Western Australia Iron Ore

Orebody 31 Hydrogeological Impact Assessment

Summary Document

Department: Resource Planning - Hydrology

Contents

Introduction

Overview

Location

Orebody 31 (OB31) is located approximately 40 kilometres (km) east of Newman Township in the Pilbara region of Western Australia (Figure 1). OB31 is situated to the east of the existing Orebody 17/18 (OB17/18) Mine within Mineral Lease ML244SA, which is subject to the Iron Ore (Mount Newman) Agreement Act 1964 (Newman Agreement Act). OB31 has not previously been developed and as such is considered a greenfield development.

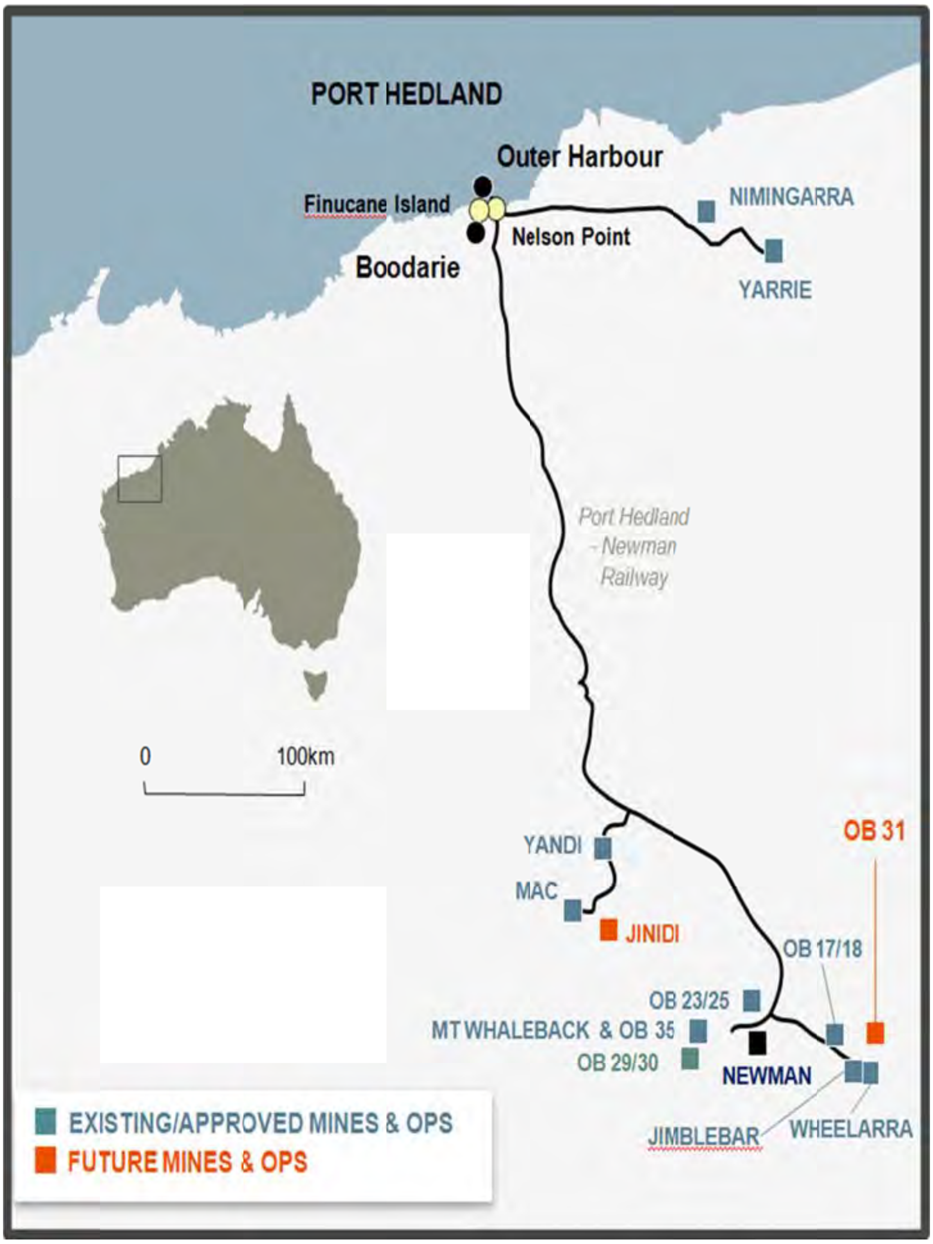
Other operations and approvals in the area

BHP Billiton Iron Ore Pty Ltd (BHP Billiton Iron Ore) currently operates a number of iron ore mines and associated rail and port infrastructure within the Pilbara region of Western Australia. Current mining operations in proximity to OB31 include:

- Newman Joint Venture hub, located approximately two km west of Newman Township, which consists of Mount Whaleback and Orebodies 29, 30 and 35;
- OB17/18 Mine, located approximately 30 km east of Newman Township;
- Wheelarra Hill (Jimblebar) Mine, located approximately 40 km east of Newman Township and five to 10 km south of OB31; and
- Eastern Ridge (Orebodies 23, 24 and 25), located approximately eight km northeast of Newman Township.

The closest operations to OB31 are the OB17/18 Mine and Wheelarra Hill (Jimblebar) Mine (Figure 1).

Figure 1: Location Plan



Project components

The OB31 project consists of the following:

- one single open pit, based on initial studies (future update subject to final drilling results);
- three new OSAs, based on initial studies (future update subject to final drilling results);
- a primary crushing facility;
- haulage (heavy vehicles (HV)) and light vehicles (LV) access roads linking OB31 to existing OB17/18 mine infrastructure;
- power, water, fibre optic cable and other associated services which may be required along road and/or conveyor alignments;
- topsoil and vegetation stockpiles;
- offices, ablutions, LV and HV parking areas, laydown areas, hydrocarbon storage facilities, Ammonium Nitrate storage facilities and magazine areas and other ancillary facilities; and
- water infrastructure including dewatering/potable/monitoring water bores, diesel generator sets, pipelines, turkeys nests and/or other storage facilities as required.

Hydrological processes

Mining projects can affect groundwater and surface water resources and their dependant values (DoW, 2013a). Seventy percent of OB31 lies below the water table. As such, the Proposal will require in-pit and ex-pit mine dewatering (i.e. groundwater abstraction) in advance to facilitate dry mine operating conditions.

An overview of BHP Billiton Iron Ore's hydrogeological studies and investigations (completed and proposed) are provided below.

BHP Billiton Iron Ore commissioned RPS (2014a) to undertake a groundwater field programme to increase the hydrological understanding within the Proposal area and determine the potential impacts of dewatering.

EPA Objective

The EPA applies the following objective, according to the Environmental Assessment Guideline 8 for Environmental Factors and Objectives (EPA, 2013), in its assessment of proposals that may affect hydrological processes:

To maintain the hydrological regimes of groundwater and surface water so that existing and potential uses, including ecosystem maintenance, are protected.

Relevent guidelines and approvals

The groundwater and surface impact assessment has been developed in consideration of the following guidance documents, where practicable:

- Western Australia Water in Mining Guideline (DoW, 2013a);
- Pilbara Regional Water Plan 2010-2030 (DoW, 2012a);
- Pilbara Groundwater Allocation Plan (DoW, 2013b);
- Pilbara Regional Water Supply Strategy: a long-term outlook of water demand and supply (DoW, 2013);
- Strategic Policy 2.09: Use of mine dewatering surplus (DoW, 2013c);
- Operational Policy No. 1.02: Policy on Water Conservation/Efficiency Plans, Achieving Water Use Efficiency Gains through Water Licensing (DoW, 2009b); and
- Operational Policy No. 5.08: Use of Operating Strategies in the Water Licensing Process (DoW, 2010c).

Outline of scope of this document

This impact assessment addresses potential hydrogeological impacts from dewatering and surplus water management for OB31. A number of technical studies have been completed, these are detailed in the appendices and summarised below. Although the primary impact area is in the immediate area of the OB31 project, potential regional impacts are also addressed, particularly Ethel Gorge Threatened Ecological Community (TEC). Ethel Gorge, geographically, is located outside the OB31 catchment area however is included in the impact assessment due to the potential impact from surplus water discharge to Ophthalmia Dam located immediately up gradient from the Ethel Gorge TEC. As such, this impact assessment provides a summary of potential local (immediate vicinity of OB31) impacts along with potential impacts to Ethel Gorge TEC.

Geology

Stratigraphy

OB31 is located 40 km east of Newman at the southern margin of the Pilbara Craton, which is comprised of large granitoid domes and batholiths separated by down-folded sequences of the Pilbara Supergroup sedimentary volcanic and intrusive rocks.

The Pilbara region comprises a portion of the ancient continental Western Shield that dominates the geology of Western Australia. The Western Shield is comprised of pre-Cambrian, Proterozoic and Archaean rocks. The Pilbara Craton dates back to the Archaean, and includes some of the oldest rocks in the world. It is overlain by Proterozoic rocks deposited in the Hamersley and Bangemall Basins. The Hamersley Basin which occupies most of the southern part of the Pilbara Craton can be divided into three stratigraphic groups; the Fortescue, Hamersley and Turee Creek Groups (Beard, 1975). Of the three groups, the Hamersley Group is the most relevant to the Project.

Stratigraphy in the OB31 area is mainly of the Hamersley Group (~2,630 to 2,450 Ma) which is a 2.5 km thick sequence of predominantly deep water sediments with lesser turbidites and intrusives. Lithologies include banded iron formation (BIF), hemipelagic shales, dolomite, chert, tuff and turbiditic volcanics. Since deposition, the Hamersley Group has undergone significant structural and geochemical alteration.

Orebody 31 deposit

The OB31 deposit is an east-west elongated deposit that extends ~4.8 km along strike and is ~1 km wide. The easternmost extent of OB31 is truncated by sub-parallel splays of the north-east trending Wheelarra Fault.

The proposed pit will intersect the following main rock units; the Mt Sylvia and Mt McRae Formations, Dales Gorge, Whaleback Shale and Joffre Members of the Brockman Iron Formation, Yandicoogina Member and Weeli Wolli Formation. The majority of the mineralisation occurs in the Dales Gorge and Joffre Members.

Mineralisation appears to be continuous along strike, with the majority being described as a martite-goethite mineralisation, with occasional intersections of microplaty hematite. The Joffre Member is also mineralised, with similar grades to that of the Dales Gorge Member.

Where outcrop is present, the geology is dominated by hardcapped Dales Gorge or Joffre Member units. Drilling from 1985, suggests that the hardcap thickness varies from 10 to 30 m. The Mt Sylvia and Mt McRae Formations outcrop towards the south-western and south-eastern ends of OB31, whilst the Weeli Wolli Formation outcrops to the north.

The large-scale structure at OB31 comprises an open, east-west striking anticline-syncline pair with southerly dipping axial-planes. The anticline is situated south of the syncline, with the common limb dipping ~40° north, whilst the dips of the southerly limbs are shallower. Smallerscale, parasitic (F2) folding is also reported to be present.

Orebody depth

Based on recent drilling in the area, it is estimated that the orebody depth is approximately 190 metres below ground level (mbgl), while the pit shell is estimated to be approximately up to 205 mbgl. Further drilling is planned in the area which may result in the pit being deeper than is currently estimated.

Hydrogeology

The main local aquifer is the mineralised and submineralised Brockman orebody. This aquifer extends for some distance along strike but is bounded by unmineralised Brockman Iron Formation. To the north and south, the orebody aquifer is inferred to be bounded by low permeability BIF and shales of the Weeli Wolli Formation (hanging wall) and Mt McRae Formation (footwall). In a regional sense, the orebody appears to be largely hydraulically constrained within low permeability aquitards. However, zones of higher permeability indicated by relatively higher airlift yields (1ML/d and higher) have been recorded in bores targeting the footwall (Mt McRae). These high airlift yields appear to be related to a series of faults and structures which have the potential to provide a hydraulic connection with adjoining aquifers.

Regional Hydrogeology – OB31

The Brockman Iron Formation (Brockman; BIF) comprises generally low permeability BIF and shales. However, where mineralised (typically in the Dales Gorge and Joffre Members), the Brockman has enhanced permeability and storage and can be considered an aquifer. Aquifer potential is limited to zones of mineralised and submineralised BIF forming semi-confined to unconfined aquifers. These aquifers are limited at depth and along strike by low permeability unmineralised Brockman and to the north and south by combination of the Yandicoogina Shale Member, Whaleback Shale Member and Mt McRae Shale Formation. In certain settings, the Brockman aquifer may be more hydraulically connected with surrounding units where the geometry of the valley and orebody are such that the footwall sequence of the orebody is juxtaposed to Tertiary valley-fill sediments (RPS, 2014a).

Tertiary valley-fill sediments are developed along an east–west trending valley to the south of OB31 and are thought to be approximately 100–150 m thick in this area consisting of an alternating sequence of alluvial, colluvial, Aeolian and diagenic sediments. Where saturated, the valley fill aquifer is expected to have a higher specific yield than surrounding bedrock aquifers. However, mineral exploration drilling in close proximity to OB31 did not encounter any saturated detritals in the footwall to the immediate south of the proposed OB31 pit; the Tertary aquifer is most likely further to the south of OB31 within the deeper areas of the palaeovalley. The Tertiary detrital aquifer is underlain by the Paraburdoo Member dolomite (Wittenoom Formation) that generally forms a regional semi-confined aquifer system (where weathered) located to the south of the orebody.

The Wittenoom Formation comprises mudstone, shale and dolomite with subordinate BIF in three Members – the West Angela Shale, Paraburdoo Member and Bee Gorge Member. The Paraburdoo Member comprises dolomite and has undergone weathering over much of the Pilbara, resulting in enhanced permeability, and forms the main regional aquifer in many locations.

The Bee Gorge Member is a generally low-permeability unit of argillite-mudstone with lesser dolomite, BIF and shale and overlies the Paraburdoo Member. It is generally considered to have low permeability along with the overlying My Sylvia and Mt McRae Formations, but may have increased permeability where weathered or altered (i.e. partial mineralisation).

Summary of OB31 Field Program

RPS Aquaterra (2014a) was commissioned to carry out a field programme at OB31. The field program at OB31 comprised the following:

- the drilling of 26 exploration bores to assess the hydrogeological properties of the aquifer(s) (airlift yields, groundwater levels and quality) and the geology;
- the installation of 26 standpipe piezometers to be used for short term (during test pumping) and long term water level monitoring;
- the drilling and construction of nine production bores;
- the construction of nine piezometers in suitable, existing RC holes;
- test pumping of the nine production bores to estimate aquifer properties, as well as to assess the hydraulic relationship between the various aquifer units and structural features (faults, dykes, etc.). The test pumping comprised step-rate tests of each of the nine production bores. Longer term (five to 11 days in duration) constant rate tests were undertaken on six of the nine bores; and
- collection of water samples from each production bore at the end of test pumping for laboratory analyses of major ions, as well as Total Dissolved Solids (TDS), pH and a range of metals.

OB31 Conceptual Model

Local Aquifer

The conceptual model of OB31 (Figure 2) shows the major flow processes and associated uncertainities in the current understanding. Results of the internal BHPBIO desktop hydrogeological assessments, exploration drilling, bore construction and test pumping programs at OB31 indicate that the mineralised Dales Gorge and Joffre units make up two broadly (generally east–west striking) potentially discontinuous, high-permeability aquifers that run in parallel. They are separated by the typically lower permeability Whaleback Shale aquitard.

The current hydrogeological understanding suggests that the following lithostratigraphic units can be grouped together as either aquifer or aquitard units:

- **High Permeability Aquifers (K > 5 m/d):** Mineralised Brockman Iron Formation at OB31 (largely unconfined Sy ~0.05), the weathered Paraburdoo Member dolomite and Tertiary Detritals containing thick layers of calcrete.
- **Medium Permeability Aquifers (K ~ 2–5 m/d):** Mineralised Marra Mamba (Mt Newman and McLeod), sub-mineralised Brockman Formation (Dales Gorge and Joffre) and saturated valley fill detritals.
- **Low Permeability Aquifers (K ~ 0.1–2 m/d):** Yandicoogina Member at OB31, un-mineralised Joffre and Dales Gorge Members, deeper sections of the Paraburdoo Member (unweathered) dolomite and, un-mineralised Mt Newman and McLeod Members.
- **Aquitards (K ≤0.1 m/d):** Woongarra Volcanics, Weeli Wolli Formation, Yandicoogina Member, Whaleback Shale, Mt McRae and Mt Sylvia Formations, Bee Gorge (excluding OB31), West Angela and Nammuldi Members.
- **Aquicludes (K <0.001 m/d):** Upper Mafic Volcanic Unit, Jeerinah Formation and all units below approximately 350mRL (200 m below ground surface).

The mineralised Dales Gorge aquifer is a high-permeability aquifer with estimated transmissiviies in the range of 1,000 to 1,300 m2/d (K ~ 8–9 m/d). The eastern end of the Dales Gorge aquifer may have an even higher permeability with an estimated transmissivity of around 1,800 m2/d (K~ 13 m/d). Faults have the potential to enhance vertical hydraulic connection through to the lower units including the weathered Paraburdoo Member dolomite aquifer. Along the southern margin of OB31, significant airlift yields were recorded in bores targeting the footwall (Mt Sylvia and upper Bee Gorge Members) which may be related to enhanced permeability associated with some of these structural features. The Dales Gorge aquifer is bounded to the south by the generally low permeability McRae Shale which likely retards groundwater flow in most places, except where faulting may increase permeability locally.

The mineralised Joffre aquifer along the northern side of the deposit shows zonation in permeability with eastern and western sides of the aquifer being high permeability zones with transmissivities in the range of 550 to 700 m2/d (K~ 6–7 m/d). These two high permeability zones are separated by lower permeability in the central part of the the aquifer due to a narrowing and reduced mineralisation. The mineralised Joffre aquifer is bounded to the north by the low permeability Weeli Wolli Formation and to the south by the Whaleback Shale. The mineralised Dales Gorge and Joffre aquifers transition into low permeability unmineralised stratigraphy along strike as well as at depth, laterally constraining the extents of the aquifers.

Groundwater flow and connectivity

Generally, there is a low north-easterly hydraulic gradient along the detrital valley, extending through OB31 to the Wheelarra Fault with groundwater level ranges between 501 mRL (OB18) to 496 mRL (Wheelarra Fault). Across the OB31 deposit, the hydraulic gradient ($\Delta H = 0.0004$) is to the east, towards the Wheelarra Fault with groundwater elevations ranging from around 498 mRL in the west to 496 mRL at the Wheelarra fault, east of OB31. Regional groundwater measurements indicate up to 50m change in hydraulic head between the orebody aquifer and the Weeli Wolli Formation/Woongarra Volcanics (aquitards) to the north of OB31. This indicates low flow hydraulic boundary to the north of the orebody.

Aquifer recharge and throughflow

Studies by RPS (RPS 2014a) suggest rainfall recharge to outcropping/subcropping orebody aquifers is relatively rapid and anticipated to to vary between 1 and 2% of mean annual rainfall. Recharge to the deeper regional aquifer system of the Wittenoom Formation may be a very slow process, which only occurs after significant or prolonged rainfall events.

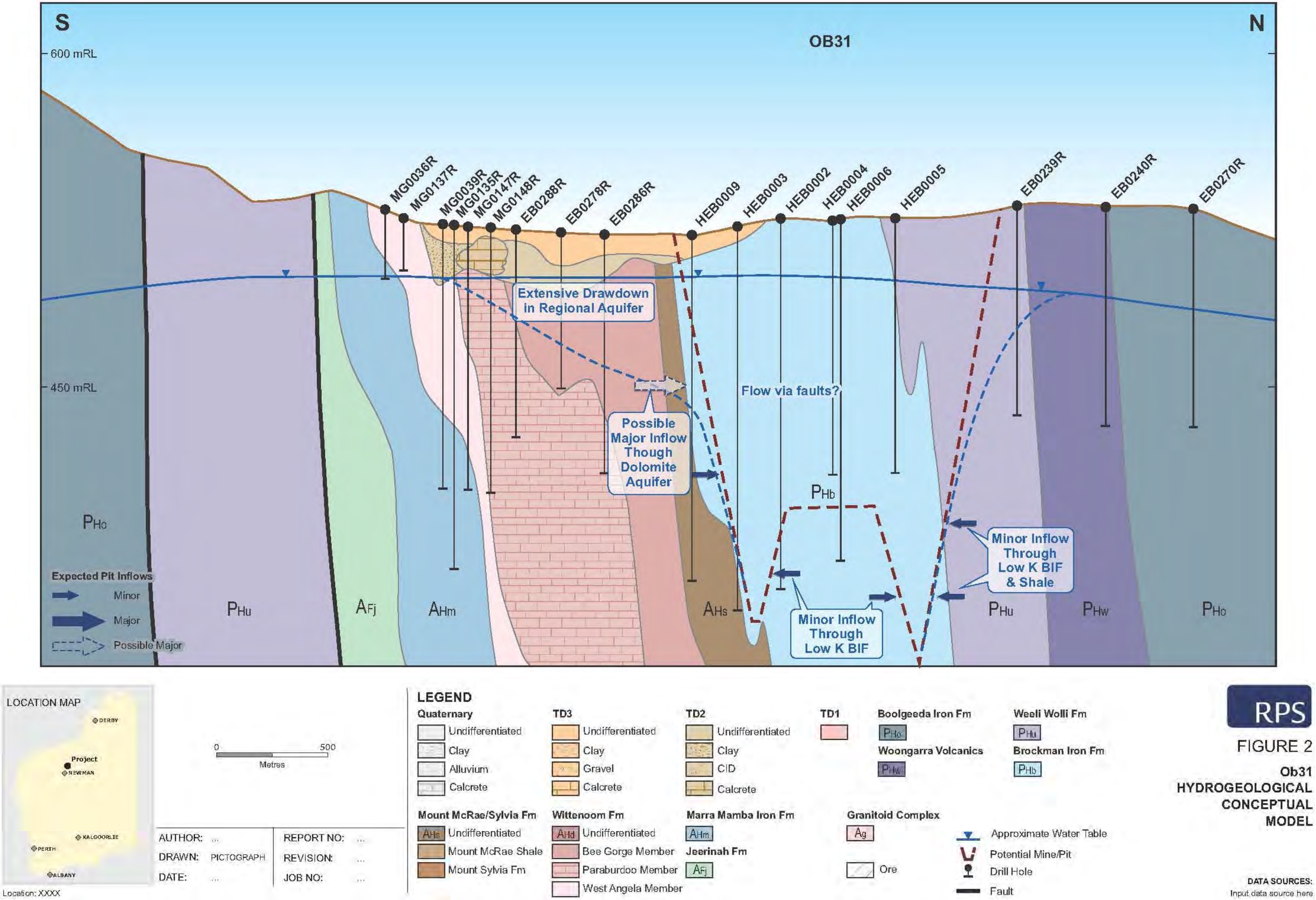


FIGURE 2

Ob31 HYDROGEOLOGICAL CONCEPTUAL MODEL

Ethel Gorge Description

Ethel Gorge (the Gorge) is located on the Fortescue River 15 km north east of Newman. The Gorge is located downstream (north) of the confluence of Homestead, Shovelanna and Warrawanda Creeks within the Fortescue River. The Gorge occurs where the Fortescue River flows through the Ophthalmia Range in a northerly direction. Downstream of the Gorge, the ephemeral river flows in a braided channel system (up to 30 m wide) to the north and then onto a broad flood plain and ultimately into the Fortescue Marsh (RPS, 2014b).

Sub-surface calcrete is extensive in the vicinity of Ethel Gorge. Where it is saturated, the calcrete hosts the regionally significant Ethel Gorge Aquifer Stygobiont Community TEC. This stygofauna calcrete habitat may extend in the surrounding alluvium (Bennelongia, 2013).

Ethel Gorge aquifers have been used for town and mine water supplies for Newman since the Ophthalmia Borefield (formerly the Ethel Gorge Borefield) was developed in 1969. Abstraction from the borefield steadily increased during the 1970s, leading to concerns regarding the long term sustainability of the resource. A managed aquifer recharge scheme – namely Ophthalmia Dam - was constructed on the Fortescue River and started operation in 1982. The dam is 5 km upstream of Ethel Gorge and was constructed to enhance recharge and augment groundwater resources in the Ethel Gorge area. The dam impounds water much of the time and forms a largely permanent surface water body in close proximity to the Gorge. Although historically the dam was built to sustain a drinking water aquifer, it now also has an important management control function to support the eco hydrology of Ethel Gorge (RPS, 2014b).

Ethel Gorge Hydrogeology

The Ethel Gorge groundwater system occurs in valley sediments bounded by predominantly low permeability basement rocks (except where the Tertiary aquifer is in contact with the weathered dolomite) (Figure 3). It consists of a highly permeable alluvial aquifer comprising an upper unit of sandy alluvium and calcrete (upper alluvial aquifer) and a lower unit of gravelly alluvium (deep aquifer). The two units are discontinuously separated by a laterally deposited lower permeability leaky aquitard sequence comprising silts and clays. Orebody aquifers, hosted in the Brockman, may have varying levels of hydraulic connection with the upper alluvial and deep aquifers respectively (evident by piezometric responses from OB25 monitoring bores) where the mineralised zone occurs on the flanks of the valley and is in direct contact with the valley fill.

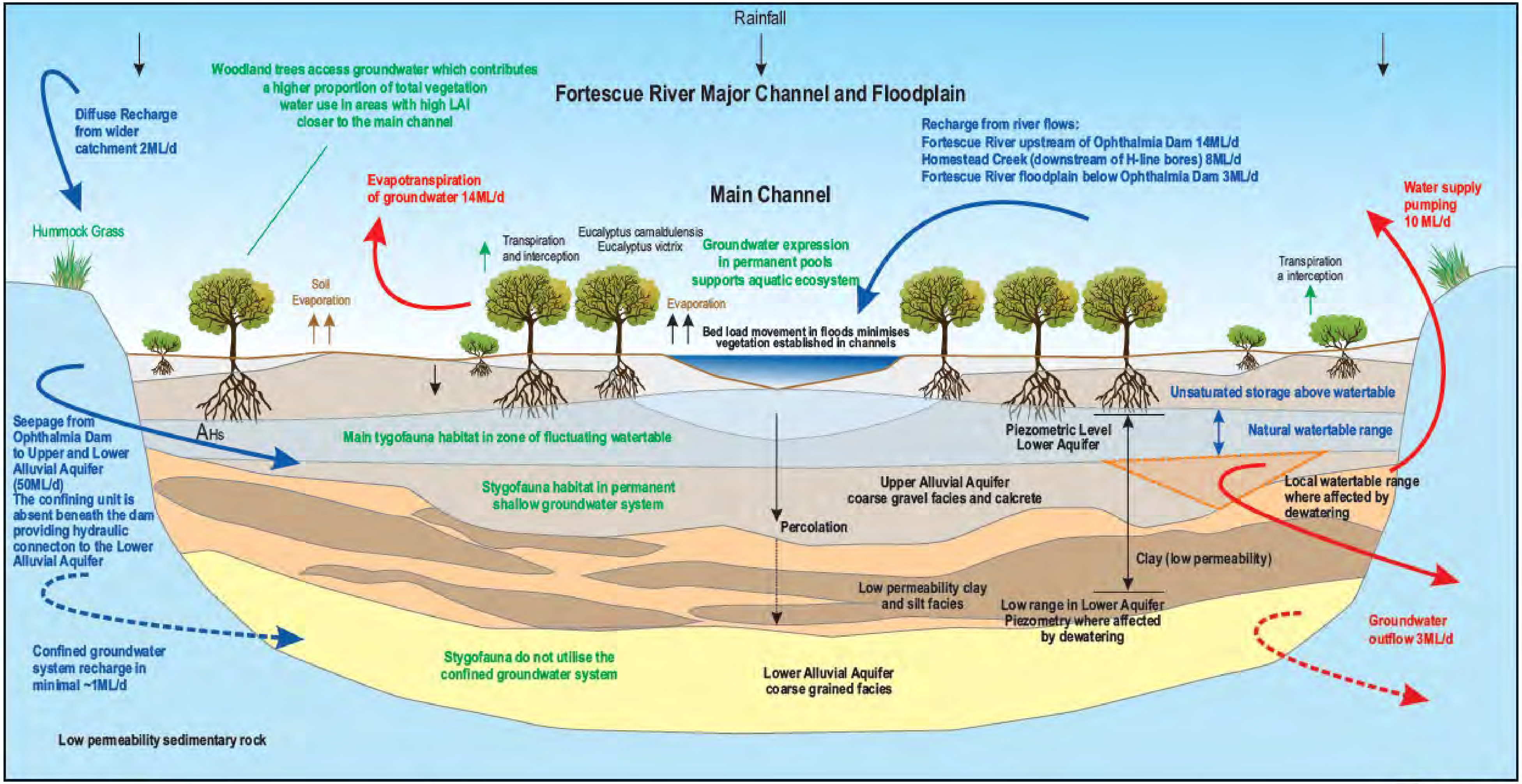
The hydraulic behaviour of the Ethel Gorge groundwater system is dominated by both the Ophthalmia Dam and the Homestead Creek drainage system during periods of high streamflow. The dam serves to detain surface water flow to increase groundwater recharge to the downgradient upper and lower alluvial aquifers.

The upper alluvial aquifer is unconfined and receives recharge from direct infiltration associated with river flow events along the Fortescue and Homestead Creeks. In addition to seasonal recharge along the river channels, the upper aquifer also receives water seeping from Ophthalmia Dam and this supports long-term trends in the volume of water stored in the aquifer and associated water levels.

Groundwater levels in the upper alluvial aquifer are within 10 mbgl across the entire valley floor area. This provides a substantial saturated thickness in the upper alluvium and calcrete, which constitutes the main extent of prospective stygofauna habitat.

The lower alluvial aquifer is largely confined by the overlying aquitard and is predominantly subject to sustained recharge from Ophthalmia Dam. Bore data indicates that the lower aquifer has piezometric heads which commonly equal or exceed water levels in the upper alluvial aquifer, particularly close to the Dam.

Aquifer parameters are within the range of regional values and the system is driven by recharge to the shallow aquifer from floods and notably from the dam, the high permeability in the calcrete and alluvium and low permeability in the basement (Table 1).



LOCATION MAP

Location: XXXX

AUTHOR: JP	REPORT NO: 020a
DRAWN: RC	REVISION: a
DATE: 03/02/2014	JOB NO: 1549B

RPS

FIGURE 3

ETHEL GORGE
GROUNDWATER DEPENDANT ECOSYSTEM
CONCEPTUAL ECOHYDROLOGICAL MODEL

DATA SOURCES:
Input data source here

Table 1: Ethel Gorge hydraulic parameters

Model Layers	Hydrgeological Unit	Horizontal Hydraulic Conductivity Kh (m/d)	Vertical Hydraulic Conductivity Kv (m/d)	Specific Storage Ss (1/m)
1 to 2	Calcrete	4.0×10^{1}	4.0×10^{0}	2.0×10^{-6}
3	Clay	1.0×10^{-1}	5.0×10^{-4}	2.0×10^{-6}
4	Gravel	5.0×10^{0}	5.0×10^{-1}	2.0×10^{-6}
1 to 6	Basement (Hamersley Group and unmineralised Brockman Iron Formation)	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-6}
	Brockman Orebody	5.0×10^{0} to 1.0×10^{1}	5.0×10^{-1} to 1.0×10^{0}	4.7×10^{-7} to 2.0×10^{-6}
	Mt McRae Shale and Mt Sylvia Formations	1.0×10^{-2}	1.0×10^{-2}	1.0×10^{-6}
	Wittenoom Formation (undifferentiated)	1.0×10^{0} to 1.0×10^{1}	1.0×10^{-1} to 1.0×10^{0}	4.7×10^{-7} to 2.0×10^{-6}
	Marra Mamba Orebody	5.0×10^{0}	5.0×10^{-1}	2.0×10^{-6}
	Basement (unmineralised Marra Mamba Iron Formation, Fortescue Basement and Metagranite/Granitoid)	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-6}
	Faults	1.0×10^{-4}	1.0×10^{-4}	1.0×10^{-6}

Recharge to the groundwater systems in the Ethel Gorge area occurs predominantly as seepage from Ophthalmia Dam at an average rate of approximately 50 ML/d (Figure 3). Other sources of recharge include direct infiltration upstream of Ethel Gorge from channel flow events (along the Fortescue River channel when the dam overflows and above the area of impoundment) and also along Homestead Creek and Shovelanna Creek which are unregulated. Total recharge from infiltration along creek channels upgradient from Ethel Gorge is approximately 24 ML/d (average) on an almost annual basis. There is also a small component of throughflow into the Ethel Gorge area from the upstream catchments; estimated to be approximately 2 ML/d in total.

Recharge volumes mainly replenish the shallow alluvial aquifer. Percolation into the lower aquifer is restricted by the lower permeability aquitard and the hydraulic loading (pressurisation) of the deep aquifer.

Groundwater discharge occurs as throughflow along Ethel Gorge (approximately 3 ML/d), evapotranspiration from riparian vegetation communities (approximately 14 ML/d) downstream of the dam and pumping (approximately 10 ML/d) for pre-dewatering steady state conditions.

Ecohydrology

Local Ecological Assets within the OB31 Project Area

Onshore Environmental have undertaken a flora survey within the OB31 project area (Onshore Environmental, 2014) and did not identify any TEC or PEC within the project area.

Onshore Environmental did not identify any groundwater dependent vegetation (GDV) over the majority of the project area. This was determined from local fine scale vegetation mapping that did not identify any phreatophytic species. There were no obligate GDV identified thoughout the project area. In the south east corner of the project, where depth to groundwater is between 5 to 25 mbgl, facultative vegetation community types were identified in the form of Eucalyptus victrix associated within the drainage line that discharges to Jimblebar Creek. There are no emphemral, permanent surface water pools or wetlands within the project area of influence that are supported by the regional water table.

Bennelongia have undertaken a Stygofuana and troglofauna sampling and desk top review study (Bennelongia, 2014). Drawdown was determined as only potentially affecting Stygofauna, species identified are known to have large habitat ranges throughout the Eastern Pilbara (Bennelongia, 2014).

Regional Ecological Assets

The OB31 project is within the Fortescue Marsh catchment area and is located 100 km up stream from the Marsh and 30 km upstream from the Fortescue River. The nearest recognised tributary to the Fortescue River catchment is Jimblebar Creek located 5 km east of the eastern-most pit extent. A small unnamed drainage line receives run off from OB31 catchment and drains to the east where it joins Jimblebar Creek.

The nearest ephemeral water body is Innawally Pool (on Jimblebar Creek), which is located 5.5 km upstream from the confluence of the unnamed creek and Jimblebar Creek (Figure 4). The nearest protected ecological asset to OB31 is the Threatened Ecological Community (TEC) community of the Ethel Gorge Stygobiont Community, located 22 km to the west; OB31 catchment does not directly drain to Ethel Gorge catchment (Figure 5).

Figure 4: Location of Innawally Pool in relation to OB31

Ethel Gorge TEC

The Ethel Gorge TEC and Ethel Gorge are identified in the EPWRMP (BHPBilliton, 2015a) as key Eastern Pilbara regional biodiversity assets and thus are considered in more detail as part of the impact assessment of OB31. The TEC is listed by the Department of Parks and Wildlife (DPaW) with some stygofauna species endemic to Ethel Gorge. The stygofauna habitat comprises saturated calcrete and alluvium aquifers, which underlies the broad Ophthalmia valley and Ethel Gorge, the latter containing the most abundant and diverse community.

Information on habitat requirements for stygofauna, including their distributions within heterogeneous groundwater environments and tolerances of differing water qualities, is very limited in the Pilbara and elsewhere (DoW 2013a). As a general rule stygofauna are often most abundant and diverse near the watertable, with species richness and abundance decreasing with distance below the watertable in association with decreasing oxygen and nutrients (Stumpp & Hose, 2013). Shallow watertable areas typically have greater stygofauna diversity, where attenuation of organic matter and oxygen by the overlying unsaturated profile is minimised. Areas with a depth to the watertable of less than 15 m from the surface have been found to favour high stygofauna diversity in alluvial aquifers in eastern Australia (Hancock & Boulton, 2008). However the depth at which stygofauna communities can persist is also influenced by different geology. Where transfer of water from the surface to aquifer is rapid, the suitable depth to watertable is likely to be greater (RPS, 2014b).

The current spatial extent of the TEC is illustrated on Figure 5, as defined by DPaW, this boundary is understood to be based on the surface expression of calcrete in the area. Over 40 years of monitoring data demonstrates that groundwater levels in this area fluctuate by up to 6 m in response to seasonal rainfall and runoff variations; however, habitat for stygofauna is considered to be maintained by zones of permanent saturation in the shallow alluvial groundwater system.

The quality of stygofauna habitat is influenced by the level of connectivity between pores, cavities, and fractures which facilitate fauna movement and dispersal. The spatial heterogeneity of the calcrete habitat at Ethel Gorge is not well understood. The zone of watertable fluctuations (i.e. the boundary between unsaturated and saturated zone) may constitute an ecotone with different species assemblages in comparison with constantly saturated and unsaturated zones respectively; however, this has not been confirmed at Ethel Gorge (RPS, 2014b).

The Ethel Gorge area also supports riparian vegetation communities along the major channels including (DEC 2013):

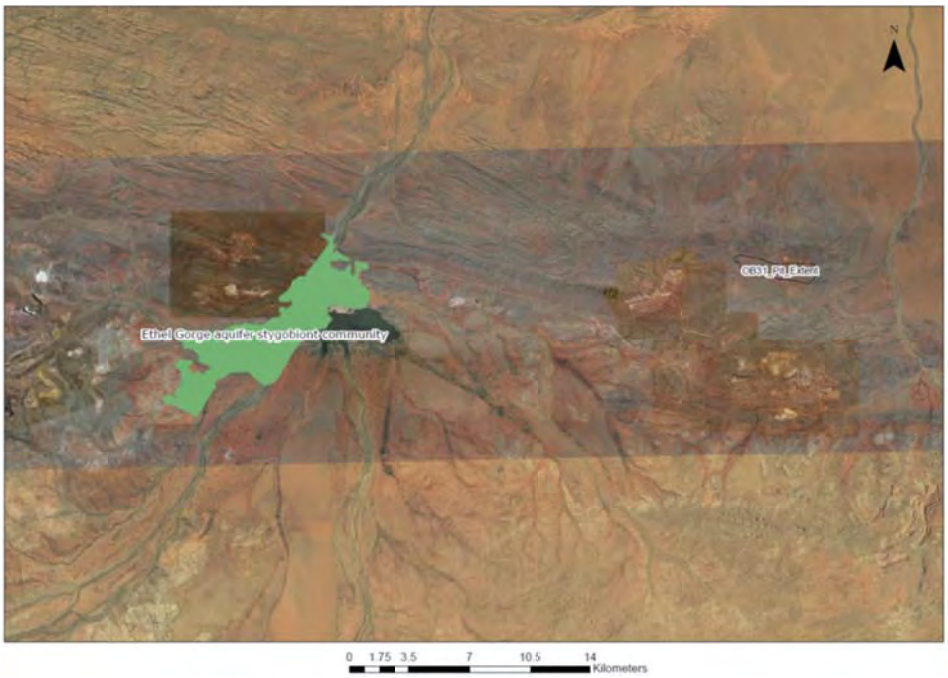
- Open Forest of *Eucalyptus victrix* (Coolibah) and *Eucalyptus camaldulensis* (River Red Gum) over sedges of *Cyperus vainatus* and *Typha domingensis* along major drainage lines.
- Open Woodland of *Eucalyptus victrix* over Low Open Woodland of *Acacia citrinoviridis* over Scattered Tussock Grasses of *Cenchrus ciliaris.*
- Open Mallee of *Eucalyptus socialis* subsp. *eucentrica* over Very Open Hummock Grassland of *Triodia pungens* on floodplains.

The entire upstream catchment area of Ethel Gorge hosts approximately 3,650 ha of Eucalypt woodland communities including the facultative phreatophytes *E. camaldulensis and E. victrix*. These species along with other vegetation species access shallow groundwater to varying degrees and contribute to groundwater discharge via evapotranspiration. Woodland transpiration is likely to occur from areas where the watertable is less than 10 to 20 mbgl which is a vast area over the broader region (3,640 ha). The proportion of groundwater used by the woodland vegetation (as a component of total water use) would be expected to be greatest where the depth to watertable is shallow (i.e. where soil moisture storage in the unsaturated profile is limited by depth). The water balance indicates the dominant groundwater discharge mechanism from the Gorge downstream from the dam is by evapotranspiration (14 ML/d) from vegetation followed by groundwater outflow (~3 ML/d) (Fiugre 3). Due to the shallow depth to water through the Gorge, there is a strong coupling between hydrology and ecology of the terrestrial environment.

The relative proportion of vegetation water use from groundwater in comparison with soil moisture remains uncertain (i.e. rainfall and runoff). It is possible that in some areas, groundwater is only accessed transiently, during prolonged dry periods where the unsaturated profile deepens. In general terms, a greater reliance on groundwater would be expected as the moisture content in the unsaturated profile decreases below plant wilting point. Vegetation communities overlying stygofauna habitat may be an important source of carbon and nutrients for stygobiont communities. Phreatophytic roots are known to be a source of organic matter to aquifer invertebrates (Jasinska *et al.*, 1996).

Historically, water levels in Ethel Gorge were much lower than those observed today when groundwater abstraction during the 1970s (before the construction of the Ophthalmia Dam) resulted in falling water levels throughout the Ophthalmia aquifers (upper and lower alluvial aquifers) over a period of about 10 years. In some areas, saturated thickness was reduced to less than 50%. Since it's commissioning in 1982, the Ophthalmia Dam has also changed the groundwater regime of the area, generally contributing to elevated groundwater levels by prolonging the period of recharge. Despite these highly dynamic hydrologic events, stygofauna surveys carried out since the 1990s indicate a rich and abundant stygofauna community, suggesting that stygofauna were able to recover from the groundwater drawdown events.This suggests that stygofauna is less sensitive to the rate of groundwater change compared to for example phreatophytic vegetation species, which has to develop root systems to access groundwater.

Figure 5: Location of Ethel Goreg TEC to the OB31 project



Existing and potential stressors (RPS, 2014b)

Pumping related to dewatering of BHPBIO mining areas (Orebody 23 and Orebody 25) has resulted in reductions in water levels in the vicinity of these operations (Figure 3). The largest reductions are noted from the deep alluvial aquifer and represent a depressurisation response. Water levels in the shallow alluvial aquifer have generally declined by less than 10 m (within 500 m of the BWT mining areas). Thus to date the calcrete of the TEC has remained largely saturated, with limited aerial extent influenced by dewatering drawdown influences.

Long-term depressurisation of the deep alluvial aquifer, as a result of ongoing dewatering activities, has the potential to accentuate leakage into the underlying deep aquifer where the piezometric head falls below the water levels in the upper alluvial aquifer. This has the potential to reduce groundwater levels in the upper alluvial aquifer. The ability of stygofauna to recolonise areas that become re-saturated after a dewatering event is unknown; although rich stygofauna habitat within Ethel Gorge has experienced significant drawdown prior to the construction of the dam which have since resaturated. However in the Ethel Gorge area, the high watertable and seasonally variable influx of water and nutrients from storm events are likely to aid in stygofauna dispersal.

Ophthalmia borefield provides water supply to the Newman townsite, Ophthalmia borefield is part of an integrated water supply system providing water to the Newman townsite along with Homestead Borefield. Drawdown from the the operation of the Ophthalmia Borfield reduces the saturated thickenss in immediate vicinity of the production bores. The drawdown from abstraction is mitigated by Ophthalmia dam which is designed to detain surface flow within the Fortescue River in order to enhance recharge.

Impact Assessment

There are two potential impacts associated from the OB31 project with respect to altered hydrology; these are:

1. Regional water table drawdown in response to mine dewatering at OB31; and
2. Changes to surface and groundwater regimes in response to surplus water management (options local to OB31, and at discharge to Ophthalmia Dam).

These potential impacts are considered during operations and following mine closure.

Drawdown from Mine Dewatering

A groundwater model has been developed (Appendix 1) for OB31 and has been used to estimate the required dewatering volumes to enable the mine plan, the radial extent of drawdown and to assess the long term recovery during closure.

Details of the modelling program are described in Appendix A. Drawdown propagates preferentially to the west following transmissivity along the Wittenoom Formation with drawdown constrained by the Wheelarra Fault (to the south and east) and to the north by lower permeability Weeli Wolli and Yandicoogina Formations (Figure 4-2 – Appendix 1).

The OB31 numerical model also considers cumulative drawdown from existing approved BWT operations (namely Jimblebar mine). Drawdown at the proposed and existing operations is attenuated by the Wheelarra Fault, which is expected to form a regional hydraulic boundary to drawdown propagation (refer to OB31 conceptual model section).

The two metre drawdown contour extends to the Warrawandu potable borefield north of the Warrawandu accommodation village. The 2 m drawdown contour does not extend into the Ethel Gorge TEC boundary for any of the parameter sets tested in uncertainty analysis (Figure 4-2 – Appendix 1).

The key uncertainty to be recognised for estimation of dewatering volume and drawdown is the degree of hydraulic connectivity with the regional aquifer system. This is tested through uncertainty analysis, and in the long-term will be progressively addressed as a long term monitoring data set is developed from the installed network.

Impacts to GDEs

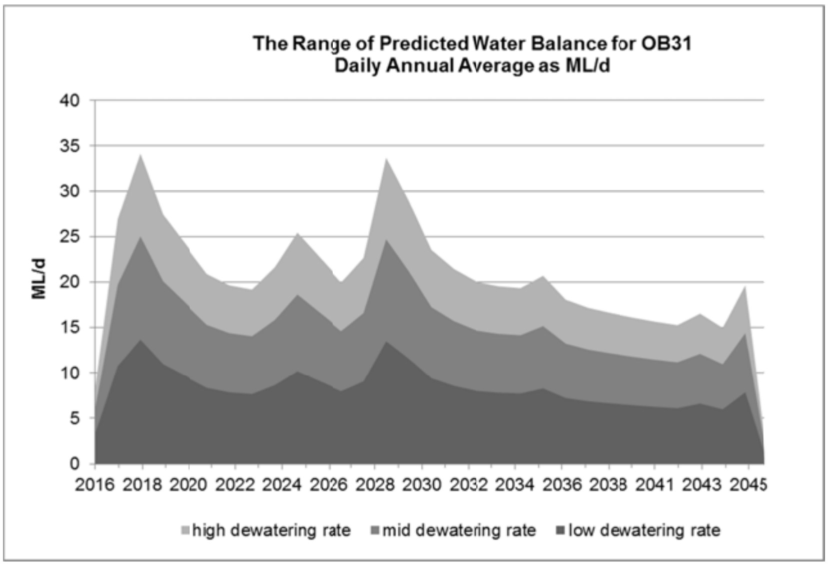
As discussed (Onshore, 2014) the only known extent of potential groundwater dependent vegetation (GDV) is to the south east of the orebody where *E. victrix* is mapped in an area with the water table surface between 5 and 20 mbgl. It is predicted this area will experience up to 30 m of drawdown. There are no other known GDV within the study area that would be affected by drawdown.

