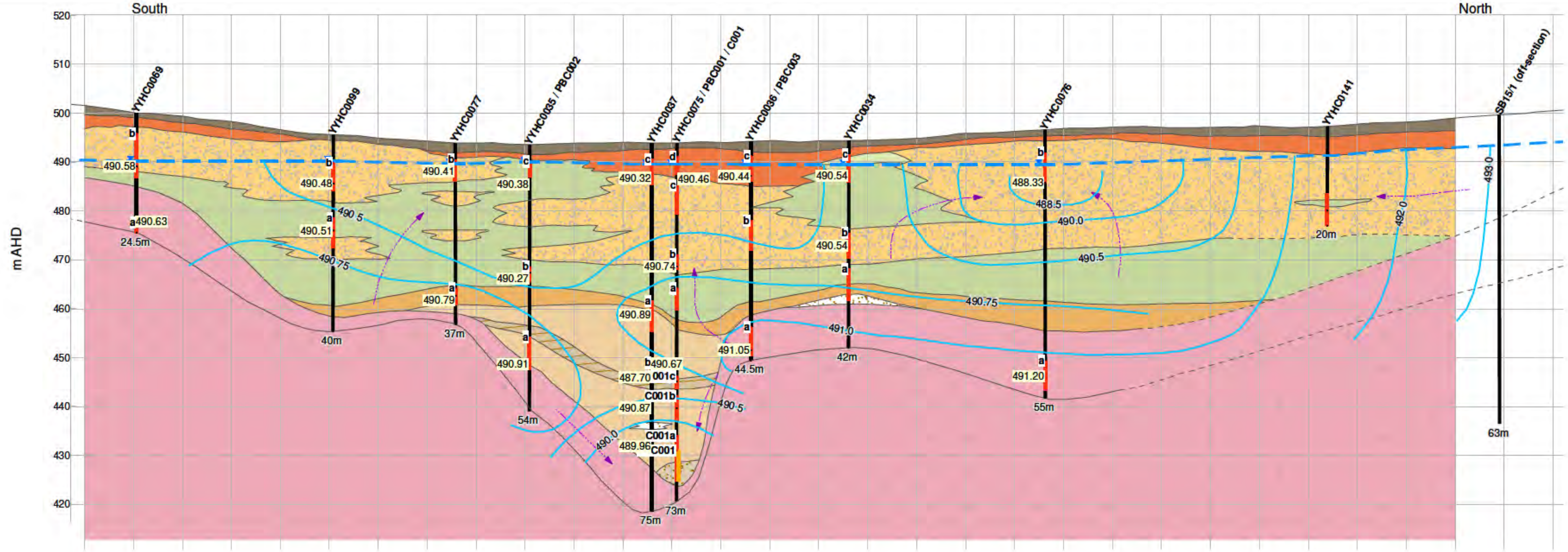

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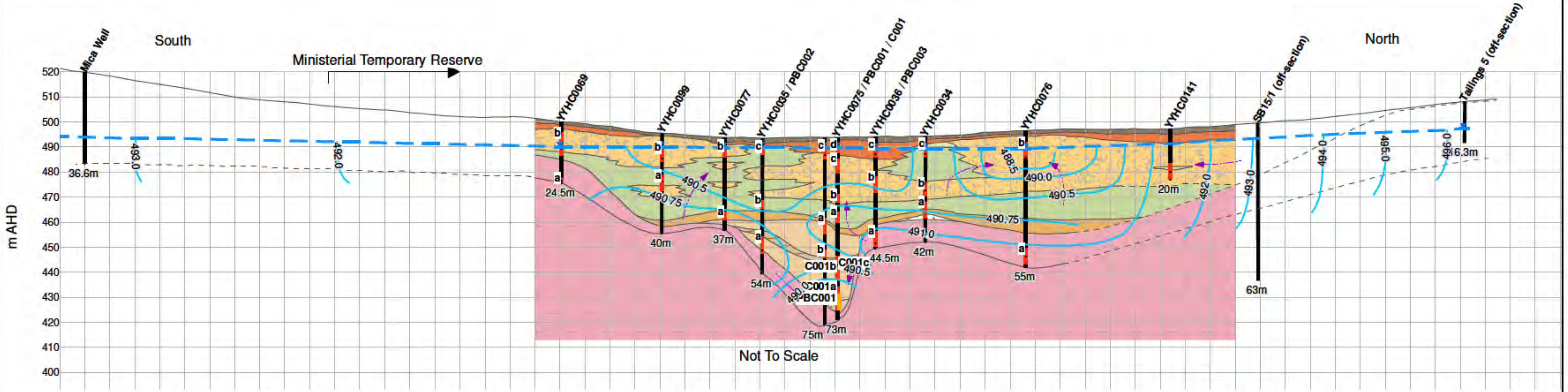
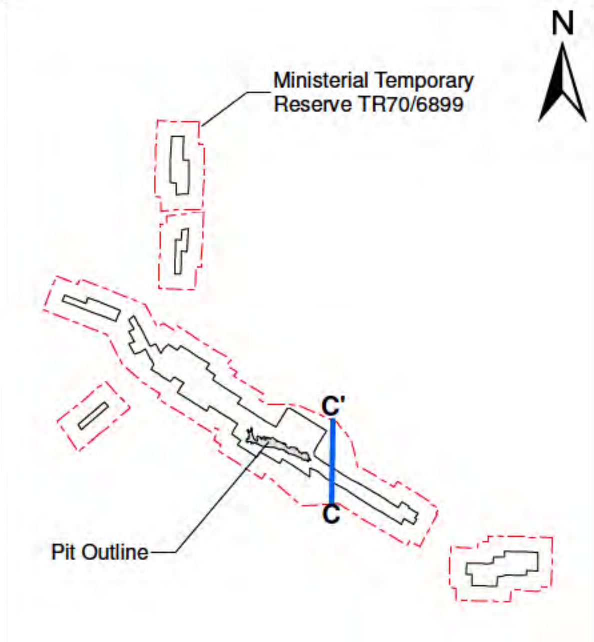
Vertical - 1:1,000
Vertical Exaggeration - 20





Legend

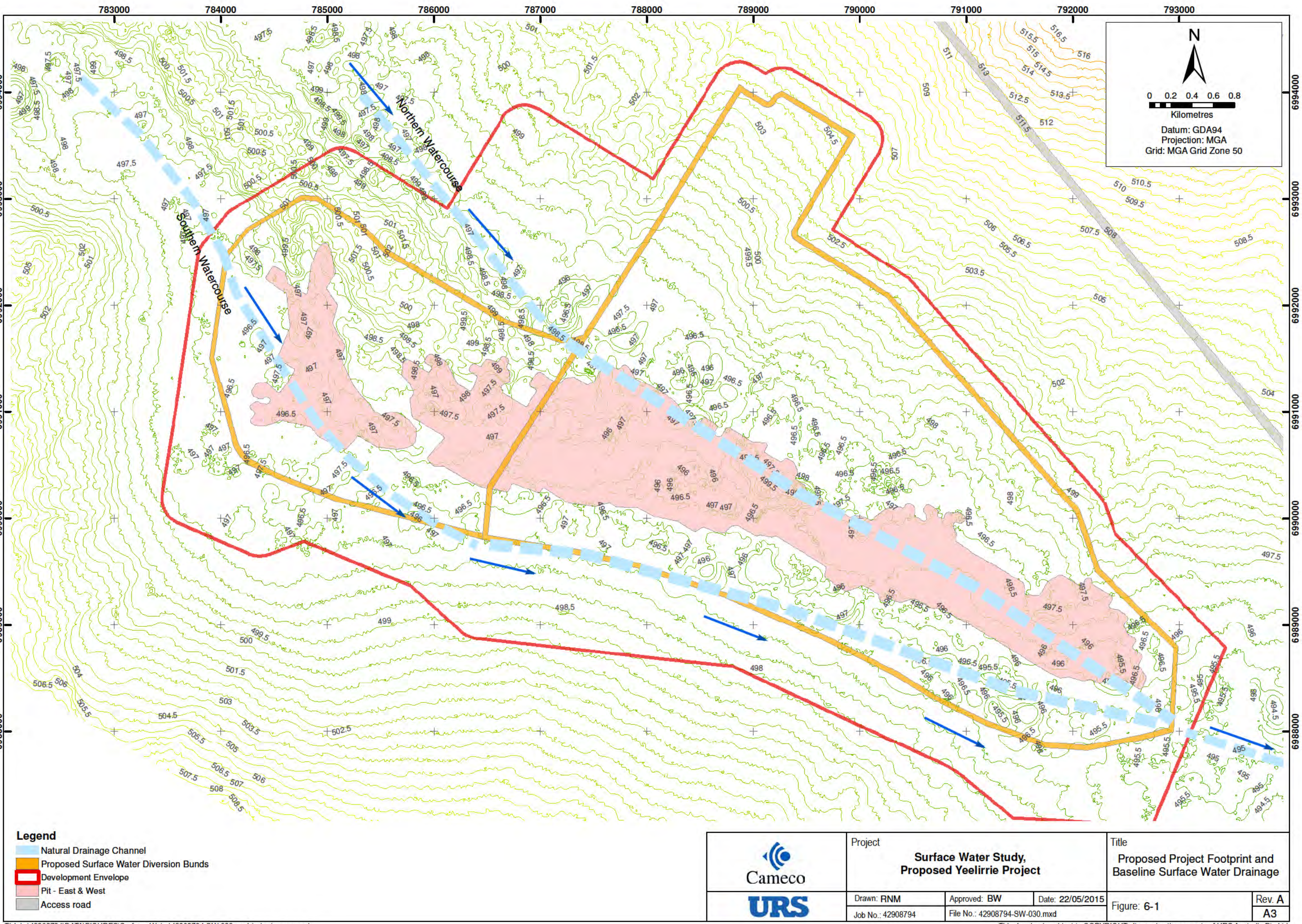
- Fresh Water Head Contours
- Inferred Groundwater Flow Lines
- Well
- Inferred Boundary
- Groundwater Level (Typically for Shallowest Screened Interval)
- Lithological Boundary
- 499.40 Monitoring Well Slotted Interval and measured fresh-water head (mAHD)
- Production Well or Multipiezometer Slotted Interval

Quaternary/Recent
- Loam (Superficial Soil / Alluvium)
- Hardpan / Carbonated Hardpan
- Calcrete (Including Porcellanous & Earthy)
- Transitional Calcrete (Including Porcellarous & Earthy)
- Carbonated Clay Quartz
- Sandy Alluvium, Silty Sand, Silty Sandstone
- Clayey Alluvium,Silty Clay, Sandy Clay, Clayey Sand (Incl Clay Quartz)

Early-Tertiary
- Ferricrete / Dessicated Clay (Tertiary Unconformity Marker Bed)
- Palaeochannel Clay (Perkolilli Shale) Upper & Lower Section
- Dark Grey Clay (Carbonaceous Marker Bed)
- Mid-Palaeochannel Sand (Lower Section)
- Basal-Palaeochannel Sand (Wollubar Sandstone)

Archaean
- Weathered Granite
- Granite (Fresh)

Cameco / URS	Project: Surface Water Study, Proposed Yeelirrie Project		Title: Interpreted Stratigraphy and Groundwater Levels - Traverse C (2009)	
	Drawn: RNM	Approved: RW	Date: 14/04/2015	
	Job No.: 42908794	File No.: 42908794-SW-029.mxd	Figure: 5-31	Rev. A A3



Cameco URS	Project: **Surface Water Study, Proposed Yeelirrie Project**	Title: Proposed Project Footprint and Baseline Surface Water Drainage
	Drawn: RNM / Approved: BW / Date: 22/05/2015	Figure: 6-1 / Rev. A
	Job No.: 42908794 / File No.: 42908794-SW-030.mxd	A3

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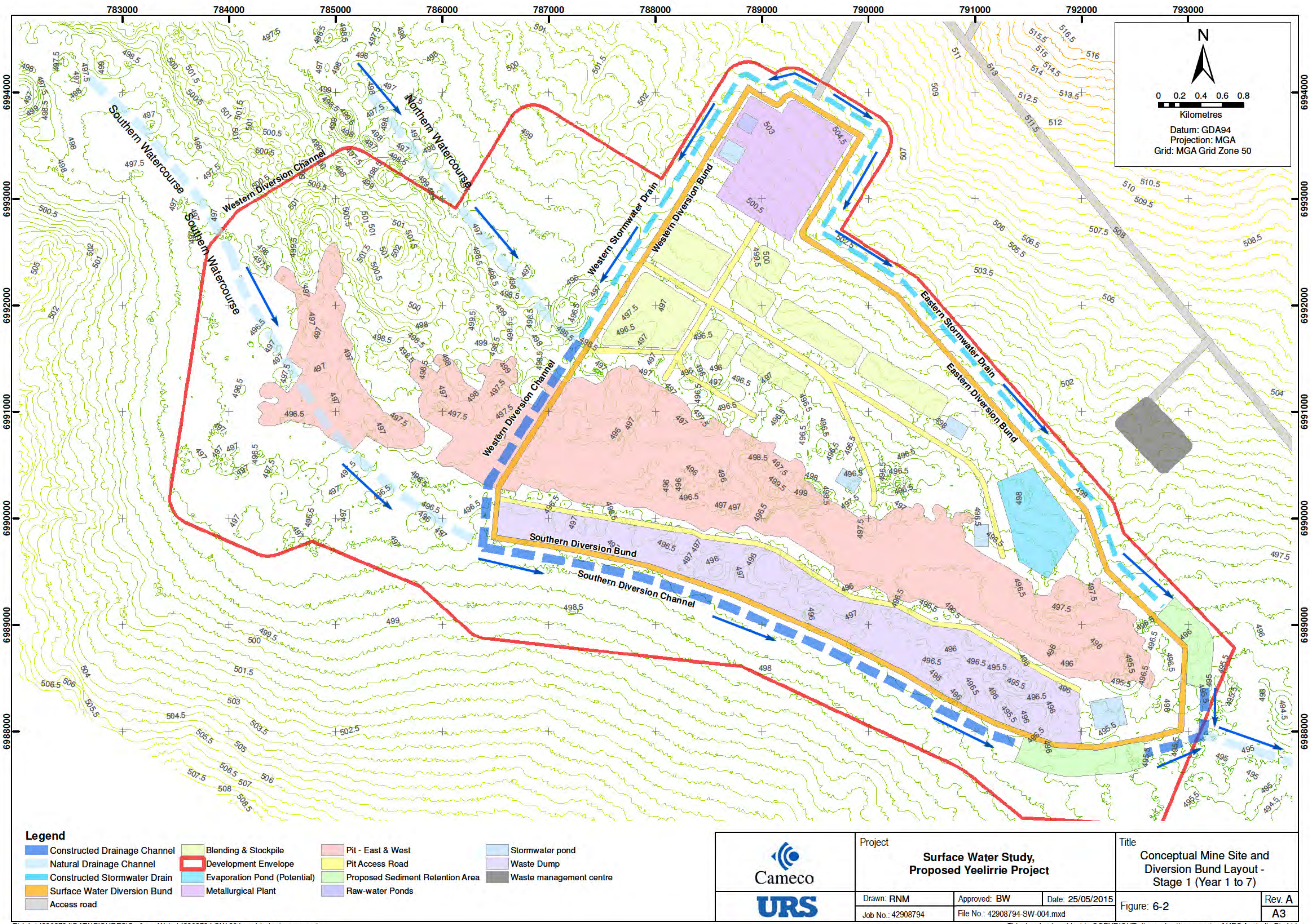

Cameco

URS

Project

Surface Water Study, Proposed Yeelirrie Project

Title

Conceptual Mine Site and Diversion Bund Layout - Stage 1 (Year 1 to 7)

Drawn: RNM	Approved: BW	Date: 25/05/2015	Figure: 6-2	Rev. A
Job No.: 42908794	File No.: 42908794-SW-004.mxd			A3

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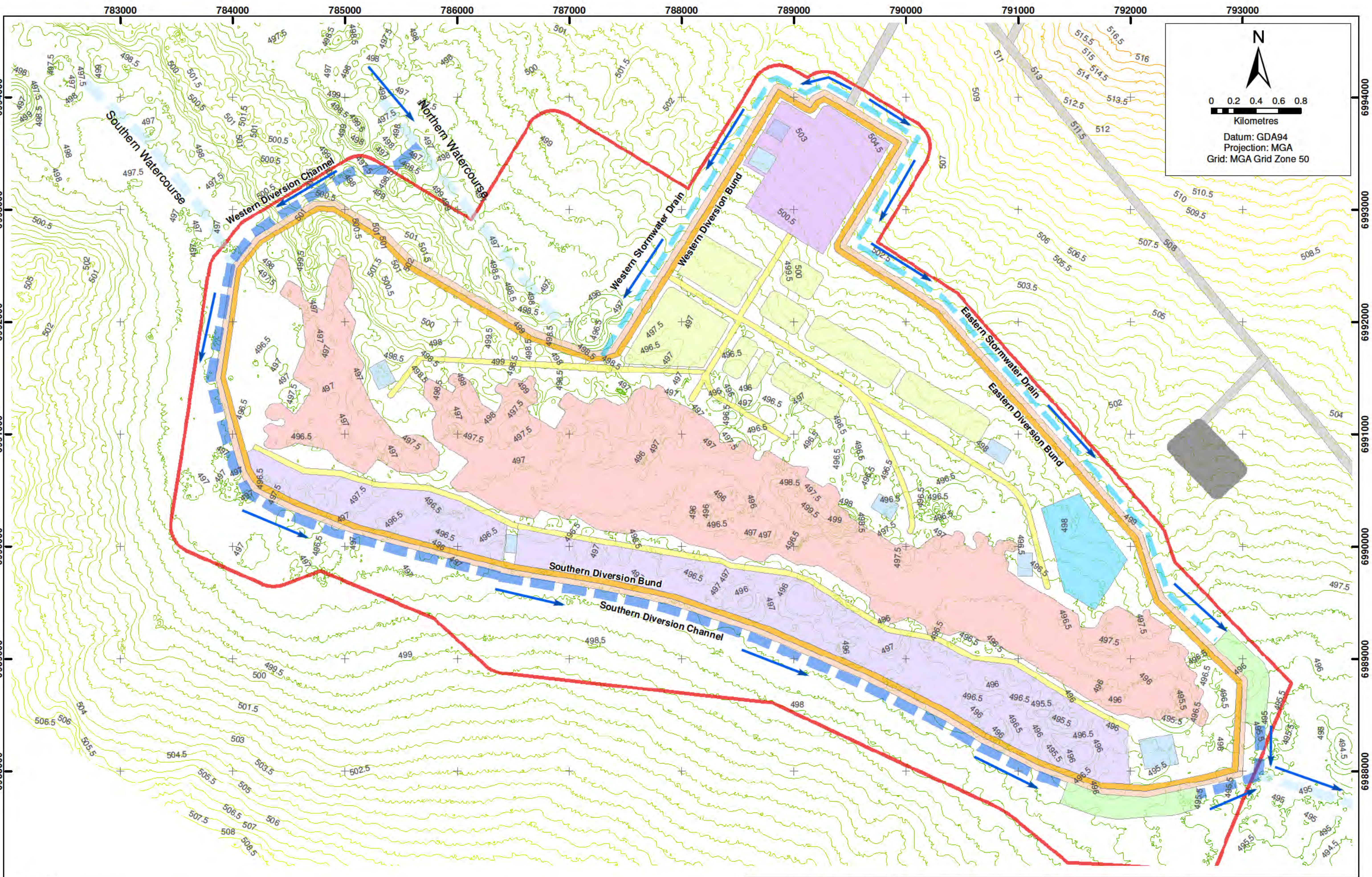

Legend

- Constructed Drainage Channel
- Natural Drainage Channel
- Constructed Stormwater Drain
- Surface Water Diversion Bund
- Access road
- Blending & Stockpile
- Development Envelope
- Evaporation Pond (Potential)
- Metallurgical Plant
- Perimter Track
- Pit - East & West
- Pit Access Road
- Proposed Sediment Retention Area
- Raw-water Ponds
- Stormwater pond; Surface Water Pond
- Waste Dump
- Waste management centre

Cameco

URS

Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: Conceptual Mine Site and Diversion Bund Layout - Stage 2 (Year 8 to 22)
Drawn: RNM	Approved: BW	Date: 25/05/2015	Figure: 6-3 — Rev. A
Job No.: 42908794	File No.: 42908794-SW-005.mxd		A3

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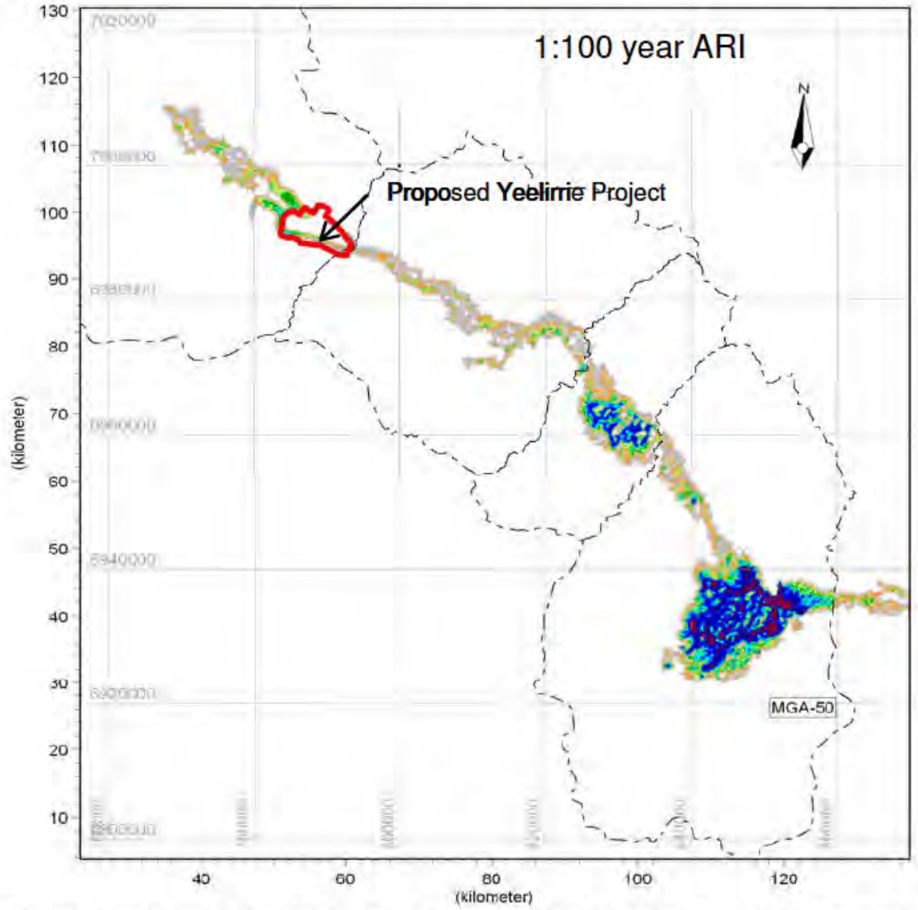
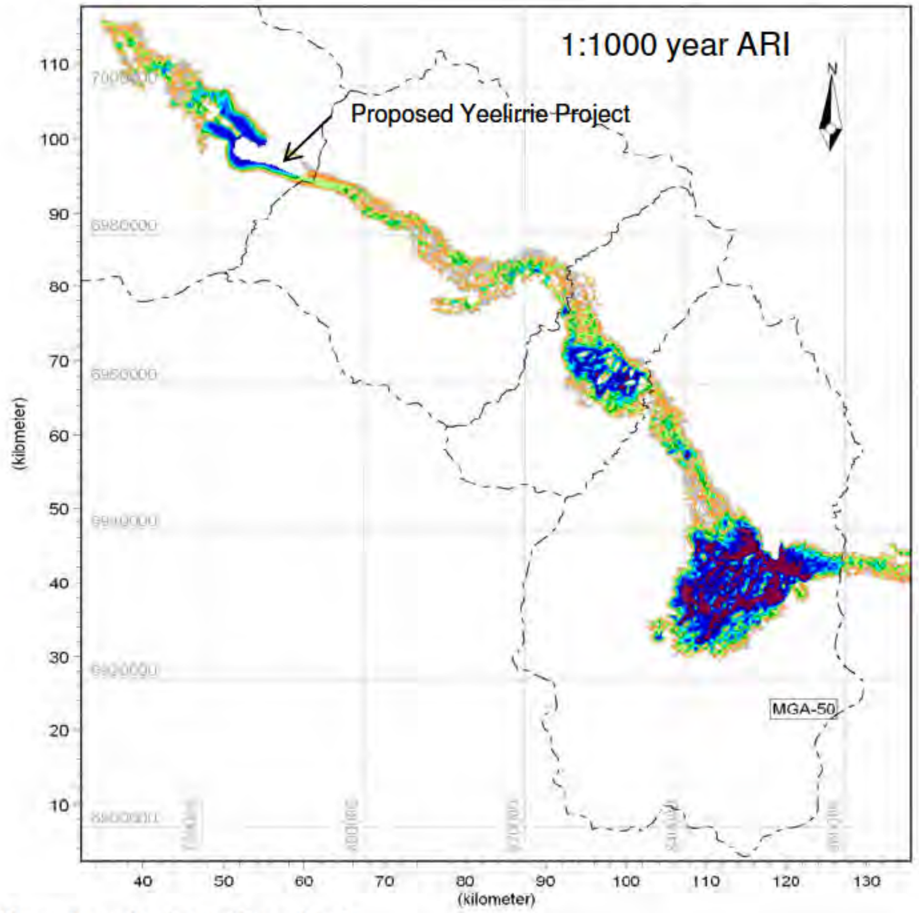
Simulated Maximum Water Depths During Mine Operations Stage 2 (Developed Scenario)



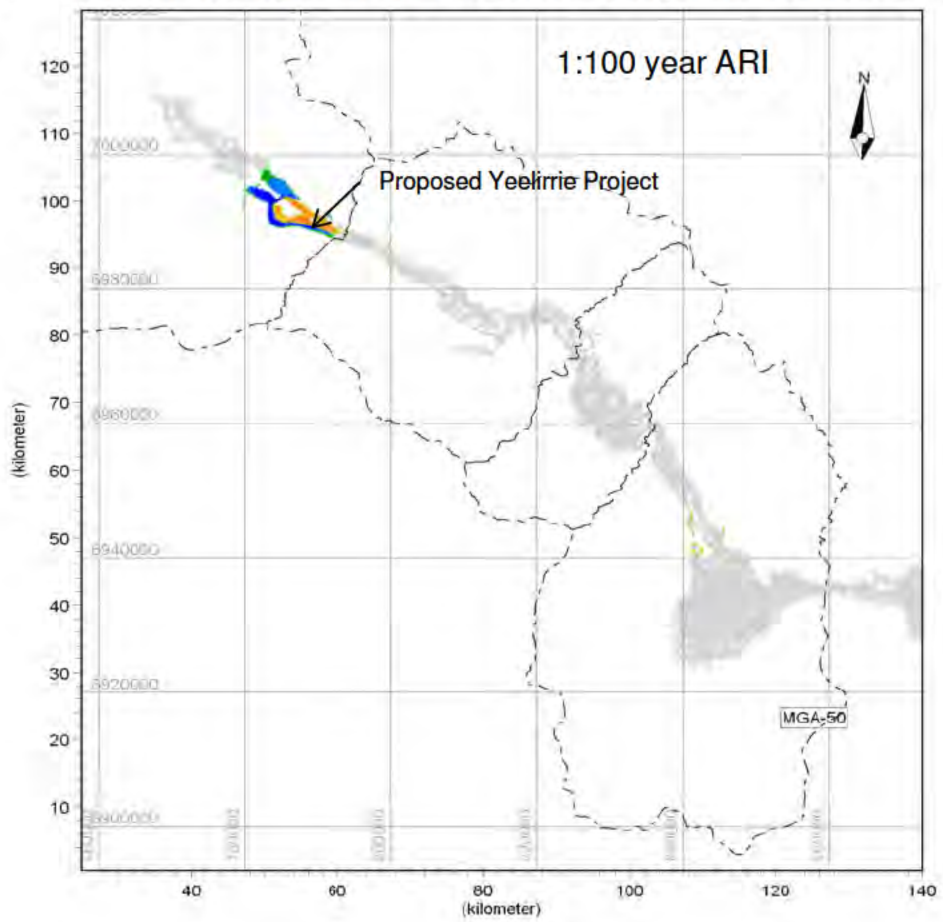


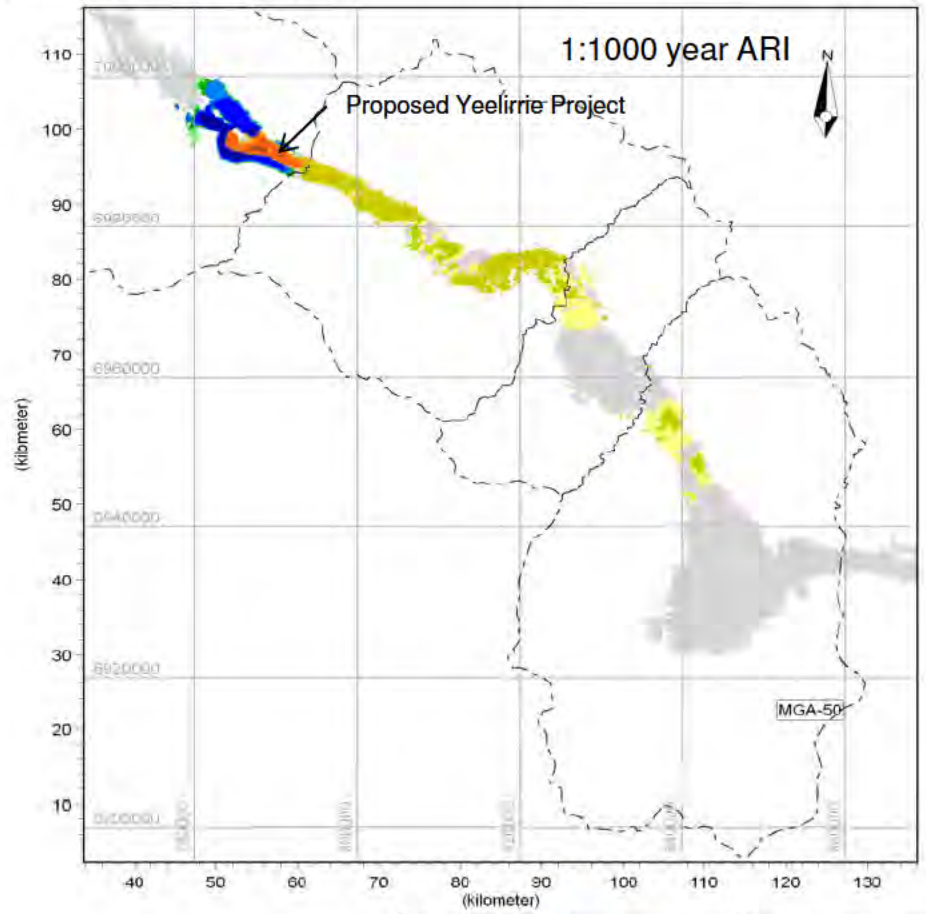
LEGEND

Maximum Water Depth (m)

- Above 5.0
- 4.0 - 5.0
- 3.0 - 4.0
- 2.5 - 3.0
- 2.0 - 2.5
- 1.5 - 2.0
- 1.0 - 1.5
- 0.5 - 1.0
- 0.0 - 0.5

Simulated Change in Maximum Water Depths During Mine Operations Stage 2 (Developed minus Baseline)





LEGEND

Change in Maximum Water Depth (m)

- Above 2.00
- 1.00 - 2.00
- 0.50 - 1.00
- 0.25 - 0.50
- 0.20 - 0.25
- -0.20 - 0.20
- -0.25 - -0.20
- -0.50 - -0.25
- -1.00 - -0.50
- -2.00 - -1.00
- -3.00 - -2.00
- Below -3.00

Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**		Title: Regional Lake Miranda Catchment Max Flood Water Depth & Difference from Baseline (100-, 1,000-year ARI)
	Drawn: RNM	Approved: BW	Date: 29/04/2015
	Job No. 42908794	File No. 42908794-SW-127.xls	Figure: 6-4 · Rev. A · A3

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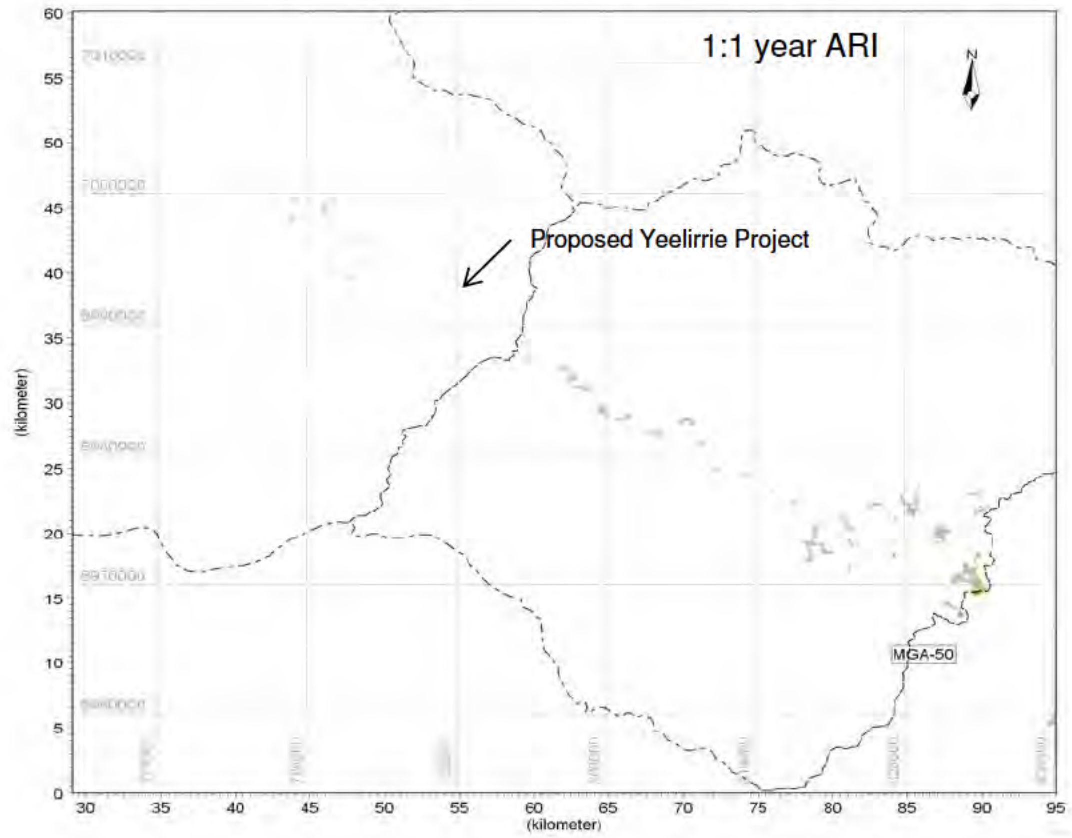
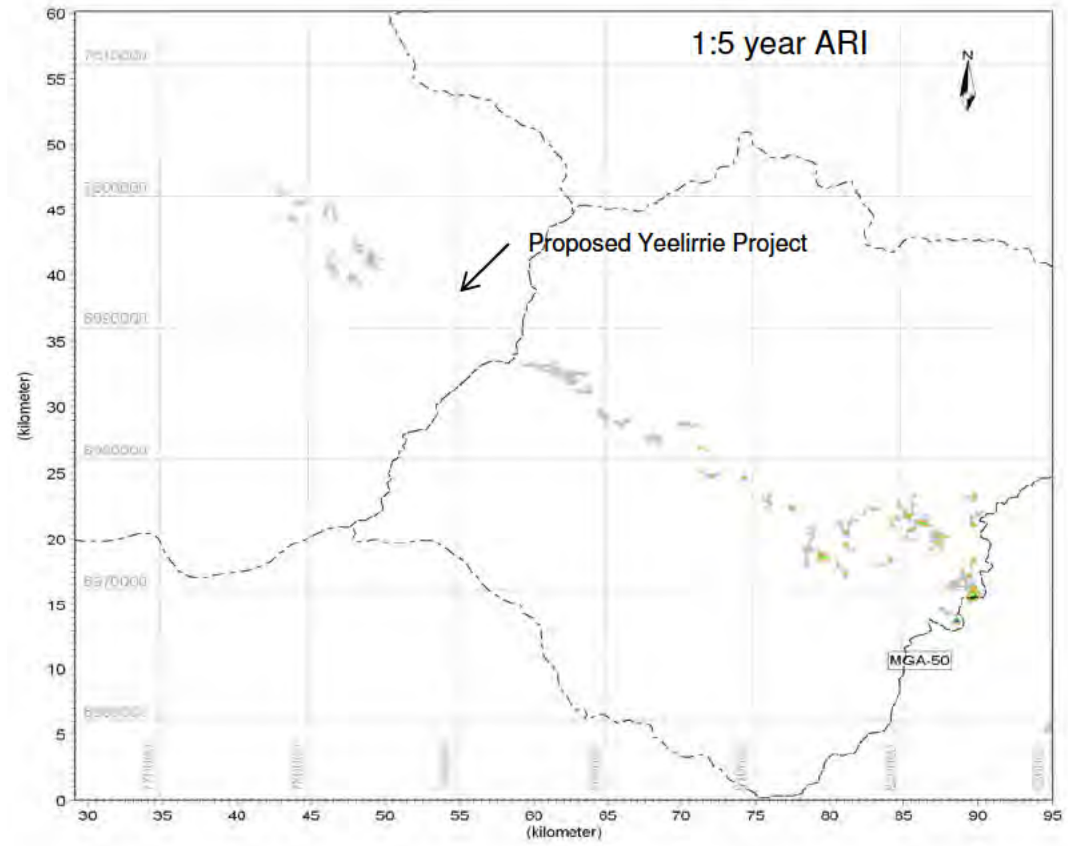
Simulated Maximum Water Depths During Mine Operations Stage 2 (Developed Scenario)



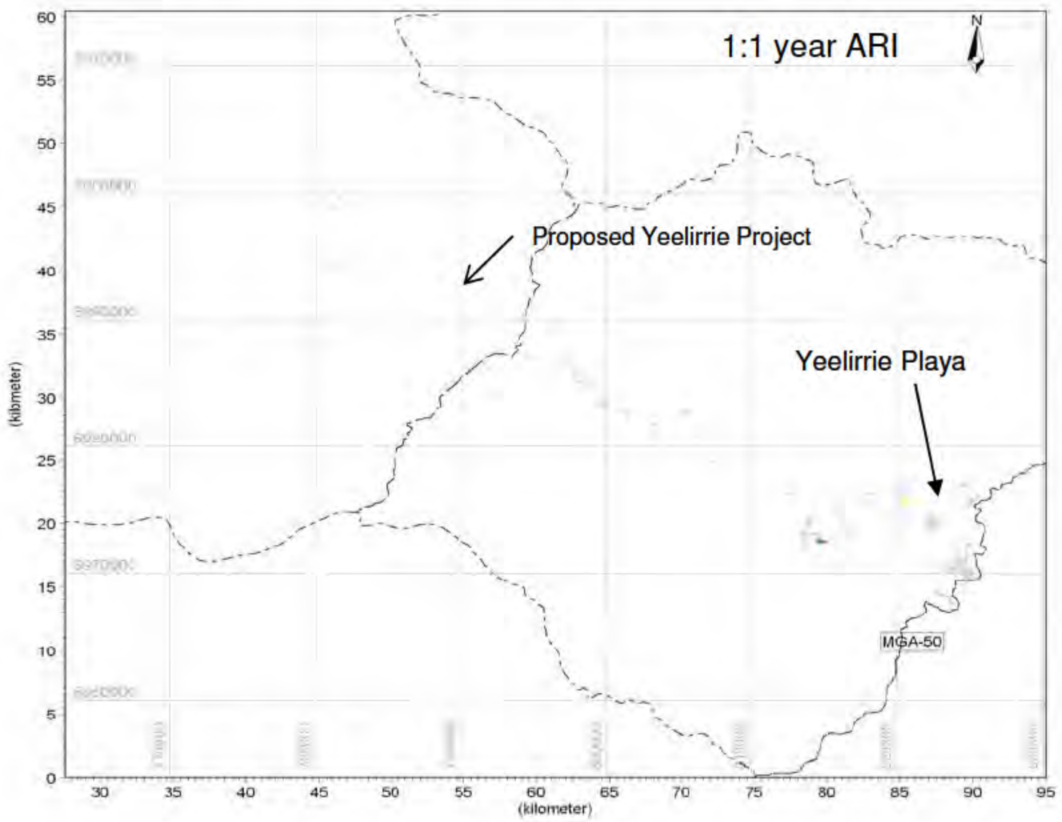


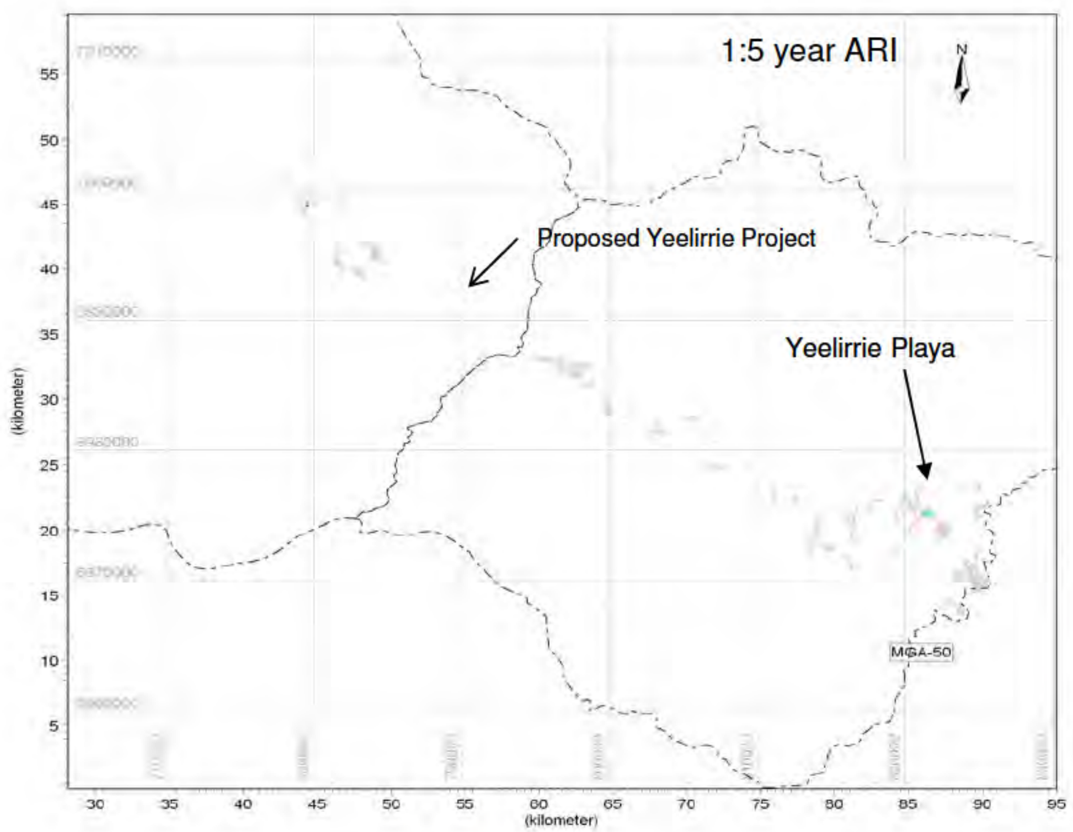
LEGEND

Maximum Water Depth (m)

- Above 5.0
- 4.0 - 5.0
- 3.0 - 4.0
- 2.5 - 3.0
- 2.0 - 2.5
- 1.5 - 2.0
- 1.0 - 1.5
- 0.5 - 1.0
- 0.0 - 0.5

Simulated Change in Maximum Water Depths During Mine Operations Stage 2 (Developed minus Baseline)





LEGEND

Change in Maximum Water Depth (m)

- Above 2.00
- 1.00 - 2.00
- 0.50 - 1.00
- 0.25 - 0.50
- 0.10 - 0.25
- -0.10 - 0.10
- -0.25 - -0.10
- -0.50 - -0.25
- -1.00 - -0.50
- -2.00 - -1.00
- -3.00 - -2.00
- Below -3.00

Cameco URS	Project: **Surface Water Study, Proposed Yeelirrie Project**	Title: Yeelirrie Playa Catchment - Maximum Water Depth and Difference from Baseline (1- and 5-year ARI)
	Drawn: RNM; Approved: BW; Date: 29/04/2015	Figure: 6-5; Rev. A
	Job No. 42908794; File No. 42908794-SW-128.xls	A3

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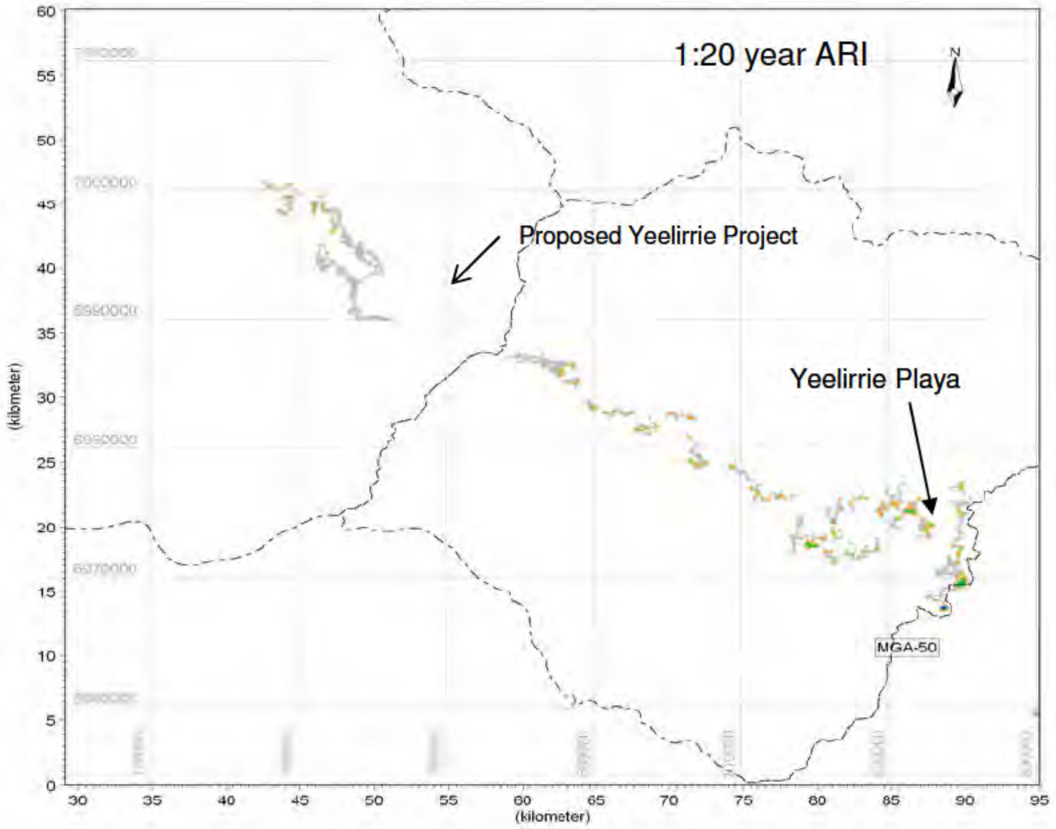
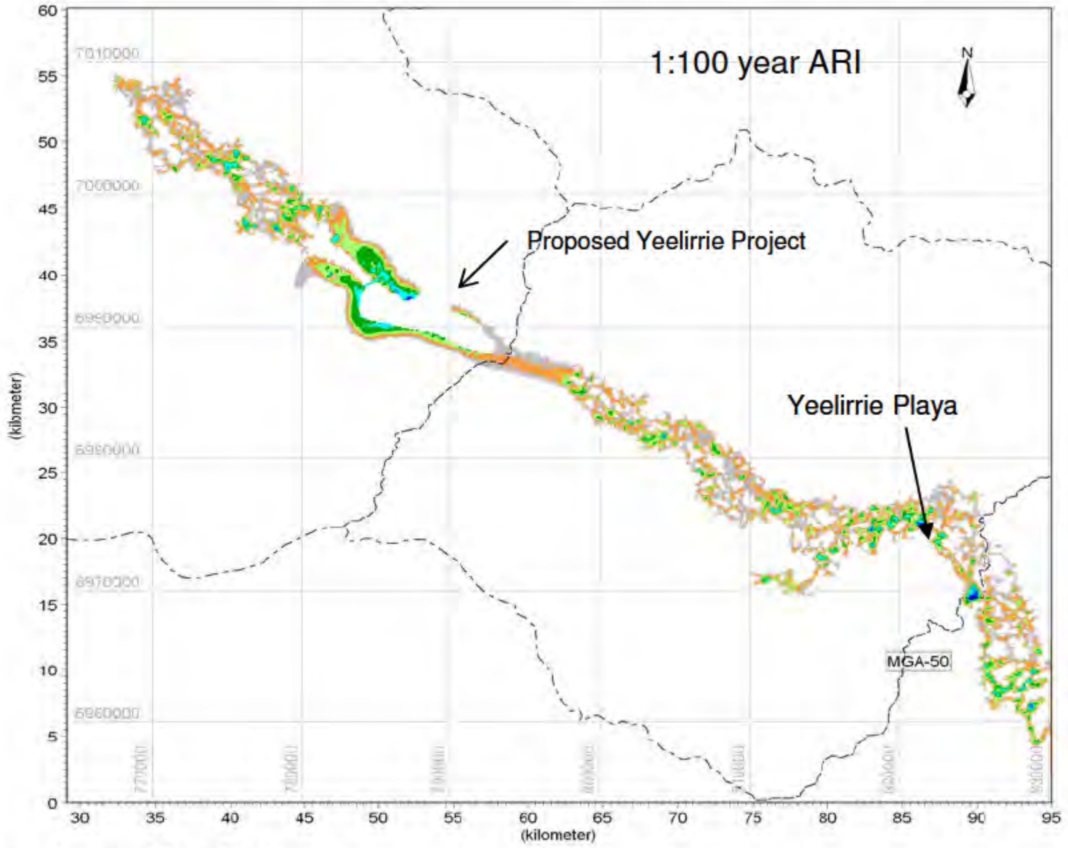
Simulated Maximum Water Depths During Mine Operations Stage 2 (Developed Scenario)



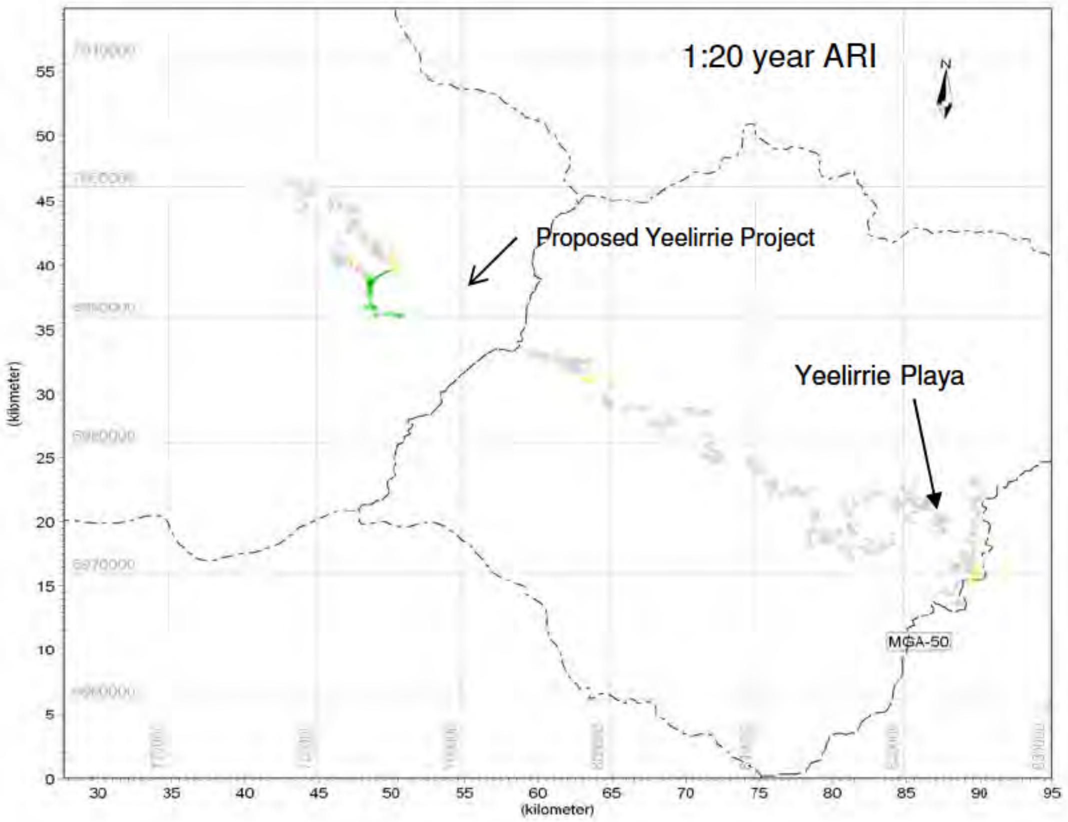


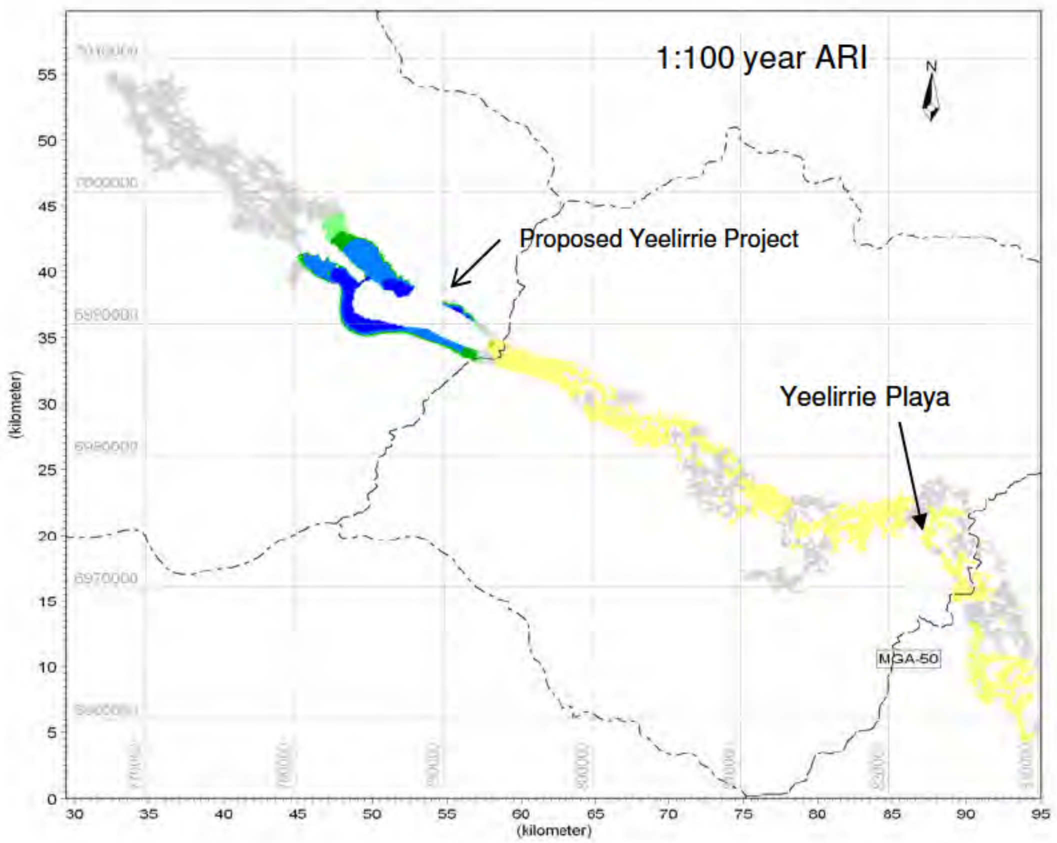
LEGEND

Maximum Water Depth (m)

- Above 5.0
- 4.0 - 5.0
- 3.0 - 4.0
- 2.5 - 3.0
- 2.0 - 2.5
- 1.5 - 2.0
- 1.0 - 1.5
- 0.5 - 1.0
- 0.0 - 0.5

Simulated Change in Maximum Water Depths During Mine Operations Stage 2 (Developed minus Baseline)





LEGEND

Change in Maximum Water Depth (m)

- Above 2.00
- 1.00 - 2.00
- 0.50 - 1.00
- 0.25 - 0.50
- 0.10 - 0.25
- -0.10 - 0.10
- -0.25 - -0.10
- -0.50 - -0.25
- -1.00 - -0.50
- -2.00 - -1.00
- -3.00 - -2.00
- Below -3.00

Cameco

URS

Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: Yeelirrie Playa Catchment - Maximum Water Depth and Difference from Baseline (20- and 100-year ARI)
Drawn: RNM	Approved: BW	Date: 29/04/2015	Figure: 6-6 Rev. A A3
Job No. 42908794	File No. 42908794-SW-129.xls		

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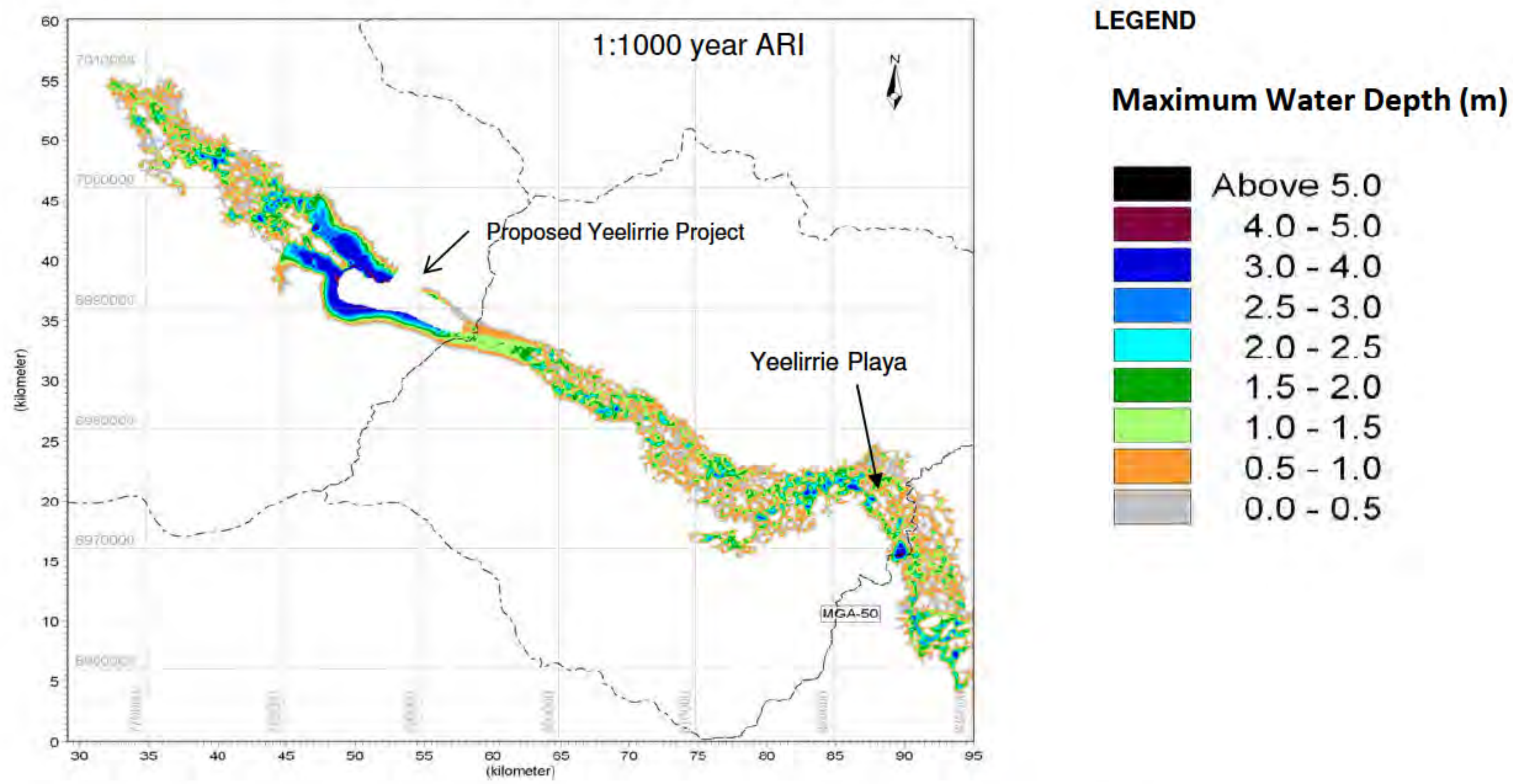
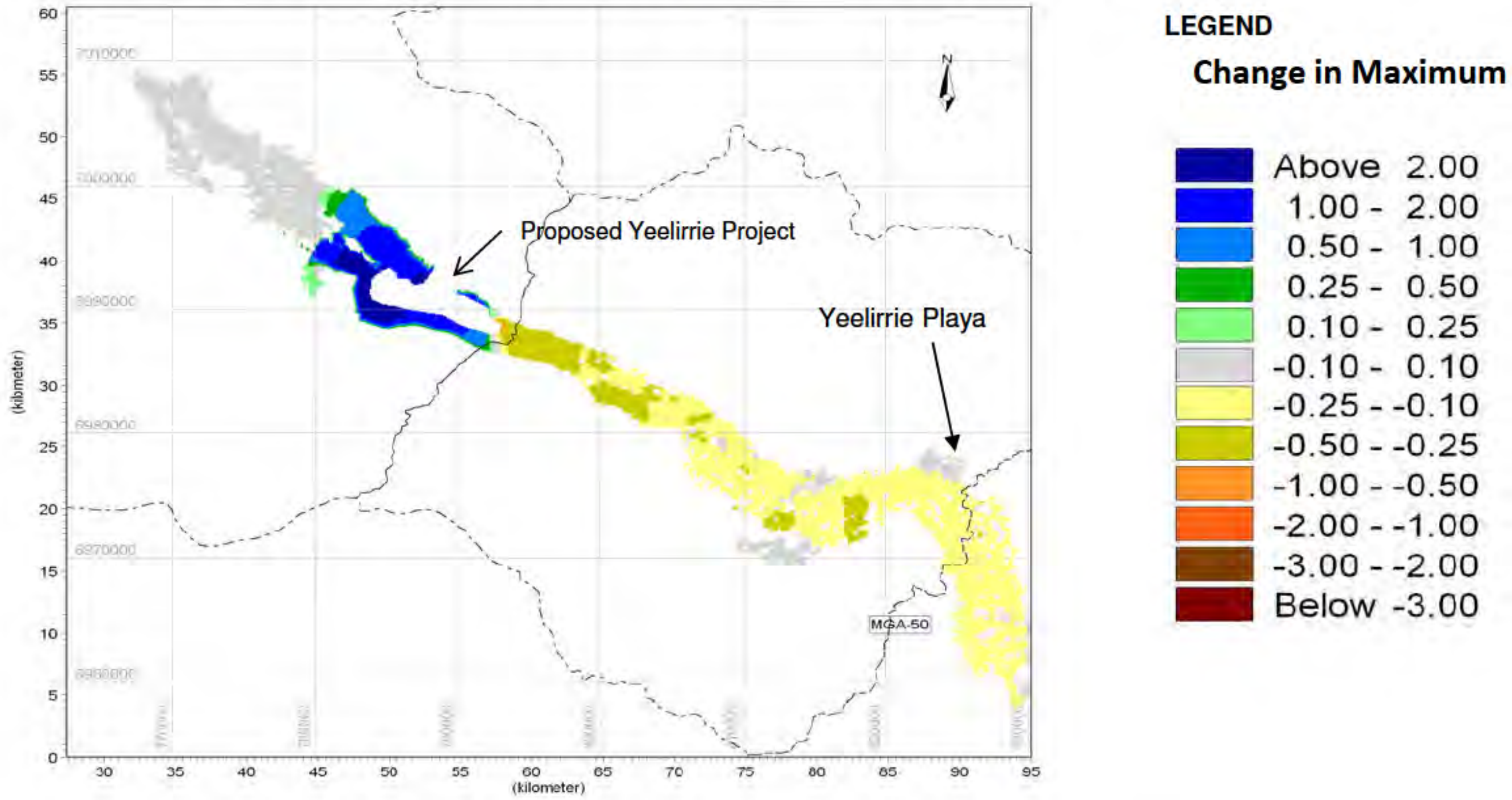
Simulated Maximum Water Depths During Mine Operations Stage 2 (Developed Scenario)