Bennelongia have undertaken stygofauna sampling within the predicted maximum extent of drawdown and the nearest known stygofuana community is the Ethel Gorge TEC (Bennelongia, 2014). As discussed above, this is not predicted to be affected by dewatering drawdown from OB31. The depth to water is deep across the majority of the study area (>30 mbgl) as such the area is unlikely to host significant stygofauna habitat areas (Bennelongia, 2014). The regional water table is predominantly in the Wittenoom Formation; the detrital calcrete systems which are often associated with stygofauna communities are largely unsaturated. As such the risk of impact to stygofauna communities is considered low in the vicinity of the mine.

Changes to surface and groundwater regimes in response to surplus water management

The numerical modelling provided estimates of the range of anticipated dewatering rates required to access below water table ore at a mining rate of 15 Mtpa (Figure 6). The predicted dewatering range relects the current hydrogeological uncertainty and potential mine development scenarios. The higher and lower dewatering estimates have been provided below. With a predicted water demand of up to 4 ML/d, a surplus water volume of up to 30 ML/d is possible.

Figure 6: The upper and lower dewatering estimate for OB31



In accordance with the Pilbara Water in Mining guidelines (DoW, 2013), multiple surplus water management options are being considered in order of preference (Table 2). The Eastern Pilbara surplus water management plan (BHPBilliton 2015b) covers three mining hubs (Jimblebar, Eastern Ridge and Whaleback) within the Newman area to address a net water surplus volume and summarise the regional cumulative water management strategic approach. The surplus plan is in recognition of the need for a regional approach which addresses the collective and cumulative management of surface and groundwater as outlined in the Pilbara Water Resource Management Strategy (BHP Billiton, 2014). The introduction of the mines which are enabled by the plan will be staged as new mines commence and as existing mines are included over the mid term.

Orebody 31 (OB31) will be the first mine to be included in the surplus plan. The plan includes only industrial water management with potable and wastewater managed through Drinking Water Source Protection Plans and the Environmental Management Plan for each hub.

The DoW policy stipulates that mine dewatering volumes must first be used for:

- Mitigation of environmental impacts; and
- Fit-for-purpose onsite activities (e.g. processing, dust suppression and mine camp use).

Any dewatering volumes that remain after these requirements have been met constitute mine dewatering surplus with options for management as follows:

1. Transfer water to meet other demands.
2. Reinjection back into an aquifer.
3. Controlled release to the environment.

For the purposes of aligning surplus water management options with DoW policy; options have been categorised based on the primary management objective as either:

1. **Transfer surplus water to a demand area**, for mine production, dust suppression, potable supply or community or 3rd party activities.
2. **Aquifer return**, includes reinjection or infiltration.
3. **Release,** includes evaporation and surface water discharge.

The approach is in line with the BHP Billiton sustainability charter and considers prioritisation of transferring surplus water to delivery points and infiltrating water to the aquifer to minimise any potential impacts to receiving receptors and offset the area of pumping influence.The surplus options considered for OB31 are outlined in Table 2.

Table 2: Surplus water management options considered

Surplus Management Options	Rationale	Limitation
Primary Option – Discharge to Ophthalmia Dam and surrounding infiltration ponds MAR system. **Application** - up to 30 ML/d.	The transfer of water and discharge to an approved MAR facility enables flexibility and regional water management sustainability and mitigates impacts to Ethel Gorge GDEs as a preventative control. A pipeline ultimately provides a regional water management solution which integrates and transfer water between multiple mining areas and surplus water area. The approach would prepare the region for future water challenges and maximise the opportunity for beneficial water use.	The long term sustainability of transferring surplus water to Ophthalmia Dam MAR system may ultimately be limited by the Dam and underlying aquifer capacity. The capacity would be reach when 1) discharged water is "rejected" into Fortescue River once the aquifer fills and spills, and 2) aquifer water quality degrades due to salt loads generated through evapotranspiration developing above unacceptable thresholds.
Backup Option – Controlled discharge to Jimblebar Creek **Application -** Up to 30 ML/d for periods of up to 3 months during wet season or when needed through failure or maintenance of Option 1.	Controlled discharge to Jimblebar Creek is being considered as an emergency backup option and seasonal discharge alternative. Ultimately, creek discharge may become more of a permanent alternative however it is recognised further assessment work is required. The creek capacity and ecological response to discharge will be assessed through a hydrodynamic trial to determine what role creek discharge may play as part of an integrated surplus water management approach.	The potential for impacts to the riparian vegetation and fauna within the Jimblebar Creek require assessment to determine the extent and period of wetting front and changes to water permanency and quality. The ultimate capacity of Creek discharge would be the impact to Fortescue Marsh should the wetting front migrate an unacceptable distance to the north.
Alternative under evaluation - Return to the Ophthalmia Range dolomite aquifer via MAR **Application** - capacity to be defined during later studies (10 ML/d potential)	Returns surplus to the groundwater to minimise drawdown and area of influence within areas of potential impact around OB31 and neighbouring mines (OB18). Drawing on Jimblebar MAR trial results, the orebody and dolomite aquifers appear to have some capacity to accommodate injected water. Up to 12 MAR bores would be required to inject the anticipated volumes along a strike length of over 20 km.	A suitable reinjection location has not been located with sufficient. MAR may have application on a smaller scale and volume and used in conjunction with Ophthalmia or Creek discharge to locally minimise drawdown effects. A MAR trial is planned for 2015 in the vicinity of OB18.

Impact assessment – Ethel Gorge

A number of surplus water management options have been evaluated as part of OB31 environmental approvals and the overall Eastern Pilbara Water Resource Management Plan (EPWRMP) (BHPBilliton, 2015a). The discharge of surplus mine dewater to Ophthalmia Dam has been selected as the preferred option. The dam and the surrounding recharge ponds do mitigate and prevent environmental impact to Ethel Gorge and can enable flexible integrated catchment scale water management. The purpose built Ophthalmia Dam MAR scheme has been in operation for over 30 years and has effectively enhanced recharge to the downstream aquifers in the Ethel Gorge TEC area and the Ophthalmia drinking water borefield to mitigate impacts from groundwater abstraction. The Ethel Gorge aquifer will have a maximum volumetric capacity and salt load tolerance. If the MAR system is used excessively as a surplus management option, an unacceptable change to hydrological conditions may ultimately occur (such as rising water levels or a degradation of water quality). An alternative or supporting surplus option may need to be considered to manage this risk.

To establish the upper surplus water discharge capacity, specific assessments have been conducted using a regional numerical model (RPS, 2014d) (Appendix 2) to predict changes to water level and, an analytical water quality model (RPS, 2014e, f) (Appendix 3) to address the development of an unacceptable salt load. These studies predicted changes in hydrological conditions by simulating a range of stresses and threatening process including:

1. the addition of OB31 surplus discharge,
2. the continued discharge of approved mines,
3. abstraction from the Ophthalmia borefield, and
4. the use of Ophthalmia Dam and the infiltration basins / ponds.

The outputs included the predicted range of changes in:

1. down gradient groundwater response, and
2. salt balance of the dam and Ethel Gorge (Appendices 2 and 3).

Importantly, the models considered various volumetric and operational configurations to establish the likely range of outcomes, sensitivities and volumetric thresholds.

Changes to Hydrological Conditions

Predicted Changes to Water Level

The primary area of assessment focused on the Ethel Gorge unconfined aquifer that supports the stygobiont community and riparian vegetation to the north of the Dam. As discussed above, historically the unconfined alluvial aquifer experiences natural variances in water level and quality, typical of the Pilbara dominated by extreme climatic conditions. The groundwater dependent communities have adapted to these natural variance conditions, such as relatively rapid rises in groundwater levels after significant runoff events, followed by decay in water levels during period of low recharge.

The Ethel Gorge aquifer has also undergone additional hydrologic change with the introduction of threatening processes since the 1970s including the operation of the Ophthalmia Borefield for water supply to Newman, the construction of the Ophthalmia Dam and adjoining recharge facilities, adjoining dewatering activities and mine surplus water infiltration. Despite these highly dynamic stresses, monitoring programs have demonstrated that the shallow unconfined aquifer in Ethel Gorge continues to support high biodiversity stygofauna community and riparian vegetation.

The volumetric capacity (the water level threshold at which impact occurs) and the water balance of the Ethel Gorge aquifer is primarily controlled by Evapotranspiration (EVT), infiltration of rainfall runoff and Dam leakage. These parameters have a degree of uncertainty.

In order to determine the sustainable discharge capacity various discharge volumes (15 ML/d up to 120 ML/d) and two EVT rates were incorporated into the Ethel Gorge numerical model and Ophthalmia Dam water balance model. The EVT rates applied in the model are considered to cover the range of outflow uncertainty (Appendix 2) and the surplus volumetric scenarios reflect the full range of potential mine development scenarios and schedules, over and above OB31, enabling cumulative effects to be considered.

Initially, the model was run for 30 years on yearly time steps for a “no discharge” scenario to establish baseline hydrological conditions. The model was also run for incremental increases in dewatering discharge (15, 30, 60 and 120 ML/d). Water was directed into the Dam and once the dam was full any additional surplus was directed into the recharge basins and ponds to reflect operational reality. The various scenarios were compared with the predicted baseline conditions to evaluate the change in water levels in the unconfined aquifer. The EVT flux for the Gorge was assessed at equivalent rates of around 1.4 and 2.0 mm/day plant water use. The modelled aquifer water levels responded by rising until the aquifer filled and rejected the recharge as seepage into Fortescue River. The timeframes and volume of discharge was established for each surplus and EVT sensitivity run (Appendix 2).

Change Assessment and Impact Predictions

As outlined in the EPWRMP, the key water management objective is to maintain water levels within the long term natural range and allow for seasonal variation to prevent the prolonged inundation of the fringing riparian vegetation.

The predictive modelling indicates the Ethel Gorge aquifer can accommodate 40 ML/d of additional long term surplus water infiltration whilst maintaining water levels within management threshold ranges. Above 50 ML/d the seasonal trends decrease and by 120 ML/d results in up to 30 ML/d of groundwater discharging into the Fortescue River drainage lines within 3 years.

Based on these preliminary results, the Ethel Gorge aquifer system can sustainably accommodate a dewatering discharge rate of at least 30ML/d, and potentially up to 50 ML/d before management thresholds are reached. As part of the adaptive management approach outlined in the EPWRMP, ongoing monitoring and conceptual refinement will be undertaken to address the uncertainty and provide operational improvements.

Changes to Water Quality

The key water quality parameter considered in the impact change assessment and the EPWRMP is total dissolved solids (TDS), although it is recognised that a number of other water quality and physical parameters may be important for the sustainability of the stygofauna community, including nutrients and dissolved oxygen.

Although considerable uncertainty exists as to the sensitivity of stygofauna community health to TDS the investigation thresholds represent statistically representative historical ranges of up to 4,000 mg/L. The approach is assumed to be precautionary as monitoring has shown that stygofauna abundance is not impacted for TDS >4,000 mg/L.

Details of this assessment are provided in Appendix 3. Any change in the water quality conditions are most likely to result from an increase in the salt load of the aquifer over time as surplus water with higher TDS is infiltrated into the aquifer through the dam or the recharge ponds. Modelling demonstrates that the TDS increase with distance from the dam, owing primarily to evaporative concentration effects over the mid to long term. It is predicted that the TDS could potentially exceed the thresholds within 20 years after discharge commences. However, the timeframes are dependent upon the volume of surplus water, natural recharge of fresh runoff water and the operation of the MAR system.

High level hydrogeochemcial assessment was undertaken to determine potential impact of discharge the Brockman Orebody Aquifer water type to the Ophthalmia and subsequent potential changes in chemistry. A preliminary review of the data for the OB31 aquifer suggests a Ca+Mg/Na+K type without a dominant signature. Ethel Gorge water tends toward a relatively high proportion of Na, Cl; and Ophthalmia Dam water has an HCO_3 type signature. Potential hydrogeochemical impact as a result of discharge includes:

1. Carbonate saturation (elevated alkalinity / bicarbonate ion concentration);
2. Sulfide oxidation leading to potential decrease in pH and mobilisation of metals; and
3. Chloride salinity.

Water quality monitoring will be undertaken in accordance with the adaptive management approach outlined within the Eastern Pilbara Water Resource Management Plan.

Managed Aquifer Recharge via local borefield

MAR via a local injection borefield has been evaluated. Based on the current assessment, this option is considered less favourable due to; the potential for recirculation back to the dewatering operation; and the expected capacity of the dolomite and valley fill aquifer system being inadequate to receive all surplus to be managed. As such this option is not expected to represent a sole solution for surplus but may form an option for periodic peak surplus management. The depth to water table is greater than 60 m below the ground surface within the injection area, reducing the potential adverse impact from mounding, particularly as there is no groundwater dependent vegetation identified over the majority of the study area. The viability of a long-term MAR scheme will be assessed with additional numerical modelling once a transient model calibration is undertaken.

Creek discharge to Jimblebar Creek (and potential expansion to Carramulla Creek)

There are two potential creek discharge options including Jimblebar Creek and Caramulla Creek which are being explored as short-term contingency or seasonal options at this stage. Creek discharge is the least preferable surplus management option in acknowledgement of the DoW's guidance (2013).

There is very limited data regarding the sub-surface storage capacity of both creek systems. A proposed hydrodynamic trial will enable the assessment of creek response to discharge, particularly the propagation of the wetting front, to indicate the degree of sub-surface storage available. The hydrodynamic trial has been designed to provide a long term monitoring data set. Several production bores within the orebody will be run for a fixed rate for a fixed period, with the principal aim to assess the degree of along strike connectivity, regional connectivity and pore pressure responses in low permeability units. The water produced will be discharged to Jimlbebar Creek where wetting front monitoring will enable assessment of hydraulic leakage of the alluvium.

Permanent or temporal discharge will be evalauted as part of ongoing assessments. Preliminary biodiversity studies have identified limited high value biodiversity assets along or within the creek down gradient of the proposed discharge point (Fortescue Marsh 100 km downstream). If the trial indicates the lower dewatering estimate, it is possible that a combination of various sustainable discharge options will be explored. Riparian vegetation baseline surveys are being undertaken as part of the project to identify species that may be sensitive to altered hydrology, as this will enable a more thorough assessment of the influence of creek discharge on the local biodiversity values.

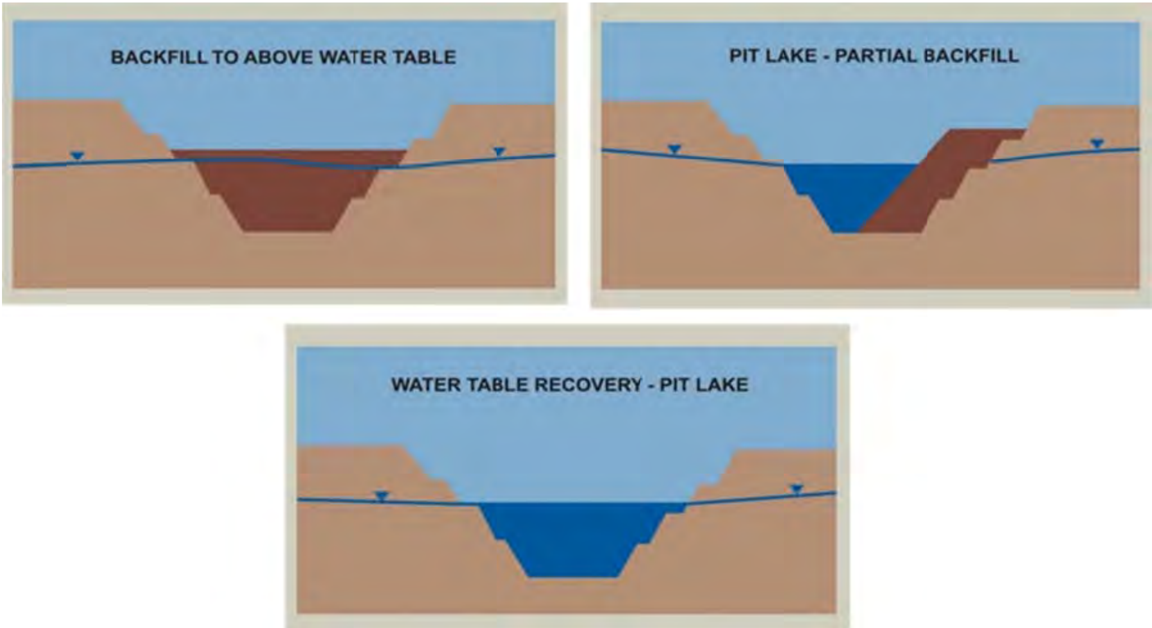
Hydrological Legacy after Mine Closure

The purpose of the closure assessment is to determine the long term hydrological impact of different closure management options for OB31. The focus of this work is the hydrological impact particularly relating to pit void management. As discussed previously, OB31 is approximately 70% BWT and once the orebody is mined out the pit void will extend well below the premining water table.

The OB31 numerical model (Appendix 1) was used to determine the long term hydrological change using three different closure management options including:

- completely infilled pit void to 5 m above the premining water level,
- partial back fill void and
- an empty void with the development of a pit lake (Figure 7).

Figure 7: Schematic representation of the different pit closure options assessed

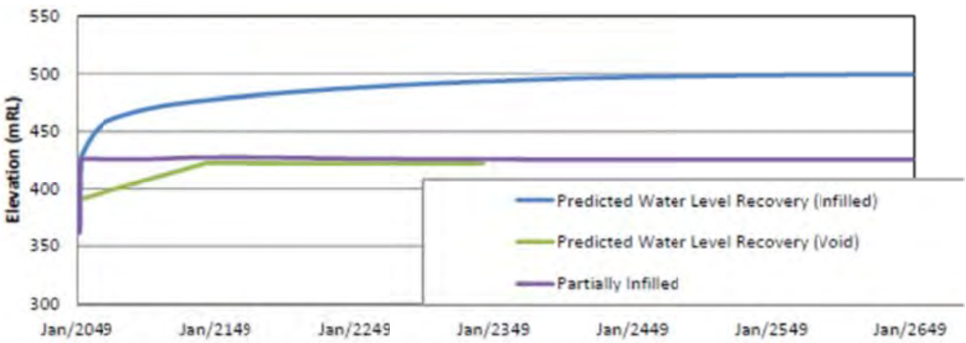


Each of the closure management options were implemented in modelling from 2048 following the cessation of dewatering at OB31. Full details of the closure prediction model set up and scenario is provided in Appendix A. For the backfilled void (assuming backfilled material of equivalent hydraulic parameters as the ore body aquifer) the water levels will rebound to premining level after an extended period of time as flow from the regional aquifer and recharge replenishes the storage of the backfilled void. For the empty void, a pit lake develops at a rate governed by the rate of groundwater and surface inflows and loss via direct evaporation. Under the open void scenario rebound to the premining water level is unlikely due to the ongoing evaporative loss from the pit lake.

The modeling predicted these dynamics, with the infilled void rebounding 100 m within 50 years of the cessation of dewatering. There was full recovery of water levels to premining levels after 600 years (90% recovery after 300 years). The partially backfilled void rebounded 55 m within 20 years of closure and achieved steady state water level after 70 years. For the pit lake scenario, water levels recover rapidly in the first 20 years following dewatering; however, the rate of rebound decreases significantly to a steady level of 420 mAHD (70 m below the premining level) (Figure 8). Each of the closure management options present different long term hydrological states. The completely backfilled void recreates the premining hydraulic gradient with through flow occurring to the north and north east. The pit lake and partial backfill options create a regional groundwater sink. The final water level is lower than the regional water table and so groundwater discharges to the pit lake where evaporation occurs.

Each closure options present different potential hydrological legacy conditions. The backfilled void recreates a premining hydrological condition; however, increases the risk of downstream impact through the potential transport of any potential acid metaliferious drainage associated with mine waste. Conversely, the pit lake sustains a drawdown footprint however reduces downstream impacts by containing poor quality water within the pit.

Figure 8: Predicted water level recovery following mining at OB31 in each of the pushback phases (Appendix 1)



Water Management Plan

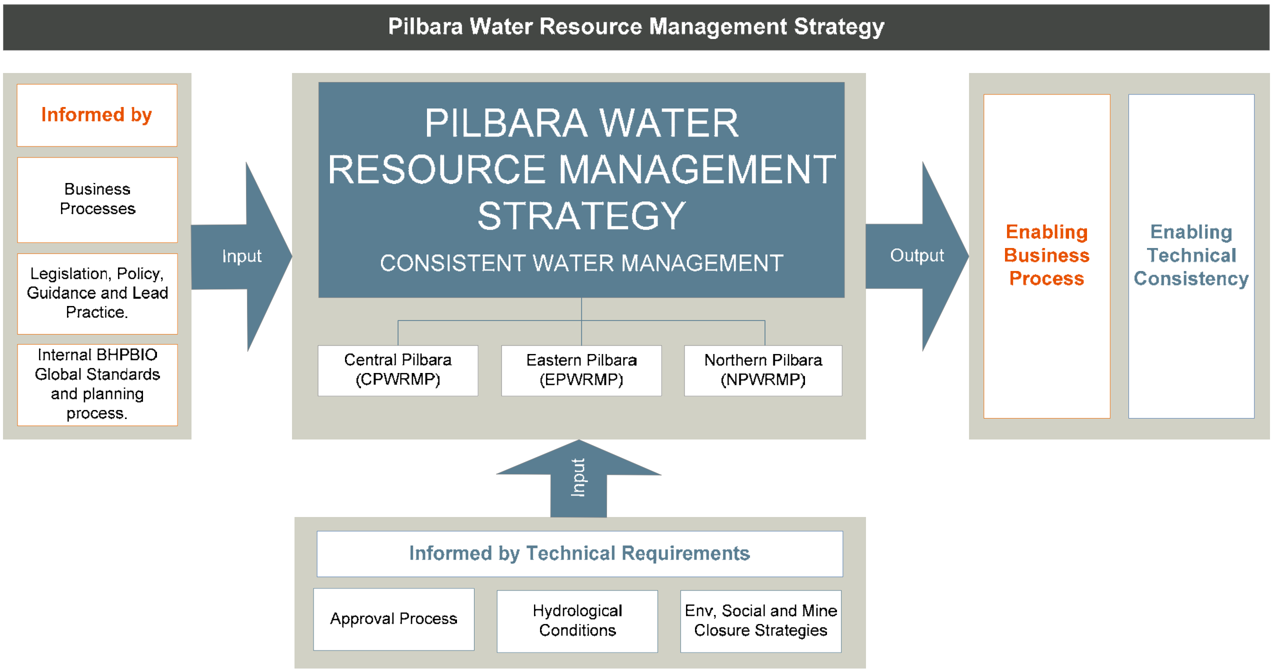
Eastern Pilbara Water Resource Management Plan

WAIO has formulated and operates under a regional water management strategy that delivers sustainable, feasible and cost effective measures to address our existing and future challenges. Importantly, the approach prepares the business for various and changing water balance scenarios and directs proactive management measures to mitigate potential impacts relating to hydrological change on a regional scale.

The objective is to enable sustainable water resource management for below water table mining operations and operations which intercept surface water flow by setting outcome-based conditions and adaptive management techniques to mitigate and offset our operational effects on water levels and quality through 1) preferentially returning surplus dewater to the aquifer and 2) maintaining baseline hydrological conditions at the key environmental receptors.

The PWRMS was designed and planned to provide a consistent approach to water management across the business, as well as providing operational and approval flexibility, as shown below:

Figure 9: Overview of the Pilbara Water Resource Management Strategy -



The EPWRMP (BHPBilliton, 2015a) aims to provide a consistent method to identify:

1. the hydrological changes (groundwater and surface water quantity, levels and quality) resulting from BHPBIO mining and closure activities,
2. the receiving receptors (water resources, environment, social and third party operations),
3. the potential impacts, and
4. the required risk-based adaptive management to mitigate potential impacts to acceptable levels.

The EPWRMP is guided by a water outcome-based objective:

To manage the range of potential hydrological changes (groundwater, surface water and/or soil moisture) resulting from BHPBIO Eastern Pilbara Hub operations impacting on receiving receptors to an acceptable level.

This objective is supported by thresholds to monitor whether a hydrological change can result in an impact to a receiving receptor as a result of BHP Billiton Iron Ore operations. Two receptors have been identified as having the potential to be impacted by changes in hydrological processes associated with the implementation of the Orebody 31 proposal, these being the Ethel Gorge TEC and Jimblebar Creek.

Early warning triggers are also defined to provide the point at which water management options must be considered and implemented to avoid potential impact to a receiving receptor; the trigger is intended to operate sufficiently early to allow water management options to be activated well oin advance of the breach of a threshold value for the receiving receptor.

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Appendix 1 OB31 groundwater numerical model

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resourcing the future

Planning

OB31 – DEWATERING PREDICTIONS

Document information

Function	Resource Planning - Hydrology
Author	Gareth Price
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0			

Table of Contents

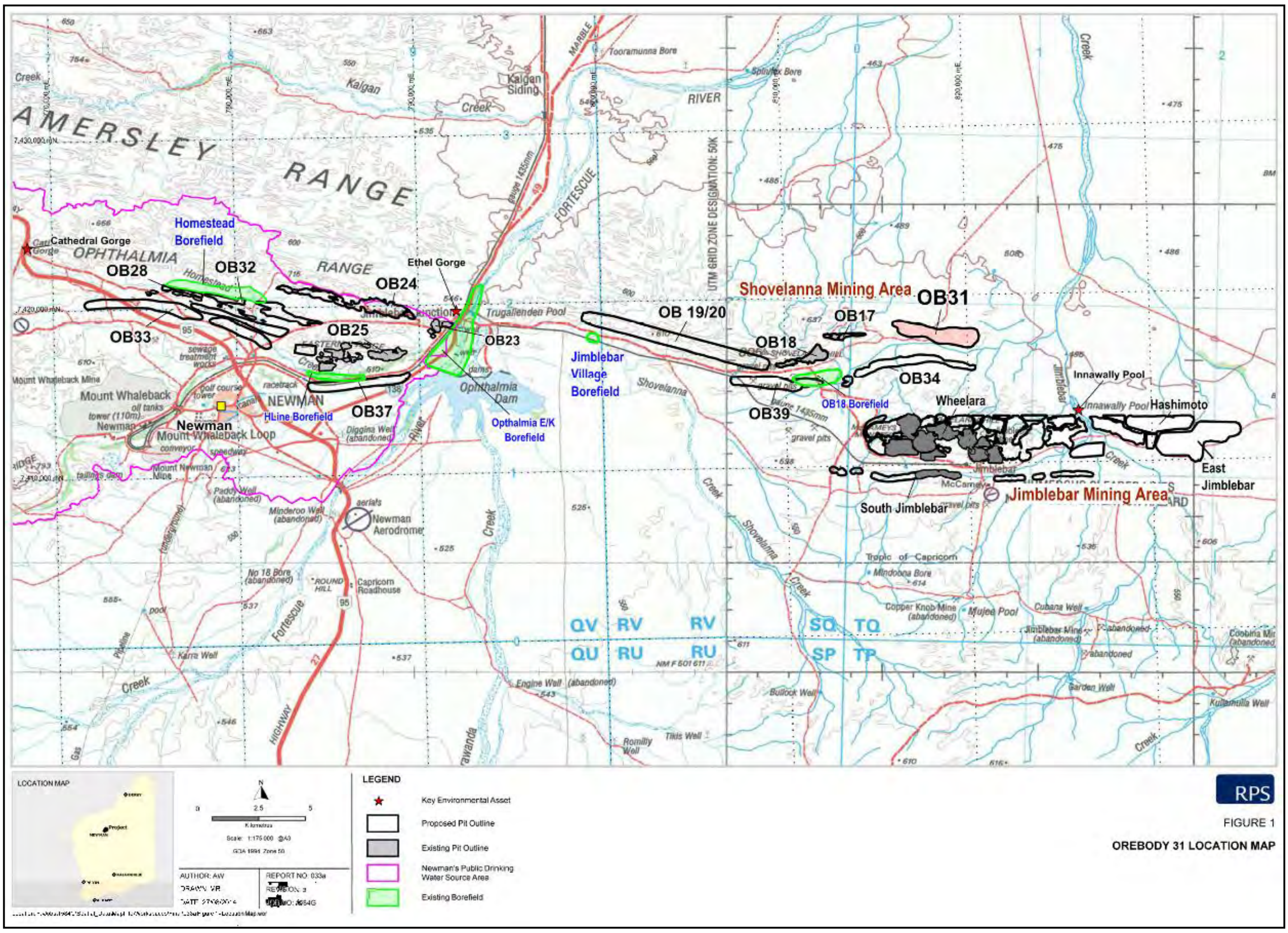
1 INTRODUCTION

1.1 BACKGROUND

The Orebody 31 (OB31) deposit is located approximately 40 km east of Newman and lies within BHPBIO's Shovelanna – Ninga – Mesa Gap mining area (hereafter referred to as the Shovelanna mining area). BHPBIO's current mining operations at OB17 and OB18, as well as the future proposed mining areas at OB19/20, OB34 and OB39 are also located within this area. The locations of these orebodies within the Shovelanna mining area are shown in Figure 1.1.

BHP Billiton Iron Ore (BHPBIO) are currently seeking approval to develop OB31 to sustain iron ore production as the OB18 mine is depleted. The purpose of this modeling study is to support engineering design and environmental impact from dewatering operations at OB31.

Figure 1.1 – Location map



1.2 OBJECTIVES AND SCOPE OF WORK

The objectives of the study were to:

- develop and calibrate a groundwater numerical model of the OB31 area suitable for simulating long term dewatering activities;
- to use the model to predict the dewatering required to support mining at OB31; and
- to test the uncertainty in these predictions.

1.3 PREVIOUS WORK

A regional scale groundwater model was developed as part of the hydrogeological assessment for the Jimblebar Iron Ore Project (Aquaterra, 2009). The model included the Shovelanna, South Jimblebar, Wheelarra Hill and Hashimoto mining areas. In 2012, the model was modified in the South Jimblebar area and calibrated to long term monitoring data from operation of the Jimblebar water supply borefield and the South Jimblebar Hydrodynamic Trial (RPS Aquaterra, 2012). Although the Shovelanna area was included in all versions of this model, no calibration was undertaken and no predictive stresses have been applied in this area in the previous studies. The preferred method for this modelling was therefore to utilise and update this existing regional model with the most recent understanding of the Shovelanna hydrogeological system.

2 CONCEPTUAL MODEL

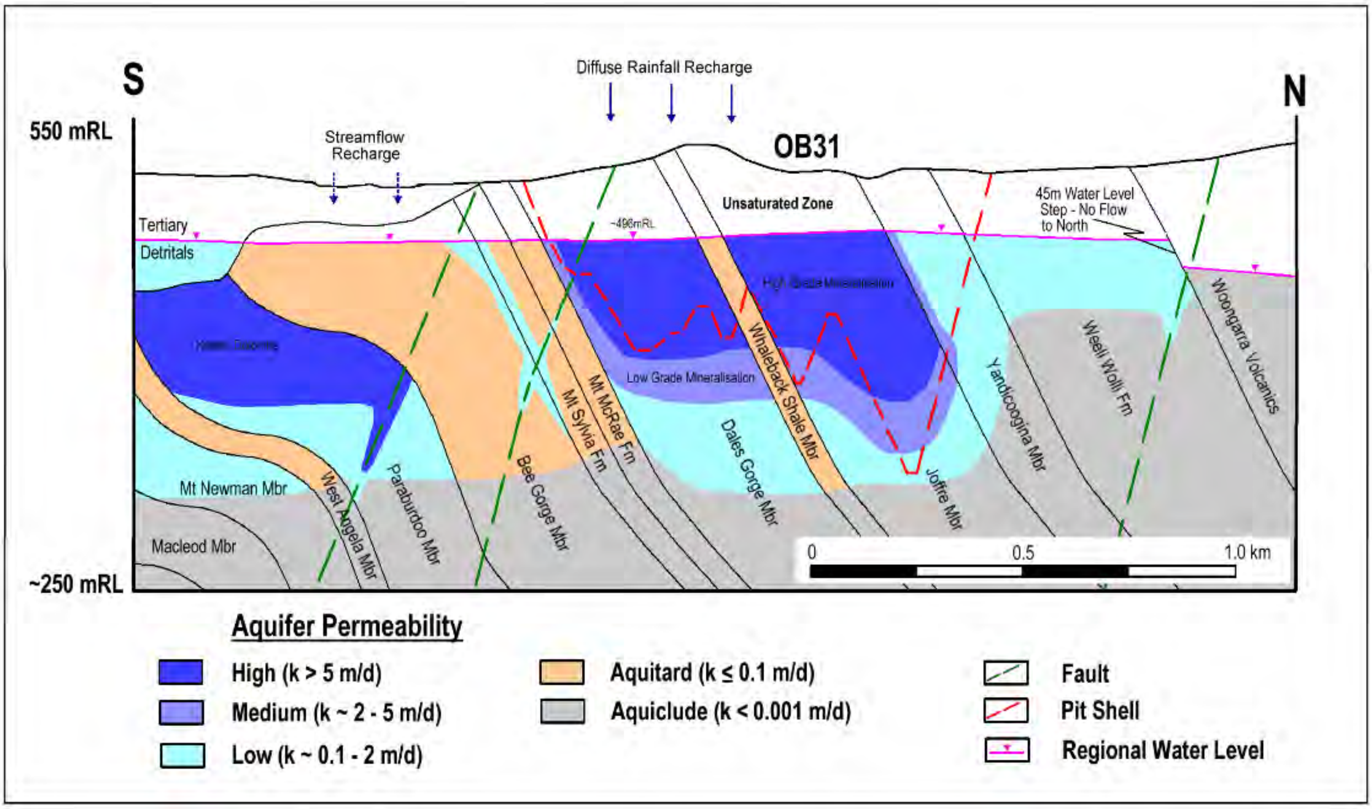
OB31 high grade ore is found within mineralised members of the Brockman Iron Formation. These mineralised units form an aquifer with elevated hydraulic conductivity and storage. The mineralisation is concentrated mainly within the Dales Gorge and Joffre Members. It is these hydrostratigraphic units (orebody aquifers) therefore that will need to be dewatered during mining of OB31.

The groundwater level gradient at OB31 is relatively flat with groundwater flow from west to east through the orebody aquifers. The depth to groundwater ranges from around 15 to 45 metres below surface. The water level elevation varies between 495 and 498 mRL. It is likely that recharge to the groundwater system via rainfall and throughflow from outside the groundwater catchment is very low.

The thickness of the orebody aquifers generally vary between 80 and 120 m, but reach a maximum thickness of approximately 150 m in the south-eastern section of the deposit. It is estimated that approximately 70% of the deposit lies below the regional water level.

The orebody aquifers are bounded immediately to the north and south by the lower hydraulic conductivity stratigraphies (Figure 2.1) of banded iron formation and shale of the Weeli Wolli Formation (north) and Mt McRae Shale (south). At a regional scale the aquifers are bounded by the low permeability Wheelarra Fault to the east.

Figure 2.1 – Hydrogeological cross section



The Dales Gorge and Joffre Members are continuous to the west (and also beneath the orebody), however, as the mineralisation envelope is not expected to extend in this direction, the permeability will be much lower in these units away from OB31.

The regional aquifer system is comprised of Tertiary Detritals underlain by weathered Paraburdoo dolomite and is confined to a relatively narrow strip along the northern edge of OB34 and OB39. Due to the presence of the McRae Shale the regional aquifer system is not in direct hydraulic connection with the orebody aquifer. However, testing of the area south-east of the OB31 aquifers has indicated that connection through the shale may be provided by structural features (e.g. southerly dipping thrust faults).

The hydrogeological investigations undertaken at OB31 have provided sufficient information for the main flow mechanisms to be defined. However, as the aquifers have not been tested for a significant amount of time (commensurate to the time needed for dewatering) uncertainties remain. The greatest uncertainties in terms of the factors that will control the scale of dewatering required at OB31 are:

- The extent and degree of hydraulic connection between the orebody aquifer and the regional aquifer system along the southern margin of the OB31 deposit.
- The westward extent of permeable (submineralised) Dales Gorge and Joffre units.
- The continuity of the regional aquifer system and the degree of hydraulic connection with Ethel Gorge to the west and Jimblebar Creek to the east.
- The hydraulic characteristics of the Wheelarra Fault System to the east of OB31.

3 NUMERICAL MODEL

3.1 MODEL SET-UP

The groundwater model was developed using the Modflow Surfact code (Hydrogeologic, Version 3.0) operating under the Groundwater Vistas graphical user interface (Rumbaugh and Rumbaugh, 1996 to 2007).

The model domain and grid and the location of model boundary conditions is shown in Figure 3.1.

The model uses a minimum model grid size of 50 m by 50 m and is divided into 291 rows and 671 columns.

The model and all associated data are specified using the GDA94 Zone 51 coordinate system. The model domain covers an area of 48 km (west to east) by 20 km (south to north).

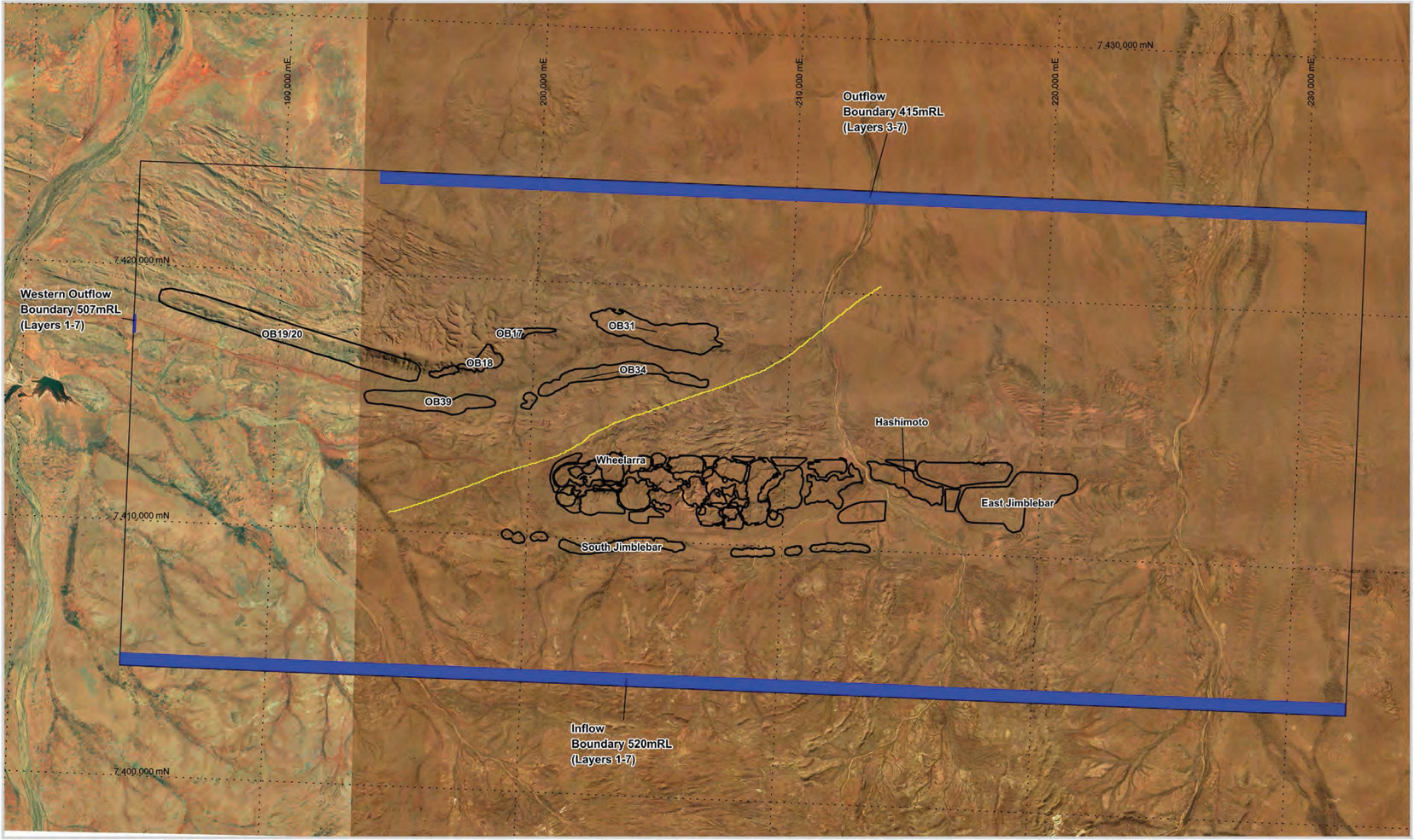
The hydrogeology of the OB31 and surrounding areas is represented by seven layers as summarised in

Table 3.1.

Table 3.1 – Model layer set-up

Layer	Description	Thickness
1 - 3	Tertiary valley fill aquifer (alluvium) Upper sections of OB31 and South Jimblebar orebody aquifers. Aquifers associated with mineralised Marra Mamba and Brockman iron formations west of Wheelarra fault (OB17, 18, 34 and OB39). Weathered dolomite aquifer (Paraburdoo Member) (West of Wheelarra fault). Weathered to fresh basement rocks adjacent to OB17, 18, 19, 20, 31, 34 and OB39 and Tertiary valley-fill / South Jimblebar orebody.	Layer 1: approximately 120 m thick Layer 2: 36 m thick Layer 3: 36 m thick
4 - 5	Lower sections of OB31 and South Jimblebar orebody aquifers. Lower sections/patches of Tertiary valley fill aquifer (alluvium) (West of Wheelarra fault). Weathered dolomite aquifer (Paraburdoo Member). Basement rocks surrounding the weathered dolomite and orebody aquifers	Layer 4: 30 m thick Layer 5: 30 m thick
6	Fresh dolomite aquifer (Paraburdoo Member). South Jimblebar orebody aquifer. Basement rocks surrounding the dolomite and orebody aquifers.	Layer 6: 24 m thick
7	Basement rocks.	Layer 7: 52 m thick

Layer 1 has a variable thickness as defined by the top set at ground level and the base set at 458 mRL. The thicknesses of the remaining layers are uniform. The hydrogeological units represented in Layer 3 are illustrated in Figure 3.2.



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Kilometres

Scale: 1:125,000 @A3

GDA 1994 Zone 50

AUTHOR:	JP	REPORT NO:	033
DRAWN:	MR	REVISION:	c
DATE:	12/06/2014	JOB NO:	1584G

Location: F:\Jobs\1584GB\Spatial_Data\Mapinfo\Workspaces\033a\Final\033a Figure 5 - Model Extent

LEGEND

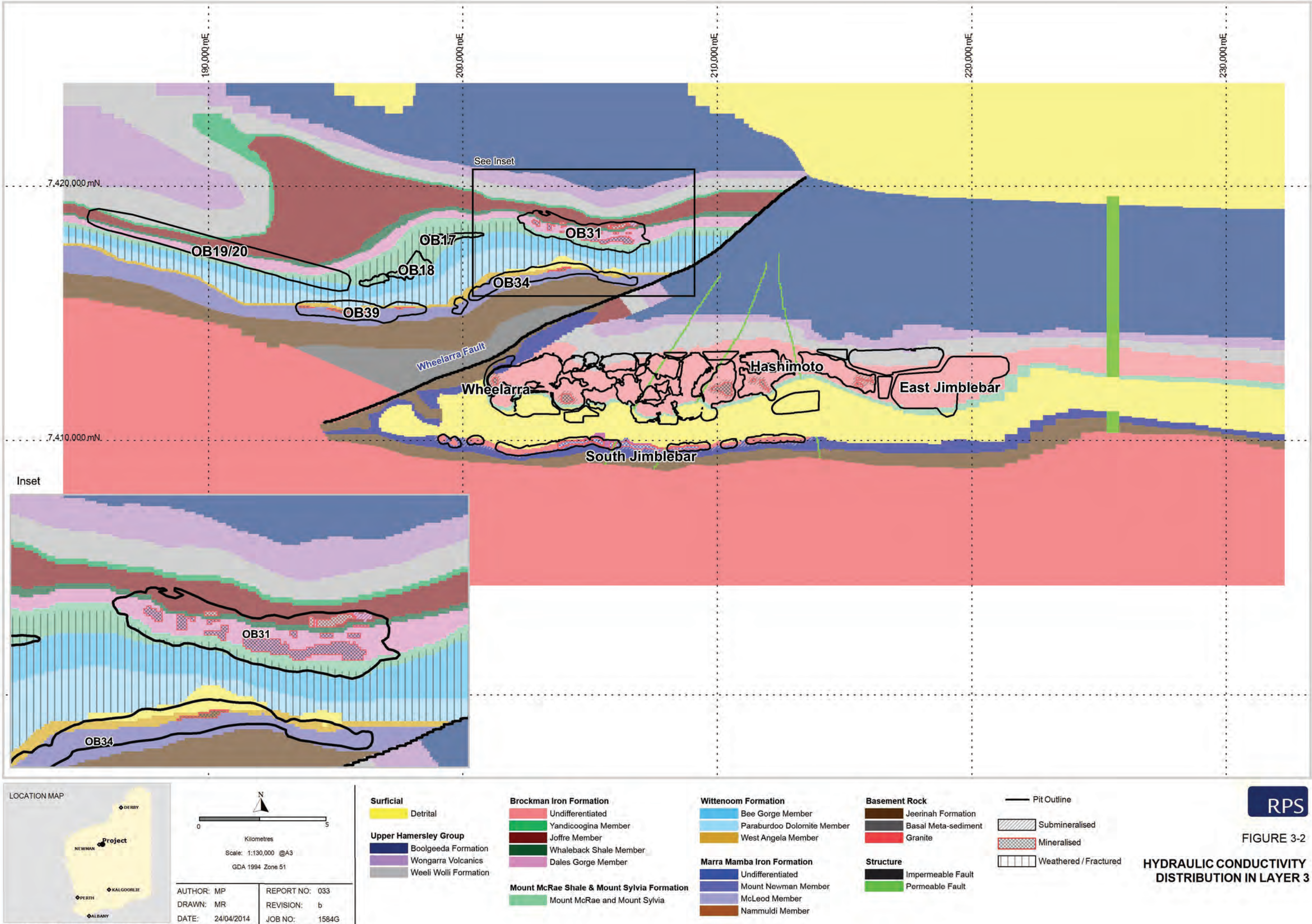
- Pit Outline
- Wheelarra Fault represented as Horizontal Flow Boundary (model Layers 1 to 7)
- Modelled Constant Head Boundary

DATA SOURCES:
BHPB Iron Ore

RPS

FIGURE 3-1

MODEL EXTENT AND BOUNDARY CONDITIONS



AUTHOR:	MP	REPORT NO:	033
DRAWN:	MR	REVISION:	b
DATE:	24/04/2014	JOB NO:	1584G

RPS

FIGURE 3-2

HYDRAULIC CONDUCTIVITY DISTRIBUTION IN LAYER 3

Location: F:\Jobs\1584G\Spatial_Data\MapInfo\Workspaces\Final\033a Figure 6 - Hydraulic Conductivity Distribution in Layer 3.wor

3.2 REGIONAL THROUGHFLOW

To reproduce the regional groundwater throughflow characteristics, fixed head boundaries are included across the southern, western and northern boundaries of the model domain as shown in Figure 3.1. The heads are set at:

- Southern inflow = 520 mRL
- Western inflow = 507 mRL
- Northern outflow = 415 mRL

All other model boundaries are assigned as the no-flow type and are aligned consistent with catchment boundaries or perpendicular to the inferred direction of groundwater flow.

3.3 RAINFALL RECHARGE

Recharge is assigned as a proportion of recorded average annual rainfall (310 mm per year) to the following areas:

- Valley-fill alluvium (0.5% average annual rainfall)
- Creek channels in valley floors (1.0% average annual rainfall)
- Outcropping orebody aquifers (2.5% average annual rainfall)

3.4 EVAPOTRANSPIRATION

Evapotranspiration (EVT) from phreatophytic vegetation was incorporated in the model and defined based on detailed vegetation mapping. The EVT surface was assigned 5 m below the ground surface with extinction depth of 15 m. The EVT rate was assigned a constant value of 1 m/year or 2.64 x10^{-4} m/d.

3.5 CALIBRATION

3.5.1 Pre-development groundwater levels

The model was calibrated to pre-development groundwater levels measured at a total of 353 hydrogeological investigation bores and mineral resource exploration bores in the Shovelanna mining area (including OB17, OB18, OB19/20, OB31, OB34 and OB39).

3.5.2 Time variant groundwater responses

The model was calibrated against almost ten years of observations associated with groundwater abstraction from the OB18 water supply borefield. The borefield has been operated since 2005 with average abstraction rates in the order of 2,000 kL/d. The OB18 borefield consists of six production bores and 14 monitoring bores. Whilst this data is somewhat distant from OB31, it does provide valuable information on the hydraulic characteristics of the regional aquifer system.

The model was also calibrated against data collected from constant rate test pumping tests at three separate locations within the OB31 orebody aquifer. The tests were conducted over the period October 2013 to March 2014. Details of the selected tests are summarised in

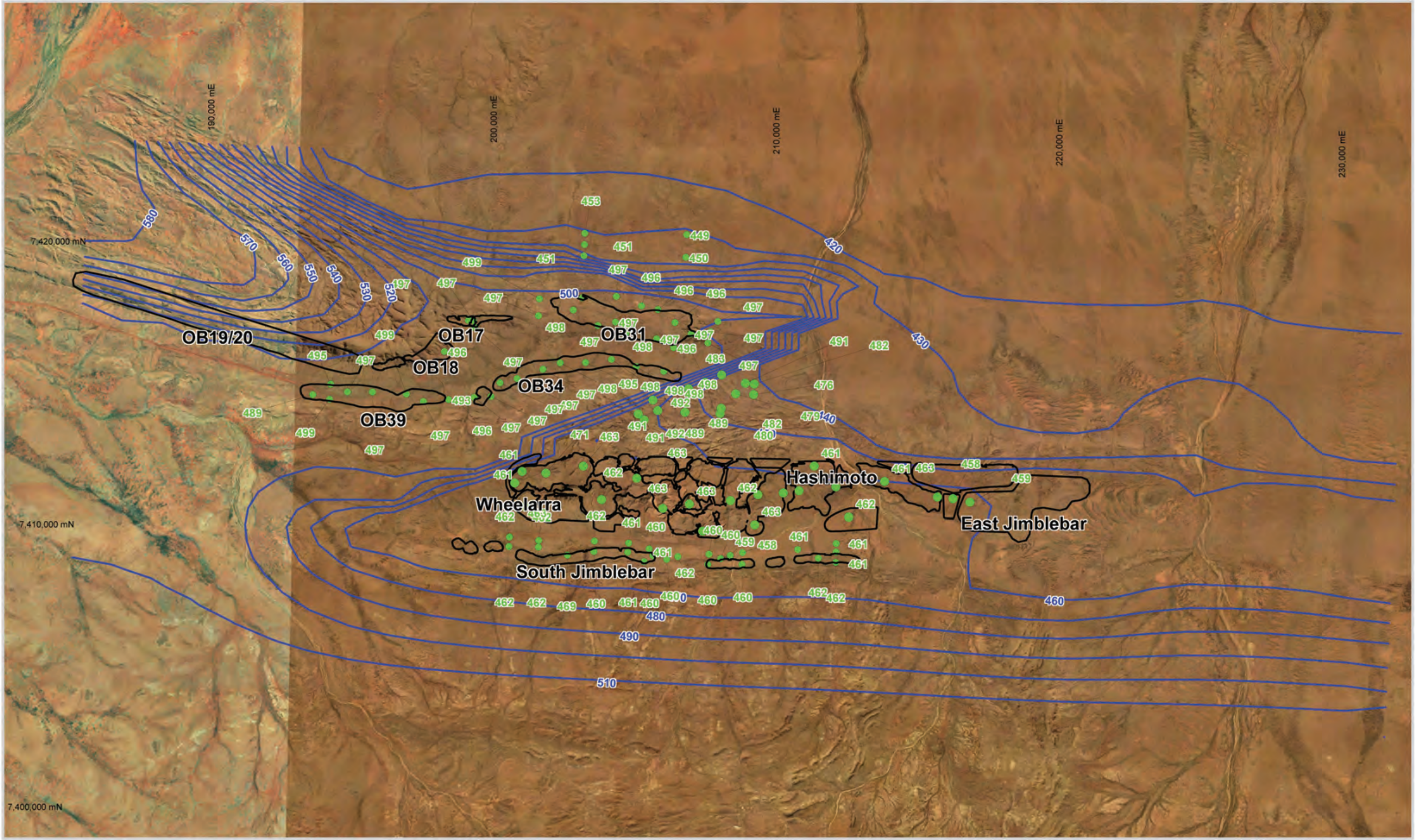
Table 3.12.

Table 3.2 OB31 Constant Rate Test Pumping Details

Production Bore ID	Test Duration (days)	Constant Pumping Rate (kL/d)
HEB0021	5	8,640
HEB0022	11	4,320
HEB0033	10	4,752

3.5.3 Results

The model was able to reproduce these data with an appropriate level of accuracy. The observed and simulated predevelopment groundwater levels are shown in Figure 3.3. This shows that west of the Wheelarra Fault the simulated values match the observed well. Just to the east of the fault there is a small area where the simulated values are significantly lower than the observed, although this is unlikely to influence the model dewatering predictions.



LOCATION MAP

DERBY

NEWMAN

Project

KALGOORLIE

PERTH

ALBANY

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Kilometres

Scale: 1:125,000 @A3

GDA 1994 Zone 51

AUTHOR: MP

DRAWN: MR

DATE: 24/04/2014

REPORT NO: 033

REVISION: c

JOB NO: 1584G

LEGEND

485 Observed Water Level (mRL)

Predicted Water level (mRL)

Orebody outline

RPS

FIGURE 3-3

MEASURED WATER LEVELS AND PREDICTED STEADY STATE WATER LEVEL CONTOURS

Location: F:\Jobs\1584G\Spatial_Data\MapInfo\Workspaces\Final\033a Figure 19 - MEASURED WATER LEVELS AND PREDICTED STEADY STATE WATER LEVEL CONTOURS.wor

Figure 3.4 provides some examples of observed and simulated groundwater levels close to the OB18 water supply borefield. These show that the model replicates the rate of groundwater drawdown well in this area and, that in this area at least, the hydraulic parameters applied to the regional aquifer and the surrounding units are appropriate.

Figure 3.4 – Calibration to OB18 water supply borefield data

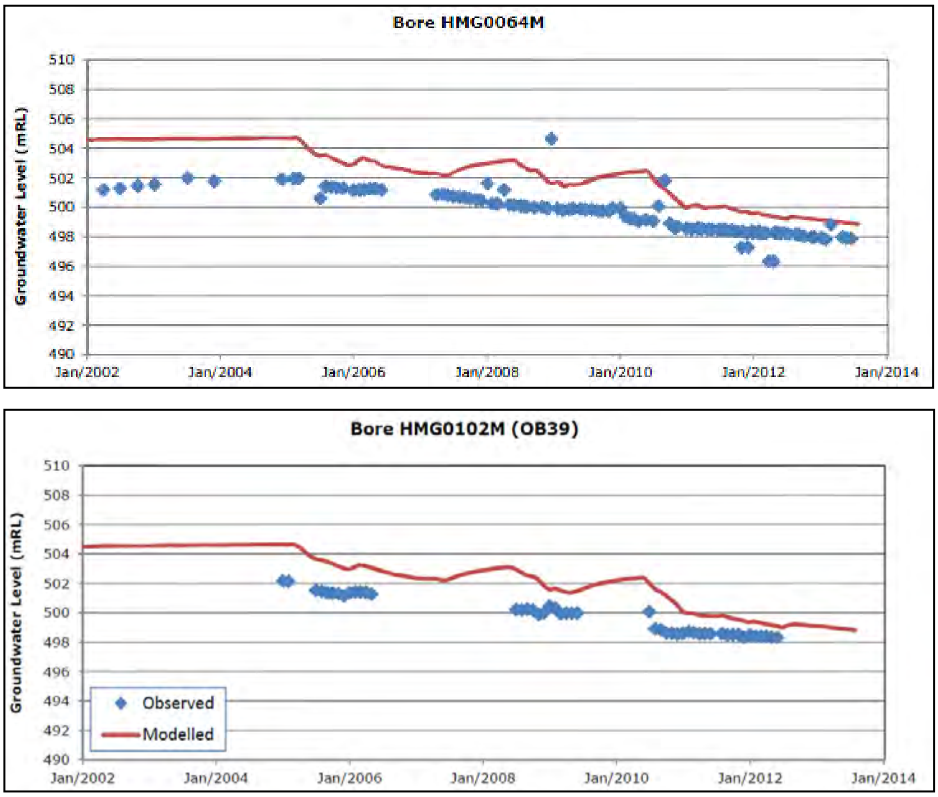
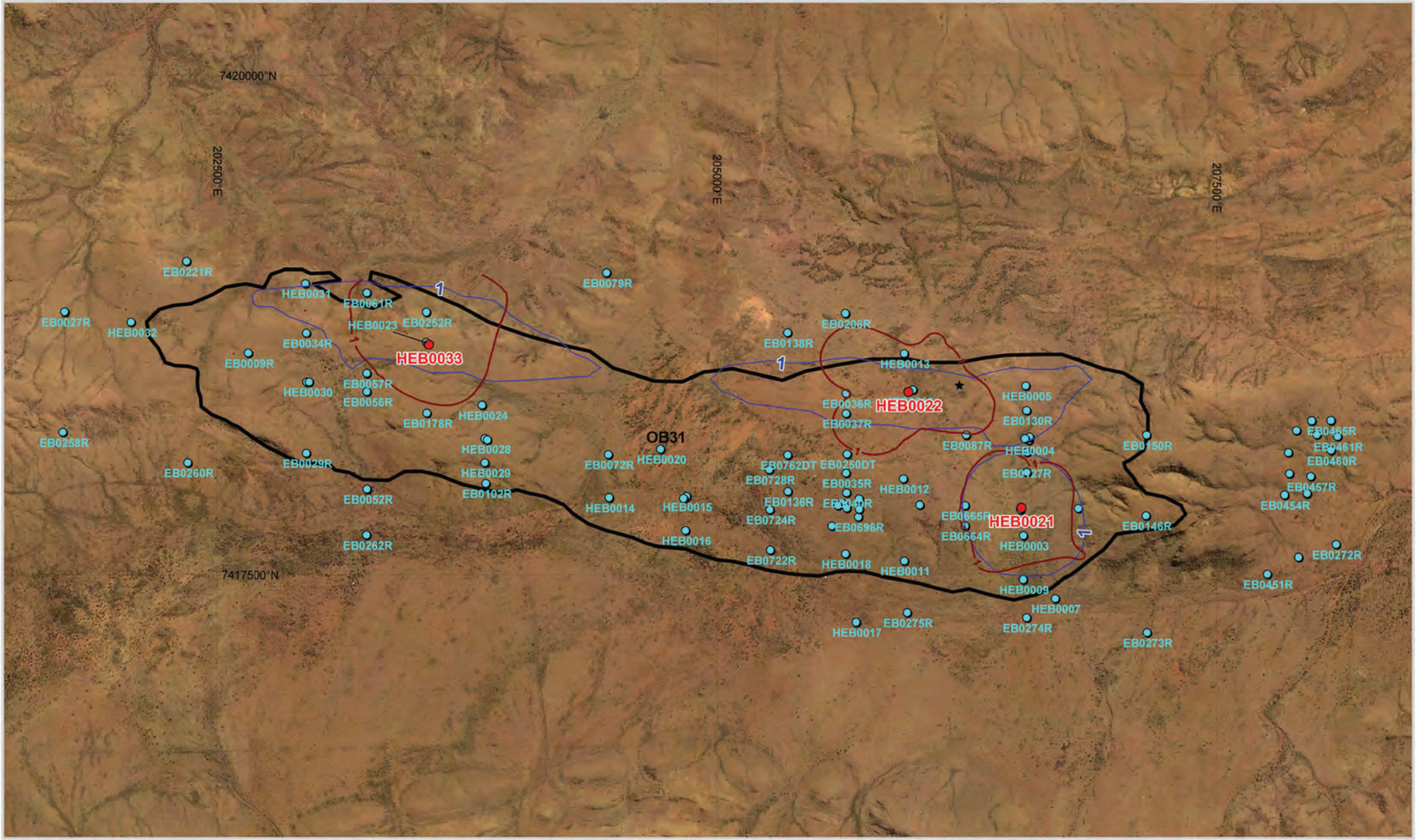


Figure 3.5 shows the observed and simulated 1 m drawdown contours produced by the three constant rate tests. The observed response at HEB0021 is replicated very well by the model. The response at the other two tests is not replicated as well however as the simulated response is more elongated along the east / west direction than the observed, which is more radial.



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GDA 1994 Zone 51

AUTHOR:	MP	REPORT NO:	033
DRAWN:	MP	REVISION:	b
DATE:	23/06/2014	JOB NO:	1584G

Location:F:\Jobs\1584G\Spatial_Data\MapInfo\Workspaces\Final\033a Figure 26 - Pumping test at OB31.wor

LEGEND

- Observed Drawdown (m)
- Predicted Drawdown (m)
- OB31 Pit Outline
- Pumping bore
- Monitoring bore

RPS

FIGURE 3-5

OREBODY 31 OBSERVED AND PREDICTED DRAWDOWN IN THE WATER TABLE

Whilst every effort has been made to calibrate the model to these three datasets, it is clear that the information is not sufficient to provide a robust transient calibration in the Shovelanna area for the purposes of the dewatering predictions over a 30 year mine life. Therefore a significant amount of uncertainty remains in the model parameterisation, in particular with respect to the regional hydraulic connection and orebody aquifer storage and extent.

3.5.4 Hydraulic parameters

A summary of the hydraulic parameters of the key hydrostratigraphic units included in the model is provided in

Table 3.13. These values were determined through the process of model calibration and the use of estimates based on experience and knowledge of similar systems in the Pilbara.

Table 3.3: Base Case hydraulic parameters

Hydrogeological Unit	Description	Horizontal Hydraulic Conductivity (m/d)	Vertical Hydraulic Conductivity (m/d)	Specific Storage (m^{-1})	Specific Yield (%)
Yandicoogina Member	Fractured	0.1	0.1	1.0 × 10-5	1
	Fresh	1.0 × 10-3	1.0 × 10-3	1.0 × 10-5	0.1
Joffre Member	Fresh	1.0 × 10-3	1.0 × 10-3	4.7 × 10-7	0.1
	Fresh / Fractured	5.0 × 10-2	5.0 × 10-2	4.7 × 10-7	1
	Mineralised	8.0	8.0	4.7 × 10-7	2
Whaleback Shale	-	1.0 × 10-3	1.0 × 10-3	2.0 × 10-4	1
Dales Gorge Member	Fresh	1.0 × 10-3	1.0 × 10-3	4.7 × 10-7	0.1
	Submineralised	8	8	4.7 × 10-7	5
	Mineralised	10	10	4.7 × 10-7	5
Mt McRae Shale	-	1.0 × 10-3	1.0 × 10-3	2.0 × 10-4	0.1
Mt Sylvia Formation and Bee Gorge Member	Upper	0.1	0.1	4.7 × 10-7	0.1
	Lower	1.0 × 10-3	1.0 × 10-3	4.7 × 10-7	0.1
Paraburdoo Member	Weathered	10	10	4.7 × 10-7	0.5
	Fresh	1.0 × 10-3	1.0 × 10-3	4.7 × 10-7	0.1

4 DEWATERING PREDICTIONS

4.1 APPROACH

The historical time variant model was adapted for the purposes of simulating future dewatering of OB31. To investigate the significance of the uncertainties with hydraulic parameters the model was run twice, once with the Base Case hydraulic parameters and once with a modified set of parameters (known as the "Upper Bound"). The Upper Bound run was designed to test the upper limit of dewatering estimates. To do this key aquifer parameters controlling regional connection and aquifer storage were increased to their highest possible values.

4.2 MODEL SET-UP AND ASSUMPTIONS

The predictive model was run for a period of 31 years (YEJ2018 to YEJ2048). Inflow and outflow boundary condition settings were unchanged from the historical model.

Dewatering was simulated using drain boundary conditions. The drain elevations were set consistent with the projected base of the pit varying with time as summarised in Table 4.1. No proactive dewatering was simulated. The drains were left in place until the end of the model and dewatering was therefore assumed to continue to the end of YEJ2048.

Pumping from South Jimblebar was assumed to continue at 2014 rates until the end of the model. Abstraction from the OB18 borefield was assumed to cease at the start of the predictive model, with that water being made up from the OB31 abstraction.

The Base Case model used the parameter values shown in Table 3.3. The following changes were made to the Upper Bound model:

- The hydraulic conductivity of unmineralised Dales Gorge Member was increased to 0.1 m/d (Base Case 0.001 m/d).
- The hydraulic conductivity of Mt McRae Shale Formation was increased to 0.1 m/d (Base Case 0.001 m/d).
- The confined storage of all units west of the Wheelarra Fault was increased to 5×10^{-6} (Base Case 5×10^{-7}).
- The specific yield of all units west of Wheelarra Fault was increased to 1% (Base Case 0.1% and 0.5%).

- The specific yield of mineralised Dales Gorge Member was increased to 10% (Base Case 5%).

4.3 MINE PLAN

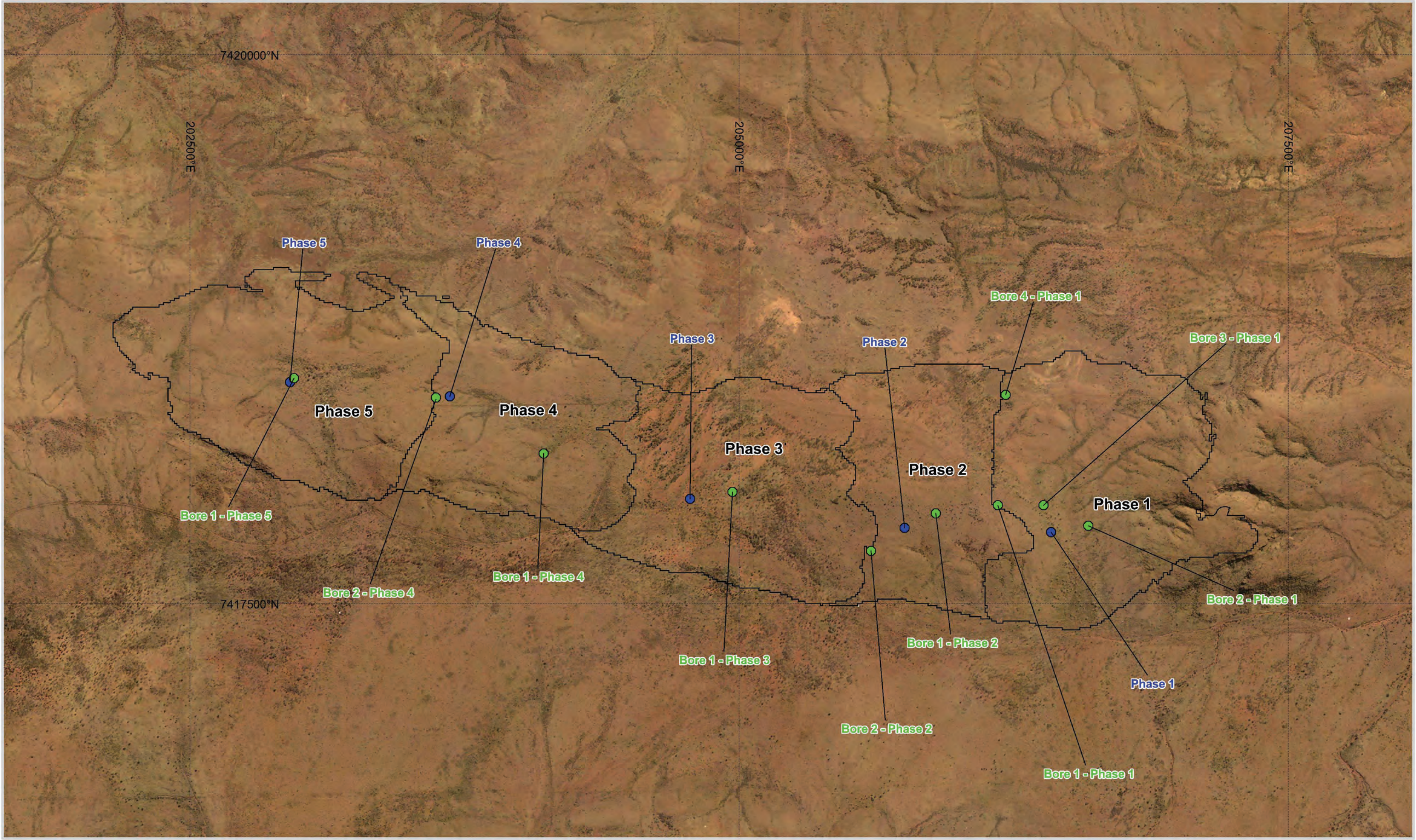
The mine plan includes five Phases (Phases 1 to 5) within the proposed mine area as shown in Figure 4.1.

Mining is planned to commence at the western end of OB31 and progress to the east. The mine schedule adopted for dewatering predictions is summarised in

Table 3.1. Elevations shown in bold type indicate mining below the water table.

Table 4.1: OB31 Mine Schedule Phases 1 to 5

	Phase 1 (mRL)	Phase 2 (mRL)	Phase 3 (mRL)	Phase 4 (mRL)	Phase 5 (mRL)
YEJ2018				540	516
YEJ2019				540	504
YEJ2020				540	**480**
YEJ2021				528	**456**
YEJ2022				528	**444**
YEJ2023				516	**372**
YEJ2024				504	
YEJ2025				**492**	
YEJ2026				**468**	
YEJ2027			516	**456**	
YEJ2028			516	**432**	
YEJ2029			**492**	**372**	
YEJ2030			**468**		
YEJ2031		516	**456**		
YEJ2032	552	516	**420**		
YEJ2033	552	**492**	**372**		
YEJ2034	552	**480**			
YEJ2035	552	**468**			
YEJ2036	528	**456**			
YEJ2037	528	**432**			
YEJ2038	516	**420**			
YEJ2039	504	**372**			
YEJ2040	**492**				
YEJ2041	**480**				
YEJ2042	**468**				
YEJ2043	**456**				
YEJ2044	**444**				
YEJ2045	**432**				
YEJ2046	**408**				
YEJ2047	**408**				
YEJ2048	**360**				



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GDA 1994 Zone 51

AUTHOR: MP	REPORT NO: 033
DRAWN: MP	REVISION: b
DATE: 12/06/2014	JOB NO: 1584G

LEGEND

- Pit Outline
- Modelled observation bore location
- Pumping bore used to simulate dewatering

RPS

FIGURE 4-1

OREBODY 31
MINING PHASES

Location: F:\Jobs\1584G\Spatial Data\MapInfo\Workspaces\Final\033a Figure 27 - OB31 mining phases.wor

4.4 RESULTS

The predicted regional drawdown in YEJ2048 is shown for both cases in Figure 4.2. The figures show that drawdown:

- local to the OB31 aquifer is in excess of 100 m.
- does not extend across the Wheelarra Fault either from OB31 to the Jimblebar area or vice versa
- to the westernmost part of OB39 is just under 10 m in the Base Case and almost 30 m in the Upper Bound.
- is focused through the higher permeability material that runs west to east through the catchment.

The predicted dewatering rates from the Base Case model are shown in Figure 4.3. With these best estimate parameters the model predicts that:

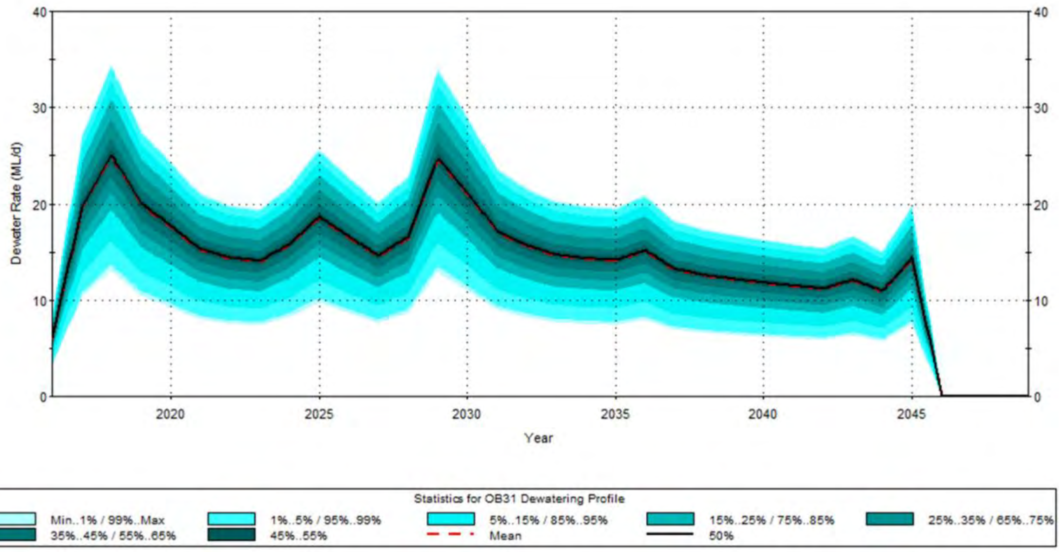
- Maximum dewatering of about 11,500 kL/d will occur in YEJ2021.
- Average dewatering over the mine life will be around 4,900 kL/d.
- Excluding the peaks, the background dewatering is relatively constant at about 4,000 kL/d.

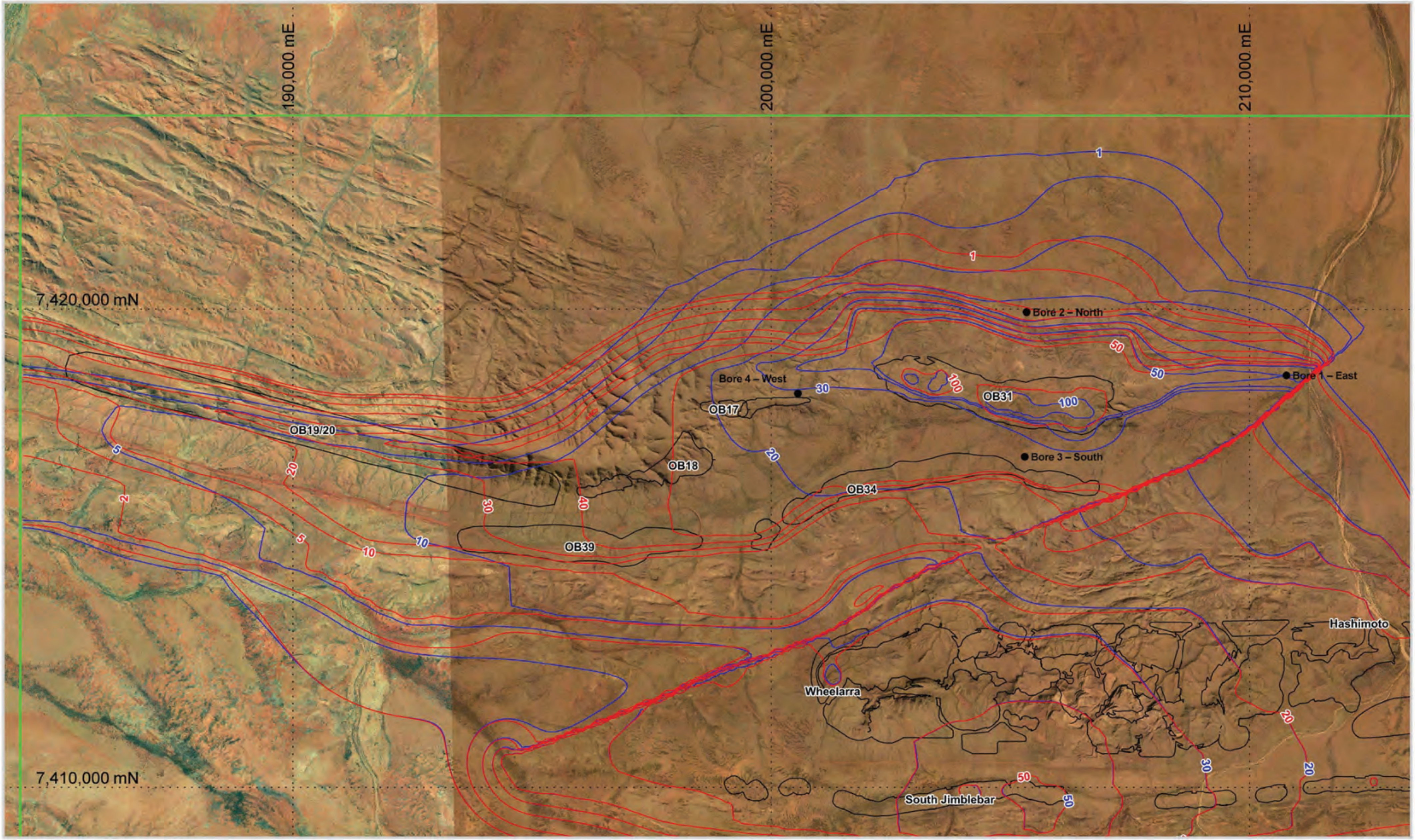
The Upper Bound run produces roughly double the dewatering of the Base Case. With greater aquifer storage and connection with the regional aquifer system the model predicts that:

- Maximum dewatering of about 21,000 kL/d will occur in YEJ2021 and YEJ2032.
- Average dewatering over the mine life will be around 11,600 kL/d.

In both models several peaks in dewatering are predicted after the initial maximum in YEJ2021. These are related to the commencement of mining at lower elevations and/or new Phases.

Figure 4.3 – Predicted OB31 life of mine dewatering





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DRAWN: MP	REVISION: c
DATE: 12/06/2014	JOB NO: 1584G

Location: F:\Jobs\1584G\Spatial Data\MapInfo\Workspaces\Final\033b Figure 32 - Predicted high case drawdown.wor

LEGEND

- Pit Outline
- Predicted drawdown (m) - Base case
- Predicted drawdown (m) - Upper Bound
- Model Domain

RPS

FIGURE 4-2

PREDICTED DRAWDOWN (BASE CASE AND UPPER BOUND) YEJ2048

5 CLOSURE

5.1 INTRODUCTION

The Base Case model was used to simulate post closure (from YEJ2048) groundwater conditions at OB31. The models were run with three closure scenarios (fully backfilled, partially backfilled and no backfill). The models were time variant models and run until the groundwater levels returned to equilibrium in the local OB31 area. The various assumptions and model settings required are outlined below:

- There is no further pumping in the catchment from YEJ2048
- Both partial and complete backfilling of the void is finished at the same time that mine dewatering ceases (i.e. in YEJ2048)
- Backfill hydraulic parameters are identical to the OB31 orebody aquifer
- Recharge to backfilled material is unchanged from the pre-mine condition
- Voids are simulated by:
    - Increasing specific yield and hydraulic conductivity to 99% and 100 m/d respectively.
    - Assigning evaporation to the void footprint at 50% of measured pan evaporation (which equals 1.85 m/yr)
    - Assigning recharge of 100% average rainfall to the void area
    - Assigning 20% of incident run-off from the pit catchment to the void
- In the partial backfill scenario it is assumed that the southern half of the voids are backfilled to 5 m above pre-development water level and the northern half is left as a void. The void and backfill settings are the same as above.

5.2 RESULTS

Complete backfilling of the OB31 pit voids is predicted to result in recovery of the local groundwater table to the pre-development level (roughly 500 mRL). Full recovery occurs slowly (over many hundreds of years) however 75% of the recovery occurs within the first 50 years.

If the OB31 pits are not backfilled the model predicts that a lake will form and reach its final level within 20 years. The lake is predicted to stabilise at 420 mRL in Phases 1, 3, 4 and 5. However, due to the lack of hydraulic connection at depth between the Phase 2 pit void and the other voids, the lake in Phase 2 stabilises at a lower level (385 mRL). In this situation therefore, the local groundwater system will not return to its pre-development level.

In the partial backfill case a continuous pit lake forms in the remaining pit void. The water level of the lake is predicted to be about 425 mRL. The backfill therefore has the effect of connecting the Phase 2 void with the others. Equilibrium is predicted within 70 years of closure.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Numerical groundwater flow modelling has provided predictions of the time variant dewatering requirements to develop the OB31 deposit. Based on the best estimates for hydraulic parameters and the local and regional geological setting the dewatering is expected to average 4,900 kL/d over the mine life. As calibration data is limited in the area a realistic upper limit to the dewatering estimates has also been provided. This shows that if regional aquifer connectivity and orebody aquifer storage are higher than assumed in the best estimate case, the dewatering may average 11,600 kL/d.

6.2 UNCERTAINTY AND LIMITATIONS

The main uncertainties associated with the model are:

- Lack of any long term transient calibration data in the OB31 area commensurate with long term mine dewatering.
- Uncertainty over hydraulic connection between the orebody aquifers and the regional aquifers through the Mt McRae Shale.
- Uncertainty in the hydraulic characteristics of the orebody stratigraphic along strike (to the west).
- Assumptions inherent in the mine plan (i.e. rate, sequence, timing and depth of pushbacks).
- Assumptions in closure settings (particularly backfill properties and evaporation rates)

6.3 RECOMMENDATIONS

It is recommended that long-term pumping and monitoring (in the form of a hydrodynamic trial conducted over several months) be implemented in the OB31 deposit. This will assess the hydraulic connection between the OB31 aquifers and the regional aquifer system, as well as the connection across the Wheelarra Fault. The monitoring and abstraction data should then be used to advance the model calibration. This will then provide more confidence in the best estimate dewatering predictions and reduce the range of possibilities.

7 REFERENCES

Aquaterra, (2009): *Hydrogeological Assessment for South Jimblebar Iron Ore Project*. Ref. 1008/057b. Perth, Aug 2009.

RPS Aquaterra, (2012): *South Jimblebar Hydrogeological Assessment in support of 5c Groundwater Licence*, Ref 1008Q/090a.

Appendix 2 Ethel Gorge regional numerical model – OB31 Cumulative impact study

RPS

REGIONAL NUMERICAL MODELLING OF OREBODY 31 SUMMARY REPORT

REGIONAL NUMERICAL MODELLING OF OREBODY 31 SUMMARY REPORT

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Document Status

	Issue Date	Purpose of Document
Revision A	06.02.15	Client Review

	Name	Position	Signature	Date
Author	Kathryn Rozlapa	Principal Modeller		22.09.14 06.02.15
Reviewer	Alan Woodford	Principal Hydrogeologist		22.09.14

Disclaimer

TABLE OF CONTENTS

TABLES

FIGURES (compiled at end of report)

1. INTRODUCTION

1.1 Objectives

The objective of the study was to predict the changes to groundwater levels resulting from mine related dewatering at Orebody 31 (OB31) and associated discharge of surplus water to Ophthalmia Dam (the Dam). The main focus was on the area of Stygobiont habitat located in the vicinity of Ethel Gorge. The work was carried out to support the OB31 environmental approvals.

1.2 Background

Orebody31 is located approximately 40km east of Newman and lies within BHPBIO's Shovelanna mining area. Orebody 31 is also located 22km to the east of Ethel Gorge (the Gorge). The Gorge is downstream (north) of the confluence of Homestead, Shovelanna and Warrawanda Creeks within the Fortescue River catchment (Figure 1). The Gorge is formed where the Fortescue River flows through the Ophthalmia Range in a northerly direction. Surface and groundwater flows from the entire upstream catchment area are focused into the Gorge resulting in relatively shallow groundwater levels, typically less than 10m below ground level (mbgl). The area hosts the Ethel Gorge Stygobiont Threatened Ecological Community (TEC) (Figure 1).

Both the OB31 and Ethel Gorge areas have been the focus of studies involving drilling, testing, ongoing monitoring and groundwater modelling.

Studies for the OB31 area date back to the mid-1990s. Most recently, a drilling and testing programme was completed for the OB31 area (RPS 2014a) and used to support a hydrogeological conceptualisation and modelling study for the area (RPS 2014b). Key areas of uncertainty still remain in the OB31 area and it is anticipated that these will be addressed as part of future hydrogeological studies.

Numerous previous studies for the Gorge date back to 1970. The availability and synthesis of this data provides confidence in the Gorge hydrological system and most recently this data was used to complete a detailed hydrogeological conceptualisation for the area and surrounding catchments (RPS 2014c).

A regional numerical groundwater flow model was developed for the groundwater catchment that supports the Gorge and the TEC as part of a case study for BHP Billiton's Strategic Environmental Assessment (SEA). The model has been developed based on the detailed hydrogeological conceptualisation for the Gorge and includes the findings of the recently completed OB31 hydrogeological and modelling study (RPS 2014b)

This report provides a summary of the Gorge hydrogeological conceptualisation, the groundwater flow model and the model predictions. The model is described in full in RPS 2014d (in prep).

1.3 Ethel Gorge Conceptualisation

The conceptual hydrogeology of the Gorge is described in detail in the Eastern Pilbara Hub (EPH) Eco Hydrological Conceptualisation Report (RPS 2014c). That report also contains a description of the regional hydrogeology (i.e. the Gorge's hinterland catchment). Water and salt-balance studies for the aquifer between the Dam and the Gorge have also been undertaken (AQ2/RPS 2014a, b). Below is a brief summary of salient features of the hydrogeology of the Gorge and the TEC.

The Gorge groundwater system occurs in valley sediments bounded by low permeability basement rocks. It consists of a highly permeable alluvial aquifer comprising an upper unit of sandy-alluvium and calcrete (upper alluvial aquifer) and a lower unit of gravelly-alluvium (deep aquifer). The two units are separated by a low permeability clay sequence.

The Gorge groundwater system has been dominated by Ophthalmia Dam since it's commissioning in 1981. The dam was designed to substantially increase groundwater recharge and loading on the alluvial aquifer to offset drawdown from the Ophthalmia Borefield. The Dam is a Managed Aquifer Recharge (MAR) scheme which impounds and retards flood waters in the Fortescue River to allow larger volumes of infiltration over a prolonged period. Groundwater levels in the aquifer have been sustained at much higher levels since the dam was constructed than would otherwise have been the case. Salient features of the groundwater system are summarised below:

- Groundwater flows from south to north aligned with the Fortescue River valley. Groundwater levels decrease from ~510mAHD at Ophthalmia Dam to ~500mAHD in the Gorge.
- The upper alluvial aquifer is unconfined and receives most of the water seeping from the Dam. This seepage supports long-term trends in the volume of water stored in the aquifer and water levels.
- The upper aquifer also receives recharge from direct infiltration associated with river flow events. However, seasonal recharge may be limited by aquifer capacity (i.e. where seepage from the dam maintains the aquifer at near full conditions).
- Groundwater levels in the upper alluvial aquifer range between 0 and 10mbgl across the entire area. This provides a substantial saturated thickness in the upper alluvium and calcrete, which constitutes the main stygofauna habitat.
- The lower aquifer is confined by the overlying clay and water level changes are mainly a result of hydraulic loading from water in the dam rather than the physical movement of water into this aquifer. Bore data indicates that the lower aquifer has piezometric heads which commonly equal or exceed water levels in the upper alluvial aquifer, particularly in the area immediately downstream of the Dam.
- Recharge to the groundwater system around the Gorge TEC occurs predominantly as seepage from Ophthalmia Dam. Other sources of recharge include direct infiltration from channel flow events (along the Fortescue River channel: both downstream of the Dam when it overflows; and immediately upstream of the area of impoundment). Recharge also occurs along Homestead Creek and Shovelanna Creek. Analytical estimates indicate that:
  - Recharge (seepage) from Ophthalmia Dam occurs at an average rate of around 50ML/d.
  - Total recharge from infiltration along creek channels is around 24ML/d (average) on an almost annual basis.
  - Throughflow into the Ethel Gorge area from the upstream catchments is estimated to be around 2ML/d in total.
  - Prior to construction of the dam, natural groundwater recharge to area of the Gorge TEC would have been around 30ML/d on average.
- Recharge mainly replenishes the shallow alluvial aquifer. Percolation into the lower aquifer is restricted by the low permeability clay and the minimal (or reversed) vertical hydraulic gradients (i.e. high potentiometric levels in the deep aquifer as a result of hydraulic loading).
- Prior to any mine dewatering, groundwater discharge occurred as throughflow along the Gorge (around 3ML/d), evapotranspiration from riparian vegetation communities (around 63ML/d) and water supply pumping (around 10ML/d).
- The Stygofauna Community is likely to be concentrated in the shallow alluvial aquifer.
- Groundwater levels in the alluvial aquifer that hosts the TEC have fluctuated over time, mostly related to climatic cycles of wetter and drier periods, and more recently due to dewatering at OB23 and abstraction from Ophthalmia borefield. Over the period of record, depth to water has ranged between 0 and 15mbgl, although depth to groundwater levels has generally been shallow since the dam was constructed.

1.4 Regional Conceptualisation

Beyond the area of Ophthalmia Dam and the TEC, the broader Gorge catchment comprises the headwaters of the Fortescue River and Warrawanda, Shovelanna and Homestead Creeks. The regional groundwater flow system is hosted in aquifers associated with the Tertiary detritals and underlying Paraburdoo Member dolomite which are generally surrounded by low-permeability lithologies. The regional aquifer is present beneath most of the present day strike oriented valleys between ridges of Brockman and Marra Mamba Iron Formations. The regional aquifer is also present where major drainages have eroded valleys across strike and there are deep sequences of Tertiary detritals. In places the regional aquifer may only comprise either the Tertiary detritals or the dolomite, and in other places the regional aquifer comprises both units.

There are also zones of high-permeability material associated with orebodies in the Brockman and Marra Mamba Iron Formations that form local aquifers within low-permeability surrounds (orebody aquifers). The extent to which the orebody aquifers are in hydraulic connection with the broader regional groundwater system varies with site-specific geology. Most of the orebodies are sufficiently distant from the Gorge that the effects of dewatering will be small. The potential for hydraulic connection between OB31 and the Gorge and TEC is discussed below.

1.4.1 East of Ethel Gorge (including the Orebody 31 Area)

Orebody 31 is hosted in the Brockman Iron Formation and forms a semi-confined aquifer. It is estimated that approximately 60% of the deposit lies below the regional water level (situated at 496mAHD on average).

The orebody aquifer is bound to the north by low permeability shale of the Weeli Wolli Formation (hanging wall). Directly to the north of OB31, regional water levels indicate a 50m hydraulic “step” between the orebody and the Weeli Wolli Formation/Woongarra Volcanics (aquitards). This suggests limited or no groundwater flow from OB31 to the north.

To the south the aquifer is bound by low permeability Mt McRae Shale (footwall) Formation. There may be enhanced permeability associated with structural features, which may provide hydraulic connection between the orebody aquifer and the regional aquifer to the south.

To the east, the orebody aquifer is bounded by the low permeability Wheelarra Fault system. Sub-mineralised Brockman units are also anticipated to extend westwards from the western end of the deposit towards OB17 and OB18.

Based on limited hydrogeological information from the OB18 and Jimblebar Village Borefields, it is assumed that the regional aquifer extends as a single, continuous unit from south of OB31 westwards through to the Gorge. It is however anticipated that the Tertiary detritals thin significantly and are unsaturated along the valley section to the south of OB19, and that hydraulic continuity in this area occurs via the underlying weathered / fractured dolomite.

Dewatering is anticipated to result in the lowering of water levels by up to 140m below the regional water table at OB31. There is the potential for the impacts of dewatering from OB31 to extend to the west toward the Gorge and the TEC through the regional aquifer.

1.4.2 Orebody 25 and Orebody 23

OB25 (Pit 3) and OB23 are hosted in Brockman Iron Formation on the north of Homestead Creek, The orebody is an aquifer and is bound on three sides by basement aquitards, isolating the pits to the north, east and west. To the south, the pits extend into the Homestead Creek channel and a substantial thickness of saturated Tertiary detritals are exposed in the pits' footwalls. The detritals are permeable and result in hydraulic connection with the Homestead Creek regional aquifer.

Dewatering has been active in these pits since 2006 from a combination of sumps and bores; the latter including both bores drilled in the orebody and ex-pit bores drilled directly into the Tertiary valley-fill.

2. ETHEL GORGE REGIONAL MODEL

2.1 Model Simulations

A numerical simulation model has been developed of the Gorge hydrogeological system. The simulation model was calibrated for the period January 1970 to October 2012. Model predictions were completed for a simulated operating period of November 2012 to Year Ending June (YEJ) 2033 and a simulated closure period of YEJ 2034 to YEJ 2073.

2.2 Model Setup

The Ethel Gorge regional groundwater flow model uses the Modflow Surfact groundwater modelling code (Hydrogeologic 1996) operating under the Groundwater Vistas graphical user interface (Version 6.63 Environmental Solutions Inc. 1996 to 2001).

The model domain is shown in Figure 2. The model extends 23km upstream and 15km downstream of Ethel Gorge. The model domain also extends 30km east of Ethel Gorge to include the OB17, 18, and 31 mining areas and 30km to the west to include the OB23, 24, and 25 mining areas. The model uses a minimum cell size of 50m close to the Gorge and the TEC area and in the vicinity of orebody aquifers. The model grid size increases to a maximum cell size of 200m by 100m close to model boundaries.