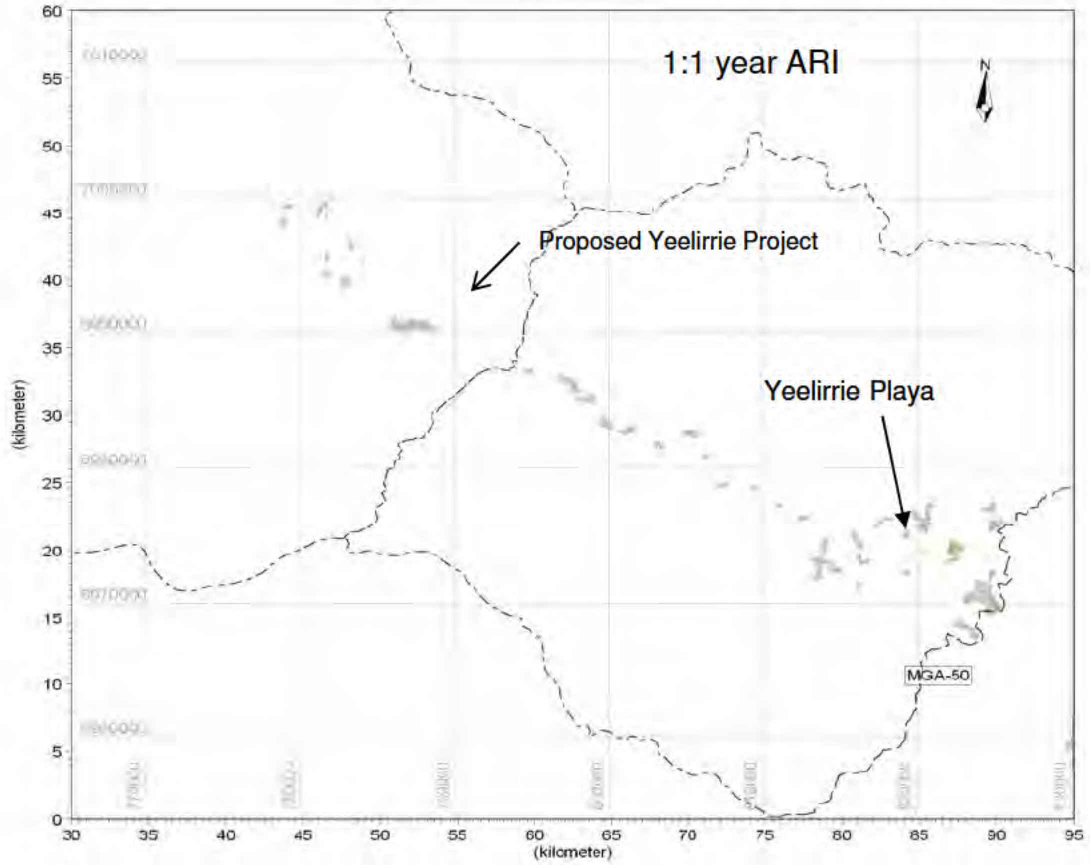


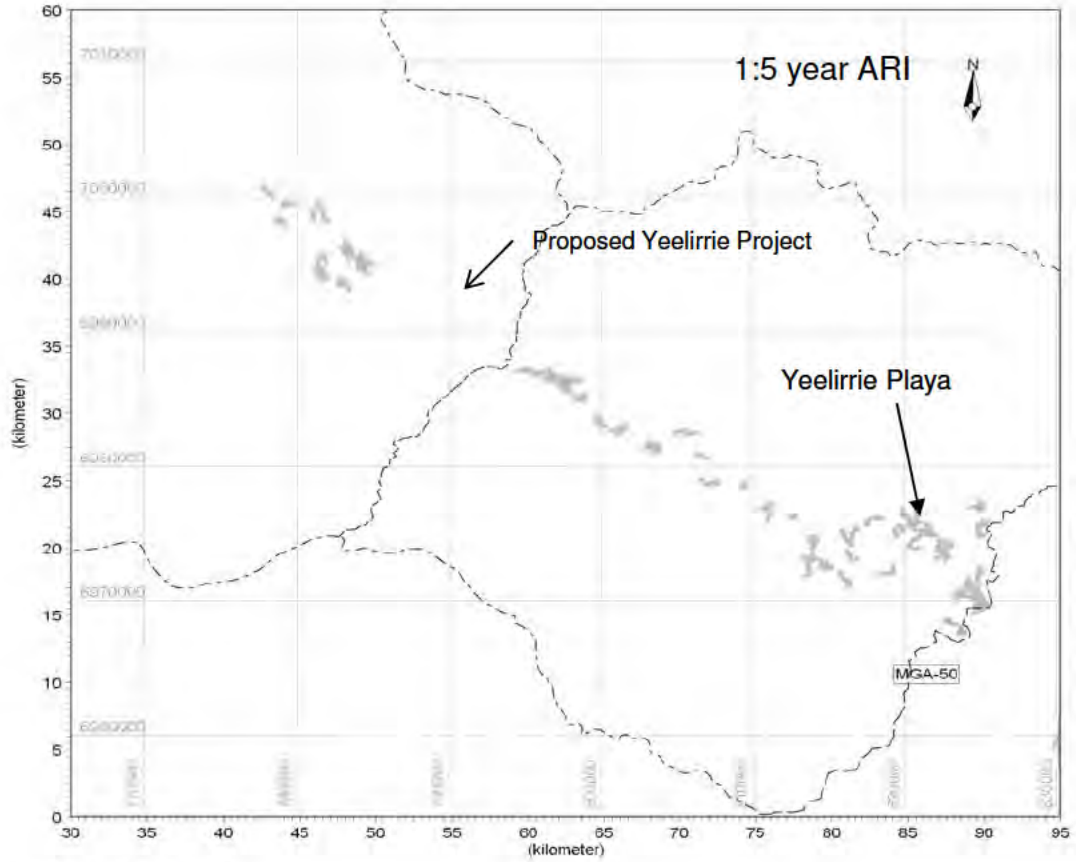
Simulated Change in Maximum Water Depths During Mine Operations Stage 2 (Developed minus Baseline)



Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**		Title: Yeelirrie Playa Catchment - Maximum Water Depth and Difference from Baseline (1,000-year ARI)
	Drawn: RNM	Approved: BW	Date: 29/04/2015
	Job No. 42908794	File No. 42908794-SW-130.xls	Figure: 6-7 / Rev. A / A3

Simulated Maximum Flow Velocities During Mine Operations Stage 2 (Developed Scenario)



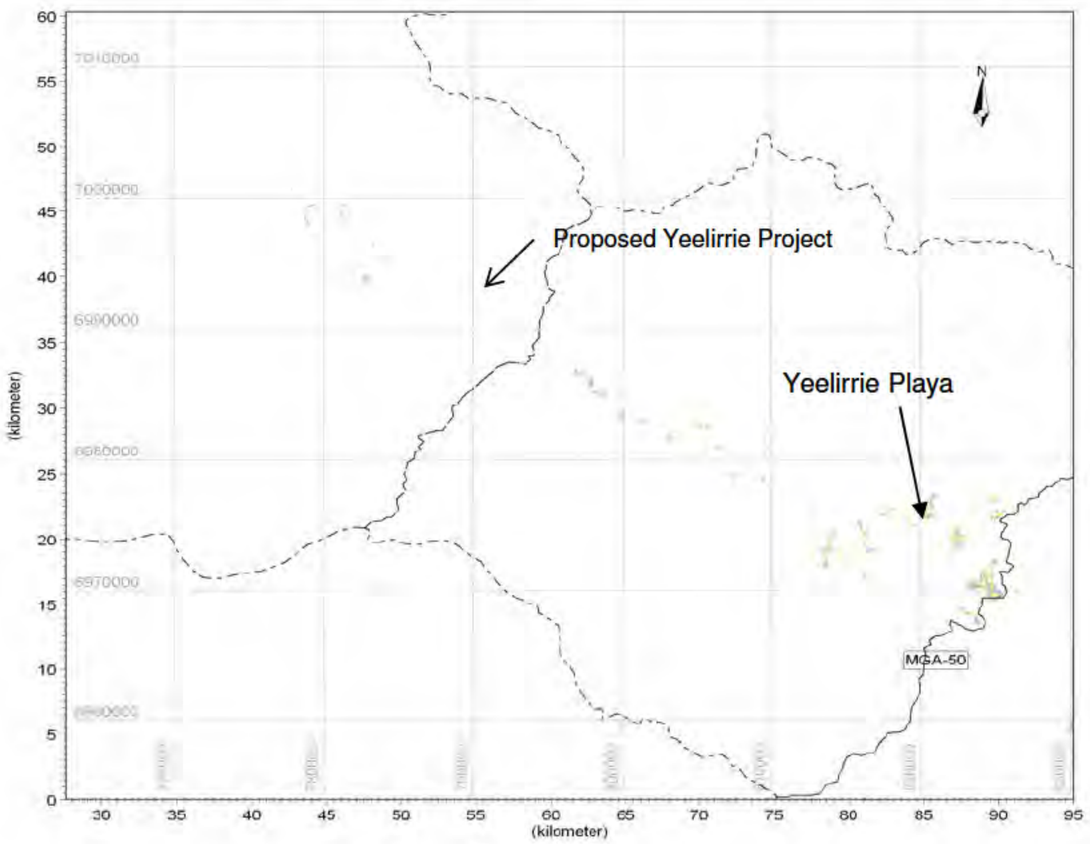


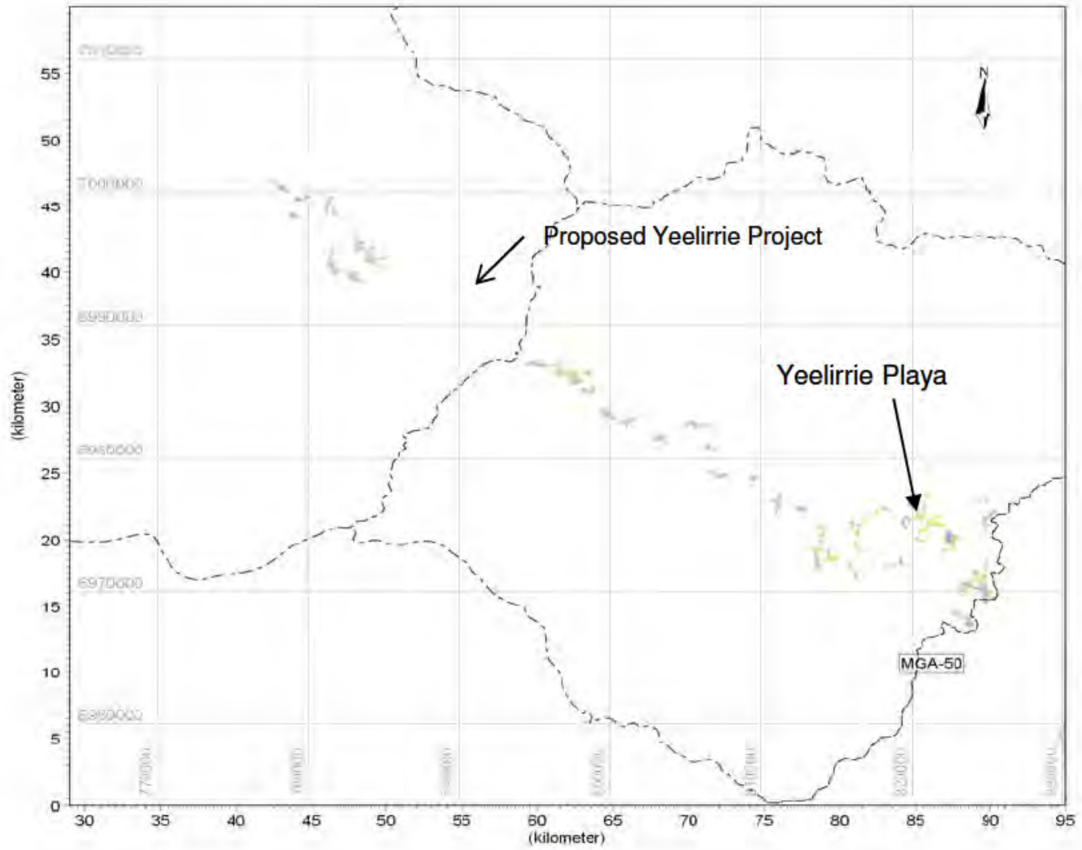
LEGEND

Maximum Velocity (m/s)

- Above 2.0
- 1.0 - 2.0
- 0.8 - 1.0
- 0.6 - 0.8
- 0.4 - 0.6
- 0.2 - 0.4
- Below 0.2

Simulated Change in Maximum Flow Velocities During Mine Operations Stage 2 (Developed minus Baseline)





LEGEND

Change in Maximum Water Velocity (m/s)

- Above 0.8
- 0.6 - 0.8
- 0.4 - 0.6
- 0.2 - 0.4
- 0.0 - 0.2
- -0.2 - 0.0
- -0.4 - -0.2
- -0.6 - -0.4
- -0.8 - -0.6
- Below -0.8

Cameco URS	Project: **Surface Water Study, Proposed Yeelirrie Project**		Title: Yeelirrie Playa Catchment - Maximum Flow Velocities and Difference from Baseline (1- and 5-year ARI)
	Drawn: RNM	Approved: BW	Date: 29/04/2015
	Job No. 42908794	File No. 42908794-SW-131.xls	Figure: 6-8 Rev. A A3

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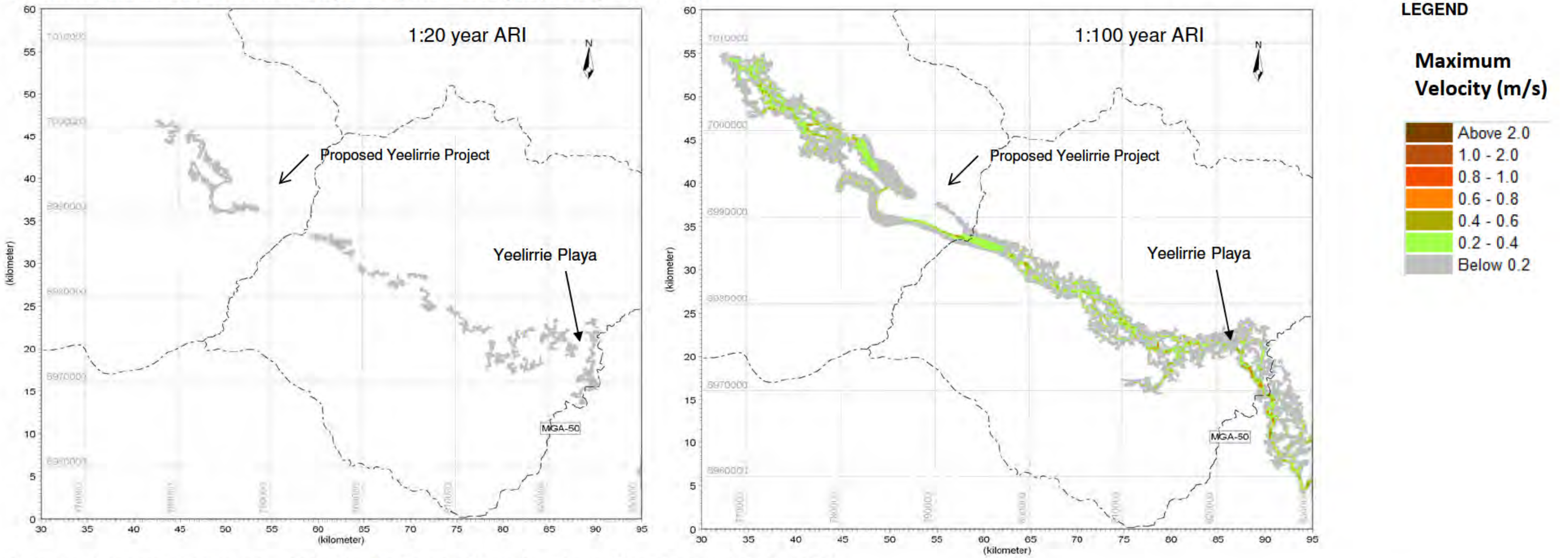
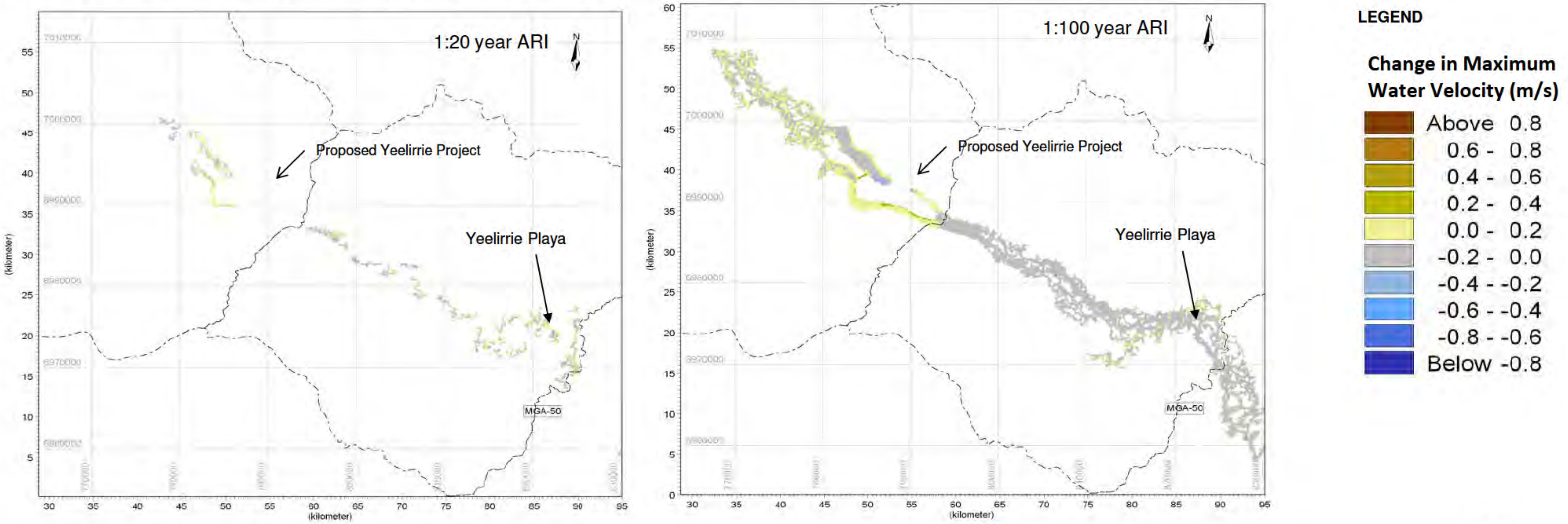
Simulated Maximum Flow Velocities During Mine Operations Stage 2 (Developed Scenario)



Simulated Change in Maximum Flow Velocities During Mine Operations Stage 2 (Developed minus Baseline)



Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**		Title: Yeelirrie Playa Catchment - Maximum Flow Velocities and Difference from Baseline (20- and 100-year ARI)
	Drawn: RNM	Approved: BW	Date: 29/04/2015
	Job No. 42908794	File No. 42908794-SW-132.xls	Figure: 6-9 — Rev. A — A3

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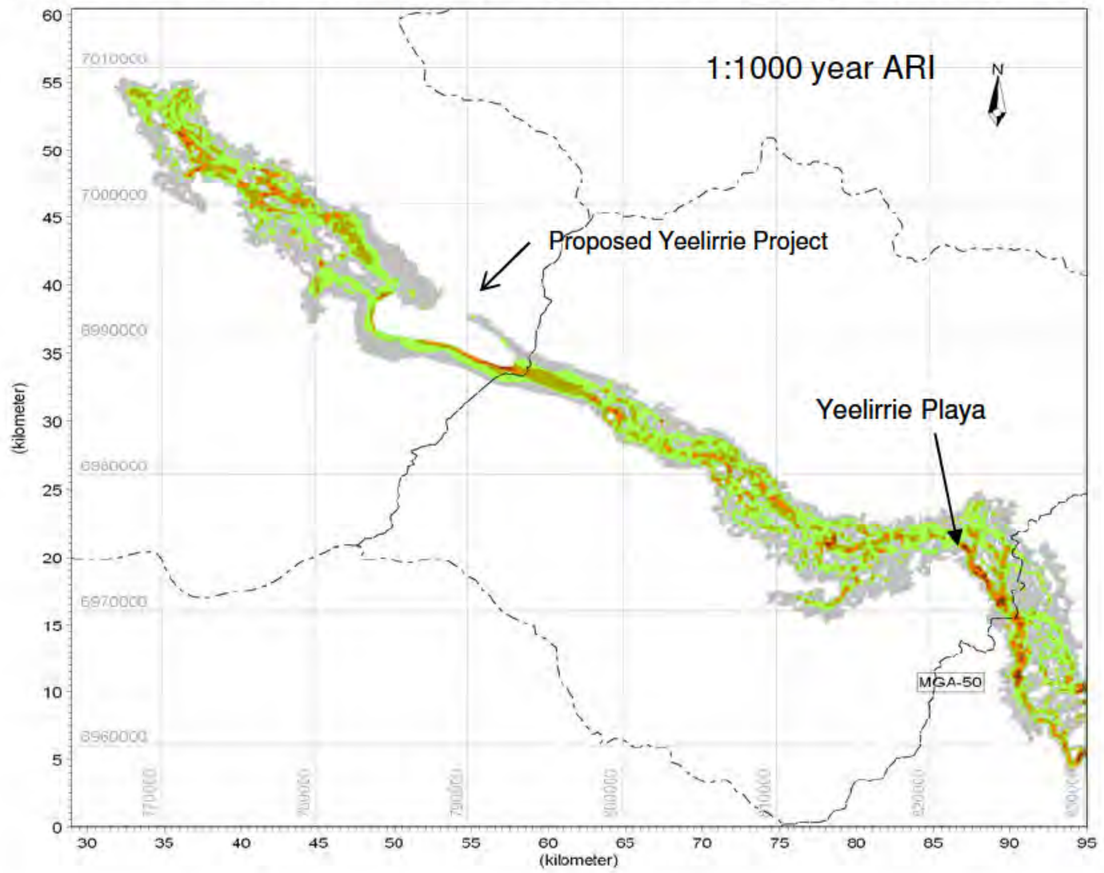
Simulated Maximum Flow Velocities During Mine Operations Stage 2 (Developed Scenario)

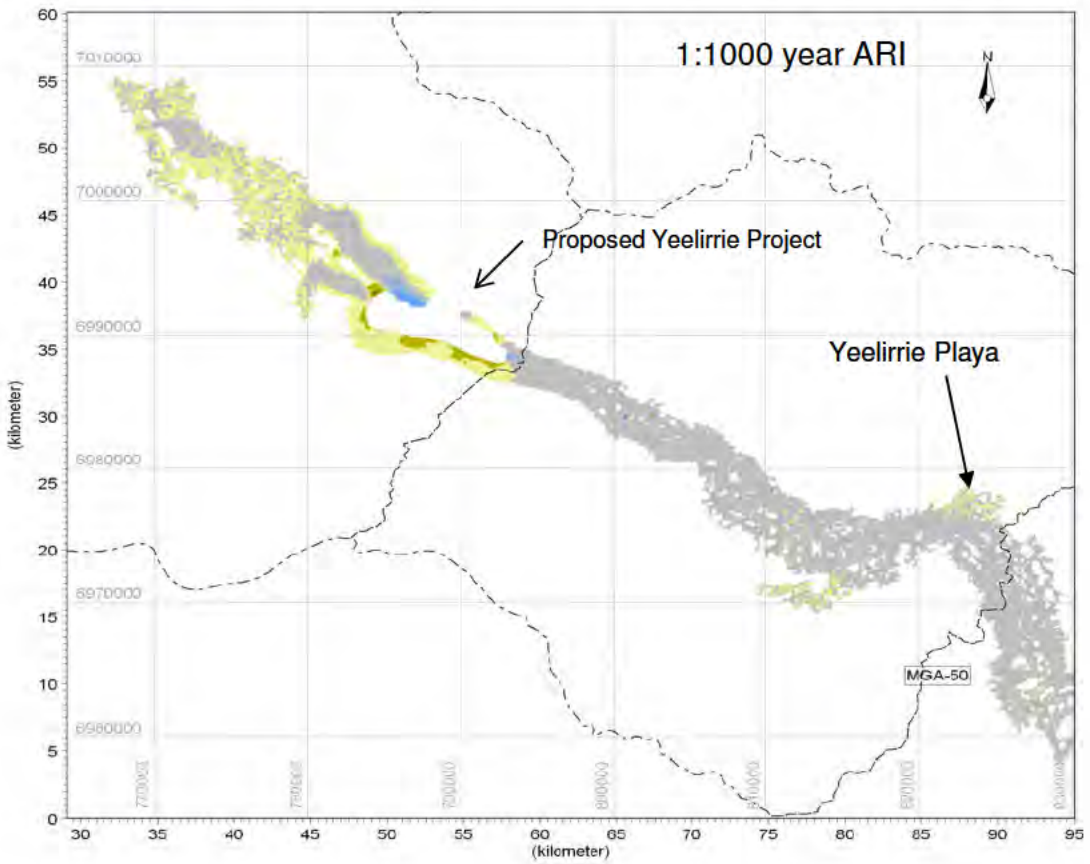


LEGEND

Maximum Velocity (m/s)

- Above 2.0
- 1.0 - 2.0
- 0.8 - 1.0
- 0.6 - 0.8
- 0.4 - 0.6
- 0.2 - 0.4
- Below 0.2

Simulated Change in Maximum Flow Velocities During Mine Operations Stage 2 (Developed minus Baseline)



LEGEND

Change in Maximum Water Velocity (m/s)

- Above 0.8
- 0.6 - 0.8
- 0.4 - 0.6
- 0.2 - 0.4
- 0.0 - 0.2
- -0.2 - 0.0
- -0.4 - -0.2
- -0.6 - -0.4
- -0.8 - -0.6
- Below -0.8

Cameco / URS	Project: Surface Water Study, Proposed Yeelirrie Project			Title: Yeelirrie Playa Catchment - Maximum Flow Velocities and Difference from Baseline (1,000-year ARI)	
	Drawn: RNM	Approved: BW	Date: 29/04/2015	Figure: 6-10	Rev. A
	Job No. 42908794	File No. 42908794-SW-133.xls			A3

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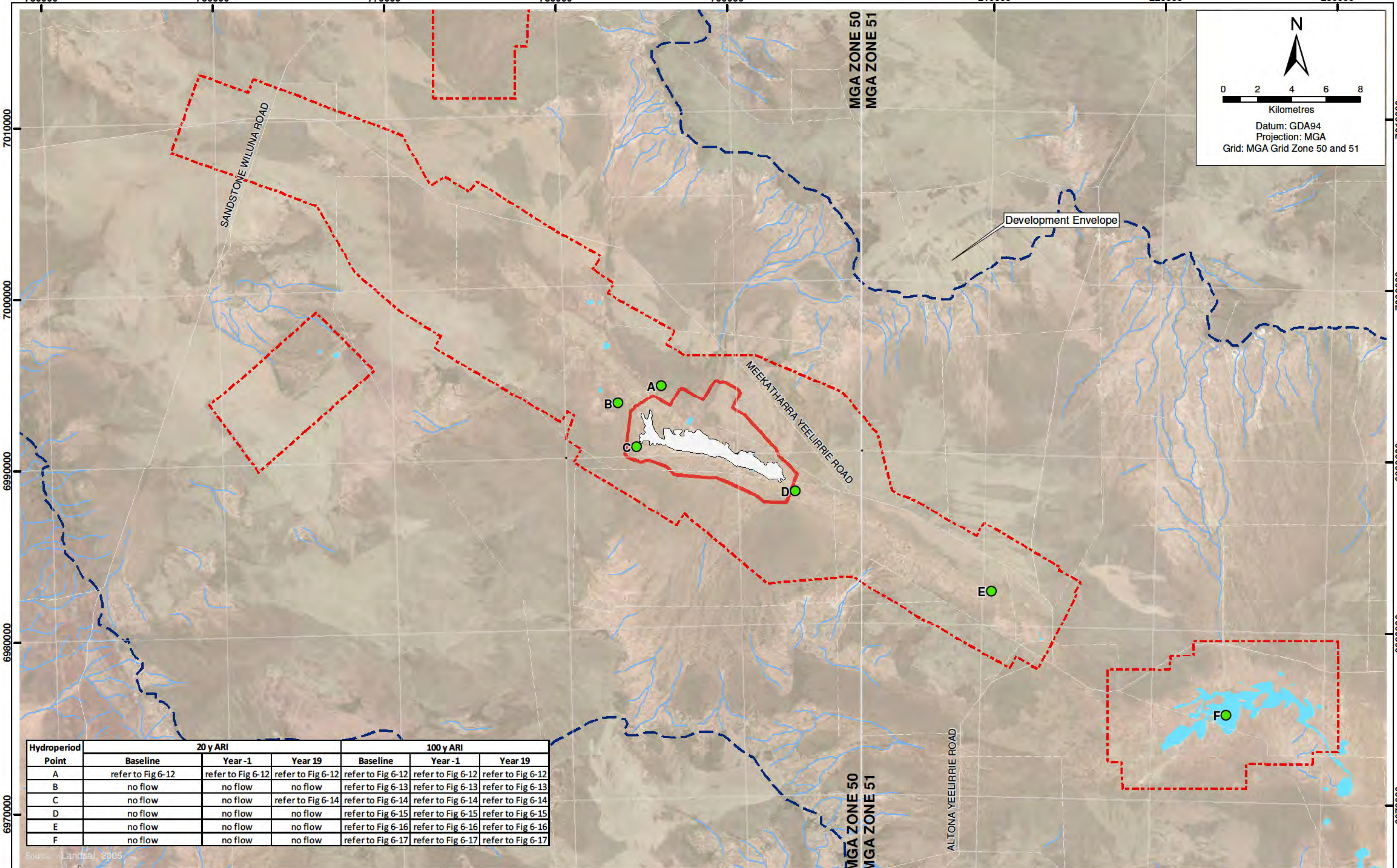

Hydroperiod Point	20 y ARI			100 y ARI		
	Baseline	Year -1	Year 19	Baseline	Year -1	Year 19
A	refer to Fig 6-12	refer to Fig 6-12	refer to Fig 6-12	refer to Fig 6-12	refer to Fig 6-12	refer to Fig 6-12
B	no flow	no flow	no flow	refer to Fig 6-13	refer to Fig 6-13	refer to Fig 6-13
C	no flow	no flow	refer to Fig 6-14	refer to Fig 6-14	refer to Fig 6-14	refer to Fig 6-14
D	no flow	no flow	no flow	refer to Fig 6-15	refer to Fig 6-15	refer to Fig 6-15
E	no flow	no flow	no flow	refer to Fig 6-16	refer to Fig 6-16	refer to Fig 6-16
F	no flow	no flow	no flow	refer to Fig 6-17	refer to Fig 6-17	refer to Fig 6-17

Legend

A Locations For Hydrological Assessments

Roads (GA, 2007)
- Major Road
- Minor Road
- Track

Watercourses

Playas

Ministerial Temporary Reserve TR70/6899

Pit Outline

Lake Miranda Catchment

Cameco

URS

Project: **Surface Water Study, Proposed Yeelirrie Project**

Title: Locations For Hydroperiod Assessments

Drawn: RNM | Approved: BW | Date: 4/05/2015

Job No.: 42908794 | File No.: 42908794-SW-031.mxd

Figure: 6-11 | Rev. A | A3

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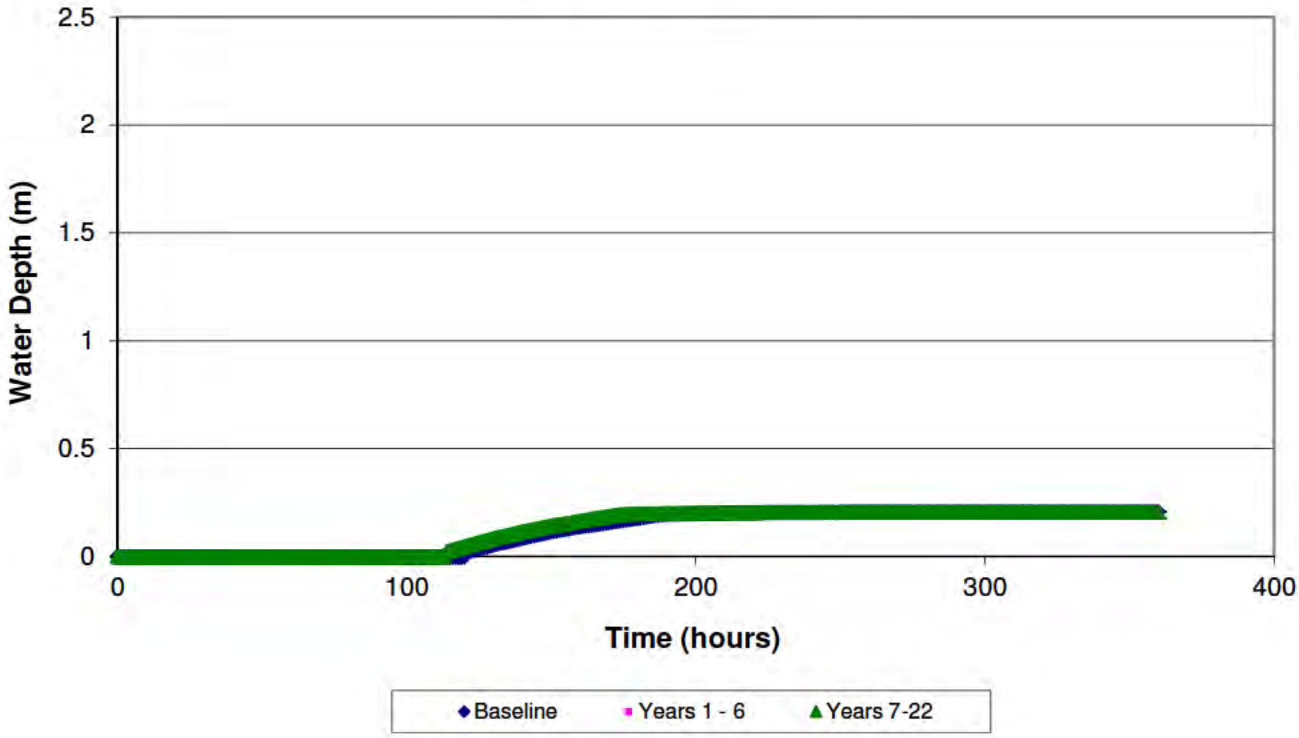
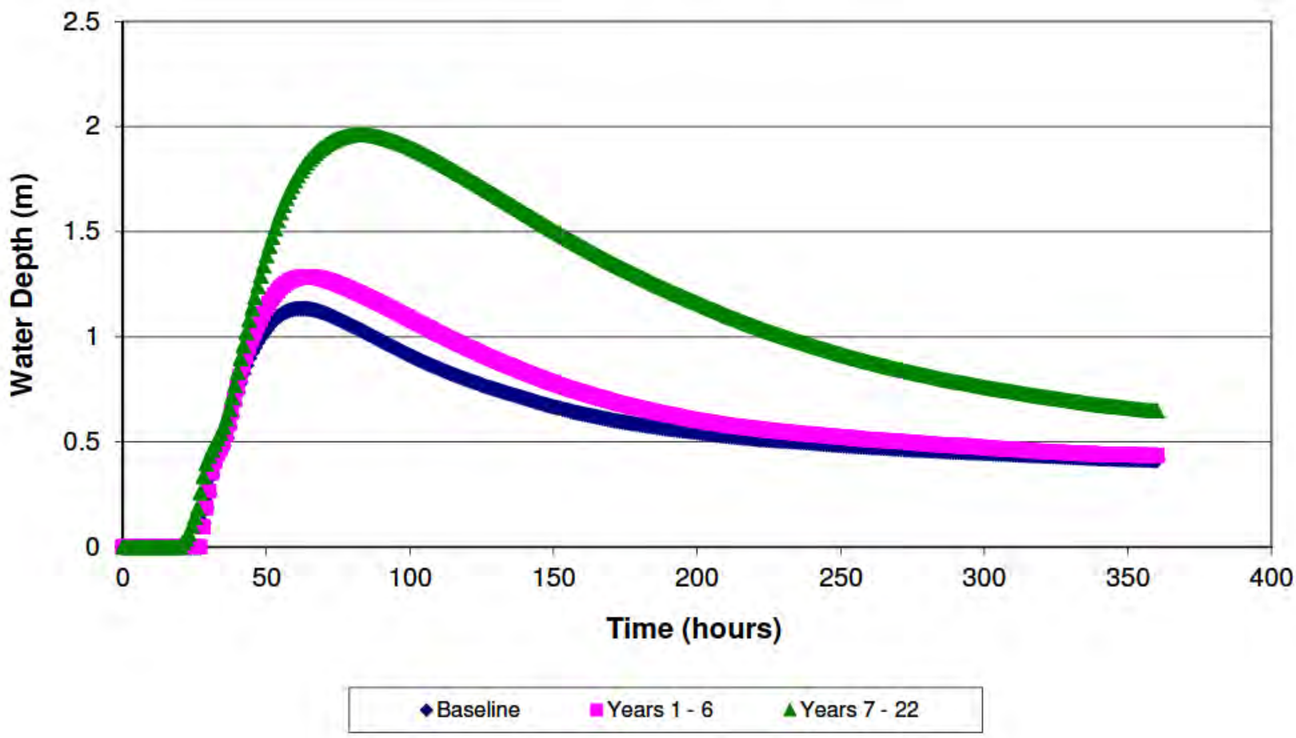
(a) 1:20 Year ARI



(b) 1:100 Year ARI



Cameco	Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: Simulated Change in Flood Hydrographs at Location A	
URS	Drawn: SH/RNM	Approved: BW	Date: 1/04/2015	Figure: 6-12	Rev. A
	Job No. 42908794	File No. 42908794-SW-134.xls			A4

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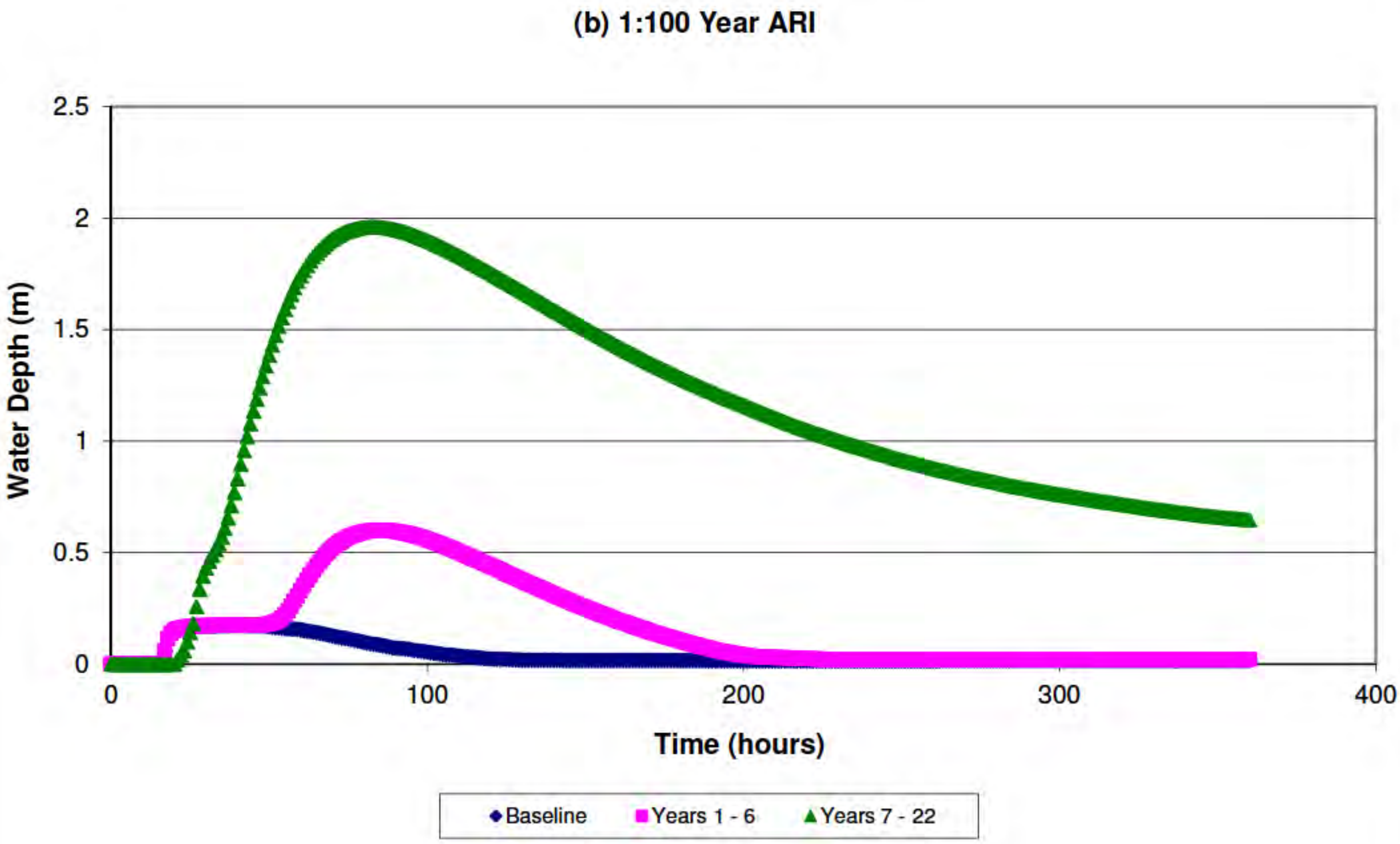

Project:	Title:
Surface Water Study, Proposed Yeelirrie Project	Simulated Change in Flood Hydrographs at Location B

Drawn: SH/RNM	Approved: BW	Date: 1/04/2015	Figure: 6-13	Rev. A
Job No. 42908794	File No. 42908794-SW-134.xls			A4

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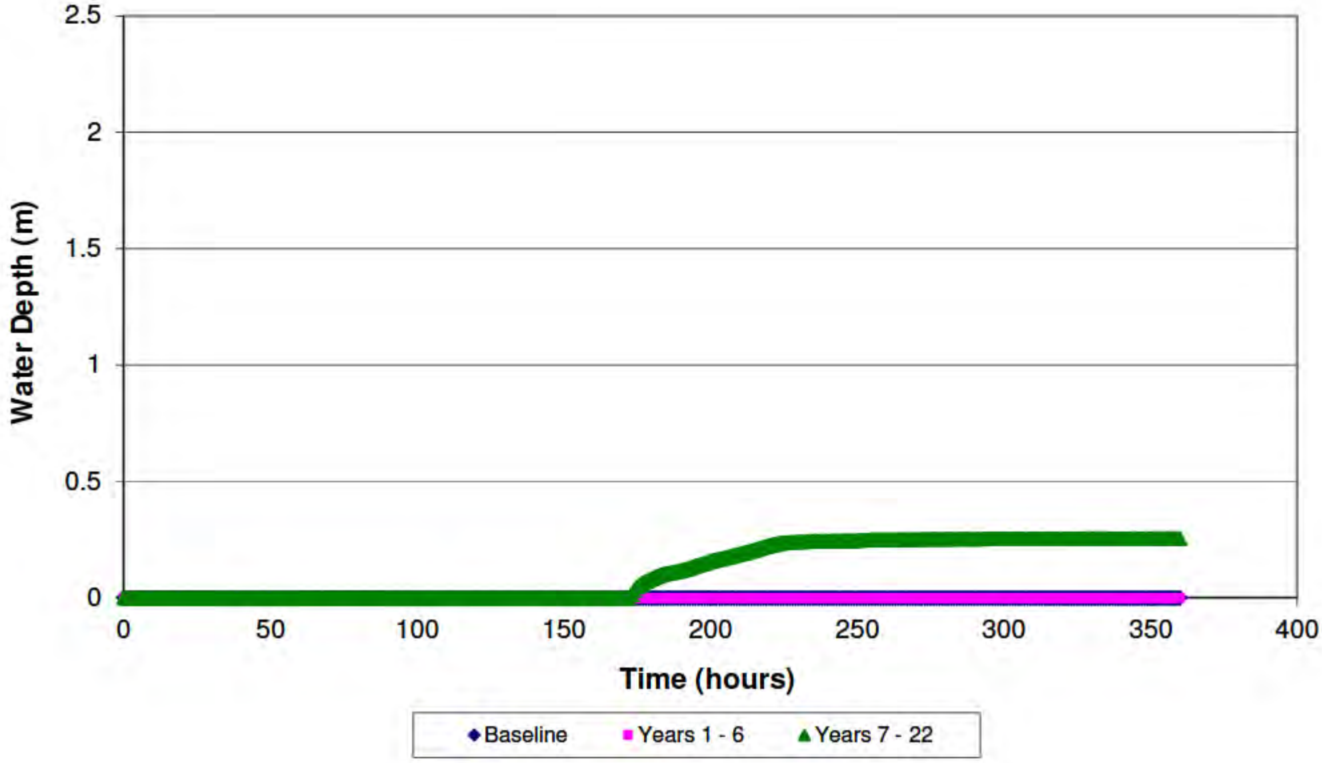
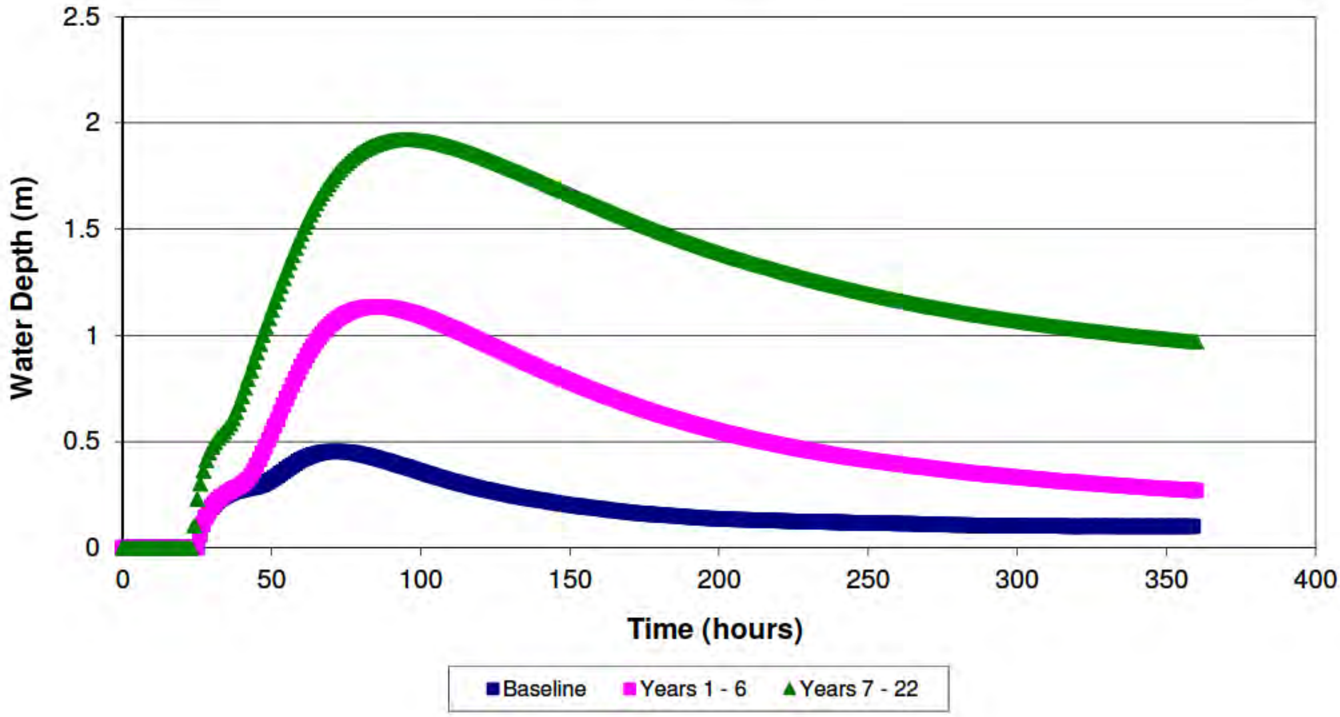
(a) 1:20 Year ARI



(b) 1:100 Year ARI



Cameco	Project: **Surface Water Study, Proposed Yeelirrie Project**				Title: Simulated Change in Flood Hydrographs at Location C	
URS	Drawn: SH/RNM	Approved: BW	Date: 1/04/2015		Figure: 6-14	Rev. A
	Job No. 42908794	File No. 42908794-SW-134.xls				A4

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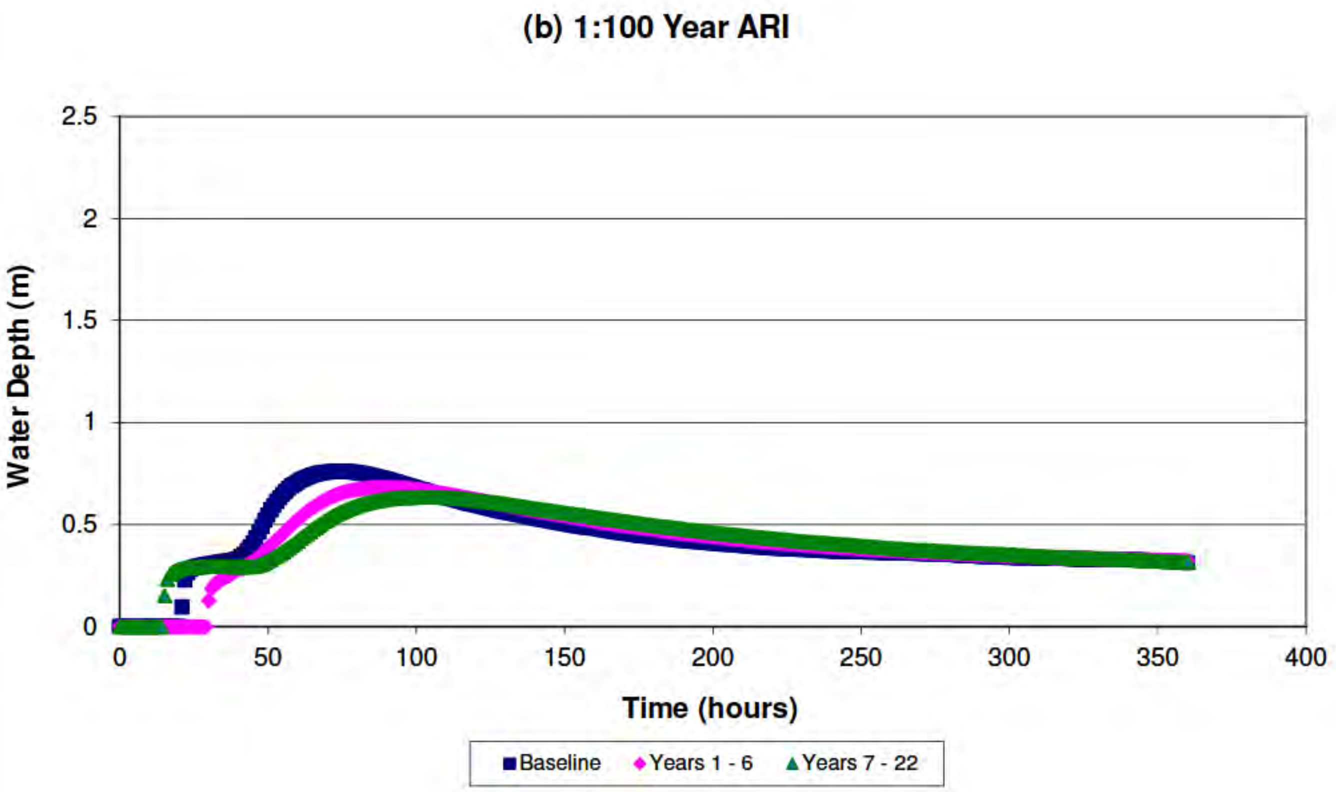

Cameco	Project: **Surface Water Study, Proposed Yeelirrie Project**				Title: Simulated Change in Flood Hydrographs at Location D	
URS	Drawn: SH/RNM	Approved: BW	Date: 1/04/2015		Figure: 6-15	Rev. A
	Job No. 42908794	File No. 42908794-SW-134.xls				A4

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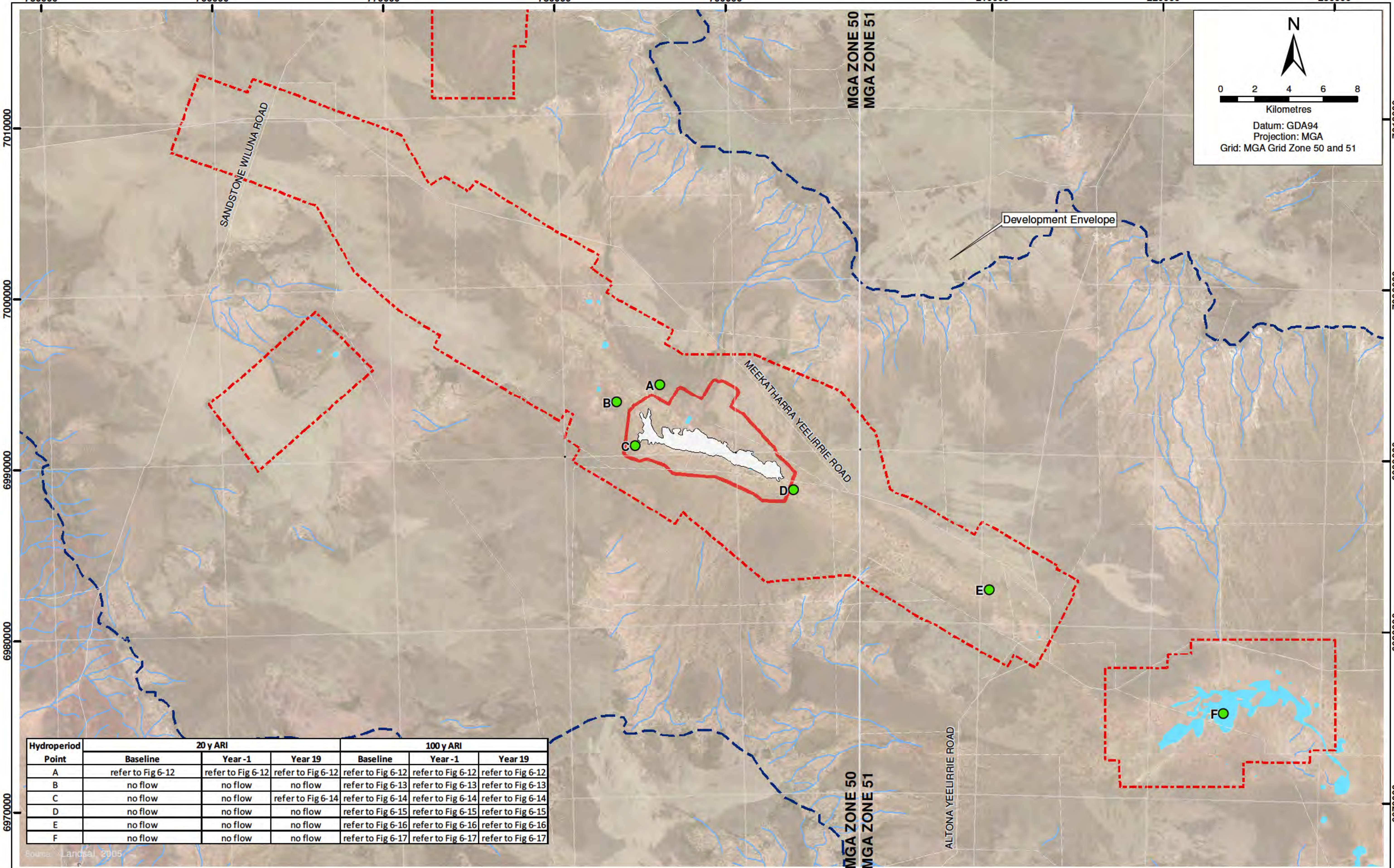

Hydroperiod Point	20 y ARI			100 y ARI		
	Baseline	Year -1	Year 19	Baseline	Year -1	Year 19
A	refer to Fig 6-12	refer to Fig 6-12	refer to Fig 6-12	refer to Fig 6-12	refer to Fig 6-12	refer to Fig 6-12
B	no flow	no flow	no flow	refer to Fig 6-13	refer to Fig 6-13	refer to Fig 6-13
C	no flow	no flow	refer to Fig 6-14	refer to Fig 6-14	refer to Fig 6-14	refer to Fig 6-14
D	no flow	no flow	no flow	refer to Fig 6-15	refer to Fig 6-15	refer to Fig 6-15
E	no flow	no flow	no flow	refer to Fig 6-16	refer to Fig 6-16	refer to Fig 6-16
F	no flow	no flow	no flow	refer to Fig 6-17	refer to Fig 6-17	refer to Fig 6-17

Legend

- A ● Locations For Hydrological Assessments
- Watercourses
- Playas
- Ministerial Temporary Reserve TR70/6899
- Pit Outline
- Lake Miranda Catchment

Roads (GA, 2007)

- Major Road
- Minor Road
- Track

Cameco

URS

Project: **Surface Water Study, Proposed Yeelirrie Project**

Title: Locations For Hydroperiod Assessments

Drawn: RNM	Approved: BW	Date: 8/05/2015	Rev. A
Job No.: 42908794	File No.: 42908794-SW-031.mxd	Figure: 6-16	A3

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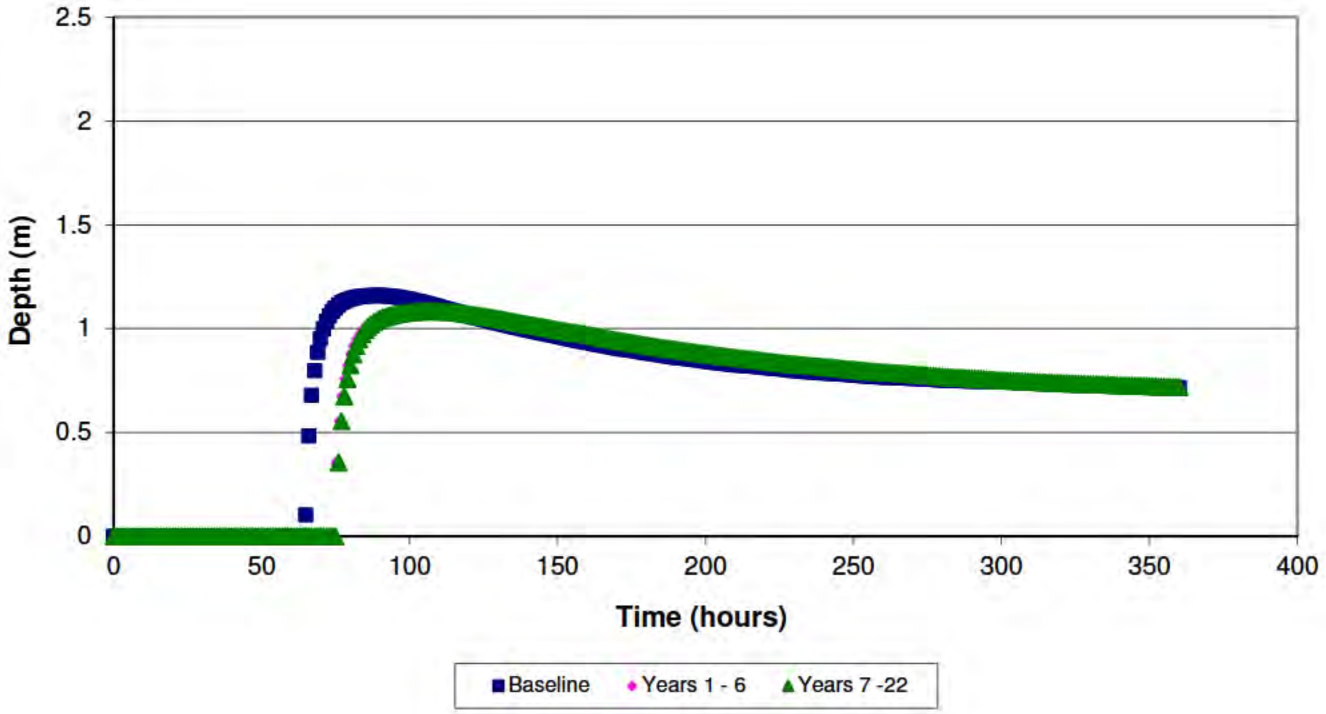
(b) 1:100 Year ARI



Cameco	Project: **Surface Water Study, Proposed Yeelirrie Project**				Title: Simulated Change in Flood Hydrographs at Location E	
URS	Drawn: SH/RNM	Approved: BW	Date: 1/04/2015		Figure: 6-16	Rev. A
	Job No. 42908794	File No. 42908794-SW-134.xls				A4

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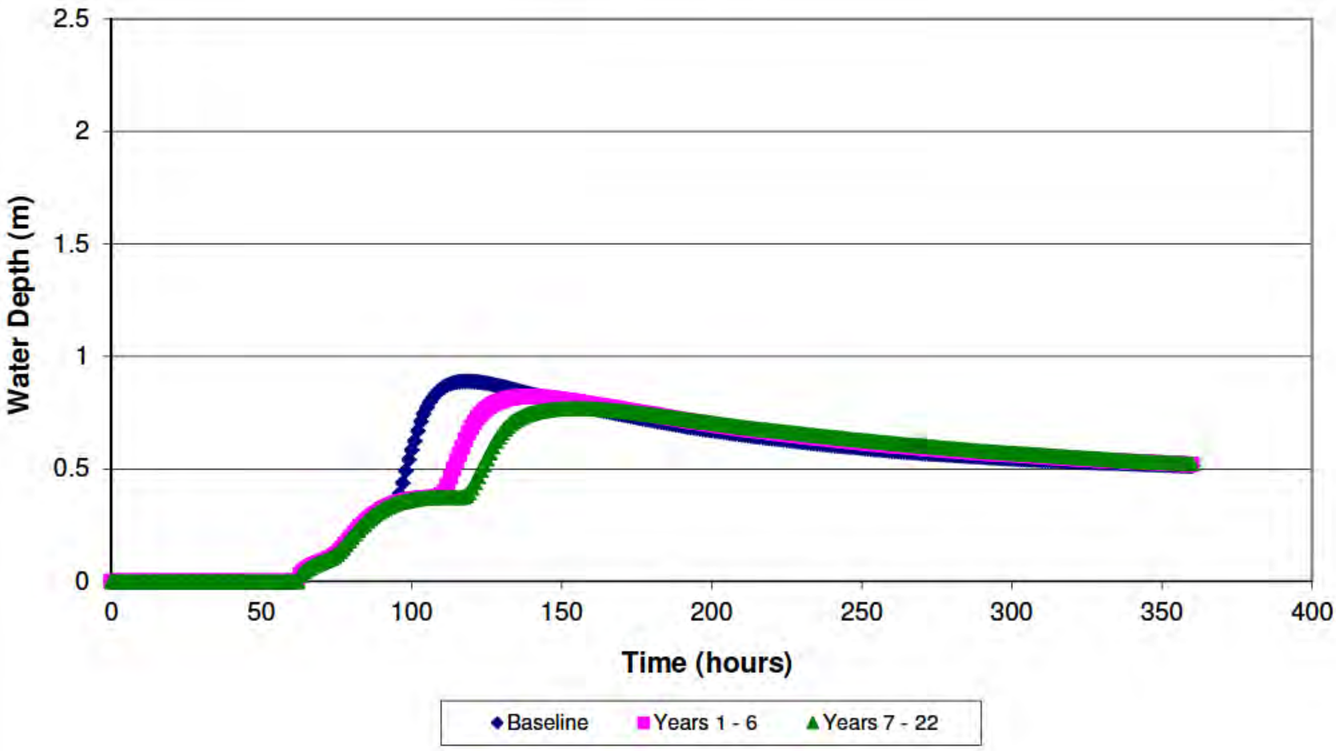
(b) 1:100 Yr ARI



Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: Simulated Change in Flood Hydrographs at Location F	
	Drawn: SH/RNM	Approved: BW	Date: 1/04/2015	Figure: 6-17	Rev. A
	Job No. 42908794	File No. 42908794-SW-134.xls			A4

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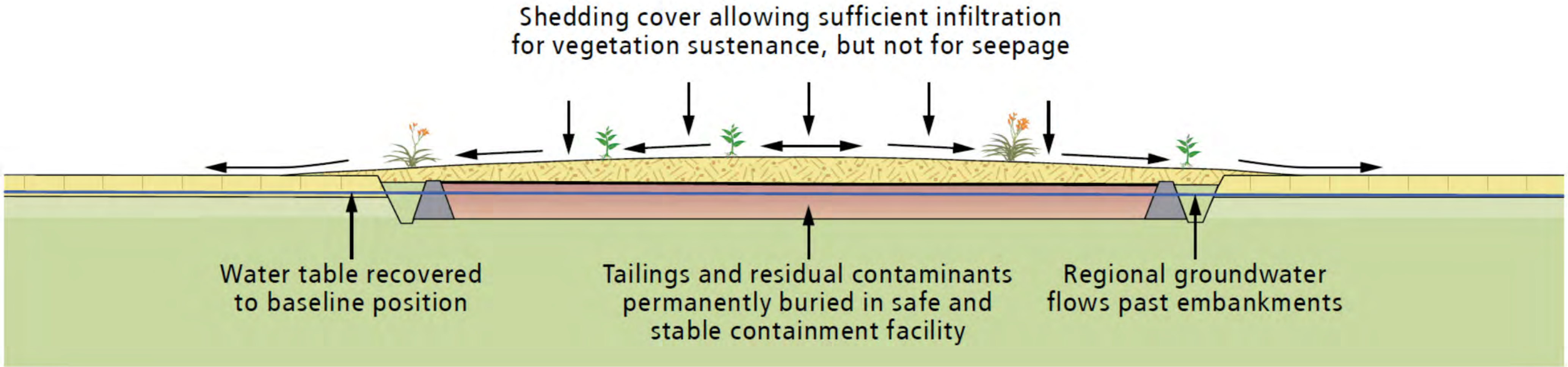

Source: BHP Billiton

Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: Base Case Conceptual Mine Closure Landform Design Cross Section	
	Drawn: RNM	Approved: BW	Date: 4/05/2015	Figure: 7-1	Rev. A
	Job No. 42908794	File No. 42908794-SW-135.xls			A4

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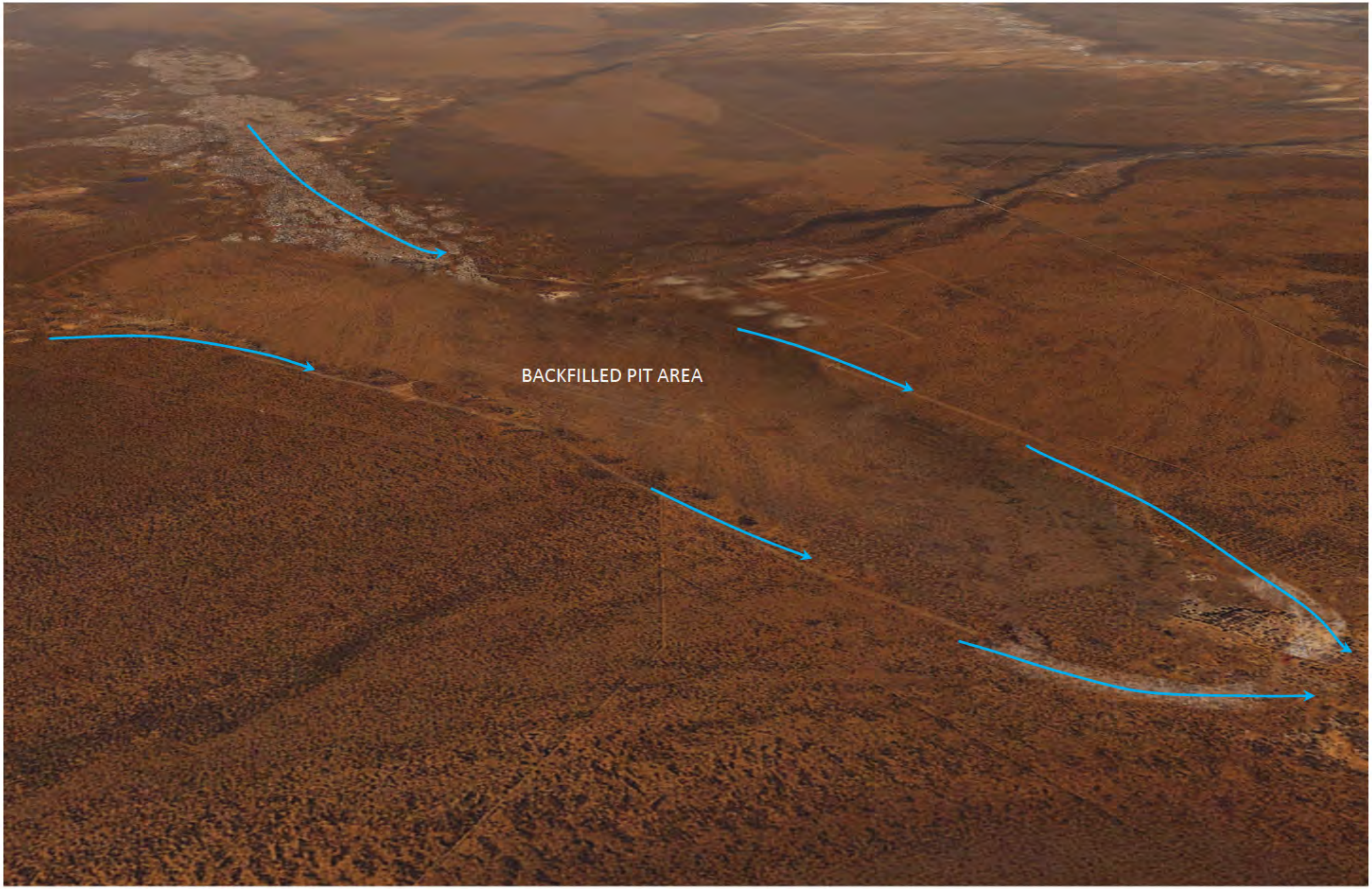

Drainage Lines

Source: BHP Billiton

Cameco

URS

Project:

Surface Water Study, Proposed Yeelirrie Project

Title:

Base Case Conceptual Mine Closure Landform Isometric Image View

Drawn:	RNM	Approved:	BW	Date:	29/04/2015	Figure:	7-2	Rev. A
Job No.	42908794	File No.	42908794-SW-136.xls					A4

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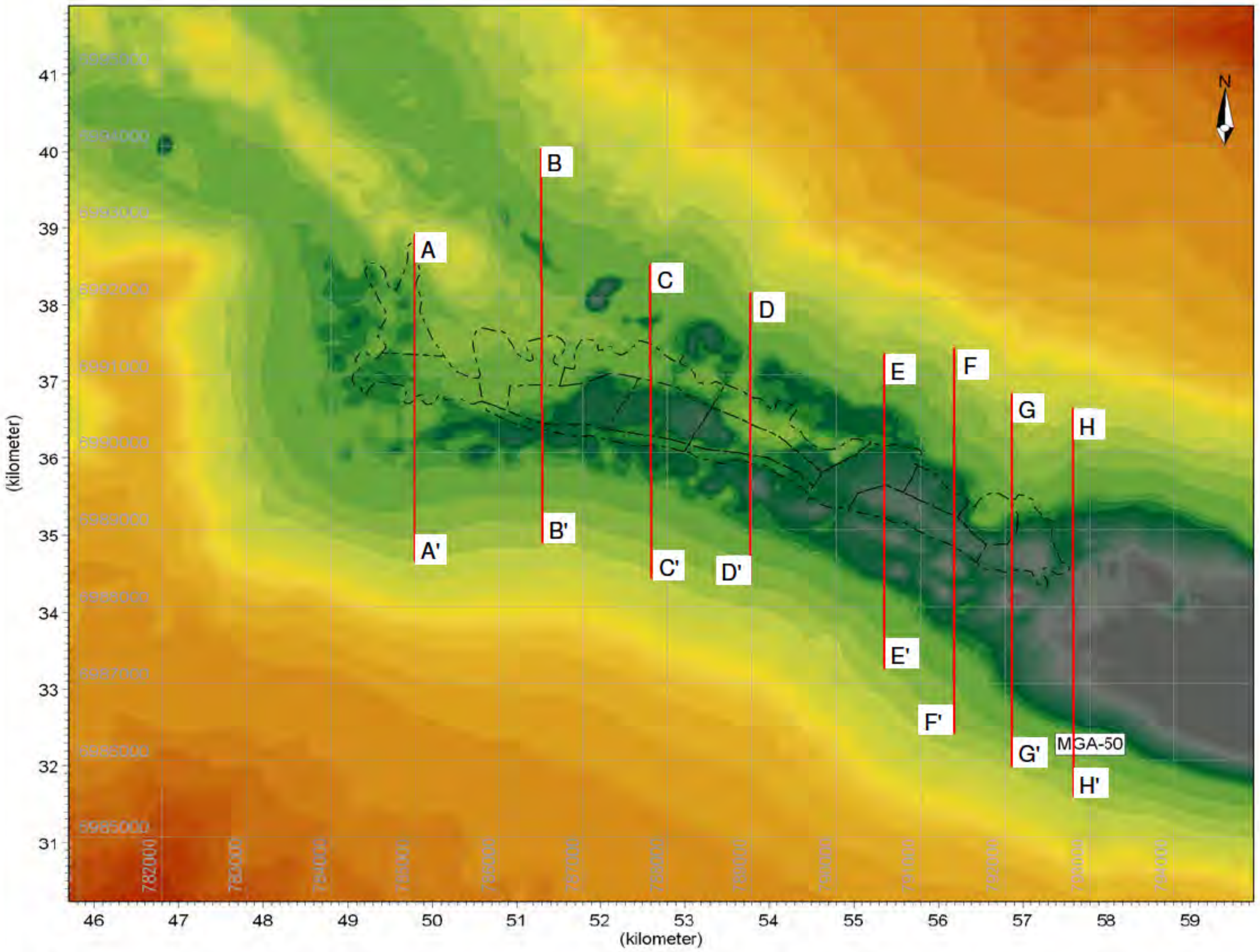
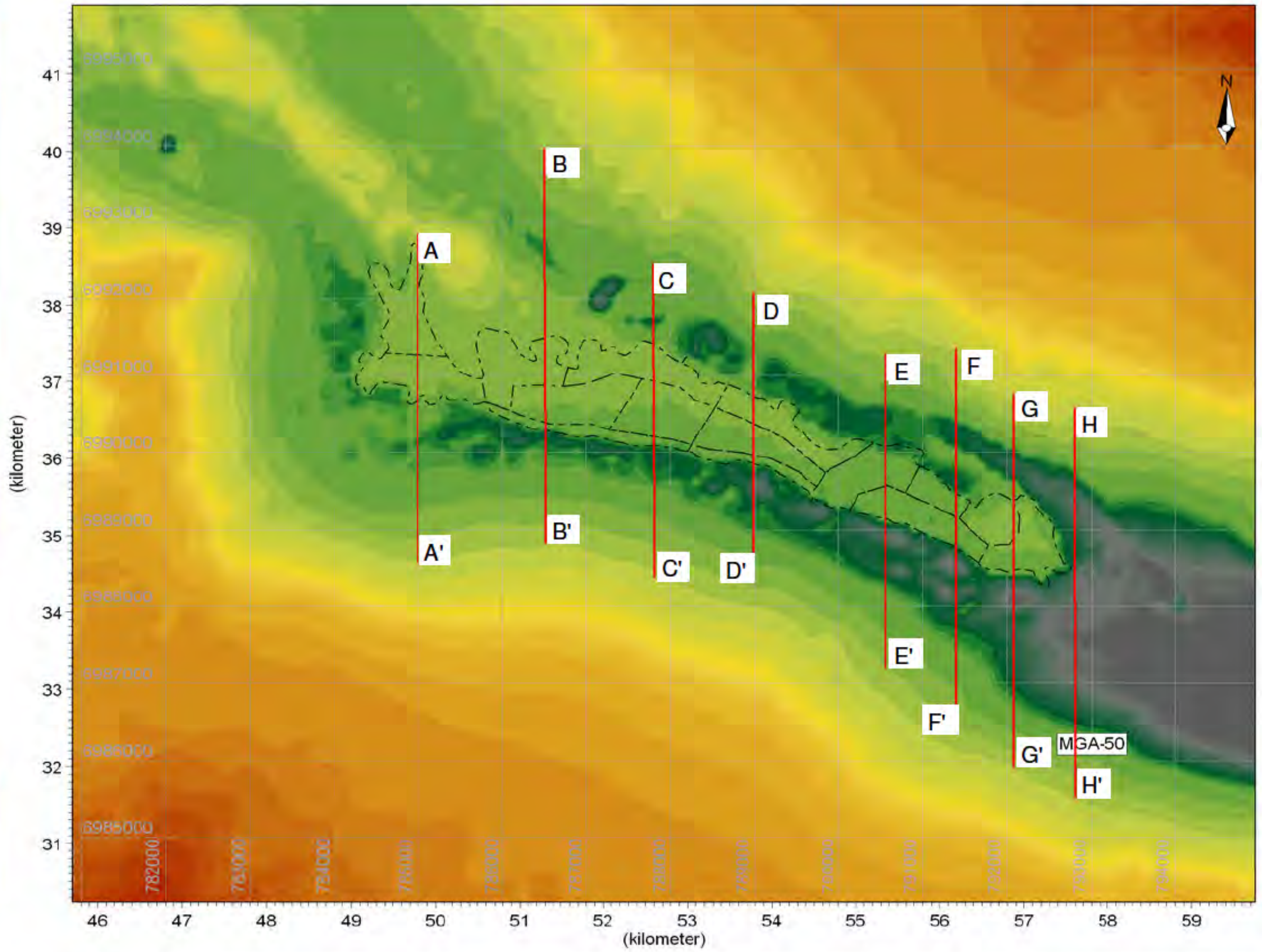
(a) Baseline Landform with Cross Sections



(b) Conceptual Post-closure Landform with Cross Sections

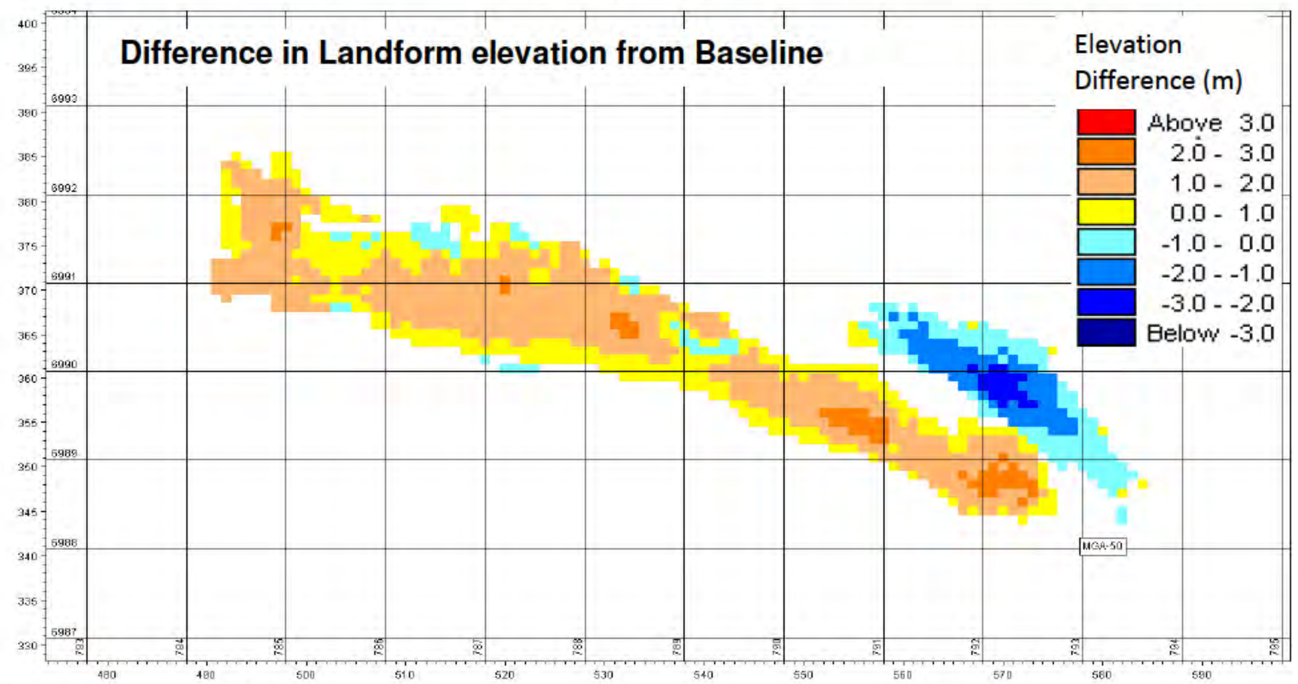


Topography Elevation (mAHD)

Above 536.0	499.0 - 500.0
532.0 - 536.0	498.0 - 499.0
529.0 - 532.0	497.5 - 498.0
525.0 - 529.0	497.0 - 497.5
521.0 - 525.0	496.6 - 497.0
518.0 - 521.0	496.4 - 496.6
510.0 - 518.0	496.2 - 496.4
507.0 - 510.0	496.0 - 496.2
505.0 - 507.0	495.8 - 496.0
504.0 - 505.0	495.6 - 495.8
503.5 - 504.0	495.4 - 495.6
503.0 - 503.5	495.2 - 495.4
502.5 - 503.0	493.0 - 495.2
502.0 - 502.5	Below 493.0
501.0 - 502.0	
500.0 - 501.0	

A —— A' Approximate Location of Cross Section

Difference in Landform elevation from Baseline



Cameco URS	Project: **Surface Water Study, Proposed Yeelirrie Project**	Title: Base Case Conceptual Landform Design Cross Section Locations
	Drawn: RNM · Approved: BW · Date: 29/04/2015	Figure: 7-3 · Rev. A
	Job No. 42908794 · File No. 42908794-SW-137.xls	A3

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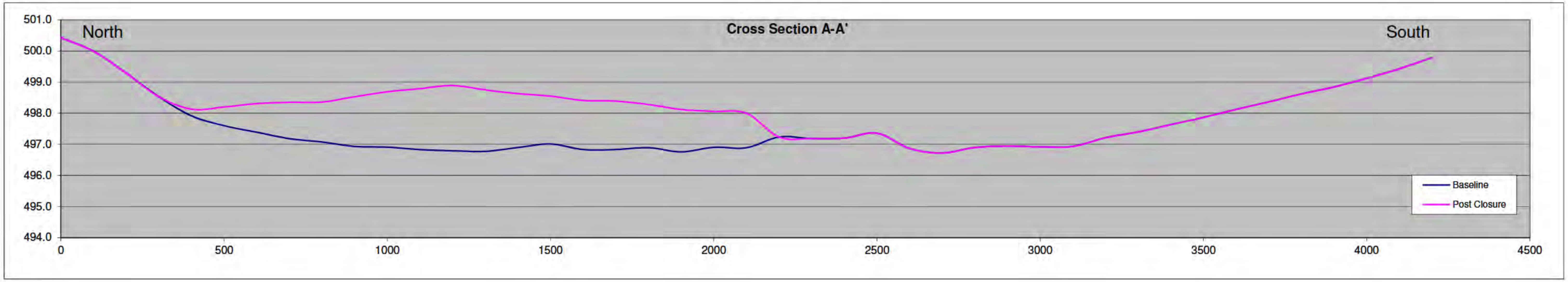

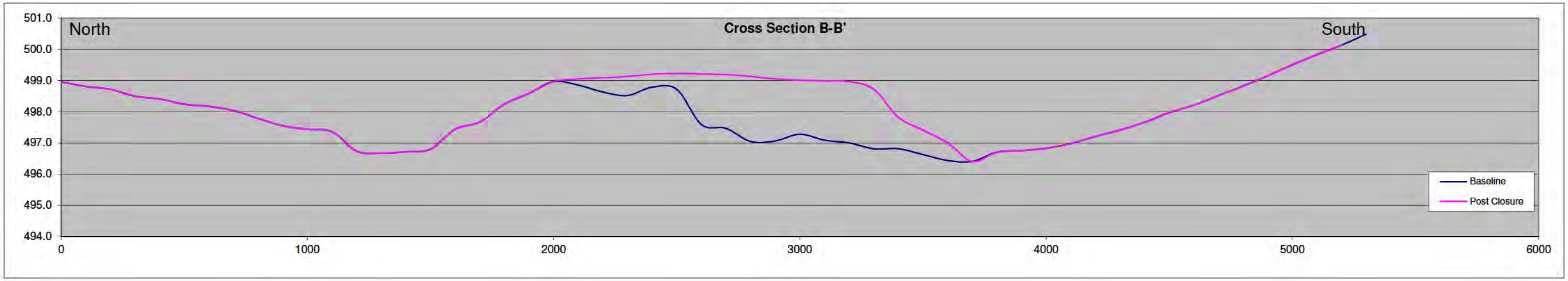

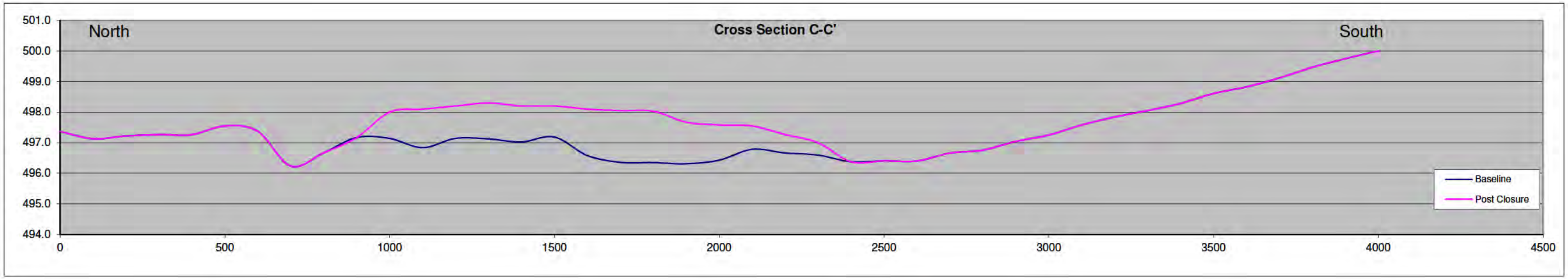

Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: Base Case Conceptual Landform Design Cross Sections A, B and C	
	Drawn: RNM	Approved: BW	Date: 29/04/2015	Figure: 7-4	Rev. A
	Job No. 42908794	File No. 42908794-SW-138.xls			A3

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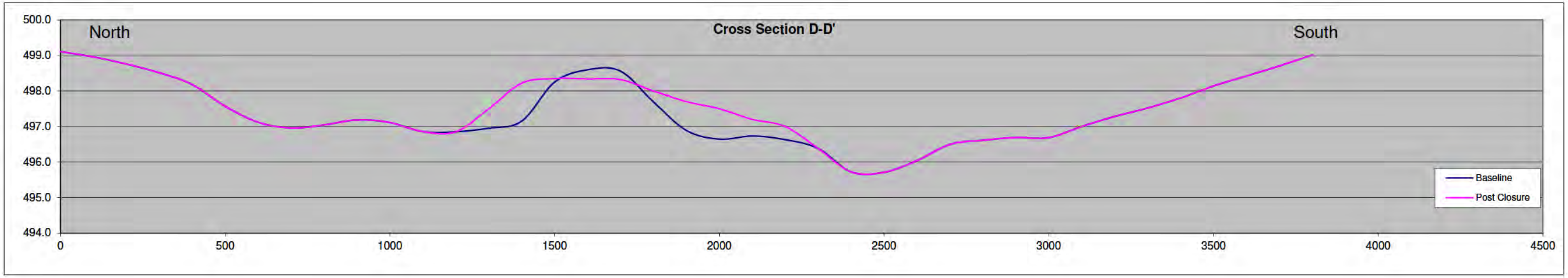

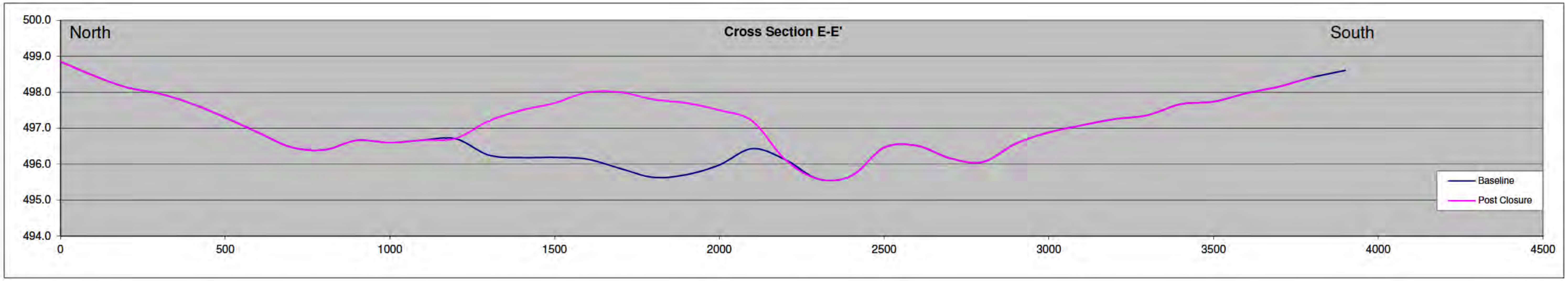

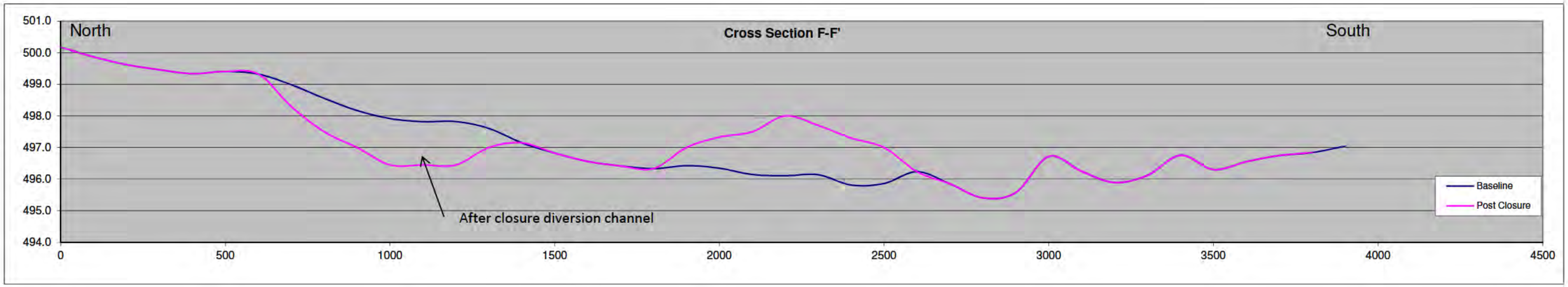

Cameco

URS

Project: **Surface Water Study, Proposed Yeelirrie Project**

Title: Base Case Conceptual Landform Design Cross Sections D, E and F

Drawn: RNM | Approved: BW | Date: 29/04/2015

Job No. 42908794 | File No. 42908794-SW-138.xls

Figure: 7-5 | Rev. A | A3

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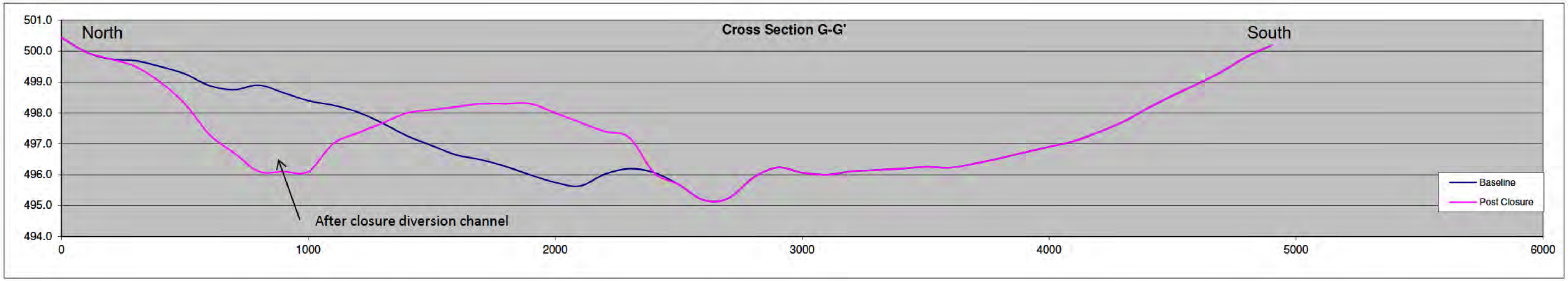

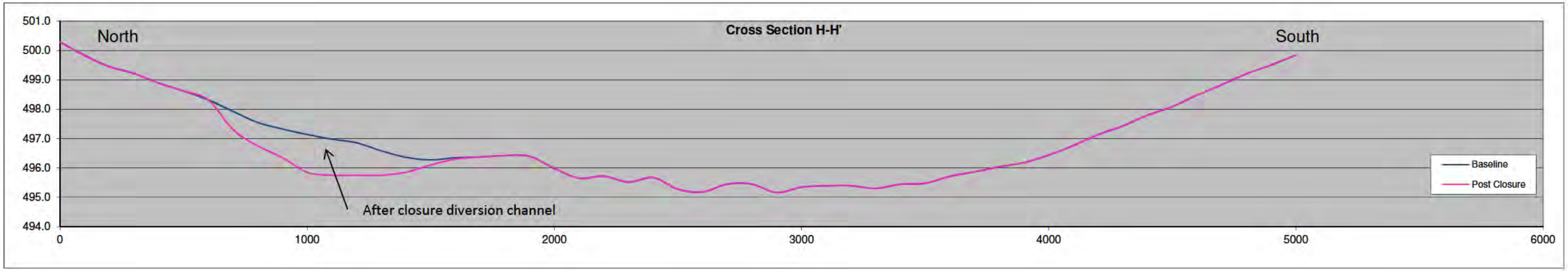

Cameco

URS

Project:

Surface Water Study,
Proposed Yeelirrie Project

Title:

Base Case Conceptual Landform Design
Cross Sections G and H

Drawn: RNM	Approved: BW	Date: 29/04/2015	Figure: 7-6	Rev. A
Job No. 42908794	File No. 42908794-SW-138.xls			A3

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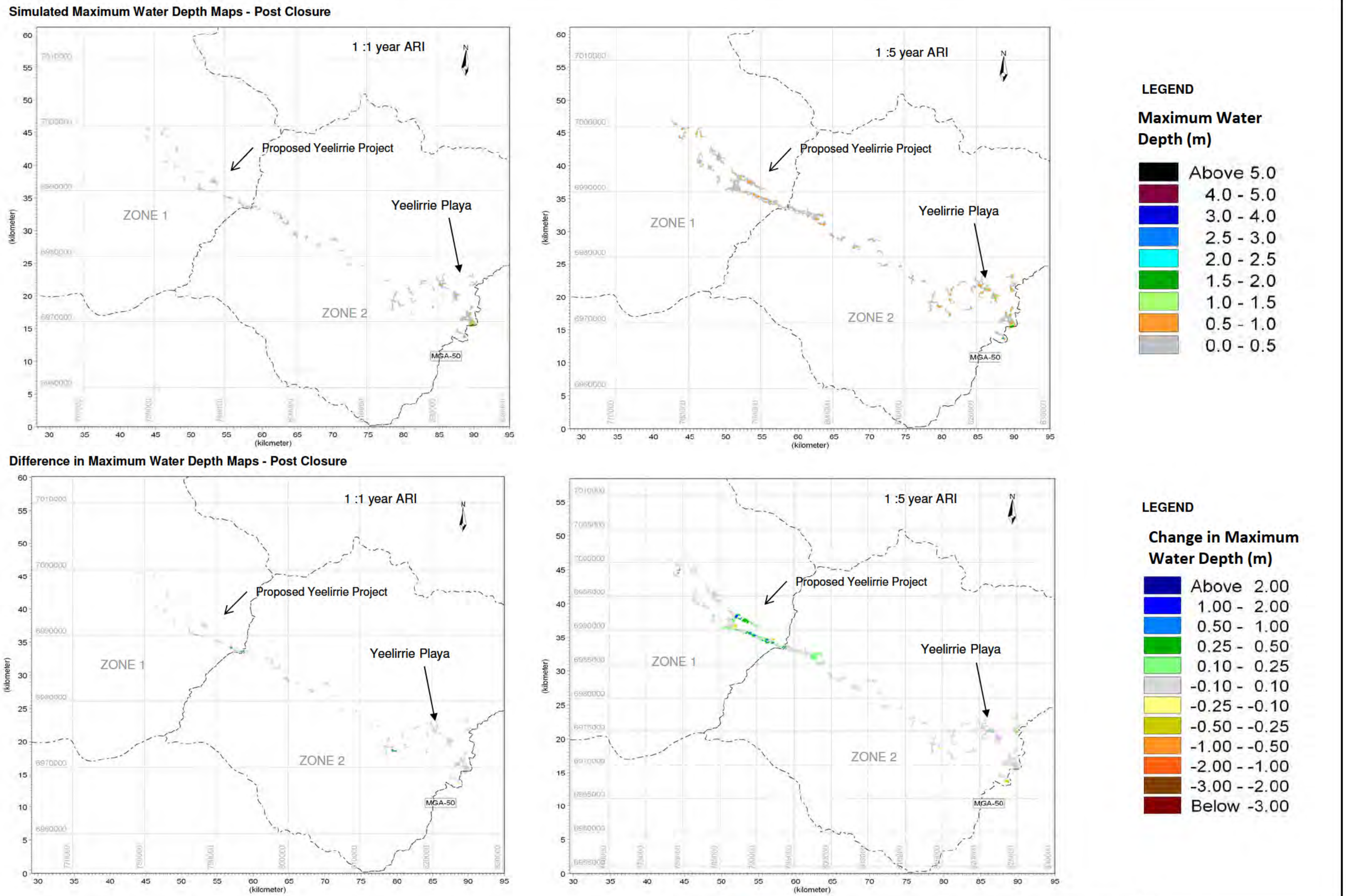

Cameco

URS

Project: **Surface Water Study, Proposed Yeelirrie Project**

Title: Base Case Conceptual Landform Design Difference in Maximum Water Depths from Baseline (1-, 5-year ARI)

Drawn: RNM	Approved: BW	Date: 29/04/2015	Figure: 7-7	Rev. A	
Job No. 42908794	File No. 42908794-SW-139.xls			A3	

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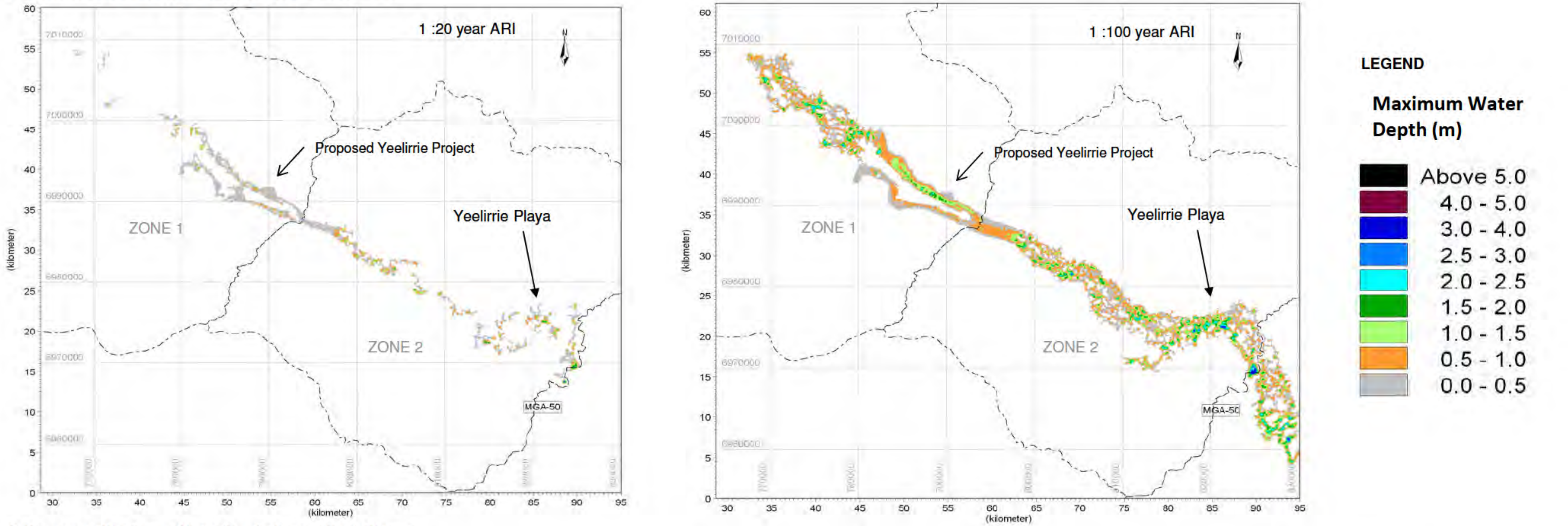
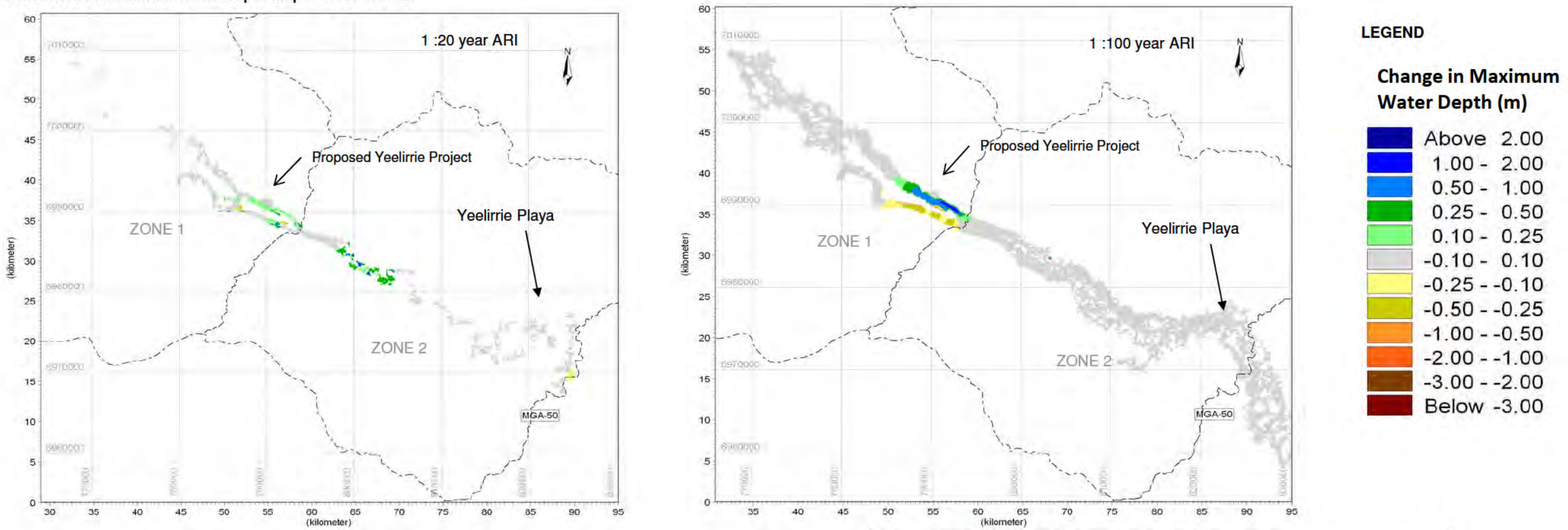
Simulated Maximum Water Depth Maps - Post Closure



Difference in Maximum Water Depth Maps - Post Closure



Cameco URS	Project: Surface Water Study, Proposed Yeelirrie Project			Title: Base Case Conceptual Landform Design Difference in Maximum Water Depths from Baseline (20-, 100-year ARI)	
	Drawn: RNM	Approved: BW	Date: 29/04/2015	Figure: 7-8	Rev. A
	Job No. 42908794	File No. 42908794-SW-139.xls			A3

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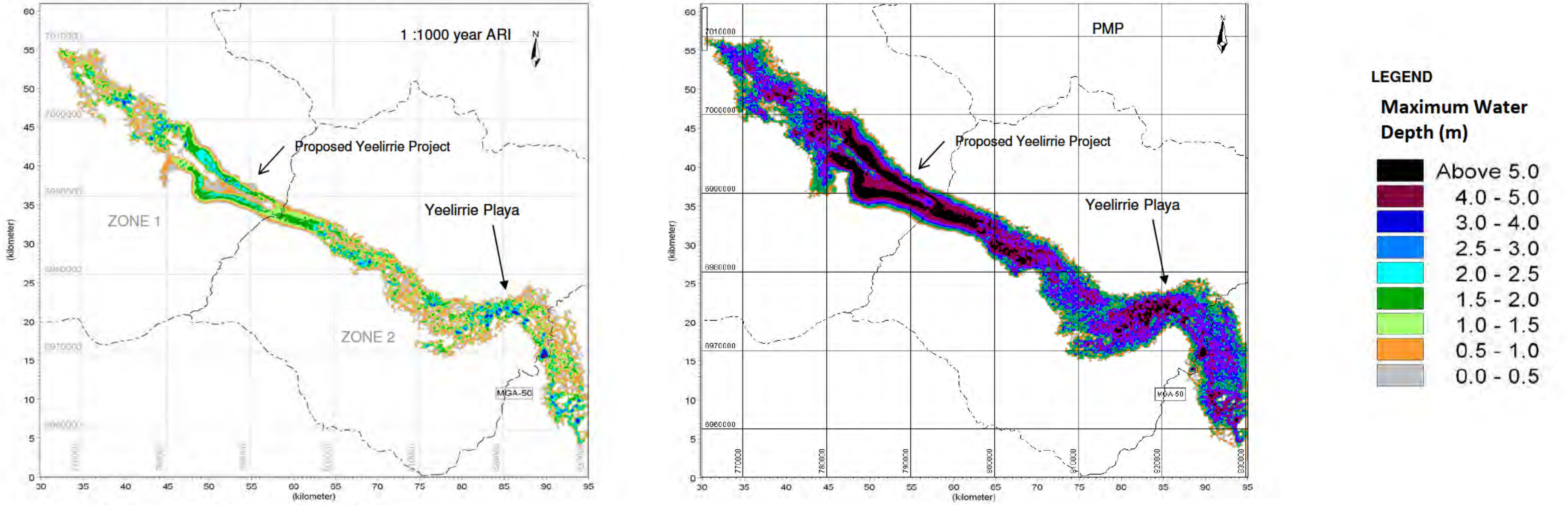
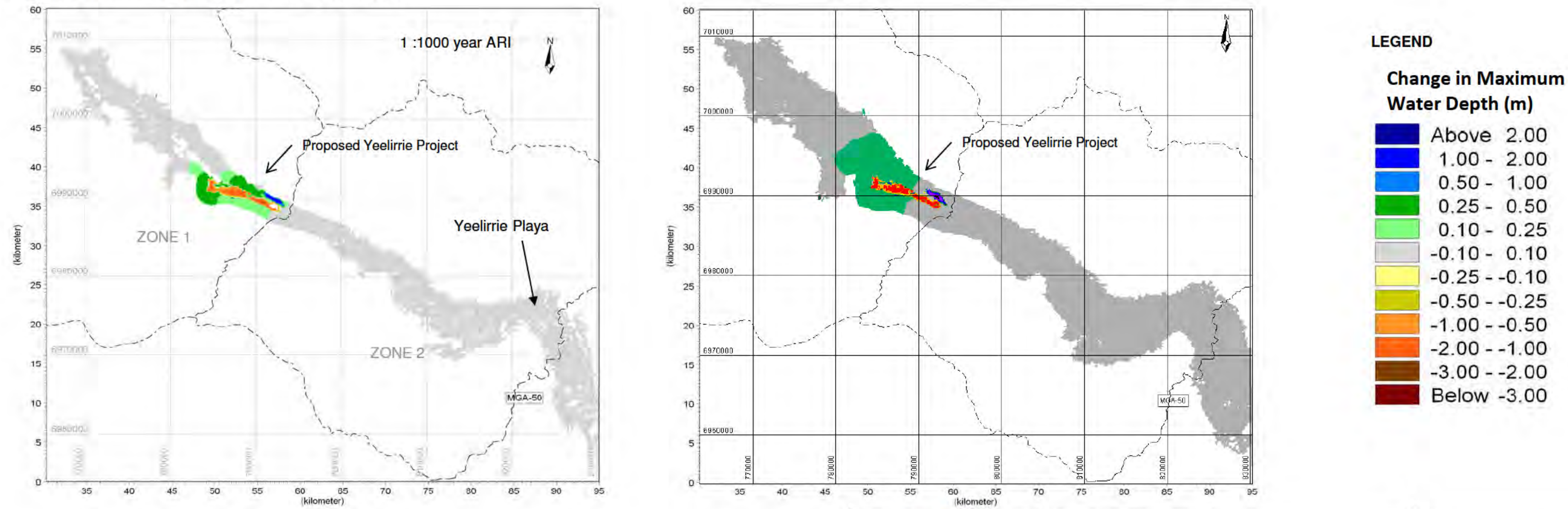
Simulated Maximum Water Depth Maps - Post Closure



Difference in Maximum Water Depth Maps - Post Closure



Cameco
URS

Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: Base Case Conceptual Landform Design Difference in Maximum Water Depths from Baseline (1,000-year ARI and PMP)
Drawn: RNM	Approved: BW	Date: 29/04/2015	Figure: 7-9 — Rev. A
Job No. 42908794	File No. 42908794-SW-139.xls		A3

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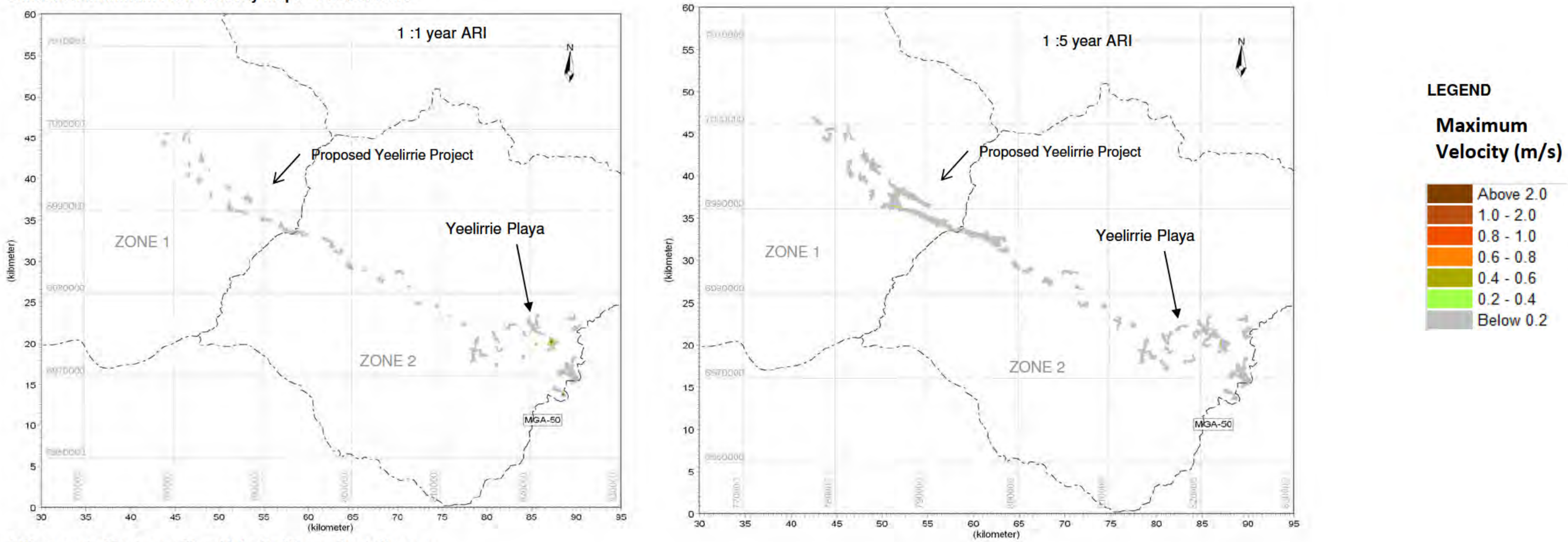
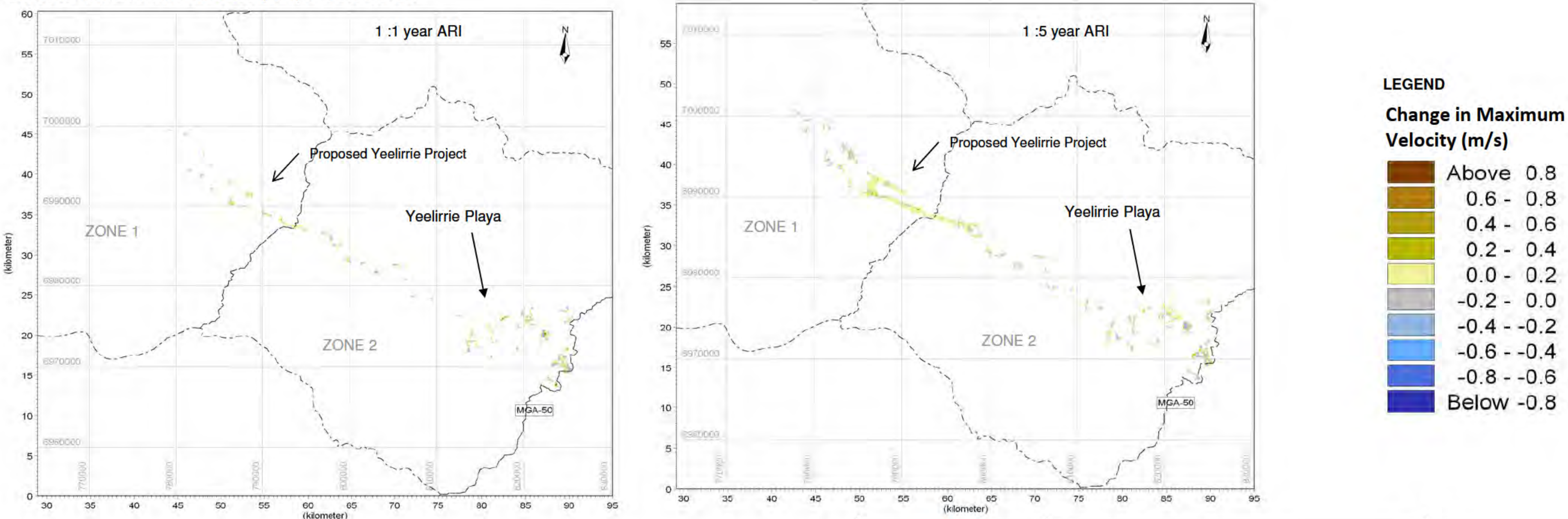
Simulated Maximum Flow Velocity Maps - Post Closure



Difference in Maximum Flow Velocity Maps - Post Closure



Cameco / URS	Project: Surface Water Study, Proposed Yeelirrie Project		Title: Base Case Conceptual Landform Design Difference in Maximum Flow Velocities from Baseline (1- 5-year ARI)	
	Drawn: RNM	Approved: BW	Date: 29/04/2015	Rev. A
	Job No. 42908794	File No. 42908794-SW-139.xls	Figure: 7-10	A3

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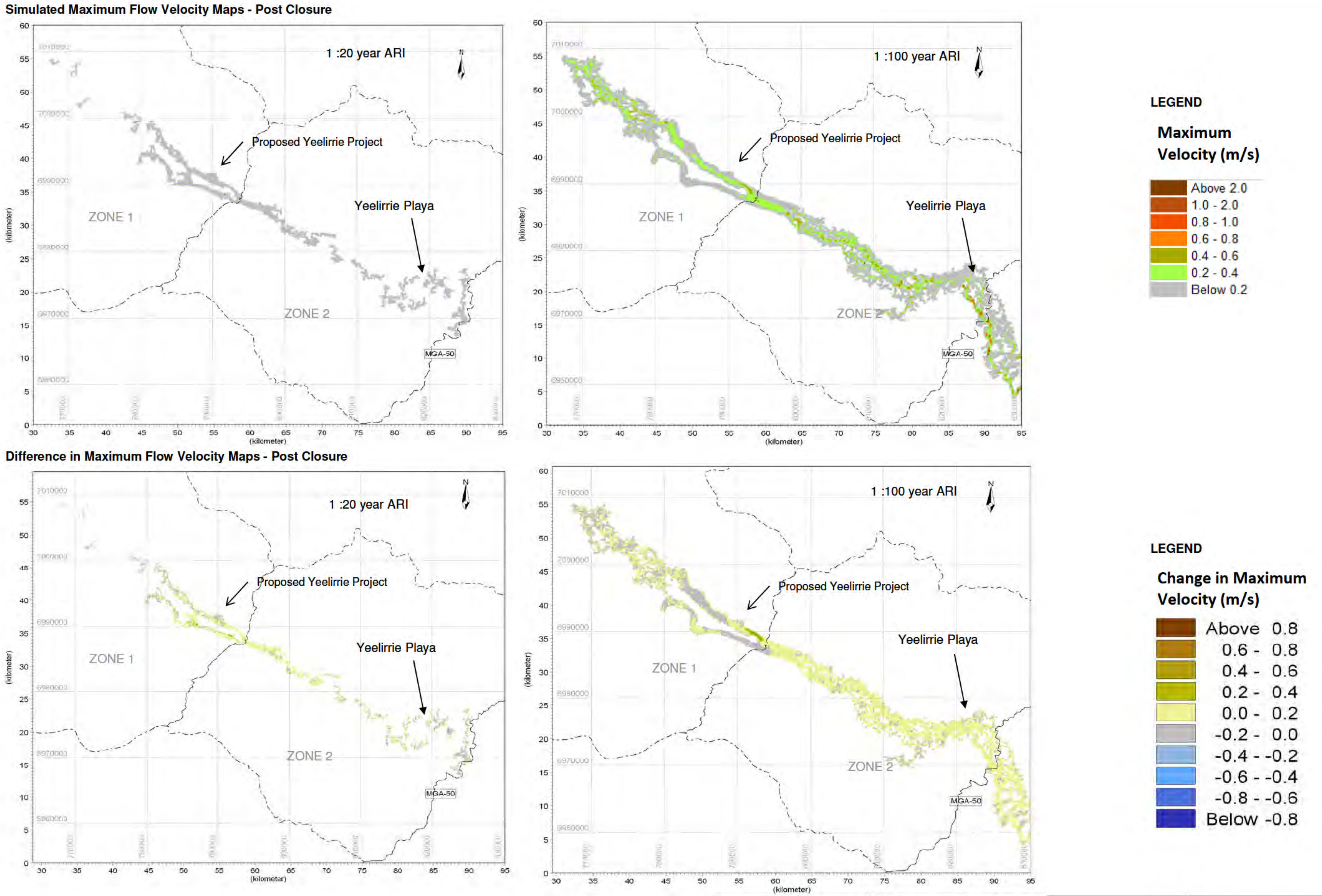

Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**			Title: Base Case Conceptual Landform Design Difference in Maximum Flow Velocities from Baseline (20-, 100-year ARI)	
	Drawn: RNM	Approved: BW	Date: 29/04/2015	Figure: 7-11	Rev. A
	Job No. 42908794	File No. 42908794-SW-139.xls			A3

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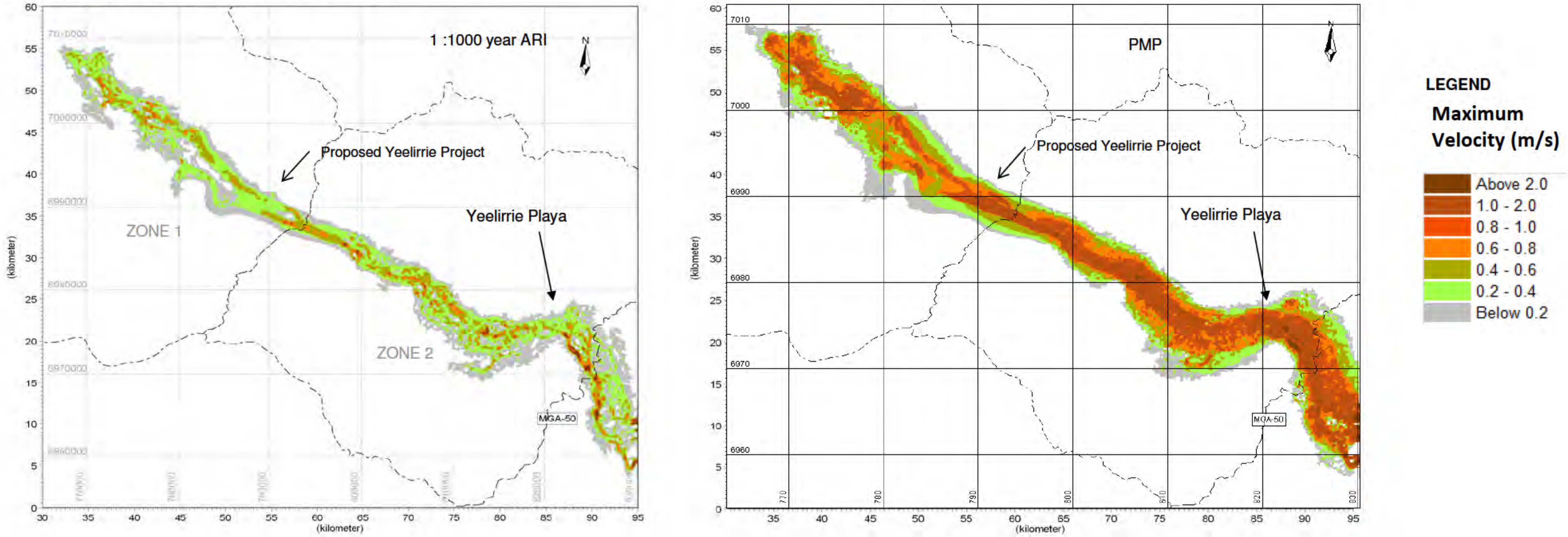
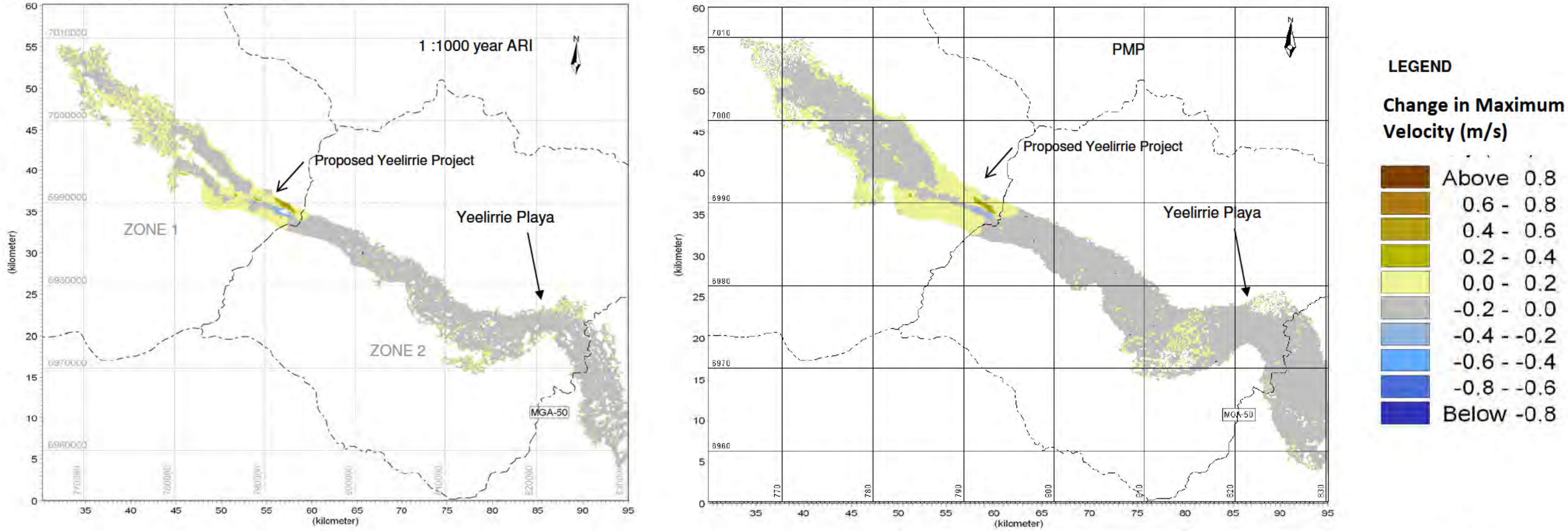
Simulated Maximum Flow Velocity Maps - Post Closure



Difference in Maximum Flow Velocity Maps - Post Closure



Cameco
URS

Project: **Surface Water Study, Proposed Yeelirrie Project**

Title: Base Case Conceptual Landform Design Difference in Maximum Flow Velocities from Baseline (1,000-year ARI and PMP)

Drawn: RNM	Approved: BW	Date: 29/04/2015	Figure: 7-12	Rev. A
Job No. 42908794	File No. 42908794-SW-139.xls			A3

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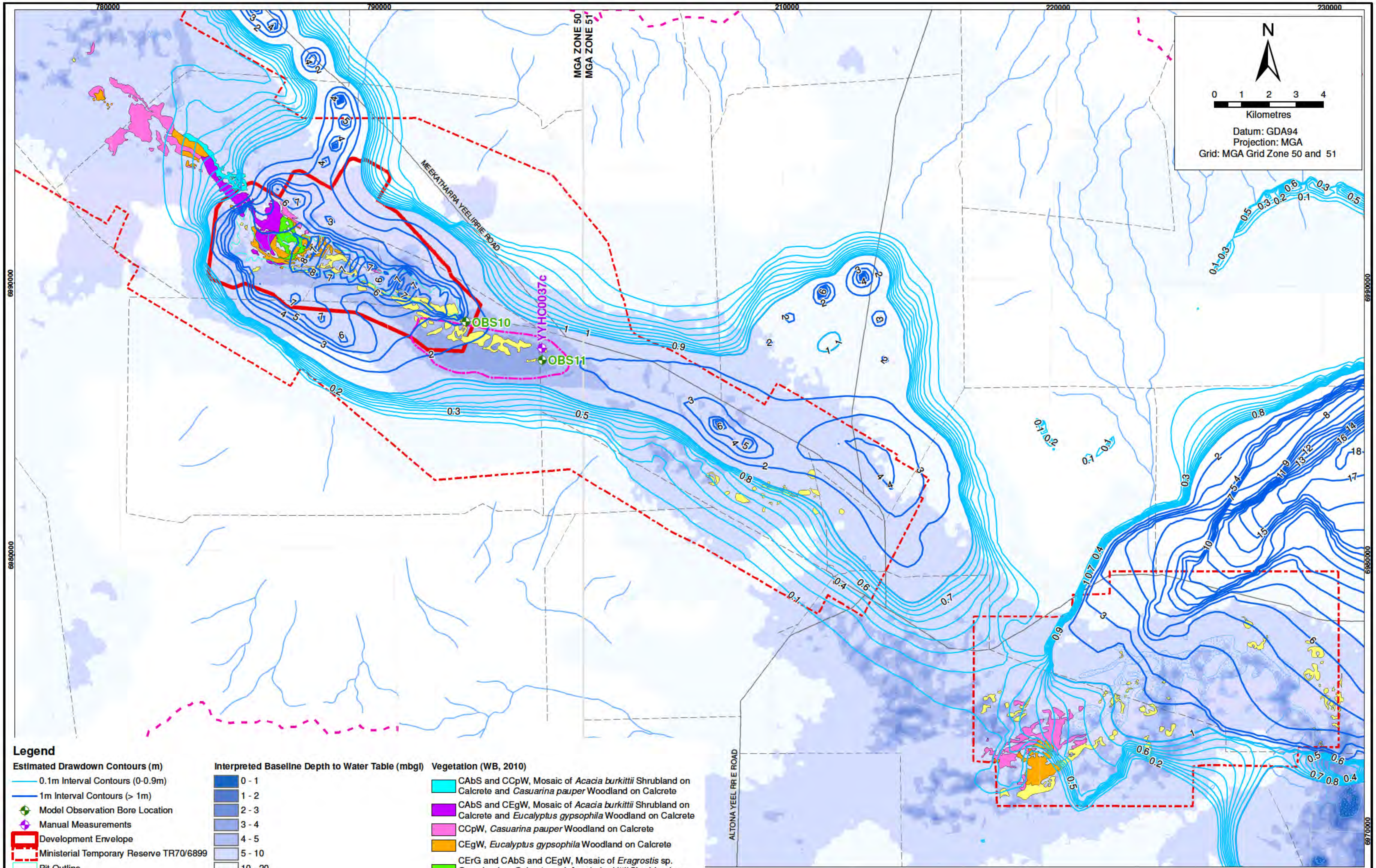

Legend

Estimated Drawdown Contours (m)
- 0.1m Interval Contours (0-0.9m)
- 1m Interval Contours (> 1m)
- Model Observation Bore Location
- Manual Measurements
- Development Envelope
- Ministerial Temporary Reserve TR70/6899
- Pit Outline
- Yeelirrie Catchment
- Homesteads
- Minor Road
- Track
- Minor Watercourses
- Non-Perennial Lake

Interpreted Baseline Depth to Water Table (mbgl)
- 0 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- 10 - 20
- > 20

Vegetation (WB, 2010)
- CAbS and CCpW, Mosaic of *Acacia burkittii* Shrubland on Calcrete and *Casuarina pauper* Woodland on Calcrete
- CAbS and CEgW, Mosaic of *Acacia burkittii* Shrubland on Calcrete and *Eucalyptus gypsophila* Woodland on Calcrete
- CCpW, *Casuarina pauper* Woodland on Calcrete
- CEgW, *Eucalyptus gypsophila* Woodland on Calcrete
- CErG and CAbS and CEgW, Mosaic of *Eragrostis* sp. Grassland on Calcrete and *Acacia burkittii* Shrubland on Calcrete and *Eucalyptus gypsophila* Woodland on Calcrete
- CMxS, *Melaleuca xerophila* Shrubland on Calcrete

Cameco / URS	Project: **Surface Water Study, Proposed Yeelirrie Project**		Title: Predicted Maximum Water Table Drawdown (Year 19)	
	Drawn: RNM	Approved: RW	Date: 8/05/2015	Rev. A
	Job No.: 42908794	File No.: 42908794-SW-021.mxd	Figure: 8-1	A3

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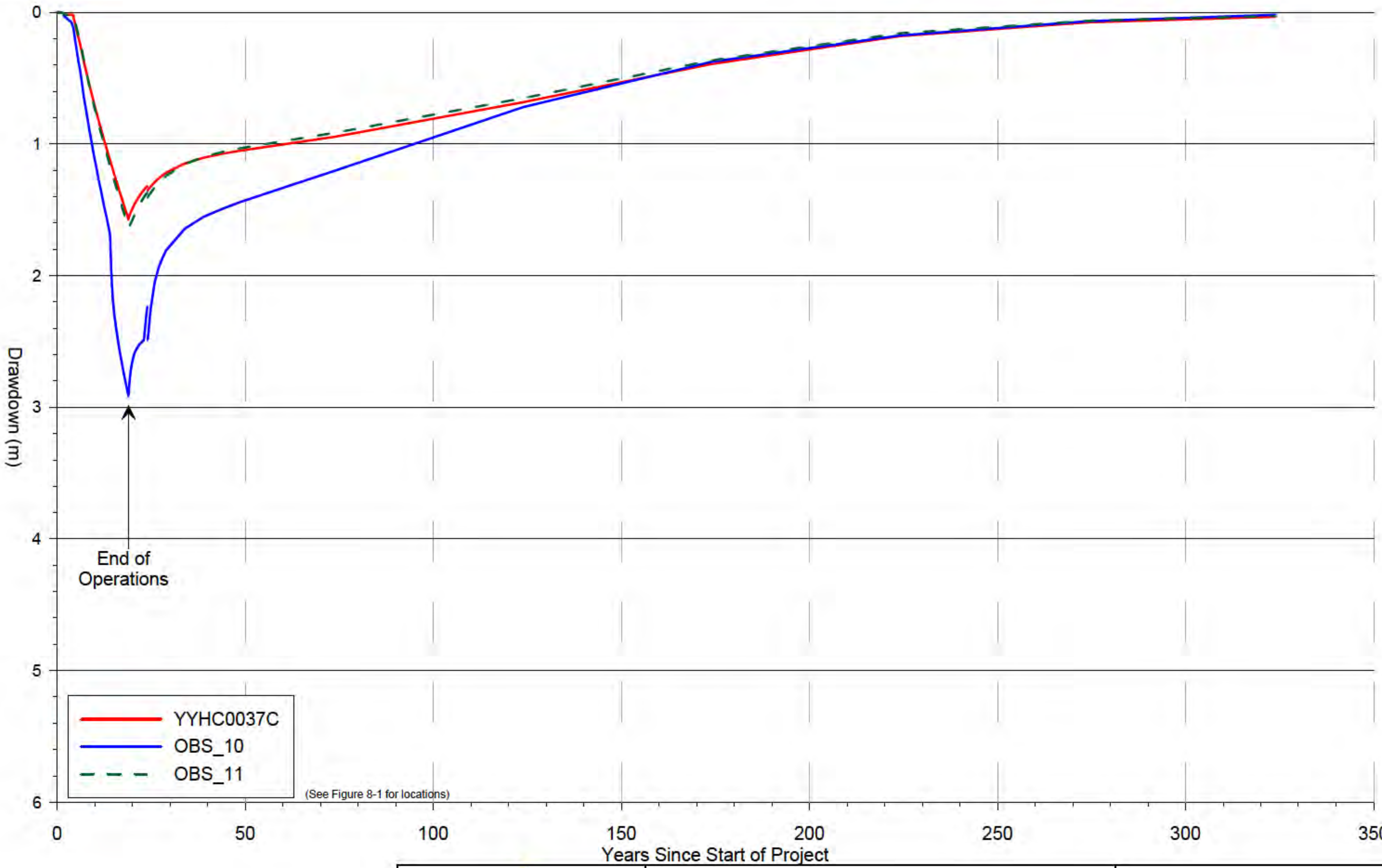

Cameco URS	Project: **Surface Water Study Proposed Yeelirrie Development**		Title: Predicted Drawdown Downstream of the Proposed Mine Site	
	Drawn: RW	Approved: BW	Date: 06/05/2015	Figure: 8-2	Rev. A
	Job No. 42908794	File No. 42908794-SW-112.grf			A4

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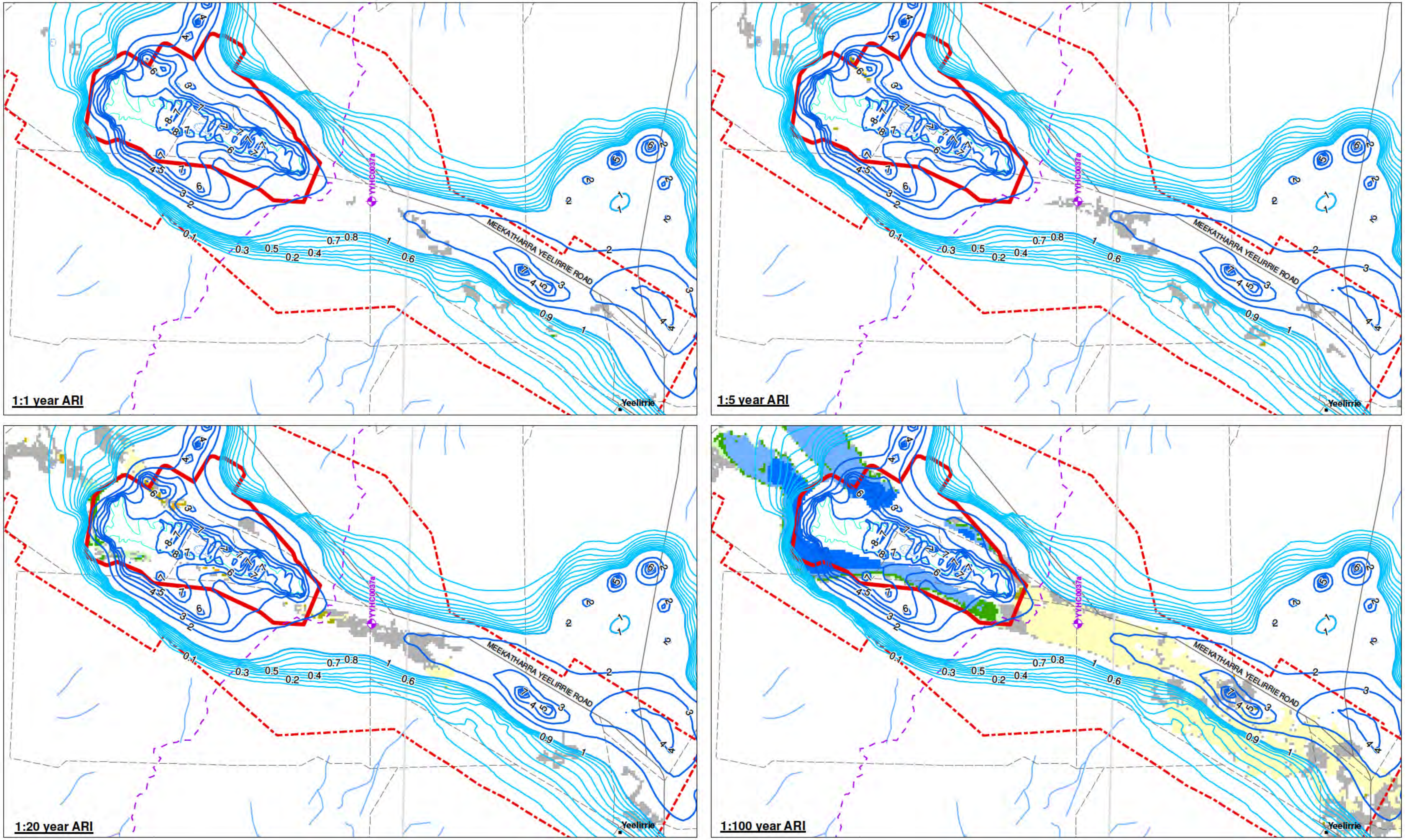

Legend

- Manual Measurements
- Development Envelope
- Ministerial Temporary Reserve TR70/6899
- Pit Outline
- Yeelirrie Catchment
- Homesteads
- Minor Road
- Track
- Minor Watercourses
- Non-Perennial Lake
- 0.1m Interval Contours (0-0.9m)
- 1m Interval Contours (> 1m)

Difference In Max Depth (m)

- Above 2.00
- 1.00 - 2.00
- 0.50 - 1.00
- 0.25 - 0.50
- 0.10 - 0.25
- -0.10 - 0.10
- -0.25 - -0.10
- -5.0 - -0.25
- Below -0.50

N

0 1 2 3 4
Kilometres

Datum: GDA94
Projection: MGA
Grid: MGA Grid Zone 50

Cameco

URS

Project	Title
Surface Water Study, Proposed Yeelirrie Project	Predicted Flood Depth Changes and Maximum Water Table Drawdown (Year 19)

Drawn: RNM	Approved: RW	Date: 8/05/2015	Figure: 8-3	Rev. A
Job No.: 42908794	File No.: 42908794-SW-022.mxd			A3

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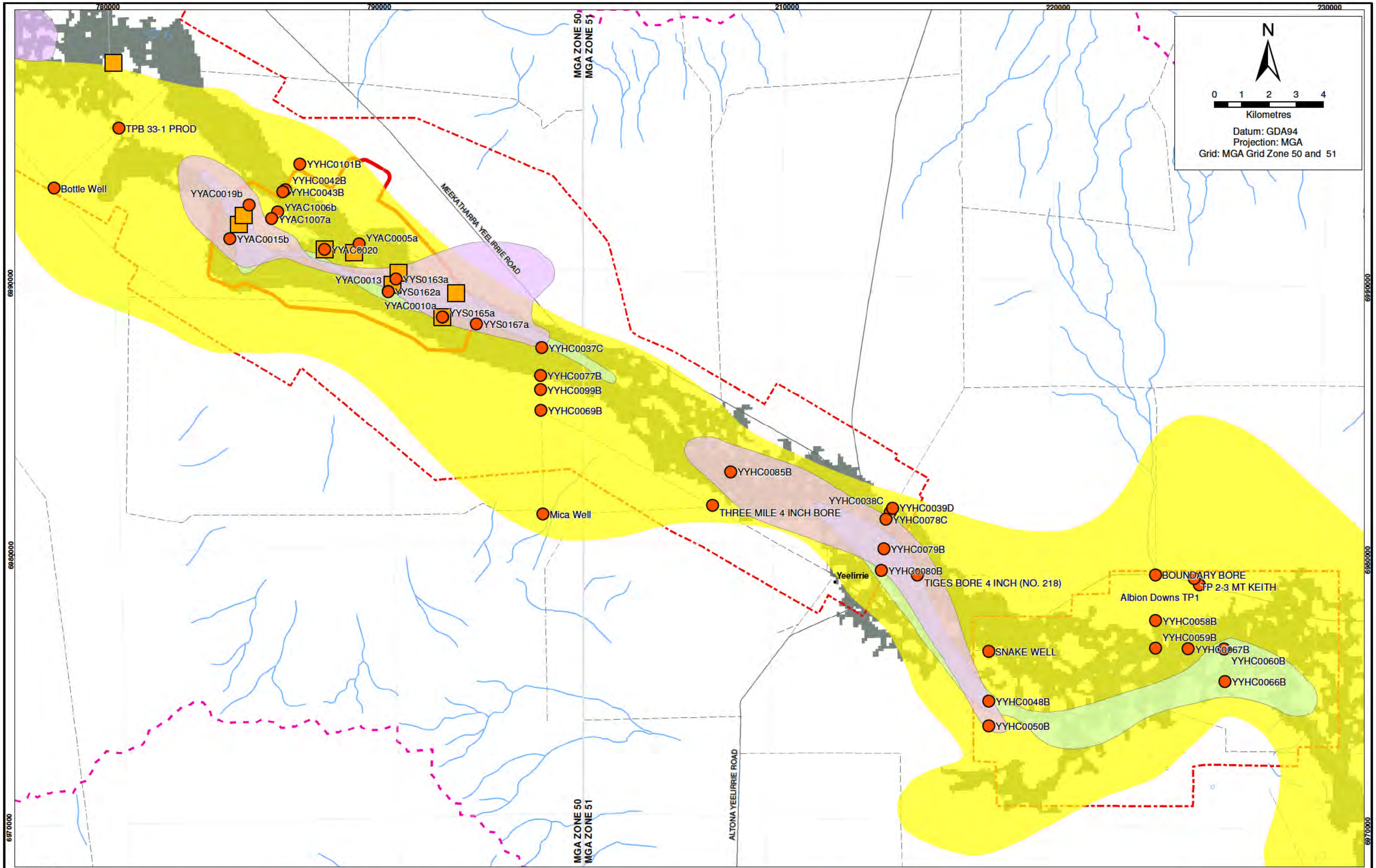


Legend

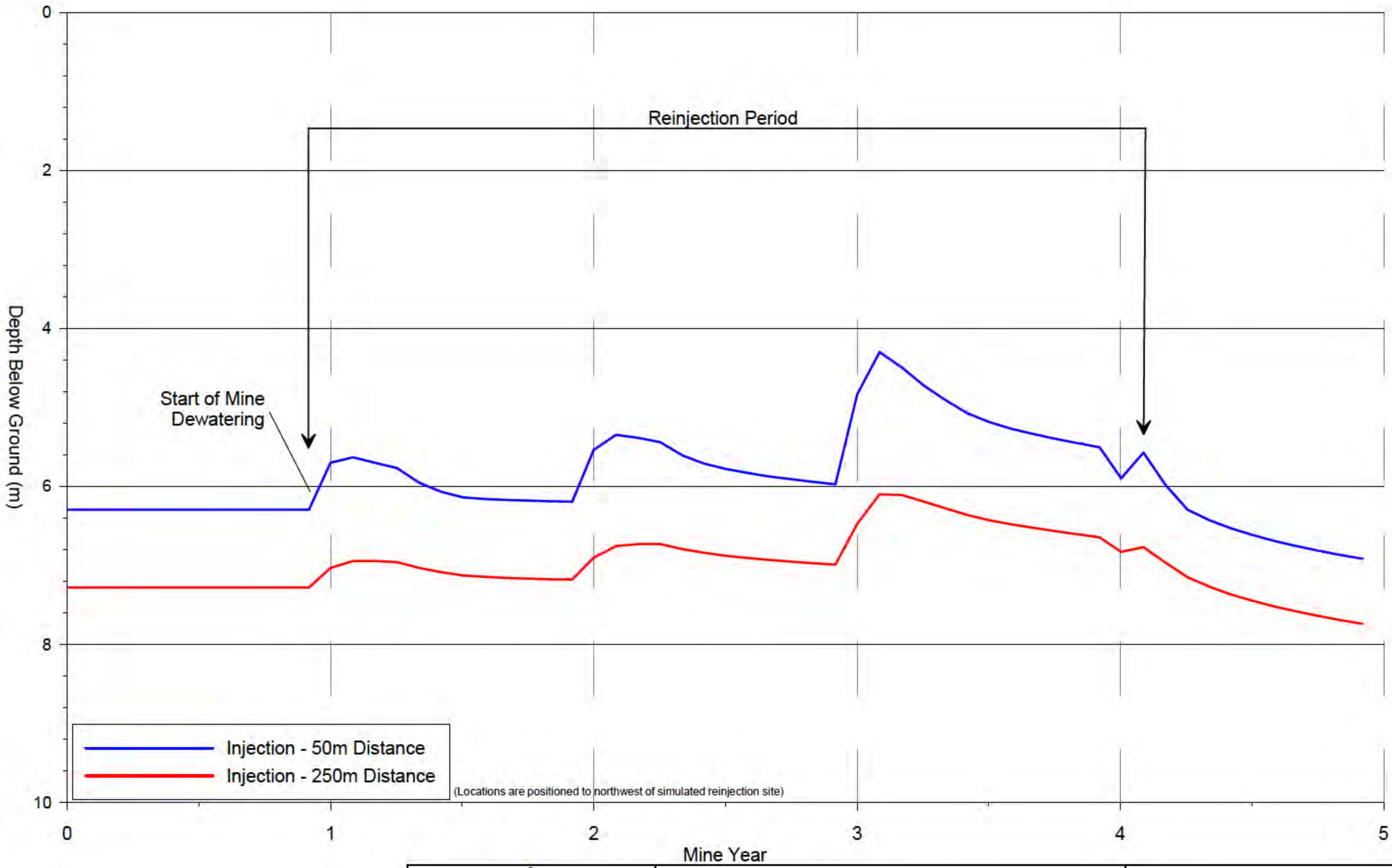
- TDS Above ANZECC Stockwater Guidelines (Oct, 2000)
- Salinity (TDS) > 4000 mg/L
- Uranium Concentration > 0.2 mg/L
- Selenium Concentration > 0.05 mg/L
- Radium 226 Activity > 5 Bq/L
- Predicted Extent of 100 Year ARI Flood
- Development Envelope
- Ministerial Temporary Reserve TR70/6899
- Pit Outline
- Yeelirrie Catchment
- Homesteads
- Minor Road
- Track
- Minor Watercourses
- Non-Perennial Lake

Note:
Exceedences above ANZECC Stock Water Guidelines for: Arsenic, Vanadium and Lead 210 not shown as either below Guideline Trigger or no Guideline value applies.

Cameco

URS

Project			Title
Surface Water Study, Proposed Yeelirrie Project			Interpreted Distribution of Groundwater Not Meeting Stock Water Quality Criteria
Drawn: RNM	Approved: RW	Date: 8/05/2015	Figure: 8-4
Job No.: 42908794	File No.: 42908794-SW-023.mxd		Rev. A A3



Cameco

URS

Project: **Surface Water Study Proposed Yeelirrie Development**

Title: Predicted Water Table Mounding From Reinjection

Drawn: RW | Approved: BW | Date: 06/05/2015 | Figure: 8-5 | Rev. A

Job No. 42908794 | File No. 42908794-SW-113.grf | A4

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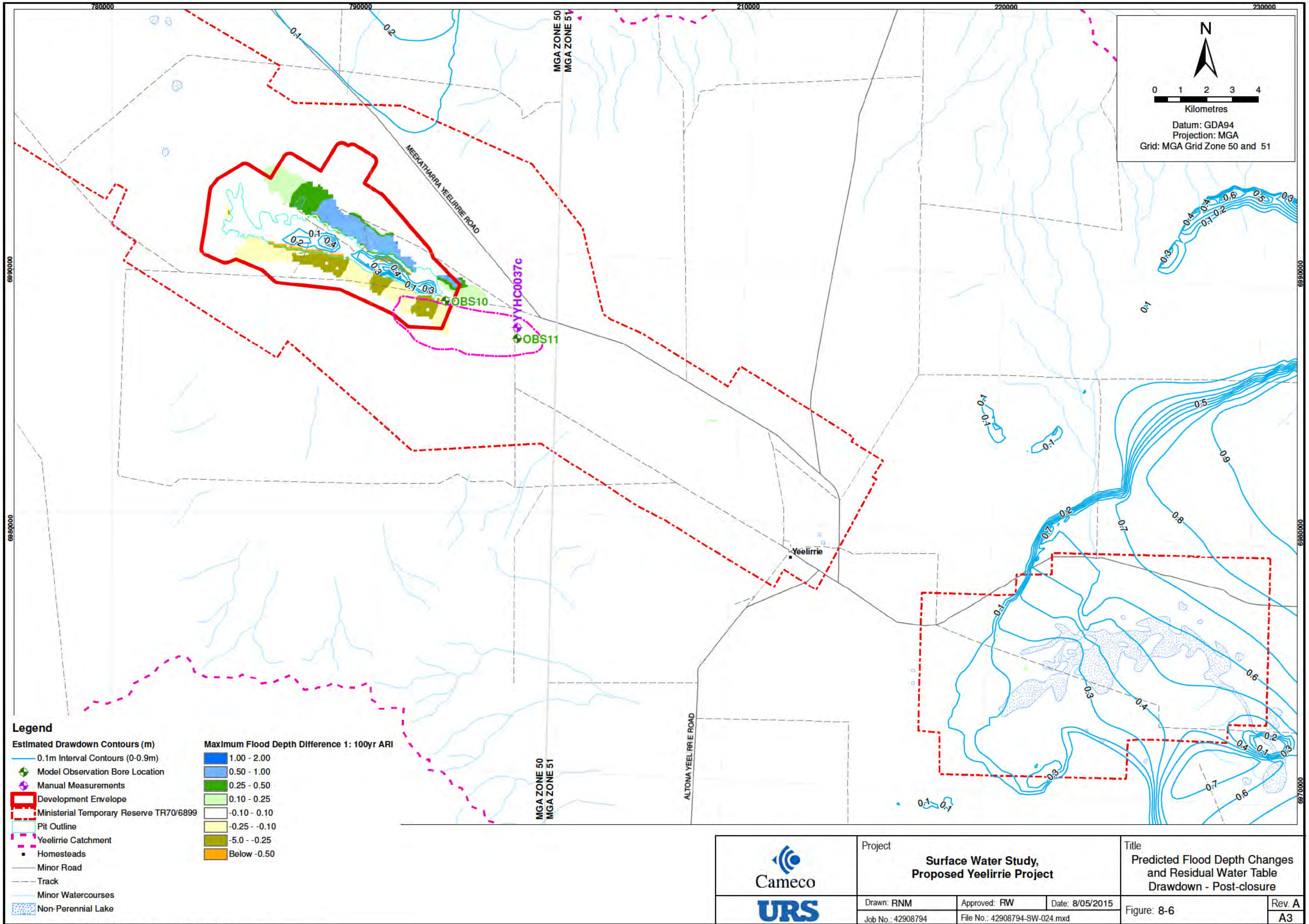

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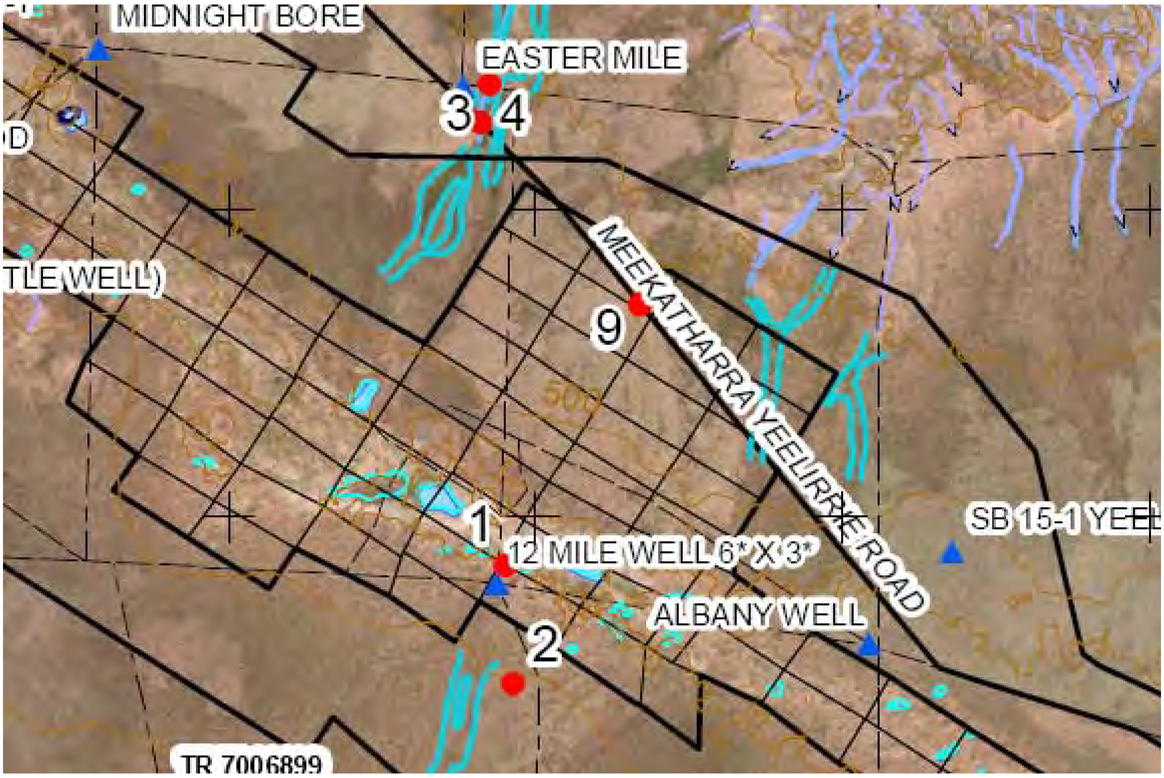
APPENDIX A SITE RECONNAISSANCE VISIT

A.1 North East of 12 Mile Well

The North East of 12 Mile Well inspection point is located east of the 12 Mile Well on the track between 12 Mile Well and Albany Well, as shown below.

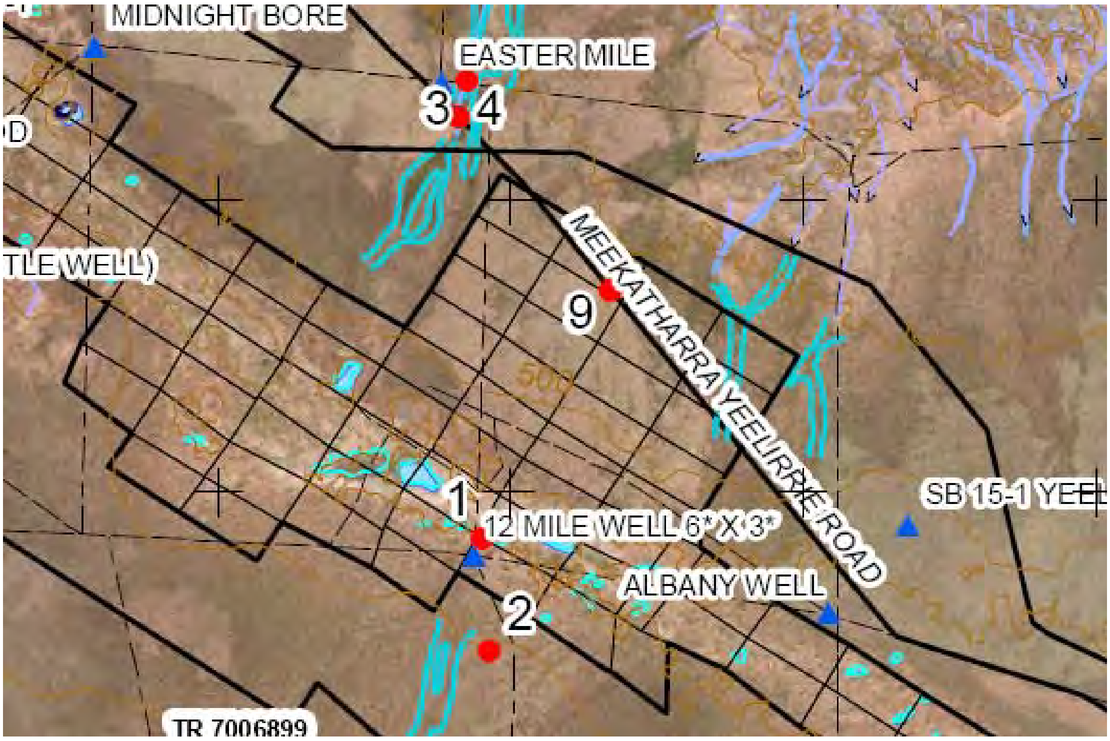


Location No.	1 (See map above)
Location Name	North East of 12 Mile Bore
Location Co-ordinates	E 789529, N 6989239, GDA94, Zone 50
Site Description	Drainage path on southern side of Calcrete formation, capturing surface runoff from the local area (Calcrete formation and surrounds).
Drainage Geometry	Small localised drainage channel, approximately 0.15m deep and 1.5m wide. Otherwise, there were no defined channels with distinguishable bed and banks. Small, slow conveyance of surface runoff expected.
Substrate Type	Red sands.
Stability of banks	No banks present. In general, no evidence of erosion.
Water	No water was present at the time of the site inspection, although evidence of recently ponded water (greener vegetation than surrounds and evidence of recent Kangaroo inhabitance).
Debris and tree roots	Evidence of leaf matter and twigs deposited by water.

 Low lying area where surface runoff would pool	 Small localised channel.
 Evidence of leaf matter and twigs deposited by water.	

A.2 South of 12 Mile Well

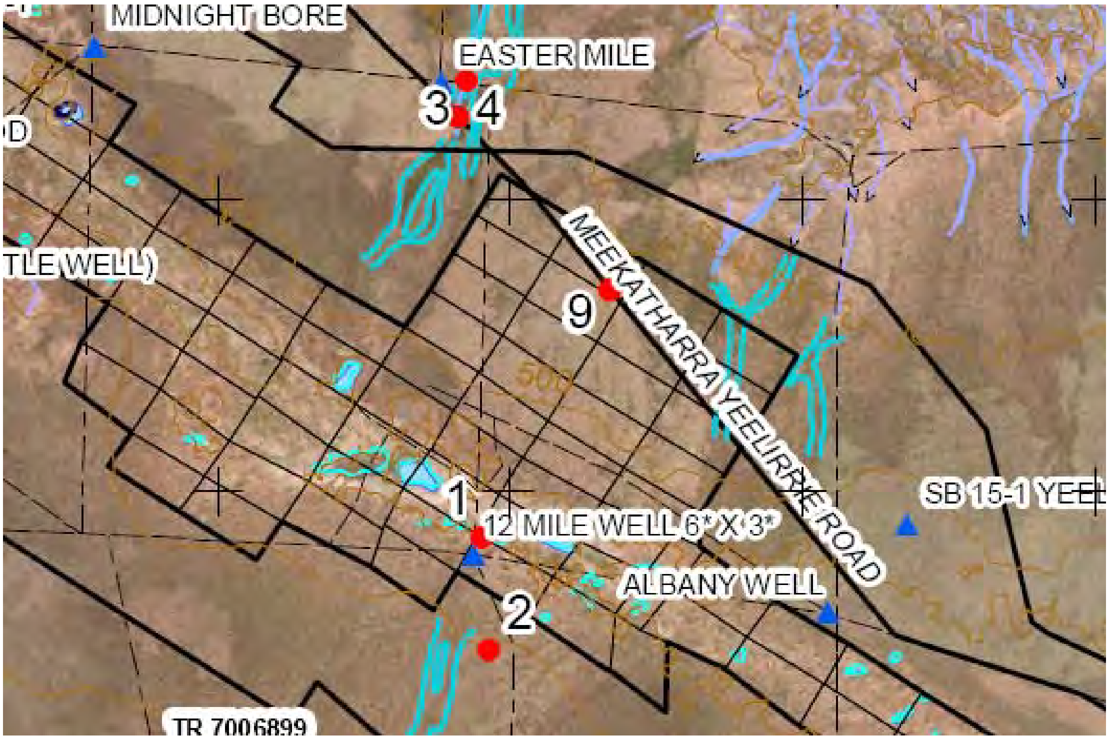
This inspection point is located south of 12 Mile Well, on the western side of the track to Mallee Hen Well, as shown below.



Location No.	2 (See map above)
Location Name	South of 12 Mile Well
Location Co-ordinates	E 789627, N 6987279, GDA94, Zone 50
Site Description	Expected location of southern catchment drainage path.
Drainage Geometry	No evidence of drainage feature - expect that this area would convey sheet flow only.
Substrate Type	Red sands.
Stability of banks	No banks evident. No evidence of erosion
Water	No evidence of water in this area recently.
Debris and tree roots	Some debris and tree roots – not expected to block flow path.

A.3 Easter Mile Drainage Feature Upstream

The inspection point is located to the east of Easter Mile, on the access track between Easter Mile and Twin Bore, as shown below.

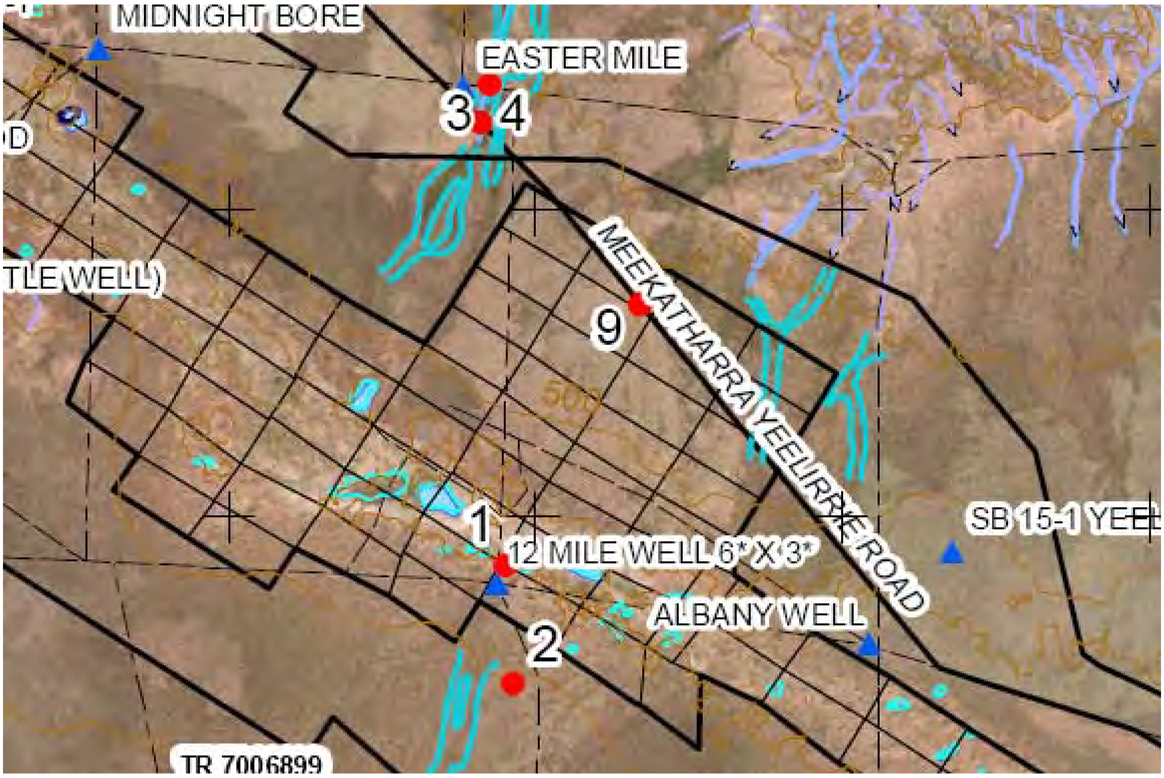


Location No.	3 (See map above)
Location Name	Easter Mile Drainage Feature Upstream
Location Co-ordinates	E 789268, N 6997050, GDA94, Zone 50
Site Description	Drainage path conveying surface runoff from the northern breakaway to the central drainage path (unconfirmed whether this drainage feature terminates prior to reaching the central drainage path).
Drainage Geometry	Braided drainage feature, with approximately 3 drainage lines of varied geometry.
Substrate Type	Red sands.
Stability of banks	The drainage line banks were not vegetated, however there was no significant erosion present. There was increased ground cover between the braided drainage lines.
Water	No surface water present and no evidence of previously ponded water in this area.
Debris and tree roots	Evidence of leaf matter and twigs deposited by water, between the braided drainage lines – indicating that flow has exceeded the drainage line capacity recently. Some debris built up behind the small trees between the braided drainage lines to a height of approximately 200mm.

 Middle drainage line	 Debris behind trees – evidence of flow
 Eastern drainage line	

A.4 Easter Mile Drainage Feature Downstream

The inspection point is located on Meektharra Yeelirrie Road, south of Easter Mile, as shown below.



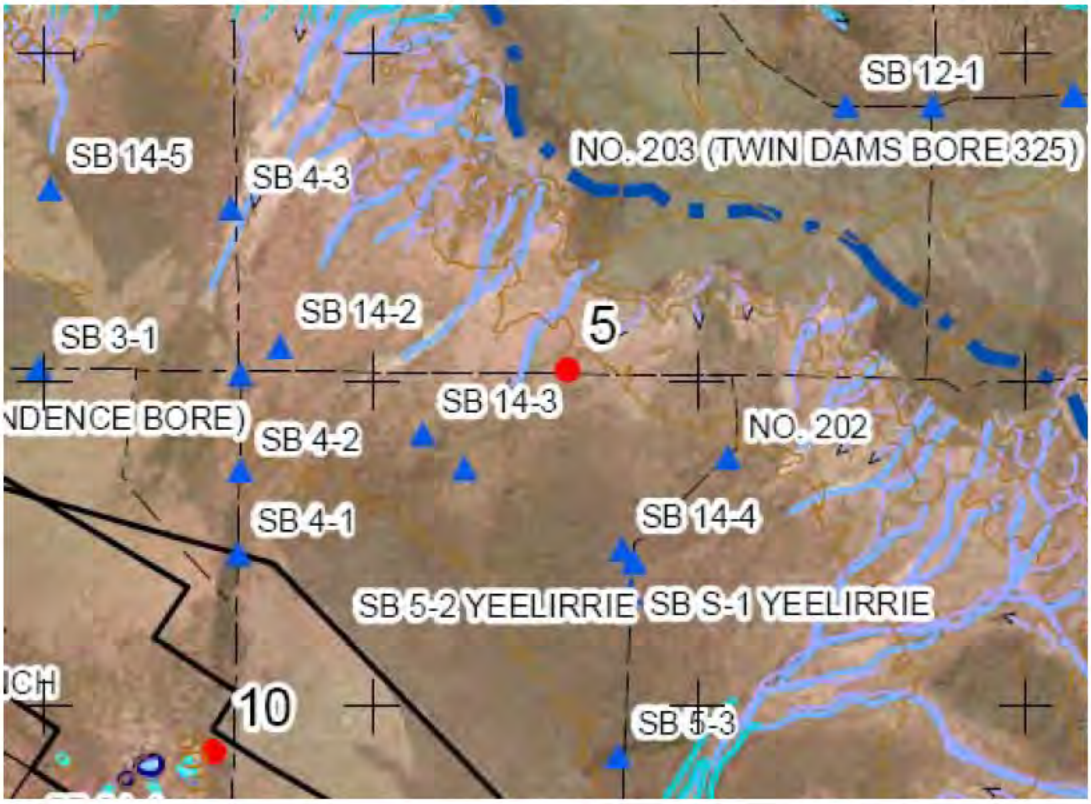
Location No.	4 (See map above)
Location Name	Easter Mile Drainage Feature Downstream
Location Co-ordinates	E 789126, N 6996460, GDA94, Zone 50
Site Description	Drainage path conveying surface runoff from the northern breakaway to the central drainage path. This site is located downstream of Location 4, however it is unconfirmed whether this drainage feature terminates prior to reaching the central drainage path.
Drainage Geometry	Braided drainage feature, with approximately 3 drainage lines of varied geometry.
Substrate Type	Red sands.
Stability of banks	The drainage line banks were not vegetated, however there was no significant erosion present. There was Increased ground cover between the braided drainage lines.
Water	No surface water present and no evidence of previously ponded water in this area.
Debris and tree roots	Evidence of leaf matter and twigs deposited by water, between the braided drainage lines – indicating that flow has exceeded the drainage line capacity recently. Some debris built up behind the small trees between the braided drainage lines to a height of approximately 200mm. Cleared trees and roots from Meekatharra Yeelirrie Road could block flow in this area.

Drainage line downstream of Meekatharra Yeelirrie Road – note trees and debris.

Eastern drainage line upstream of Meekatharra Yeelirrie Road.

A.5 Northern Catchment Boundary

The inspection point is located on at the northern catchment boundary, on the track east of Independence Bore, as shown below.

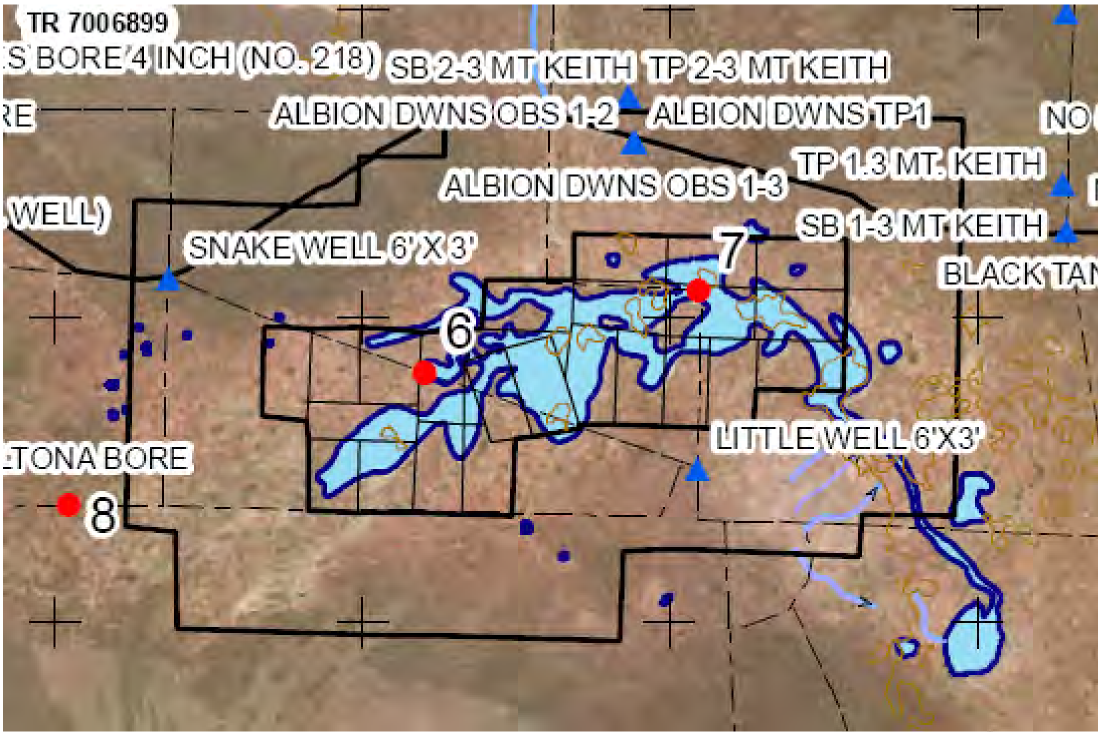


Location No.	5 (See map above)
Location Name	Northern Catchment Boundary
Location Co-ordinates	E 787999, N 7005182, GDA94, Zone 50

Panoramic of Yeelirrie looking south from northern breakaway.

A.6 Clay/Salt Pans Site 1

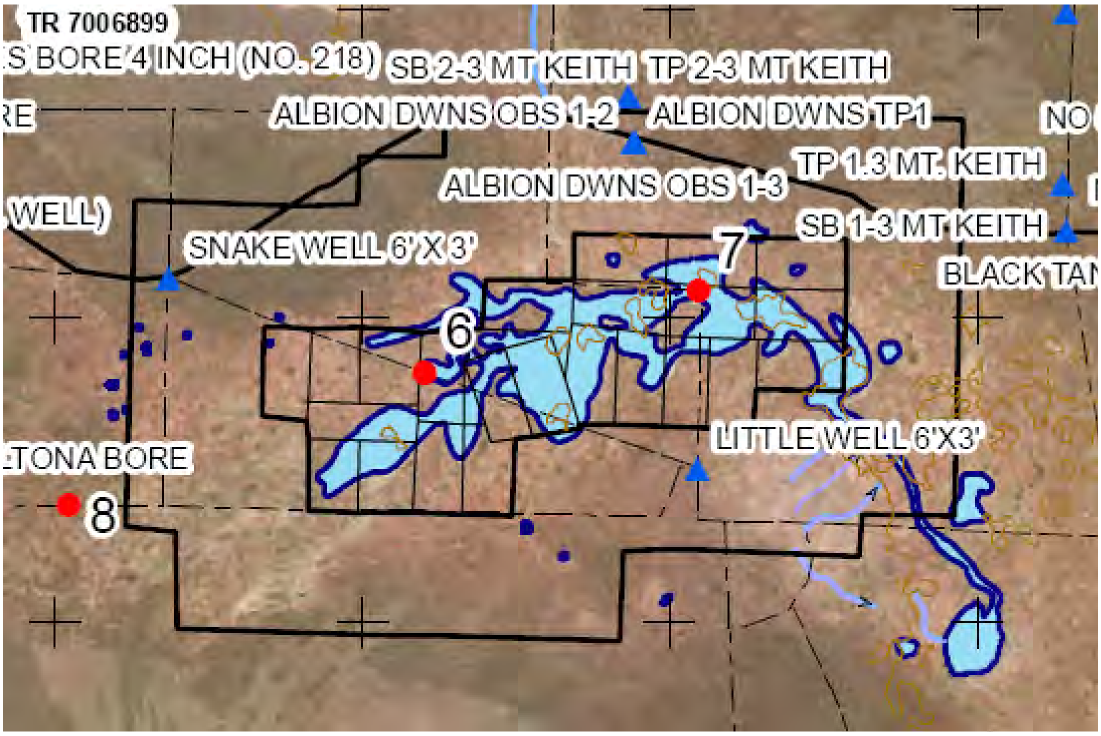
The inspection point is located within the clay/salt pans between Snake Well and Little Well, as shown below.



Location No.	6 (See map above)
Location Name	Clay/Salt Pans
Location Co-ordinates	E 816022, N 6974110, GDA94, Zone 50
Site Description	Central drainage path at the downstream section of the Yeelirrie Project Site. Upstream section of a chain of clay/salt pans.
Drainage Geometry	No defined channel. Very flat low lying area.
Substrate Type	Clay and red sands. Salt on the surface of the clay and red salts.
Stability of banks	No banks. No grass cover and small shrubs. Trees present in less salty areas. Evidence of disturbance by cattle.
Water	No surface water present. Evidence of previously ponded water in this area. Salt residue remaining.
Debris and tree roots	Nil

A.7 Clay/Salt Pans Site 2

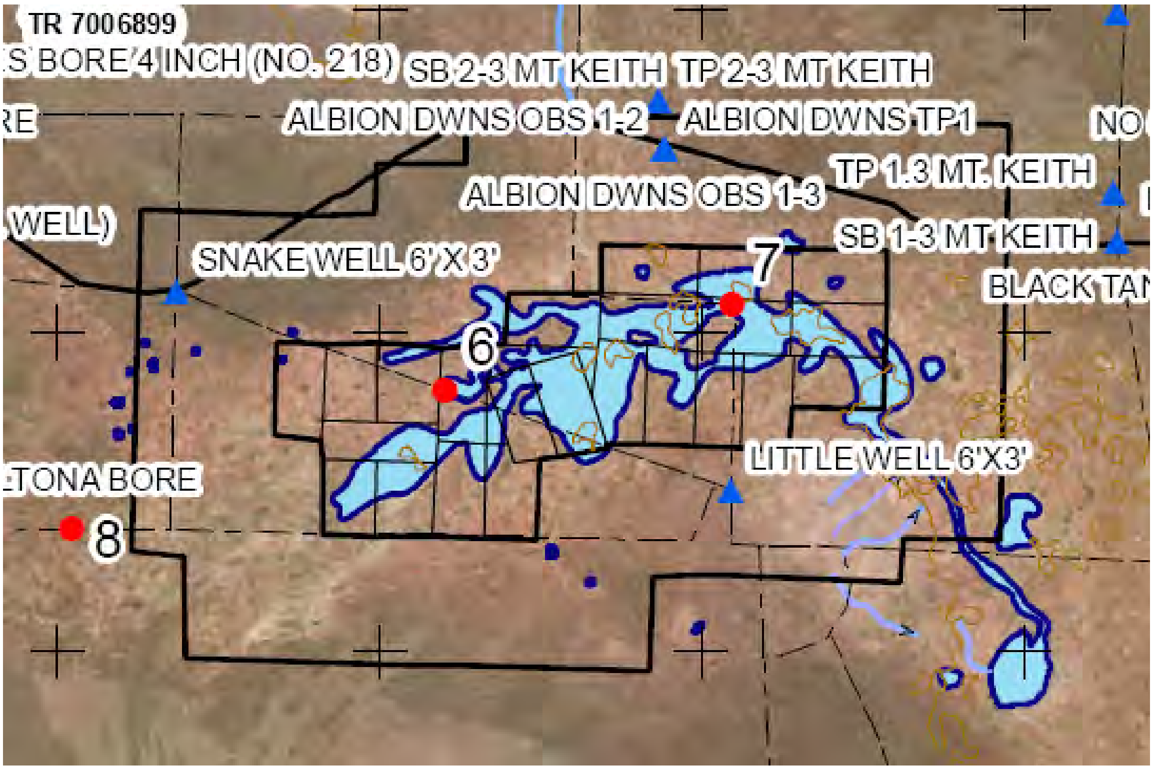
The inspection point is located within the clay/salt pans north of Little Well, as shown below.