The model uses six layers to define the Tertiary detrital aquifers, orebody aquifers, and basement formations. The Gorge paleovalley aquifer is simulated by four model layers (upper alluvium, calcrete, clay aquitard and an underlying alluvial aquifer). The extents and thicknesses of the paleovalley aquifer have been based on bore logs. Orebody aquifers and surrounding basement units are represented by all six model layers as appropriate. Where available the extent of low grade mineralisation (supplied by BHPB) has been used to define the extent of orebody aquifers.

In the OB31 area, the Ethel Gorge model has been set up based on the calibrated groundwater model developed for the OB31 hydrogeological and modelling study (RPS 2014b).

Specified head and specified flow boundaries have been applied to provide inflow from the catchment outside of the modelled area and also (in some cases) outflow from the model to downstream catchments. These boundaries are shown in Figure 2.

2.3 Simulation of Groundwater Recharge

In addition to the inflow boundaries described above, groundwater recharge to the modelled catchment occurs via rainfall recharge, seepage from surface water flows in the Fortescue River, Homestead Creek, Warrawanda Creek, Shovelanna Creek and Whaleback Creek and Managed Aquifer Recharge (MAR) associated with Ophthalmia Dam.

Direct rainfall recharge is applied to the areas of surficial alluvium and outcropping orebody aquifers and bedrock.

Recharge from surface water flows is simulated using the Streamflow Routing Package (STR). This approach simulates leakage from the stream cells based on a specified total flow along a modelled stream. This feature also allows for the discharge of groundwater to surface in the event that groundwater levels reach or exceed the specified stream bed elevation. Gauged flows for the Fortescue River, measured upstream of Ophthalmia Dam were used to calculate stream flows for ungauged creeks within the model domain (Homestead Creek, Warrawanda Creek and Whaleback Creek). The extents of modelled creeks and rivers are shown in Figure 3.

MAR associated with Ophthalmia Dam was included for simulation periods after construction of the dam in the early 1980s (using the Lake Package (LAK2)). This package allows for leakage to the underlying aquifer system based on the difference between the elevation of surface water (held in the reservoir) and the underlying groundwater level. This model feature also allows for the wetted area of the impounded water to vary with elevation of impounded water. The modelled extent of Ophthalmia Dam is shown in Figure 3.

Over the model calibration period, measured dam water levels are used as direct inputs to the LAK2 package. For all model predictions, dam water levels are estimated using the analytical water balance model for Ophthalmia Dam (AQ2/RPS 2014a, b). Dam water levels for the prediction period are generated by the water balance model assuming that the Dam receives streamflow from upstream and the projected dewatering surplus profile (provided by BHPB).

Overflows from Ophthalmia Dam are included as surface water inputs to the Fortescue River just downstream of the Dam. These inputs are included at recorded rates in the STR package (outlined above) over the calibration period and calculated by the Dam water balance model over the prediction period.

2.4 Simulation of Groundwater Discharge

Groundwater discharge from within the modelled catchment occurs predominantly via evapotranspiration (EVT) along with groundwater abstraction and groundwater through-flow.

The vegetation along surface drainages and flood plains rely on groundwater as a source of water. Red Gums and Coolibahs, with root depths of up to 20m, are facultative phreatophytes and vadophytes and will contribute to an evaporative loss from the water table both directly (where roots penetrate the water table) and indirectly (where the water table is below the roots but matric suction induced by the roots causes a capillary rise of groundwater into the unsaturated zone). Evapotranspiration is represented in the model using the evapotranspiration (ET) package.

Evapotranspiration losses are included across the modelled catchment as shown in Figure 3 along the major surface drainages. From ground surface to 5m depth, EVT is specified at a maximum rate of 900mm per year (with no seasonality included). This represents direct water use by shallow rooting vegetation. From 5 to 20m below ground surface the EVT rate declines linearly from the maximum to zero. This represents progressively declining tree-water use as the depth to water increases and fewer trees have the rooting-depth and matric potential to utilise these resources.

Aquifers in and around Ethel Gorge have been used for town and mine water supplies for Newman since the Ophthalmia Borefield was developed in 1969. The OB18 water supply borefield has been operated since 2002. Since 2006, orebody aquifers at OB23 and 25 have been dewatered. The locations of these borefields are shown in Figure 3.

All historical groundwater pumping for water supply (from Ophthalmia the OB18 Borefield) and mine dewatering is simulated, with pumping from water supply and dewatering bores modelled using the Fracture Well (FWL) Package. The only exception to this is at OB25 Pit 1, where ongoing dewatering is simulated using the Drain (DRN) Package. For all model predictions, future dewatering of each mining area was also simulated using the DRN package by assuming that groundwater levels are reduced to the projected base of mining over the scheduled active mining period (i.e. no advanced dewatering is included).

2.5 Simulation of Mine Closure

For some mine areas (OB17, OB18, OB23, OB24 and OB25 Pits 1 and 3) mining will be complete prior to the completion of mining at OB31 (YEJ 2048). At these mining areas the mine closure strategy is included in the model set up as outlined below:

- Once mining and dewatering is complete, the dewatering conditions are removed and groundwater levels are allowed to recover through the infilled or empty mine voids.
- For mine voids that are infilled, it is assumed that the infill material has the same aquifer parameters (storage and hydraulic conductivity) as the original orebody aquifer material. It is also assumed that the final infilled surface is engineered such that there is no change to the recharge conditions in the rehabilitated mine area.
- For mine voids that are left empty, the mine void is simulated using the final mine void geometry (based on final pit plans) and aquifer properties (high hydraulic conductivity and unconfined storage). The aquifer properties are implemented (at mine closure) using the Time Variant Material (TMP) Package. Recharge from the final pit void catchment and to the pit void lake is included consistent with the adopted climatic sequence (20% of incident rainfall runs off from the pit catchment along with 100% of incident rainfall to the pit lake

surface). Evaporation from pit void lakes that develop within mined out areas is also included at a constant rate of 50% of Pan Evaporation (1.7m per year) consistent with Department of Agriculture estimates of evaporation from agricultural dams (Department of Agriculture, 1987).

2.6 Model Calibration

The groundwater model has been calibrated to measured water levels over the period January 1970 to October 2012. The water levels in the calibration data set show responses to a range of groundwater stresses and hydrological conditions in the catchment as follows:

- Groundwater drawdown from the early 1970s resulting from abstraction from the Ophthalmia Borefield.
- The recovery of groundwater levels from the early 1980s resulting from the operation of Ophthalmia Dam.
- Changes in groundwater levels from dewatering at OB23 and 25 since 2006.
- A range of hydrological conditions, including a period of higher than average rainfall from 1997 to 2001.
- Measured water levels in the immediate OB31 area.

  Groundwater responses to pumping from the OB18 water supply borefield (since 2006) and short term testing at OB31.

The model calibration data set includes close to 150 calibration bores. The locations of, and water level data from, selected monitoring bores included in the model calibration data set in the Gorge and TEC areas are shown in Figure 4. In general, the model calibration performance is good, with water level magnitudes and trends well simulated by the model over the calibration period. In particular, the measured water level trends associated with operation of Ophthalmia Borefield, MAR from Ophthalmia Dam and dewatering at OB23 and 25 are well replicated by the model.

Calibrated aquifer parameters are summarised in Table 2.1. The values are consistent with typical values for similar hydrogeological units in the Pilbara, and are consistent with and draw from work completed for other modelling studies completed in the catchment (for example studies completed for OB23 and 25 (RPS Aquaterra 2013) and OB31 (RPS 2014, b)).

Table 2.1: Model Aquifer Parameters

Model Layers	Hydrogeological Unit	Horizontal Hydraulic Conductivity Kh (m/d)	Vertical Hydraulic Conductivity Kv (m/d)	Specific Storage Ss (1/m)	Specific Yield Sy (%)
1 to 2	Calcrete	4.0×10^{1}	4.0×10^{0}	2.0×10^{-6}	3
3	Clay	1.0×10^{-1}	5.0×10^{-4}	2.0×10^{-6}	30
4	Gravel	5.0×10^{0}	5.0×10^{-1}	2.0×10^{-6}	7
1 to 6	Basement (Hamersley Group and unmineralised Brockman Iron Formation)	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-6}	0.1
	Brockman Orebody	5.0×10^{0} to 1.0×10^{1}	5.0×10^{-1} to 1.0×10^{0}	4.7×10^{-7} to 2.0×10^{-6}	5
	Mt McRae Shale and Mt Sylvia Formations	1.0×10^{-2}	1.0×10^{-2}	1.0×10^{-6}	0.1
	Wittenoom Formation (undifferentiated)	1.0×10^{0} to 1.0×10^{1}	1.0×10^{-1} to 1.0×10^{0}	4.7×10^{-7} to 2.0×10^{-6}	0.01 to 0.1
	Marra Mamba Orebody	5.0×10^{0}	5.0×10^{-1}	2.0×10^{-6}	5
	Basement (unmineralised Marra Mamba Iron Formation, Fortescue Basement and Metagranite/Granitoid)	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-6}	0.1
	Faults	1.0×10^{-4}	1.0×10^{-4}	1.0×10^{-6}	1.0×10^{-4}

2.7 Model Confidence

The greatest density of hydrogeological data is located around the Gorge. The data covers a significant time period that also incorporates varied groundwater stresses. Those that are most relevant to the modelling objectives are the influence of Ophthalmia Dam, water supply abstraction and mine dewatering. Confidence in future predictions in the area of the Gorge, influenced by similar stresses, is therefore high.

The model settings in the areas around OB31 and between OB31 and the Gorge are based on more limited data. However, these do include responses to several years of abstraction from the water supply borefield near OB18 and short term aquifer testing at OB31. Combined with relevant experience in similar hydrogeological environments, this data has been used to set realistic parameters and hydrostratigraphic geometries in these areas.

There is therefore some uncertainty in the prediction of drawdown migration from OB31 towards the Gorge. This uncertainty has been addressed in the model by using conservative settings where necessary. For example:

- Some hydraulic connection is assumed between the OB31 aquifer and the regional aquifer to the south.
- The regional aquifer is assumed to be continuous from the south of OB31 to the Gorge area.
- It is assumed that east of OB31 there is no hydraulic connection across the Wheelarra Fault.

3. MODEL PREDICTIONS

3.1 Background

The Ethel Gorge model was used to assess the groundwater level changes in the catchment associated with the development of the OB31 mining area (including dewatering and discharge to the dam). To achieve this, two model prediction runs were completed. Both were identical in terms of model set-up (parameters, recharge, evapotranspiration and water supply pumping) and mining activities (all approved mines within the domain). However, in one run OB31 related dewatering and discharges to the dam were included and in the other run they were excluded. The difference in the predicted water levels from the two runs was therefore assumed to equal the water level change due to water management activities at OB31 only.

The predictions were completed for an operational period which extended from November 2012 (or the end of the model calibration) until YEJ 2048, when mining is anticipated to finish at OB31.

The predictions included a future climate sequence based on observed rainfall and stream flow conditions in the catchment for the period 1980 to 1996 (repeated as required to extend to the length of the operational prediction period). Both prediction models were run assuming a monthly time increment, consistent with the calibrated model, to allow for simulation of seasonal variations in recharge processes resulting from rainfall and surface water flows in the catchment.

3.2 Prediction Setup

3.2.1 General Settings

Details of the features included in both models are outlined below:

- Water supply pumping from the Ophthalmia and Homestead water supply borefields is included at a total pumping rate of 24ML/d. Predictions also include optimisation of water supply pumping to maintain total abstraction at the total required demand over the operational period.
- Evapotranspiration is included consistent with the calibrated model (i.e. constant at 900mm per year).
- Stream flows in the Fortescue River and Homestead, Warrawanda, Shovelanna and Whaleback Creeks were assigned consistent with the 1980 to 1996 climatic sequence.
- Ophthalmia Dam levels and overflows for the predictions are calculated using the dam water balance model.
- Dewatering at OB17, 18, 23, 24, 25 and 31 is included according to the schedule outlined in Table 3.1.
- At closure (see Table 3.1) OB25 Pits 1 and 3 are assumed to be infilled and OB17, 18, 23, 25 are treated as voids.

The features and mining areas included in both model prediction runs are shown in Figure 5. In order to set-up the model run without mining at OB31 the following two changes were required.

- Dewatering at OB31 was removed.
- Discharge of surplus water from OB31 to the Dam was removed from the dam water balance model and the groundwater model settings updated with the results.

3.3 Results

The predicted influence of mine water management at OB31 on the regional groundwater system is presented as water level change contours (at the end of OB31 mining (YEJ 2048)), predicted Dam seepage and as hydrographs of water level change at several key locations. The results are summarised below.

3.3.1 Predicted Water Level Change Contours

Contours of the predicted water level change due to mining at OB31 in YEJ2048 are shown in Figure 6, as well as the location of the TEC boundary. Negative contours indicate that the water levels are lower due to mining at OB31.

The influence of OB31 dewatering is predicted to extend west through the regional aquifer and the orebody aquifers (which are assumed to be continuous) towards Ethel Gorge. A 1m reduction in water level is predicted up to 19km west of the OB31 area (or 5 km east of the Gorge). Close to the Gorge and in the TEC area however, no reduction in water levels is predicted.

3.3.2 Predicted Ophthalmia Dam Water Balance

Model predicted Ophthalmia Dam Seepage for both predictions (with and without OB31) are presented in Figure 7. Figure 7 also shows the difference in dam seepage between both predictions (with OB31 included minus OB31 excluded). No difference in dam seepage is predicted until 2019 when excess dewatering from OB31 is discharged to the Dam. From 2019 to 2048 there is generally more dam seepage predicted for the case that includes OB31 (by up to 7,000 kL/d) with the greatest difference in dam seepage is predicted between 2031 and 2032. This corresponds to the periods when the greatest volumes of excess dewatering from OB31 is discharged to the Dam.

When predicted seepage rates for both cases are at minimum levels, predicted seepage rates for the case that includes OB31 are higher due to the additional dewatering discharge to the Dam. Subsequent increases in dam water levels (from surface water flows) are predicted to result in peak or maximum seepage rates that are lower for the with OB31 case. This is because of the water level conditions in the immediate Dam area. For the case that includes OB31, water levels in the underlying aquifer will be slightly higher and therefore less seepage from the Dam is predicted.

3.3.3 Predicted Water Level Change Hydrographs

The predicted change in water levels at selected observation locations are shown in Figures 8 and9 (monitoring locations are shown in Figures 5 and 6). At most of the monitoring locations the predicted water level change is less than 1 m. The only exception to this is at the East of Ethel Gorge observation location (Figure 7). Water levels are predicted to be about 15m lower at this location by YEJ 2048 due to dewatering at OB31.

Table 3.1: Mining Schedule for Approved Deposits

Year Ending June	Orebody 23	Orebody 25 Pit 1	Orebody 25 Pit 3	Orebody 24	Orebody 17	Orebody 18	Orebody 31
2013	X	X	X				
2014	X	X	X		X	X	
2015	X	X	X		X	X	
2016	Empty Void	X	X		X	X	
2017		X	X	X	X	X	
2018		X	X	X	X	X	
2019		X	X	X	X	X	X
2020		Infilled Void	Infilled Void	X	X	X	X
2021				X	Empty Void	Empty Void	X
2022				X			X
2023				X			X
2024				X			X
2025				X			X
2026				Empty Void			X
2027							X

Year Ending June	Orebody 23	Orebody 25 Pit 1	Orebody 25 Pit 3	Orebody 24	Orebody 17	Orebody 18	Orebody 31
2028							X
2029							X
2030							X
2031							X
2032							X
2033							X
2034							X
2035							X
2036							X
2037							X
2038							X
2039							X
2040							X
2041							X
2042							X
2043							X
2044							X
2045							X
2046							X
2047							X
2048							X

X denotes mining below the water table.

4. DISCHARGE SCENARIOS

4.1 Objective

The Ethel Gorge regional groundwater flow model has been used to assess the impact on Ethel Gorge and the nearby threatened ecological community (TEC) of a range of hypothetical mine water discharge rates (i.e. from dewatering volumes in excess of water demand requirements) to Ophthalmia Dam and nearby recharge ponds.

The modifications specific to this assessment are described in this document, along with the results.

4.2 Model Set-up

4.2.1 Introduction

The model has been used to assess the response of the groundwater system to the discharge to the Dam and recharge ponds of hypothetical, constant volumes of water over a sustained period. The volumes considered were; 0, 15, 30, 60 and 120ML/d. In order to assess the significance of the assigned evapotranspiration (EVT) rates on the outcomes, the model was run with two different maximum EVT settings; 900mm/yr and 600mm/yr. The model results from these variations are referred to as “Case 1” and “Case 2” respectively.

Model predictions were completed for a period of 18 years. In order to consider the effects of these discharges in isolation from other mining related system stresses, the model was run without any mining related dewatering in the catchment (either historically or into the future).

4.2.2 Calibration

The 900mm/yr EVT rate was adopted in the main calibrated model. This model replicates closely the observed groundwater level fluctuations and absolute levels, particularly in the area of the Dam. The effect of reducing the maximum EVT rate to 600mm/yr on the calibration accuracy was assessed by re-running the calibration with the modified value. Other than this change, no other modifications were made to model parameters or settings. This showed that the 600mm/yr scenario was also able to replicate observed trends and levels to a satisfactory level of accuracy. The simulation of groundwater trends and responses to seasonal climatic events are very similar in the two models. The main difference is in the absolute groundwater levels, particularly in the area of the TEC. In the 600mm/yr scenario, the groundwater levels here are a few metres higher than the 900 mm/yr scenario.

This confirms that the use of the lower EVT rate is valid for this exercise as the calibration is not significantly affected by the change.

4.2.3 Simulation of Discharge

Discharge Scenarios

Five discharge scenarios were completed (Table 4.1). Each scenario was run twice, once for each EVT setting. The model was therefore run a total of 10 times.

The discharge is distributed as follows:

- 75% as direct discharge to the Dam
- 25% as direct discharge to the Eastern Ridge (ER) recharge ponds

When the water balance model predicts that the Dam will overtop from seasonal rainfall and creek flow, this water has previously been allocated in the model as a flow directly into the creek downstream of the Dam. This process continues in this version of the model, however, if overtopping occurs in excess of this “background” rate due to the discharge volumes attributed to the Dam, this water is directed to the Ophthalmia Recharge Basin downstream of the Dam, rather than adding it to the creek flow.

The representation of each component is described further below.

Table 4.1: Summary of Model Predictions

Discharge Scenario	Discharge Rate (ML/d)	EVT Rate
Zero	None	Case 1 (900 mm/year)
15 ML/d	11.25 ML/d to Dam 3.75 ML/d to ER Recharge Ponds	Case 1 (900 mm/year)
30 ML/d	22.5 ML/d to Dam 7.5 ML/d to ER Recharge Ponds	Case 1 (900 mm/year)
60 ML/d	45 ML/d to Dam 15 ML/d to ER Recharge Ponds	Case 1 (900 mm/year)
120 ML/d	90 ML/d to Dam 30 ML/d to ER Recharge Ponds	Case 1 (900 mm/year)
Zero	None	Case 2 (600 mm/year)
15 ML/d	11.25 ML/d to Dam 3.75 ML/d to ER Recharge Ponds	Case 2 (600 mm/year)
30 ML/d	22.5 ML/d to Dam 7.5 ML/d to ER Recharge Ponds	Case 2 (600 mm/year)
60 ML/d	45 ML/d to Dam 15 ML/d to ER Recharge Ponds	Case 2 (600 mm/year)
120 ML/d	90 ML/d to Dam 30 ML/d to ER Recharge Ponds	Case 2 (600 mm/year)

Recharge Ponds

From the start of the model onwards, 25% of the mine discharge was assumed to report to the ER Recharge Ponds with 50% of this total volume assumed to recharge the underlying water table. Therefore 12.5% of the total discharge to the ER recharge ponds is assumed to recharge the underlying water table and 12.5% is lost as evaporation from the open water surface of the ponds and the unsaturated zone.

The locations of the ER recharge ponds are shown in Figure 10.

Ophthalmia Dam Water Levels

The remaining 75% of the mine discharge is assumed to report to the Dam. The analytical water balance model was used to calculate Dam water levels for each discharge volume. The results are then used to set the Dam level in the numerical model. Dam water levels and overflows were calculated for the Zero, 15ML/d and 30ML/d discharge scenarios assuming that there was no cap or upper limit on Dam seepage. For the 60ML/d and 120ML/d discharge scenarios, Dam water levels and overflows were calculated assuming that Dam seepage was capped at 55ML/d. This upper limit on Dam seepage in the analytical model is consistent with work completed in 2014 that suggested that there is an upper limit of total seepage from Ophthalmia Dam once it is "full", of approximately 55ML/d.

Ophthalmia Dam Overflows

For all discharge scenarios (zero to 120ML/d), Dam overflows were included in model predictions as specified creek flows immediately downstream of the Dam, consistent with the Dam spill frequency and volumes calculated for the Zero discharge prediction (i.e. the natural overtopping volumes). For use in the model these overflows are averaged into monthly volumes.

In addition to these flows, for the 15 to 120ML/d mine discharge scenarios, Dam overflows in excess of the natural overtopping volumes were assumed to be detained and recharged to groundwater via the Ophthalmia Dam Recharge Basin located immediately downstream of the Dam.

The location of the Ophthalmia Dam Recharge Basin is shown in Figure 10. To facilitate incorporation into the model, these additional overtopping volumes were averaged over the calendar year in which they occurred, and, as with the recharge ponds, 50% of the volume allocated to the basins was assumed to infiltrate to groundwater. The remaining 50% is assumed to be lost to evaporation.

The difference in Dam overflows between the Zero and discharge scenarios, and therefore the volume of water directed to the recharge basins, are shown in Figures 11 and 12.

4.2.4 Other Settings

As per the original modelling, all future climate inputs (rainfall, stream flow, etc.) are based on the observed conditions in the catchment for the period 1980 to 1996.

All mine dewatering in the catchment is removed, however the Ophthalmia borefield is active and simulated at a constant rate of 12ML/d throughout the simulations.

No allowance was made in model predictions to include changes in vegetation density or distribution that may result from the discharges.

4.3 Results

4.3.1 Groundwater Levels

The predicted groundwater levels at a number of locations within the TEC and beyond are displayed in Figure 13. The first 10 years of predictive data is shown as this is the period in which the system reaches a pseudo-equilibrium with the discharge inflows. These show that:

- The lower EVT rate (Case 2) results in higher groundwater levels within the TEC at the start of the model run. The buffer against increasing groundwater levels is therefore reduced compared to Case 1.
- At discharge rates from Zero to 30 ML/d strong responses to seasonal climactic conditions are maintained into the future. At discharge rates of 60 to 120ML/d the seasonal responses are reduced and the groundwater system appears to approach capacity.
- At the highest rates of discharge, the system appears to near capacity within a few years.

4.3.2 Depth to Groundwater

Plots of the depth to groundwater after four years of discharge are shown in Figures 14 to 23. The areas where groundwater levels are predicted to be less than 2m beneath the ground surface are distinguished with the areas where the depth is greater than 2m. The 2m threshold is considered to be an important tree health indicator in this area.

In terms of the location of groundwater predicted to be less than 2m from the ground surface the results show that:

- The area of less than 2m to groundwater increases as discharge increases. This occurs mostly in the west of the TEC around Homestead Creek and south of the Dam (upstream). By the 120ML/d scenario, the model predicts that most of the TEC north of the Dam has groundwater levels within 2m of the surface.
- There is little difference in in the 15 and 30ML/d discharge scenarios, other than some areas beneath the Homestead Creek to the west.
- The less than 2m zone extends further south of the Dam (upstream) and is more widespread within the TEC in the 600mm/yr EVT scenarios compared to the 900mm/yr EVT scenarios.

These results may be controlled quite strongly by the grid size used in the modelling. In the area of Ethel Gorge the grid cells are 50m by 50m. As the topographic data has been resampled to this grid, finer detail topographic lows (i.e. the creek) that may control the groundwater level as it increases will not be captured by the model.

4.3.3 Evapotranspiration

The predicted EVT flux from the area of TEC north of the Dam has been processed to provide an insight into the predicted "actual" rates of EVT in this area (as opposed to the potential rates defined in the model set-up) and the sensitivity of these rates to the two EVT settings (maximum 600 and 900mm/yr). The area is within the TEC and downstream of Ophthalmia dam where ET is assigned and covers roughly 7km^2. The results are presented in Table 4.2.

Table 4.2: Predicted EVT in the TEC Downstream of the Dam

Discharge Scenario (ML/d)	Predicted Average EVT Rate (mm/d / mm/yr)	
	Case 1	Case 2
Zero	1.9 / 694	1.4 / 511
15	2.0 / 730	1.4 / 511
30	2.0 / 730	1.4 / 511
60	2.0 / 730	1.4 / 511
120	2.1 / 767	1.4 / 511

The results show that within the TEC the predicted "actual" evapotranspiration is not particularly sensitive to the range of discharge scenarios considered. It also confirms that the predicted rates are in line with the conceptual understanding of plant water use in this area.

The main mechanism for removing the proportion of discharge water that enters the groundwater system is therefore not an increase in EVT.

The model predicts that as the discharge volumes increase, the amount of water flowing north via creek baseflow increases. For the 15 and 30ML/d discharge scenarios, this increase is relatively minor. For the 60 and 120ML/d scenarios the increase is significant. For example, at times in the 120ML/d discharge scenario, flow along the creek (south of the Dam but within the TEC) exceeds 20ML/d.

4.4 Conclusion

The purpose of these model scenarios was to gain an insight into the response and capacity of Ophthalmia Dam and the downstream aquifer to, and under, different hydraulic loading regimes. It is understood there is uncertainty in the assumed EVT rate used in the model, this work has shown regardless of the rate applied, the same potential discharge rate of between 30 and 60 ML/d is sustainable for the system. It is also evident that the predicted actual EVT flux changes only marginally with increasing dewatering discharge to Ophthalmia Dam, and the additional discharge volume results in greater storage and ultimately increase in base flow to the Creek system.

5. CONCLUSIONS

The Ethel Gorge regional groundwater model has been used to predict the influence of dewatering at OB31 on the TEC. These predictions include dewatering and closure associated with the Approved mining areas in the Ethel Gorge catchment (OB17, 18, 23, 24, 25 and 31). These predictions also include ongoing water supply pumping in the catchment and operation of Ophthalmia Dam (including the discharge of excess dewatering from mining operations).

The results show that by the end of mining, dewatering at OB31 results in a reduction of water levels of up to 1m about 19km west of OB31 (within the regional aquifer and adjacent orebody aquifers). The results also show that dewatering of OB31 is unlikely to cause any impact on water levels in the Ethel Gorge and TEC areas.

The confidence in model predictions in the area of the Gorge is considered to be high. There is however uncertainty in the hydraulic connection (through the regional aquifer) between the Gorge and OB31. Some calibration of the model was possible in these areas, but where assumptions were required they have been made conservatively. This should result in a model that is more likely to overestimate the migration of drawdown from OB31 than to underestimate it.

6. REFERENCES

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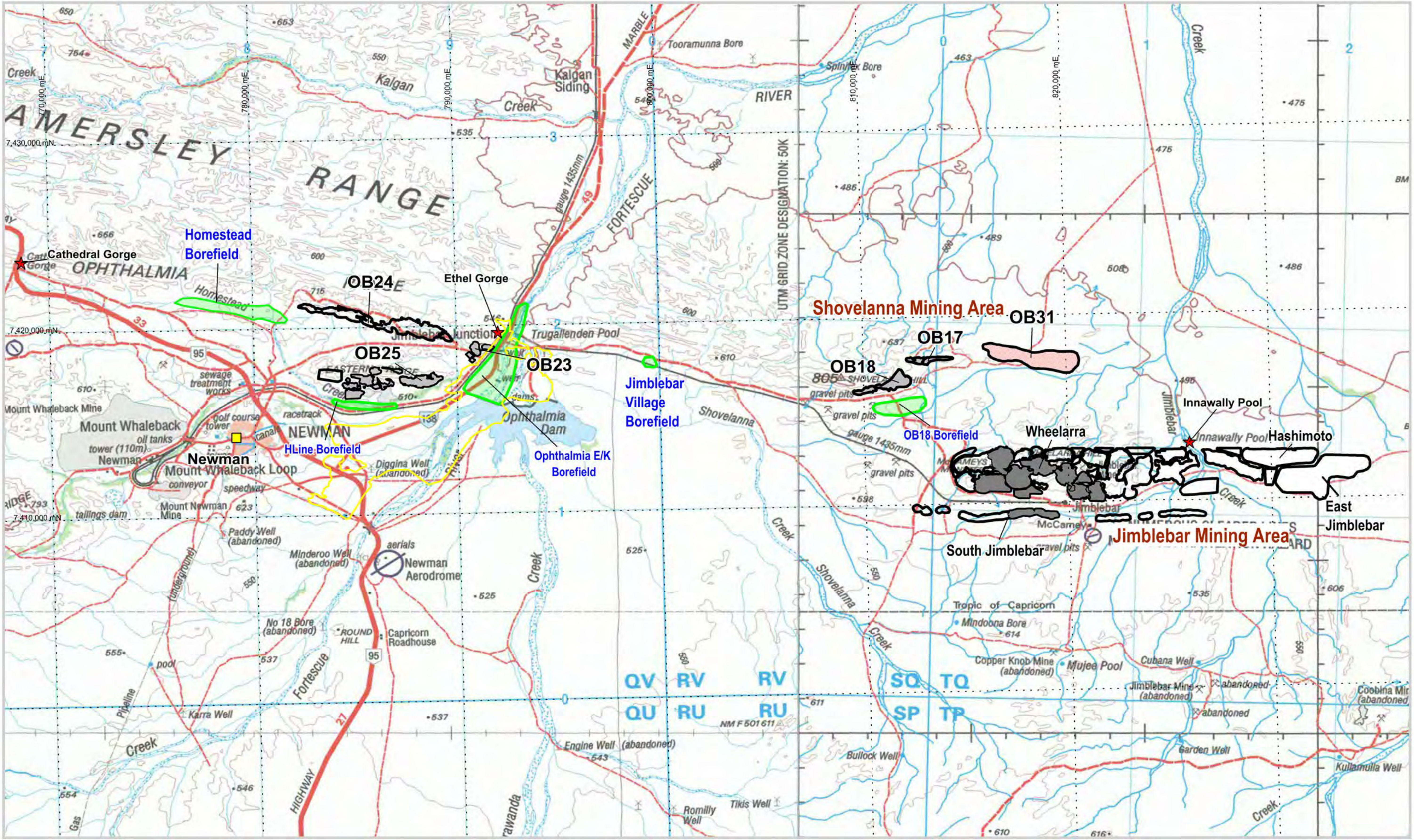
FIGURES



0 2.5 5
Kilometres
Scale: 1:175 000 @A3
GDA 1994 Zone 50

AUTHOR: AW
DRAWN: MR
DATE: 01/09/2014

REPORT NO: 055
REVISION: a
JOB NO: 1584G

LEGEND

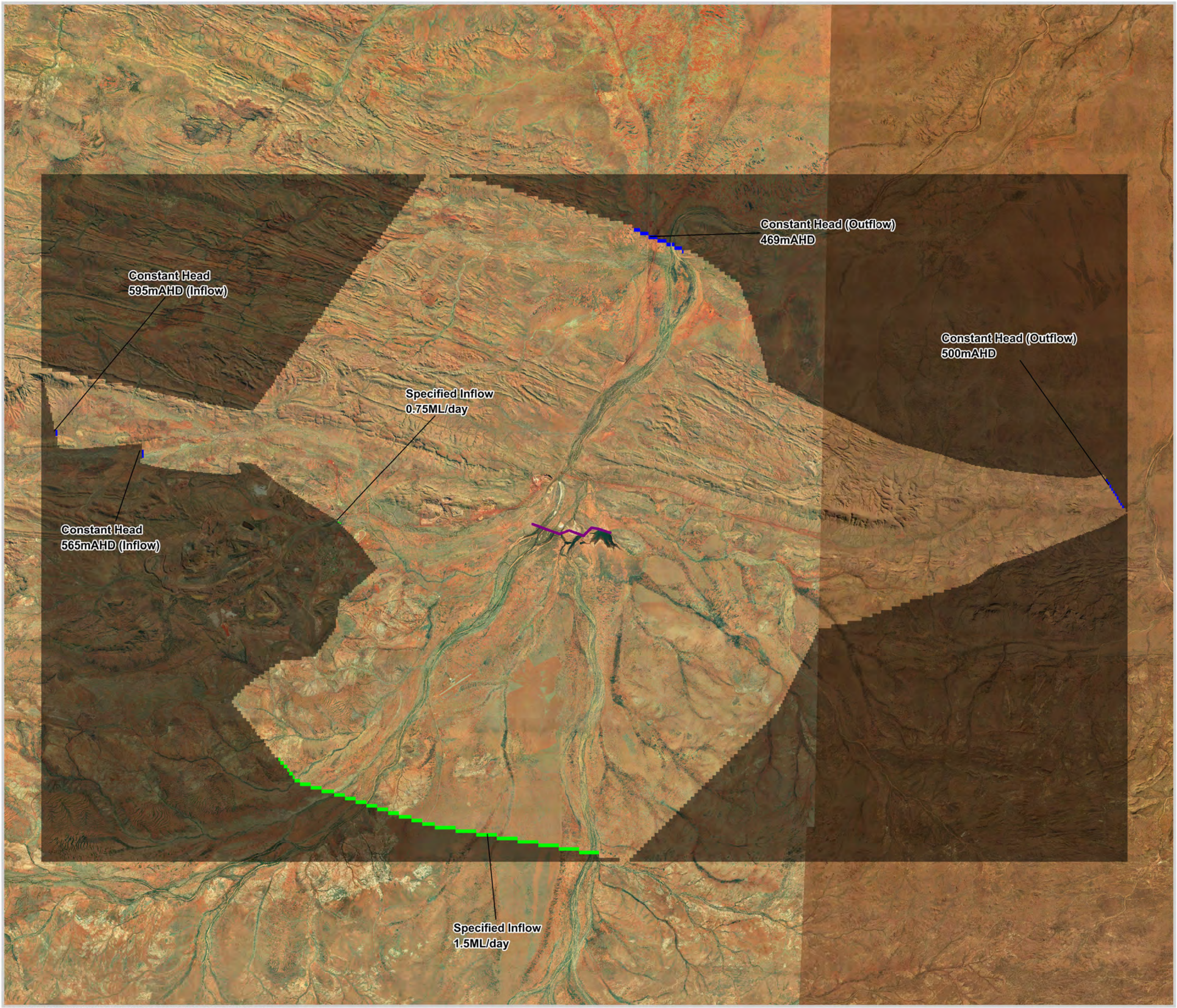
- Key Environmental Asset
- Proposed Pit Outline
- Existing Pit Outline
- TEC Boundary
- Existing Borefield

RPS

FIGURE 1

LOCATION MAP

Location: F:\Jobs\1584G\Spatial_Data\MapInfo\Workspaces\055a\055a Figure 1 - Location Map.wor



Legend

- Ophthalmia Dam
- Model Boundary
- Constant Head Boundary
- Specified Flux Boundary
- No Flow Boundary

Kilometres

Scale: 1:200,000 @A3

GDA 1994 Zone 50

RPS

Figure 2

MODEL EXTENT AND BOUNDARY CONDITIONS

AUTHOR:	DVB	REPORT NO:	110
DRAWN:	MR	REVISION:	a
DATE:	19/08/2014	JOB NO:	1606D

Location: F:\Jobs\1606D\Spatial Data\MapInfo\Workspaces\110a\110a Figure 2 - Model Boundary and conditions

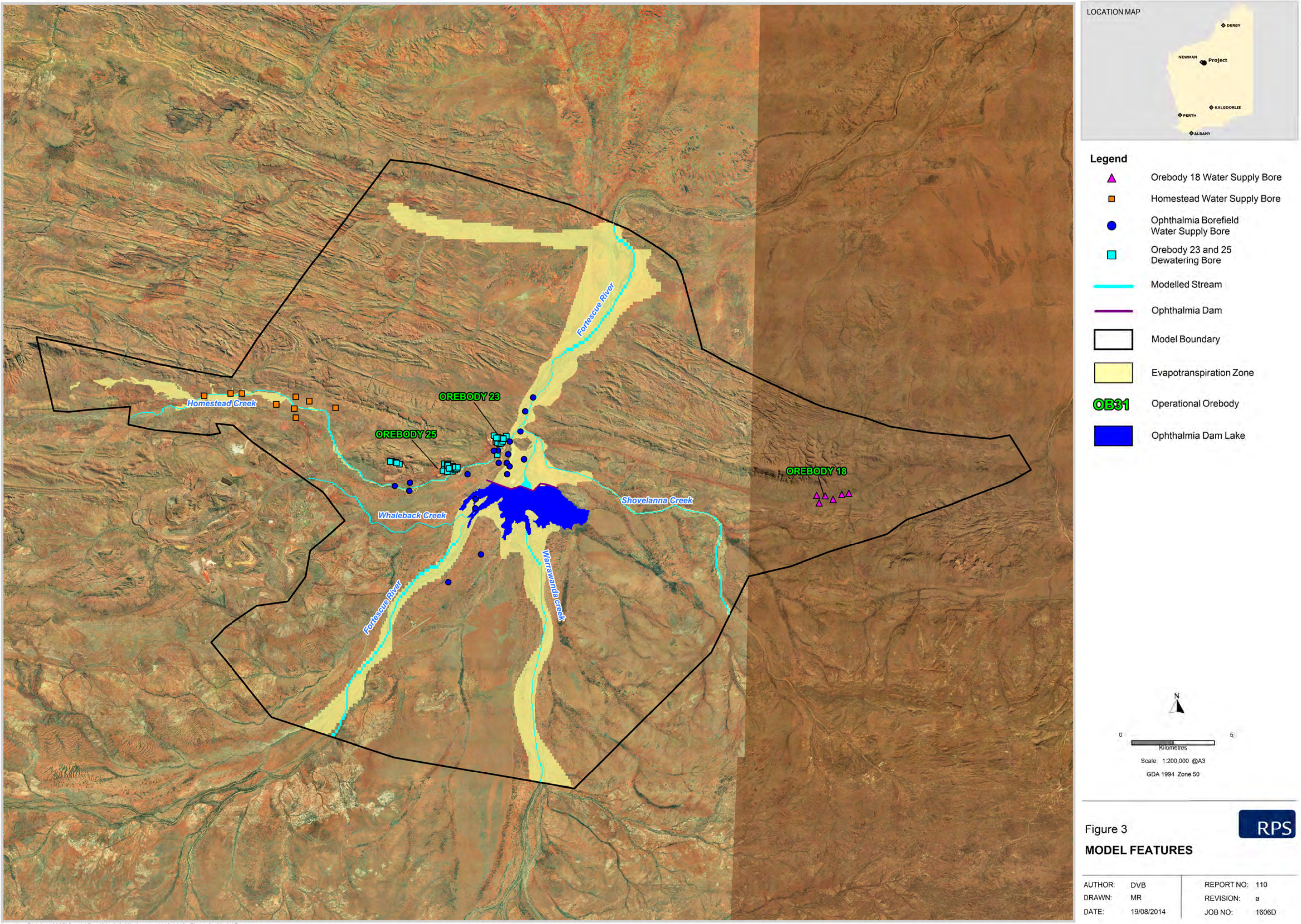


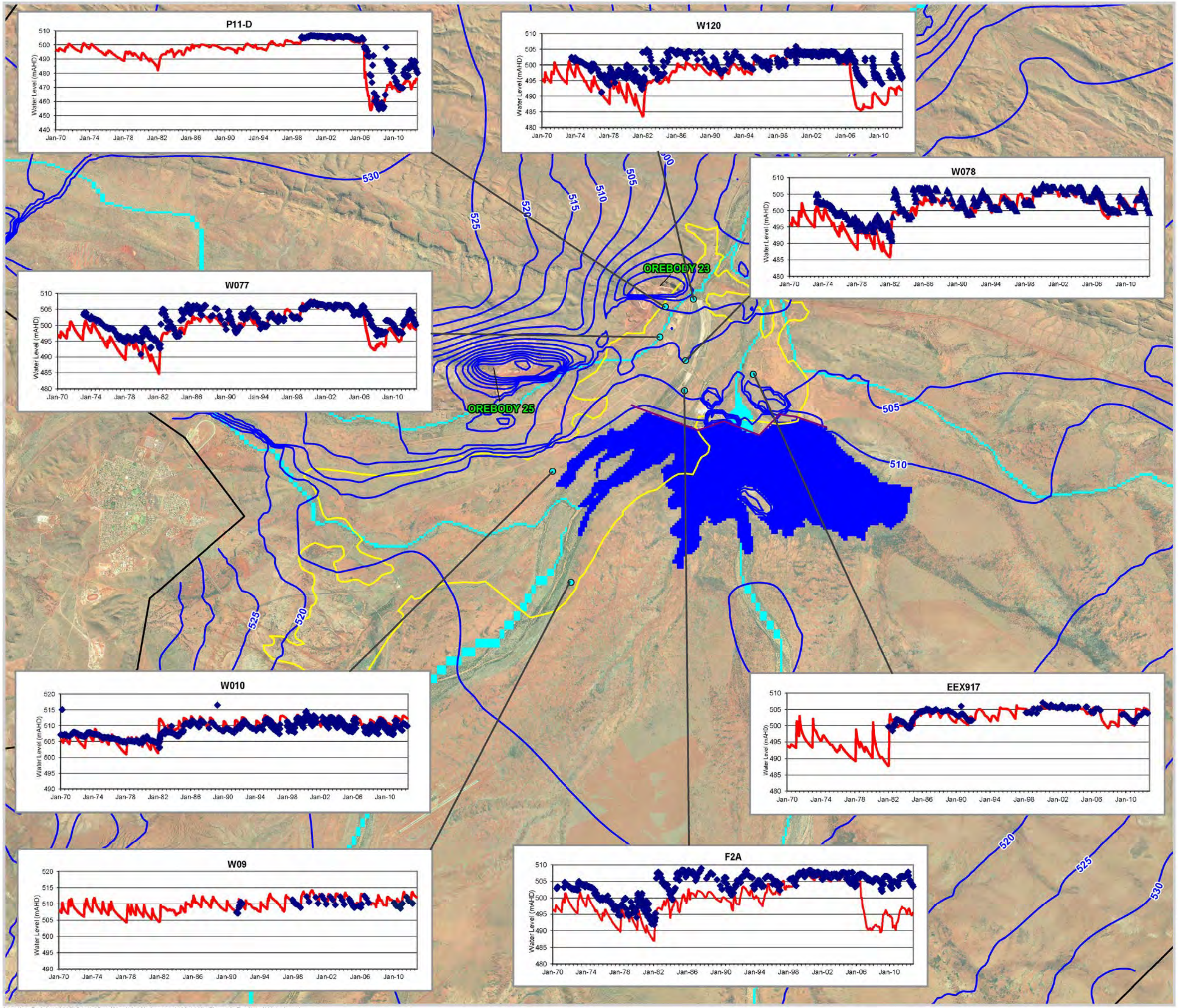
Figure 3

MODEL FEATURES

RPS

AUTHOR:	DVB	REPORT NO:	110
DRAWN:	MR	REVISION:	a
DATE:	19/08/2014	JOB NO:	1606D

Location: F:\Jobs\1606D\Spatial Data\MapInfo\Workspaces\110a\110a Figure 3 - Model Features



Legend

- Selected Observation Bore
- Ophthalmia Dam
- 500 Predicted Groundwater Level Contour mAHD (Oct 2012)
- Modelled Stream
- Model Boundary
- TEC Boundary
- Ophthalmia Dam Lake
- OB31 Operational Orebody

Note: SEA Project includes Approved and SEA Project Orebodies

Aerial: Landgate 2013

Scale: 1:80,000 @A3

GDA 1994 Zone 50

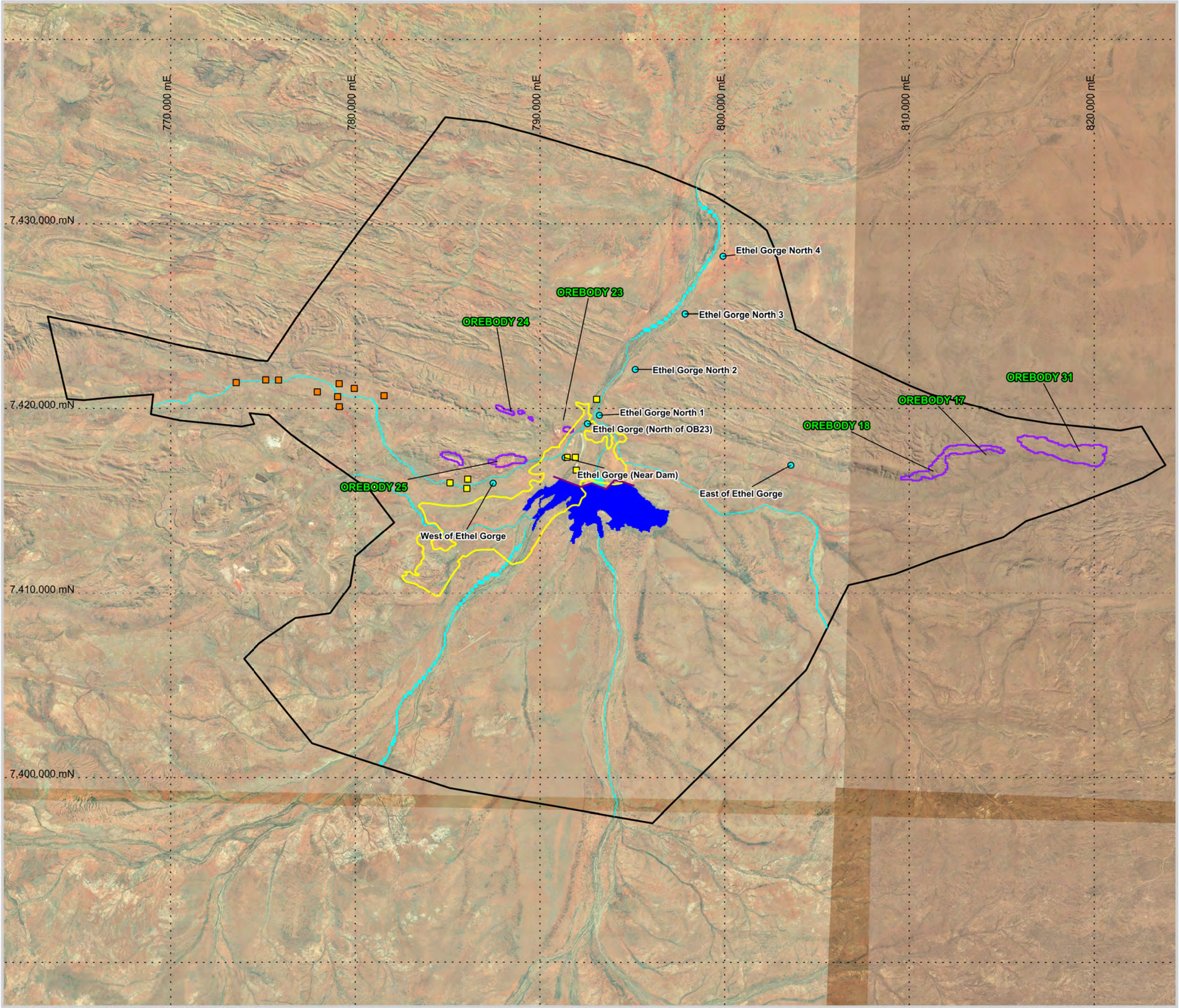
Figure 4

SELECTED CALIBRATION HYDROGRAPHS AND PREDICTED WATER LEVEL CONTOURS (OCTOBER 2012)