Location No.	7 (See map above)
Location Name	Clay/Salt Pans
Location Co-ordinates	E 820472, N 6975423, GDA94, Zone 50
Site Description	Central drainage path at the downstream section of the Yeelirrie Project Site. Central section of a chain of clay/salt pans.
Drainage Geometry	No defined channel. Very flat low lying area.
Substrate Type	Clay and red sands. Salt on the surface of the clay and red salts.
Stability of banks	No banks. No grass cover and small shrubs. Trees present in less salty areas. Evidence of disturbance by cattle.
Water	No surface water present. Evidence of previously ponded water in this area. Salt residue remaining.
Debris and tree roots	Nil

A.8 East of Altona Bore

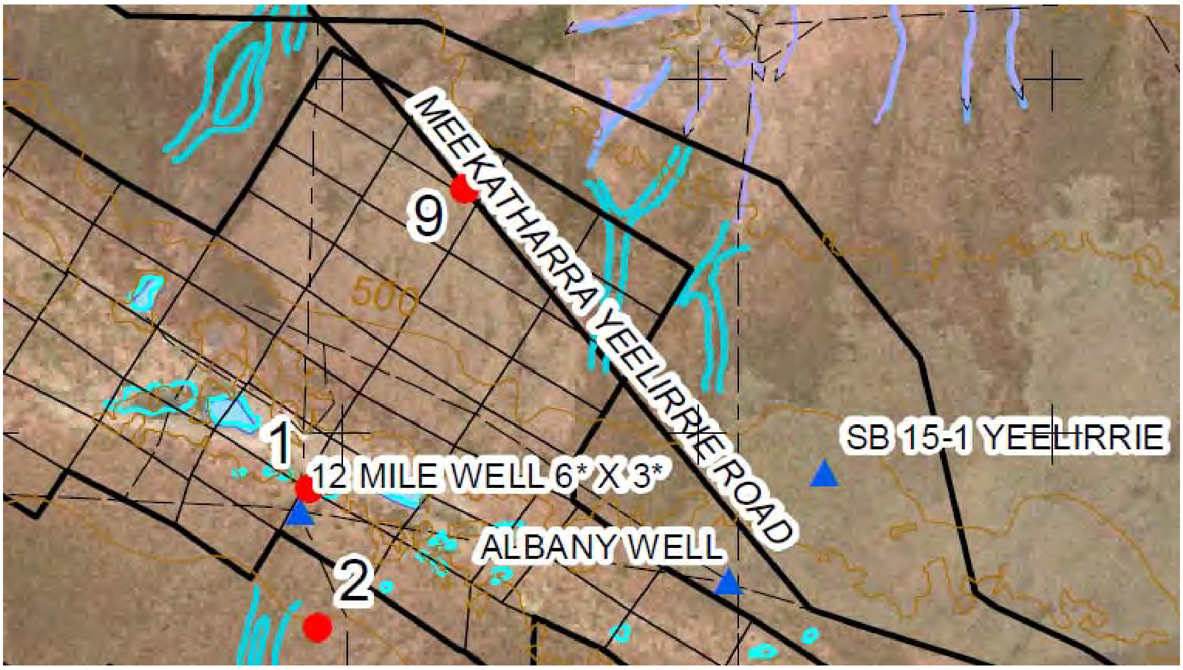
This inspection point is located to the west of Altona Bore, on the access track between Altona Bore and Little Well, as shown below.



Location No.	8 (See map above)
Location Name	East of Altona Bore
Location Co-ordinates	E 810246, N 6971910, GDA94, Zone 50
Site Description	Expected location of southern catchment drainage path.
Drainage Geometry	Numerous sheet flow paths evident along the track (100 m plus wide) separated by 1m (approx) high bunds of crushed calcrete.
Substrate Type	Red sands.
Stability of banks	No banks evident. No evidence of erosion
Water	No evidence of water in this area recently.
Debris and tree roots	Nil.

A.9 Proposed Plant Area

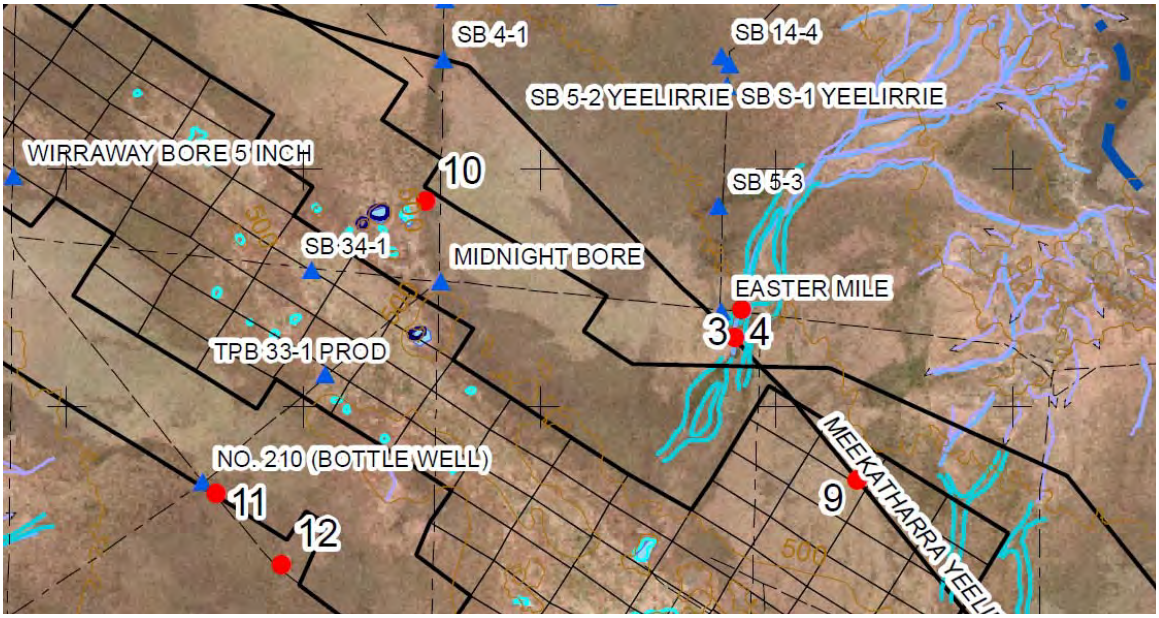
This inspection point is located within the proposed plant area site, adjacent to Meekatharra Yeelirrie Road, as shown below.



Location No.	9 (See map above)
Location Name	Proposed Plant Area
Location Co-ordinates	E 791721, N 6993462, GDA94, Zone 50

A.10 Midnight Bore Drainage Feature

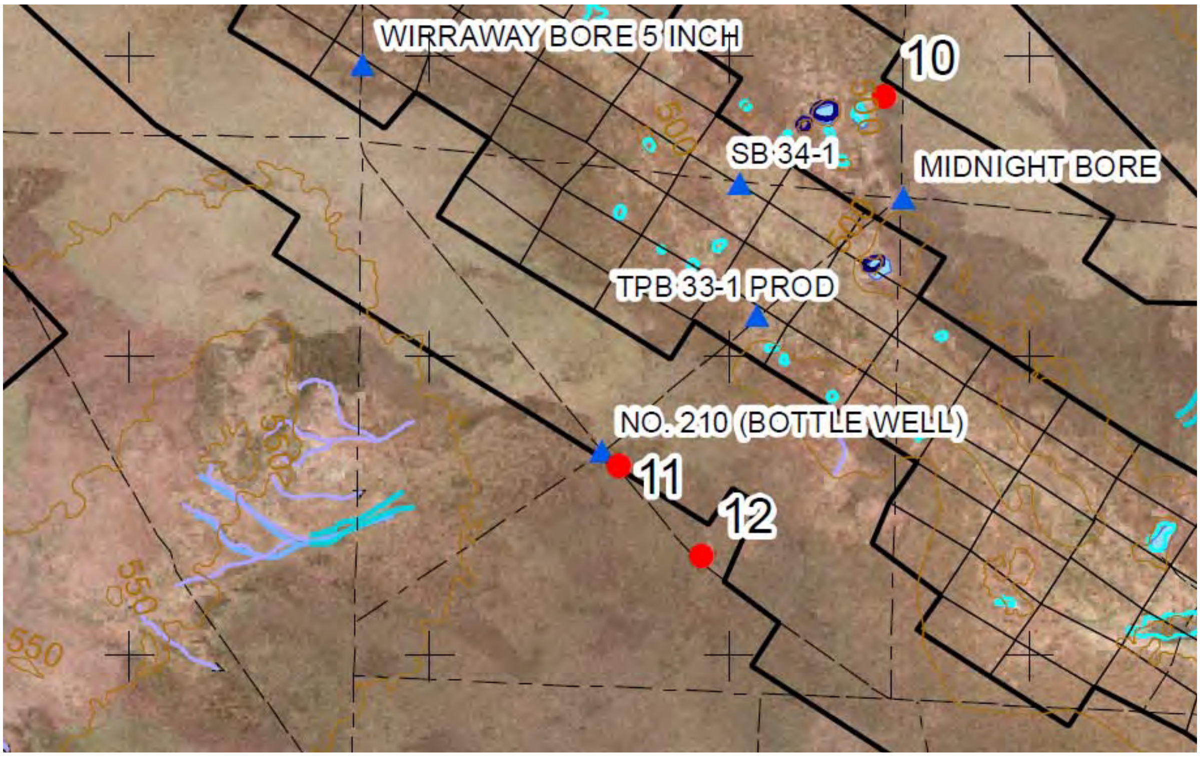
This inspection point is located north of Midnight Bore, on the access track between Midnight Bore and SB 4-1, as shown below.



Location No.	10 (See map above)
Location Name	North of Midnight Bore
Location Co-ordinates	E 782594, N 6999343, GDA94, Zone 50
Site Description	Expected location of northern catchment drainage path.
Drainage Geometry	No defined channel evident. Possible sheet flow path.
Substrate Type	Red sands. Possible groundwater infiltration location, due to the tree growth in this area, as comparison to surrounding areas.
Stability of banks	No banks evident. Earth mounded around tree roots – maybe from sheet flow or wind erosion.
Water	No evidence of water in this area recently.
Debris and tree roots	Nil.

A.11 South East of Bottle Well Site 1

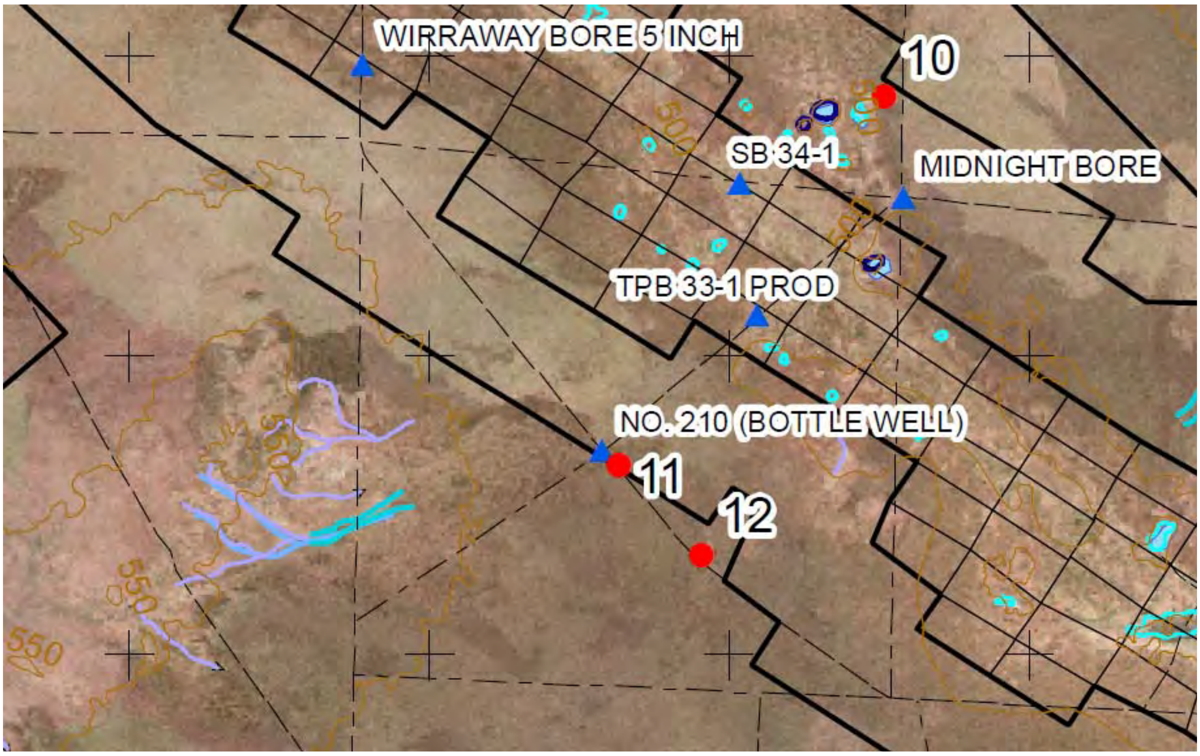
This inspection point is located south east of Bottle Well, as shown below.



Location No.	11 (See map above)
Location Name	South east of Bottle Well Site 1
Location Co-ordinates	E 778149, N 6993166, GDA94, Zone 50
Site Description	Potential location of southern catchment drainage path.
Drainage Geometry	No defined channel evident. Possible sheet flow path.
Substrate Type	Red sands.
Stability of banks	No banks evident.
Water	Evidence of water ponded on track – green ground cover, although no evidence upstream or downstream of this location. The water potentially ponded on the track because of a small bund on the downstream side of the track, from grading.
Debris and tree roots	Nil.

A.12 South East of Bottle Well Site 2

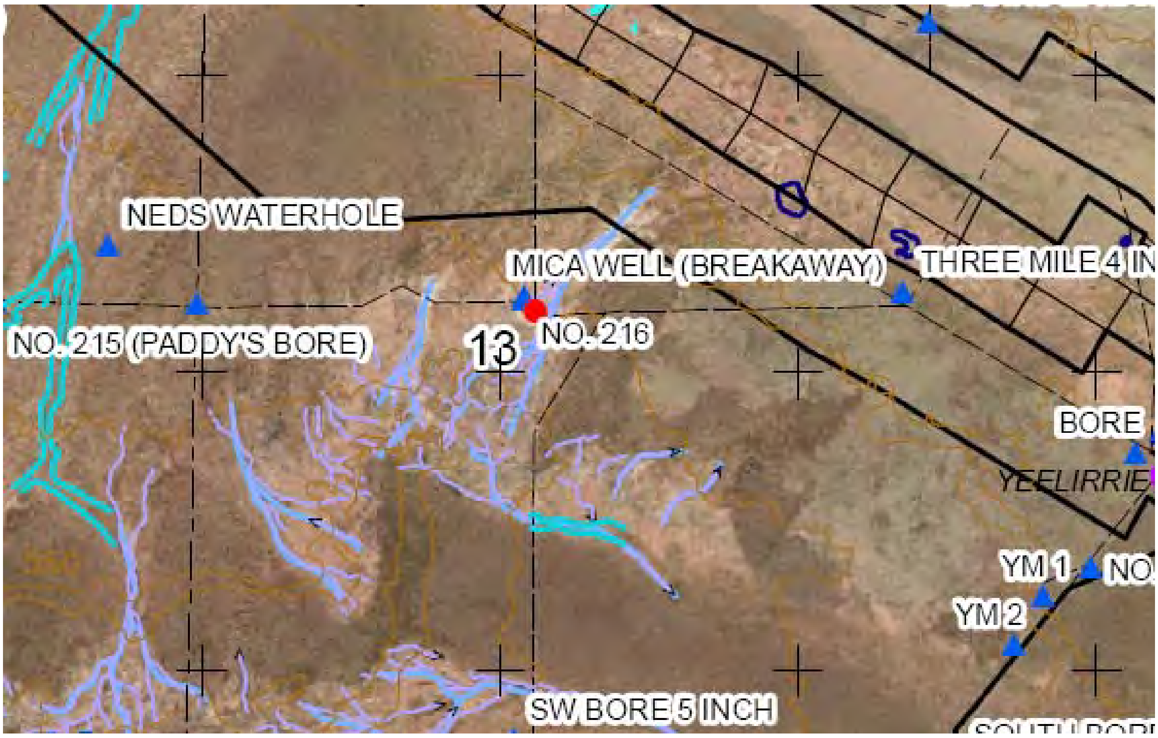
This inspection point is located further south east of Bottle Well than Site 1, as shown below.



Location No.	12 (See map above)
Location Name	South east of Bottle Well Site 2
Location Co-ordinates	E 779555, N 6991667, GDA94, Zone 50
Site Description	Potential location of southern catchment drainage path.
Drainage Geometry	No defined channel evident. Possible sheet flow path.
Substrate Type	Red sands.
Stability of banks	No banks evident.
Water	No evidence of water in this area recently.
Debris and tree roots	Nil.

A.13 Mica Well Drainage Feature

This inspection point is located just southeast of Mica Well where drainage line cross the track, as shown below.



Location No.	13 (See map above)
Location Name	Southeast of Mica Well
Location Co-ordinates	E 795691, N 6980939, GDA94, Zone 50
Site Description	Potential location of southern catchment drainage path (d/s of minesite).
Drainage Geometry	Quite well-defined channel evident. Possible sheet flow path.
Substrate Type	Red sands.
Stability of banks	No banks evident.
Water	No evidence of water in this area recently.
Debris and tree roots	Nil.


Quite well-defined channel section


Sign of bank erosion


Gullies feeding into the main channel. Break away in the background.

APPENDIX B INFILTRATION TESTS

B.1 Infiltration Test Methodology

A total of 27 double-ring infiltration tests (DR2, 5, 6, 8, and 13 to 32 inclusive) were conducted in the four soil types, or catchment units, within the Lake Miranda Catchment. The infiltration test sites, 24 in total, are shown on Figure 4-1; sites DR13, DR18 and DR25 hosted two infiltration tests each. Initial tests were completed with a 300 mm inner steel ring and 450 mm outer ring. Due to the number of tests in remote areas, volumes of water required for each test, and limited water supplies, a 150 mm diameter inner ring and 300 mm outer ring were subsequently used.

The double-ring infiltration tests involved:

- Installation of a 450-mm tall double-ring galvanised iron infiltrometer with an embedded depth of at least 150mm.
- Filling of both inner and outer rings with water.
- Measuring and recording the decline in head in the inner ring against time, until a steady-state (mm head decline per minute) was achieved. A steady-state infiltration rate was assumed when four consecutive two-minute interval readings had the same rate of head decline. If a steady-state infiltration rate was not reached, the infiltrometer was topped-up and water level measurements taken until either a steady-state rate was achieved or it was evident that the rate was not going to stabilise.
- Generally, tests lasted between 15 minutes and one hour.

Once the infiltration rate had stabilised, the final gradient of the infiltration versus time plot was taken as the infiltration rate (mm/hr) for each test site. The average infiltration rate was then determined for each catchment unit, which was then compared against guidance values for similar soils. Appropriate soil infiltration losses (initial loss in mm and continuing loss in mm/hr) were then selected to represent a reasonable worst case scenario for the hydrological modelling.

Tables 4-1 and 4-2 present the summary and discrete data on each infiltration test. Figure 4-2 shows time-series plots of the measured infiltration rates. Attachment B provides data and results of the infiltration test programme, including photographs of test sites and test data sheets.

Table-B-1 Infiltration Test Results Summary

Catchment unit	Number of Sites	Number of Tests	Field Infiltration Rate (m/day)	
			Range	Mean
Wash Plain	9	10	3.6 – 7.9	5.8
Sand Plain	11	13	3.6 - 13.7	10.8
Calcrete	2	2	1.1 – 3.6	2.3
Playa/Clay Pan	2	2	0 – 0.3	0.2

Based on the findings of the site investigations, the sand plain catchment unit soils have the highest infiltration rates in the Lake Miranda Catchment; approximately twice those of the wash plain catchment units. Conversely, the playa, clay pan soils have the lowest infiltration rates.

In about 40% of the sand-plain tests, a steady-state infiltration rate did not occur. In these cases, the infiltration rate was observed to decrease as the water level in the double ring infiltrometer declined, so it appears that the infiltration rate is proportional to water head in the higher transmissivity areas of the sand plains, which is expected based on the relatively free-draining characteristics of these soils.

Table-B-2 Discrete Infiltration Test Data

Test Site	Inner Ring Diameter	Infiltration Rate	
		(mm/min)	(mm/hr)
Wash Plain			
DR2	300	4	240
DR6	300	4.5	270
DR8	300	2.5	150
DR16	150	4	240
DR20	150	5.5	330[1]
DR21	150	4	240
DR25	150	3.5	210
DR25	300	4	240
DR28	150	4.5	270
DR32	150	3.5	210
Sand Plain			
DR13	150	7.5	450
DR13	300	7.5	450
DR14	150	9.5	570[1]
DR18	150	7.5	450[1]
DR18	300	9.5	570[1]
DR19	150	6.5	390[1]
DR22	150	8.5	510[1]
DR24	180	7.5	450[1]
DR26	150	2.5	150[2]
DR27	150	7.5	450
DR29	150	6.5	390
DR30	150	4.6	276
DR31	150	7.5	450
Calcrete			
DR15	150	2.5	150
DR23	150	0.75	45
Playa and Clay Pan			
DR5	300	0	0
DR17	150	0.23	14
Notes:			
1 Steady-state infiltration rate was not achieved.			
2 Soils not typical of sand plain, result not used in calculating mean rate.			

ATTACHMENT B-1
Infiltration Test Field Summary Sheet

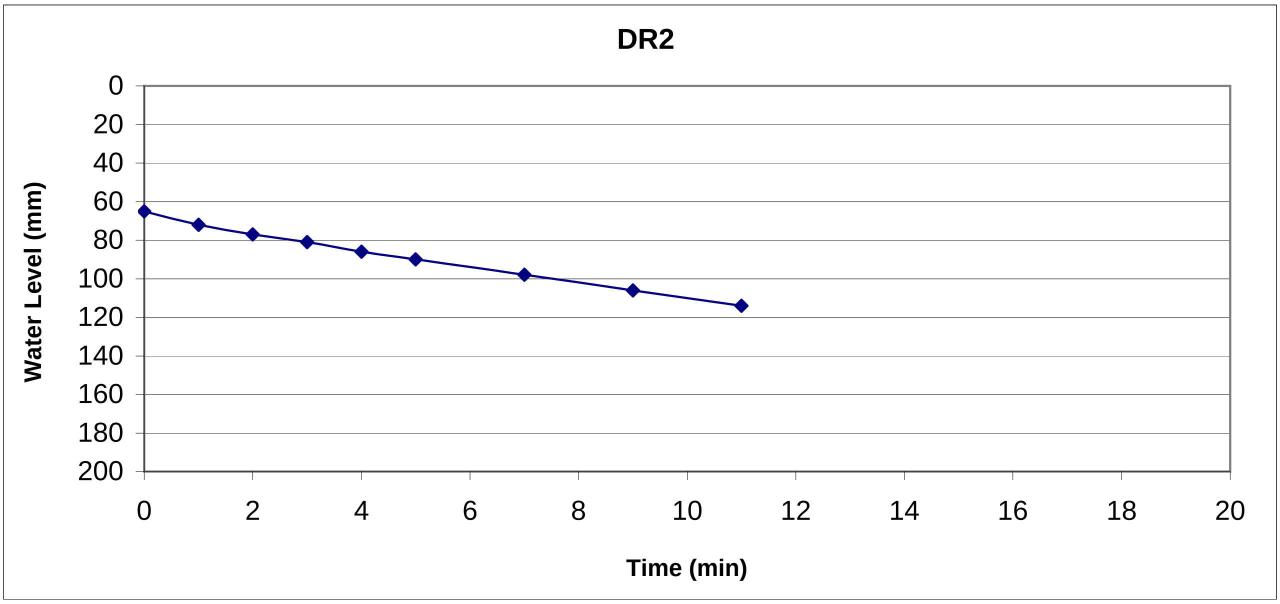
Infiltration test locations	Nearest soil sampling locations	Zone	Easting	Northing	RL (m AHD)	GPS time	Date	Time	Weather	Remarks
Double Ring Infiltration Tests - Field Work SW1										
DR2	SB17	50	791021	6994229	516	3:05 PM	28/6/2009	3:05 PM	cloudy	Spinifex ground cover with acacia shrub, potential plant site. Near Meekathara/Yeelirrie main road.
DR5	SB35	51	224174	6974480	479	9:15 AM	27/6/2009	9:15 AM	fine	First major salt pan, salt tolerant ground cover, 3 days after rain.
DR6	SB1	50	768819	7018249	546	12:36 PM	25/6/2009	12:35 PM	cloudy	Spinifex ground cover with acacia shrub, along sheet flow area.
DR8	SB16	50	789228	6997061	520	1:52 PM	26/6/2009	1:50 PM	cloudy	In braided channels, under big trees. About 200mm of debris collected behind big trees.

Double Ring Infiltration Tests - Field Work SW2										
Infiltration test locations	**Nearest soil sampling locations**	**Zone**	**Easting**	**Northing**	**RL (m AHD)**	**GPS time**	**Date**	**Time**	**Weather**	**Remarks**
DR13		50	761074	7020309	557	9:57 AM	14/01/2010	10:00 AM	Sunny	Spinifex and Small Scrub
DR14		50	756918	6993861	526	9:43 AM	18/01/2010	9:45 AM	Sunny	Spinifex and small to medium shrubs
DR15		50	773901	7000429	512	11:29 AM	18/01/2010	11:30 AM	Sunny	Large shrubs and trees, some small scrub
DR16		50	783011	7004411	527	1:35 PM	18/01/2010	1:35 PM	Sunny	Trees and bare soil, young eucalypts
DR17		50	782467	6996569	500	11:08 AM	19/01/2010	11:10 AM	Sunny	Claypan, no veg
DR18	SB38	50	786452	6997319	518	2:29 PM	18/01/2010	2:30 PM	Sunny	Spinifex and medium scrub, small trees
DR19		50	780926	6990647	507	2:26 PM	17/01/2010	2:30 PM	Sunny	Large shrubs and trees, young eucalypts
DR20		50	795633	6993306	519	3:57 PM	17/01/2010	4:00 PM	Sunny	Some medium shrubs and trees
DR21		50	787580	6981218	527	1:15 PM	17/01/2010	1:15 PM	Sunny	Mainly trees and some small shrubs
DR22		51	213565	6990897	517	10:13 AM	17/01/2010	10:15 AM	Sunny	Bare soil with some small shrubs
DR23	SB46	51	211578	6981271	491	7:39 AM	18/01/2010	7:40 AM	Sunny	Bare soil, large shrub and trees
DR24	SB48	51	217913	6976527	483	8:53 AM	17/01/2010	8:50 AM	Sunny	Spinifex and tall shrub/trees
DR25		51	223987	6984290	498	7:40 AM	17/01/2010	7:40 AM	Sunny	medium to tall shrub and trees
DR26		51	232526	6979547	486	1:40 PM	16/01/2010	1:40 PM	Sunny	spinifex and trees/large shrubs
DR27		51	221107	6965887	506	3:52 PM	16/01/2010	3:50 PM	Sunny	spinifex and medium shrub
DR28		51	247851	6973249	518	10:31 AM	16/01/2010	10:30 AM	Sunny	near to creek line, small to medium shrubs and trees
DR29		51	244971	6965695	487	11:30 AM	16/01/2010	11:30 AM	Sunny	spinifex and small to medium shrubs
DR30		51	246543	6947600	475	9:05 AM	16/01/2010	9:00 AM	Sunny	spinifex and small shrubs to trees
DR31		51	249691	6917262	498	2:31 PM	15/01/2010	2:30 PM	Sunny	spinifex and small scrub
DR32		51	256511	6926185	460	2:33 PM	15/01/2010	2:30 PM	Sunny	large shrubs and trees.

ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test:	DR 2	**Diameter of inner ring:** **Area of inner ring:**	300 mm 70686 mm2
Location:	Wash/Sand plain, Yeelirrie		
Test Conducted by:	Boon Eow, Rebekah Morrison		
Description of soil:	Red brown loam, low plasticity, fine to medium grained quartz sand and clay major, sandy matrix, dry soil.		
Observations:	Spinifex ground cover with acacia shrub, potential plant and TSF site. Near Meekathara/Yeelirrie main road.		
Date: **Photo Ref:**	28/06/09 304-307		

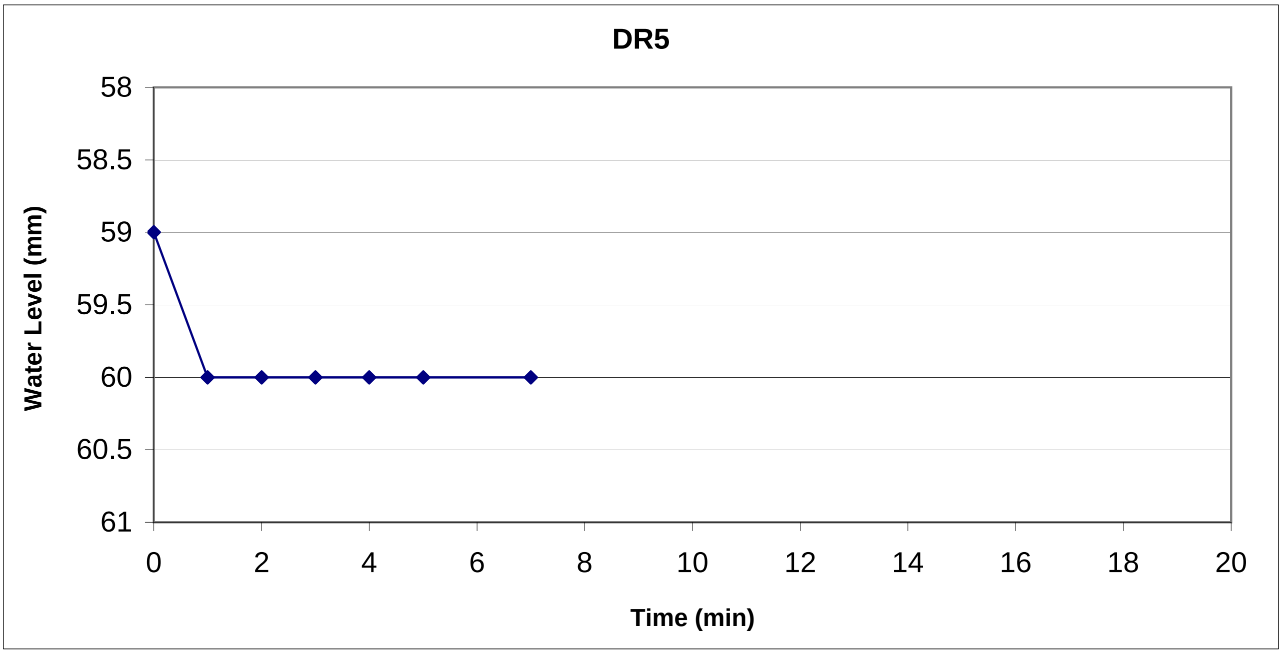
Actual Time (hh:mm:ss)	Time Interval (mins)	Cumulative time (mins)	Measured water level (mm)	Drop in water level (mm)	Cum. Drop in water level (mm)	Computed Volume of water used (ml)	Cum. Volume of water used (ml)
15:29	0	0	65		0	0	0
15:30	0:01	1	72	7	7	495	495
15:31	0:01	2	77	5	12	353	848
15:32	0:01	3	81	4	16	283	1131
15:33	0:01	4	86	5	21	353	1484
15:34	0:01	5	90	4	25	283	1767
15:36	0:02	7	98	8	33	565	2333
15:38	0:02	9	106	8	41	565	2898
15:40	0:02	11	114	8	49	565	3464
					Tot. Volume	3464	



ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

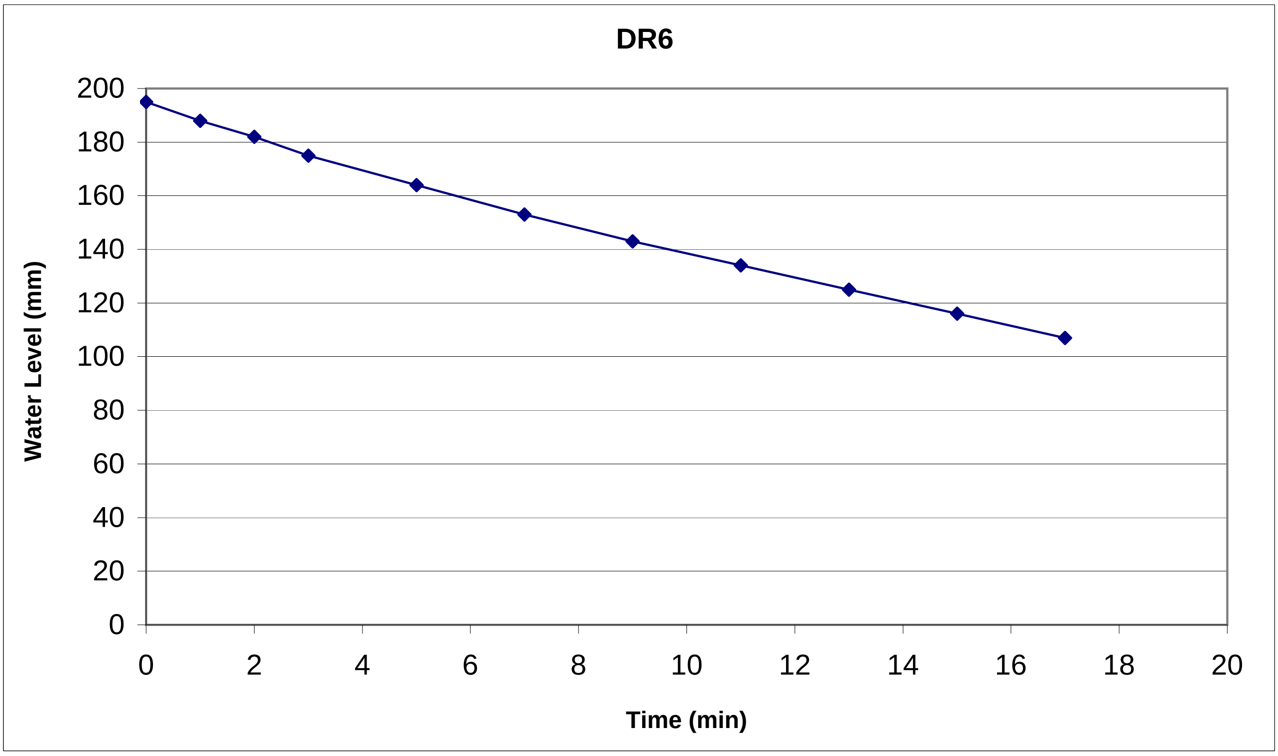
Test:	DR 5	**Diameter of inner ring:** **Area of inner ring:**	300 mm 70686 mm2
Location:	Salt pan, Yeelirrie		
Test Conducted by:	Boon Eow, Rebekah Morrison		
Description of soil:	Red brown clay, moderate plasticity, silty, sandy matrix, minor fine grained quartz, subrounded, moderately sorted		
Observations:	First major salt pan, salt tolerant ground cover, 3 days after rain.		
Date: **Photo Ref:**	27/06/09 230-235		

Actual Time (hh:mm:ss)	Time Interval (mins)	Cumulative time (mins)	Measured water level (mm)	Drop in water level (mm)	Cum. Drop in water level (mm)	Computed Volume of water used (ml)	Cum. Volume of water used (ml)
10:28	0	0	59		0	0	0
10:29	0:01	1	60	1	1	71	71
10:30	0:01	2	60	0	1	0	71
10:31	0:01	3	60	0	1	0	71
10:32	0:01	4	60	0	1	0	71
10:33	0:01	5	60	0	1	0	71
10:35	0:02	7	60	0	1	0	71
					Tot. Volume	71	



Test:	DR 6	**Diameter of inner ring:** **Area of inner ring:**	300 mm 70686 mm2
Location:	Catchment north of minesite, Yeelirrie		
Test Conducted by:	Boon Eow, Phil Trevenon		
Description of soil:	Red brown loam, low plasticity, sandy matrix, medium grained sand, Debris suggesting sheet flow area. (more of a sand plain area than granite area).		
Observations:	Spinifex ground cover with acacia shrub, along sheet flow area.		
Date: **Photo Ref:**	25/06/09 213-215		

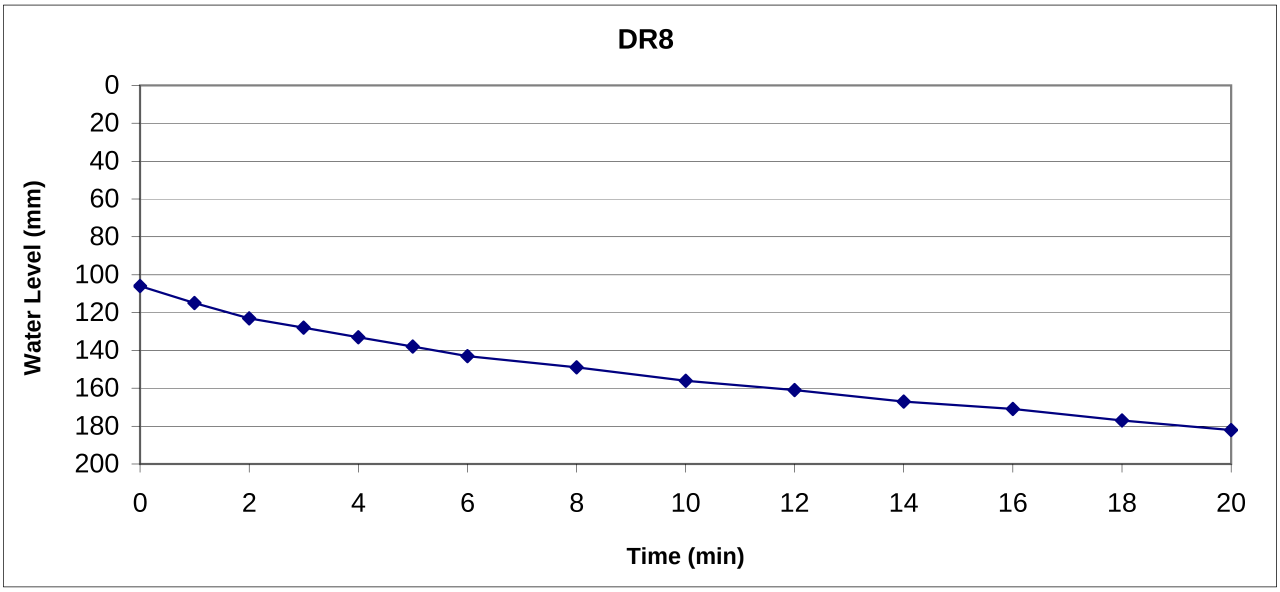
Actual Time (hh:mm:ss)	Time Interval (mins)	Cumulative time (mins)	Measured water level (mm)	Drop in water level (mm)	Cum. Drop in water level (mm)	Computed Volume of water used (ml)	Cum. Volume of water used (ml)
13:24	0	0	195		0	0	0
13:25	0:01	1	188	7	7	495	495
13:26	0:01	2	182	6	13	424	919
13:27	0:01	3	175	7	20	495	1414
13:29	0:02	5	164	11	31	778	2191
13:31	0:02	7	153	11	42	778	2969
13:33	0:02	9	143	10	52	707	3676
13:35	0:02	11	134	9	61	636	4312
13:37	0:02	13	125	9	70	636	4948
13:39	0:02	15	116	9	79	636	5584
13:41	0:02	17	107	9	88	636	6220
					Tot. Volume	6220	



ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test:	DR 8	**Diameter of inner ring:** **Area of inner ring:**	300 mm 70686 mm2
Location:	Drainage channel near Easter Bore, Yeelirrie		
Test Conducted by:	Boon Eow, Phil Trevenon		
Description of soil:	Dark brown loam, hardpan, medium plasticity, fine grained quartz sand and clay major, sandy matrix, damp soil, high organic content.		
Observations:	In braided channels, under big trees. About 200mm of debris collected behind big trees.		
Date: **Photo Ref:**	26/06/09		

Actual Time (hh:mm:ss)	Time Interval (mins)	Cumulative time (mins)	Measured water level (mm)	Drop in water level (mm)	Cum. Drop in water level (mm)	Computed Volume of water used (ml)	Cum. Volume of water used (ml)
14:34	0	0	106		0	0	0
14:35	0:01	1	115	9	9	636	636
14:36	0:01	2	123	8	17	565	1202
14:37	0:01	3	128	5	22	353	1555
14:38	0:01	4	133	5	27	353	1909
14:39	0:01	5	138	5	32	353	2262
14:40	0:01	6	143	5	37	353	2615
14:42	0:02	8	149	6	43	424	3039
14:44	0:02	10	156	7	50	495	3534
14:46	0:02	12	161	5	55	353	3888
14:48	0:02	14	167	6	61	424	4312
14:50	0:02	16	171	4	65	283	4595
14:52	0:02	18	177	6	71	424	5019
14:54	0:02	20	182	5	76	353	5372
					Tot. Volume	5372	

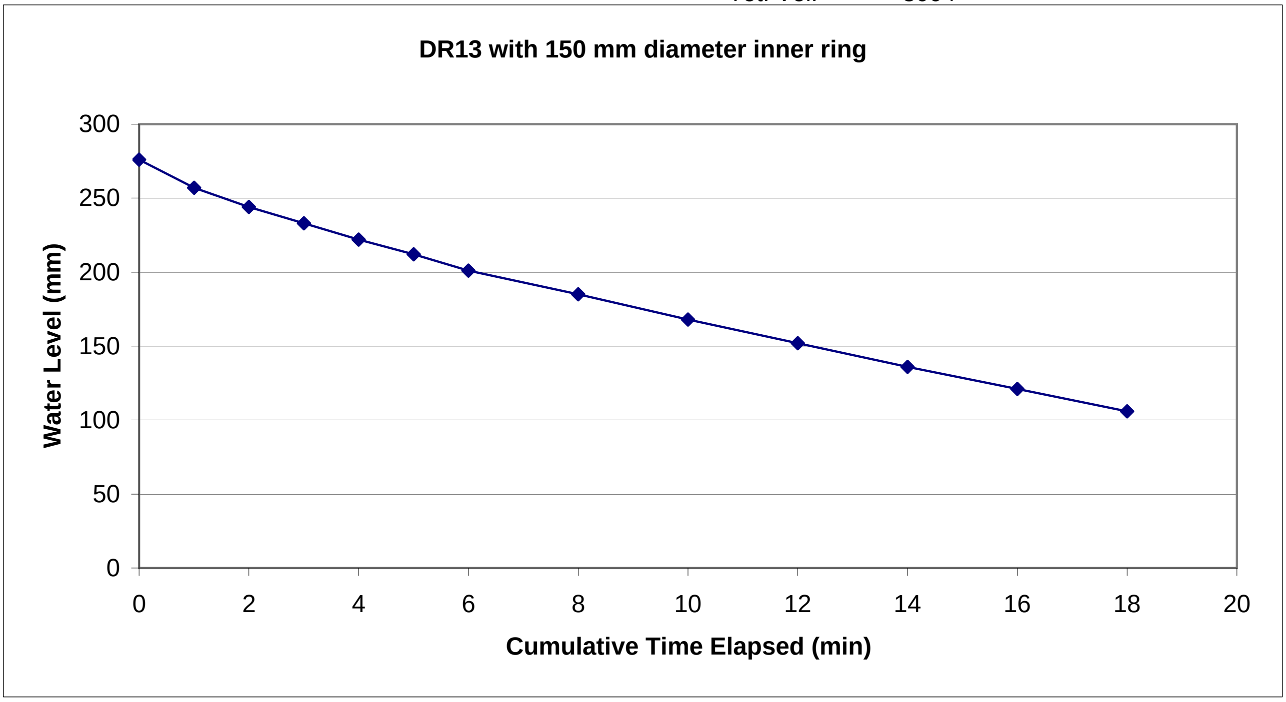


ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test: DR13	**Diameter of inner ring:** 150 mm **Area of inner ring:** 17671 mm^2
Location: Zone 50	*Northing:* 7020309 *Easting:* 761074
Test Conducted by:	LW/BE
Description of soil:	Silty SAND, red brown.
Observations:	Vegetation: Spinifex and small scrub
Photo Ref:	

Cumulative time (mins)

Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
10:44		0	276	0		
10:45	1	1	257	19	336	
10:46	1	2	244	13	230	
10:47	1	3	233	11	194	
10:48	1	4	222	11	194	
10:49	1	5	212	10	177	
10:50	1	6	201	11	194	
10:52	2	8	185	16	283	
10:54	2	10	168	17	300	
10:56	2	12	152	16	283	
10:58	2	14	136	16	283	
11:00	2	16	121	15	265	
11:02	2	18	106	15	265	end of test
				Tot. Vol.	3004	

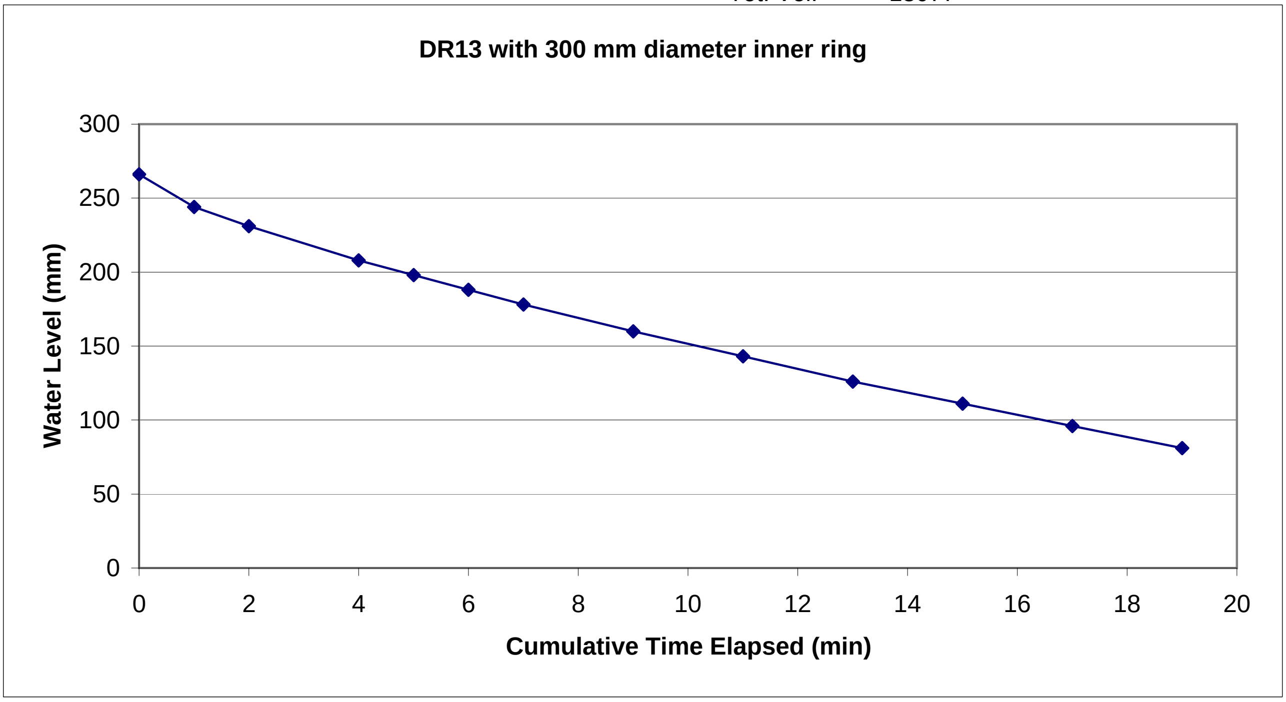


ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test: DR13	**Diameter of inner ring:** 300 mm **Area of inner ring:** 70686 mm^2
Location: Zone 50	*Northing:* 7020309 *Easting:* 761074
Test Conducted by:	LW/BE
Description of soil:	Silty SAND, red brown.
Observations:	Vegetation: Spinifex and small scrub
Photo Ref:	

Cumulative time (mins)

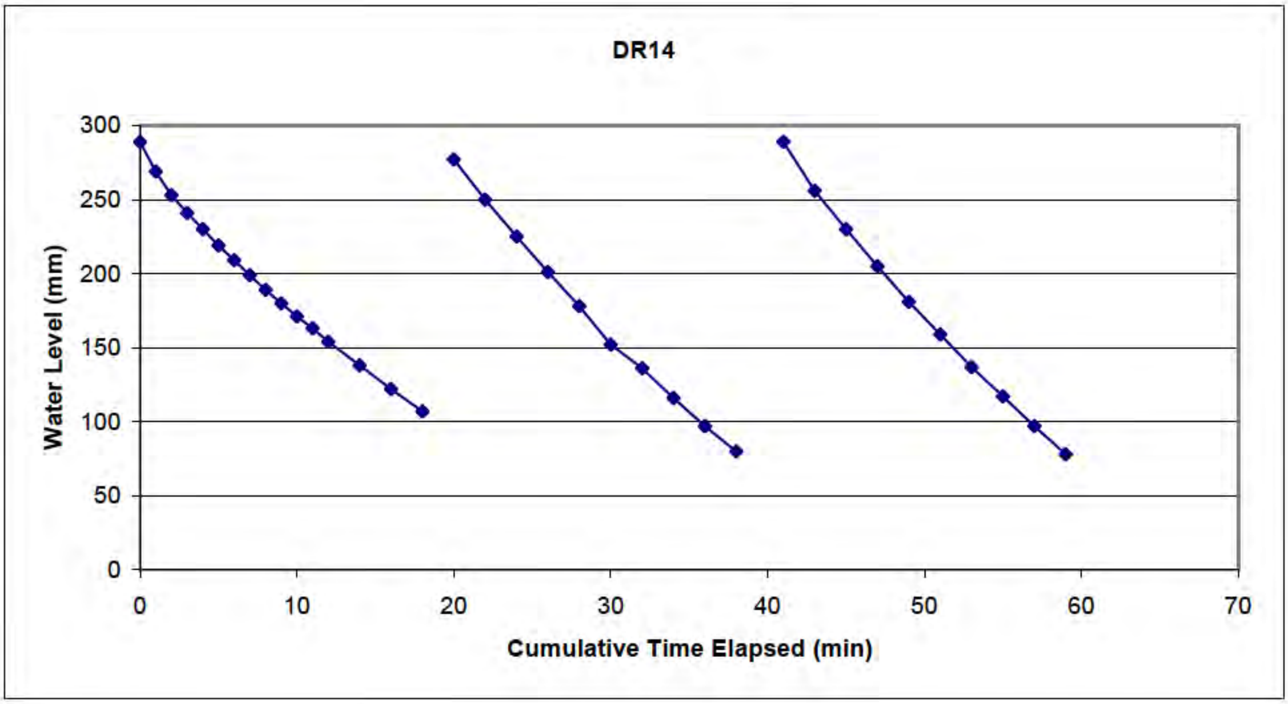
Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
10:21		0	266	0		
10:22	1	1	244	22	1555	
10:23	1	2	231	13	919	
10:25	2	4	208	23	1626	
10:26	1	5	198	10	707	
10:27	1	6	188	10	707	
10:28	1	7	178	10	707	
10:30	2	9	160	18	1272	
10:32	2	11	143	17	1202	
10:34	2	13	126	17	1202	
10:36	2	15	111	15	1060	
10:38	2	17	96	15	1060	
10:40	2	19	81	15	1060	
				Tot. Vol.	13077	



ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test: DR14	**Diameter of inner ring:**	150 mm
	Area of inner ring:	17671 mm^2
Location: Zone 50	*Northing:* 6993861	*Easting:* 756918
Test Conducted by:	LW/MC	
Description of soil:	Silty SAND, fine to medium grained quartz, sub angular to sub rounded, coarse grains on surface. Red brown, compact and dry.	
Observations:	Vegetation: Spinifex and small to medium scrub. Crusting on surface on patches without vegetation. This made ring very hard to drive in, 3 attempts made. Test conducted close to vegetation.	
Photo Ref:		

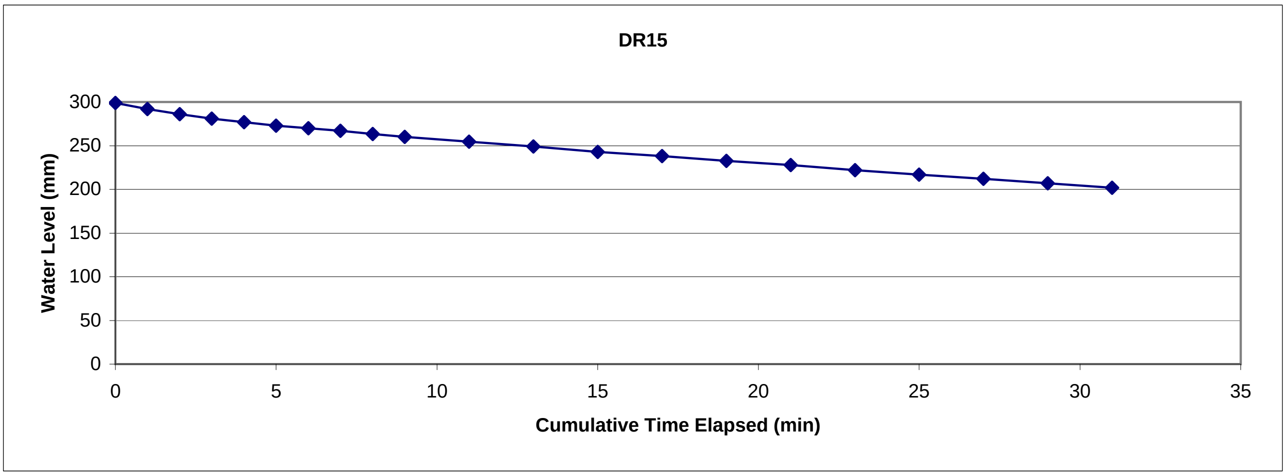
Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
9:49		0	289	0		
9:50	1	1	269	20	353	
9:51	1	2	253	16	283	
9:52	1	3	241	12	212	
9:53	1	4	230	11	194	
9:54	1	5	219	11	194	
9:55	1	6	209	10	177	
9:56	1	7	199	10	177	
9:57	1	8	189	10	177	
9:58	1	9	180	9	159	
9:59	1	10	171	9	159	
10:00	1	11	163	8	141	
10:01	1	12	154	9	159	
10:03	2	14	138	16	283	
10:05	2	16	122	16	283	
10:07	2	18	107	15	265	
10:09	2	20	277			topped up water level
10:11	2	22	250	27	477	
10:13	2	24	225	25	442	
10:15	2	26	201	24	424	
10:17	2	28	178	23	406	
10:19	2	30	152	26	459	
10:21	2	32	136	16	283	
10:23	2	34	116	20	353	
10:25	2	36	97	19	336	
10:27	2	38	80	17	300	
10:29	3	41	289			topped up water level
10:31	2	43	256	33	583	
10:33	2	45	230	26	459	
10:35	2	47	205	25	442	
10:37	2	49	181	24	424	
10:39	2	51	159	22	389	
10:41	2	53	137	22	389	
10:43	2	55	117	20	353	
10:45	2	57	97	20	353	
10:47	2	59	78	19	336	
				Tot. Vol.	10426	


DR14
Water Level (mm)
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
Cumulative Time Elapsed (min)

Test: DR15	**Diameter of inner ring:**	150 mm
	Area of inner ring:	17671 mm^2
Location: Zone 50	*Northing:* 7000429	*Easting:* 773901
Test Conducted by:	LW/MC	
Description of soil:	SILT and weathered calcete rubble, brown to grey, dry, compact.	
Observations:	Vegetation: Large shrubs and trees (mulga). Some small scrub, bare soil. Test on ridge, lower ground either side. Much easier to drive in rings than DR23	
Photo Ref:		

Cumulative time (mins)

Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
11:35		0	299	0		
11:36	1	1	292	7	124	
11:37	1	2	286	6	106	
11:38	1	3	281	5	88	
11:39	1	4	277	4	71	
11:40	1	5	273	4	71	
11:41	1	6	270	3	53	
11:42	1	7	267	3	53	
11:43	1	8	263.5	3.5	62	
11:44	1	9	260	3.5	62	
11:46	2	11	254.5	5.5	97	
11:48	2	13	249	5.5	97	
11:50	2	15	243	6	106	
11:52	2	17	238	5	88	
11:54	2	19	232.5	5.5	97	
11:56	2	21	228	4.5	80	
11:58	2	23	222	6	106	
12:00	2	25	217	5	88	
12:02	2	27	212	5	88	
12:04	2	29	207	5	88	
12:06	2	31	202	5	88	
				Tot. Vol.	1714	

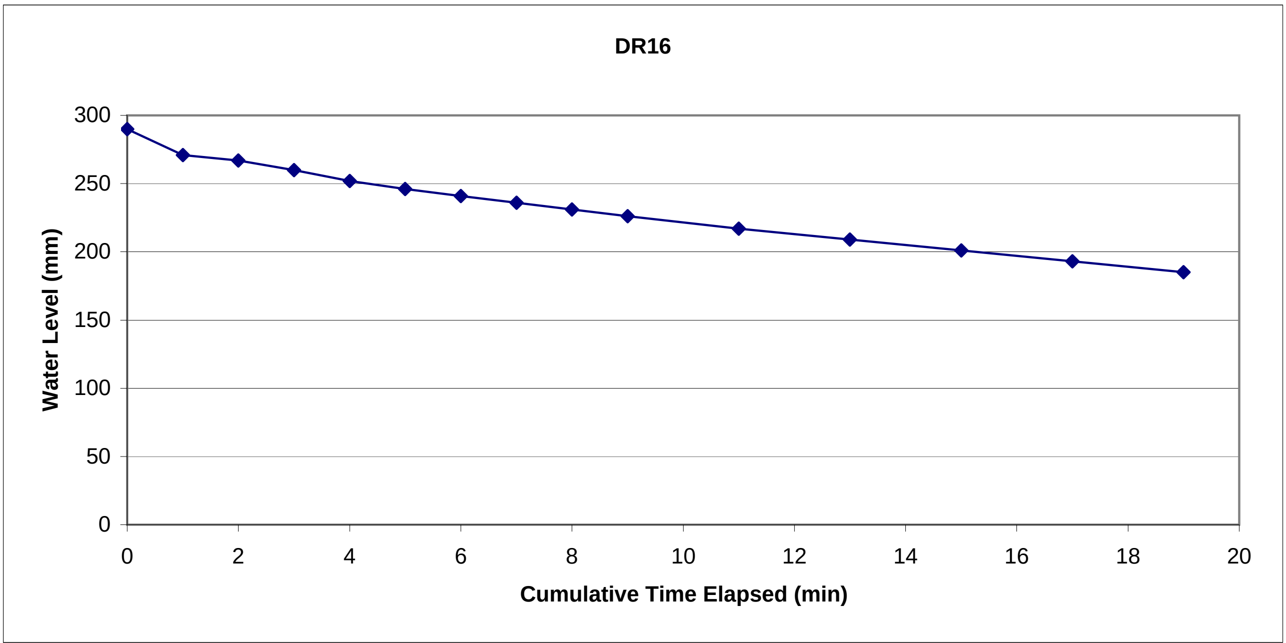


ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test: DR16	**Diameter of inner ring:**	150 mm
	Area of inner ring:	17671 mm^2
Location: Zone 50	*Northing:* 7004411 *Easting:* 783011	
Test Conducted by:	LW/MC	
Description of soil:	SILT, minor clay and sand, red brown, dry, very compact.	
Observations:	Vegetation: Trees (mulga and young eucalypts) and large shrubs. Crust on surface.	
Photo Ref:		

Cumulative time (mins)

Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
13:46		0	290	0		
13:47	1	1	271	19	336	
13:48	1	2	267	4	71	
13:49	1	3	260	7	124	
13:50	1	4	252	8	141	
13:51	1	5	246	6	106	
13:52	1	6	241	5	88	
13:53	1	7	236	5	88	
13:54	1	8	231	5	88	
13:55	1	9	226	5	88	
13:57	2	11	217	9	159	
13:59	2	13	209	8	141	
14:01	2	15	201	8	141	
14:03	2	17	193	8	141	
14:05	2	19	185	8	141	
				Tot. Vol.	1856	



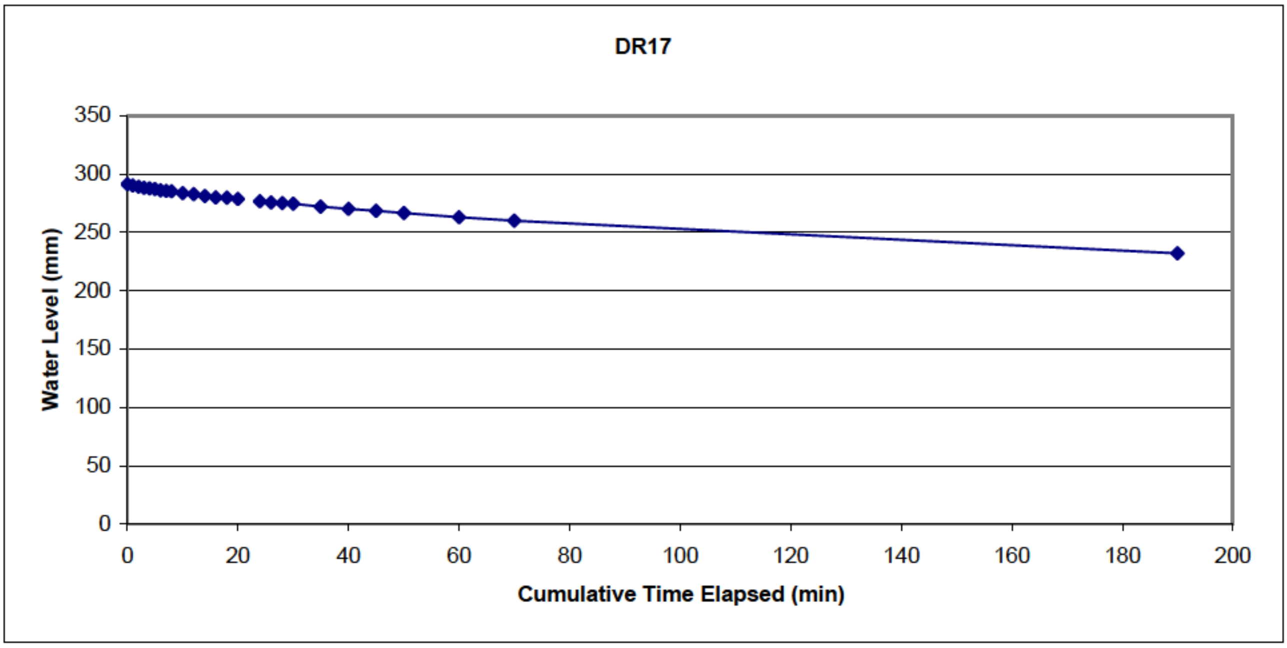
ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test:	**Diameter of inner ring:**	150 mm
DR17	**Area of inner ring:**	17671 mm^2
Location: Zone 50	*Northing:* 6996569 *Easting:* 782467	
Test Conducted by:	LW/MC	
Description of soil:	CLAY, grey/reddish brown, dry, very compact, low plasticity (?)	
Observations:	Vegetation: Claypan, no vegetation. Small to med shrubs and trees boardering claypan. Hard and cracked surface.	
Photo Ref:		