RPS

AUTHOR:	DVB	REPORT NO:	110
DRAWN:	MR	REVISION:	a
DATE:	19/08/2014	JOB NO:	1606D

Location: F:\Jobs\1606D\Spatial Data\MapInfo\Workspaces\110a\110a Figure 4 - Predicted Water Level



Legend

- Observation Location
- Homestead Water Supply Bore
- Ophthalmia Water Supply Bore
- Ophthalmia Dam
- Modelled Stream
- Model Boundary
- TEC Boundary
- Ophthalmia Dam Lake
- OB31 Approved Orebody

DATA SOURCES:
Aerial: Landgate 2013

0 5
Kilometres
Scale: 1:200,000 @A3
GDA 1994 Zone 50

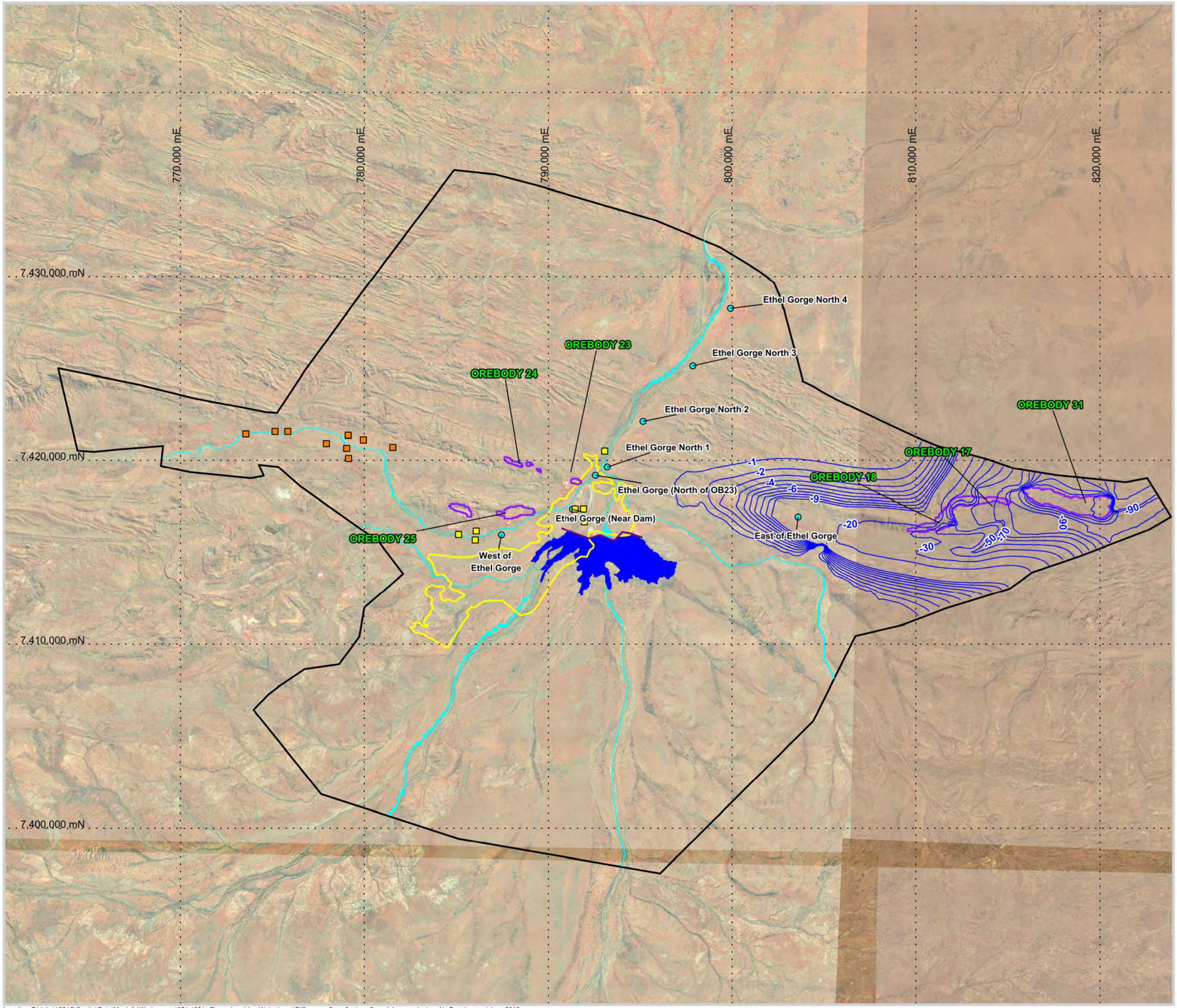
RPS

Figure 5

PREDICTIVE MODEL FEATURES

AUTHOR:	DVB	REPORT NO:	055
DRAWN:	MR	REVISION:	a
DATE:	01/09/2014	JOB NO:	1584G

Location: F:\Jobs\1584G\Spatial Data\MapInfo\Workspaces\055a\055a Figure 5 Approved case



Legend

- Observation Location
- Homestead Water Supply Bore
- Ophthalmia Water Supply Bore
- Ophthalmia Dam
- Predicted Difference Contour (-ve)*
- Stream
- Model Boundary
- Mine Area
- TEC Boundary
- Ophthalmia Lake
- OB31 Approved Orebody

*Contours shown (m): -1,-2,-3,-4,-5,-6,-7,-8,-9,-10, -20,-30,-40,-50,-60,-70,-80,-90,-100,-110,-120,-130)

DATA SOURCES:
Aerial: Landgate 2013

N
0 Kilometres 5
Scale: 1:200,000 @A3
GDA 1994 Zone 50

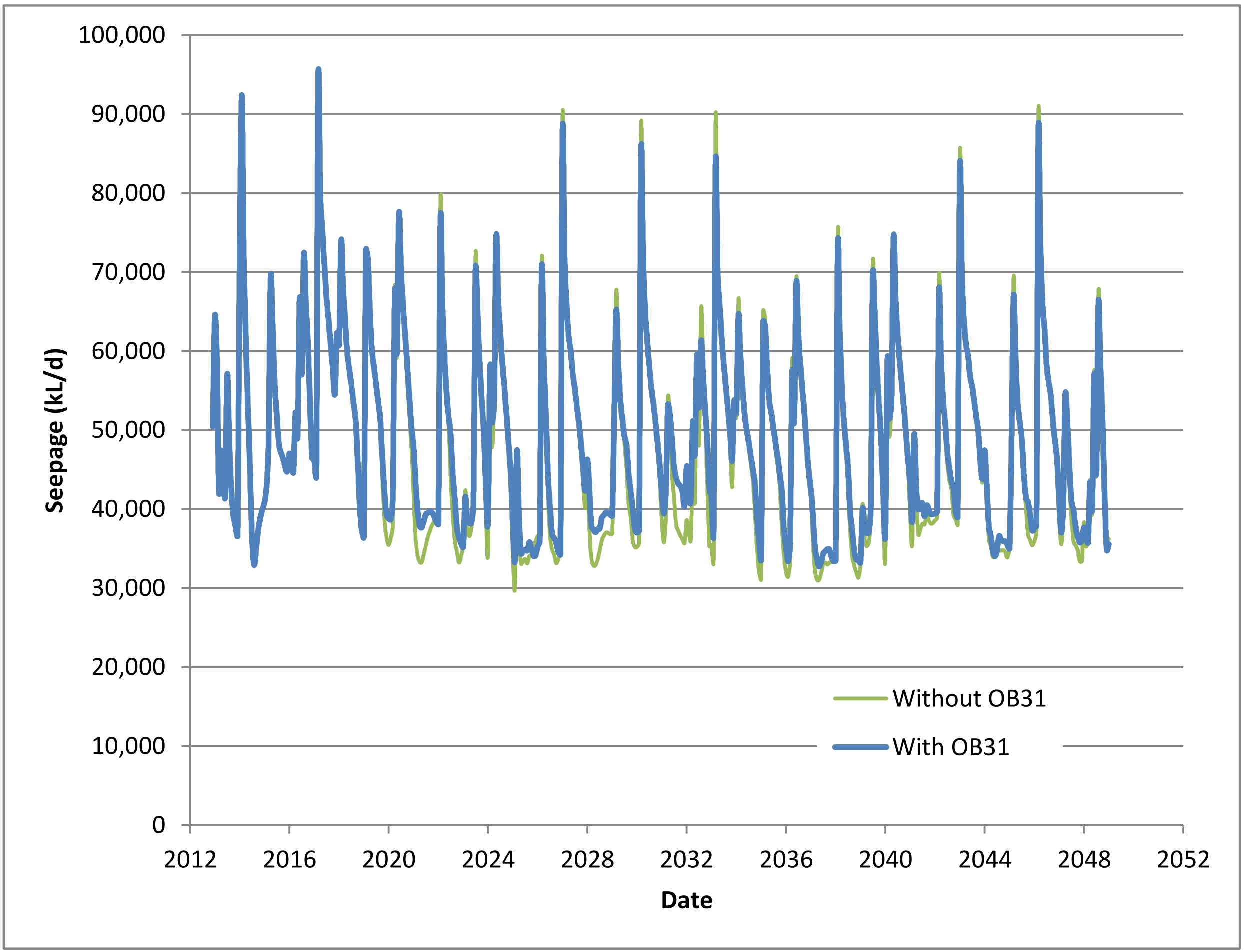
Figure 6

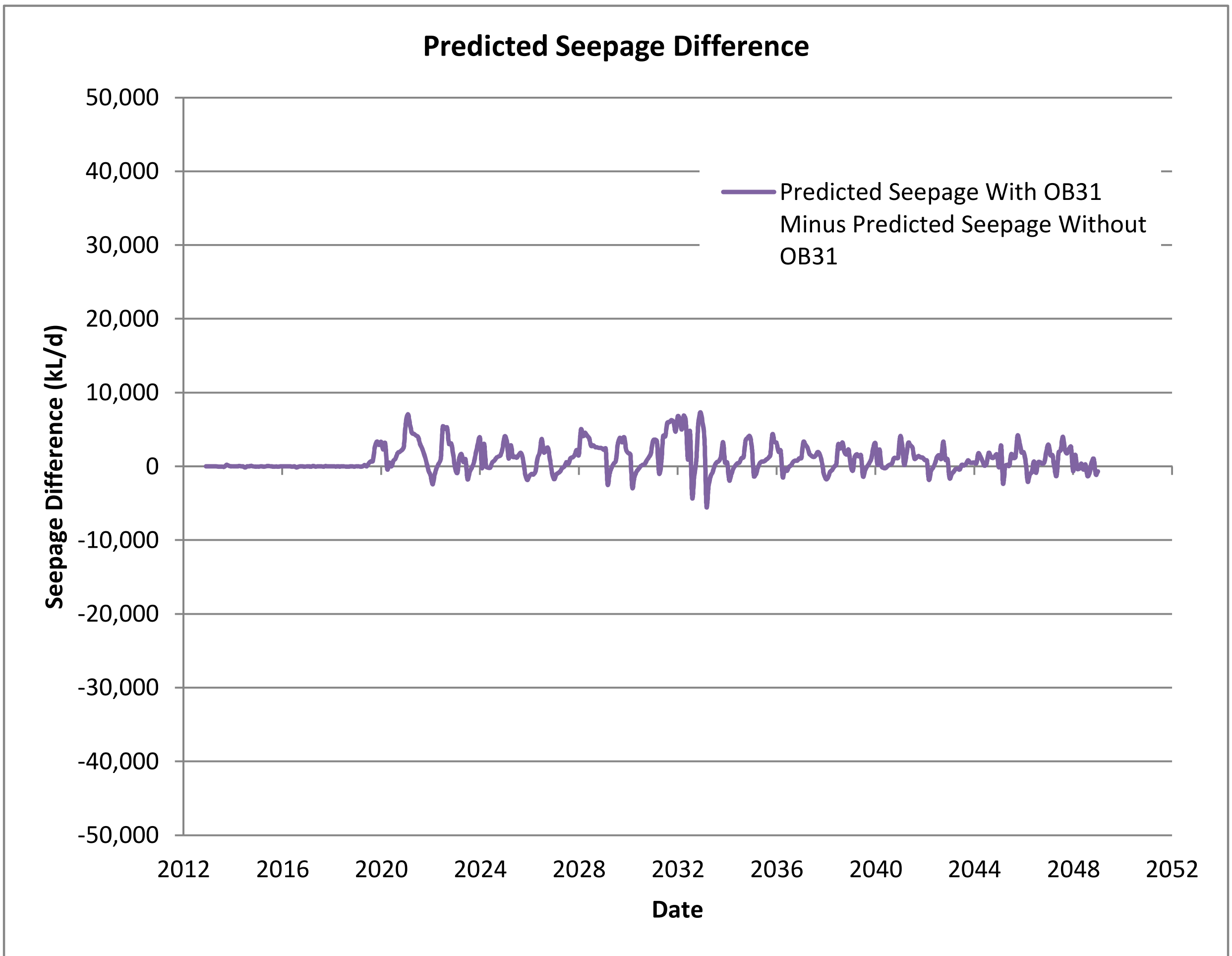
PREDICTED REDUCTION IN GROUNDWATER LEVEL IN 2048 DUE TO OB31 DEWATERING

RPS

AUTHOR:	DVB	REPORT NO:	055
DRAWN:	MR	REVISION:	a
DATE:	01/09/2014	JOB NO:	1584G

Location: F:\Jobs\1584G\Spatial Data\MapInfo\Workspaces\051a\051a Figure 1 and 1a - Water Level Difference: Case 2 minus Case 1 Approved minus No Development June 2048

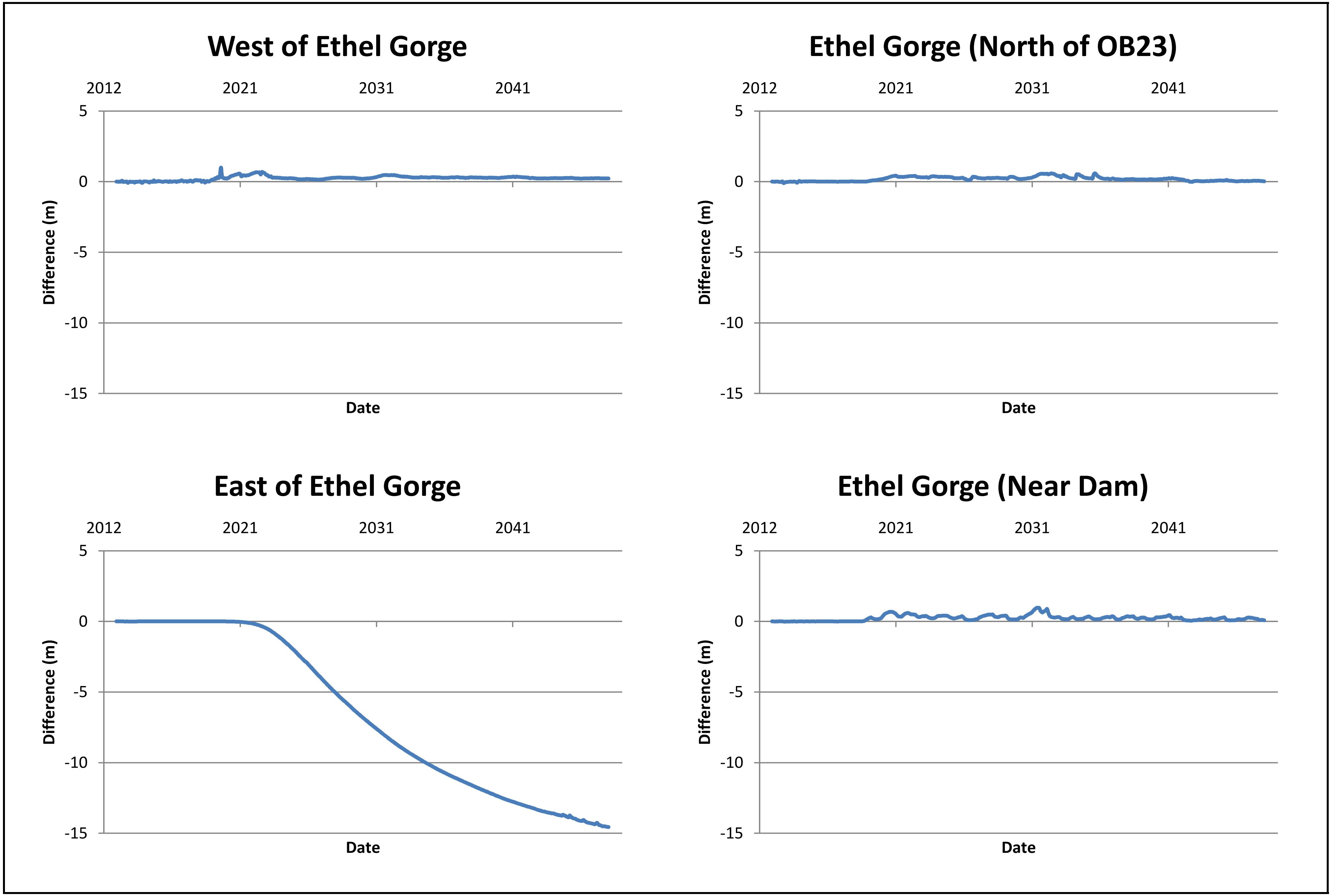




RPS

PREDICTED OPHTHALMIA DAM SEEPAGE FIGURE 7

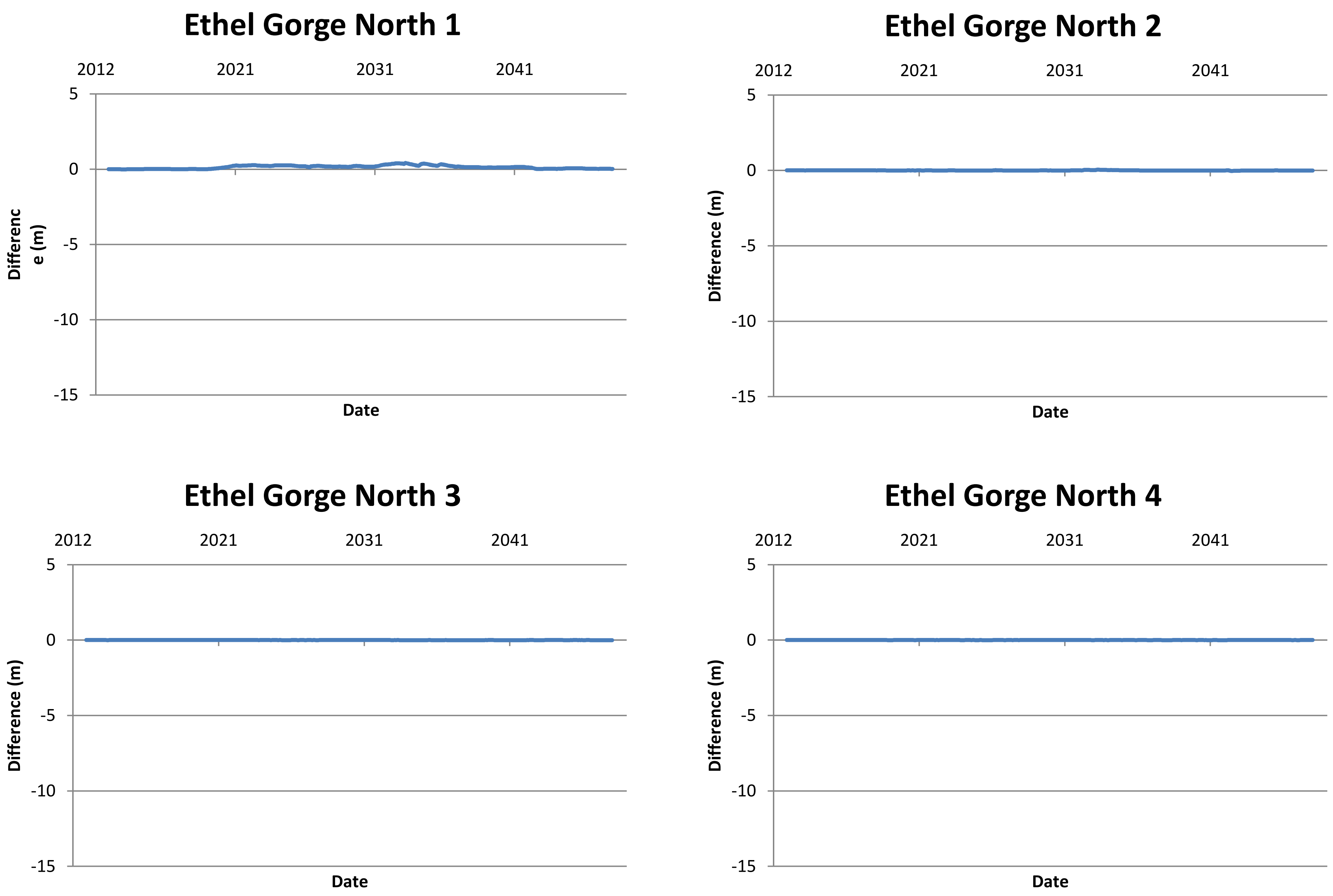
F:\Jobs\1584G\Modelling\Model Results\PDB24\[PDB24 gwc.xls]2graphs



RPS

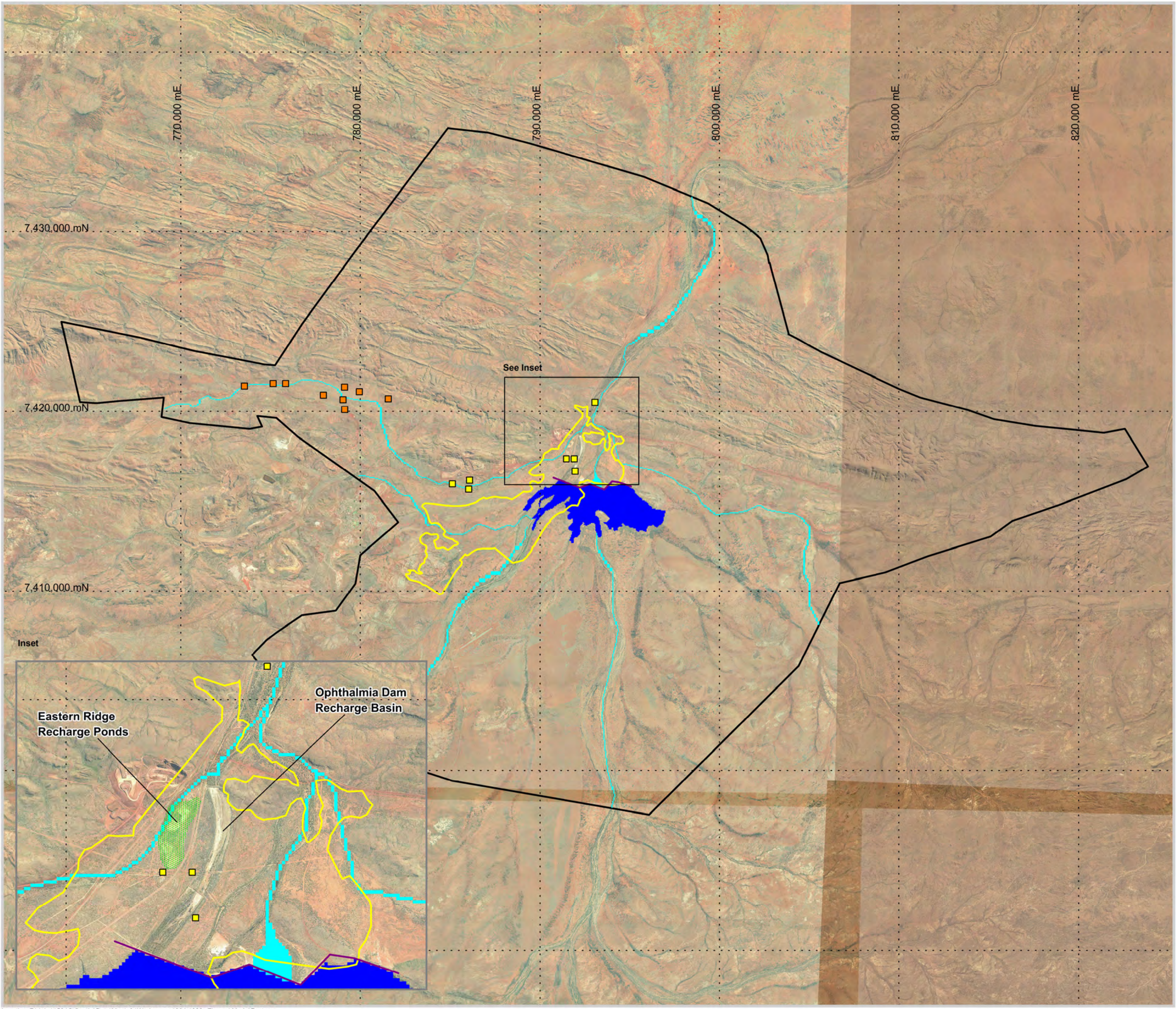
PREDICTED REDUCTION IN WATER LEVEL DUE TO OB31 DEWATERING FIGURE 8

F:\Jobs\1584G\Modelling\Model Results\PDB24\[hydrographs_approved&ob31 all data.xlsx]hydrographs_1 (2)



PREDICTED REDUCTION IN WATER LEVEL DUE TO OB31 DEWATERING FIGURE 9

F:\Jobs\1584G\Modelling\Model Results\PDB24\[hydrographs_approved&ob31 all data.xlsx]hydrographs_2 (2)



Legend

- Homestead Water Supply Bore
- Ophthalmia Water Supply Bore
- Ophthalmia Dam
- Modelled Stream
- Model Boundary
- TEC Boundary
- Ophthalmia Dam Lake

DATA SOURCES:
Aerial: Landgate 2013

N

0 5
Kilometres

Scale: 1:200,000 @A3

GDA 1994 Zone 50

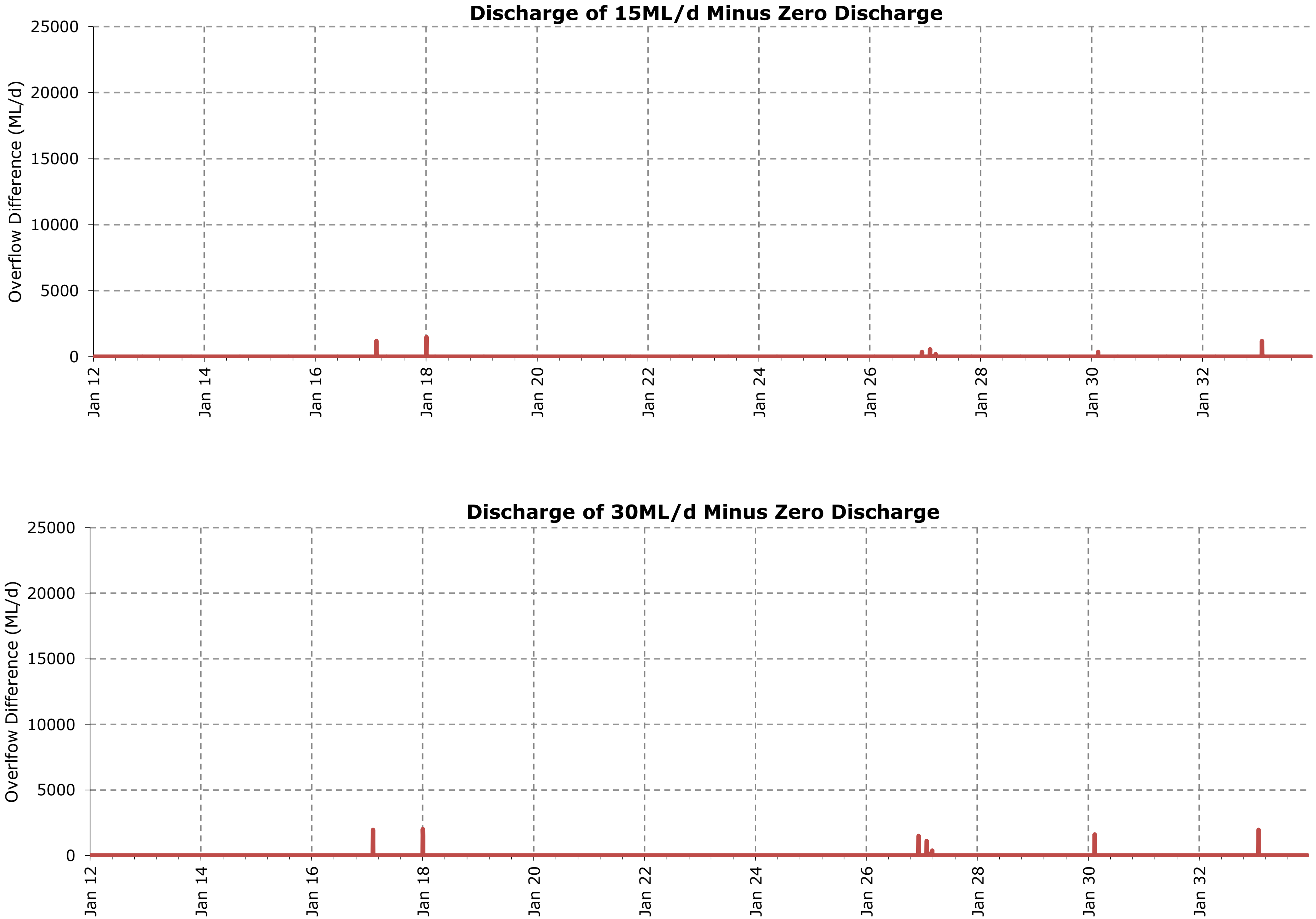
RPS

Figure 10

MODEL FEATURES

AUTHOR:	KR	REPORT NO:	064
DRAWN:	MR	REVISION:	a
DATE:	13/01/2015	JOB NO:	1584G

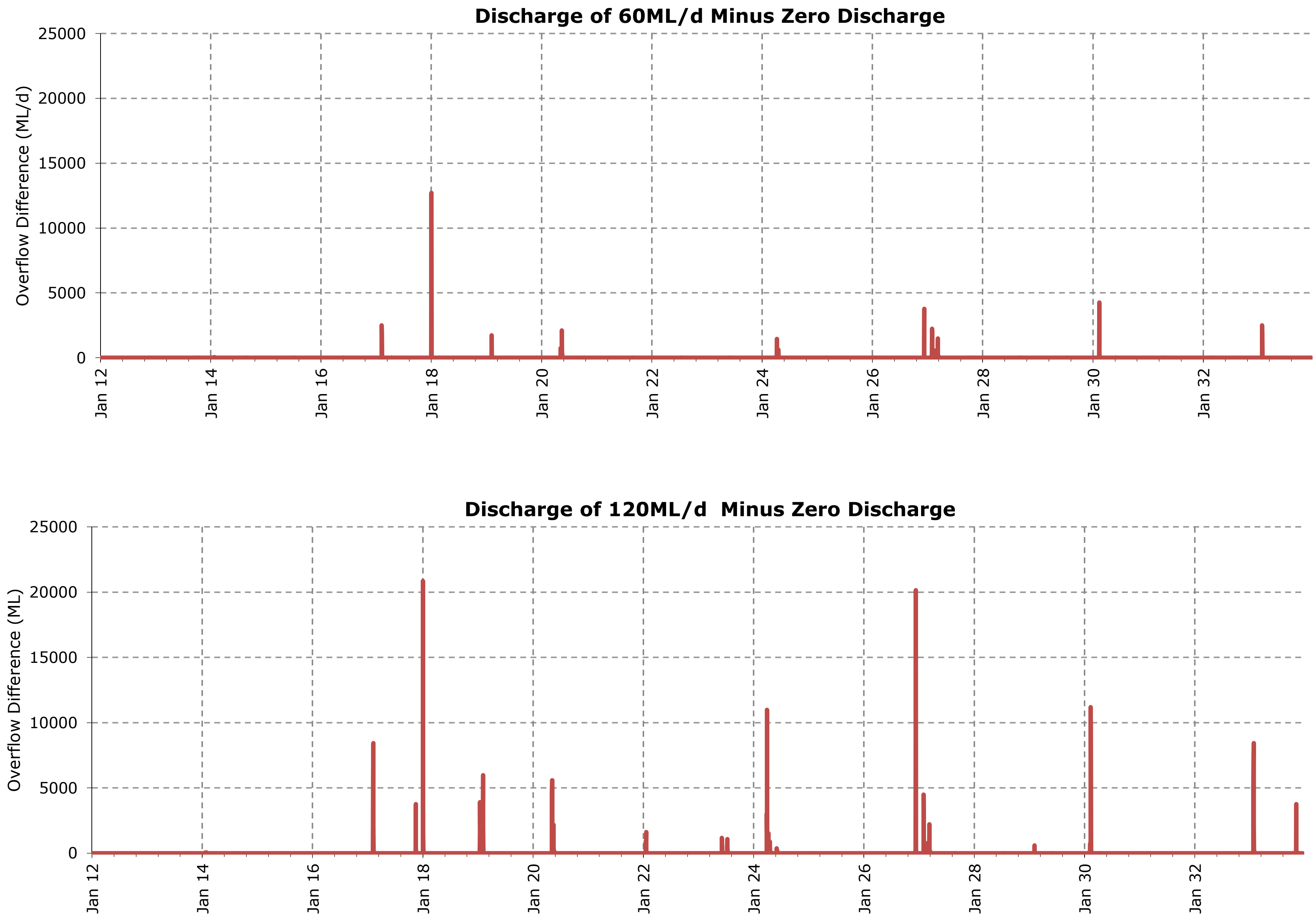
Location: F:\Jobs\1584G\Spatial Data\MapInfo\Workspaces\064a\008a Figure 1 Model Features



RPS

DIFFERENCE IN CALCULATED DAM OVERFLOW(DISCHARGE OF 15ML/D, 30ML/D AND ZERO DISCHARGE PREDICTIONS) FIGURE 11

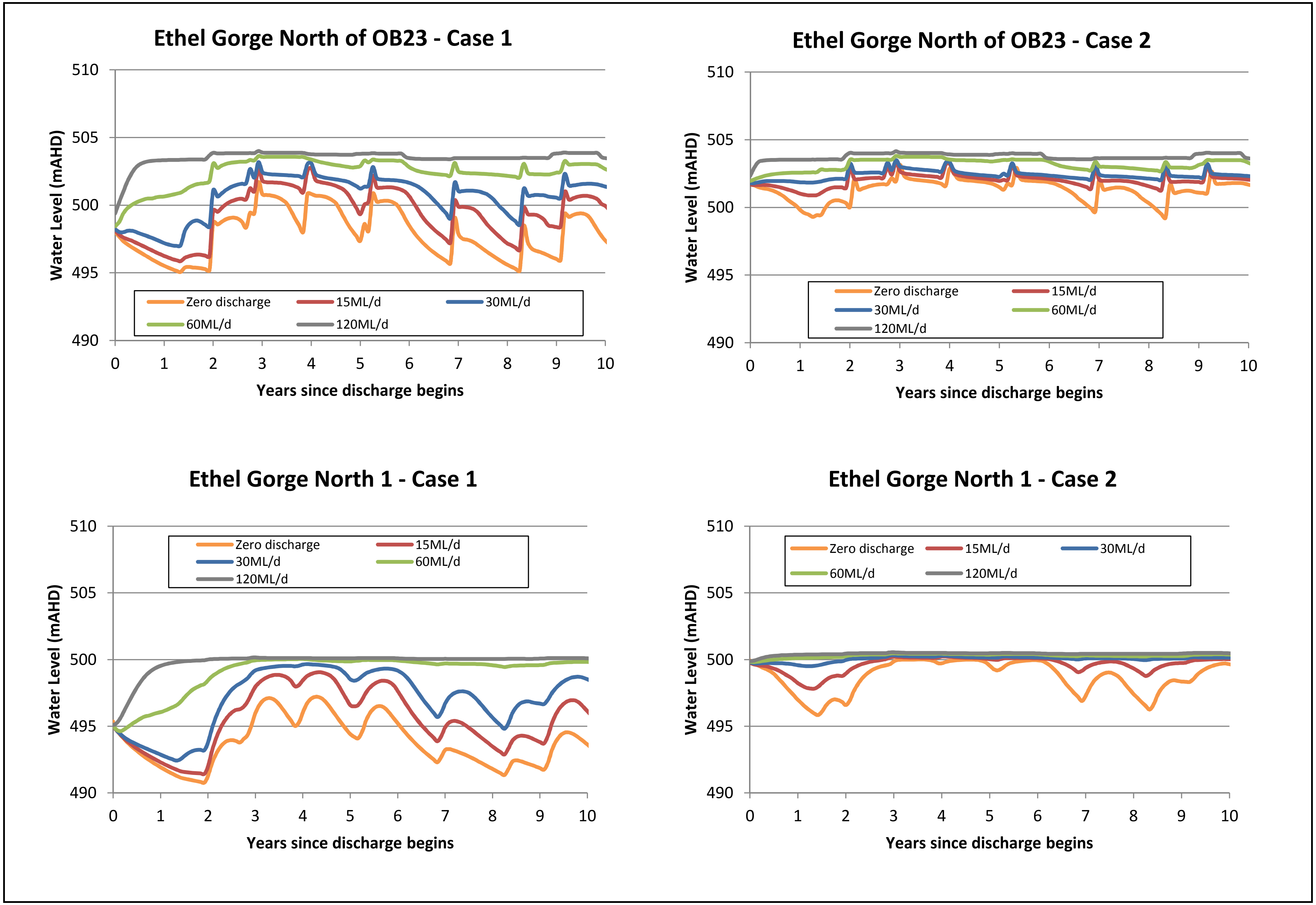
F:\Jobs\1606J\300\[Results for KR.xlsx]differences



RPS

DIFFERENCE IN CALCULATED DAM OVERFLOW(DISCHARGE OF 60ML/D, 120ML/D AND ZERO DISCHARGE PREDICTIONS) FIGURE 12

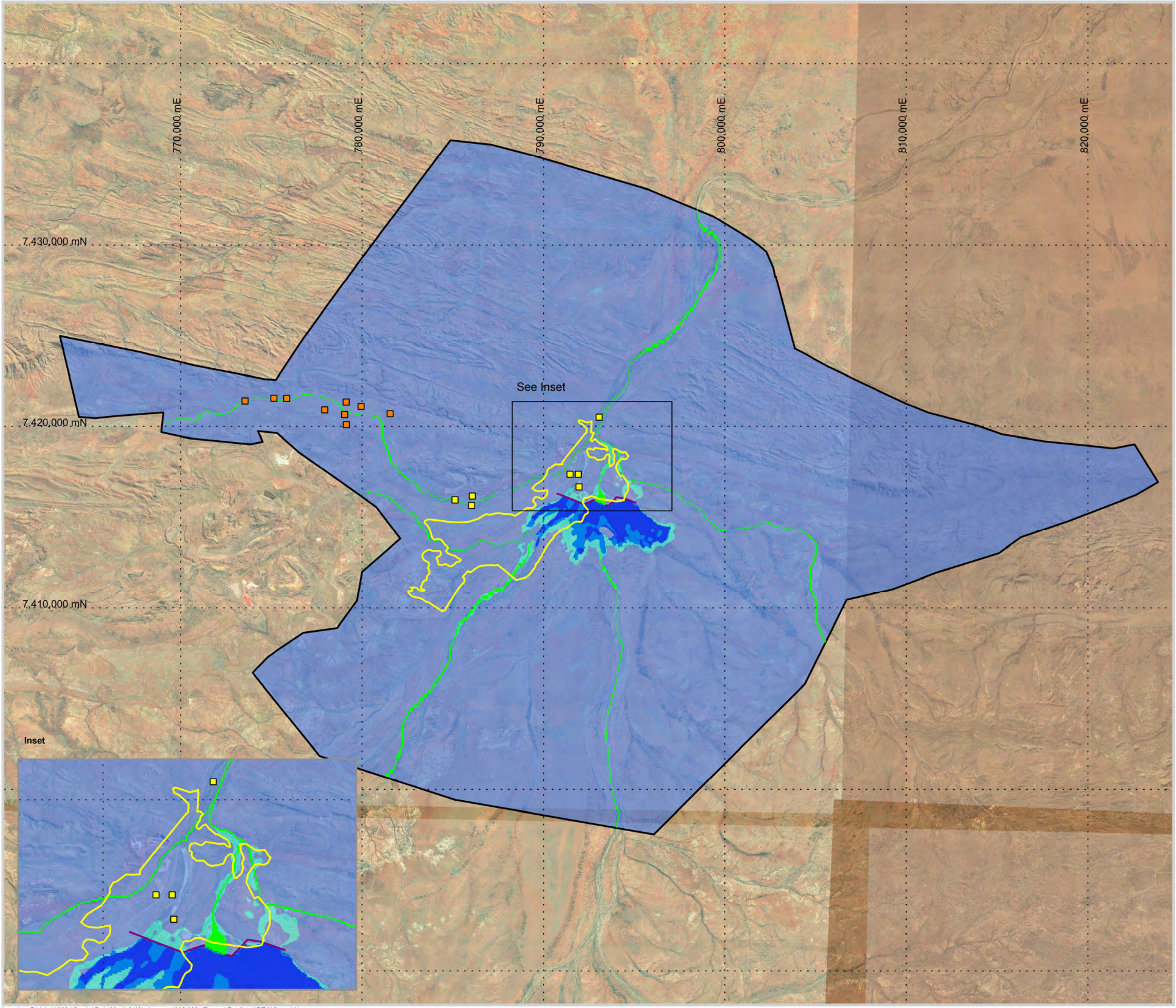
F:\Jobs\1606J\300\[Results for KR.xlsx]differences (2)



RPS

PREDICTED WATER LEVELS, CASES 1 AND 2. FIGURE 13

F:\Jobs\1584G\600\064a\Discharge-Scenario-Figures\[GW-Level_Figure_4.xlsx]Figure



Legend

- Homestead Water Supply Bore
- Ophthalmia Water Supply Bore
- Ophthalmia Dam
- Modelled Stream
- Model Boundary
- TEC Boundary
- Ophthalmia Dam Lake
- Depth to Water < 2m
- Depth to Water > 2m

DATA SOURCES:
Aerial: Landgate 2013

Kilometres

Scale: 1:200,000 @A3

GDA 1994 Zone 50

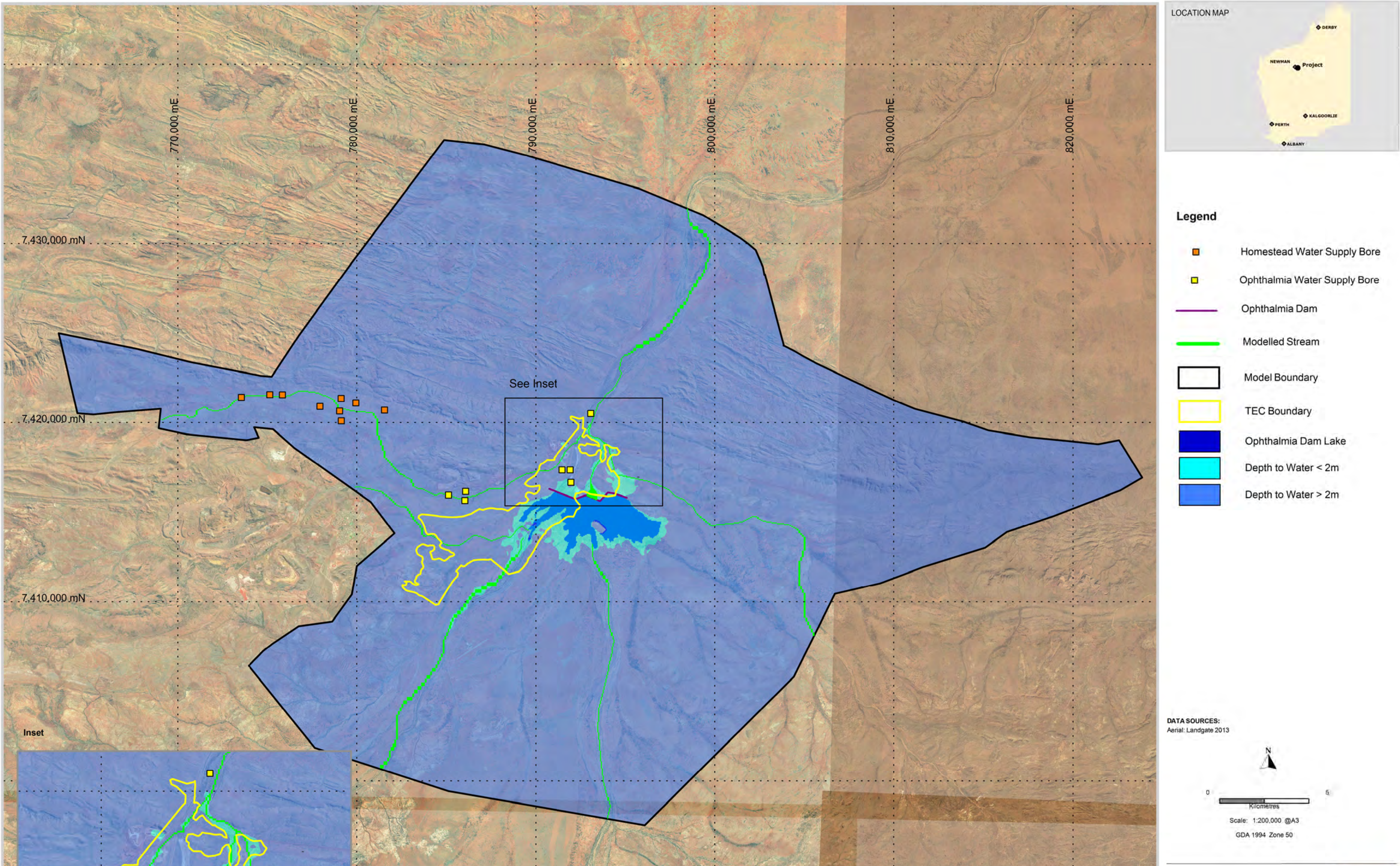
RPS

Figure 14

PREDICTED DEPTH TO WATER CASE 1
ET NO EXCESS DEWATERING DISCHARGE

AUTHOR:	KR	REPORT NO:	064
DRAWN:	MR	REVISION:	a
DATE:	13/01/2015	JOB NO:	1584G

Location: F:\Jobs\1606J\Spatial Data\MapInfo\Workspaces\008\008a Figure 1 Predicted DTW Case 1 No excess



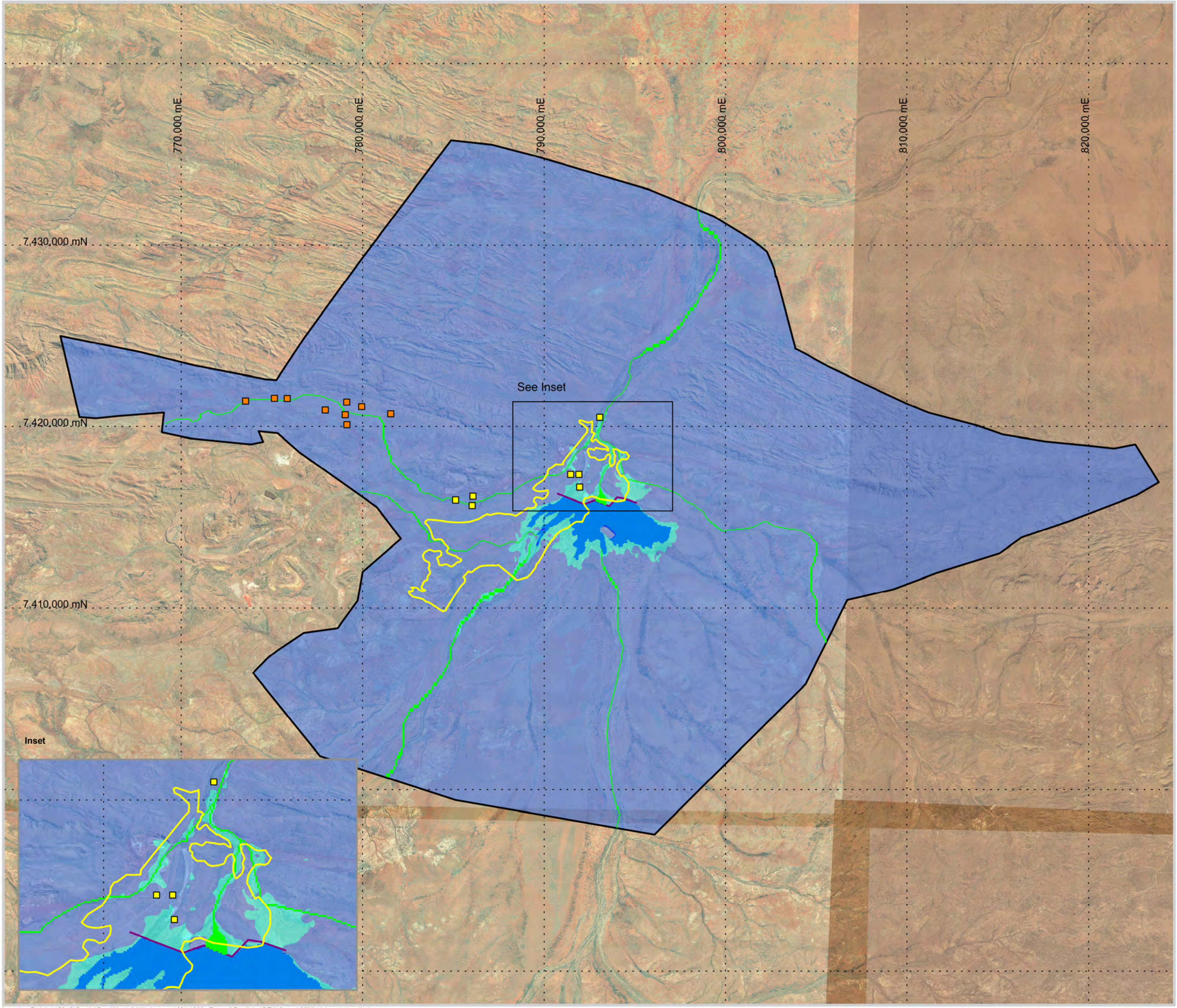
RPS

Figure 15

PREDICTED DEPTH TO WATER CASE 1 ET 15 ML/D DEWATERING DISCHARGE

AUTHOR:	KR	REPORT NO:	064
DRAWN:	MR	REVISION:	a
DATE:	13/01/2015	JOB NO:	1584G

Location: F:\Jobs\1584G\Spatial Data\MapInfo\Workspaces\064a\008a Figure 2 Predicted DTW Case 1 15ML/d dewatering discharge



Legend

- Homestead Water Supply Bore
- Ophthalmia Water Supply Bore
- Ophthalmia Dam
- Modelled Stream
- Model Boundary
- TEC Boundary
- Ophthalmia Dam Lake
- Depth to Water < 2m
- Depth to Water > 2m

DATA SOURCES:
Aerial: Landgate 2013

N

0 5
Kilometres

Scale: 1:200,000 @A3

GDA 1994 Zone 50

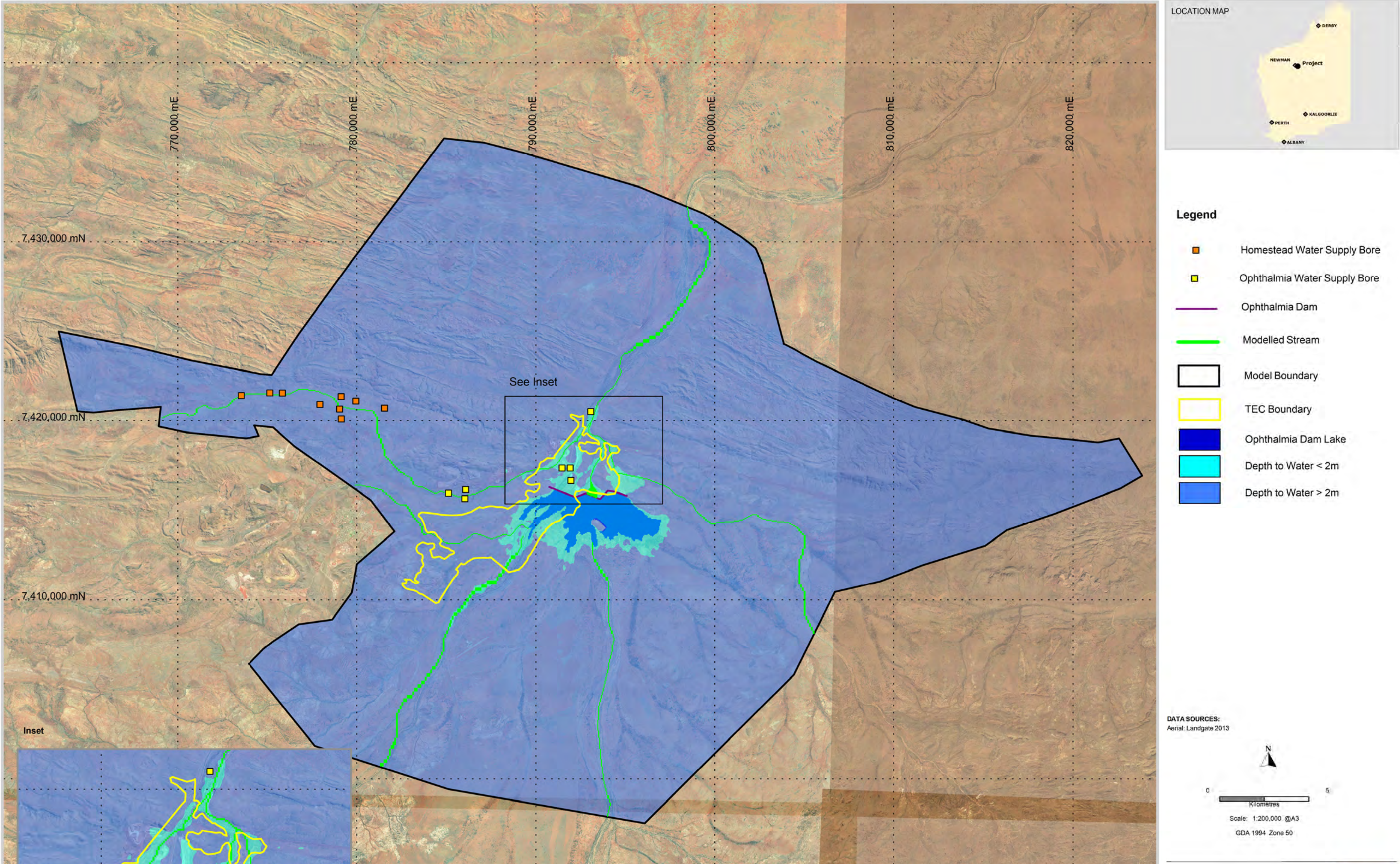
RPS

Figure 16

PREDICTED DEPTH TO WATER CASE 1 ET 30 ML/D DEWATERING DISCHARGE

AUTHOR:	KR	REPORT NO:	064
DRAWN:	MR	REVISION:	a
DATE:	13/01/2015	JOB NO:	1584G

Location: F:\Jobs\1584G\Spatial Data\MapInfo\Workspaces\064a\008a Figure 3 Predicted DTW Case 1 30ML/d dewatering discharge



RPS

Figure 17

PREDICTED DEPTH TO WATER CASE 1 ET 60 ML/D DEWATERING DISCHARGE

AUTHOR:	KR	REPORT NO:	064
DRAWN:	MR	REVISION:	a
DATE:	13/01/2015	JOB NO:	1584G

Location: F:\Jobs\1584G\Spatial Data\MapInfo\Workspaces\064a\008a Figure 4 Predicted DTW Case 1 60ML/d dewatering discharge

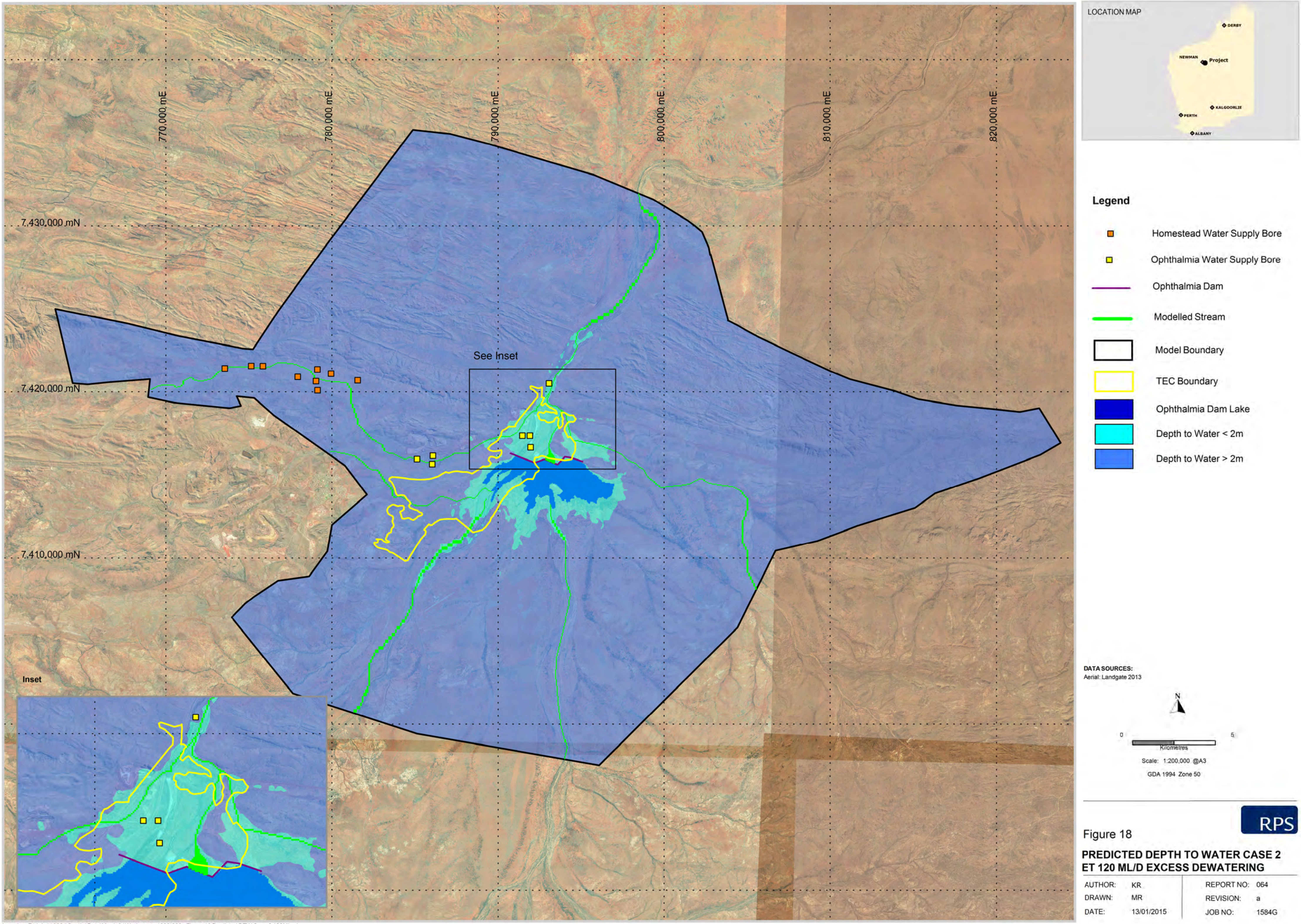
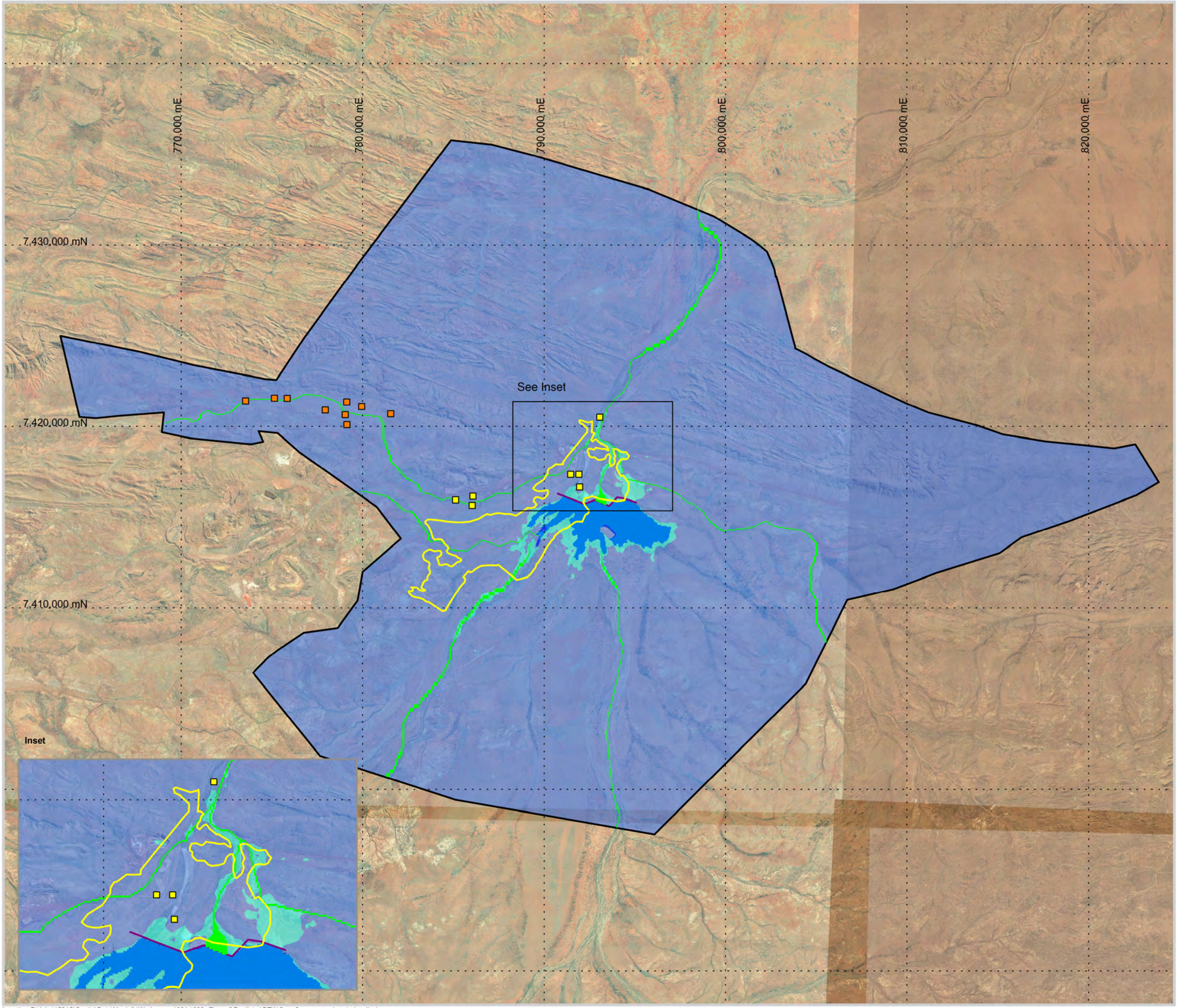


Figure 18

PREDICTED DEPTH TO WATER CASE 2 ET 120 ML/D EXCESS DEWATERING

AUTHOR:	KR	REPORT NO:	064
DRAWN:	MR	REVISION:	a
DATE:	13/01/2015	JOB NO:	1584G

Location: F:\Jobs\1606J\Spatial Data\MapInfo\Workspaces\008\008a Figure 10 Predicted DTW Case 2 120ML_d



Legend

- Homestead Water Supply Bore
- Ophthalmia Water Supply Bore
- Ophthalmia Dam
- Modelled Stream
- Model Boundary
- TEC Boundary
- Ophthalmia Dam Lake
- Depth to Water < 2m
- Depth to Water > 2m

DATA SOURCES:
Aerial: Landgate 2013

N

0 Kilometres 5

Scale: 1:200,000 @A3

GDA 1994 Zone 50

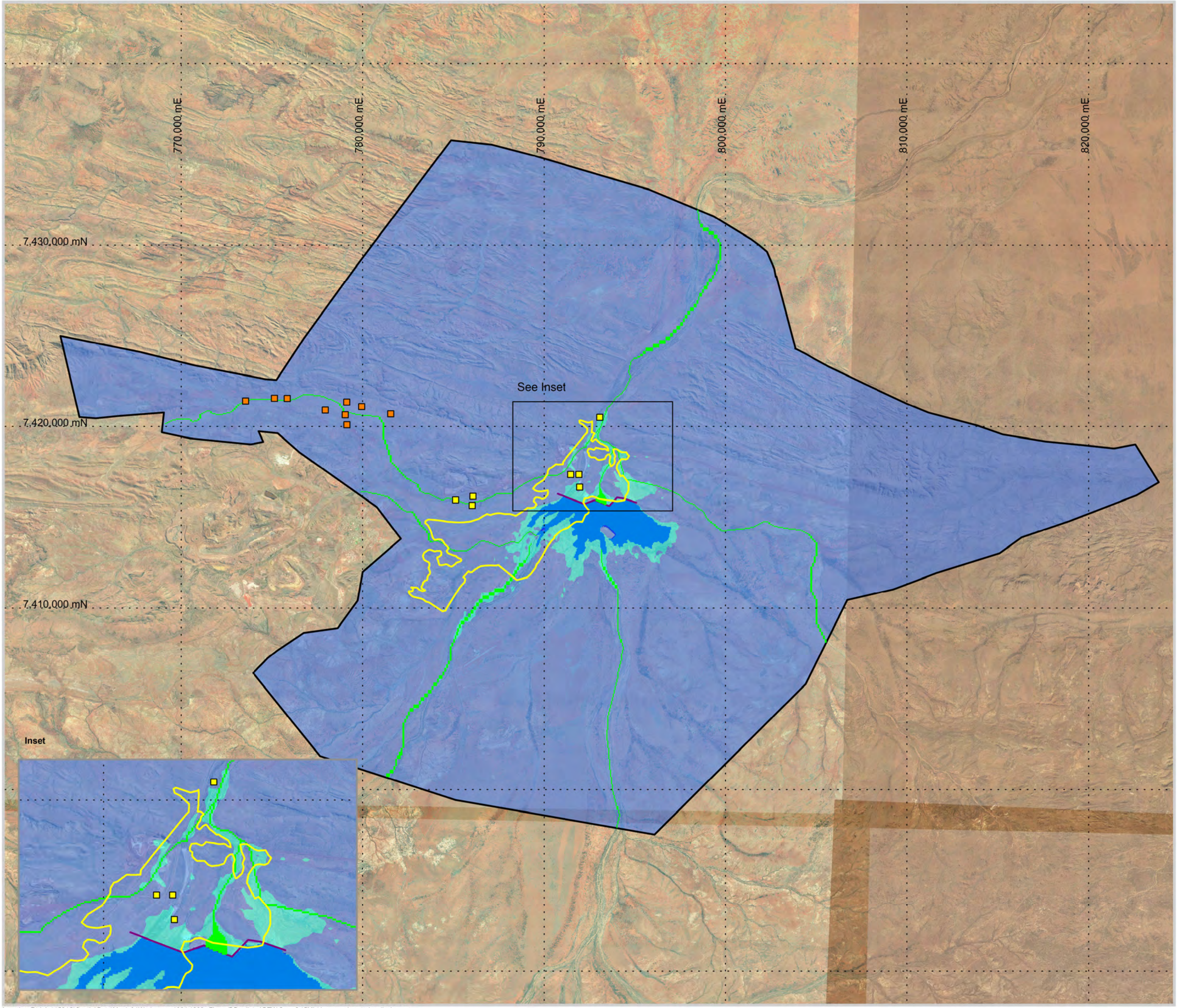
RPS

Figure 19

PREDICTED DEPTH TO WATER CASE 2 ET NO EXCESS DEWATERING DISCHARGE

AUTHOR:	KR	REPORT NO:	064
DRAWN:	MR	REVISION:	a
DATE:	13/01/2015	JOB NO:	1584G

Location: F:\Jobs\1584G\Spatial Data\MapInfo\Workspaces\064a\008a Figure 6 Predicted DTW Case 2 no excess dewatering discharge



Legend

- Homestead Water Supply Bore
- Ophthalmia Water Supply Bore
- Ophthalmia Dam
- Modelled Stream
- Model Boundary
- TEC Boundary
- Ophthalmia Dam Lake
- Depth to Water < 2m
- Depth to Water > 2m

DATA SOURCES:
Aerial: Landgate 2013

N

0 5
Kilometres
Scale: 1:200,000 @A3
GDA 1994 Zone 50

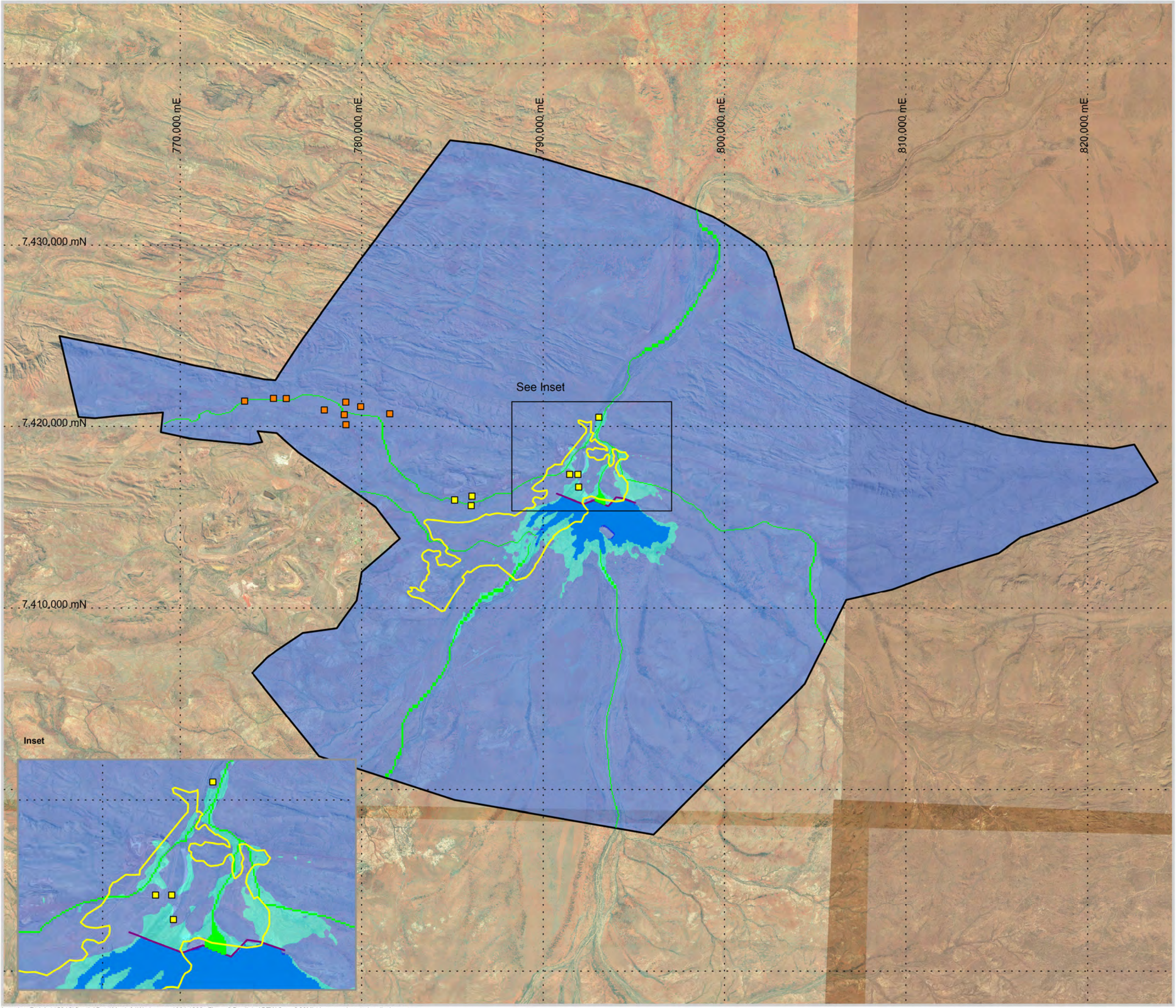
RPS

Figure 20

PREDICTED DEPTH TO WATER CASE 2 ET 15 ML/D EXCESS DEWATERING DISCHARGE

AUTHOR:	KR	REPORT NO:	064
DRAWN:	MR	REVISION:	a
DATE:	13/01/2015	JOB NO:	1584G

Location: F:\Jobs\1584G\Spatial Data\MapInfo\Workspaces\064a\008a Figure 7 Predicted DTW Case 2 15ML/d excess dewatering discharge



Legend

- Homestead Water Supply Bore
- Ophthalmia Water Supply Bore
- Ophthalmia Dam
- Modelled Stream
- Model Boundary
- TEC Boundary
- Ophthalmia Dam Lake
- Depth to Water < 2m
- Depth to Water > 2m

DATA SOURCES:
Aerial: Landgate 2013

N

0 Kilometres 5

Scale: 1:200,000 @A3

GDA 1994 Zone 50

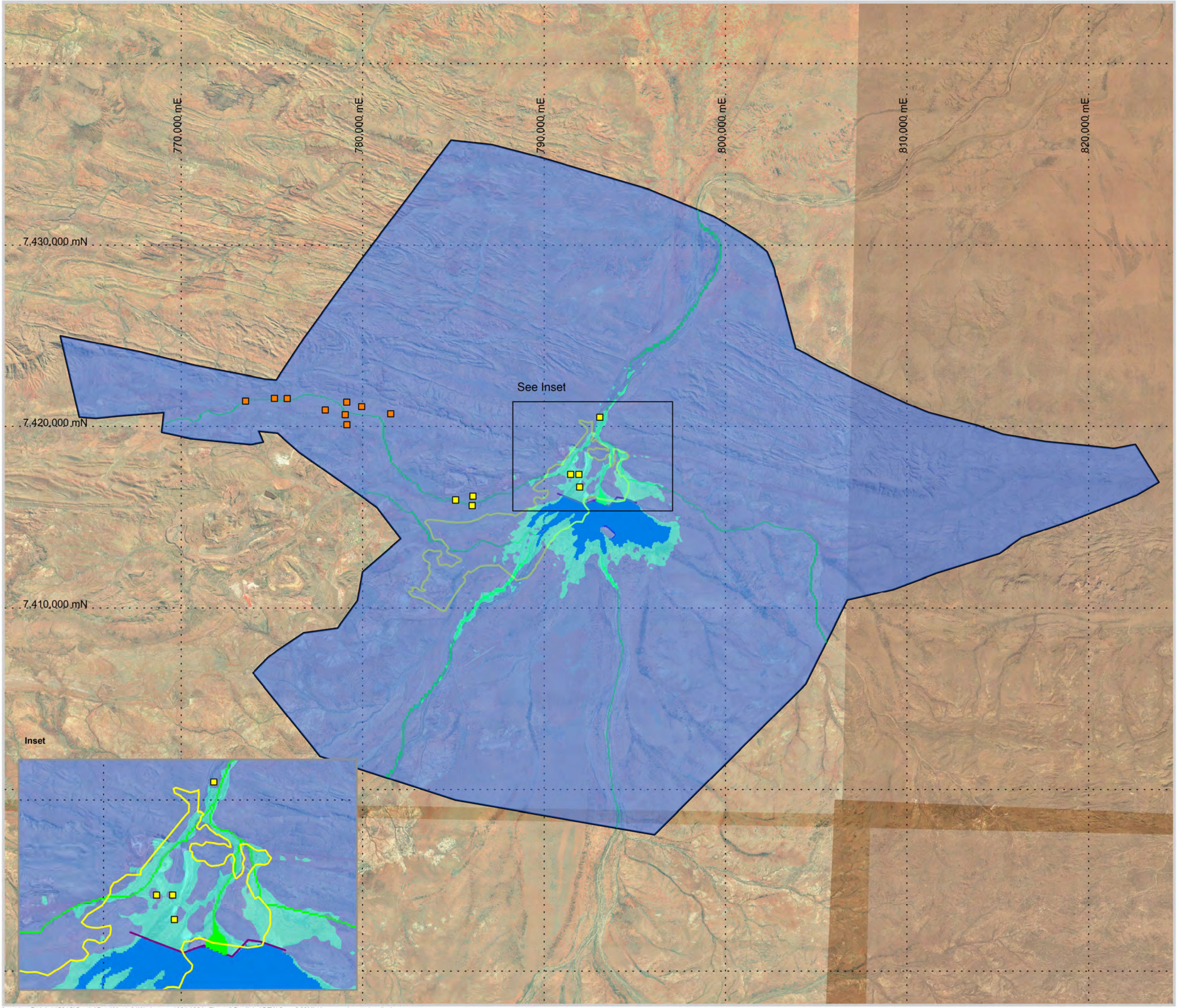
RPS

Figure 21

PREDICTED DEPTH TO WATER CASE 2
ET 30 ML/D EXCESS DEWATERING DISCHARGE

AUTHOR:	KR	REPORT NO:	064
DRAWN:	MR	REVISION:	a
DATE:	13/01/2015	JOB NO:	1584G

Location: F:\Jobs\1584G\Spatial Data\MapInfo\Workspaces\064a\008a Figure 8 Predicted DTW Case 2 30ML/d excess dewatering discharge



Legend

- Homestead Water Supply Bore
- Ophthalmia Water Supply Bore
- Ophthalmia Dam
- Modelled Stream
- Model Boundary
- TEC Boundary
- Ophthalmia Dam Lake
- Depth to Water < 2m
- Depth to Water > 2m

DATA SOURCES:
Aerial: Landgate 2013

N

0 5
Kilometres

Scale: 1:200,000 @A3

GDA 1994 Zone 50

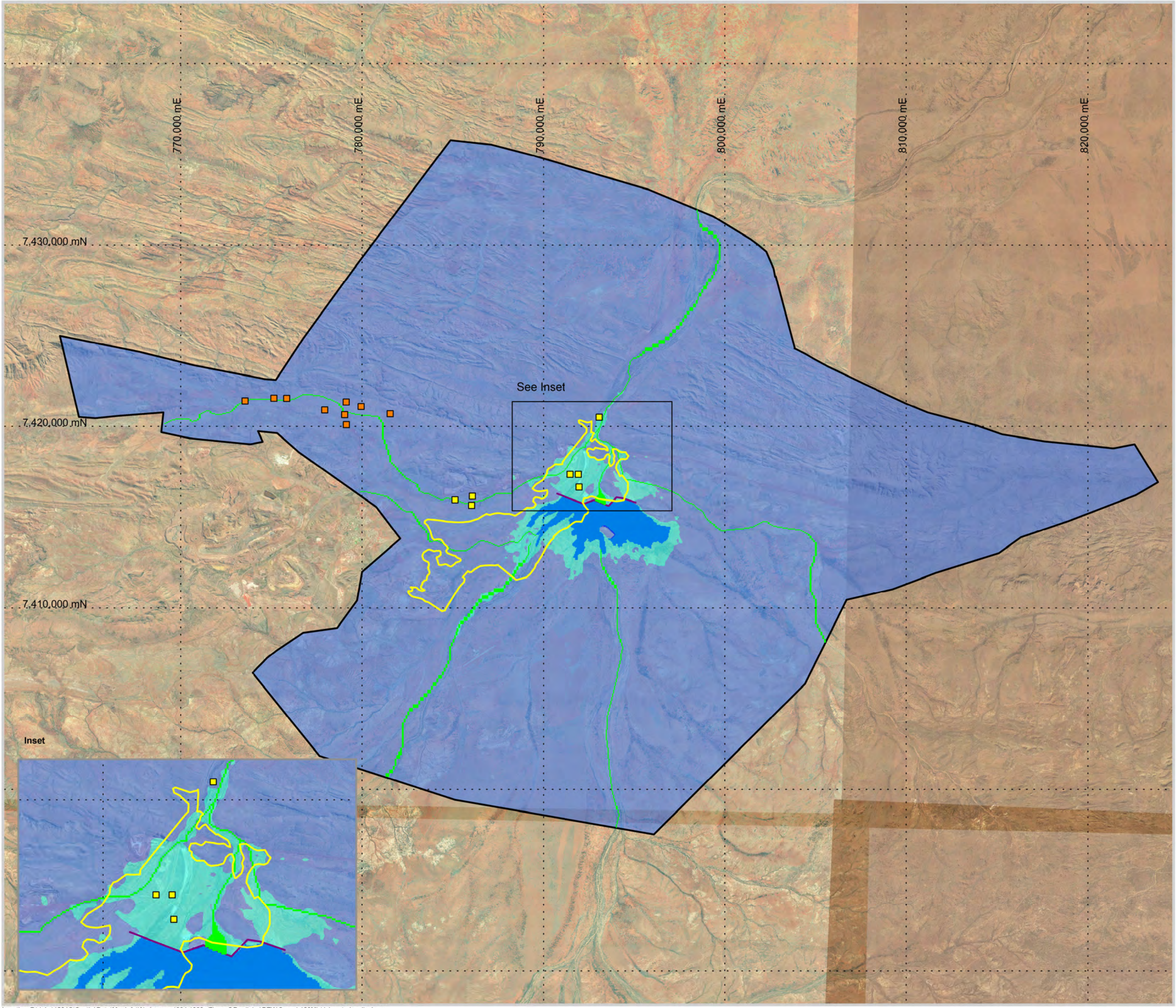
RPS

Figure 22

PREDICTED DEPTH TO WATER CASE 2
ET 60 ML/D EXCESS DEWATERING DISCHARGE

AUTHOR:	KR	REPORT NO:	064
DRAWN:	MR	REVISION:	a
DATE:	13/01/2015	JOB NO:	1584G

Location: F:\Jobs\1584G\Spatial Data\MapInfo\Workspaces\064a\064a Figure 9 Predicted DTW Case 2 60ML/d excess dewatering discharge



Legend

- Homestead Water Supply Bore
- Ophthalmia Water Supply Bore
- Ophthalmia Dam
- Modelled Stream
- Model Boundary
- TEC Boundary
- Ophthalmia Dam Lake
- Depth to Water < 2m
- Depth to Water > 2m

DATA SOURCES:
Aerial: Landgate 2013

Kilometres

Scale: 1:200,000 @A3

GDA 1994 Zone 50

RPS

Figure 23

PREDICTED DEPTH TO WATER CASE 1 ET 120 ML/D DEWATERING DISCHARGE

AUTHOR:	KR	REPORT NO:	064
DRAWN:	MR	REVISION:	a
DATE:	13/01/2015	JOB NO:	1584G

Location: F:\Jobs\1584G\Spatial Data\MapInfo\Workspaces\064a\008a Figure 5 Predicted DTW Case 1 120ML/d dewatering discharge

Appendix 3 Ophthalmia Dam and Ethel Gorge water and salt balance study

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MEMORANDUM

COMPANY:	BHPBIO		
ATTENTION:	Jon Hanna		
FROM:	Duncan Storey		
DATE:	20 October 2014	JOB NO: 1703B	DOC NO: 037b
SUBJECT:	Ethel Gorge Assessment of the Impact of OB31 Dewatering Discharge into Ophthalmia Dam - Groundwater and Salt Balance Modelling		

1. BACKGROUND

Ethel Gorge (the Gorge) is on the Fortescue River some 15 km north-east of Newman. The Gorge is downstream (north) of the confluence of Homestead, Shovelanna and Warrawanda Creeks within the Fortescue River. It is formed where the Fortescue River flows through the Ophthalmia Range in a northerly direction. Downstream of the Gorge, the river flows in a narrow channel to the north, then onto a broad floodplain and ultimately into the Fortescue Marsh.

Ophthalmia Dam is located 3 km upstream of the Gorge. The dam is a managed aquifer recharge (MAR) structure, completed in late 1981, that detains flows in the Fortescue River to replenish the downstream alluvial and calcrete aquifers.

The area hosts the Ethel Gorge Stygobiont Threatened Ecological Community (TEC). Additionally, the vegetation of the major river-channels includes some uncommon communities of dense riparian and woodland vegetation that are of local conservation significance and add to the environmental amenity of the area. Thus, the ecology of the Ethel Gorge area is defined by surface and subsurface inflows and the presence of a shallow groundwater system associated with the Fortescue River and its floodplain.

Ophthalmia Dam currently receives excess dewatering discharges from the OB23/25 mining operations with approval for additional discharges from the OB29/30/35 and Jimblebar mining operations. BHPBIO are now considering discharging surplus water from the proposed OB31 mining operations. The salinity of dewatering excess is higher than the salinity of surface water inflows to the dam. Additional discharge into the dam will potentially increase the rate and salinity of water seeping from the dam into the groundwater system that supports the Ethel Gorge TEC. This report describes the potential change in the salinity down gradient of the dam as a result of the additional discharge from OB31.

2. OVERALL APPROACH AND SCOPE OF WORKS

The overall approach is based on developing a water and salt balance model that identifies and quantifies key elements in groundwater system and provides scale on how changes in these key elements may affect the aquifer that supports the Ethel Gorge TEC. A summary of the scope of the study is outlined below:

1. Review available information and refresh hydrogeological understanding of the Ethel Gorge groundwater system and its support of the TEC.
2. Determine the likely capacity of the aquifer to accept recharge (i.e. will the aquifer effectively be fully saturated or are periods of water level recession likely).
3. Based on the above, update the Ethel Gorge conceptual model to add more detail on the key processes that affect water quality (in relation to salinity) in the area of the TEC.

4. Develop an analytical water and salt balance model for the Ethel Gorge aquifer.
5. Run the model to predict future changes at Ethel Gorge, based on the seepage and flow volumes predicted from the water balance model for the dam for several operating scenarios.
6. Compare predicted changes in salinity against the observed range at Ethel Gorge.

Three broad scenarios have been considered:

1. A Base Case which represents a cessation of all dewatering discharge into the dam (Case 1).
2. An "Approved Case" which represents how the groundwater system will respond on the basis of the mines and operating practices that are currently approved to discharge to the dam (Case 2 and 3).
3. An "OB31 Case" which represents how the system will respond to the additional of discharge from OB31 (Case 4 and 5).

The option of releasing more water from the dam (to reduce the retention period and salt concentration) has also been considered within each scenario (Cases 3 and 5). For all cases, the climate sequence is based on repetitions of the climate sequence observed between 1980 and 1996 which is a relative dry period and is considered an appropriate conservative period for this study.

3. EXISTING ENVIRONMENT - ETHEL GORGE

3.1 Previous Work

The Ethel Gorge groundwater system has been affected by BHPBIO operations since the 1960s. The Gorge has been subject to many previous studies and there are considerable monitoring data collected in and around the Gorge as part of regional monitoring and specific monitoring at nearby mining and water supply operations. A synthesis of this previous work has recently been used to develop comprehensive and new hydrogeological and eco-hydrological models for the Gorge (RPS 2014). The new hydrogeological model also underpins numerical simulation modelling of the regional groundwater system that is being used to predict the future-impacts, on groundwater resources, of various mine-development scenarios (RPS 2014). A detailed review of these recent studies is not repeated here. Rather, a summary is presented below and additional comment is made where the current work adds to previous work.

3.2 Ethel Gorge TEC

3.2.1 Stygofauna

A unique and diverse stygofauna assemblage was identified in the shallow alluvial and calcrete aquifers of Ethel Gorge in the late 1990s (Bradbury, 2000). This was subsequently classified as the Ethel Gorge Aquifer Stygobiont Community TEC and was described by TEC Scientific Committee (2006) as inhabiting the “Ethel Gorge/Ophthalmia Basin alluvium calcrete aquifer”. Understanding of the distribution of the TEC has evolved since it was first discovered and in November 2012, the extent of surface calcrete at Ethel Gorge was determined to be the boundary of the TEC itself, and a buffer of 6 km beyond the calcrete was added. The distribution of the TEC is shown in Figure 1.

A review of stygofauna in the Pilbara was recently published by Halse (2014) and characterisation of the Ethel Gorge TEC was undertaken for BHPBIO by Bennelongia (2013). Salient points from this work were:

- Ethel Gorge is one of nine areas in the Pilbara that have an unusually high density of stygofauna.
- There is little correlation between stygofauna presence and specific geology at Ethel Gorge. However, Halse et al. (2014) note that alluvium and calcrete are generally the most supportive of stygofauna habitat and so it seems likely that the stygofauna in Ethel Gorge will be richest in the palaeochannel aquifers of the Fortescue River valley.
- Corroborating this, sampling results suggest the stygofauna community is richest around OB23 and the lower/central Ophthalmia areas and the community does not seem to extend as far south as the DPaW TEC 2011 boundary would suggest.

- A total of 78 species of stygofauna have been recorded from the area including Copepods, Ostracods, Oligochaetes and Amphipods.
- In isolation, the range of many of the individual species extends beyond the Ethel Gorge area and it appears the TEC cannot be defined on the basis of one species alone. Rather, the TEC should be defined on the basis of a combination of indicator species.
- The reasons for the concentration of stygofauna in Ethel Gorge are unknown although the occurrence of extensive vegetation may be related to the nutrient cycle for the stygofauna. However, Halse (2014) suggests water quality maybe not be a great influence on stygofauna where the salinity (Total Dissolved Solids - TDS) is 10,000 mg/L or less.
- The controls on the distribution and prevalence of stygofauna may vary between individual species. (As such, identifying the consequence of a change in water quality across multiple species would not be possible).
- A major risk to all stygofauna communities is loss of habitat caused by groundwater water level decline (e.g. as a result of groundwater abstraction or natural climatic variation).

3.2.2 Vegetation

The vegetation of the major drainage channels in the area comprises 3,650 ha of uncommon communities of dense riparian and woodland vegetation which are of local conservation significance and add to the environmental amenity. Major vegetation types include (DEC 2013):

- Open Forest of *Eucalyptus victrix* (Coolibah) and *Eucalyptus camaldulensis* (River Red Gum) over sedges of *Cyperus vainatus* and *Typha domingensis* along major drainage lines.
- Open Woodland of *Eucalyptus victrix* over Low Open Woodland of *Acacia citrinoviridis* over Scattered Tussock Grasses of *Cenchrus ciliaris.*
- Open Mallee of *Eucalyptus socialis* subsp. *eucentrica* over Very Open Hummock Grassland of *Triodia pungens* on floodplains.

The vegetation includes facultative phreatophytes (*E. camaldulensis; E. victrix*) that are known to use the shallow groundwater and hence contribute to groundwater discharge through evapotranspiration (ET). The proportion of vegetation water use contributed by groundwater, in comparison with surface inputs to the unsaturated profile (i.e. rainfall and run-off), is unknown. It is possible that in some areas groundwater is only accessed transiently, during prolonged dry periods where the unsaturated profile dries out. However, in general terms a greater contribution from groundwater would be expected as the depth to watertable decreases and the soil moisture store decreases. . Vegetation communities overlying stygofauna habitat may be an important source of carbon and nutrients for stygobiont communities. Phreatophytic vegetation roots are known to be a source of organic matter to aquifer invertebrates (Jasinska *et al.* 1996).

The results of an analytical water balance and subsequent calibration of a numerical model for the Ethel Gorge suggest that ET losses over 60,000 kL/d on average (RPS 2014). This equates to an ET rate of 600 mm/yr and is the major source of groundwater discharge from the Ethel Gorge catchment. The water balance also shows that the main source of groundwater to support such a high rate of ET is seepage and recharge from Ophthalmia Dam. By implication, it appears the enhanced recharge from the dam has decreased the depth to the water table down gradient from the dam thus decreasing the unsaturated moisture volume and increased groundwater uptake from vegetation. Under natural conditions pre-dam construction the ET losses were not likely to be as high. Areas of dense woodland where ET occurs are shown on Figure 1.

3.3 Groundwater System

3.3.1 Hydrogeology

The Ethel Gorge groundwater system occurs in valley sediments bounded by low permeability basement rocks. It consists of a highly permeable alluvial aquifer comprising an upper unit of sandy-alluvium and calcrete (upper alluvial aquifer) and a lower unit of gravelly-alluvium (deep aquifer). The two units are separated by an extensive low permeability clay sequence.