Cumulative time (mins)

Actual Time (hh:mm:ss)	**Time interval (mins)**	**Cumulative time elapsed (mins)**	**Water Level Reading (mm)**	**Drop in WL (mm)**	**Volume of water used (ml)**	**Notes**
11:22		0	291	0		
11:23	1	1	290	1	18	
11:24	1	2	289	1	18	
11:25	1	3	288	1	18	
11:26	1	4	287.5	0.5	9	
11:27	1	5	287	0.5	9	
11:28	1	6	286	1	18	
11:29	1	7	285.5	0.5	9	
11:30	1	8	285	0.5	9	
11:32	2	10	283.5	1.5	27	
11:34	2	12	282.5	1	18	
11:36	2	14	281	1.5	27	
11:38	2	16	280	1	18	
11:40	2	18	279.5	0.5	9	
11:42	2	20	278.5	1	18	
11:44	2	22				windy - couldn't read
11:46	2	24	276.5	2	35	
11:48	2	26	275.5	1	18	
11:50	2	28	275	0.5	9	
11:52	2	30	274.5	0.5	9	
11:57	5	35	272	2.5	44	
12:02	5	40	270	2	35	
12:07	5	45	268.5	1.5	27	
12:12	5	50	266.5	2	35	
12:22	10	60	263	3.5	62	
12:32	10	70	260	3	53	
14:32	120	190	232	28	495	
				Tot. Vol.	1043	

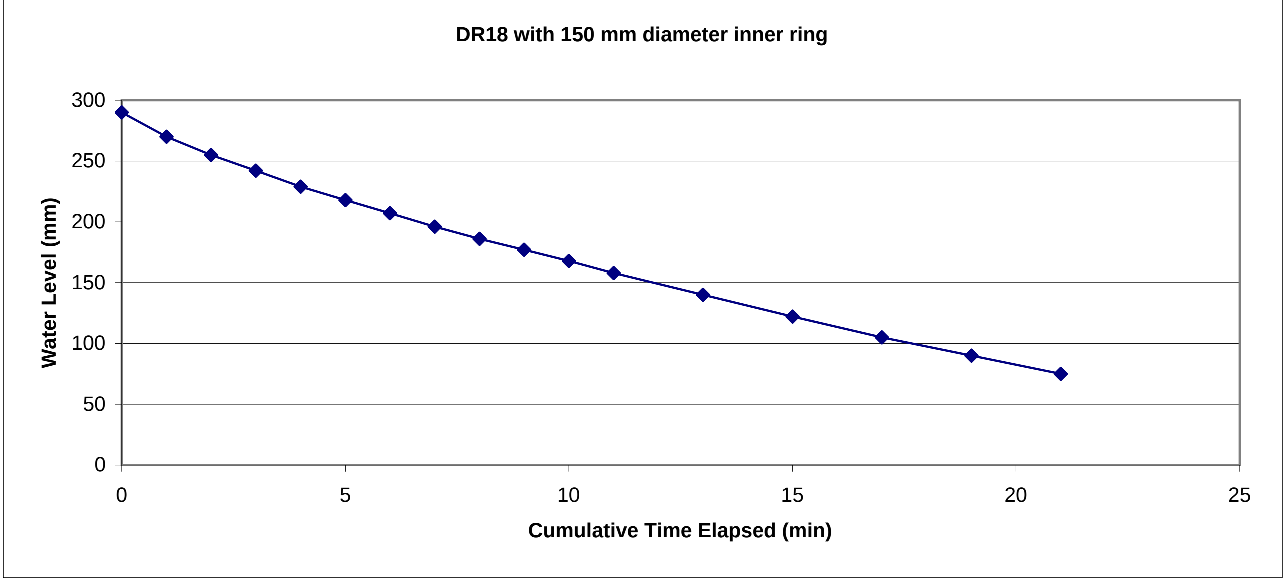
ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet



Test: DR18	**Diameter of inner ring:**	150 mm
	Area of inner ring:	17671 mm^2
Location: Zone 50	*Northing:* 6997319	*Easting:* 786452
Test Conducted by:	LW/MC	
Description of soil:	Silty SAND, fine to medium grained, angular to sub rounded, red brown, dry, moderately compact.	
Observations:	Vegetation: Spinifex, smal and medium shrub and small trees.	
Photo Ref:		

Cumulative time (mins)

Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
14:35		0	290	0		
14:36	1	1	270	20	353	
14:37	1	2	255	15	265	
14:38	1	3	242	13	230	
14:39	1	4	229	13	230	
14:40	1	5	218	11	194	
14:41	1	6	207	11	194	
14:42	1	7	196	11	194	
14:43	1	8	186	10	177	
14:44	1	9	177	9	159	
14:45	1	10	168	9	159	
14:46	1	11	158	10	177	
14:48	2	13	140	18	318	
14:50	2	15	122	18	318	
14:52	2	17	105	17	300	
14:54	2	19	90	15	265	
14:56	2	21	75	15	265	rate dropping with head
				Tot. Vol.	3799	

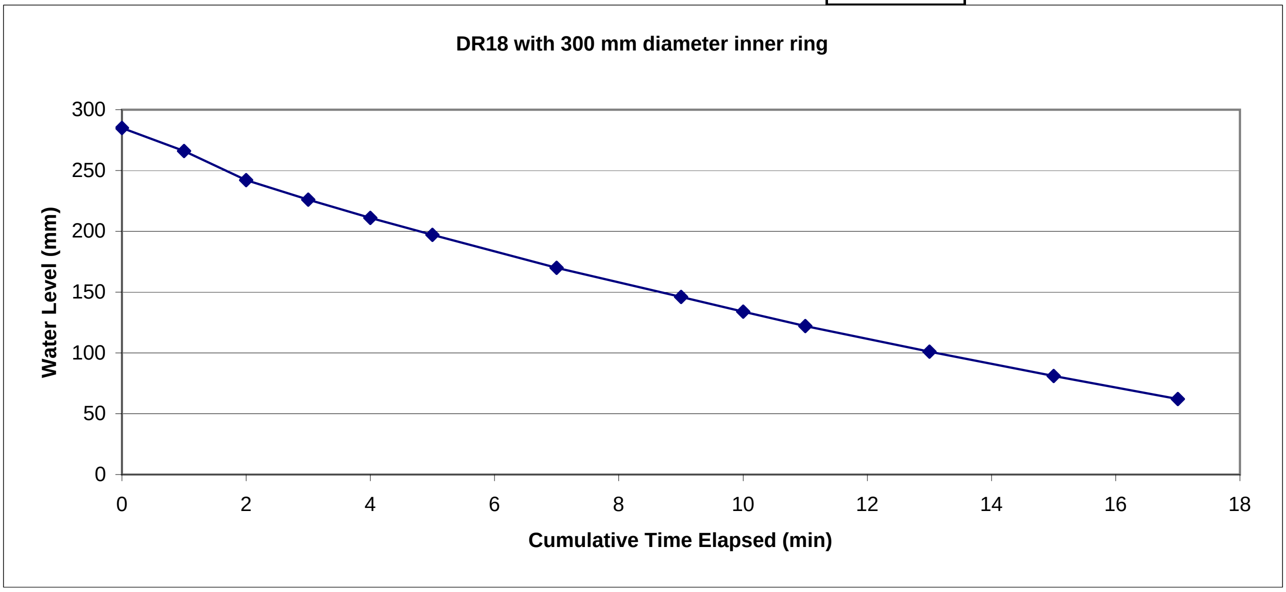


ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test: DR18	**Diameter of inner ring:** 300 mm **Area of inner ring:** 70686 mm^2
Location: Zone 50	*Northing:* 6997319 *Easting:* 786452
Test Conducted by:	LW/MC
Description of soil:	Silty SAND, fine to medium grained, angular to sub rounded, red brown, dry, moderately compact.
Observations:	Vegetation: Spinifex, smal and medium shrub and small trees.
Photo Ref:	

Cumulative time (mins)

Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
14:58		0	285	0		
14:59	1	1	266	19	1343	
15:00	1	2	242	24	1696	windy so hard to read
15:01	1	3	226	16	1131	
15:02	1	4	211	15	1060	
15:03	1	5	197	14	990	
15:05	2	7	170	27	1909	27/2=13.5
15:07	2	9	146	24	1696	24/2=12
15:08	1	10	134	12	848	
15:09	1	11	122	12	848	
15:11	2	13	101	21	1484	
15:13	2	15	81	20	1414	
15:15	2	17	62	19	1343	rate dropping with head
				Tot. Vol.	15763	



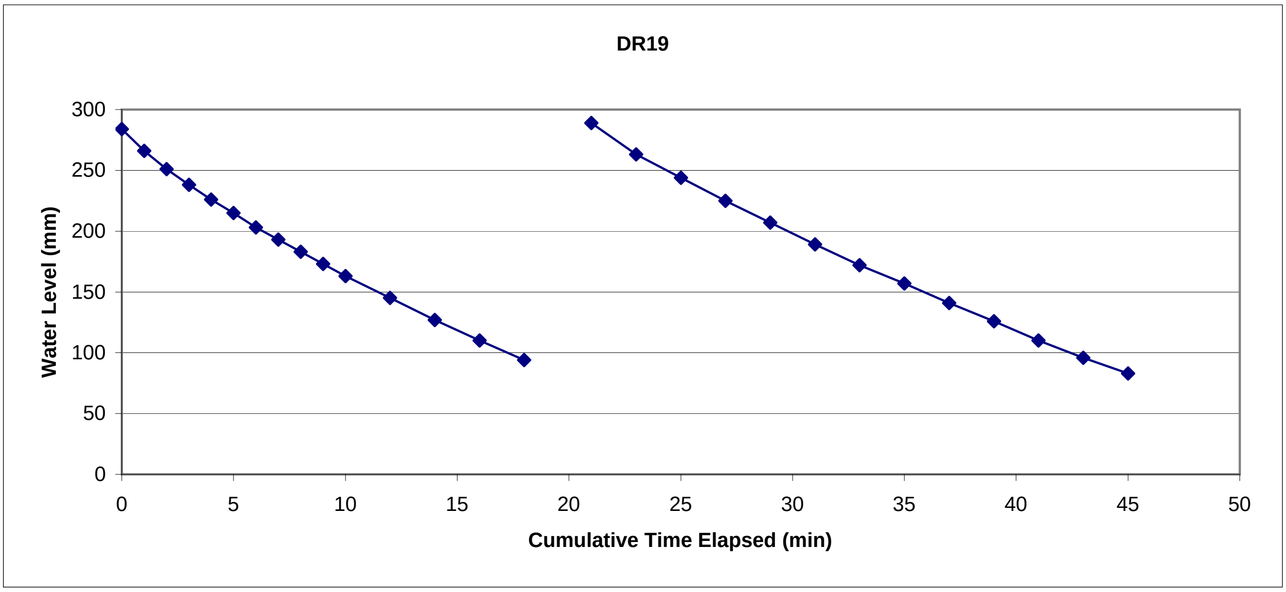
ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test: DR19	**Diameter of inner ring:**	150 mm
	Area of inner ring:	17671 mm^2
Location: Zone 50	*Northing:* 6990647	*Easting:* 780926
Test Conducted by:	LW/MC	
Description of soil:	Sandy SILT, fine to coarse grained qtz, sub angular to sub rounded, red brown, dry, compact.	
Observations:	Vegetation: Spinifex, large shrubs and trees (mulga and young eucalypts).	
Photo Ref:		

Cumulative time (mins)

Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
14:34		0	284	0		
14:35	1	1	266	18	318	
14:36	1	2	251	15	265	
14:37	1	3	238	13	230	
14:38	1	4	226	12	212	
14:39	1	5	215	11	194	
14:40	1	6	203	12	212	
14:41	1	7	193	10	177	
14:42	1	8	183	10	177	
14:43	1	9	173	10	177	
14:44	1	10	163	10	177	
14:46	2	12	145	18	318	
14:48	2	14	127	18	318	
14:50	2	16	110	17	300	
14:52	2	18	94	16	283	
14:55	3	21	289			topped up water level
14:57	2	23	263	26	459	
14:59	2	25	244	19	336	
15:01	2	27	225	19	336	
15:03	2	29	207	18	318	
15:05	2	31	189	18	318	
15:07	2	33	172	17	300	
15:09	2	35	157	15	265	
15:11	2	37	141	16	283	
15:13	2	39	126	15	265	
15:15	2	41	110	16	283	
15:17	2	43	96	14	247	
15:19	2	45	83	13	230	rate dropping with head
				Tot. Vol.	6998	

ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

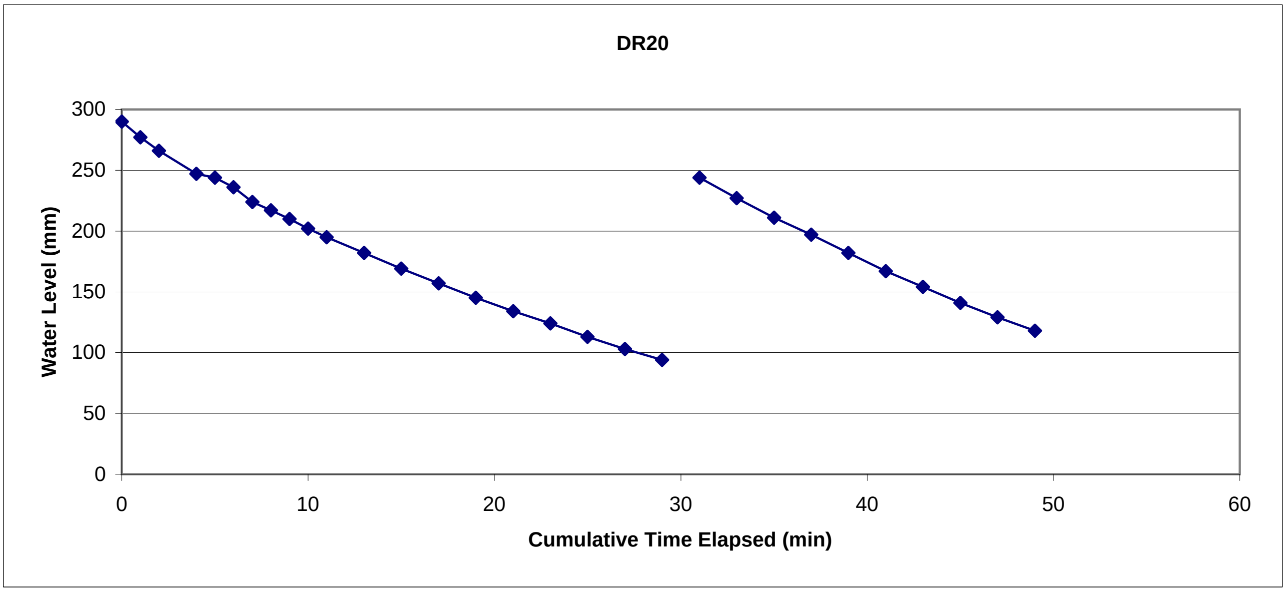


ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test: DR20	**Diameter of inner ring:**	150 mm
	Area of inner ring:	17671 mm^2
Location: Zone 50	*Northing:* 6993306	*Easting:* 795633
Test Conducted by:	LW/MC	
Description of soil:	Sandy, clayey SILT, fine to coarse grained qtz, angular to sub rounded, some gravel sized qtz on surface, red brown, dry, compact.	
Observations:	Vegetation: Medium shrubs and trees, lotsof bare soil.	
Photo Ref:		

Cumulative time (mins)

Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
16:05		0	290	0		
16:06	1	1	277	13	230	
16:07	1	2	266	11	194	
16:09	2	4	247	19	336	
16:10	1	5	244	3	53	
16:11	1	6	236	8	141	
16:12	1	7	224	12	212	
16:13	1	8	217	7	124	
16:14	1	9	210	7	124	
16:15	1	10	202	8	141	
16:16	1	11	195	7	124	
16:18	2	13	182	13	230	
16:20	2	15	169	13	230	
16:22	2	17	157	12	212	
16:24	2	19	145	12	212	
16:26	2	21	134	11	194	
16:28	2	23	124	10	177	
16:30	2	25	113	11	194	
16:32	2	27	103	10	177	
16:34	2	29	94	9	159	
16:36	2	31	244			topped up water level
16:38	2	33	227	17	300	
16:40	2	35	211	16	283	
16:42	2	37	197	14	247	
16:44	2	39	182	15	265	
16:46	2	41	167	15	265	
16:48	2	43	154	13	230	
16:50	2	45	141	13	230	
16:52	2	47	129	12	212	
16:54	2	49	118	11	194	rate dropping with head
				Tot. Vol.	5690	

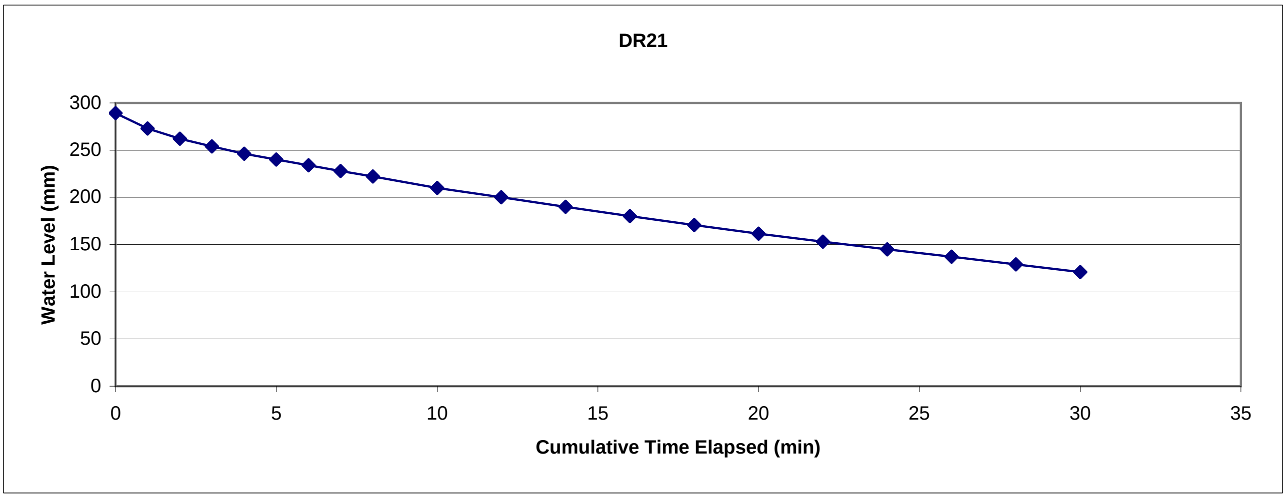

DR20
Water Level (mm)
300
250
200
150
100
50
0
0
10
20
30
40
50
60
Cumulative Time Elapsed (min)

ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test: DR21	**Diameter of inner ring:** 150 mm **Area of inner ring:** 17671 mm^2
Location: Zone 50	*Northing:* 6981218 *Easting:* 787580
Test Conducted by:	LW/MC
Description of soil:	Clayey SILT, minor sand, red brown, dry, very compact.
Observations:	Vegetation: Large shrubs and trees, some small shrubs. Some crusting on surface.
Photo Ref:	

Cumulative time (mins)

Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
13:26		0	289	0		
13:27	1	1	273	16	283	
13:28	1	2	262	11	194	
13:29	1	3	254	8	141	
13:30	1	4	246	8	141	
13:31	1	5	240	6	106	
13:32	1	6	234	6	106	
13:33	1	7	228	6	106	
13:34	1	8	222	6	106	
13:36	2	10	210	12	212	
13:38	2	12	200	10	177	
13:40	2	14	190	10	177	
13:42	2	16	180	10	177	
13:44	2	18	170.5	9.5	168	
13:46	2	20	161.5	9	159	
13:48	2	22	153	8.5	150	
13:50	2	24	145	8	141	
13:52	2	26	137	8	141	
13:54	2	28	129	8	141	
13:56	2	30	121	8	141	
				Tot. Vol.	2969	

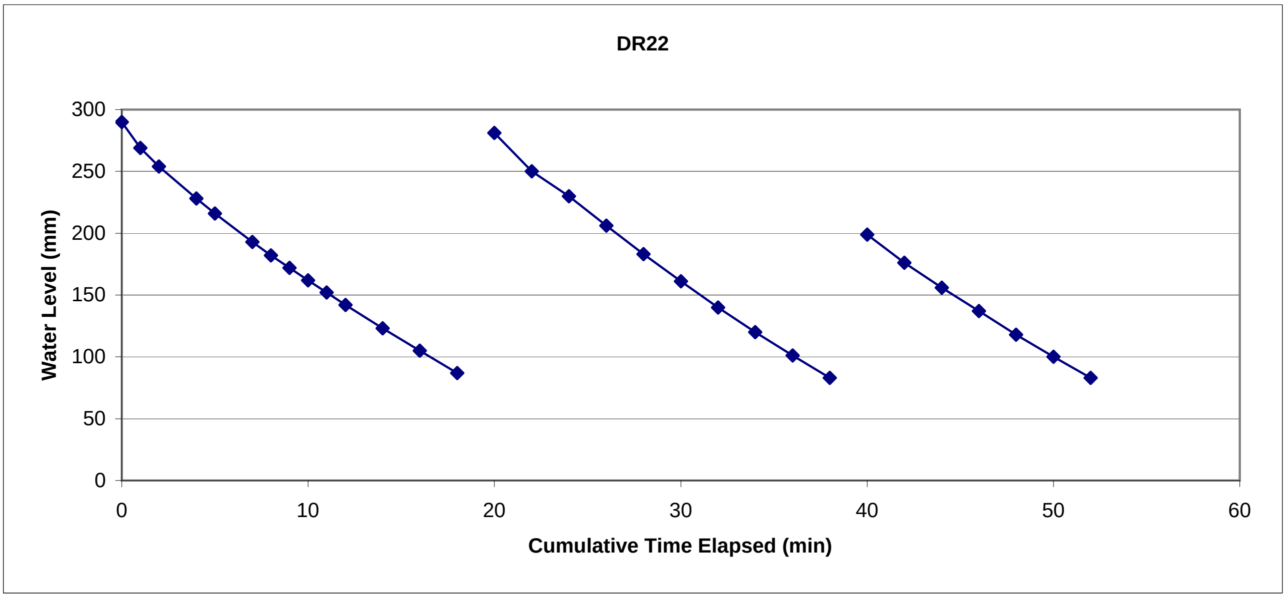


ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test: DR22	**Diameter of inner ring:**	150 mm
	Area of inner ring:	17671 mm^2
Location: Zone 51	*Northing:* 6990897	*Easting:* 213565
Test Conducted by:	LW/MC	
Description of soil:	Sandy SILT/Silty SAND, fine to medium grained qtz, some coarse on surface, angular to sub rounded, dry, moderately compact.	
Observations:	Vegetation: Sparse vegetation cover, some very small scrub. Very easy to drive in rings. Some evidence of water ponding/crusting on surface in some places.	
Photo Ref:		

Cumulative time (mins)

Actual Time (hh:mm:ss)	**Time interval (mins)**	**Cumulative time elapsed (mins)**	**Water Level Reading (mm)**	**Drop in WL (mm)**	**Volume of water used (ml)**	**Notes**
10:18		0	290	0		
10:19	1	1	269	21	371	
10:20	1	2	254	15	265	
10:22	2	4	228	26	459	26/2=13
10:23	1	5	216	12	212	
10:25	2	7	193	23	406	23/2=11.5
10:26	1	8	182	11	194	
10:27	1	9	172	10	177	
10:28	1	10	162	10	177	
10:29	1	11	152	10	177	
10:30	1	12	142	10	177	
10:32	2	14	123	19	336	
10:34	2	16	105	18	318	
10:36	2	18	87	18	318	
10:38	2	20	281			topped up water level
10:40	2	22	250	31	548	
10:42	2	24	230	20	353	
10:44	2	26	206	24	424	
10:46	2	28	183	23	406	
10:48	2	30	161	22	389	
10:50	2	32	140	21	371	
10:52	2	34	120	20	353	
10:54	2	36	101	19	336	
10:56	2	38	83	18	318	
10:58	2	40	199			topped up water level
11:00	2	42	176	23	406	
11:02	2	44	156	20	353	
11:04	2	46	137	19	336	
11:06	2	48	118	19	336	
11:08	2	50	100	18	318	
11:10	2	52	83	17	300	
				Tot. Vol.	9136	

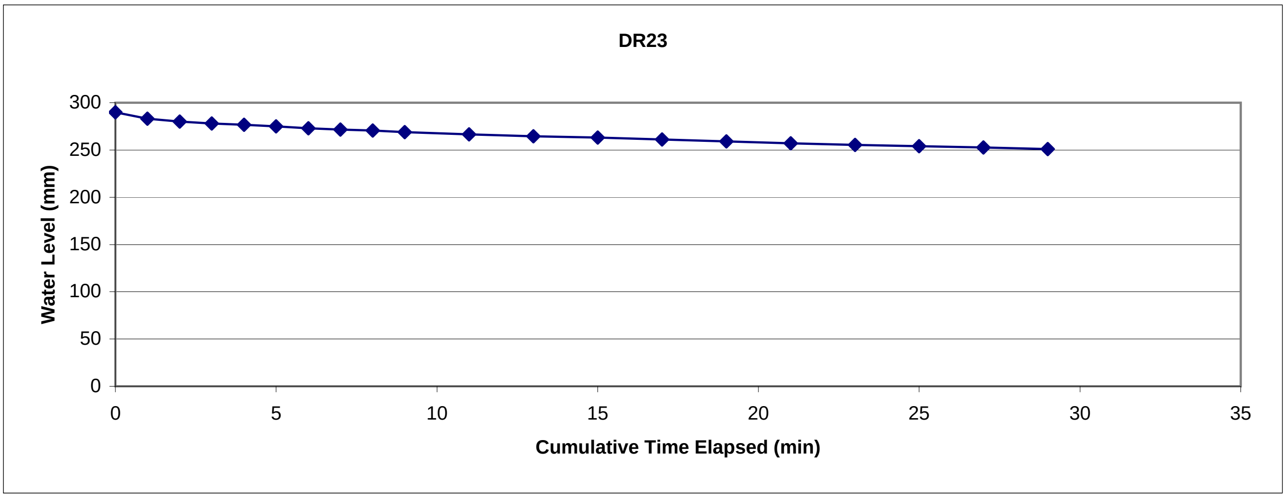

DR22
Water Level (mm)
300
250
200
150
100
50
0
0
10
20
30
40
50
60
Cumulative Time Elapsed (min)

ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test: DR23	**Diameter of inner ring:** 150 mm **Area of inner ring:** 17671 mm^2	
Location: Zone 51	*Northing:* 6981271	*Easting:* 211578
Test Conducted by:	LW/MC	
Description of soil:	SILT and weathered calcrete rubble, red brown to greyish brown, calcrete is grey, dry, compact.	
Observations:	Vegetation: Large shrubs/trees. Lots of bare soil. Test conducted on slight ridge, lower ground on either side. Very difficult to drive in rings.	
Photo Ref:		

Cumulative time (mins)

Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
8:01		0	290	0		
8:02	1	1	283	7	124	
8:03	1	2	280	3	53	
8:04	1	3	278	2	35	
8:05	1	4	276.5	1.5	27	
8:06	1	5	275	1.5	27	
8:07	1	6	273	2	35	
8:08	1	7	271.5	1.5	27	
8:09	1	8	270.5	1	18	
8:10	1	9	269	1.5	27	
8:12	2	11	266.5	2.5	44	
8:14	2	13	264.5	2	35	
8:16	2	15	263	1.5	27	
8:18	2	17	261	2	35	
8:20	2	19	259	2	35	
8:22	2	21	257	2	35	
8:24	2	23	255.5	1.5	27	
8:26	2	25	254	1.5	27	
8:28	2	27	252.5	1.5	27	
8:30	2	29	251	1.5	27	
				Tot. Vol.	689	



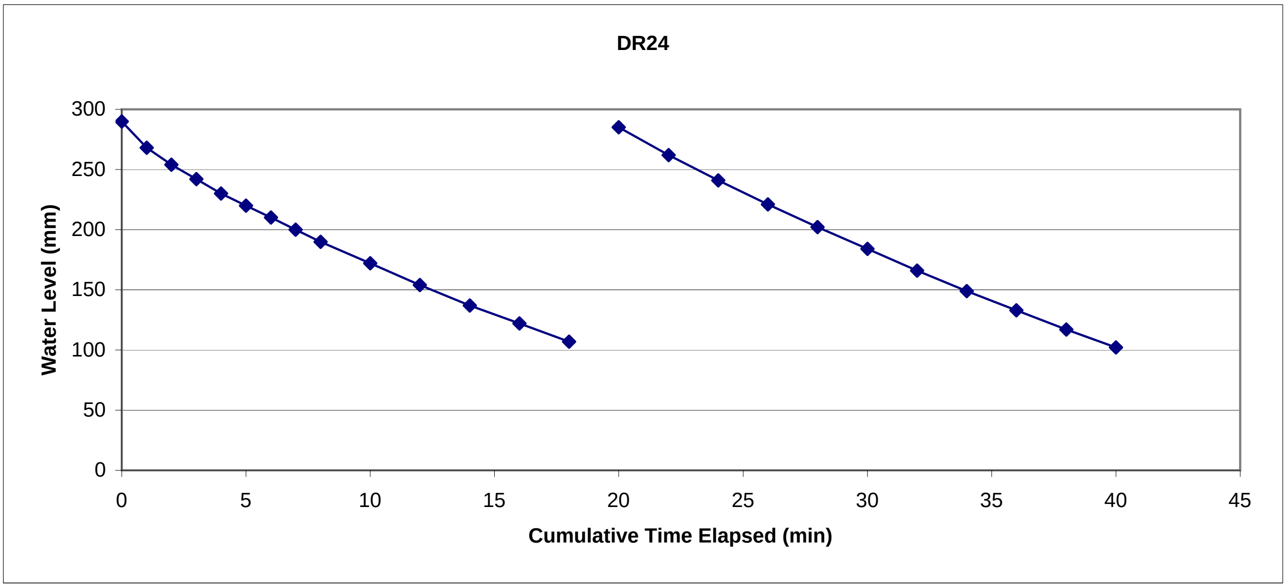
ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test: DR24	**Diameter of inner ring:** 150 mm **Area of inner ring:** 17671 mm^2
Location: Zone 51	*Northing:* 6976527 *Easting:* 217913
Test Conducted by:	LW/MC
Description of soil:	Sandy SILT, fine to coarse grained qtz, sub angular to sub rounded, minor clay, red brown, dry, compact, alluvium.
Observations:	Vegetation: Spinifex and large shrubs/trees. Evidence of water ponding, crust in places. Inside ring infiltrated slightly faster that outside one. Took soil sample SB48.
Photo Ref:	

Cumulative time (mins)

Actual Time (hh:mm:ss)	**Time interval (mins)**	**Cumulative time elapsed (mins)**	**Water Level Reading (mm)**	**Drop in WL (mm)**	**Volume of water used (ml)**	**Notes**
9:01		0	290	0		
9:02	1	1	268	22	389	
9:03	1	2	254	14	247	
9:04	1	3	242	12	212	
9:05	1	4	230	12	212	
9:06	1	5	220	10	177	
9:07	1	6	210	10	177	
9:08	1	7	200	10	177	
9:09	1	8	190	10	177	
9:11	2	10	172	18	318	
9:13	2	12	154	18	318	
9:15	2	14	137	17	300	
9:17	2	16	122	15	265	
9:19	2	18	107	15	265	
9:21	2	20	285			
9:23	2	22	262	23	406	
9:25	2	24	241	21	371	
9:27	2	26	221	20	353	
9:29	2	28	202	19	336	
9:31	2	30	184	18	318	
9:33	2	32	166	18	318	
9:35	2	34	149	17	300	
9:37	2	36	133	16	283	
9:39	2	38	117	16	283	
9:41	2	40	102	15	265	
				Tot. Vol.	6468	

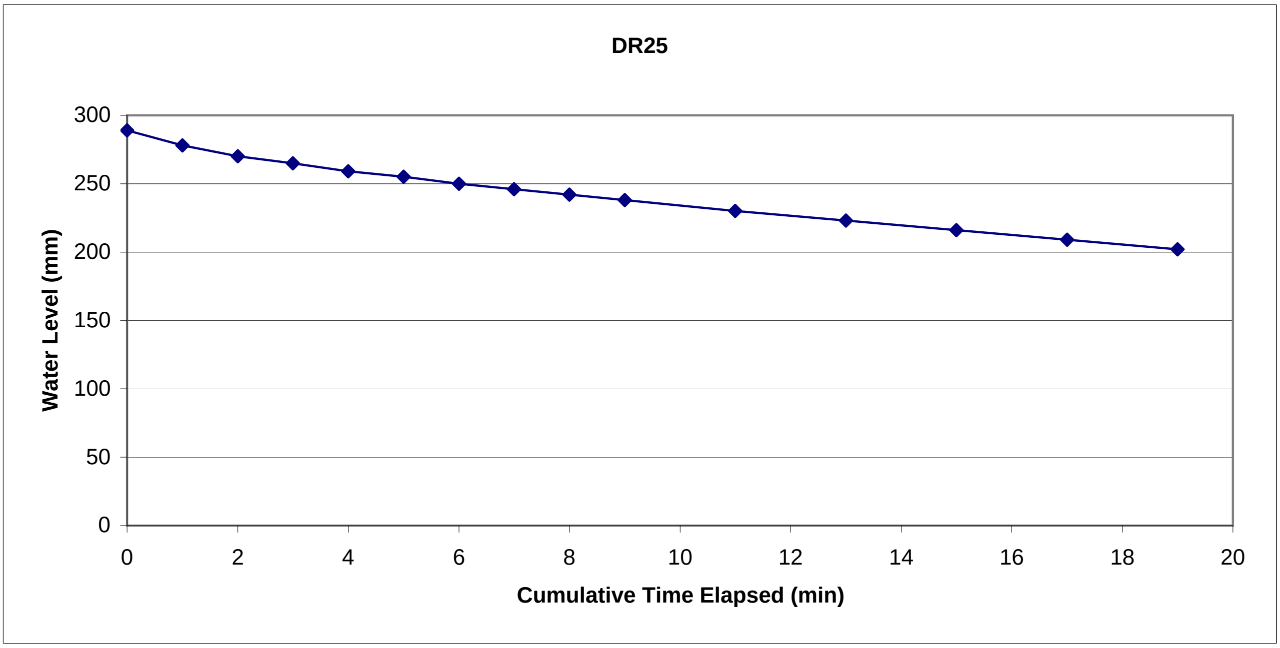
ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet



Test: DR25	**Diameter of inner ring:**	150 mm
	Area of inner ring:	17671 mm^2
Location: Zone 51	*Northing:* 6984290	*Easting:* 223987
Test Conducted by:	LW/MC	
Description of soil:	Sandy and clayey SILT, fine to coarse grained qtz, gravel on surface, dry, compact.	
Observations:	Vegetation: Medium to large shrubs and trees. Evidence of water ponding, crust on surface in places. Near to creek line, relatively easy to drive in double ring.	
Photo Ref:		

Cumulative time (mins)

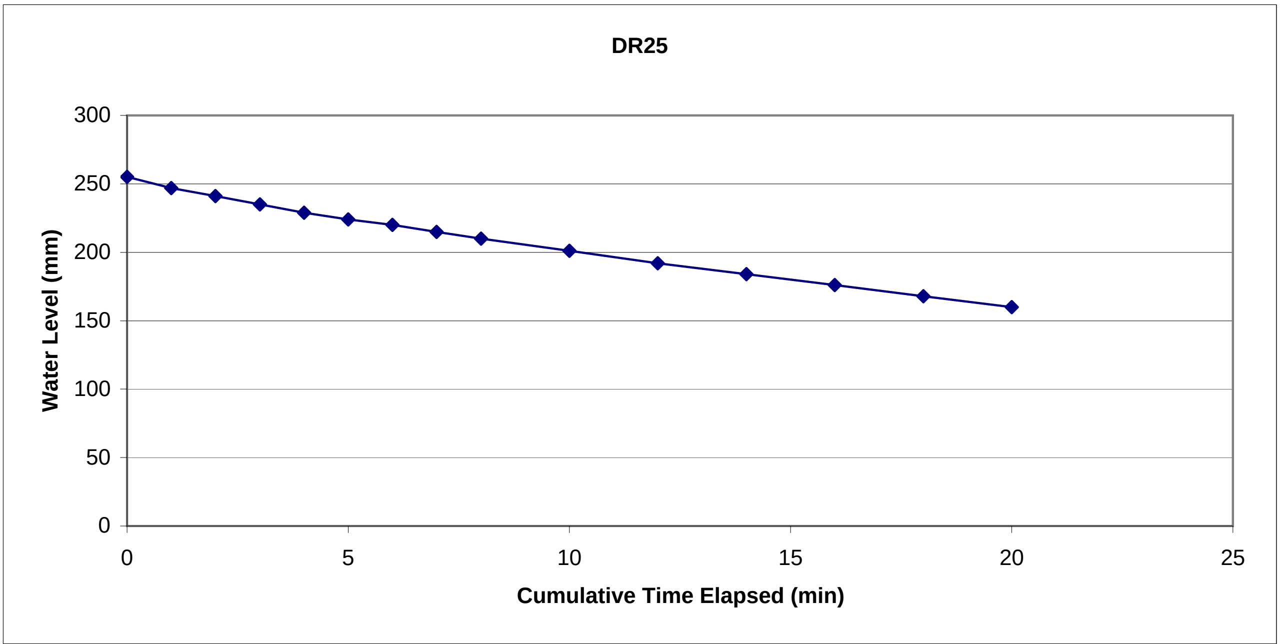
Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
7:56		0	289	0		
7:57	1	1	278	11	194	
7:58	1	2	270	8	141	
7:59	1	3	265	5	88	
8:00	1	4	259	6	106	
8:01	1	5	255	4	71	
8:02	1	6	250	5	88	
8:03	1	7	246	4	71	
8:04	1	8	242	4	71	
8:05	1	9	238	4	71	
8:07	2	11	230	8	141	
8:09	2	13	223	7	124	
8:11	2	15	216	7	124	
8:13	2	17	209	7	124	
8:15	2	19	202	7	124	
				Tot. Vol.	1537	



Test: DR25	**Diameter of inner ring:** 300 mm
	Area of inner ring: 70686 mm^2
Location: Zone 51	*Northing:* 6984290 *Easting:* 223987
Test Conducted by:	LW/MC
Description of soil:	Sandy and clayey SILT, fine to coarse grained qtz, gravel on surface, dry, compact.
Observations:	Vegetation: Medium to large shrubs and trees. Evidence of water ponding, crust on surface in places. Near to creek line, relatively easy to drive in double ring.
Photo Ref:	

Cumulative time (mins)

Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
7:53		0	255	0		
7:54	1	1	247	8	565	
7:55	1	2	241	6	424	
7:56	1	3	235	6	424	
7:57	1	4	229	6	424	
7:58	1	5	224	5	353	
7:59	1	6	220	4	283	
8:00	1	7	215	5	353	
8:01	1	8	210	5	353	
8:03	2	10	201	9	636	
8:05	2	12	192	9	636	
8:07	2	14	184	8	565	
8:09	2	16	176	8	565	
8:11	2	18	168	8	565	
8:13	2	20	160	8	565	
				Tot. Vol.	6715	

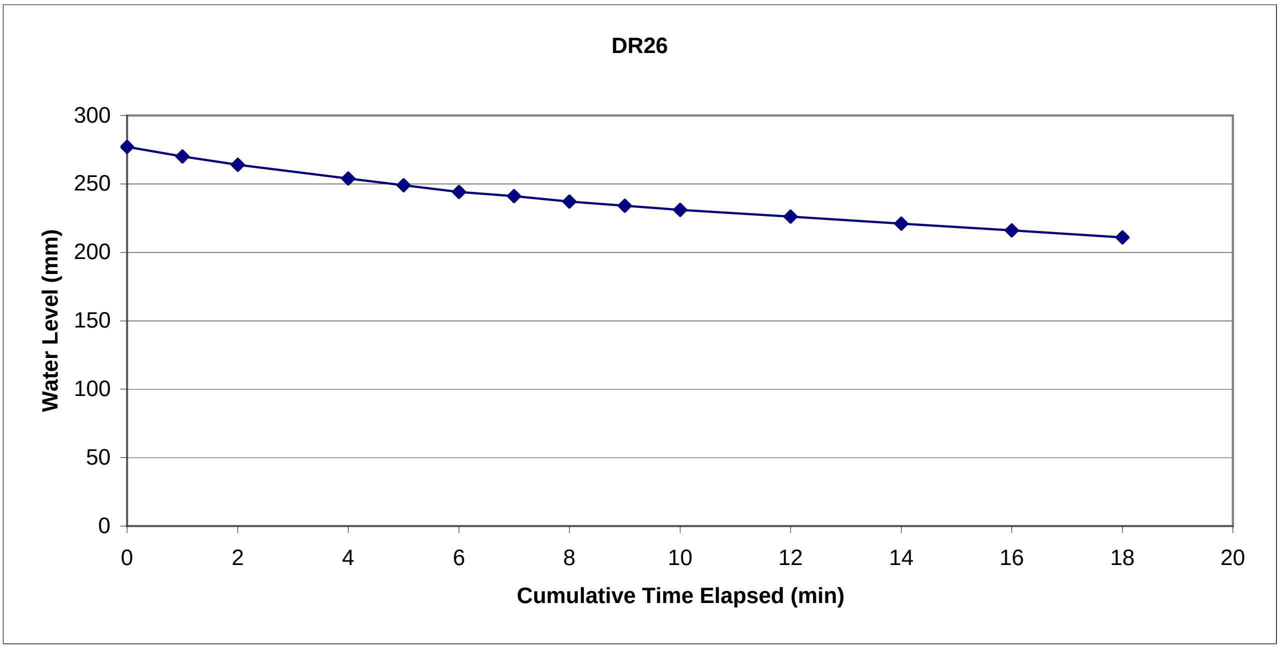


ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test: DR26	**Diameter of inner ring:**	150 mm
	Area of inner ring:	17671 mm^2
Location: Zone 51	*Northing:* 6979547	*Easting:* 232526
Test Conducted by:	LW/MC	
Description of soil:	Clayey SILT, red brown, dry, very compact. Not typical sand plain.	
Observations:	Vegetation: Spinifex and large shrubs/trees Very difficult to drive in ring. Evidence of water ponding, crust on surface in some places.	
Photo Ref:		

Cumulative time (mins)

Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
13:57		0	277	0		
13:58	1	1	270	7	124	
13:59	1	2	264	6	106	
14:01	2	4	254	10	177	
14:02	1	5	249	5	88	
14:03	1	6	244	5	88	
14:04	1	7	241	3	53	
14:05	1	8	237	4	71	
14:06	1	9	234	3	53	
14:07	1	10	231	3	53	
14:09	2	12	226	5	88	
14:11	2	14	221	5	88	
14:13	2	16	216	5	88	
14:15	2	18	211	5	88	
				Tot. Vol.	1166	



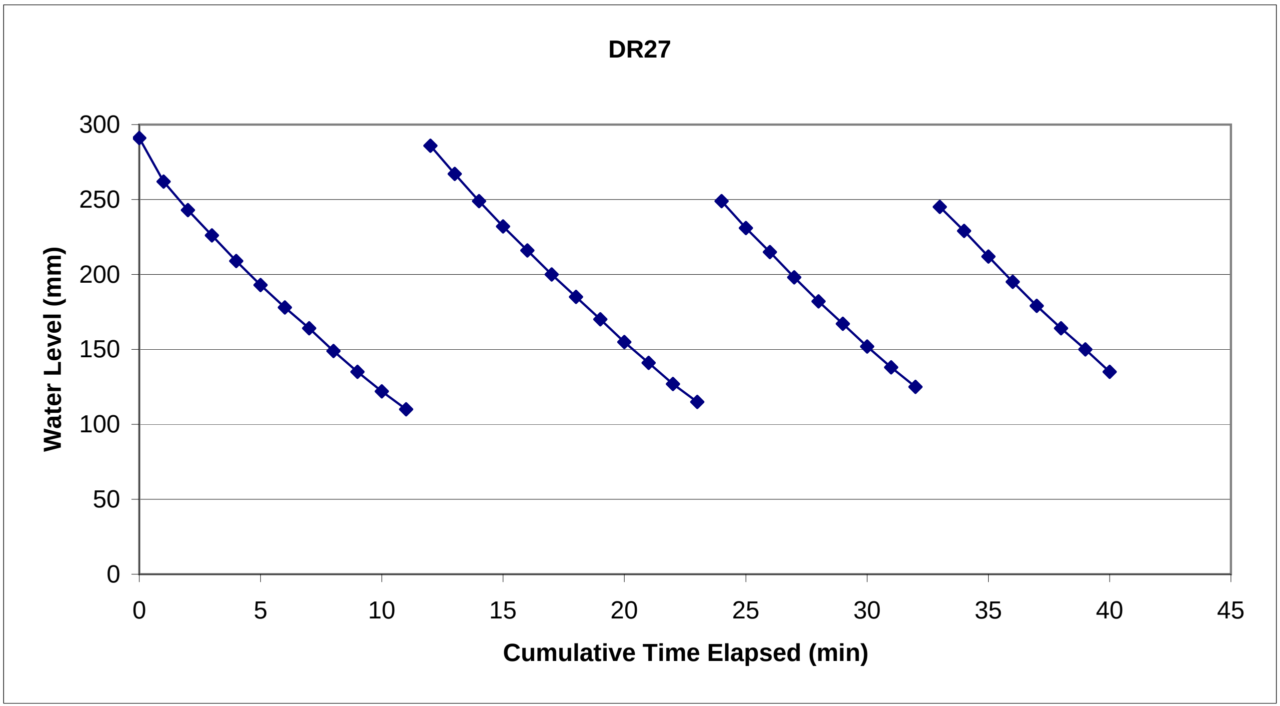
ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test: DR27	**Diameter of inner ring:** 150 mm **Area of inner ring:** 17671 mm^2	
Location: Zone 51	*Northing:* 6965887	*Easting:* 221107
Test Conducted by:	LW/MC	
Description of soil:	Silty SAND, fine to medium grained (some coarse on surface), moderately sorted, dry, moderately compact.	
Observations:	Vegetation: Spinifex and small to medium scrub, fire affected. Easy to drive in rings but 10 m away ground was very hard and evidence of water ponding/crust on surface.	
Photo Ref:		

Cumulative time (mins)

Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
15:58		0	291	0		
15:59	1	1	262	29	512	
16:00	1	2	243	19	336	
16:01	1	3	226	17	300	
16:02	1	4	209	17	300	
16:03	1	5	193	16	283	
16:04	1	6	178	15	265	
16:05	1	7	164	14	247	
16:06	1	8	149	15	265	
16:07	1	9	135	14	247	
16:08	1	10	122	13	230	
16:09	1	11	110	12	212	
16:10	1	12	286			water level topped up
16:11	1	13	267	19	336	
16:12	1	14	249	18	318	
16:13	1	15	232	17	300	
16:14	1	16	216	16	283	
16:15	1	17	200	16	283	
16:16	1	18	185	15	265	
16:17	1	19	170	15	265	
16:18	1	20	155	15	265	
16:19	1	21	141	14	247	
16:20	1	22	127	14	247	
16:21	1	23	115	12	212	
16:22	1	24	249			water level topped up
16:23	1	25	231	18	318	
16:24	1	26	215	16	283	
16:25	1	27	198	17	300	
16:26	1	28	182	16	283	
16:27	1	29	167	15	265	
16:28	1	30	152	15	265	
16:29	1	31	138	14	247	
16:30	1	32	125	13	230	
16:31	1	33	245			water level topped up
16:32	1	34	229	16	283	

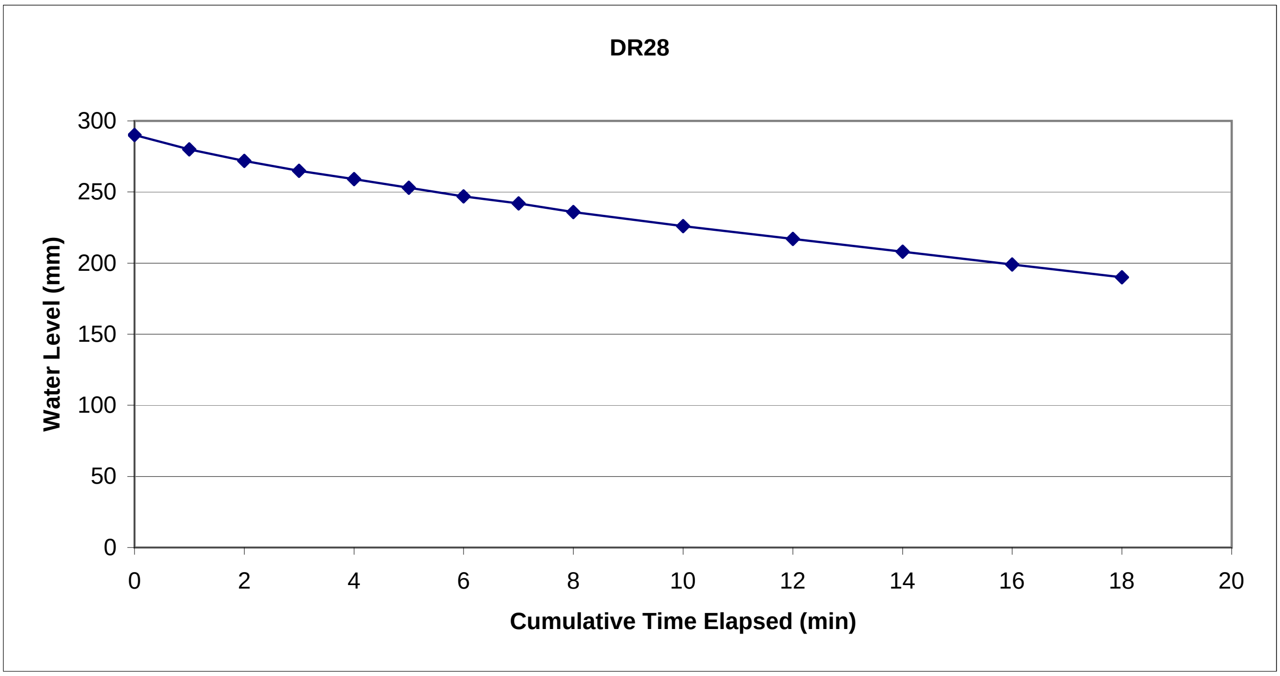
16:33	1	35	212	17	300	
16:34	1	36	195	17	300	
16:35	1	37	179	16	283	
16:36	1	38	164	15	265	
16:37	1	39	150	14	247	
16:38	1	40	135	15	265	rate affected by head
				Tot. Vol.	10355	


DR27
Water Level (mm)
0
50
100
150
200
250
300
0
5
10
15
20
25
30
35
40
45
Cumulative Time Elapsed (min)

Test: DR28	**Diameter of inner ring:** 150 mm
	Area of inner ring: 17671 mm^2
Location: Zone 51	*Northing:* 6973249 *Easting:* 247851
Test Conducted by:	LW/MC
Description of soil:	Sandy/gravelly SILT, minor clay, red brown, dry, compact.
Observations:	Vegetation: Trees and medium shrubs. Near to creek line
Photo Ref:	

Cumulative time (mins)

Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
10:20		0	290	0		
10:21	1	1	280	10	177	
10:22	1	2	272	8	141	
10:23	1	3	265	7	124	
10:24	1	4	259	6	106	
10:25	1	5	253	6	106	
10:26	1	6	247	6	106	
10:27	1	7	242	5	88	
10:28	1	8	236	6	106	
10:30	2	10	226	10	177	
10:32	2	12	217	9	159	
10:34	2	14	208	9	159	
10:36	2	16	199	9	159	
10:38	2	18	190	9	159	
				Tot. Vol.	1767	

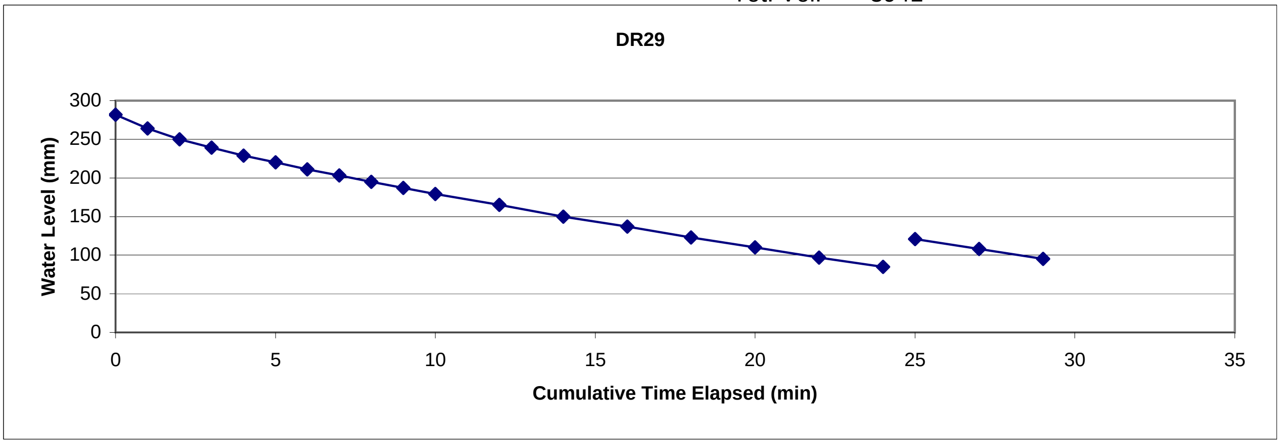


ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test: DR29	**Diameter of inner ring:** 150 mm **Area of inner ring:** 17671 mm^2	
Location: Zone 51	*Northing:* 6965695	*Easting:* 244971
Test Conducted by:	LW/MC	
Description of soil:	Silty SAND, fine to coarse grained, red brown, dry, compact.	
Observations:	Vegetation: Spinifex and small to medium shrubs/trees.	
Photo Ref:		

Cumulative time (mins)

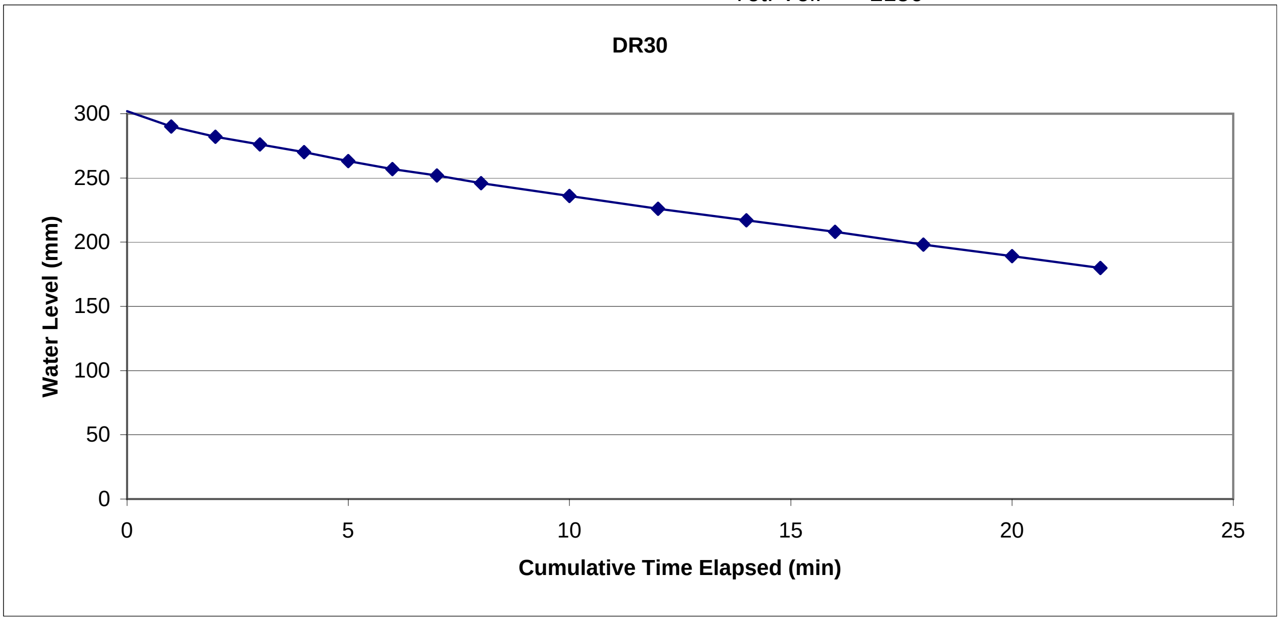
Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
11:35		0	282	0		
11:36	1	1	264	18	318	
11:37	1	2	250	14	247	
11:38	1	3	239	11	194	
11:39	1	4	229	10	177	
11:40	1	5	220	9	159	
11:41	1	6	211	9	159	
11:42	1	7	203	8	141	
11:43	1	8	195	8	141	
11:44	1	9	187	8	141	
11:45	1	10	179	8	141	
11:47	2	12	165	14	247	
11:49	2	14	150	15	265	
11:51	2	16	137	13	230	
11:53	2	18	123	14	247	
11:55	2	20	110	13	230	
11:57	2	22	97	13	230	
11:59	2	24	85	12	212	
12:00	1	25	121			
12:02	2	27	108	13	230	
12:04	2	29	95	13	230	
				Tot. Vol.	3941	



Test:	**Diameter of inner ring:**	150 mm
DR30	**Area of inner ring:**	17671 mm^2
Location: Zone 51	*Northing:* 6947600 *Easting:* 246543	
Test Conducted by:	LW/MC	
Description of soil:	Silty SAND, fine to coarse grained, angular to sub rounded, minor clay, dry, compact.	
Observations:	Vegetation: Spinifex and small scrub to trees, some young eucalypts. Evidence of water ponding, crust on surface.	
Photo Ref:		

Cumulative time (mins)

Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
8:49		0	302	0		
8:50	1	1	290	12	212	
8:51	1	2	282	8	141	
8:52	1	3	276	6	106	
8:53	1	4	270	6	106	
8:54	1	5	263	7	124	
8:55	1	6	257	6	106	
8:56	1	7	252	5	88	
8:57	1	8	246	6	106	
8:59	2	10	236	10	177	
9:01	2	12	226	10	177	
9:03	2	14	217	9	159	
9:05	2	16	208	9	159	
9:07	2	18	198	10	177	
9:09	2	20	189	9	159	
9:11	2	22	180	9	159	
				Tot. Vol.	2156	

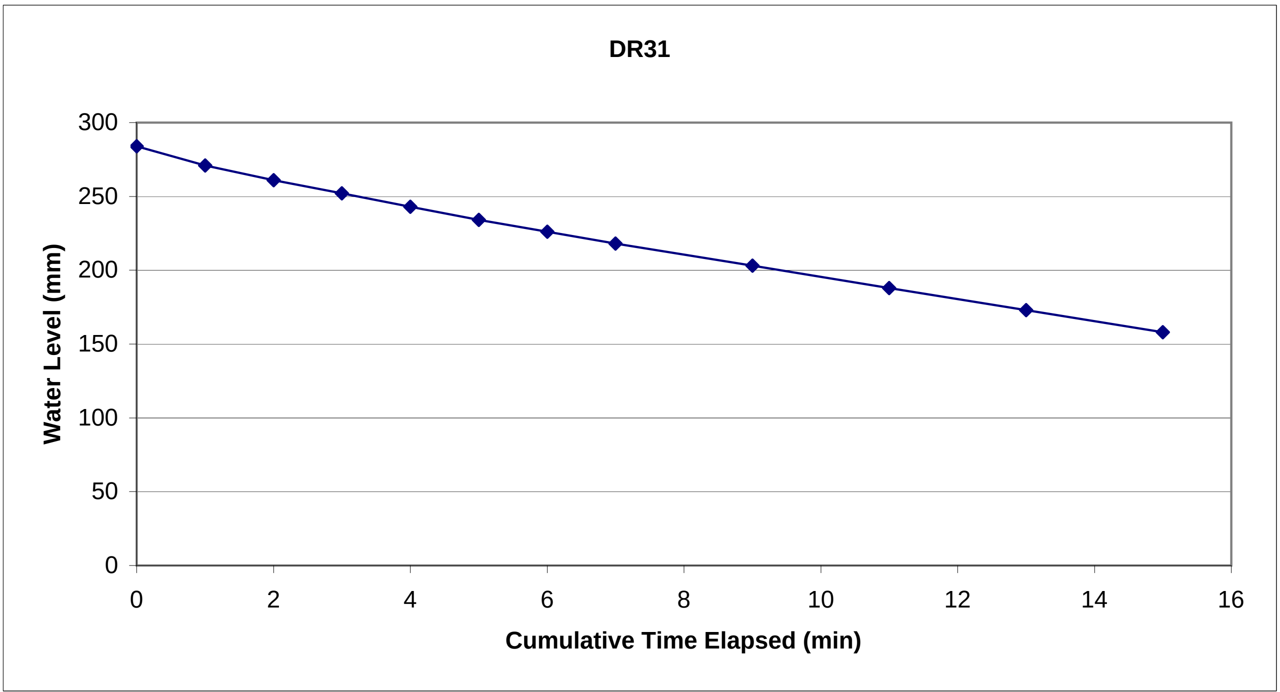


ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test: DR31	**Diameter of inner ring:**	150 mm
	Area of inner ring:	17671 mm^2
Location: Zone 51	*Northing:* 6917262	*Easting:* 249691
Test Conducted by:	LW/BE	
Description of soil:	Silty SAND/Sandy SILT, fine to medium grained (some coarse) qtz, red brown, dry, compact.	
Observations:	Vegetation: Spinifex and small scrub.	
Photo Ref:		

Cumulative time (mins)

Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
14:40		0	284	0		
14:41	1	1	271	13	230	
14:42	1	2	261	10	177	
14:43	1	3	252	9	159	
14:44	1	4	243	9	159	
14:45	1	5	234	9	159	
14:46	1	6	226	8	141	
14:47	1	7	218	8	141	
14:49	2	9	203	15	265	
14:51	2	11	188	15	265	
14:53	2	13	173	15	265	
14:55	2	15	158	15	265	
				Tot. Vol.	2227	

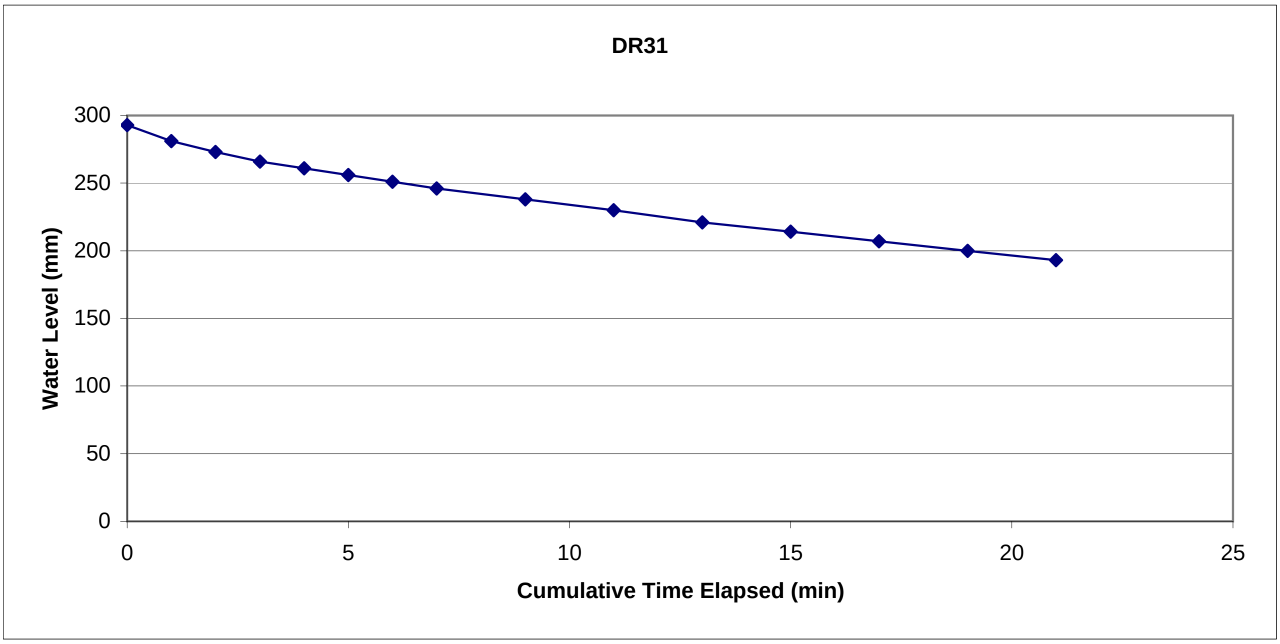


ATTACHMENT B-2
Yeelirrie Surface Water Stage 1
Infiltration Test Data Sheet

Test: DR32	**Diameter of inner ring:**	150 mm
	Area of inner ring:	17671 mm^2
Location: Zone 51	*Northing:* 6926185	*Easting:* 256511
Test Conducted by:	LW/BE	
Description of soil:	Silty CLAY, minor sand, red brown, dry, compact.	
Observations:	Vegetation: Large shrubs and trees.	
Photo Ref:		

Cumulative time (mins)

Actual Time (hh:mm:ss)	Time interval (mins)	Cumulative time elapsed (mins)	Water Level Reading (mm)	Drop in WL (mm)	Volume of water used (ml)	Notes
15:52		0	293	0		
15:53	1	1	281	12	212	
15:54	1	2	273	8	141	
15:55	1	3	266	7	124	
15:56	1	4	261	5	88	
15:57	1	5	256	5	88	
15:58	1	6	251	5	88	
15:59	1	7	246	5	88	
16:01	2	9	238	8	141	
16:03	2	11	230	8	141	
16:05	2	13	221	9	159	
16:07	2	15	214	7	124	
16:09	2	17	207	7	124	
16:11	2	19	200	7	124	
16:13	2	21	193	7	124	
				Tot. Vol.	1767	



Photographs of Infiltration Test Locations - Field Work SW1

DR6

DR8

Photographs of Infiltration Test Locations - Field Work SW2


DR15


DR16


DR17


DR18


DR19


DR20


DR21


DR22


DR23


DR24


DR25


DR26


DR27


DR27


DR28
SOUTH


DR28
North West


DR29


DR30


DR32

APPENDIX C SOIL SAMPLING PROGRAMME

C.1 Introduction

The soil sampling programme was completed in order to characterize the physical and chemical conditions. The field classification of the soils, which were based on the physical conditions, was used to confirm the land system classification that was used in the hydrological modelling. The analytical testing and related results were used for evaluating the groundwater-related conceptual model described in the groundwater study (URS, 2011); the analytical test methods and results are included in the report.