The hydraulic behaviour of the Ethel Gorge groundwater system has been dominated by Ophthalmia Dam, since it's commissioning in 1981. The dam serves to substantially increase groundwater recharge and hydraulic loading on the alluvial aquifer. Groundwater levels in the aquifer have been sustained at much higher levels since the dam was constructed than would otherwise have been the case. Salient features of the groundwater system are summarised below:

- Groundwater flows from south to north aligned with the Fortescue River valley. Groundwater levels fall from ~510 mAHD at Ophthalmia Dam to ~500 mAHD in Ethel Gorge.
- The upper alluvial aquifer is unconfined and receives most of the water seeping from Ophthalmia Dam and this supports long-term trends in the volume of water stored in the aquifer and water levels.
- In addition to seepage from the dam, the upper aquifer also receives recharge from direct infiltration associated with river flow events. However, seasonal recharge maybe limited by aquifer capacity (i.e. where seepage from the dam maintains the aquifer at near full saturation conditions).
- Groundwater levels in the upper alluvial aquifer range between 0 and 10 mbgl across the entire area providing substantial saturated thickness in the upper alluvium and calcrete, supporting the main stygofauna habitat.
- The lower aquifer is largely confined by the overlying clay and is predominantly subject to hydraulic loading from Ophthalmia Dam. Bore data indicates that the lower aquifer has piezometric heads which commonly equal or exceed water levels in the upper alluvial aquifer, particularly close to the Dam (i.e. lower aquifer hydraulic head is equivalent to the dam water level).
- Recharge to the upper and lower aquifer in the Ethel Gorge area occurs predominantly as seepage from Ophthalmia Dam at an average rate of around 50,000 kL/d. Other sources of recharge include direct infiltration from channel flow events (along the Fortescue River channel when the dam overflows and upgradient from the dam) and also along Homestead Creek and Shovelanna Creek which are unregulated. Total recharge from infiltration along creek channels is around 24,000 kL/d (average) on an almost annual basis. There is also a small component of throughflow into the Ethel Gorge area from the upstream catchments; estimated to be around 2,000 kL/d in total.
- By comparison, it is estimated that prior to construction of the dam, natural groundwater recharge to the catchment would have been around 30,000 kL/d on average.
- Recharge mainly replenishes the shallow alluvial aquifer. Percolation into the lower aquifer is restricted by the low permeability clay layer and the minimal (or reversed) vertical hydraulic gradients (i.e. high potentiometric levels in the deep aquifer as a result of hydraulic loading).
- Prior to any mine dewatering, groundwater discharge occurred as throughflow along Ethel Gorge (3,000 kL/d), evapotranspiration from riparian vegetation communities (63,000 kL/d) and water supply pumping (10,000 kL/d). This is considered to reflect steady state conditions.
- The TEC is likely to be concentrated in the shallow alluvial aquifer.
- Groundwater levels in the alluvial aquifer that hosts the TEC have fluctuated over time, mostly related to variability in climate and more recently due to dewatering at OB23. Over the period of record, depth to water has ranged from close to surface to 15 m below ground level (mbgl), although groundwater levels have generally been shallow since the dam was constructed. Notwithstanding historical fluctuations, recent sampling suggests stygofauna remain abundant.

The geology and hydrogeology of the Ethel Gorge area is summarised on Figure 1. The figure also shows the locations of bores, the hydrographs from which have been used to illustrate water level trends.

3.3.2 Current Groundwater Water Quality

Figure 2 illustrates groundwater quality for the Ethel Gorge catchment. Available data are limited although some broad trends can be inferred. The Expanded Durov plot shows that:

- Water types range between:
  - Bicarbonate type water with no dominant cation, characteristic of recharge water in the Pilbara.
  - Waters with no dominant anion or cation characteristic of an intermediate groundwater that has been subject to some mixing, dissolution and evapotranspiration.
  - Sodium/chloride type waters characteristic of a mature groundwater that has undergone both evolution through mixing and concentration through evapotranspiration.

- Total dissolved solids (TDS) generally increases to the north towards Ethel Gorge as salts are concentrated through progressive evapotranspiration from the shallow water table and the groundwater becomes more mature.
- TDS ranges from 500 mg/L to 2,300 mg/L. Groundwater is generally fresher in Homestead Creek than the Fortescue River and Shovelanna Creek. Average groundwater salinity in the Fortescue River ranges between 1,100 mg/L at Ophthalmia Dam and 2,300 mg/L in Ethel Gorge.
- The deep alluvial aquifer contains lower-salinity groundwater than the shallow alluvial aquifer, probably because evapotranspirative concentration occurs only in the shallow aquifer.

The trend in downstream increasing TDS is seen in samples from bores in Homestead Creek and the Fortescue River. An indication of the extent of salt-concentration, as aquifer residence time increases, can be gleaned by plotting TDS against distance upstream from Ethel Gorge; for the Fortescue River, distance has been approximated by the northing of the sampled bore while easting has been used for Homestead Creek. The results are also shown in Figure 2.

The trend of increasing TDS towards Ethel Gorge can be discerned although there is considerable variation in the data, about the trend. The samples have been collected at different points in time and variation likely results, in part, from natural variations in TDS in aquifer over time (between recharge events for example). Moreover, the distance of each bore from the main river channels (and hence main recharge zones) also varies, and this will add complexity to the distribution of salt in the aquifer.

The highest single recorded measurement of TDS for groundwater from the Fortescue River is 3,100 mg/L in proximity to the confluence with Shovelanna Creek and it is possible that groundwater inflow from Shovelanna Creek catchment into the Fortescue River is of higher salinity also potentially due to the long residence time. However, volumes of any such inflow are likely to be small and have minimal impact on the overall water quality of the Ethel Gorge groundwater system and TEC.

Generally, TDS increases towards the Gorge and based on a line of best fit through the data, the rate of increase is greater in the Fortescue catchment (0.25 mg/L/m of aquifer) than in the Homestead catchment (0.1 mg/L/m of aquifer). The groundwater in Homestead Creek is also generally fresher than the groundwater in the Fortescue River. The current salinity of groundwater through the defined TEC ranges between ~1000 mg/L and 2,300 mg/L (although the highest recorded reading of 3,100 mg/L is on the eastern edge of the TEC). The depth to water is generally shallower in the Fortescue River flood plain and areas of potential evapotranspiration are more extensive. This may contribute to the greater rate of increase in groundwater salinity. However, it is also likely the Dam has contributed to an increase in groundwater salinity on the Fortescue River flood plain (cf 4.2 below).

4. WATER AND SALT BALANCE MODEL FOR THE ETHEL GORGE GROUNDWATER SYSTEM

4.1 Groundwater and Salt Balance Model

The broad parameters of the groundwater balance for Ethel Gorge were determined by RPS (2014) and are summarised in Table 1.

To help understand the overall groundwater balance in more detail and identify key processes that influence the movement of groundwater and associated salt in the Ethel Gorge aquifer, a more detailed groundwater and salt balance model has been developed.

The Ethel Gorge groundwater system from Ophthalmia Dam to below Ethel Gorge was divided into six zones (Zones 0 to 5); the zones are shown on Figure 2. A groundwater and salt balance for each Zone was then simulated. The simulation model is summarised in Table 2 and illustrated in Figure 3. Further information is provided below:

- All balances are calculated on monthly time steps.
- The main water input in Zone 0 is seepage from Ophthalmia Dam. The quantity and quality of water seeping from the dam has been derived from a parallel surface water balance model for the dam (reported separately, RPS 2014); the results from this surface water model are used as an input to the groundwater and salt balance model outlined here.
- Other inputs to Zone 0 include an allowance for recharge along the Fortescue River in the area upstream of the dam and a small volume of groundwater inflow from upstream aquifers.

- Inputs to the remaining zones downstream (1–5) are groundwater inflow (i.e. outflow from the Zone above) and surface water recharge from flood water that spills from the dam. The spill-sequence was derived from the RPS (2014) surface water model.
- Evapotranspiration is a key output from all zones and is calculated with a depth dependant function based on an average rate (at the surface) of 600 mm/yr. The volume lost to ET is calculated by applying the derived ET rate to the area of potentially phreatophytic vegetation within the zone.
- There is a small rate of steady groundwater throughflow across the model of 1500 kL/d and this is the minimum groundwater flow between zones. The volume of groundwater outflow can increase where the volume of groundwater in storage in that Zone increases and water levels rise.
- Potential changes in groundwater storage are calculated as the net of inflow and recharge less evapotranspiration. The associated change in groundwater level is calculated by applying the volumetric storage change across surface area of the Zone and calculating an equivalent water depth (based on a specific yield of between 7% and 10%).
- Where the potential storage change is negative and water levels decline, no additional groundwater outflow from the Zone is allowed (in addition to 1,500 kL/d base regional flow). Where the potential storage change is positive and groundwater levels would rise, the actual storage increase and calculated rise in groundwater level is constrained to allow a portion of the recharge to be allocated to additional groundwater outflow.
- The simulation of surface water recharge across the model takes account of dam-spills (estimated from the surface-water balance model) and also the estimated aquifer capacity (based on calculated depth to water). Recharge to the groundwater balance of any zone only occurs where groundwater levels are calculated to be below the ground surface (i.e when the aquifer has capacity to accept recharge).
- The TDS in the groundwater of each Zone is calculated based on total salt in-situ (i.e. salt already in place plus salt in) divided by water in situ (i.e. water already in storage plus groundwater additions less evapotranspiration losses). The resulting TDS is adopted as the TDS for groundwater outflow from the Zone and for the starting in-situ concentration at the beginning of the next time-period.
- For all zones downstream of Zone 0, the groundwater outflow and TDS concentration from the Zone upstream are the groundwater inputs to the adjacent Zone downstream.

RPS

Table 1: Ethel Gorge Overall Water Balance

Chloride Balance

Ref	Item	No.	Chloride Conc	Units	Remarks/Formula
	Concentrations				
1	Rainfall		0.5	mg/L	
2	GW throughflow conc		500	mg/L	measured AAR
3	Surface Water Flood Concentration		6	mg/L	measured Ethel Groge
4	Water Supply concentration		100	mg/L	measured AAR
	Measured Parameters				
5	Catchment Area	5030		km^2	
6	rainfall	320		mm/yr	Newman rain gauge
7	Rainfall Volume	1,609,600,000		m^3/year	5*6
8	Surface Water Outflow	41,401,000		m^3/year	Calculated
9	Water Supply Pumping	3650000		m^3/year	measured AAR
	Chloride Movement				
10	Chloride inflow from rain		8.0480E+11	mg/year	1*7
11	Cl outflow - surface water flood		2.4841E+11	mg/year	8*3
12	Cl in consumptive water supply		1.8250E+11	mg/year	9*4*consumption factor
	Unaccounted for Chloride - groundwater outflow				
13	(Cl rain) - (Cl out through surface flow)		3.7389E+11	mg/year	Balance of Cl flux
	Water Balance				
14	**calculated GW outflow**	**2,047**		**m^3/d**	13/2; Volume required to remove (13)Cl at 500mg/L

Steady State Groundwater Balance

Feature	kL/d	Remarks
Groundwater Recharge		
Direct Recharge along Fortescue	13700	hydrograph analysis - ~annual
Direct recharge along Homestead/below Dam	10500	hydrograph analysis - ~annual
Seepage from Dam	50000	water balance calculation based on dam water levels (RPS and PB ~5-6mm/day)
Diffuse Recharge over remainder of catchment	2000	inflow from upstream catchment area
Total Groundwater Recharge	**76200**	recharge~0.8% of catchment rainfall
Groundwater Discharge		
Groundwater Outflow	2047	calculated from Cl balance
Water Supply Pumping	10300	measured data
Evapotranspiration	63853	calculated by difference (equates to 600mm/yr over 3650ha)
Total Groundwater Discharge	**76200**	
Comments		
Recharge as % of annual average rainfall	*1.7%*	*Dam increases recharge (cf CPH ~0.8%)*
Est Pre-Dam Recharge % annual average rainfall	*0.7%*	*Without Dam, comparable with CPH*

Cl-based calculation of groundwater outflow

RPS

Table 2: Detailed Groundwater and Salt Balance Model for Ethel Gorge

Zone	Key Inputs: Water Flux	Key Inputs: Data Source	Key Inputs: Comment on Salt Flux	Key Processes	Key Outputs: Water Flux	Key Outputs: Data Source	Key Outputs: Comment on Salt Flux
0	Recharge from flood flows over the area of the zone above the dam lake	Estimated from regional water balance model (Table 1)	Input at background surface water salinity (~50mg/L)	Seepage of water through base of Ophthalmia Dam into aquifer - major flux into groundwater system. Salt increases due to evaporation from dam between flood events. Net of groundwater input/output results in water level rise/fall and increase/decrease groundwater outflow.	Groundwater outflow in alluvial aquifer	Background regional flow estimated from regional water balance model (Table 1). Additional outlfow calculated	Salt output at prevailing concentration in groundwater (net of salt mass in via recharge/inflow and water out to evapotranspiration)
	Groundwater inflow from the shallow aquifer in the upper-Fortescue catchment	Estimated from regional water balance model (Table 1)	Salt input at background groundwater salinity (~1000mg/L)		Surface water spill when Dam overflows	Event frequency and salinity derived from Dam water balance model (RPS 2014)	Salt output a prevailing concentration in dam lake; derived from dam water balance model
	Seepage from Opthalmia Dam	Flux and salinity calculated from Dam water balance model (RPS 2014)	Input at salinity of dam lake; increases over time between flood events as salt concentrated by evaporation; derived from dam water balance model		Evapotranspiration losses	Based on Ethel Gorge regional study - 600mm/yr (Table 1) adjusted by water table depth dependant function	No salt flux; concentration of salts
1	Groundwater inflow from the Zone above	Background regional flow estimated from regional water balance model (Table 1). Additional inflow calculated. Salinity calculated	Input at salinity of groundwater in Zone above	Net of groundwater input/output results in water level rise/fall and increase/decrease outflow. When water levels are at surface all recharge is rejected and water flux is only groundwater inflow/outflow. High water levels result in salt increase - concentration through ET and reduced dilution from surface water.	Groundwater outflow in alluvial aquifer	Background regional flow estimated from regional water balance model (Table 1). Additional outflow calculated. Salinity calculated	Salt output at prevailing concentration in groundwater (net of salt mass in via recharge/inflow and water out to evapotranspiration)
	Recharge from surface water spills from Ophthalmia Dam	Event frequency and salinity derived from Dam water balance model (RPS 2014); flux calculated.	Input at salinity of dam lake; increases over time between fllod events as salt concentrated by evaporation; derived from dam water balance model		Surface water spill when Dam overflows	Event frequency and salinity derived from Dam water balance model (RPS 2014)	Salt output at prevailing concentration in dam lake; derived from dam water balance model
					Evapotranspiration losses	Based on Ethel Gorge regional study - 600mm/yr (Table 1) adjusted by water table depth dependant function	No salt flux; concentration of salts
2	Groundwater inflow from the Zone above	Background regional flow estimated from regional water balance model (Table 1). Additional inflow calculated. Salinity calculated	Input at salinity of groundwater in Zone above	Net of groundwater input/output results in water level rise/fall and increase/decrease outflow. When water levels are at surface all recharge is rejected and water flux is only groundwater inflow/outflow. High water levels result in salt increase - concentration through ET and reduced	Groundwater outflow in alluvial aquifer	Background regional flow estimated from regional water balance model (Table 1). Additional outflow calculated. Salinity calculated	Salt output at prevailing concentration in groundwater (net of salt mass in via recharge/inflow and water out to evapotranspiration)
	Recharge from surface water spills from Ophthalmia Dam	Calculated from Dam water balance model (RPS 2014)	Input at salinity of dam lake; increases over time between fllod events as salt concentrated by evaporation; derived from dam water balance model		Surface water spill when Dam overflows	Event frequency and salinity derived from Dam water balance model (RPS 2014)	Salt output at prevailing concentration in dam lake; derived from dam water balance model
					Evapotranspiration losses	Based on Ethel Gorge regional study - 600mm/yr (Table 1) adjusted by water table depth dependant function	No salt flux; concentration of salts
3	Groundwater inflow from the Zone above	Background regional flow estimated from regional water balance model (Table 1). Additional inflow calculated. Salinity calculated	Input at salinity of groundwater in Zone above	Net of groundwater input/output results in water level rise/fall and increase/decrease outflow. When water levels are at surface all recharge is rejected and water flux is only groundwater inflow/outflow. High water levels result in salt increase - concentration through ET and reduced	Groundwater outflow in alluvial aquifer	Background regional flow estimated from regional water balance model (Table 1). Additional outflow calculated. Salinity calculated	Salt output at prevailing concentration in groundwater (net of salt mass in via recharge/inflow and water out to evapotranspiration)
	Recharge from surface water spills from Ophthalmia Dam	Event frequency and salinity derived from Dam water balance model (RPS 2014); flux calculated.	Input at salinity of dam lake; increases over time between fllod events as salt concentrated by evaporation; derived from dam water balance model		Surface water spill when Dam overflows	Event frequency and salinity derived from Dam water balance model (RPS 2014)	Salt output at prevailing concentration in dam lake; derived from dam water balance model
					Evapotranspiration losses	Based on Ethel Gorge regional study - 600mm/yr (Table 1) adjusted by water table depth dependant function	No salt flux; concentration of salts

Zone	Key Inputs			Key Processes	Key Outputs		
	Water Flux	Data Source	Comment on Salt Flux		Water Flux	Data Source	Comment on Salt Flux
4	Groundwater inflow from the Zone above	Background regional flow estimated from regional water balance model (Table 1). Additional inflow calculated. Salinity calculated	Input at salinity of groundwater in Zone above	When water levels are at surface all recharge is rejected and water flux is only groundwater inflow/outflow. High water levels result in salt increase - concentration through ET and reduced dilution from surface water. Opportunity for additional dilution when aquifer capacity allows due to flow from Homestead/Shovelana.	Groundwater outflow in alluvial aquifer	Background regional flow estimated from regional water balance model (Table 1). Additional outflow calculated. Salinity calculated	Salt output at prevailing concentration in groundwater (net of salt mass in via recharge/inflow and water out to evapotranspiration)
	Recharge from flood flows in Homestead and Shovelana Creek		Input at background surface water salinity (~50mg/L)		Surface water spill when Dam overflows	Event frequency and salinity derived from Dam water balance model (RPS 2014)	Salt output at prevailing concentration in dam lake; derived from dam water balance model
	Recharge from surface water spills from Ophthalmia Dam	Event frequency and salinity derived from Dam water balance model (RPS 2014); flux calculated.	Input at salinity of dam lake; increases over time between fllod events as salt concentrated by evaporation; derived from dam water balance model		Evapotranspiration losses	Based on Ethel Gorge regional study - 600mm/yr (Table 1) adjusted by water table depth dependant function	No salt flux; concentration of salts
5	Groundwater inflow from the Zone above	Background regional flow estimated from regional water balance model (Table 1). Additional inflow calculated. Salinity calculated	Input at salinity of groundwater in Zone above	Net of groundwater input/output results in water level rise/fall and increase/decrease outflow. When water levels are at surface all recharge is rejected and water flux is only groundwater inflow/outflow. High water levels result in salt increase - concentration through ET and reduced dilution from surface water. Opportunity for additional dilution when aquifer capacity allows due to flow from Homestead/Shovelana.	Groundwater outflow in alluvial aquifer	Background regional flow estimated from regional water balance model (Table 1). Additional outflow calculated. Salinity calculated	Salt output at prevailing concentration in groundwater (net of salt mass in via recharge/inflow and water out to evapotranspiration)
	Recharge from flood flows in Homestead and Shovelana Creek		Input at background surface water salinity (~50mg/L)		Evapotranspiration losses	Based on Ethel Gorge regional study - 600mm/yr (Table 1) adjusted by water table depth dependant function	No salt flux; concentration of salts
	Recharge from surface water spills from Ophthalmia Dam	Event frequency and salinity derived from Dam water balance model (RPS 2014); flux calculated.	Input at salinity of dam lake; increases over time between fllod events as salt concentrated by evaporation; derived from dam water balance model				

- In reality, for all zones, all fluxes of water or salt will be added to or removed from an existing in-situ mass of water and salt (i.e. the volume of groundwater in storage in the aquifer and the associated concentration of TDS in the aquifer). The volumes of water and salt in storage are difficult to estimate. However, they are important components in the salt-balance as they provide buffering capacity and influence model-sensitivity. Estimates of groundwater in storage have been based on the surface area of the zone, an assumed thickness of the upper alluvial aquifer (30 m) and a specific yield of between 7% and 10%. The resulting volume has then been multiplied by a "sensitivity" factor to take account of potential extra water in storage from sources such as:
  - Alluvial/bedrock interactions on the valley margins
  - Areas of shallow alluvial aquifer beyond the boundaries of the zones adopted in the model
  - Areas where the alluvial aquifer maybe more the 30 m thick.
- The sensitivity factor for in-situ-storage was derived during model "calibration". The factor was adjusted on the basis of:
  - Matching the quantum and trend of predicted salinity changes with the observed history between 1981 and 2013
  - Ensuring the simulated aquifer was "robust-enough" to demonstrate rates of change that have been observed in the real system (i.e so that the simulated aquifer was not too sensitive and fluctuated widely on a short-term basis)
  - Using a broadly consistent sensitivity factor across the entire model domain.
- The derived sensitivity factor is 3.

The model outlined above is not a numerical simulation model with refined grid and distributed parameters. It is an analytical model designed to identify and scale the key processes that influence the groundwater quality over broad sections of the regional aquifer system. As such, the aim was to replicate broad trends in the observed data, in terms of groundwater levels and quality rather than simulate the actual observed response at a specific location.

Notwithstanding, where data were available, an example hydrograph, and historical TDS measurements, from monitoring bores in each Zone have been used to compare actual trends with modelled trends (i.e. calibration) and are presented in the results where relevant.

4.2 Evolution of Current Groundwater Quality

Figure 4 shows the application of the model to the period 1981 to 2011 and the results are summarised in Table 3 (Current Mining with Dam). The model was used to estimate the trends in water level and salinity given the known climate sequence, inflows and outflows from the dam.

Initial salinity and water levels for the model were based on measured data from 1980-1981. Measured data suggest the pre-dam salinity ranged between 900 mg/L (upstream) and 1,200 mg/L (downstream) and depth to water was around 12 mbgl in Zones 0 to 3 and around 5 mbgl in Zones 4 and 5. Groundwater salinity generally increased towards Ethel Gorge (although to a lesser extent than is currently the case). However, there would also have been significant variation in groundwater quality around this trend, both in time, space.

To corroborate the predicted trends, average salinity for each zone has been estimated from available monthly measurements in a selection of bores for which data are available. No single bore has a complete time series of data and so an average for each zone has been derived based on a compilation between bores. One monitoring bore was selected in each zone to provide a representative water level time series. The representative hydrograph and zone-average-salinity are shown on the graphs in Figure 4.

The model results indicate that the dam has augmented water levels in the Ethel Gorge aquifer (and TEC) and has also contributed to a general increase in aquifer salinity.

RPS

Table 3: Ethel Gorge Groundwater and Salt Balance Model - Summary of Results

Scenario	Description	Zone	Starting Salinity (mg/L)	Ending Salinity (mg/L)	% Change in TDS	Average Salinity Exceeds Measured Zone Max	Average Salinity Exceeds Measured TEC Max	Remarks
Pre Dam	Estimate of natural longterm salinity distribution without dam. Based on observed climate sequence 1981-2012.	0	900	833	-7%	-	-	Ending values represent estimated longterm steady state values pre Dam. Average salinity in the TEC is estimated to be around 1,100mg/L although substantial variation would be expected. Overall salinity change over period <1% consistent with steady state model.
		1	975	1016	4%	-	-	
		2	1075	1199	12%	-	-	
		3	1175	1245	6%	-	-	
		4	1175	1167	-1%	-	-	
		5	1175	1061	-10%	-	-	
Current Mining (with Dam)	1981-2012 Evolution of current salinity distribution	0	900	681	-24%	-	-	Average increase in regional salinity 51% as a result of Ophthalmia Dam. Average high salinity within the TEC increased from ~1500mg/L pre Dam to 2,100mg/L currently. Average salinity remains within measured range (which has peaked at 3,100mg/L).
		1	975	1340	37%	-	-	
		2	1075	1984	85%	-	-	
		3	1175	2108	79%	-	-	
		4	1175	2076	77%	-	-	
		5	1175	1760	50%	-	-	
A1 NO dewatering discharge	NO dewatering discharge 2012-2048 simulation period	0	681	645	-5%	-	-	No change in salinity. Maximum TDS above current values for Zones 5 only. TDS within range measured in TEC (3,100mg/L).
		1	1340	1294	-3%	-	-	
		2	1984	1794	-10%	-	-	
		3	2108	2065	-2%	-	-	
		4	2076	2036	-2%	-	-	
		5	1760	1811	3%	-	-	
A2 (Approved Orebodies without OB31) No Outlet from Dam	All orebodies currently approved NO OB31 and with NO artificial discharge from dam. 2012-2048 simulation period	0	681	645	-5%	-	-	Small changes in a localised area, negligable change in average salinity overall. Maximum TDS above current values for Zones 1-5. TDS within range measured in TEC (3,100mg/L).
		1	1340	1294	-3%	-	-	
		2	1984	1794	-10%	-	-	
		3	2108	2065	-2%	-	-	
		4	2076	2036	-2%	-	-	
		5	1760	1811	3%	-	-	
A3 (Approved Orebodies without OB31) with Outlet from Dam	All orebodies currently approved NO OB31 and WITH extra discharge from dam. 2012-2048 simulation period	0	681	937	38%	Y	-	Change over a wide area. Average increase in salinity 268%. Maximum TDS marginally above current values for Zones 0-5. TDS exceeds range that has been measured within the TEC (3,100mg/L) in Zones 1-5.
		1	1340	5047	277%	Y	Y	
		2	1984	9167	362%	Y	Y	
		3	2108	10422	394%	Y	Y	
		4	2076	7764	274%	Y	Y	
		5	1760	6391	263%	Y	Y	
A4 (Approved Orebodies with OB31) No Outlet from Dam	All orebodies currently approved WITH OB31 and with NO artificial discharge from dam. 2012-2048 simulation period	0	681	1004	47%	Y	-	Some change over a wide area. Average increase in salinity 41%. Maximum TDS above current values for Zones 0-5. TDS exceeds range that has been measured within the TEC (3,100mg/L) in Zone 4.
		1	1340	1524	14%	Y	-	
		2	1984	2335	18%	Y	-	
		3	2108	3062	45%	Y	-	
		4	2076	3289	58%	Y	Y	
		5	1760	2839	61%	Y	-	
A5 (Approved Orebodies with OB31) with Outlet from Dam	All orebodies currently approved WITH OB31 and WITH extra discharge from dam. 2012-2048 simulation period	0	681	966	42%	Y	-	Change over a wide area. Average increase in salinity 243%. Maximum TDS above current values for Zones 0-5. TDS exceeds range that has been measured within the TEC (3,100mg/L) for Zones 1-5.
		1	1340	4824	260%	Y	Y	
		2	1984	8400	323%	Y	Y	
		3	2108	9498	351%	Y	Y	
		4	2076	7098	242%	Y	Y	
		5	1760	6006	241%	Y	Y	
A6 (Approved Orebodies with OB31) High Case no Outlet from Dam	All orebodies currently approved WITH OB31 (High Case Shovelanna and Jimblebar) NO artificial Discharge	0	681	1081	59%	Y	-	Some change over a wide area. Average increase in salinity 48%. Maximum TDS above current values for Zones 0-5. TDS exceeds range that has been measured within the TEC (3,100mg/L) for Zone s 4 and 5
		1	1340	1601	19%	Y	-	
		2	1984	2434	23%	Y	-	
		3	2108	3061	45%	Y	-	
		4	2076	3185	53%	Y	Y	
		5	1760	3361	91%	Y	Y	
A7 (Approved Orebodies with OB31) High Case with Outlet from Dam	All orebodies currently approved WITH OB31 (High Case Shovelanna and Jimblebar) WITH artificial Discharge	0	681	1029	51%	Y	-	Some change over a wide area. Average increase in salinity 39%. Maximum TDS above current values for Zones 0-5. TDS within range measured in TEC (3,100mg/L).
		1	1340	1927	44%	Y	-	
		2	1984	2629	33%	Y	-	
		3	2108	3062	45%	Y	-	
		4	2076	2592	25%	Y	-	
		5	1760	2510	43%	Y	-	

Immediately beneath the dam (Zone 0), it appears the salinity of groundwater fell as a result of increased volumes of infiltrating fresh water associated with seepage from the dam. However, elsewhere, aquifer salinity increased by between 40% and 80% with an average increase of 50%. The predicted salinity trends are consistent with the observed trend.

For much of the period between 1981 and 2011, there was more groundwater throughflow than would have been the case without the dam. Increases in throughflow were driven by seepage from the dam. This caused higher groundwater levels to be maintained throughout the aquifer even without periodic overflows from the dam. Indeed, some of the potential recharge from periodic overflows, when they did occur, would have been rejected as the aquifer was essentially fully saturated. Prior to the dam, groundwater salinity would have been subject to seasonal dilution by much lower salinity infiltrating surface water; after the dam was constructed, dilution was reduced. Moreover, ET probably increased as a result of generally shallower water levels.

This concept was well illustrated during the period 2000 to 2006, when the aquifer was essentially at capacity. As a result, there was little surface water recharge and groundwater salinity (measured and modelled) noticeably increased. Groundwater quality in each zone has therefore been influenced by the inflow of higher salinity groundwater from upstream and concentration by ET (maintained at high rates by the near-surface water table). The net impact was that overall salinity in the aquifer increased.

The calculated distribution of salinity for end-2011 (the end of the prediction-period) ranges between 700 mg/L and 2,100 mg/L across the TEC. This range and distribution is consistent with the available data and has been adopted as the starting salinity for future-scenarios.

4.3 Groundwater Quality Pre-Dam

To add confidence to the conclusion that groundwater salinity increased as a result of Ophthalmia Dam, the model was used to simulate pre-dam conditions.

It was assumed that:

- The salinity would be lower than that currently observed; the initial conditions derived for 1981 (the start of the prediction outlined above) were adopted as being representative of the pre-dam aquifer.
- Under pre-development conditions, the regional salinity was in long term steady state and the model should therefore replicate reasonably stable groundwater salinity.
- The observed climate sequence from the period 1981 to 2011 was adopted as being representative of the long-term.
- Flood events, that are generated in the surface water model, from this climate sequence, were routed straight through the groundwater balance model without attenuation by and seepage in the dam. The only recharge to the model was natural infiltration from these flood events.

Figure 5 shows the application of the model to simulate pre-dam conditions and the results are summarised in Table 3 (Pre Dam).

Modelled salinity across the aquifer (and the TEC) ranges between 800 mg/L and 1,250 mg/L. The range, and hence salinity gradient, is somewhat less than that predicted for post-Dam conditions. Indeed, it is more consistent with the salinity gradient observed in the unregulated Homestead Creek. For each model zone, the calculated salinity is stable over the 20 year period which suggests the model is stable and replicating long-term steady-state conditions. The predicted salinity in each zone is also comparable with the maximum TDS value that had been measured in that zone prior to the dam being constructed.

Figure 5 also shows the groundwater level that would have occurred without the dam. For comparison, observed hydrographs for post-dam conditions are also shown. Comparing the water levels suggests the dam resulted in an increase in groundwater levels of around ~5m. The increase is less pronounced around Ethel Gorge itself (Zone 4) where groundwater levels are naturally shallow.

Essentially, the prediction indicates that the aquifer was more self-regulating under natural conditions. Groundwater levels would fall between recharge events, which served two functions: evapotranspiration would progressively decline and so the rate of salt-concentration would reduce; and the decline in groundwater levels would leave aquifer capacity to accept low-salinity recharge from infiltrating surface water during flood events. The latter would dilute salt concentrations in the aquifer.

4.4 Verification of the Groundwater and Salt Balance Model

The groundwater balance and salt model has been used to identify the key processes that influence groundwater quality in the Ethel Gorge aquifer. Analysis of the results suggests that Ophthalmia Dam sustains groundwater at artificially high levels, that this results in higher ET, less local (diluting) recharge and consequently increased salinity. Based on these key processes, the groundwater balance and salt model has replicated evolution of current groundwater salinity distribution since the dam was constructed.

When the key hydrological processes are adjusted in the model to simulate the Ethel Gorge aquifer without Ophthalmia Dam, predicted groundwater salinities and groundwater levels are lower than those currently observed; they are comparable with data available for the pre-dam period. Moreover, predicted groundwater salinity for a pre-dam period is stable over the long term which suggests the model is replicating a natural steady-state system.

The key processes that must be included in the model to match the available hydrogeological history are consistent across both scenarios. The model replicates the trend and quantum of available salinity and water level data for both scenarios. In combination, this provides verification of the analytical groundwater balance and salt model for the Ethel Gorge groundwater system.

5. ADDITIONAL WATER DISPOSAL TO OPHTHALMIA DAM - IMPACT ASSESSMENT

5.1 Scenarios

In relation to the disposal of future excess dewatering water into Ophthalmia Dam, a range of scenarios were considered in the surface water balance model for the dam (RPS 2014). For all cases, the climate sequence is based on repetitions of the climate sequence observed between 1980 and 1996. Scenarios are summarised in Table 4 below.

Table 4: Operating Scenarios

Scenario	Dewatering Discharge	Outlet Structure Discharge
A1	Zero	Zero
A2	Approved without OB31 (High Case Jimblebar Profile)	Zero
A3	Approved without OB31 (High Case Jimblebar Profile)	50% x Dewatering
A4	Approved with OB31 (Low Case Shovelanna and Jimblebar Profiles)	Zero
A5	Approved with OB31 (Low Case Shovelanna and Jimblebar Profiles)	50% x Dewatering
A6	Approved with OB31 (High Case Shovelanna and Jimblebar Profiles)	Zero
A7	Approved with OB31 (High Case Shovelanna and Jimblebar Profiles)	50% x Dewatering

The results are shown on Figure 6 and summarised in Table 3; detailed graphs are presented in the annexes. All of the proposed operating scenarios will result in as much or more water potentially seeping into the groundwater system. As such, it is changes to groundwater quality rather than quantum (level) that are likely to pose threats to the Ethel Gorge TEC.

On this basis, the predicted groundwater salinity for each of the scenarios below has been assessed and is presented in Figure 6 and the annexes. The maximum recorded salinity for each zone and the maximum recorded salinity within the TEC overall are also shown to provide some context to the predicted changes in salinity. Only two indicative water levels are presented, representing the consequences of maximising retention in the dam or discharging additional water from the dam.

5.2 Changes to Regional Groundwater System

The base case (case A1) represents a cessation of all dewatering discharge to Ophthalmia Dam. Under the base case, the groundwater salinity overall would remain close to current levels. The salinity of groundwater in Zones 0 and 1 would remain close to current levels throughout the prediction period. The salinity of groundwater in Zones 2, 3, 4 and 5 will increase for a period of up to 5 years and then slowly decline to a level comparable with the groundwater salinity before the discharge of dewatering excess started. It is predicted that average salinity throughout the Ethel Gorge aquifer will remain below the highest levels that have been recorded. Indeed, the predicted salinity changes are so small they are likely to fall within the sensitivity range of the model. Average salinity would range between 650 mg/L and 2,100 mg/L within the TEC.

Overall, the graphs in Figure 6 suggest that the discharge of higher-salinity water into Ophthalmia Dam will result in an increase in regional groundwater salinity under most circumstances (Cases A3 to A7). The increase is particularly marked when additional water is artificially discharged from the dam on a more or less continuous basis (Cases A3 and A5 - additional comment on this is provided below).

Without artificial discharge from the dam, the increase in salinity as a result of OB31 discharge is moderate and salinity generally remains below the highest levels that have already been recorded within the TEC. The rate of increase is related to the volume of excess disposal:

- For discharge from the approved orebodies (low-case production) and OB31 (Case A4), the overall increase in salinity is predicted to be 41% (ranging between 14% and 61% across the different zones).
- For discharge from the approved orebodies (high-case production) and OB31 (Case A6), the overall increase in salinity is 48% (ranging between 19% and 91% across the different zones).

For both cases, the increase in salinity means the groundwater salinity in each zone will ultimately exceed the maximum salinity that has been recorded in that zone to date. However, the increases are moderate in comparison to the highest levels of salinity that have already been recorded in the TEC overall; it is only in two zones (4 and 5), for Case 6, that salinity slightly exceeds these historical maximum levels.

The model was used to explore the impacts of artificially releasing impounded water through the dam outlet structure (Cases A3, A5 and A7). From the surface water model, this has a small impact in reducing the salinity of water in the dam lake by reducing retention periods. However, this additional outflow from the dam will result in extra recharge downstream. The two water level traces shown on the graphs in Figure 6 illustrate differences in water level, depending on whether additional water is released. When additional water is released from the dam, the predicted water levels are within 1m of the ground surface over most of the model area, for most of the prediction period (line A5-zone-WL) on the graphs. This will result in the model predicting much higher rates of evapotranspiration (and hence salt-concentration).

The model suggests that the artificial release of more water from the dam tends to accentuate the processes that have resulted in the increased salinity that has been observed between 1981 and present. Thus for two scenarios that consider the additional release of water (A3 and A5), the predicted groundwater salinity is higher than without additional release from the dam:

- For discharge from the approved orebodies only with artificial release (Case A3), large increases in salinity are predicted across all zones. In all zones except zone 0, salinity is predicted to exceed to highest levels that have been recorded in the TEC.
- For discharge from the approved orebodies (low-case production)and OB31 with artificial release (Case A5), large increases in salinity are predicted across all zones. In all zones except zone 0, salinity is predicted to exceed to highest levels that have been recorded in the TEC.

Additional discharge during the high-production scenario does not however result in such large increases in salinity:

- For discharge from the approved orebodies (high-case production) and OB31 with artificial release, a moderate increase in salinity is predicted (40% average) across all zones. The salinity does not exceed the maximum level recorded in the TEC in any of the zones.

When additional water is released from the dam for low-production approved orebodies with and without OB31, the predicted salinity exceeds the historically recorded zone-maximum salinity in all zones. However, for the high-production scenario, the release of water from the dam results in less salinity build-up. This is because the average quality of surface water spilling from the dam, over the prediction period, and recharging downstream areas is significantly better for Case A7.

5.3 Potential Impacts on the TEC in Each Zone.

Zone 0. For all future scenarios, the predicted groundwater salinity remains at or below 1,000 mg/L and within the range that has been historically recorded within this zone; well below the maximum values that have already been experienced elsewhere within the TEC.

Zone 1. For all future scenarios, it is predicted that Zone 1 will experience a similar or higher salinity. Predicted changes in salinity range between 0% and 277%. The maximum predicted salinity is 5,000mg/L. However, the highest predicted levels of salinity all relate to the artificial outlet of water from the dam. If this operating practice is discounted, then the maximum predicted average salinity is 1, 600 mg/L which is only slightly in excess of the maximum value that has already been recorded within this zone and within the salinity range that has been experienced elsewhere within the TEC.

Zone 2. For all future scenarios, it is predicted that Zone 2 will experience a higher salinity than is currently observed. Predicted changes in salinity range between 18% and 300%. The maximum predicted TDS is 8,400mg/L. However, the highest predicted levels of salinity all relate to the artificial outlet of water from the dam. If this operating practice is discounted, then the maximum predicted average salinity is 2,400 mg/L which is only slightly in excess of the maximum value that has already been recorded within this zone and within the salinity range that has been experienced elsewhere within the TEC.

Zone 3. For all future scenarios, it is predicted that Zone 3 will experience a higher salinity than is currently observed. Predicted changes in salinity range between 14% and 350%. The maximum predicted TDS is 9,400 mg/L. This exceeds the highest TDS that has been recorded within the overall TEC. However, the highest predicted levels of salinity all relate to the artificial outlet of water from the dam. If this operating practice is discounted, then the maximum predicted average salinity is 3,000 mg/L which is within the range that has already been recorded within the zone.

Zone 4. For all future scenarios, it is predicted that Zone 4 will experience an elevated salinity. Predicted changes in salinity range between 25% and 242%. The maximum predicted TDS is 7,100 mg/L which exceeds the highest TDS that has been recorded within the overall TEC. As with Zones 2 and 3, highest predicted levels of salinity all relate to the artificial outlet of water from the dam. If this operating practice is discounted, then the maximum predicted average salinity is 3,300 mg/L. This is comparable with the historical range for the zone and only just above the range of salinity that has already been recorded within the overall TEC.

Zone 5. For all future scenarios, it is predicted that Zone 5 will experience a higher salinity than is currently observed. Predicted changes in salinity range between 43% and 241%. The maximum predicted TDS is 6,000 mg/L which is above the highest levels of salinity that have been recorded anywhere in the TEC. However, the highest predicted levels of salinity all relate to the artificial outlet of water from the dam. If this operating practice is discounted, then the maximum predicted average salinity is 3,3,000 mg/L. This is comparable with the historical range for the zone and only just above the range of salinity that has already been recorded within the overall TEC

6. SUMMARY AND CONCLUSIONS

Average salinity in the Ethel Gorge aquifer that hosts the TEC currently ranges between 700 mg/L and 2,100 mg/L. Measured salinity is ~3,000mg/L in localised areas. It is likely that the presence of Ophthalmia Dam has increased groundwater salinity across the TEC and that historically (pre-dam), salinity was in the range 800 mg/L to 1,300 mg/L. The fact that salinity has already increased and stygofauna remain abundant would suggest at least some degree of adaptability in the TEC to changing groundwater quality.

It is predicted that groundwater salinity will increase as the dam is used to discharge excess dewatering water. For scenarios that include the development of OB31, the average salinity increase until 2048 is calculated to be between 40% and 250% (depending on Dam operating scenario). The maximum increases within a specific zone could be up to 350% and the maximum groundwater salinity within the TEC could increase to 9,000 mg/L. Such a value falls above the range of salinity that has been recorded to date within the TEC or regional aquifer.

However, the largest predicted increases in salinity relate to the artificial outlet of water from the dam, in particular when the surface water body does not have the dilution effects of extra dewatering discharge from high-case production scenarios. If this operating practice is discounted, then overall average increases in salinity are around 40%, the maximum increase within a specific zone is 90%, all but one or two zones remain within historical limits of measured salinity and the maximum predicted average salinity within the TEC as a whole is 3,300 mg/L which is only marginally above the range that has historically been recorded.

Notwithstanding, on a local scale, there will be increases in groundwater salinity beyond ambient levels. Table 3 showed that even without the artificial discharge of water from the dam, all of the identified zones could experience average groundwater salinity beyond the level that has historically been recorded in that zone. The adaptability of the TEC to local increases in salinity is unknown. However, the increase remains modest and generally within the range that has been experienced elsewhere in the TEC (the modelling suggests the system could be managed such that between 0 and 2 zones may marginally exceed the overall recorded maxima. Moreover, Halse (2014) has suggested 10,000 mg/L is a key threshold in water quality for stygofauna; all predicted salinity levels remain well below this.

A key factor that influences the response of the groundwater system is the source of water within the aquifer. There is no capacity for surface water recharge (and its beneficial diluting effects) when the aquifer is fully saturated due to large volumes of seepage from the dam. Moreover, when water levels are high, evapotranspiration is maintained at high rates all of the time with an associated concentration of salts within the aquifer.

Climate will play a key role in the extent to which salinity in the aquifer actually does increase. The large seepage volumes from the dam are the main groundwater flux in the regional system. Thus, the quality of this seepage water plays a key role in influencing groundwater quality in the aquifer. The largest impact here is exerted by climate; for a prolonged wet period, the water seeping from the dam is diluted by more low salinity surface water inflow. While none of the predicted increases in salinity approach the generic salinity threshold suggested by Halse (10,000 mg/L) nor do they generally exceed the highest values that have already been recorded within the TEC, it is under the conditions of a prolonged wet period that salinity throughout the regional aquifer system and TEC will remain at its' lowest.

We trust this report meets your current requirements. Should you require any further information, please do not hesitate to contact us.