A two-stage soil-sampling programme was completed within the Yeelirrie Catchment:

- Stage 1: 25 to 28 June 2009, catchment scale.
- Stage 2: 14 to 19 January 2010, Proposed Development Area focus.

The soil sampling assisted in defining the catchment unit-related landscapes, which were utilized in the hydrological modelling. As described in Section 3.4, the land systems of the Yeelirrie Catchment have been categorised herein into five catchment units based on their likely or possible relevance to surface water and groundwater regimes within the study area.

C.2 Stage 1 Soil Sampling

During Stage 1, 40 soil samples (26 surface and 13 deep samples)(see Figure 4-3) were collected from locations focused on characterising the catchment units within the study area:

The central drainage channel areas, including calcrete and playas. Soil characteristics: red-brown loam, low plasticity, fine to medium-grained quartz sand with clay, sandy matrix, dry.

Major drainage channels leading into the central valley-floor watercourses. Soil characteristics: red-brown loam, low to moderate plasticity, fine to medium grained quartz sand with clay, sandy matrix, moist. Shrubs and trees present on surface with flood debris on trees indicative of water flow.

Wash plain catchment unit. Soil characteristics: red-brown loam, low plasticity, fine to medium-grained sand, sandy matrix, dry, cemented calcrete locally on surface.

Sand plain catchment unit. Soil characteristics: red-brown loam, low plasticity, medium-grained sands, sandy matrix.

Playas and clay pans. Soil characteristics: red-brown clay, moderate plasticity, silty, sandy matrix, minor fine grained quartz, sub-rounded, moderately sorted, moist, minor calcrete, ferrous minerals and salt tolerant plants at surface.

C.3 Stage 2 Soil Sampling

During the Stage 2 soil-sampling programme, an additional 15 samples (SB38 to SB52) were collected, with sampling targeting the proposed Yeelirrie Project area; the reaches of the central valley-floor watercourses downstream of the proposed Project area; and the Yeelirrie Playa.

Tables C-1 and C-2 describe the locations and characteristics of the collected soil samples for both programmes.

URS

Table C-1 Stage 1 Soil Sample Descriptions

Catchment Unit		Soil Sample	Sample Depth		Soil Description
			Surface	Deep	
Wash Plain and Sand Plain		SB1	√		Red brown loam, low plasticity, sandy matrix, medium-grained sand.
		SB5	√		Red brown loam, low plasticity, sandy matrix, fine to medium-grained sand, dry soil, local cemented calcrete at surface (tan).
		SB25	√		Red brown loam, low plasticity, sandy matrix, damp, fine to medium grained, cemented calcrete at surface, cryptogam (tan).
		SB28	√	√	Red brown loam, low plasticity, sandy matrix, fine to medium-grained sand, dry soil.
Wash Plain and Sand Plain	Valley-Floor Channels	SB17	√		Red brown loam, low plasticity, fine to medium-grained quartz sand and clay major, sandy matrix, dry soil.
		SB24	√		Red brown loam, low plasticity, fine to medium-grained quartz sand and clay major, sandy matrix, dry soil with thin crust on
		SB27	√	√	Red brown loam, low plasticity, fine to medium-grained quartz sand and clay major, sandy matrix, dry soil.
	Major Drainage Channels	SB3	√		Red brown loam, low plasticity, fine to medium-grained quartz sand and clay major, sandy matrix, damp soil, presence of
		SB9	√	√	Dark brown loam, moderate plasticity, fine to medium-grained quartz sand and clay major with high organic content, sandy matrix, ground cover amongst cryptogam on damp soil.
		SB10	√		Red brown wash plain, low plasticity, fine to medium-grained quartz sand and clay major, sandy matrix, Damp soil with
		SB14	√		Red brown loam, low plasticity, fine to medium-grained quartz sand and clay major, sandy matrix, dry soil.
		SB15	√		Red brown loam, low plasticity, fine to medium-grained quartz sand and clay major, sandy matrix, damp soil.
		SB16	√	√	Dark brown loam, medium plasticity, fine-grained quartz sand and clay major, sandy matrix, damp soil, high organic content.
		SB19	√	√	Red brown loam, low plasticity, fine to medium-grained quartz sand and clay major, sandy matrix, damp soil with thin crust on
		SB20	√	√	Red brown loam, moderate plasticity, fine to medium-grained quartz sand and clay major, sandy matrix, damp soil. Organic
		SB21	√		Red brown loam, low plasticity, fine to medium-grained quartz sand and clay major, sandy matrix, damp soil. Presence of
		SB31	√		Red brown loam, low plasticity, fine to medium-grained quartz sand and clay major, sandy matrix, damp soil, high organic
		SB32	√		Red brown loam, low plasticity, fine to medium-grained quartz sand and clay major, sandy matrix, slightly damp soil.
		SB32a	√		Red brown medium to coarse grained washed sand, low plasticity, more cohesive soil and eroded ferricrete.
		SB33	√		Red brown loam, low plasticity, fine to medium-grained quartz sand and clay major, sandy matrix, damp soil. Thin surface
		SB34	√	√	Red brown loam, low plasticity, fine to medium-grained quartz sand and clay major, sandy matrix, slightly damp soil with
Playa	Valley Floor Channels	SB2	√	√	Red brown loam, low plasticity, fine to medium-grained quartz sand and clay major, sandy matrix, dry soil, ferrous minerals.
		SB29	√	√	Red brown clay, moderate plasticity, silty, sandy with fine-grained, sub-rounded, moderately-sorted quartz, dry soil.
		SB37	√	√	Pale brown surface, red brown clay at shallow depth, moderate plasticity, fine to medium-grained, silty, sandy matrix, damp soil, calcrete at surface, ferrous minerals.
	Yeelirrie Playa	SB35	√	√	Red brown clay, moderate plasticity, silty, sandy matrix, fine-grained, clay crust formed on surface. Salt crystals present on surface, gypsum-like substance at shallow (100 mm) depth, ferrous minerals.
		SB36	√	√	Red brown clay, moderate plasticity, silty, sandy matrix, some clay, slightly damp soil, ferrous minerals.

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Table C-2 Stage 2 Soil Sample Descriptions

Catchment Unit		Soil Sample	Sample Depth	Soil Description
			Surface	
Sand Plain		SB44	√	Silty sand, fine to very coarse-grained, sub angular to sub rounded, reddish brown, compact and dry alluvium.
		SB50	√	Sandy silt, fine to coarse-grained quartz, angular to sub-rounded, minor clay, red brown, compact and dry.
Playa	Valley-Floor Channels	SB38	√	Clay, grey/reddish brown, dry, very compact and low plasticity.
		SB39	√	Clay, grey brown, dry and compact.
		SB40	√	Sandy silt, fine to coarse-grained quartz, angular to sub angular, red brown, dry, compact and minor organic matter (roots). Alluvium.
		SB41	√	Sandy silt, fine to coarse-grained quartz, angular to sub angular, red brown, dry and compact alluvium.
		SB42	√	Sandy silt fine to coarse-grained quartz, sub angular to sub rounded, minor clay, reddish brown, compact and dry.
		SB43	√	Sandy silt, fine to coarse-grained, angular to sub-rounded, brown, compact and dry alluvium.
		SB45	√	Sandy clay, minor silt, fine to coarse-grained quartz, sub angular to sub rounded, reddish brown, compact and dry alluvium.
		SB46	√	Silty clay, minor sand, reddish, dry and compact.
		SB47	√	Sandy silt with clay, fine to coarse grained, sub-angular to sub-rounded, red-brown, dry and moderately compact.
		SB48	√	Sandy silt, fine to coarse-grained quartz, sub-angular to sub-rounded, minor clay, red brown, dry and compact alluvium.
		SB49	√	Silty clay, minor sand, weathered calcrete rubble, reddish brown, dry and compact.
	Yeelirrie Playa	SB51	√	Silty clay, minor sand, brown, dry, compact and minor organic matter (roots).
		SB52	√	Silty clay, minor sand, brown, dry, compact and minor organic matter (roots).

C.4 Soil Sampling Methodology

The following methods were utilised for completing the soil sampling.

The soil sample locations were planned for providing spatial coverage, as reasonably possible, within the different catchment units. The sampling was completed at location of undisturbed ground.

Surface soil samples were collected from the top 0.1 m of the natural ground surface, away from disturbed surfaces such as dirt tracks. A geological pick was used to break up the soil. Deep soil samples (to depths of about 1 m) were collected using a hand-auger. The samples were then classified based the physical characteristics.

URS

APPENDIX D SURFACE WATER QUALITY SAMPLING

D.1 Field Results – Surface Water Sampling

Sample Location	Date	Time	Weather Conditions	Flow	EC	pH	Temp	Field Redox Potential	Corrected Redox Potential**	DO		Comments
				(m/sec)	(µS/cm)		(°C)	(mV)	(mV)	(%)	(mg/L)	(Colour, turbidity, sheen, odour)
SW1	26/06/2009	9.15	cloudy	n/a	185	7.73	9.0	114	334	62.0	7.30	near SB37
SW2	27/06/2009	13.4	drizzle	n/a	276	7.36	20.4	123	334	86.1	8.78	West of Mica Well

** Field measurements use meter with **Ag/AgCl type** ORP electrode.
Measurement converted to Standard Hydrogen Electrode using:
SHE Eh (mV) = Observed Eh (mV) + (226.62 - 0.7634*T)

D.2 Analytical Results – Surface Water Sampling

Location				SW1	SW1	SW2	SW2	SW3	SW3	SW4	SW5	SW5	SW6	SW6
Sample ID				SW1	SW1CHK	SW2	SW2Rpt	Site A	Site ACHK	Site B	Site A	Site ACHK	Site B	Site BCHK
Date Sampled				26/06/2009	26/06/2009	27/06/2009	27/06/2009	22/03/2010	22/03/2010	22/03/2010	21/03/2010	21/03/2010	21/03/2010	21/03/2010
Sample Type				Primary Sample	Lab Duplicate	Primary Sample	Lab Duplicate^	Primary Sample	Lab Duplicate	Primary Sample	Primary Sample	Lab Duplicate	Primary Sample	Lab Duplicate
Analyte	LOR	Units	ANZECC 2000*											
Physico-Chemical Parameters														
Electrical Conductivity	1	µs/cm		-	-	-	-	9	-	27	620	-	74	-
pH	0 01	ph unit		-	-	-	-	6.46	-	6.77	9.59	-	6.83	-
Metals (Dissolved)														
Aluminium	0 01	mg/L	0.055	-	-	-	-	0.1	-	0.11	6.28	6.36	0.04	-
Antimony	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	<0.001	<0.001	<0.001	-
Arsenic	0.001	mg/L	0.024	<0 001	<0 001	<0 001	-	<0 001	-	<0 001	0.014	0.014	<0.001	-
Barium	0.001	mg/L	-	-	-	-	-	<0 001	-	0.002	0.1	0.097	0.004	-
Beryllium	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	<0.001	<0.001	<0.001	-
Bismuth	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	<0.001	<0.001	<0.001	-
Boron	0 05	mg/L	0 37	-	-	-	-	<0.05	-	<0 05	0.45	0.46	<0 05	-
Bromine	0.1	mg/L	-	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-
Cadmium	1E-04	mg/L	0 0002	<0.0001	<0.0001	<0.0001	-	<0.0001	-	<0 0001	0.0002	0.0001	<0 0001	-
Cerium	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	0.005	0.005	<0.001	-
Chromium	0.001	mg/L	0.001	0.007	0.006	<0 001	-	<0 001	-	<0.001	0.007	0.006	<0.001	-
Cobalt	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	0.001	0.001	<0.001	-
Copper	0.001	mg/L	0 0014	0.006	0.006	0.003	-	0.003	-	0.002	0.009	0.009	0.005	-
Iron	0 05	mg/L	-	3.66	3.12	<0.05	-	<0.05	-	0.07	1.43	1.41	<0 05	-
Lead	0.001	mg/L	0 0034	0.002	0.002	<0 001	-	<0 001	-	<0.001	<0.001	<0.001	<0.001	-
Lithium	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	0.002	0.002	<0.001	-
Manganese	0.001	mg/L	1.9	-	-	-	-	0.008	-	0.039	0.079	0.079	0.049	-
Mercury	1E-04	mg/L	-	<0.0001	<0.0001	<0.0001	-	<0.0001	-	<0 0001	<0 0001	<0 0001	<0 0001	<0 0001
Molybdenum	0.001	mg/L	-	0.001	<0 001	0.001	-	<0 001	-	<0.001	<0.001	<0.001	<0.001	-
Nickel	0.001	mg/L	0.011	0.004	0.004	<0 001	-	<0 001	-	<0.001	0.005	0.005	0.002	-
Rhenium	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	<0.001	-	<0.001	-
Selenium	0 01	mg/L	-	<0.01	<0.01	<0.01	-	<0.01	-	<0 01	<0 01	<0 01	<0 01	-
Silver	0.001	mg/L	0.00005	-	-	-	-	<0 001	-	<0.001	<0.001	<0.001	<0.001	-
Strontium	0.001	mg/L	-	0.006	0.005	0.022	-	0.002	-	0.01	0.022	0.022	0.005	-
Thallium	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	<0.001	<0.001	<0.001	-
Thorium	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	<0.001	<0.001	<0.001	-
Tin	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	<0.001	<0.001	<0.001	-
Tungsten	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	<0.001	<0.001	<0.001	-
Uranium	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	0.033	0.034	<0.001	-
Vanadium	0 01	mg/L	-	<0.01	<0.01	<0.01	-	<0.01	-	<0 01	0.08	0.08	<0 01	-
Yttrium	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	0.001	0.001	<0.001	-
Zinc	0.005	mg/L	0.008	0.012	0.01	<0 005	-	0.009	-	0.034	0.02	0.02	0.069	-
Metals (Total)														
Aluminium	0 01	mg/L	-	-	-	-	-	0.28	-	1.29	568	567	4.09	-
Antimony	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	<0 01	<0 01	<0.001	-
Arsenic	0.001	mg/L	-	0.003	0.002	0.001	-	<0 001	-	<0.001	0.021	0.026	0.001	-
Barium	0.001	mg/L	-	-	-	-	-	<0 001	-	0.004	0.218	0.219	0.018	-
Beryllium	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	<0 01	<0 01	<0.001	-
Bismuth	0.001	mg/L	-	-	-	-	-	-	-	-	<0 01	<0 01	<0.001	-
Boron	0 05	mg/L	-	-	-	-	-	-	-	-	1.38	1.44	<0 05	-
Bromine	0.1	mg/L	-	0.9	0.6	0.3	-	-	-	-	-	-	-	
Cadmium	1E-04	mg/L	-	0.0003	0.0003	0.0001	-	<0.0001	-	<0 0001	0.0012	0.0011	<0 0001	-
Cerium	0.001	mg/L	-	-	-	-	-	-	-	-	0.42	0.419	0.018	-
Chromium	0.001	mg/L	-	0.084	0.081	0.015	-	<0 001	-	0.003	0.417	0.423	0.009	-
Cobalt	0.001	mg/L	-					<0 001	-	<0.001	0.096	0.097	0.003	-
Copper	0.001	mg/L	-	0.058	0.055	0.01	-	<0 001	-	0.002	0.199	0.196	0.007	-
Iron	0 05	mg/L	-	54.1	52.6	8.22	-	0.27	-	1.64	167	168	5.36	-
Lead	0.001	mg/L	-	0.068	0.066	0.009	-	<0 001	-	<0.001	0.067	0.067	0.005	-
Lithium	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	0.148	0.152	0.002	-
Manganese	0.001	mg/L	-	-	-	-	-	0.014	-	0.056	6.7	6.75	0.139	-
Mercury	1E-04	mg/L	-	<0.0001	<0.0001	<0.0001	-	<0.0001	-	<0 0001	<0 0001	-	<0 0001	
Molybdenum	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	<0 01	<0 01	<0.001	-
Nickel	0.001	mg/L	-	0.055	0.051	0.008	-	<0 001	-	0.001	0.238	0.237	0.006	-
Rhenium	0.001	mg/L	-	-	-	-	-	-	-	-	<0 01	-	<0.001	-
Selenium	0 01	mg/L	0.011	-	-	-	-	<0.01	-	<0 01	<0.1	<0.1	<0 01	-
Silver	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	<0 01	<0 01	<0.001	-
Strontium	0.001	mg/L	-	-	-	-	-	0.002	-	0.01	0.876	0.876	0.01	-
Thallium	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	<0 01	<0 01	<0.001	-
Thorium	0.001	mg/L	-	-	-	-	-	<0 001	-	0.001	0.061	0.064	0.005	-
Tin	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	<0 01	<0 01	<0.001	-
Tungsten	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	<0 01	<0 01	<0.001	-
Uranium	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	0.437	0.439	<0.001	-
Vanadium	0 01	mg/L	-	-	-	-	-	<0.01	-	<0 01	0.47	0.48	0.01	-
Yttrium	0.001	mg/L	-	-	-	-	-	<0 001	-	<0.001	0.115	0.114	0.004	-
Zinc	0.005	mg/L	-	0.154	0.142	0.034	-	<0 005	-	<0.005	0.82	0.8	0.021	-
Dissolved Organic Carbon														
Dissolved Organic Carbon	1	mg/L	-	8	7	7	-	-	-	-	-	-	-	-
Total Dissolved Solids														
Total Dissolved Solids	5	mg/L	-	4130	-	824	-	<5	-	23	16800	16800	123	-
Nutrients														
Ammonia as N	0 01	mg/L	0.9	0.28	0.27	0.04	-	-	-	-	-	-	-	-
Nitrate (as N)	0 01	mg/L	0.7	0.3	-	0.02	-	0.04	-	0.15	0.62	-	0.64	-
Nitrite (as N)	0 01	mg/L	-	0.05	-	<0.01	-	0.02	0.02	0.03	0.05	-	0.03	-
Nitrate and Nitrite (as N)	0 01	mg/L	-	0.36	0.36	0.02	-	0.06	0.06	0.18	0.68	-	0.67	-
Phosphorus (total)	0 01	mg/L	-	-	-	-	-	0.05	-	0.06	1.78	-	0.34	0.31
Major Ions														
Bromide	0.1	mg/L	-	-	-	-	-	<5	-	<1	92.4	92	2.4	-
Calcium	1	mg/L	-	1	1	2	-	<1	-	2	<1	-	<1	<1
Chloride	1	mg/L	-	13	13	61	-	<1	<1	<1	97	-	1	-
Fluoride	0.1	mg/L	-	<0.1	<0.1	<0.1	-	<0.1	-	<0.1	<0.1	-	<0.1	-
Magnesium	1	mg/L	-	2	2	<1	-	<1	-	<1	<1	-	<1	<1
Potassium	1	mg/L	-	10	11	4	-	2	-	4	9	-	4	4
Sodium	1	mg/L	-	26	28	45	-	<1	-	1	119	-	2	2
Sulfate as SO4 2-	1	mg/L	-	2	2	11	-	<1	-	3	10	-	2	2
Sulfur as S	1	mg/L	-	<1	<1	4	-	<1	-	<1	3	-	<1	<1
Total Anions	-	meq/l	-	1.52	-	2.5	-	0.07	-	0.17	9.23	-	0.14	-
Total Cations	-	meq/l	-	1.67	-	2.14	-	0.04	-	0.25	5.42	-	0.2	-
Ionic Balance	-	-	-	4.70%	-	-7.76%	-	pass	-	pass	26%	-	pass	-
Alkalinity														
Hydroxide Alkalinity as CaCO3	1	mg/L	-	<1	<1	<1	-	<1	-	<1	<1	-	<1	-
Carbonate Alkalinity as CaCO3	1	mg/L	-	<1	<1	<1	-	<1	-	<1	79	-	<1	-
Bicarbonate as CaCO3	1	mg/L	-	56	54	27	-	4	-	5	236	-	2	-
Total Alkalinity	1	mg/L	-	56	54	27	-	4	-	5	314	-	2	-
Silica (Dissolved)														
Silica	0.1	mg/L	-	-	-	-	-	2.4	-	4	18	-	9.7	-
Radiological Suite														
Radium-226	0.1	Bq/L	-	<0.1	-	<0.1	-	-	-	-	-	-	-	-
Radium-228	0.1	Bq/L	-	0.591 ± 0.228	-	0.396 ± 0.208	-	-	-	-	-	-	-	-
Lead-210	0.1	Bq/L	-	3.24 ± 0.37	-	4.63 ± 0.74	-	-	-	-	-	-	-	-
Uranium-238	5	µg/L	-	15	10^	<5	<5^	-	-	-	-	-	-	-
Thorium-232	5	µg/L	-	75	75^	20	20^	-	-	-	-	-	-	-
Total Uranium (calculated)[1]		Bq/L	-	0.385	-	<0.1	-	-	-	-	-	-	-	-
Monocyclic Aromatic Hydrocarbons														
Benzene	5	µg/L	-	<5	-	<5	-	-	-	-	-	-	-	-
Toluene	5	µg/L	-	<5	-	<5	-	-	-	-	-	-	-	-
Ethylbenzene	5	µg/L	-	<5	-	<5	-	-	-	-	-	-	-	-
m&p-Xylene	5	µg/L	-	<5	-	<5	-	-	-	-	-	-	-	-
o-Xylene	5	µg/L	-	<5	-	<5	-	-	-	-	-	-	-	-
Styrene	5	µg/L	-	<5	-	<5	-	-	-	-	-	-	-	-
Isopropylbenzene	5	µg/L	-	<5	-	<5	-	-	-	-	-	-	-	-
n-Butylbenzene	5	µg/L	-	<5	-	<5	-	-	-	-	-	-	-	-
n-Propylbenzene	5	µg/L	-	<5	-	<5	-	-	-	-	-	-	-	-
p-Isopropyltoluene	5	µg/L	-	<5	-	<5	-	-	-	-	-	-	-	-
sec-Butylbenzene	5	µg/L	-	<5	-	<5	-	-	-	-	-	-	-	-
tert-Butylbenzene	5	µg/L	-	<5	-	<5	-	-	-	-	-	-	-	-
1,2,4-Trimethylbenzene	5	µg/L	-	<5	-	<5	-	-	-	-	-	-	-	-
1,3,5-Trimethylbenzene	5	µg/L	-	<5	-	<5	-	-	-	-	-	-	-	-
Total MAHs	-	µg/L	-	-	-	-	-	-	-	-	-	-	-	-

Legend
- Not Analysed
[1] Total Uranium = U-234 + U-235 + U-238 assuming 1ppm U-238 = 0 0124 Bq of U-238
^WRS lab duplicate result
pass - ionic balance is within control limits
* Default trigger values from ANZECC freshwater quality guidelines for 95% protection of slightly to moderately disturbed ecosystems

APPENDIX E LITERATURE REVIEW

E.1 Mt Keith Operation

The Mount Keith Water Supply Phase 1 Completion report was prepared by Australian Groundwater Consultants Pty Limited in June 1971 to determine the feasibility of obtaining a maintainable yield of15 million gallons/day from the area surrounding Mt Keith. The area has an arid continental climate in which evaporation exceeds precipitation throughout the year. The rainfall is markedly free of seasonal variations, most rainfall resulting from local convective storm cells which occur at random both temporally and spatially. The dominant characteristic of the rainfall in the area is its variability. Investigations of the Albion Downs Basin, located adjacent to the Yeelirrie site, found low salinity waters occupying over half of the saturated section of the overburden within the Albion Downs Basin. Underflow was detected to the south towards Lake Miranda and the northerly salinas.

E.2 Mt Margaret Nickel-Cobalt Project PER Report

The Mt Margaret Project is located in the north eastern Goldfields in the Murchison Region. The Northern Goldfields region is a semi-arid environment with cool winters and hot, dry summers. It generally has low topographic relief characterised by scattered low mesas and tablelands of broken duricrust (breakaways) and occasional upstanding bedrock peaks. The physiography of the region is

described as Salina land, being characterised by extensive sheet wash areas that shed runoff to salt lakes (Salinas) and strings of clay pans (playas) within broad drainage valleys. All drainages in the region are ephermeral, only flowing after heavy rainfalls. The hydrological setting is similar to that of Yeelirrie Uranium Project. Surface water management has been identified as one of the key issues in environmental management. The existing environment, potential impact and proposed management of surface water is covered in the PER.

E.3 Hydrological Study Lake Raeside

URS has conducted a hydrological study on Lake Raeside (URS, 2003), for the Deep South Gold Mine, to characterise the baseline surface hydrology and to assess the impacts of mining and dewatering activities which will discharge water to Lake Raeside. Lake Raeside is located in southeast of Lake Miranda Catchment.

Climate

Water balance is dominated by low rainfall and high evaporative demand. On average, about 6% of rainfall become runoff, <1% percolates to groundwater and the remainder evaporates from plants and soil surface. Potential evaporation is greater than rainfall in every moth of the year and totals more than ten times rainfall.

Runoff can occur throughout the year, but most runoff was predicted to occur in Feb to March. During summer (Nov to April), runoff-producing rainfall events typically result from remnant tropical cyclones that weaken and become rain-bearing troughs and depressions as they move in a southeasterly direction. Thunderstorm activity during summer can also result from southern extensions of the Inter-tropic Convergence zone.

During winter, runoff events are normally the result of rain bearing frontal systems associated with anticyclones moving from west to east. Rain from these systems tends to occur between May and August.

Rainfall and particularly runoff throughout the study area is highly variable Coefficient of variation (i.e. standard deviation divided by the average) of annual rainfall is 48%, which is more than double the variability in Perth (18%). Coefficient of variation of annual runoff is 420%, which is very high. Runoff statistics are dominated by very large runoff events that occur infrequently.

Lake Lithology and Stratigraphy

The strata of Lake Raeside consist of red-brown clay with varying amounts and sizes of gypsum crystals. The upper 1m of the clay is soft, becoming firm to stiff below. The top 0.05m contains abundant sand-sized gypsum crystals, with scattered gypsum crystals, up to 50mm long, below. The static water level is 0.1 m below ground level.

Hydraulic Conductivity

Lake Bed hydraulic conductivity was estimated by slug testing in 2.1m – 2.2m piezometers (falling head tests. The estimated hydraulic conductivity ranged from about 8 x 10-5 to 6 x 10-4, within the normal range for clay. The vertical hydraulic conductivity would be expected to be about one order of magnitude less than the horizontal component.

Infiltration Tests

Infiltration testing was carried out with 195 mm x 0.6m casing with evaporation control. Results range from 0.8 to 0.2 m/day (33 to 8 mm/hr) giving an effective average value of 3 x 10-4 m/day for horizontal hydraulic conductivity, and 3 x 10-5 m/day for vertical hydraulic conductivity.

E.4 Murrin Murrin

Dames and Moore conducted desktop surface hydrology studies for the Murrin Murrin Expansion Project CER and PER. The project area lies between lake Raeside and Lake Carey, to the north of Lake Raeside.

A catchment average volumetric runoff coefficient of 0.5 was used in flood calculations.

E.5 Mine Water Discharge to Lake Miranda

URS conducted baseline and quarterly monitoring of mine water discharge into Lake Miranda. Lake Miranda, surface area 200 km2, is centrally located in a 1,400 km2 low relief catchment. Baseline surface water sampling indicated the lake is saline with a TDS concentration of around 25,000 mg/L and a slightly basic pH. Results of sediment sample analysis indicate that Lake Miranda is a saline lake with a clay base.

The mine water discharge was a short term discharge arrangement with 1,300 ML of mine water being discharged over 7 months. On “best case” (high rainfall and free lake water flow) year it represented an estimated increase in input (to the lake) of 1% and in the “worst case” a 20% input increase (average rainfall and restricted flow).

E.6 Flood Hydrology Assessment – Sunrise Deposit

A desktop flood hydrology assessment was carried out by Dames and Moore as part of a requirement for a Notice of Intent. The document describes the surface water hydrology in the area of Sunrise Deposit and makes qualitative assessment of peak flow discharges using rainfall runoff characteristic from ARR and the Rational Method.

E.7 Flood Control around Cleo and Sunrise Mining Operations

A hydrological study was carried out by Dames and Moore, it present design discharges for drainage diversion channels. ARR and Rational Methods are used to calculate the design flows.

E.8 Hydrogeological Review of CTD Expansion and Seepage Mitigation (Sunrise Dam Gold Mine)

URS undertook a hydrogeological study of the implications of expansion of the tailing storage facility (CTD). This work involved a field program to characterize hydrogeology within the expansion footprint including infiltration testing.

E.9 Tropicana Hydrological Investigation

URS conducted a pre-feasibility stage hydrological investigation for the Tropicana Project. This was a desk top study using ARR to estimate rainfall intensities and catchment runoff coefficients and the Rational Method to estimate peak flows in the catchment. HEC RAS was then used to simulate flow in two main drainage channels in the project area to evaluate flood risk.

E.10 Drainage and Flood Management Plan, Argo Mine

URS undertook a desktop study to evaluate flood issues relating to the pit, develop conceptual designs for managing flooding and identify key issues for consideration when developing a flood management plan. Argo mine is one of a number in and around Lake Lefroy, near Kambalda, south of Kalgoorlie. General drainage direction is from east to west, most runoff enters Lake Lefroy.

E.11 Gold Mining Developments on Lake Lefroy

Dames and Moore conducted a hydrological study as part of the PER. Lake Lefroy occurs within the Lefroy palaeodrainage, a river valley incised into the Archean Yilgarn Craton during Jurassic Period, this historically drained from south west to north east. The lake bottom is flat and has a well developed halite crust. It is estimated that the lake is dry for 25% of the year and <50% of the lake becomes flooded every year with water generally not exceeding 30 cm deep. The lake water is hypersaline and neutral to weakly acid.

E.12 Proposed Additional Disposal to Lake Carey from Mine Operations

The catchments near the Wallaby Project are generally flat with rocky outcrops along the margins that act as drainage divides. Local catchments all drain to Lake Carey a large playa lake surrounded by low relief topography comprising Aeolian dunes and bedrock outcrops. Lake Carey forms regional soak for surface and groundwater.

E.13 Seepage Modelling – Water Storage Facilities on Lake Carey

URS undertook technical assessments of bunded storages on Lake Carey. These included site assessments, to characterize the hydraulic properties of the lake sediments. Site assessment included infiltration testing and slug testing of shallow hand augured piezometers.

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MRD (WA), 1975. Eastern Goldfields Flood Report Cyclone Trixie. By G.A. Knuckey, Bridge Section, Main Road Department Western Australia. February, 1975.

URS, 2000a. Addendum to Notice of Intent: Cosmos Nickel Project, Dewatering Discharge to Lake Miranda. Prepared for Sir Samuel Mines NL. Report No 46032-001-071/DK:517-F2481.2/DOC/PER. Dated 26 September 2000

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URS, 2002. Preliminary Report: Ecological Risk assessment of Hypersaline Groundwater Disposal to Lake Carey, Salt Study.. Prepared for Placer (Granny Smith) P/L. Report No 17667-110-562/532-F4660.2. Dated May 2002.

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URS, 2003b Hydrological Study, Lake Raeside. Report prepared for Sons of Gwalia. Report No. 21377-030-562/566.F5598.1 dated 14 March 2003.

URS, 2004. Drainage and Flood Managemtn Plan, Argo Mine. Prepared for Gold Fields, St Ives Gold Mine. Report No 46390-008-562. Dated 12 August 2004.

URS, 2007a Draft Report: Hydrogeological Review of CTD Expansion and Seepage Mitigation. Prepared for AngloGold Ashanti Australia P/L. Report No 42905665/498-F7165.1. Dated 7 July 2005.

URS, 2007b Tropicana Hydrological Investigation. Prepared for AngloGold Ashanti Australia P/L. Report No 42906543. Dated 22 August 2003.

Western Botanical, 2009. BHPB Yeelirrie Uranium Project Interim Impact Assessment Report. Prepared for URS Australia Pty Ltd. Report reference: WB613. Dated 19 October 2009.

Table-E-1 Yeelirrie Surface Water Phase 2 Study - Literature Review Summary Table

NOTE: unpublished data/report - cannot be quoted or referenced

Report	Climate	Infiltration	Hydraulic Conductivity	Runoff Coefficients	Water Quality	Other
Murrin Murrin PER/CER				0.5, volumetric runoff coefficient used in flood calcs for Cyclone Bobby. C10 calced at 0.122-0.184		
Mine Water Discharge to Lake Miranda					Baseline SWQ 25,000mg/L TDS, slightly basic pH	1,300 ML of mine water, discharged over 7 months represented and estimated increase in input (to the lake) of between 1% (best case) and 20% (worst case)
Tropicana Hydrological Investigation		unpublished data - cannot be referenced data requires analysis		Eolian sands; red quartz sand , froming seif dunes and sand plains = 0.0002 Colluvium; silty sands containing detrital ferruginal laterite = 0.05		
SDGM						
Flood Hydrology Assessment - Sunrise Deposit						
Flood Control Around Cleo and Sunrise Mining Operations				ARR used for Arid Interior of WA. C10=0.346L^-0.42		Appendix B is a DME report on the Effects of Cyclone Bobby on WA Mines
Hydrogeolgical Review of CTD Expansion and Seepage Mitigation (SDGM)		Alluvium ranges from 0.02 to 3.2 m3/day/m2, see Table 5 for more detail	Alluvium ranges from 0.002 to 0.8 m/day, see Table 5 for results			
St Ives/Lake Lefroy						
Drainage and Flood Management Plan, Argo Mine						
Gold Mining Developments on Lake Lefroy (PER)	Evaporation exceeds rainfall by a factor of 10			runoff estimates vary from 0.5 to 0.21	Salinities of up to 462,000 mg/L have been recorded in surface water. See notes for WQ testing results	
The Hydrology of Lake Lefroy					Lake salinity 20,000 to 25,000 µS/cm	
Lake Lefroy Discharge Evaluation 2004						
Lake Carey						
Proposed Additional Disposalto Lake Carey from Mining Operations - Wallaby						
Seepage Modelling – Water Storage Facilities on Lake Carey						
Ecological Risk Assessment of Hypersaline Groundwater Disposal to Lake Carey						
Mt Margaret Nickel-Cobalt PER						
Hydrological Study Lake Raeside		0.2-0.8 m/d	0.00008 - 0.0006	on ave 6% of rainfall becomes runoff		

APPENDIX F HYDROLOGICAL MODEL PARAMETERS AND SENSITIVITY ANALYSIS

This appendix contains the following components:

F 1 Hydrological Model Parameters

F 2 Probable Maximum Precipitation (PMP) Method Selection

F 3 Hydrological Model Sensitivity Analysis

F.1 Hydrologocal Model Parameters

F.1.1 Initial and Continuing Loss Parameters

Initial loss and continuing loss parameters were initially derived from AR&R (1987). Subsequently, there was consideration of the potential influences on these losses of catchment units and measured infiltration rates. Reconciliation of the initial and continuing loss parameters in the hydrological models within the catchment units includes:

- Initial losses vary depending on the ARI of the rainfall event. These losses peak at about a 10-year ARI and decline for higher and lower ARIs.
- AR&R (1987) initial loss parameters for the arid interior are available up to a 20-year ARI. Initial losses during 100-year ARI events are assumed equivalent to the 2-year ARI
- Continuing losses are broadly constant for all catchment units and soil types.
- Breakaways: There are no infiltration test data. Assumed losses occur between the losses derived for the Wash Plain and Calcrete catchment units.
- Wash Plain: Assumed based on initial loss and continuing loss parameters for loamy soils of the arid interior areas derived from AR&R (1987).
- Sand Plain: Initial losses derived AR&R (1987) for sandy soils in other parts of WA (mainly the Mitchell Plateau). The continuing losses were factored from the AR&R (1987) arid interior loss values by proportioning infiltration rates relative to wash plain infiltration rates. For example, sand plain infiltration rates were approximately double the wash plain rates. In order to reflect this difference, the loss values for the sand plain are about double those for the wash plain.
- Playa: There are two infiltration test data. Assumed initial losses occur at about 50% of the Calcrete, and continuing losses at about 60% of the Calcrete values.
- Calcrete: Initial and continuing losses are from AR&R (1987), with subsequent factoring based on infiltration rate comparisons with the other catchment units.

Table F-1 summarises the interpreted initial and continuing loss for the catchment units.

Table F-1 Initial and Continuing Losses for Each Catchment Unit

Catchment Unit	Average Field Infiltration Rate (mm/hour)	Continuing Loss (mm/hour)	Initial Losses (mm)			
			ARI (Years)			
			1	5	20	100
Breakaway	NA	2.0	10.0	20.0	25.0	10.0
Wash Plain	230	3.0[1]	20[1]	31[1]	38[1]	20[1]
Sand Plain	440	5.7[2]	50[2]	70[2]	75[2]	50[2]
Playa	7	0.80	4.50	6.5	8.5	4.3
Calcrete	100	1.3[3]	8.7[3]	13.5[3]	16.5[3]	8.7[3]
Notes						
1: AR&R (1987) Arid Interior, Loamy Soils.						
2: Assumed from AR&R, Western Australia sandy soils.						
3: Factored from AR&R (1987).						

The average field infiltration rates are significantly higher than the loss rates suggested by AR&R. The assumed AR&R loss rates will result in higher runoff volumes and peak flows but are considered a reasonable worst case scenario. The field infiltration rates have been used to assign loss values proportionately where appropriate. The initial and continuing losses also partly take into consideration the presence of cryptograms (as discusses in Section 3.2) in terms of likely reducing the infiltration rates and increasing runoff.

Composite initial and continuing losses for the discrete sub-catchment areas were derived from an area-weighted mean of the losses by catchment unit shown in Table F-2. Proportions of the sand plain catchment unit in each sub-catchment are a predominant influence on the composite initial and continuing losses.

Outlined in Table F-2 are the composite initial and continuing losses derived for the Yeelirrie Playa and Lake Miranda Catchment models. Within the Yeelirrie Playa Catchment, the A4, B, C and D sub-catchments (Figure 5-6) have been discretised into upper-catchment and valley-floor domains. The composite losses for the valley-floor domains were calculated from the estimated losses from the playa and calcrete catchment units (Table F-2). These losses are typically comparatively low in proportion to the total losses for other catchment unit areas.

F.1.2 Roughness Coefficients (Manning's n) Parameters

Roughness coefficients have been assigned to each catchment unit as shown in Table F-3. The density, height and morphology of vegetation in the overland flow areas and drainage channels influence the roughness coefficient, which in turn affect runoff coefficients and flow velocities. Flood plain roughness coefficients were utilised for the playa and associated channels, assuming winter values for medium to dense vegetation cover, as considered appropriate for catchments predominantly characterised by sheet flow and with few channels.

For each sub-catchment, a composite roughness coefficient was determined based on the area-weighted distributions of each catchment unit. Interpreted composite roughness coefficients range from 0.07 to 0.08. These values reflect the sand plain dominance in the catchment. The valley floor sub-catchments all have composite roughness coefficients of 0.04. Roughness coefficients assigned to the main flow path channels take into account the vegetated nature of the main flow path and the increased roughness associated with debris, rills and other obstructions to flow along the valley floor.

Table F-2 Composite Initial and Continuing Loss Parameters in XPrafts Models

Sub catchment	Area (km²)	Proportional Area (%)					Continuing Loss (mm/hour)	Initial Loss (mm) ARI (Years)			
		Break-away	Wash Plain	Sand Plain	Calcrete	Playa		1	5	20	100+
Yeelirrie Playa Catchment Model											
A1	867	19	17	63	1		4.5	36.8	53.1	61.6	
A2	925	21	23	56	0.4		4.3	34.6	50.5	58.7	
A3	383	23	22	51	3		4.1	32.7	47.9	55.9	
A4_U[1]	247	18	21	55	7		4.2	33.9	49.2	54.5	
A4_VF[2]	26				56	44	0.8	6.8	10.4	12.9	
B_U[1]	459	6	10	84	1		5.2	44.4	62.8	68.0	
B_VF[2]	7				53	47	0.8	6.7	10.2	12.7	
C_U[1]	196	32	40	29	0		3.5	25.4	38.7	44.5	
C_VF[2]	26				50	50	0.7	6.6	10.0	12.5	
D_U[1]	1,418	17	33	51	0		4.2	33.6	49.0	54.6	
D_VF[2]	87				28	72	0.5	5.7	8.4	10.7	
Lake Miranda Catchment Model											
A1	867	19	17	63	1		4.5			58.5	36.8
A2	925	21	23	56	0.4		4.3			55.9	34.6
A3	383	23	22	51	3		4.1			53.3	32.7
A4	274	16	19	49	16		3.9			50.8	31.5
B	466	6	10	82	2		5.1			67.3	43.9
C	222	28	41	25	6		3.0			38.1	21.8
D	1505	16	32	48	4		3.7			48.1	29.3
E	664	21	22	52	5		4.1			53.5	33.0
F	2257	14	43	40	4		3.7			47.9	28.4

Notes:
1: Upper sub-catchment areas
2: Valley Floor sub-catchment areas.

Table F-3 Manning's n Values by Catchment Unit

Catchment unit	Manning's *n*
Breakaway	0.045
Wash Plain	0.11
Sand plain	0.07
Playa	0.02
Central Calcrete	0.045

F.1.3 Catchment and Channel Slopes

Catchment mean slopes were assessed using Arc-GIS, and found to vary between 0.49% and 0.73%.

Channels within the sub-catchments (not main flow path channels) share the mean slope values of the sub-catchment.

Valley-floor catchment domains share the same slope as the main flow path channels.

F.1.4 Channel Lengths and Widths

Channel flow paths occur in the upper reaches of the catchments, predominantly in the breakaway catchment unit). The channels progressively lose definition once flow reaches the wash plain and sand plain catchment units and sheet flow predominates. Use of very wide channels enabled representation of these flow characteristics and conveyance of flow downstream.

Sub-catchment channel lengths were derived by measuring the main flow path length of the catchment, from the upper reaches to the outflow. Assumed channel widths in each sub-catchment are based on the mean width of the local sand plain catchment unit.

F.1.5 Main Flow Path Channels

The main channel flow path has comparatively low relief, with slopes in the range 0.02 to 0.06%.

F.2 Probable Maximum Precipitation (PMP) Method

The methodology used to determine the Probable Maximum Precipitation (PMP) for the Yeelirrie Project area is the Generalised Tropical Storm Method (GTSMR, 2005). The PMP has been defined by the World Meteorological Organisation (WMO) as “the greatest depth of precipitation for a given duration, meteorologically possible for a given storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends”.

The PMP events have been determined using the GTSMR methodology for the Yeelirrie Playa catchment area (3,140 km2) and the Lake Miranda catchment (7,660 km2). The work sheets for the PMP method selection for these catchment areas are shown overleaf.

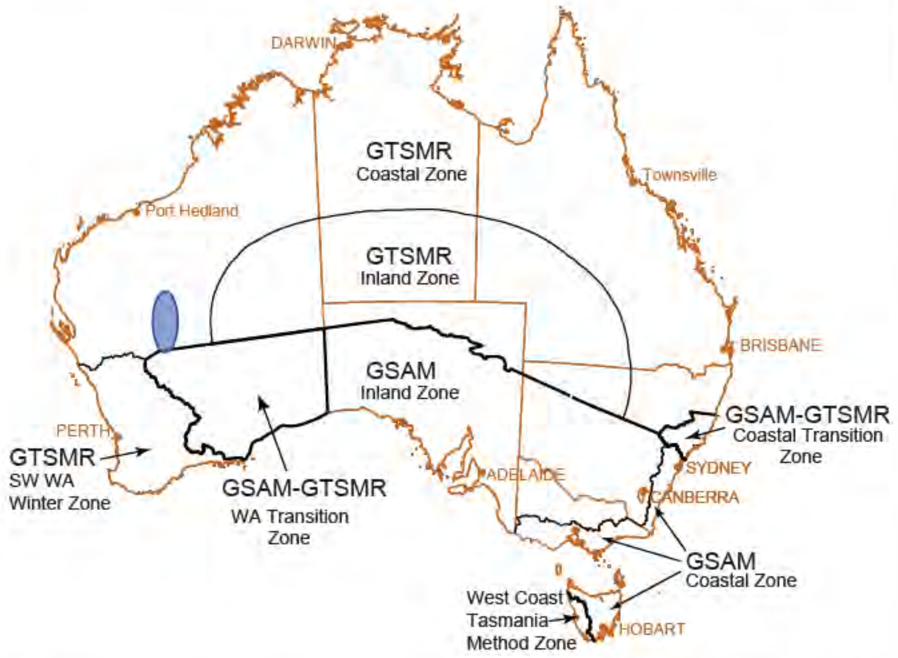
Reference:

Bureau of Meteorology (2005), Guidebook to the Estimation of Probable Maximum Precipitation: Generalised Tropical Storm Method, Hydrometeorological Advisory Service, November 2003, Reissued September 2005.

WORKSHEET 1: PMP Method Selection

Catchment Name...Yeelirrie Mine Catchment Area 3140 km^2

LONG DURATION PMP



NB This diagram can is also available as a shapefile: [CD-ROM drive]:pmp_zones\zones_all.shp
or it can be printed on A3 paper from [CD-ROM drive]:documents\method_zones.pdf

CIRCLE THE ZONE IN WHICH THE CATCHMENT IS LOCATED:

GTSMR (Coastal)	GTSMR (Inland)
GTSMR (Coastal & SWWA)	Coastal Transition - GTSMR Coastal - GSAM Coastal
GSAM (Coastal)	WA Transition - GTSMR Coastal - GSAM Inland
GSAM (Inland)	WCTas

SHORT DURATION PMP (GSDM)

Is the catchment less than 1000km²? — NO → Short duration PMP estimates can **not** be calculated for the catchment

YES ↓

Is the catchment less than 500km² and south of 30°S?

NO → PMP estimates for up to 6 hours can be calculated using the **GSDM** for this catchment

YES → PMP estimates for up to 6 hours can be calculated using the **GSDM** for this catchment and can include **winter** estimates

PMP METHOD SUMMARY

Fill in the table below with the PMP method/s applicable to the catchment, referring to Table 1.1 for any additional information needed. NB: for the Transition zones, write separate entries for GTSMR and GSAM.

METHOD	ZONE	SEASON	DURATIONS
eg GTSMR	*Coastal*	*Annual*	*24-120 hours*
eg GSDM	*6 hours*	*Annual*	*1-6 hours*
GTSMR	Coastal	Summer	24 - 120 hours

WHAT NEXT?

GTSMR:	Calculate the PMP estimates for the catchment following the procedures in this guidebook
GSDM:	Calculate the PMP estimates for up to 6 hours following the GSDM (Bureau of Meteorology, 2003) guidebook (http://www.bom.gov.au/hydro/has/gsdm_document.shtml)
GSAM:	Contact the Hydrometeorological Advisory Service, Bureau of Meteorology
WCTas:	Contact the Hydrometeorological Advisory Service, Bureau of Meteorology

WORKSHEET 2: Generalised Tropical Storm Method Revised (GTSMR)

LOCATION INFORMATION

Catchment Name: Yeelirrie Mine   State: Western Australia

GTSMR zone(s) Coastal

CATCHMENT FACTORS

Topographical Adjustment Factor	**TAF** = 1.08	(1.0 – 2.0)
Decay Amplitude Factor	**DAF** = 0.75	(0.7 – 1.0)
Annual Moisture Adjustment Factor	MAF_a = $EPW_{catchment}$/120.00	
Extreme Precipitable Water ($EPW_{catchment}$) = 85.1	$\mathbf{MAF_a}$ = 0.709	(0.4 – 1.1)
Winter Moisture Adjustment Factor (where applicable)	MAF_w = $EPW_{catchment\_winter}$/82.30	
Winter EPW ($EPW_{catchment\_winter}$) = …………	$\mathbf{MAF_w}$ = …………………	(0.4 – 1.1)

PMP VALUES (mm) - Annual

Duration (hours)	Initial Depth (D_a)	PMP Estimate $=D_a$xTAFxDAFxMAF_a	Preliminary PMP Estimate (nearest 10mm)	Final PMP Estimate (from envelope)
1	Where applicable, calculate GSDM (Bureau of Meteorology, 2003) depths			
2				
3				
4				
5				
6				
12	(no preliminary estimates available)			
24	1131	650	650	650
36	1316	756	750	750
48	1491	856	860	860
72	1798	1033	1030	1030
96	2050	1178	1180	1180
120	2169	1246	1250	1250

PMP VALUES (mm) – Winter (where applicable)

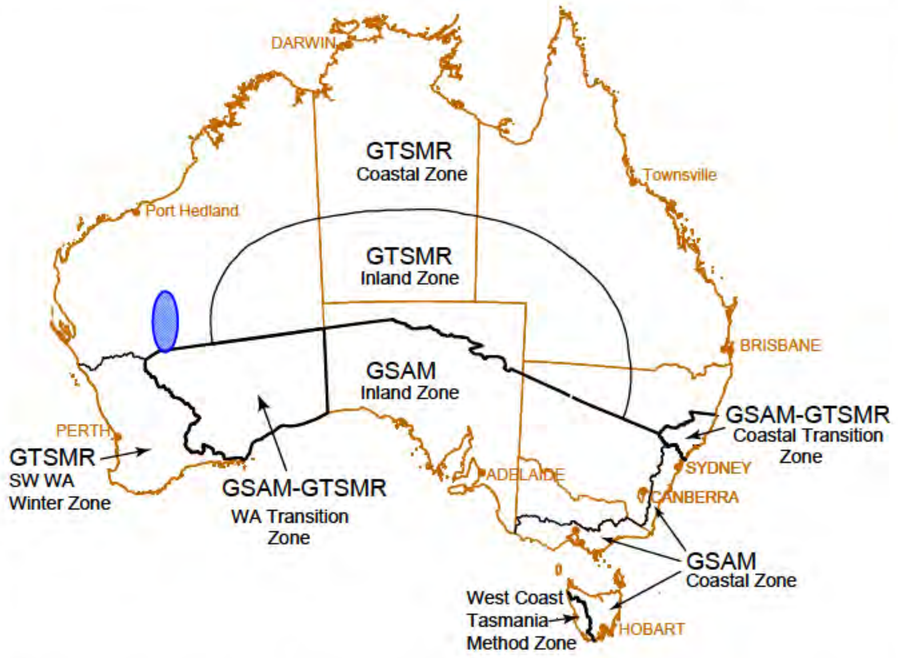
Duration (hours)	Initial Depth (D_w)	PMP Estimate $=D_w$xTAFxDAFxMAF_w	Preliminary PMP Estimate (nearest 10mm)	Final PMP Estimate (from envelope)
1	Where applicable, calculate GSDM (Bureau of Meteorology, 2003) depths			
2				
3				
4				
5				
6				
12	(no preliminary estimates available)			
24				
36				
48				
72				
96				

Prepared by: JB/LW   Date: 08/03/2010   Checked by: BE   Date 08/03/2010

WORKSHEET 1: PMP Method Selection

Catchment Name...Lake Miranda | Catchment Area 7660 km²

LONG DURATION PMP



NB This diagram can is also available as a shapefile: [CD-ROM drive]:pmp_zones\zones_all.shp
or it can be printed on A3 paper from [CD-ROM drive]:documents\method_zones.pdf

CIRCLE THE ZONE IN WHICH THE CATCHMENT IS LOCATED:

GTSMR (Coastal)	GTSMR (Inland)
GTSMR (Coastal & SWWA)	Coastal Transition - GTSMR Coastal - GSAM Coastal
GSAM (Coastal)	WA Transition - GTSMR Coastal - GSAM Inland
GSAM (Inland)	WCTas

SHORT DURATION PMP (GSDM)

Is the catchment less than 1000km²? — NO → Short duration PMP estimates can **not** be calculated for the catchment

YES ↓

Is the catchment less than 500km² and south of 30°S?

- NO → PMP estimates for up to 6 hours can be calculated using the **GSDM** for this catchment
- YES → PMP estimates for up to 6 hours can be calculated using the **GSDM** for this catchment and can include **winter** estimates

PMP METHOD SUMMARY

Fill in the table below with the PMP method/s applicable to the catchment, referring to Table 1.1 for any additional information needed. NB: for the Transition zones, write separate entries for GTSMR and GSAM.

METHOD	ZONE	SEASON	DURATIONS
eg GTSMR	*Coastal*	*Annual*	*24-120 hours*
eg GSDM	*6 hours*	*Annual*	*1-6 hours*
GTSMR	Coastal	Summer	24 - 120 hours

WHAT NEXT?

GTSMR: Calculate the PMP estimates for the catchment following the procedures in this guidebook

GSDM: Calculate the PMP estimates for up to 6 hours following the GSDM (Bureau of Meteorology, 2003) guidebook (http://www.bom.gov.au/hydro/has/gsdm_document.shtml)

GSAM: Contact the Hydrometeorological Advisory Service, Bureau of Meteorology

WCTas: Contact the Hydrometeorological Advisory Service, Bureau of Meteorology

WORKSHEET 2: Generalised Tropical Storm Method Revised (GTSMR)

LOCATION INFORMATION

Catchment Name: Yeelirrie — State: Western Australia

GTSMR zone(s) Coastal

CATCHMENT FACTORS

Topographical Adjustment Factor	**TAF** = 1.08	(1.0 – 2.0)
Decay Amplitude Factor	**DAF** = 0.75	(0.7 – 1.0)
Annual Moisture Adjustment Factor	MAF_a = $EPW_{catchment}$/120.00	
Extreme Precipitable Water ($EPW_{catchment}$) = 85.1	**MAF_a** = 0.709	(0.4 – 1.1)
Winter Moisture Adjustment Factor (where applicable)	MAF_w = $EPW_{catchment\_winter}$/82.30	
Winter EPW ($EPW_{catchment\_winter}$) = …………	**MAF_w** = ………………..	(0.4 – 1.1)

PMP VALUES (mm) - Annual

Duration (hours)	Initial Depth (D_a)	PMP Estimate $=D_a x TAF x DAF x MAF_a$	Preliminary PMP Estimate (nearest 10mm)	Final PMP Estimate (from envelope)
1	Where applicable, calculate GSDM (Bureau of Meteorology, 2003) depths			
2				
3				
4				
5				
6				
12	(no preliminary estimates available)			
24	971	558	560	560
36	1138	654	650	650
48	1295	744	740	740
72	1572	903	900	900
96	1792	1029	1030	1030
120	1882	1081	1080	1080

PMP VALUES (mm) – Winter (where applicable)

Duration (hours)	Initial Depth (D_w)	PMP Estimate $=D_w x TAF x DAF x MAF_w$	Preliminary PMP Estimate (nearest 10mm)	Final PMP Estimate (from envelope)
1	Where applicable, calculate GSDM (Bureau of Meteorology, 2003) depths			
2				
3				
4				
5				
6				
12	(no preliminary estimates available)			
24				
36				
48				
72				
96				

Prepared by: JB/LW Date: 08/03/2010 Checked by: BE Date 08/03/2010

F.3 Sensitivity Analysis

The parameterisation of the rainfall-runoff hydrological models hosts uncertainty. The uncertainty is common in arid interior catchments, particularly given the nature of the local climate, length of the available rainfall records and absence of gauged stream flow in the Lake Miranda Catchment or nearby catchments.

The sensitivity analyses have been undertaken for the 1:20, 1:100 and 1:1,000 year ARI rainfall events as smaller events only generate localised runoff. A range of sensitivity analyses on selected parameters has been undertaken. These analyses enable the gauging of the potential influences of uncertainty on the simulated baseline catchment responses to rainfall in the models. The parameters used in the sensitivity analyses include:

- Rainfall intensity.
- Initial losses.
- Continuing losses.
- Roughness coefficients.
- Climate Change.

F.3.1 Rainfall Intensity

Rainfall intensity is a key input into the hydrological models. Of all sensitivity parameters, the change in rainfall intensity has the largest influence on peak flows and particularly during higher frequency ARI events. Substantial increases in simulated peak flow increases may occur under scenarios of increased rainfall intensity.

Table F-4 shows the potential change in peak flows for various ARI events where the simulated rainfall intensity is varied. A 20% increase in rainfall intensity causes a 548% increase in the peak flow generated by a 20-year ARI event. The same increase in rainfall intensity also causes a 131% increase in the 100-year peak flow.

A reduction of 20% in rainfall intensity results in no flow from a 20-year ARI event and causes a 71% decrease in the peak flow from a 100-year ARI event.

Table F-4 Change in Peak Flows - Sensitivity Analyses for Rainfall Intensity

ARI/Event (Years)	Change in Peak Flows (%)			
	Sensitivity Analyses Change in Rainfall Intensity			
	-20%	-10%	+10%	+20%
20	-100	-91	272	548
100	-71	-39	58	131
1,000	-51	-27	33	67

This shows that the simulated peak flows are sensitive to the rainfall intensity for a design rainfall event, particularly for events less than 100 year ARI events. The sensitivity for these smaller events is relatively high because the changes in peak discharges for such events are from a relative small base. For the 20 year event the increase of rainfall intensity of 20% resulted in an increase of peak flow from 2.3 m^3/s to 14.6 m^3/s, which represents the stated increase of 548%.

This sensitivity does indicate the importance of assuming reasonable rainfall intensity rates. The use of the AR&R derived IFD curve and rainfall intensities is therefore a reasonable assumption.

F.3.2 Initial Loss

The sand plain and wash plain catchment units are predominant within the Lake Miranda Catchment and therefore strongly influence the aggregate initial loss values adopted for each sub-catchment. Sensitivity analyses on the initial loss values for sand plain and wash plain catchment units enable an understanding of changes in peak flows of runoff linked to variations of initial loss values.

Table F-5 shows the potential ranges in simulated peak flows generated on the wash plain and sand plain catchment units within Zone 1 by selected ARI rainfall events with initial loss varied by 20%.

Table F-5 Change in Peak Flows - Sensitivity Analyses on Initial Loss Values

ARI/Event (Years)	Change in Simulated Peak Flows (%)			
	Sensitivity Analyses Change in Initial Losses			
	-20%	-10%	+10%	+20%
Wash Plain Catchment unit in Zone 1				
20	68%	29%	-28%	-60%
100	3%	2%	-2%	-3%
1,000	0	0	0	-1%
Sand Plain Catchment unit in Zone 1				
20	80%	36%	-38%	-62%
100	34%	16%	-11%	-22%
1,000	5%	2%	-3%	-6%

It is evident that a -20% change in initial loss values causes the largest relative change in peak flow for the sensitivity runs that were completed. The predictive results indicate that reduced rates of initial losses may cause significant percentage increases of peak flow for 20-year or higher frequency events. Although the highest relative change in sand plain peak flow is 80% for a 20-year ARI event (Table F-6), the simulated peak flow only increases from 2.25 to 4.04 m^3/s. This relative change diminishes as the ARI increases. On the wash plain, a 68% increase in the simulated peak flow is 1.52 m^3/s.

A 3% increase in peak flows on the wash plain catchment unit for a 100-year ARI event causes an increase in peak flow from 5.4 to 5.6 m^3/s.

F.3.3 Continuing Loss

Sensitivity analyses of peak flows on both sand plain and wash plain in Zone 1 for selected ARI rainfall events where continuing losses were by varied by 20% are shown in Table F-6.

The highest frequency ARI events show the highest percentage change in peak flow. However, there is considerable change in peak flows for a 1,000-year ARI event, with a 20% decrease in continuing losses producing a 20% increase in peak flow on the sand plain catchment unit. Continuing loss parameters for the sand plain have greater impact than on the wash plain catchment unit. Further, variations to continuing losses have stronger influences than initial losses on peak flows during extreme events.

Table F-6 Change in Peak Flows -Sensitivity Analyses on Continuing Loss Values

ARI/Event (Years)	Change in Simulated Peak Flows (%) Sensitivity Analyses Change in Continuing Losses			
	-20%	-10%	+10%	+20%
Wash Plain Catchment unit in Zone 1				
20	31%	14%	-15%	-31%
100	5%	2%	-2%	-5%
1,000	3%	1%	-2%	-3%
Sand Plain Catchment unit in Zone 1				
20	36%	17%	-17%	-36%
100	34%	14%	-10%	-20%
1,000	20%	9%	-8%	-16%

F.3.4 Roughness

Variations in roughness alter the velocity at which surface water flows over a catchment unit and therefore change the shape and the peak value of the hydrograph. The interpreted baseline parameterisation of Manning's n and the simulated range of sensitivity analyses are summarised in Table F-7.

Table F-7 Manning's n Values used in Sensitivity Analyses

Catchment unit	Manning's n		
	Lower Value	Baseline Parameterisation	Higher Value
Sand Plain	0.045 (-36%)	0.07	0.11 (+57%)
Wash Plain	0.07 (-36%)	0.11	0.16 (+45%)

Table F-8 shows the simulated change in peak flows for selected ARI rainfall events resulting from variation of Manning's n values on the wash plain and sand plain catchment units. For both catchment units, the variations in roughness appear to predominantly influence the 20- and 100-year ARI events.

Table F-8 Sensitivity of Simulated Peak Flows to change in variations in Manning's n Values

ARI/Event (Years)	Change in Simulated Peak Flows (%)	
	Lower Value Scenario	Higher Value Scenario
Wash Plain Catchment unit		
20	37%	-25%
100	11%	-17%
1,000	7%	-13%
Sand Plain Catchment unit		
20	16%	-14%
100	20%	-27%
1,000	19%	-27%

F.3.5 Climate Change

Australia is expected to experience increased frequency in spells of dry days and an increase in intensity of rainfall (*Climate Change in Australia:* PMSEIC, 2007). Uncertainty analyses were utilized to determine how potential changes in rainfall intensities caused by climate change may influence simulated peak flows within Zone 1 of the Lake Miranda Catchment. Table F-9 shows the potential changes in peak flows for selected ARI rainfall events due to climate change variations in rainfall intensity. The simulated changes to rainfall intensity (for the same ARI event under changed climatic conditions) are based on median changes to rainfall intensity in *Climate Change in Australia* (PMSEIC, 2007).

The results of the analyses suggest that changes in rainfall intensity (ranging from -1% to plus 4%) would result in changes to the simulated peak flows, ranging from a lowest value of -10% for a 20-year ARI event, to a highest value of 44% for a 20-year ARI event, respectively.

Table F-9 Change in Peak Flows - Uncertainty Analyses on Climate Change Rainfall Intensities

ARI/Event (Years)	Percentage Change in Rainfall Intensity			
	-1%	2%	3%	4%
	Change in Simulated Peak Flows (%)			
20	-10%	16%	26%	44%
100	-4%	5%	10%	14%
1,000	-3%	3%	6%	10%

APPENDIX G HYDRAULIC MODEL PARAMETERS AND SENSITIVITY ANALYSIS

G.1 INTRODUCTION

The hydrological and hydraulic models developed for this study are largely uncalibrated due to the general lack of site-specific hydrological data. In the absence of calibration, sensitivity analyses have been done on critical model parameters to assess the robustness of the models and the sensitivity of the simulated results to variations in selected model parameters.

The sensitivity analysis for the hydraulic models focussed on two key input parameters: flood hydrology (peak flow hydrographs) and the surface roughness. The sensitivity simulations were undertaken for the following models:

Regional Lake Miranda hydraulic model (200 m grid): upstream, mid-point and downstream

Yeelirrie Playa hydraulic model (100 m grid): upstream, mid-point and downstream

In-bund Mine site hydraulic model (10 m grid)

The sensitivity analyses incorporated variations in peak flow rate and roughness parameters for a range of rainfall events as shown in Table 6-7.

Table-G-1 Hydraulic Model - Regional Lake Miranda and Yeelirrie Playa Sensitivity Analysis

Sensitivity Analysis		Rainfall Event (year ARI)				
		1	5	20	100	1000
Input Parameters		Simulated Percentage Change in Peak Discharge				
Peak Discharge	+20%	√	√	√	√	√
	-20%	√	√	√	√	√
Roughness	+30%	√	√	√	√	√
	-30%	√	√	√	√	√

G.2 SENSITIVITY ANALYSIS – REGIONAL LAKE MIRANDA HYDRAULIC MODEL

The sensitivity analyses for the Lake Miranda Model involved assessment of the resulting changes against expected outcomes in the models, and also allow cross checking that the separate models are generating similar behaviour. The sensitivity analyses have been undertaken at the following locations:

Upstream at the Minesite: Here the sensitivity of the simulated peak flow to variations in input hydrographs and surface roughness have been assessed. Hydraulic characteristics such as flood depths, flow velocities and hydroperiods have been checked to ensure stability and integrity of the model at the minesite.

Mid-point of the model: Simulated flood characteristics at this point have been used to verify the integrity of the model downstream of the minesite.

Downstream point at Lake Miranda: Analysis of simulated flood volumes conveyed through the model, to ensure water mass balance validation and verification of downstream boundary condition of the model, which ensure correct functionality.

The following presents the results of the sensitivity analyses for the regional Lake Miranda hydraulic model.

G.2.1 Sensitivity of the Peak Discharge at the Proposed Mine Site

The simulated response to variations in input hydrographs in the upstream catchment of peak discharge rates at this location is shown in Table 6-8.

Table-G-2 Sensitivity Analysis - Regional Lake Miranda Model: Peak Discharge at Minesite

Sensitivity Analysis		Rainfall Event (year ARI)				
		1	5	20	100	1,000
Input Parameter		Upstream Location:				
Peak Discharge	+20%	No Flow			25%	22%
	-20%	No Flow			-30%	-23%

Note: Sensitivity analysis of the 1, 5 and 20 year ARI events could not be undertaken from a total model perspective as flows from these events do not produce enough volume to create flow in the Regional Lake Miranda models

The results of the sensitivity analysis for the upstream locations show:

An increase of 20% in peak discharges for the input hydrographs upstream of the minesite results in a relatively higher (greater than 20%) simulated peak discharge at the minesite for both the 100 and 1,000 year events. This is disproportionate increase is a direct result of increase in flow velocity, changing the time of concentration to this point in the catchment which causes a disproportionate increase the peak discharge at the minesite. For the 1:1,000 year ARI event, the change in flow velocity is relatively smaller and therefore a smaller change occurs.

Similarly a 20% decrease in peak discharges for the input hydrographs upstream of the minesite results in a lower (less than -20%) simulated peak discharge rate at the minesite for both events.

Sensitivity of simulated results is related to the volume of water in the model. For a 1:100 yr ARI event, with less water in the model, the sensitivity of the simulated results to variations in input parameters is greater than for a 1:1,000 year ARI event, with more water in the model.

G.2.2 Sensitivity of the Peak Discharges to Surface Roughness

The sensitivity of peak discharges to variations (+30% and -30%) in surface roughness in the Lake Miranda Model is shown in Table 6-9. The results are shown at three locations in the model for comparison.

An increase in the surface roughness of the model increases the resistance to surface water flows which decreases the simulated peak flow rate and the shape of the hydrograph. Conversely, a decrease in surface roughness decreases the resistance in the model and consequently can increases peak flow rates.

Table-G-3 Sensitivity Analysis – Regional Lake Miranda Model: Surface Roughness

Point of Investigation	Surface Roughness (+30%)		Surface Roughness (-30%)	
	100 yr ARI	1000 yr ARI	100 yr ARI	1,000 yr ARI
	Simulated Percentage Change in Peak Discharge			
Upstream	-8%	-8%	7%	9%
Mid-point	-11%	12%	14%	13%
Downstream	-13%	-13%	15%	16%

The results of the sensitivity analysis for the upstream, mid-way and downstream locations show:

For an increase in roughness the model exhibits behaviour, which is directly reflective of its topography and the resultant depths of flow.

At the upstream point of the model the peak discharge is reduced by a relatively small percentage (as lag begins to occur). This progresses as the flows pass through the model. The results appear to have a comparative rate of change for both the 1:100 year and 1:1,000 year ARI models.

For a decrease in roughness the model exhibits a similarly gradual comparative increase in the peak discharge through the model. Peaks increase as velocities are increased with the reduction in resistance.

G.2.3 Overall assessment of the Regional Lake Miranda Model:

The simulated results are sensitive to changes in model parameters.

The rate of sensitivity is related to the catchment size and associated flow and runoff volume.

The model returns simulation results consistent with the analysed changes in input parameters.

The assumption of realistic parameters is therefore providing reliable simulation results.

The model is uncalibrated and with a rather coarse overall resolution (large grid size). Therefore a comparison of results of different simulations is more reliable than the absolute values of a particular simulation result.

G.3 SENSITIVITY ANALYSIS –YEELIRRIE PLAYA HYDRAULIC MODEL

The sensitivity analyses for the Yeelirrie Playa Model involved assessment of the resulting changes against expected outcomes in the models, and also allow cross checking that the separate models are generating similar behaviour. The sensitivity analyses have been focussed on the location upstream at the minesite where the sensitivity of the simulated peak flow to variations in input hydrographs and surface roughness have been assessed. Hydraulic characteristics such as flood depths, flow velocities and hydroperiods have been checked to ensure stability and integrity of the model at the Mine site.

G.3.1 Sensitivity of the Peak Discharge at the Minesite

The simulated response to variations in input hydrographs in the upstream catchment of peak discharge rates at this location is shown in Table 6-10.

Table-G-4 Sensitivity Analysis - Yeelirrie Playa Model: Peak Discharge

Sensitivity Analysis		Rainfall Event (year ARI)				
		1	5	20	100	1000
Input Parameters		Upstream Location:				
Peak Discharge	+20%	No Flow			28%	21%
	-20%	No Flow			-26%	-22%

Note: Sensitivity analysis of the 1, 5 and 20 year ARI events could not be undertaken from a total model perspective as flows from these events do not produce enough volume to create flow in the Yeelirrie Playa models.

The results of the sensitivity analysis for the upstream locations show:

- An increase of 20% in peak discharges for the input hydrographs upstream of the minesite results in a relatively higher (greater than 20%) simulated peak discharge at the minesite for both the 100 and 1000 year events. This disproportionate increase is a direct result of an increase in flow velocity and changing the time of concentration to this point in the catchment, which causes a disproportionate increase in the peak discharge at the minesite. For the 1:1,000 year ARI event, the change in flow velocity is relatively smaller and therefore a smaller change occurs.
- Similarly a 20% decrease in peak discharges for the input hydrographs upstream of the minesite results in a lower (less than -20%) simulated peak discharge rate at the minesite for both events.
- Sensitivity of simulated results is related to the volume of water in the model. For a 1:100 yr ARI event, with less water in the model, the sensitivity of the simulated results to

variations in input parameters is greater than for a 1:1,000 yr ARI event, with more water in the model.

G.3.2 Sensitivity of the Peak Discharges to Surface Roughness

The sensitivity of baseline peak discharges to variations (+30% and -30%) in surface roughness in the Yeelirrie Playa Model is shown in Table 6-11. The results are shown at three locations in the model for comparison.

An increase in the surface roughness of the model increases the resistance to surface water flows, which decreases the simulated peak flow rate and the shape of the hydrograph. Conversely, a decrease in surface roughness decreases the resistance in the model and, consequently, can increase peak flow rates.

Table-G-5 Sensitivity Analysis – Yeelirrie Playa Model: Surface Roughness

Catchment	Surface Roughness (+30%)		Surface Roughness (-30%)	
	100 yr ARI	1,000 yr ARI	100 yr ARI	1000 yr ARI
	Simulated Percentage Change in Peak Discharge			
Upstream	-6%	-6%	6%	7%
Mid-point	-9%	-9%	11%	11%
Downstream	-12%	-11%	13%	12%

The results of the sensitivity analysis for the upstream, mid-way and downstream locations show:

For an increase in roughness the model exhibits behaviour, which is directly reflective of its topography and the resultant depths of flow.

At the upstream point of the model the peak discharge is reduced by a relatively small percentage (as lag begins to occur). This progresses as the flows pass through the model. The results appear to have a comparative rate of change for both the 1:100 year and 1:1,000 year ARI models.

For a decrease in roughness the model exhibits a similarly gradual comparative increase in the peak discharge through the model. Peaks increase as velocities are increased with the reduction in resistance.

G.3.3 Overall assessment of the Yeelirrie Playa Model:

The simulated results are sensitive to changes in model parameters.

The rate of sensitivity is related to the catchment size and associated flow and runoff volume.

The model returns simulation results consistent with the analysed changes in input parameters.

The assumption of realistic parameters is therefore providing reliable simulation results.

The model is uncalibrated and with a rather coarse overall resolution (large grid size). Therefore a comparison of results of different simulations is more reliable than the absolute values of a particular simulation result.

APPENDIX H INTERACTION BETWEEN SURFACE WATER AND GROUNDWATER

H.1 Groundwater Recharge Responses Observed in Monitoring Bores at Yeelirrie, 2011-2015

H.2 Recharge Responses at the Water Table Based on 72-hour ARIs

H.3 Recharge Responses at Below the Water Table Based on 72-hour ARIs

H.4 Groundwater Recharge Responses for Bores Screened Across the Water Table Based on the Hydrogeological Unit

H.5 Groundwater Recharge Responses for Bores Screened Below the Water Table Based on the Hydrogeological Unit

H.6 Recharge Response and Rate Summaries

H.6.1 Rainfall - Water Table Responses Observed at Yeelirrie 2010 to 2015

H.6.2 Rainfall - Sub-water Table Responses Observed at Yeelirrie 2010 to 2015

H.6.3. Groundwater Recharge Estimates

H.6.4. Estimated Recharge Flux and Percentage of Rainfall per ARI

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Appendix H.6.1. Rainfall - Water Table Responses Observed at Yeelirrie 2010 to 2015

Interval	Hydrogeological Unit	ARI	Minimum (mm)	Maximum (mm)	Average (mm)	Sample Number
Water Table	Calcrete	1 : 1	0.04	0.09	0.07	2
		1 : 1 to 1 : 5	0.10	0.10	0.10	1
		1 : 1 to 1 : 10	0.06	0.06	0.06	1
		1 : 20	0.05	0.05	0.05	1
		All	0.04	0.1	0.07	5
	Transitional Calcrete	1 : 1	0.01	0.05	0.03	6
		1 : 1 to 1 : 5	0.00	0.08	0.02	5
		1 : 1 to 1 : 10	0.01	0.06	0.04	3
		1 : 20	0.03	0.06	0.05	3
		All	0.00	0.08	0.03	17
	Calcrete Formations	**All**	**0.00**	**0.10**	**0.05**	**22**
	Clayey alluvium	1 : 1	0.00	0.00	0.00	1
		1 : 1 to 1 : 5	0.17	0.17	0.17	1
		1 : 1 to 1 : 10	0.00	0.00	-	0
		1 : 20	0.00	0.00	-	0
		All	0.00	0.17	0.09	2
	Hardpan / Sandy alluvium	1 : 1	0.00	0.00	0.00	1
		1 : 1 to 1 : 5	0.07	0.07	0.07	1
		1 : 1 to 1 : 10	0.42	0.42	0.42	1
		1 : 20	0.00	0.00	-	0
		All	0.00	0.42	0.16	3
	Sandstone alluvium	1 : 1	0.00	0.16	0.04	5
		1 : 1 to 1 : 5	0.01	0.09	0.04	10
		1 : 1 to 1 : 10	0.00	0.39	0.09	6
		1 : 20	0.04	0.86	0.28	4
		All	0.00	0.86	0.08	28
	Alluvium Formations	**All**	**0.00**	**0.86**	**0.11**	**33**
	Clayey (weathered) Bedrock	1 : 1	0.03	0.06	0.05	2
		1 : 1 to 1 : 5	0.03	0.03	0.03	1
		1 : 1 to 1 : 10	0.02	0.02	0.02	1
		1 : 20	0.00	0.00	-	0
		All	0.02	0.06	0.04	4
	Clayey (weathered) Bedrock	**All**	**0.02**	**0.06**	**0.04**	**4**
	All Water Table Units (Alluvial - 5.5mbgl to 9.8mbgl; Weathered Bedrock 32mbgl)*	1 : 1	0.00	0.16	0.04	20
		1 : 1 to 1 : 5	0.00	0.17	0.04	19
		1 : 1 to 1 : 10	0.00	0.42	0.10	12
		1 : 20	0.03	0.86	0.16	8
		All	**0.00**	**0.86**	**0.08**	**59**

Notes:

* - Depths apply to the centres of the screened intervals

Recharge responses from YYHC0059A and YYHC0059B from March 2015 not included in the above summary

Appendix H.6.2. Rainfall - Sub-water Table Responses Observed at Yeelirrie 2010 to 2015

Interval	Hydrogeological Unit	ARI	Minimum (mm)	Maximum (mm)	Average (mm)	Sample Number
Sub-Water Table	Carbonated clay-quartz	1 : 1	0.03	0.03	0.03	1
		1 : 1 to 1 : 5	0.06	0.06	0.06	1
		1 : 1 to 1 : 10	0.04	0.04	0.04	1
		1 : 20	0.00	0.00	-	0
		All	0.03	0.06	0.04	3
	Ferricrete	1 : 1	0.02	0.02	0.02	1
		1 : 1 to 1 : 5	0.01	0.01	0.01	1
		1 : 1 to 1 : 10	0.00	0.00	0.00	1
		1 : 20	0.00	0.00	-	0
		All	0.00	0.02	0.01	3
	Calcrete & Ferricrete Formations	**All**	**0.00**	**0.06**	**0.03**	**6**
	Clayey alluvium	1 : 1	0.06	0.06	0.06	1
		1 : 1 to 1 : 5	0.18	0.18	0.18	1
		1 : 1 to 1 : 10	0.00	0.00	-	0
		1 : 20	0.00	0.00	-	0
		All	0.06	0.18	0.12	2
	Sandy & Sandstone alluvium	1 : 1	0.00	0.04	0.02	4
		1 : 1 to 1 : 5	0.01	0.10	0.05	4
		1 : 1 to 1 : 10	0.02	0.35	0.13	3
		1 : 20	0.05	0.05	0.05	1
		All	0.00	0.35	0.06	12
	Alluvium Formations	**All**	**0.00**	**0.35**	**0.09**	**14**
	All Sub-Water Table Units (18.0mbgl to 32.0mbgl)*	1 : 1	0.00	0.06	0.02	7
		1 : 1 to 1 : 5	0.01	0.18	0.06	7
		1 : 1 to 1 : 10	0.00	0.35	0.09	5
		1 : 20	0.05	0.05	0.05	1
		All	**0.00**	**0.35**	**0.06**	**20**

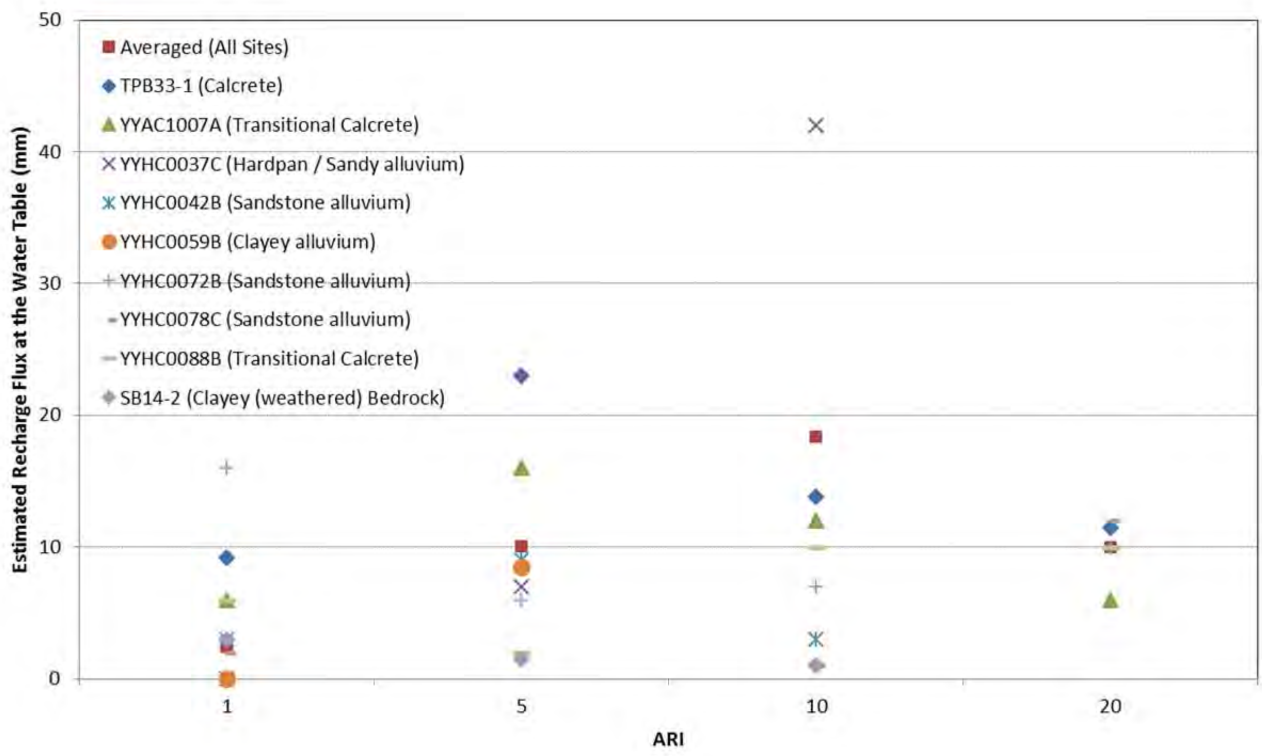
Notes:

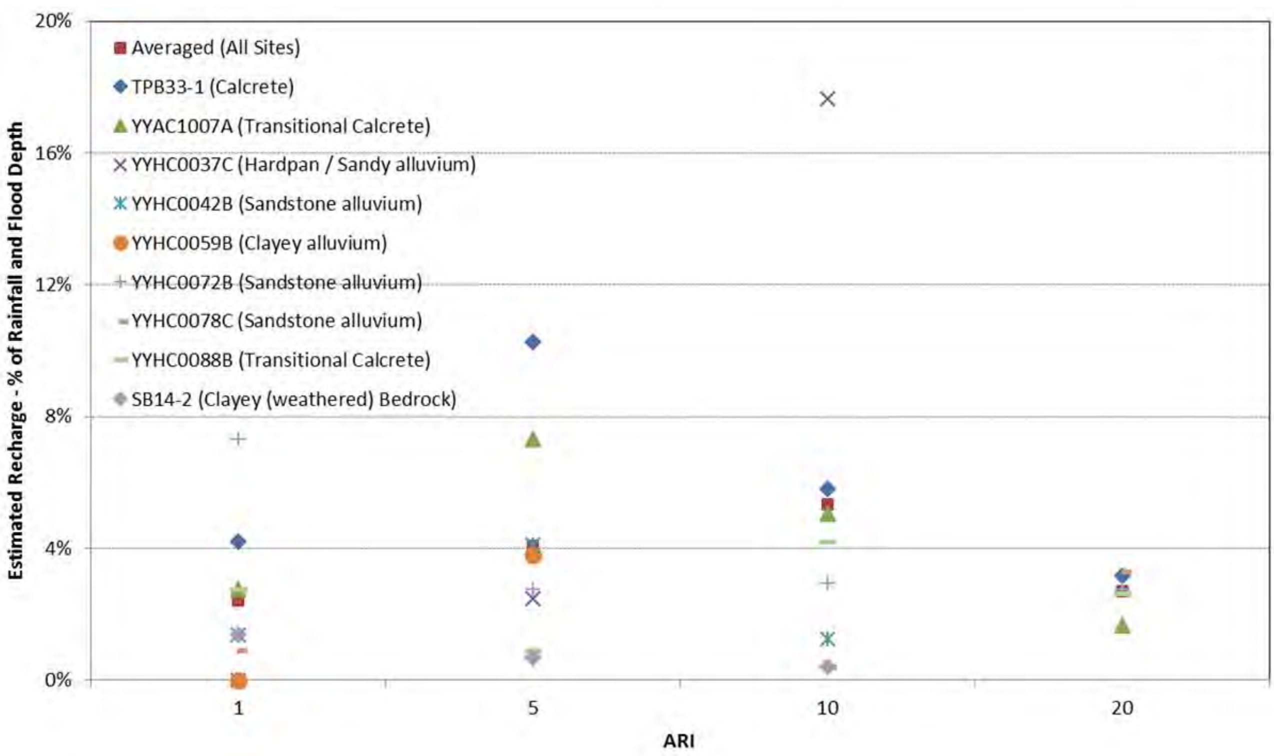
* - Depths apply to the centres of the screened intervals

Recharge responses from YYHC0059A and YYHC0059B from March 2015 not included in the above summary

Appendix H.6.3. Groundwater Recharge Estimates

Water Table Hydrogeological Unit	ARI	Regional-based Recharge (Event as % of Actual Annual Rainfall)	Example Bore Number	Event Date for Example Bore	Site-based Recharge (Event as % of Actual Annual Rainfall)	Applicable Recharge Year	Site-based Recharge (Full Years Events and Annual Rainfall)	Estimated Recharge (% of Flood Event Depth and Actual Annual Rainfall)
Calcrete	1 : 1	7.0%	TPB33-1	5-17 May 2014	4.2%	2014	14.5%	4.2%
	1 : 1 to 1 : 5	10.3%	TPB33-1	23 Jan 2014	10.3%			10.3%
	1 : 1 to 1 : 10	5.8%	TPB33-1	2-7 Mar 2015	5.8%	2015	5.8%	5.8%
	1 : 20	3.2%	TPB33-1	18 Feb 2011	3.2%	2011	3.2%	3.2%
	All	6.6%			5.9%		7.8%	5.9%
Transitional Calcrete	1 : 1	2.5%	YYHC0088B	5-17 May 2014	2.7%	2014	7.6%	2.7%
			YYAC1007A	5-17 May 2014	2.7%			2.7%
	1 : 1 to 1 : 5	1.8%	YYHC0088B	23 Jan 2014	0.9%			0.9%
			YYAC1007A	23 Jan 2014	7.3%			7.3%
	1 : 1 to 1 : 10	3.4%	YYHC0088B	2-7 Mar 2015	4.2%	2015	4.6%	4.2%
			YYAC1007A	2-7 Mar 2015	5.0%			5.0%
	1 : 20	2.6%	YYHC0088B	18 Feb 2011	2.7%	2011	2.2%	2.6%
			YYAC1007A	18 Feb 2011	1.6%			1.6%
	All	2.6%			3.4%		4.8%	3.4%
Calcrete Formations (average)	**All**	**4.6%**			**4.6%**		**6.3%**	**4.2%**
Clayey alluvium	1 : 1	0.0%	YYHC0059B	5-17 May 2014	0.0%	2014	3.8%	0.0%
	1 : 1 to 1 : 5	3.8%	YYHC0059B	23 Jan 2014	3.8%			3.8%
	All	1.9%			1.9%		3.8%	1.9%
Hardpan / Sandy alluvium	1 : 1	0.0%	YYHC0037C	5-17 May 2014	0.0%	2014	3.1%	0.0%
	1 : 1 to 1 : 5	3.1%	YYHC0037C	23 Jan 2014	3.1%			2.5%
	1 : 1 to 1 : 10	17.6%	YYHC0037C	2-7 Mar 2015	17.6%	2015	17.6%	17.6%
	All	6.9%			6.9%		10.4%	6.7%
Sandstone alluvium	1 : 1	1.9%	YYHC0078C	5-17 May 2014	0.9%	2014	7.3%	0.9%
			YYHC0042B	5-17 May 2014	1.4%			1.4%
			YYHC0072B	5-17 May 2014	7.3%			7.3%
	1 : 1 to 1 : 5	1.7%	YYHC0078C	23 Jan 2014	0.9%			0.9%
			YYHC0042B	23 Jan 2014	4.1%			4.1%
			YYHC0072B	23 Jan 2014	2.7%			2.7%
	1 : 1 to 1 : 10	3.7%	YYHC0078C	2-7 Mar 2015	0.4%	2015	1.5%	0.4%
			YYHC0042B	2-7 Mar 2015	1.3%			1.3%
			YYHC0072B	2-7 Mar 2015	2.9%			2.9%
	1 : 20	7.7%	YYHC0078C	18 Feb 2011	3.3%	2011	3.0%	3.3%
			YYHC0072B	18 Feb 2011	2.7%			2.7%
	All	3.7%			2.6%		4.0%	2.6%
Alluvium Formations (average)	**All**	**4.2%**			**3.8%**		**6.0%**	**3.3%**
Clayey (weathered) Bedrock	1 : 1	1.1%	SB14-2	5-17 May 2014	1.4%	2014	2.1%	1.4%
	1 : 1 to 1 : 5	0.7%	SB14-2	23 Jan 2014	0.7%			0.7%
	1 : 1 to 1 : 10	0.4%	SB14-2	2-7 Mar 2015	0.4%	2015	0.4%	0.4%
	All	0.7%			0.8%		1.2%	0.8%
Clayey (weathered) Bedrock	**All**	**0.7%**			**0.8%**		**1.2%**	**0.8%**
All Water Table Units (Alluvial - 5.5mbgl to 9.8mbgl; Weathered Bedrock 32mbgl)*	1 : 1	2.3%			1.6%	2011	2.8%	2.4%
	1 : 1 to 1 : 5	4.1%			3.8%	2014	7.3%	4.1%
	1 : 1 to 1 : 10	7.6%			7.0%	2015	7.4%	5.3%
	1 : 20	4.5%			3.1%			2.7%
	All	**4.4%**			**3.8%**		**6.2%**	**3.6%**





Appendix H.6.4. Estimated Recharge Flux and Percentage of Rainfall per ARI

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APPENDIX I SURFACE WATER MANAGEMENT PLAN

I.1 Context and Purpose

The proposed Yeelirrie development would require water of different volumes and quality for drinking, concrete batching (during the construction phase), ore processing and dust suppression (see Project Description for details). While extensive water reuse and recycling systems would minimise the water requirement.

Safe mining requires that the pits be dewatered, which would result in groundwater drawdowns in the vicinity of the proposed development.

The proposed development also has the potential to change the surface water flow regime in the Yeelirrie valley as a result of construction of a surface water diversion bund surrounding the mining and processing operation. There is also potential to affect surface water quality and quantity through the retention, treatment and disposal of treated stormwater from within the bunded area.

Cameco would conduct all activities carried out as part of the proposed Yeelirrie development in an environmentally responsible and sustainable manner, in accordance with its Corporate Charter and Sustainable Development Policy. This would be achieved by developing, implementing and maintaining management systems for sustainable development that also drive continual improvement.

This draft Water Management Plan would form part of the Environmental Management System (EMS) for the proposed development. The primary purpose of the plan would be to outline the detailed activities required to ensure achievement of EPA objectives relating to surface water and groundwater.

I.2 Scope

The draft Surface Water Management Plan describes the measures that would be implemented to achieve the desired surface water and groundwater management outcomes presented in the PER and reproduced below. It would apply to all water-related facilities within the project area.

In addition to the management measures, the plan also describes the processes for monitoring and responding to relevant performance indicators.

Legislation and other guidance relevant to this management plan include:

- Guide to EIA Environmental Principles, Factors and Objectives (EPA 2009)
- Intergovernmental Agreement on a National Water Initiative (COAG 2004)
- Rights in Water and Irrigation Act 1914
- National Water Initiative Objectives (National Water Commission 2009)
- Mining and Mineral Processing Water Quality Guidelines (WRC 2000a)
- Environmental Water Provisions Policy for Western Australia (WRC 2000b)
- Pilbara Water in Mining Guideline (DoW 2009).

This document, like all draft management plans for the proposed Yeelirrie Project, is a 'live document', and as such will be revised and updated as necessary.

I.3 Training, Roles and Responsibilities

Following approval of the proposal, and as part of the development of the EMS, a training, roles and responsibilities matrix would be developed and included in this section of the plan. The matrix would detail those Cameco employees and contractors who have specific responsibilities under the plan, and those responsibilities, including training requirements, would be clearly defined and communicated.

I.4 Values, Objectives and Performance Indicators

The PER for the proposed Yeelirrie development provides the management objectives for the various environmental values related to the project. The WA Environmental Protection Authority (EPA) objectives for water quantity and quality are:

- water quantity: to maintain the quantity of water so that existing and potential environmental values, including ecosystem maintenance, are protected (EPA).
- water quality: to ensure that the project does not adversely affect the environment or health, welfare and amenity of people and nearby land uses by meeting statutory requirements and acceptable standards (EPA).

The PER also describes the framework for managing impacts to these values and achieving a net environmental benefit through the application of environmental offsets.

The detailed objectives and performance indicators relevant to the management of surface and groundwater, as described in the PER, are presented in Table 4.1

Table 4.1: Objectives and performance indicators

Objective	Performance indicator
Ensure changes to the surface water flow and water quality regime outside the project footprint during operation does not cause any significant impact on the environmental values of the Yeelirrie valley.	No loss of environmental values as a result of changes to the surface water flow and quality regime.
Ensure the post-closure surface water flow and water quality regime in the Yeelirrie valley does not vary significantly from the pre-development condition.	Land surface is returned to the pre-development condition.
Ensure changes to the groundwater flow and water quality regime outside the project footprint during operation does not cause any significant impact on the environmental values of the Yeelirrie valley or on third-party groundwater users.	No unexpected loss of environmental values as a result of changes to the groundwater flow and quality regime. No loss of water availability to third-party groundwater users.
Ensure the post-closure groundwater flow and water quality regime in the Yeelirrie valley do not vary significantly from the pre-development condition.	Recovery of groundwater levels to pre-development condition. No significant seepage of solutes from the TSF such that groundwater quality at the lease boundary exceeds Department of Water criteria specified in WRC 2000b.

I.5 Management

The PER for the proposed Yeelirrie development assessed the potential impacts associated with surface water and groundwater, defined management measures to avoid or reduce these impacts and categorised the residual impacts. This section collates the management measures presented within the PER.

These measures are considered separately for surface water and groundwater in the following sections of this plan

I.5.1 Strategy

Surface water

The strategy for management of surface water is based on construction of a diversion bund around the mine and processing plant components of the proposed development to protect them from inundation by surface water flows in the Yeelirrie valley. The bund would be constructed high enough to provide protection from 1:1,000-year average return interval (ARI) flows in the valley. It would also be constructed to provide containment of up to 1:1,000-year ARI stormwater events within the bund under most operating circumstances.

The bund would be progressively developed as the mining operation expanded along the valley, as described in the PER. The intention of this is to minimise the impact of the bund on surface water flows during the operational phase. The bund would be removed as part of the decommissioning phase and the land surface returned to close to its pre-development condition to ensure the pre-mining surface water flow regime was effectively re-established.

Water quality changes as a result of stormwater contacting stockpiles and other disturbed land surfaces within the bund would be managed by retaining the water within the bund and using it within the proposed development. The proposed in-bund stormwater management system is presented in Figures 6.2 and 3. This water would be discharged to the environment outside the bund only if water demand within the bund was insufficient to use the stored stormwater, and only if its quality could meet specified criteria designed to eliminate any significant impact on the surface water resource or its dependent ecosystems.

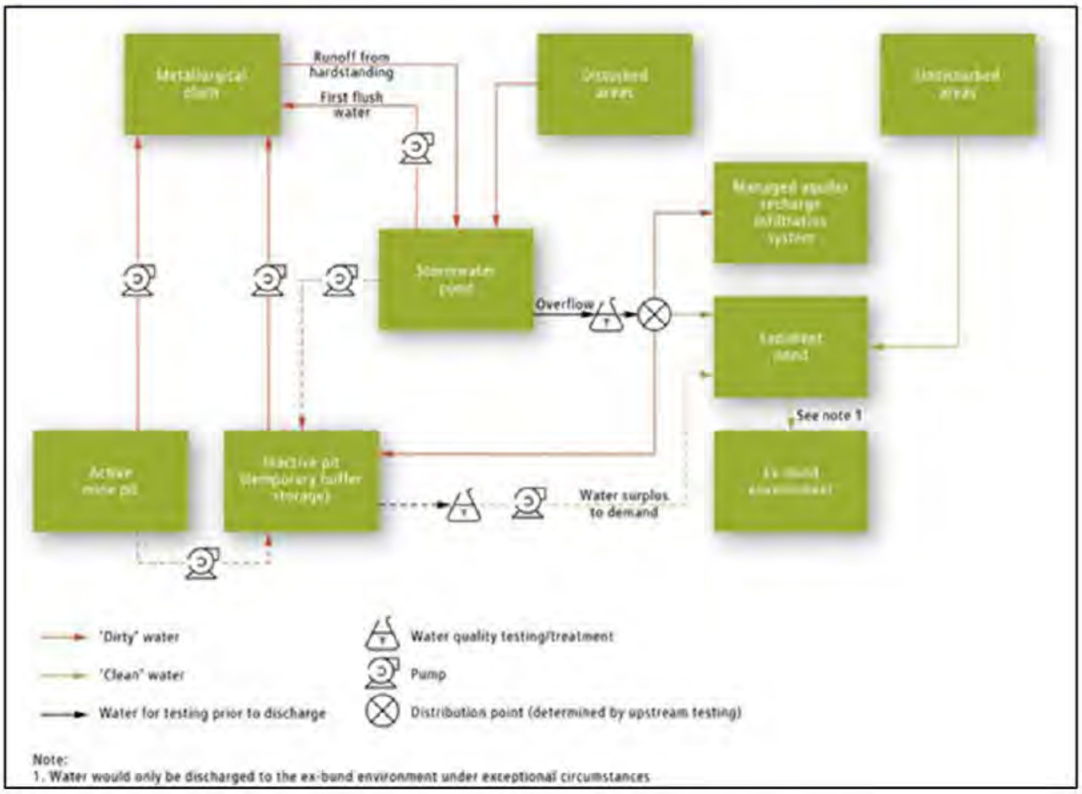

Figure 5.1: Proposed in-bund stormwater management system

Groundwater

The strategy for management of groundwater quantity is based on minimising abstractions through development and implementation of a water use efficiency plan to minimise demands.

The use of an efficient pit dewatering system and careful location of any supplementary supply wellfields away from areas supporting groundwater-dependent ecosystems (GDEs) would provide the primary means of minimising environmental impacts of any necessary groundwater abstractions. Any impacts on third-party users would be managed by making good their water supplies in consultation with the Department of Water (DoW), in accordance with any Rights in Water and Irrigation Act 1914 licences.

Unexpected groundwater impacts from the water supply wellfields would be managed by adjustment of the distribution of pumping rates between the various wellfields, and between the individual wells within the wellfields. No significant impact on groundwater quality is expected to occur as a consequence of groundwater abstractions.

Potential groundwater quality impacts from tailings seepage would be managed through containment of solutes in the tailings storage facilities (TSFs) with low-permeability walls, base and capping, with the objective of reducing potential seepage to insignificant levels.

I.5.2 Management Measures

The management measures proposed for activities associated with the proposed development in the PER are presented in Table 5.1 and Table 5.2 for surface water and groundwater respectively.

Table 5.1: Surface water management measures

Issue	Management measure
Prevention of contact of surface water flows in the Yeelirrie valley with disturbed areas and stockpiles within the proposed development	▪ A surface water diversion bund would be constructed around the proposed development to keep floodwaters out. The bund would be constructed to contain an up to 1:1000-year average return interval (ARI) flow event. ▪ The outer bund surface would be constructed with benign overburden material from mine pits. ▪ Perimeter bunds would be constructed around the individual mine pits high enough to prevent flows of magnitude greater than 1:5-year ARI entering the voids.
Minimising the proposed development impeding Yeelirrie valley surface water flows	▪ The surface water diversion bund would be progressively constructed to protect only those areas to be developed in accordance with the mine plan, in order to limit the time the final bund structure was in place and to limit its impact on surface water flow. ▪ Surface water diversion channels would be constructed to divert flows around the proposed development to minimise the impediment to flow. ▪ Surface water diversion channels would be progressively constructed to match progressive development of the bund.
Management of potential erosion and sedimentation	▪ The water diversion bund's outer surface would be protected from erosion with engineered armouring (rock rip rap or similar). ▪ Sediment retention basins would be constructed at the eastern ends of the surface water diversion channels to minimise increase in sedimentation in the valley downstream of the proposed development.
Linear infrastructure impediments to flow	▪ All above-surface linear infrastructure (such as roads and access tracks) would be constructed with profiles close to the pre-existing surface levels to prevent impacts on sheet surface water flow. ▪ Any drainage lines crossed by linear infrastructure with the potential to impede surface water flow would be constructed with culverts or other cross-drainage structures and downstream sediment traps. Any such culverts would be designed to withstand up to a 1:20-year ARI flow event.
Management of in-bund stormwater	▪ Stormwater ponds would be constructed progressively as the mine developed, with sufficient capacity to store up to a 1:1000-year ARI flood event within the bund as it became larger. ▪ Water collected from undisturbed areas within the bund would be directed to a sediment pond before water quality sampling and subsequent on-site reuse or, in exceptional circumstances, treatment (if required) and discharge into the Yeelirrie valley (see Discharge of in-bund surface water into the ex-bund environment, below) ▪ All first-flush water from disturbed areas would be directed to ponds close to the processing plant as this water would potentially have higher levels of solutes and would be preferred for use in processing. ▪ Water collected from disturbed areas would be treated for reuse in the processing plant or for later dust suppression as required. ▪ Water in excess of stormwater pond capacity would be directed to inactive mine pit(s) for temporary storage. ▪ Stormwater captured within the bund would be managed in accordance with the process shown in Figure 5.1.
Use of in-bund stormwater to supplement water supply	▪ Stormwater generated within the bund would, where practicable, be used as a preferred supplement for water supplies provided from pit dewatering to meet demand within the proposed development. This water would be used in preference to groundwater from the dedicated wellfields.

Issue	Management measure
Discharge of in-bund surface water into the ex-bund environment	▪ Where the water stored within the bund exceeded the volume that could be used on-site, disposed of through aquifer reinjection, or stored elsewhere on-site and evaporated, it may be tested, treated (if required) and discharged into the external environment. However, excess water may only be discharged to the external environment in the following circumstances: – If water was flowing outside the bund, the discharge water must not exceed the quality criteria presented in DoW 2000a. – If there was little or no flow outside the bund, the discharge water must meet either of the following, whichever had the higher values: o stock water quality criteria as defined by ANZECC/ARMCANZ) 2000 o baseline water quality measured upstream of the proposed development o water quality criteria presented in DoW 2000a.
Post-closure	▪ All infrastructure associated with the proposed development would be removed and the land surface rehabilitated in accordance with the Rehabilitation and Closure Plan. The land surface over the pit area is expected to be up to ▪ several metres higher than the pre-mining surface level. This would help ensure that most surface flows did not erode the TSF capping and minimise the potential for infiltration into the TSF cells. ▪ The shape of the surface overlying the TSF would be engineered to encourage sediment deposition from surface water flows, rather than erosion.

Table 5.2: Groundwater management measures

Issue	Management measure
Water demands and water conservation	▪ Water supply demands within the proposed development would be minimised through the application of best available practicable water conservation technologies, primarily focused on recycling and minimisation of waste discharges. ▪ Extensive water reuse and recycling systems would be developed for the proposed development to minimise the demand for raw water from the wellfields, as described in Chapter 3, Project Description. ▪ The proposed development would be designed to minimise lawn areas and low-water-use lawn would be planted. ▪ All landscape gardens would contain native species found in the Yeelirrie valley and would be free of exotic or non-indigenous species. ▪ Tap aerators, AAA-rated toilets and showerheads would be installed at all facilities within the proposed development. ▪ The water use efficiency of all relevant processes and processing equipment in the processing plant would be considered before purchase. ▪ Flow meters would be installed on all main water conduits from wellfields, and within the mine site and accommodation village, to help detect leaks early.
Groundwater abstraction	▪ Groundwater abstraction would be managed to meet the conditions attached to any groundwater well licence(s) issued by the Department of Water under the *Rights in Water and Irrigation Act 1914* in association with the proposed development.
Avoidance of impacts on groundwater-dependent ecosystems (GDEs) from changes in watertable levels	▪ Water supply wellfields would be located and abstractions managed to minimise impacts on GDEs (areas of significant vegetation, flora, and terrestrial and subterranean fauna habitat). ▪ Water supply demands would be met by all other available sources rather than by using groundwater from the wellfields. ▪ Unexpected groundwater impacts on GDEs from the wellfields would be eliminated by adjusting the distribution of pumping rates between the various wellfields, and between the individual wells within the wellfields.
Limiting dewatering impacts on water levels	▪ Appropriate groundwater level control infrastructure would be installed at the western end of the proposed development to prevent propagation of the dewatering drawdown zone into a primary GDE zone (see Chapter 3, Project Description). ▪ Drains and sumps would be used as a preferred alternative to spearpoint dewatering systems to minimise dewatering abstractions and resulting drawdowns. Drains would be constructed to the minimum depth below pit floor level to effect the required level of dewatering. ▪ Dewatering product water surplus to demand would be reinjected into the west of the mine pit, within the development footprint, for subsequent abstraction by dewatering (when the pits extended into the area) and use in the project.

Issue	Management measure
Limiting groundwater quality impacts during operation (water storage ponds and stockpiles)	▪ All water storage ponds with potential to leak contaminated water would be located within the drawdown zone to be created by the pit dewatering operations to enable any seepages to be recovered. ▪ All water storage ponds with potential to leak contaminated water would be removed during decommissioning and the land surface reinstated to the pre-mining condition. Persistence of the dewatering drawdown zone is expected to eliminate the potential for migration of such seepages beyond the site. Infiltration of rainfall through mineralised material in stockpiles would be managed through shaping the stockpile profile to prevent water ponding on the surface, and covering exposed stockpile surfaces with a hydromulch. ▪ Flat surfaces on the stockpiles would be eliminated to encourage stormwater to run off rather than infiltrate.
Limiting groundwater quality impacts during operation (TSF)	▪ All TSF design data would be confirmed by additional laboratory and scale testing throughout the detailed design phase. ▪ TSF walls and capping would be constructed of the lowest-permeability material available on-site to minimise seepage of solutes and infiltration of rainfall. ▪ Before deposition of tailings, each TSF cell would be prepared by ensuring there were no defects in the clay floor materials, and the embankment foundations would be constructed down to the low-permeability materials making up the TSF cell floor. ▪ The drainage dewatering system would be maintained until decommissioning to ensure recovery of all potential seepage, and to allow assessment of the efficacy of the tailings containment and development of alternative management measures, if required. ▪ Initial trialling in the early cells may show that the very low permeability of the consolidated and dewatered tailings may reduce seepage to the extent that the under-drains did not collect any leachate, in which case they need not continue to be used in later cells. ▪ Implement tailings management as detailed in the PER.
Minimising post-closure groundwater level impacts	▪ All above-ground groundwater abstraction infrastructure would be removed during the decommissioning phase and groundwater levels allowed to recover. ▪ Perimeter drains would be backfilled with high-permeability overburden material to offset any potential effect of the TSF impeding post-closure groundwater flow along the Yeelirrie valley. ▪ The TSF and the backfilled perimeter drains would be collectively covered with overburden (designed to provide a barrier to limit water infiltration and radon emanation and create erosion resistance); followed by a topsoil layer for revegetation purposes.
Minimising post-closure groundwater quality impacts	▪ Tailings management would be implemented, with respect to management of tailings, construction of TSF embankments and capping to the extent that they relate to water management. ▪ The surface of the TSF capping would be shaped to shed water rather than allow rainfall infiltration. ▪ The topsoil layer would be revegetated. ▪ The rehabilitated pit area would have an elevated surface profile to minimise opportunity for surface flows to inundate the area and cause erosion, or water infiltration to the TSF. ▪ The final landforms would have a 1 to 2 m fall to the north and south that resembled the original landforms of the calcrete mound to shed surface water to perimeter watercourses. ▪ The shape of the surface overlying the TSF would be engineered to encourage sediment deposition from surface water flows, rather than erosion.

I.6 Management of Risks

This section discusses key risk events that may compromise the progress towards achieving the objectives of this management plan. To reduce the likelihood and adverse outcomes of such events, appropriate preventative and response measures would be developed, as described below. The overall approach to management of risk events would be based on the application of an adaptive management method as described in Section 6.1.

I.6.1 Adaptive management

Management measures as described in Section 5.2 have been identified to help achieve the water management objectives. The potential impacts of the proposed development have been avoided and minimised as far as possible through the water resource investigations, modelling, surface and groundwater management infrastructure planning. However, while the environmental assessment has been based on extensive best-practice investigation and assessment technologies, the complexity of the water resource systems and associated environmental features has contributed to some residual uncertainties associated with the assessment of impacts and potential effectiveness of several of the proposed mitigation measures. The key uncertainties relate to quantitative understanding of the sensitivities of vegetation, flora and subterranean fauna to changes in water level and quality (understanding the water dependencies of the relevant ecosystems) potential water modelling inaccuracies.

Many of these have been identified in the management of risks. To enable the proposed development to proceed on the basis of the assessment as presented, it is proposed to apply an adaptive management approach to address these uncertainties as risks. This approach would be based on responding to information provided through implementation of a hydrological/hydrogeological and biological monitoring program and response plan, as described below.

If monitoring indicated that unexpected and significant impacts were likely, Cameco, in consultation with the regulatory agencies, would take appropriate contingency action within an adaptive management framework. Key elements of this approach are:

- Management objectives and performance measures would be regularly revisited and, where necessary, revised in agreement with the regulatory agencies.
- System model(s) would be used to explain responses to management actions and to help identify gaps and the limits of scientific and other knowledge.
- The range of possible response choices would be developed and evaluated in terms of the extent to which each choice would be likely to achieve the management objectives, and the extent to which it would generate new information or foreclose future choices.
- Monitoring would focus on significant and detectable indicators of progress toward achieving management objectives. Monitoring of control areas, where possible, would also help distinguish between natural perturbations and perturbations caused by the proposed development.

Mechanism(s) for incorporating learning into future decisions.

The proposed approach to adaptive management of the proposed development would ensure that the potential benefits of the proposal would be realised, and the ecological systems dependent on the water resources of the Yeelirrie valley would be protected in accordance with EPA objectives.

Table 6.1 and Table 6.2 present the proposed monitoring and preventative and/or contingency options to manage surface water and groundwater risks respectively.

I.6.2 Monitoring and management of risks

Table 6.1: Surface water risks

Risk	Monitoring	Preventative and/or contingency options
Erosion of TSF cap due to high rainfall event.	▪ Monitor performance of TSF capping in response to rainfall events progressively during the project life.	▪ Covering design with finished height up to 3 m above pre-mining surface, and over 2 m thickness of capping. ▪ Covering to be constructed with depositional rather than erosional characteristics. ▪ Revegetating to improve erosion resistance. ▪ Rectifying any erosion experienced during operation and modifying cap design and subsequent cap construction accordingly.
Topsoil viability unable to achieve completion criteria	▪ Availability of topsoil.	▪ Investigating and implementing potential alternative topsoil sources.
Exposure of mineralised material to surface water flows during operation.	▪ Surface water diversion bund design and construction. ▪ In-bund stormwater quality before any ex-bund discharge.	▪ Designing and constructing bund with benign material on outside surface, and engineered erosion protection. ▪ Directing in-bund stormwater flows to stormwater pond storages and water used within the processing plant.
Erosion of surface water diversion bund from passing flows.	▪ Surveillance of bund condition.	▪ Installing sediment traps downstream of surface water diversion channels. ▪ Reinstating any damaged bund surfaces, with redesign of erosion protection engineering if necessary.
Overtopping or failure of surface water diversion bund due to flood in excess of 1:1,000-year design flood.	▪ Flood heights in the Yeelirrie valley adjacent to the bund wall.	▪ 1:1,000-year ARI flood protection design is highly conservative for a 22-year project life. ▪ Valley flows in excess of the design flood are expected to mask any impacts due to the large flow volumes and solute loads compared to those that potentially may be released into those flows from the proposed development.
Inundation of ex-bund areas greater in area or duration than predicted.	▪ Flood heights, extents and duration in areas around the bund.	▪ Harvesting of water stored outside the bund for use within the proposed development if possible, to reduce inundated volumes. ▪ Effect expected to be similar to that of a lower-frequency (higher-magnitude) flood and impacts on environmental values would be similar and within the range potentially experienced under pre-mining conditions.

Hydrocarbon or chemical spills.	▪ Ongoing operator vigilance.	▪ Storage facilities, pipe and bunding design and construction would comply with all relevant regulations under the *Dangerous Goods Act 2004* (Dangerous Goods Safety [Storage and Handling of Non-explosives] Regulations 2007) and Australian Standard 1940-2004 (Storage and Handling of Flammable and Combustible Liquids) to prevent any spillage into the surrounding environment. ▪ Spill response measures and equipment would be available on-site to ensure the risk of contamination was negligible. ▪ Any areas where hydrocarbons or chemicals were to be transferred between storage facilities (tanker to fixed tanks) would be sealed surfaces with appropriate bunding and drainage with hydrocarbon traps to eliminate the potential for spills to enter the environment. ▪ The Site Incident Response Plan would be implemented in the event of a spill.
Higher than predicted dust impacts at sensitive receptors (gnamma (water) holes) as consequence of incorrect air quality modelling.	▪ Testing of waterholes in association with traditional owners.	▪ Dust management processes and procedures would be modified to reduce dust migration from site.

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Table 6.2: Groundwater risks

Risk	Monitoring	Preventative and/or contingency options
Excessive drawdowns resulting in unacceptable adverse impacts on third-party users (water quantity or quality).	▪ Groundwater levels over Yeelirrie catchment. ▪ Groundwater levels and quality in third party wells.	▪ Locating and configuring wellfields to minimise potential impacts. ▪ Investigating to determine cause of any adverse impacts. ▪ Modifying groundwater pumping regimes. ▪ Modifying wellfield locations and/or layouts. ▪ Making affected supplies good in consultation with affected party and Department of Water. ▪ Monitoring response.
Excessive drawdowns resulting in unacceptable adverse impacts on groundwater-dependent vegetation.	▪ Groundwater levels over Yeelirrie catchment. ▪ Vegetation health in potentially affected areas and control areas.	▪ Locating and configuring wellfields to minimise potential impacts. ▪ Investigating to determine cause of adverse impacts. ▪ Modifying groundwater pumping and reinjection regimes. ▪ Modifying wellfield and reinjection locations and/or layouts. ▪ Monitoring response.
Excessive drawdowns resulting in unacceptable adverse impacts on subterranean fauna.	▪ Groundwater levels over Yeelirrie catchment (saturated depths of calcrete outside proposed development footprint). ▪ Subterranean fauna population sampling (as required) in potentially affected areas and control areas.	▪ Locating and configuring wellfields to minimise potential impacts. ▪ Investigating to determine cause of adverse impacts. ▪ Modifying groundwater pumping and reinjection regimes. ▪ Modifying wellfield and reinjection locations and/or layouts. ▪ Monitoring response.
Seepage from TSF into groundwater.	▪ TSF and mine pit dewatering quality during operation.	▪ Designing and constructing TSF to minimise potential for seepage. ▪ Ensuring there was no seepage away from mine pit/TSF during operation as a result of dewatering drawdown zone. ▪ Progressively adjusting TSF design and construction in response to monitoring results so final facility would have significant seepage eliminated.

Risk	Monitoring	Preventative and/or contingency options
Hydrocarbon, or chemical spills.	▪ Ongoing operator vigilance.	▪ Storage facilities, pipe and bunding design and construction would comply with all relevant regulations under the *Dangerous Goods Act 2004* (Dangerous Goods Safety [Storage and Handling of Non-explosives] Regulations 2007) and Australian Standard 1940-2004 (Storage and Handling of Flammable and Combustible Liquids) to prevent spillage into the surrounding environment. ▪ Spill response measures and equipment would be available on-site to ensure the risk of contamination was negligible. ▪ Any areas where hydrocarbons or chemicals were to be transferred between storage facilities (tanker to fixed tanks) would be sealed surfaces with appropriate bunding and drainage with hydrocarbon traps to eliminate the potential for spills to enter the environment. ▪ Implementation of Site Incident Response Plan in the event of a spill.

I.7 References

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