Yours sincerely,
RPS Water Management

Duncan

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Senior Principal Hydrogeologist

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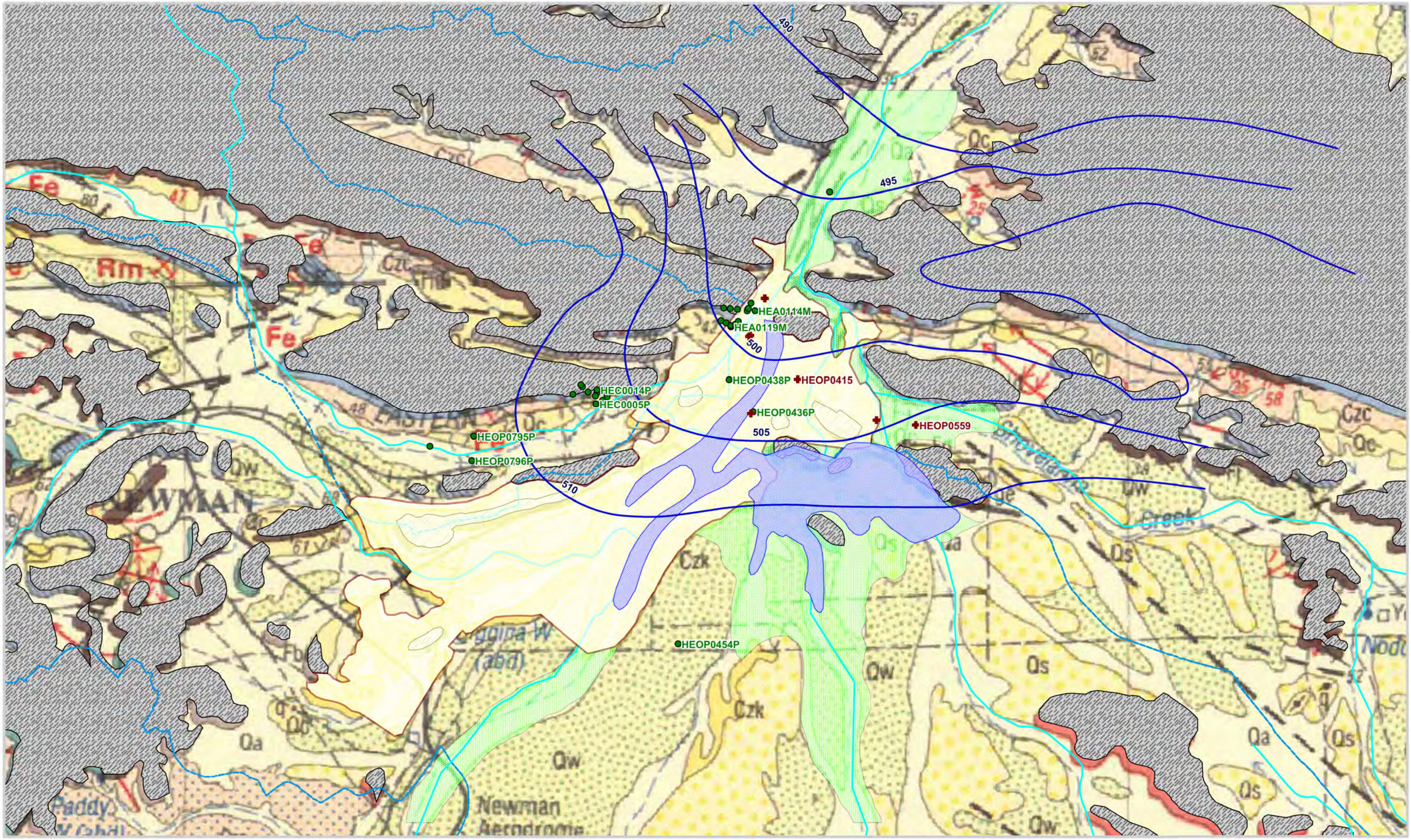
FIGURES



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DATE:	07/08/2014	JOB NO:	1703B

LEGEND

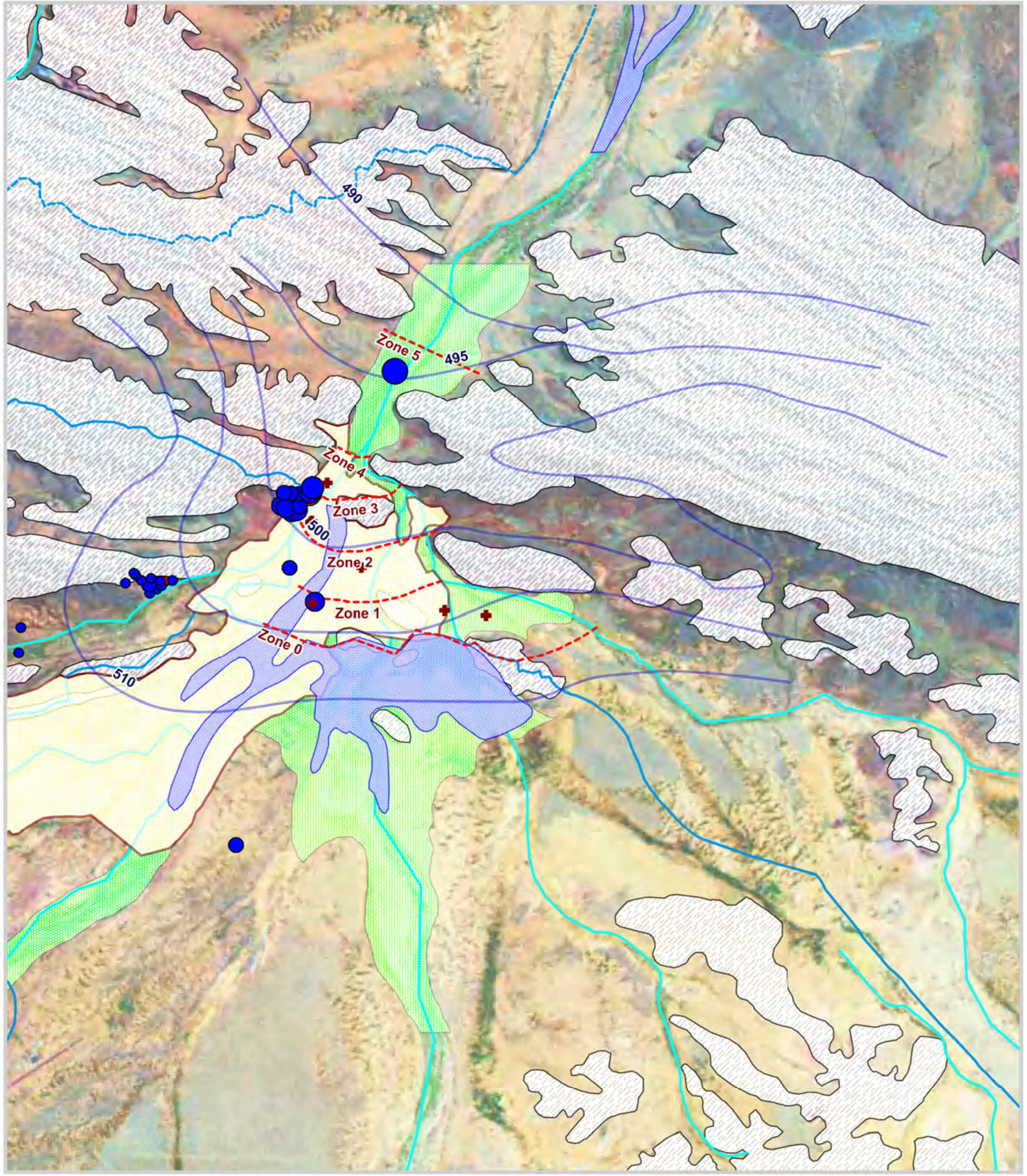
- Hydrograph Bore
- Groundwater Monitoring Bore
- 500 Pre-Mining Groundwater Level (mAHD)
- Main Drainage Line
- Ethel Gorge TEC Boundary
- Subcatchment Boundary
- Evapotranspiration Zone
- Outcrop Shading

RPS

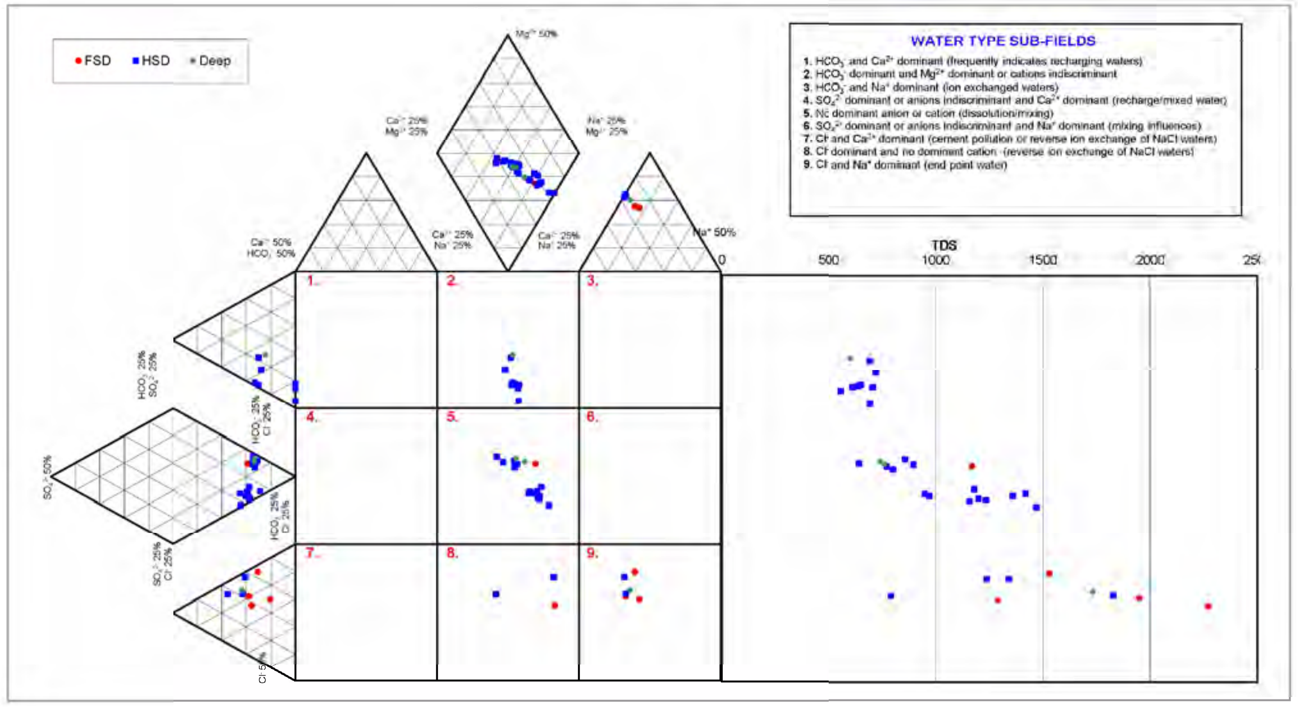
FIGURE 1

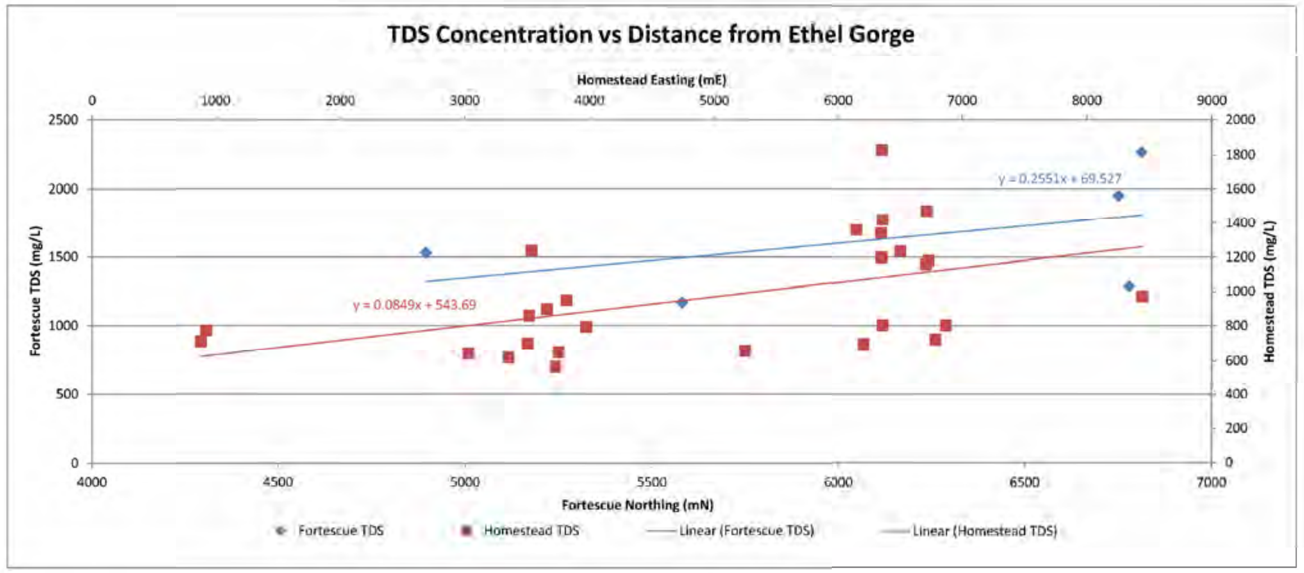
ETHEL GORGE TEC
KEY FEATURES OF HYDROGEOLOGY

Location: F:\Jobs\1703B\Spatial Data\MapInfo\Workspaces\037a\037a Figure 1 - Location



EXISTING WATER QUALITY





N

0 — 2.5

Kilometres

Scale: 1:100,000 @A3

GDA 1994 Zone 50

AUTHOR:	DS	REPORT NO:	037
DRAWN:	MR	REVISION:	b
DATE:	07/08/2014	JOB NO:	1703B

Location: F:\Jobs\1703B\Spatial Data\MapInfo\Workspaces\037a\037a Figure 2 - Existing Water Quality

LEGEND

- Hydrograph Bore
- Extent of Groundwater Salt Zone
- 500 Pre-Mining Groundwater Level (mAHD)
- Main Drainage Line
- Ethel Gorge TEC Boundary
- Subcatchment Boundary
- Evapotranspiration Zone
- Outcrop Shading

Groundwater Salinity (mg/L)

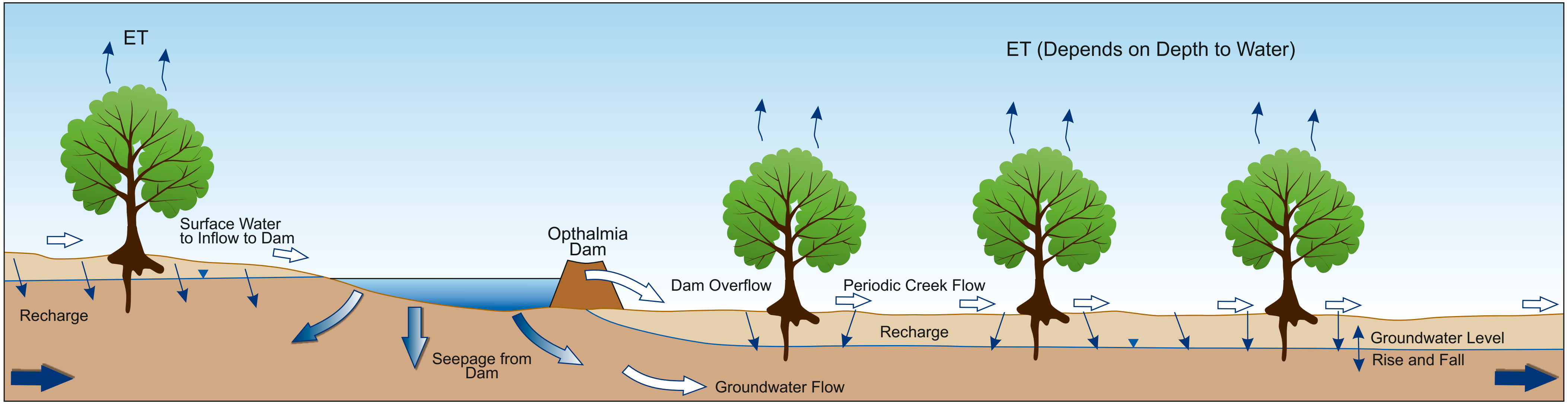
- 2100-2300
- 1700-2100
- 1300-1700
- 900-1300
- 500-900

RPS

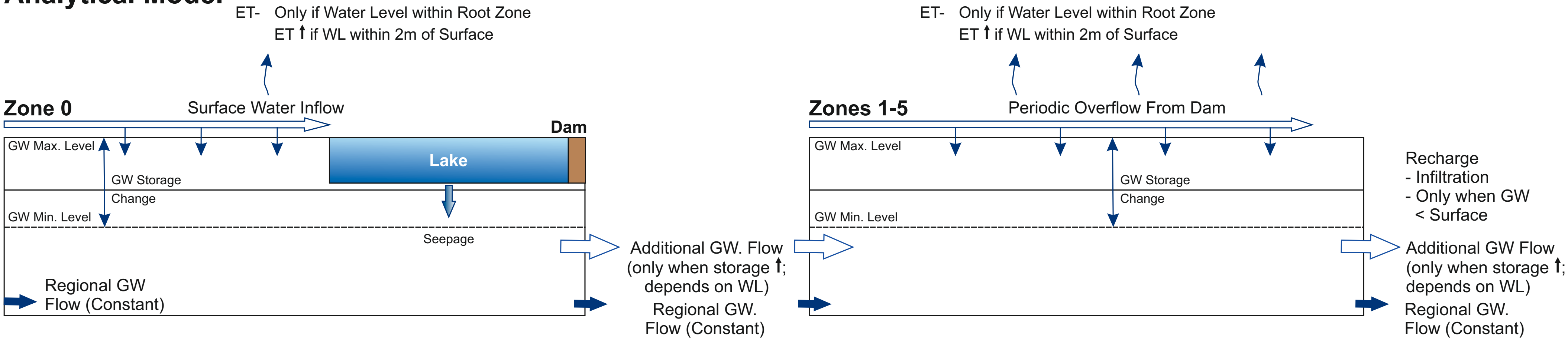
FIGURE 2

ETHEL GORGE - HYDROCHEMISTRY (2010-2012)

Conceptual Model



Analytical Model



LEGEND

- Approximate Water Table
- Direct - Infiltration
- Groundwater Flow (Fixed Flow)
- Groundwater Flow (Varying Flow)
- Surface Water Flow (Varying Flow)
- ET Flux
- Seepage from Dam (Varying)

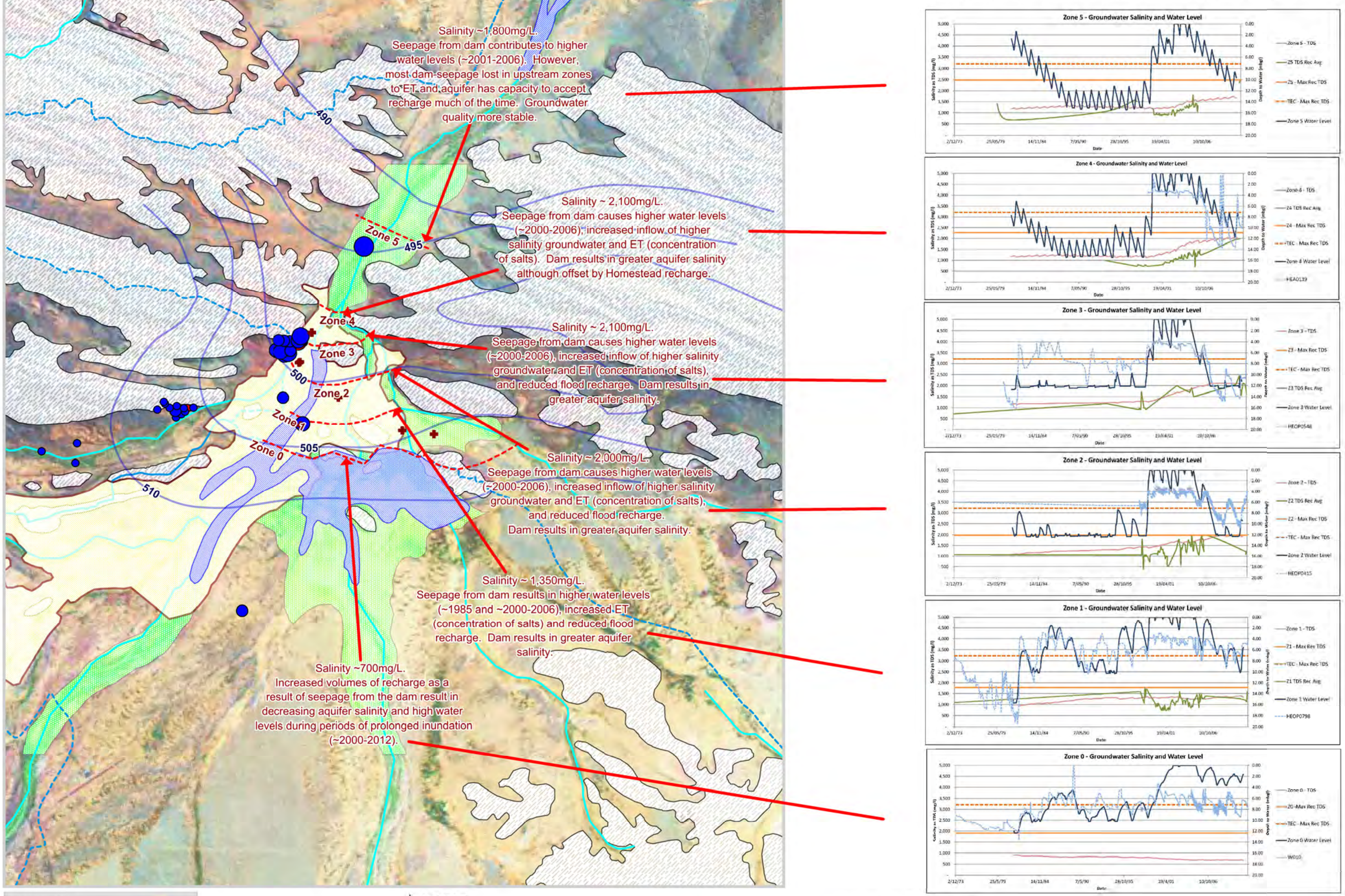
Output from Zone 1 = Input from Zone 2
Output from Zone 2 = Input from Zone 3
etc.

RPS

FIGURE 3

ETHEL GORGE SALT BALANCE MODEL - MAJOR GROUNDWATER FLUXES

WATER LEVEL TRENDS AND GROUNDWATER SALINITY



LOCATION MAP

N

0 — 2.5 Kilometres

Scale: 1:100,000 @A3

GDA 1994 Zone 50

AUTHOR: DS	REPORT NO: 037
DRAWN: MR	REVISION: b
DATE: 07/08/2014	JOB NO: 1703B

Location: F:\Jobs\1703B\Spatial Data\MapInfo\Workspaces\037a\037a Figure 4 - GW Salinity with dam (current)

LEGEND

- Hydrograph Bore
- Extent of Groundwater Salt Zone
- 500 Pre-Mining Groundwater Level (mAHD)
- Main Drainage Line
- Ethel Gorge TEC Boundary
- Subcatchment Boundary
- Evapotranspiration Zone
- Outcrop Shading

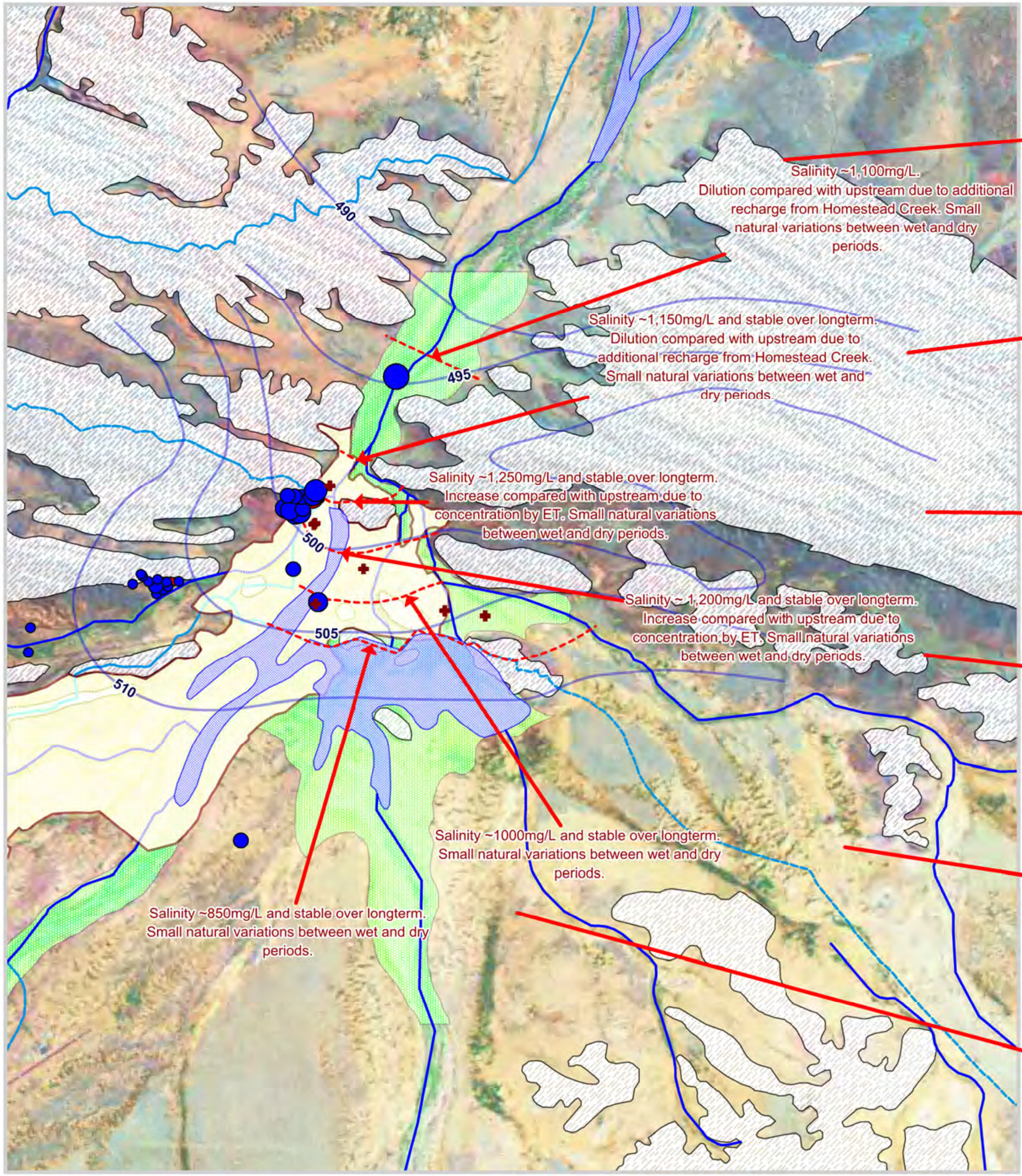
Groundwater Salinity (mg/L)

- 2100-2300
- 1700-2100
- 1300-1700
- 900-1300
- 500-900

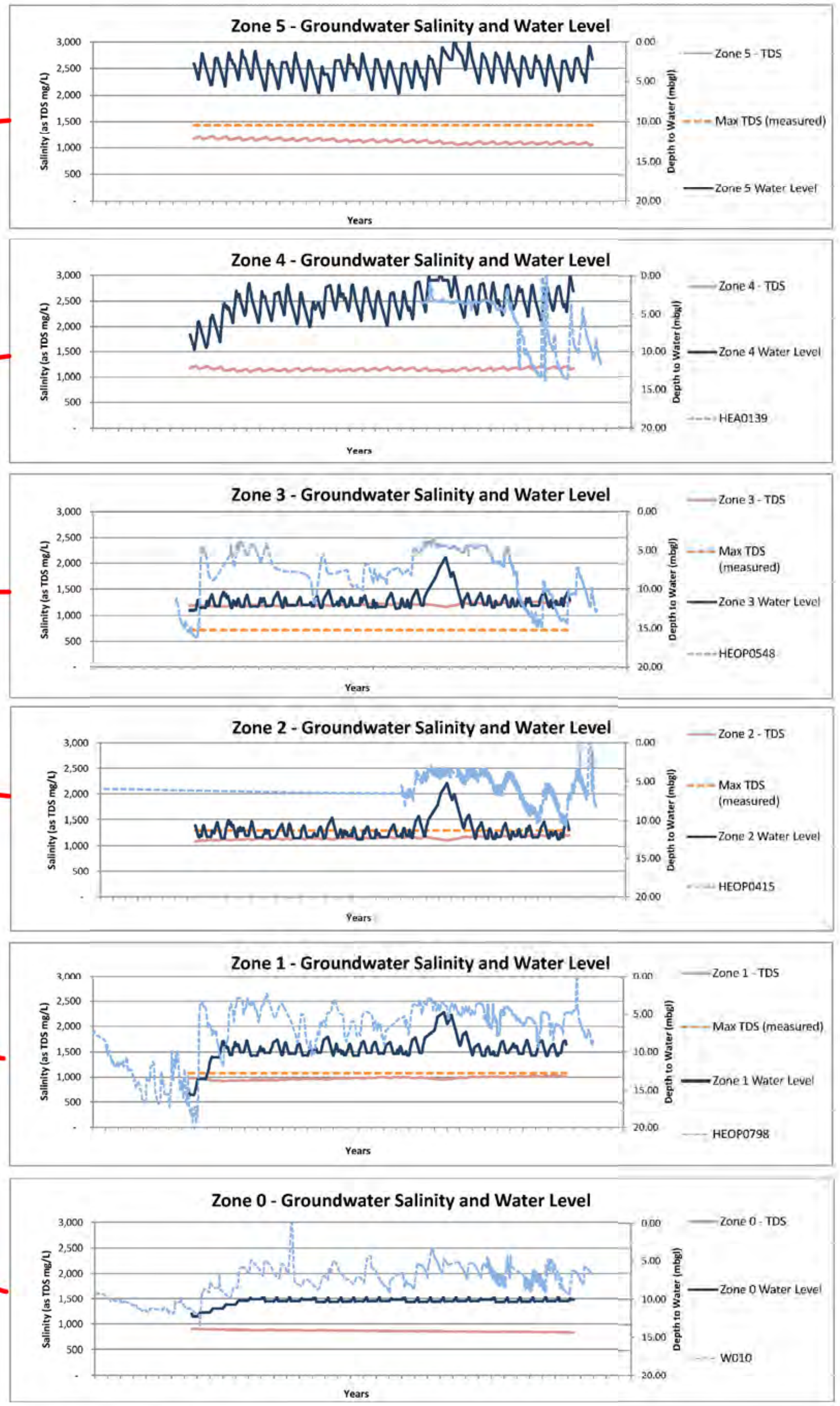
RPS

FIGURE 4

GROUNDWATER SALINITY - WITH DAM (CURRENT)



WATER LEVEL TRENDS AND GROUNDWATER SALINITY



LOCATION MAP

N

0 2.5

Kilometres

Scale: 1:100,000 @A3

GDA 1994 Zone 50

AUTHOR: DS	REPORT NO: 037
DRAWN: MR	REVISION: b
DATE: 07/08/2014	JOB NO: 1703B

LEGEND

- Hydrograph Bore
- Extent of Groundwater Salt Zone
- 500 Pre-Mining Groundwater Level (mAHD)
- Main Drainage Line
- Ethel Gorge TEC Boundary
- Subcatchment Boundary
- Evapotranspiration Zone
- Outcrop Shading

Groundwater Salinity (mg/L)

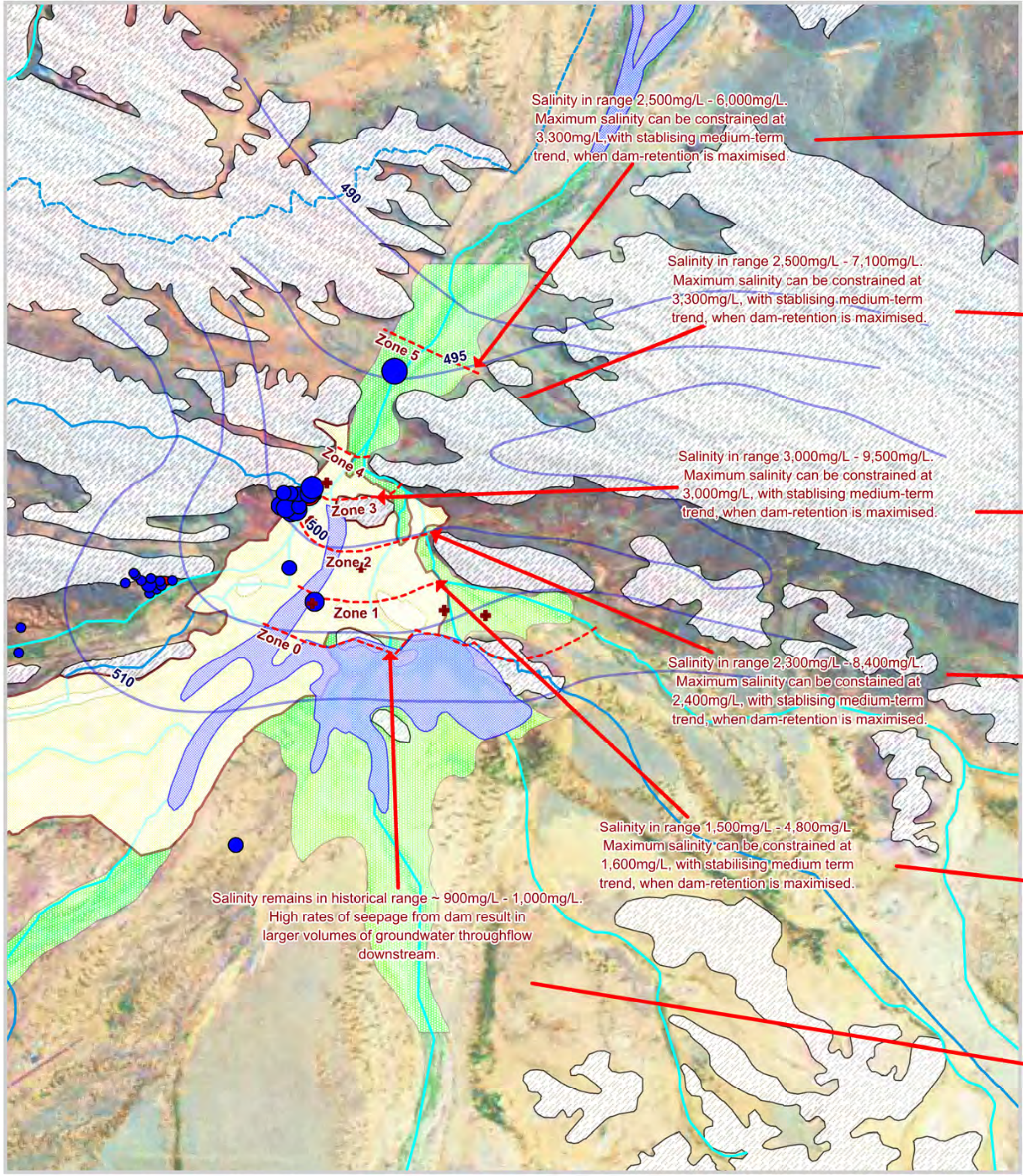
- 2100-2300
- 1700-2100
- 1300-1700
- 900-1300
- 500-900

RPS

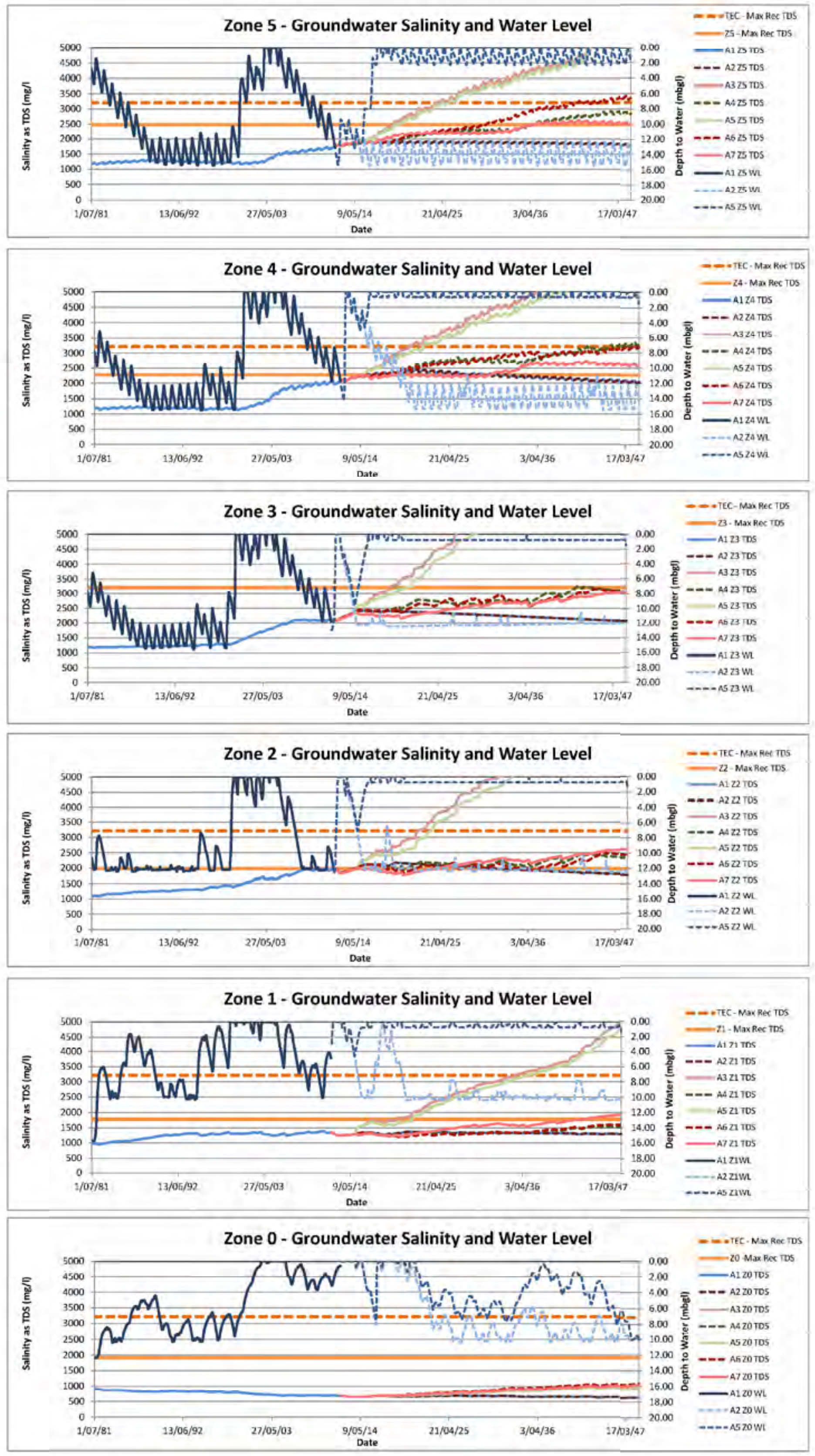
FIGURE 5

GROUNDWATER SALINITY - PRE DAM

Location: F:\Jobs\1703B\Spatial Data\MapInfo\Workspaces\037a\037a Figure 5 - GW Balance Pre Dam



WATER LEVEL TRENDS AND GROUNDWATER SALINITY



LOCATION MAP

N

0 2.5

Kilometres

Scale: 1:100,000 @A3

GDA 1994 Zone 50

AUTHOR: DS	REPORT NO: 037
DRAWN: MR	REVISION: b
DATE: 17/10/2014	JOB NO: 1703B

Location: F:\Jobs\1703B\Spatial Data\MapInfo\Workspaces\037b\037b Figure 6 - GW Salinity with dam future dewatering

LEGEND

- Hydrograph Bore
- Extent of Groundwater Salt Zone
- 500 Pre-Mining Groundwater Level (mAHD)
- Main Drainage Line
- Ethel Gorge TEC Boundary
- Subcatchment Boundary
- Evapotranspiration Zone
- Outcrop Shading

Groundwater Salinity (mg/L)

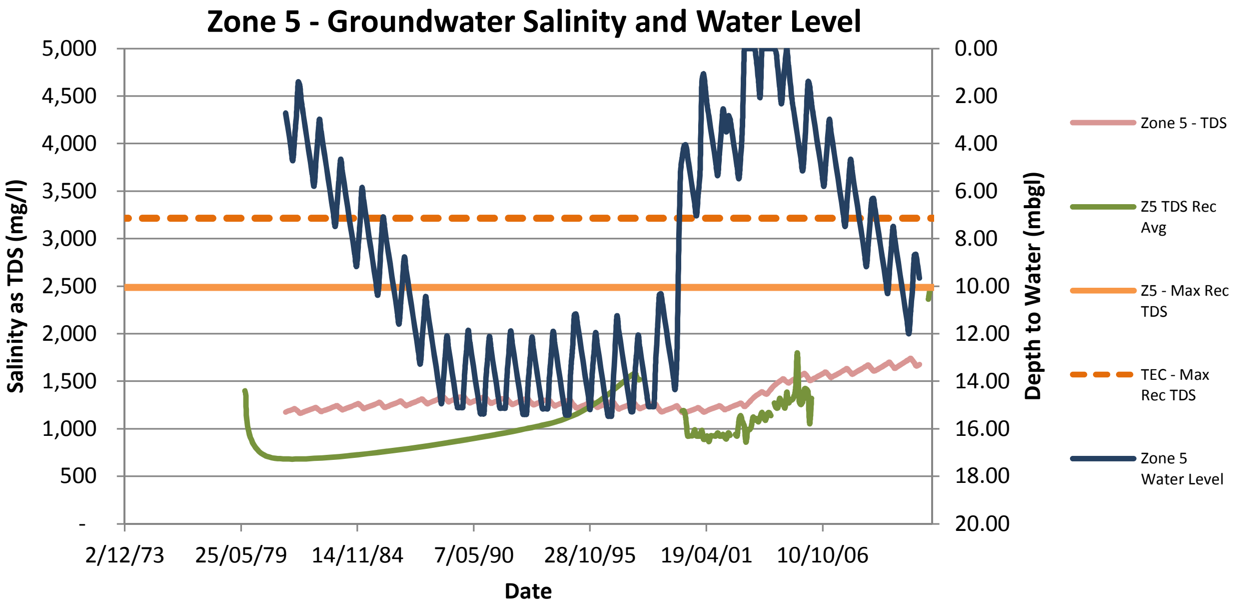
- 2100-2300
- 1700-2100
- 1300-1700
- 900-1300
- 500-900

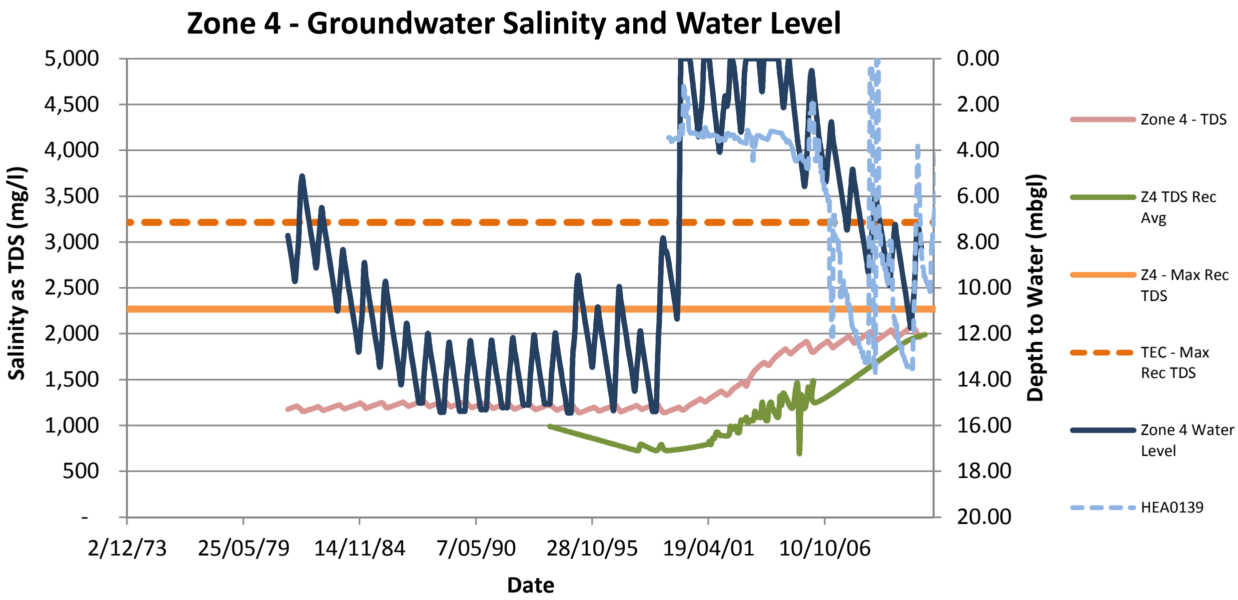
RPS

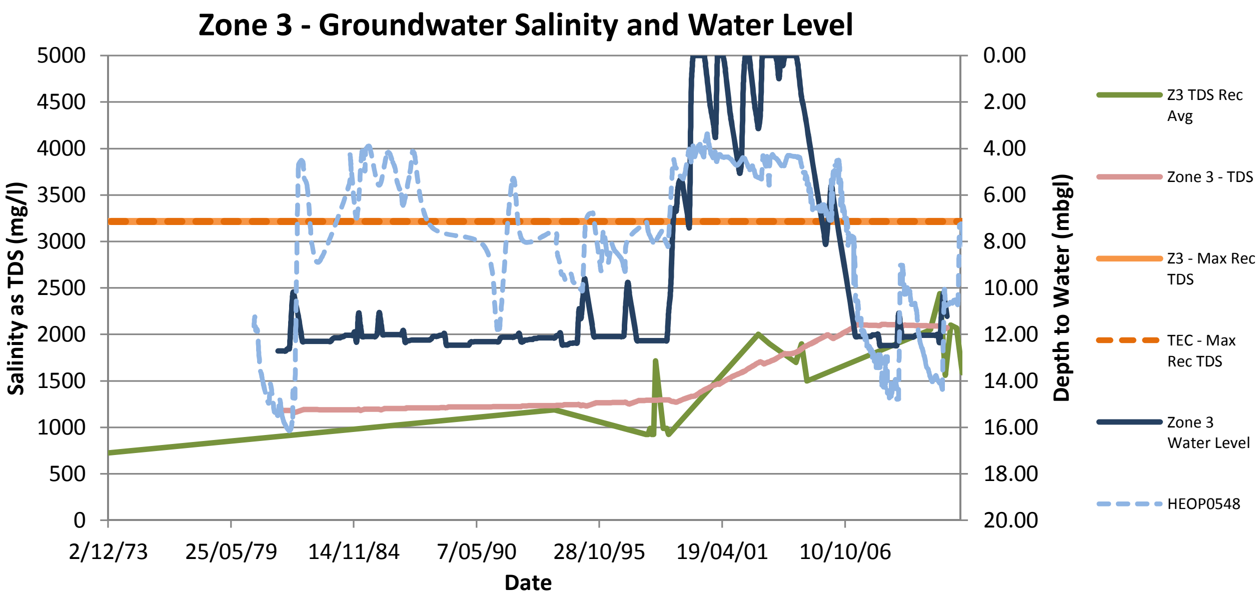
FIGURE 6

GROUNDWATER SALINITY WITH DEWATERING DISCHARGE TO OPHTHALMIA DAM - APPROVED OREBODIES & OB31

ANNEX



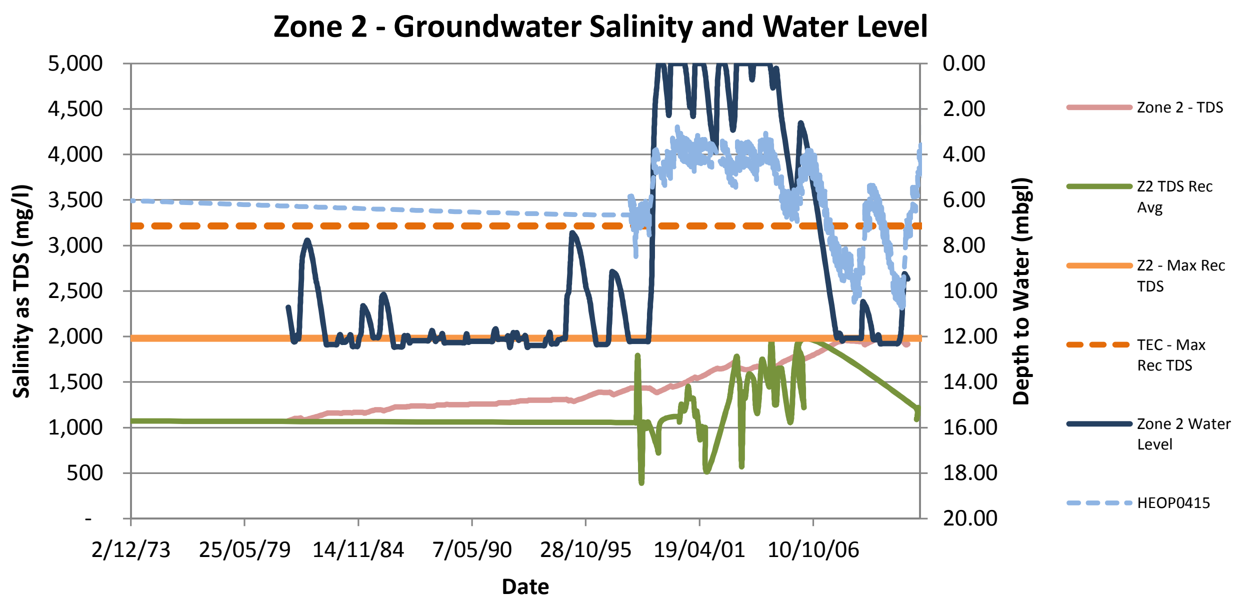


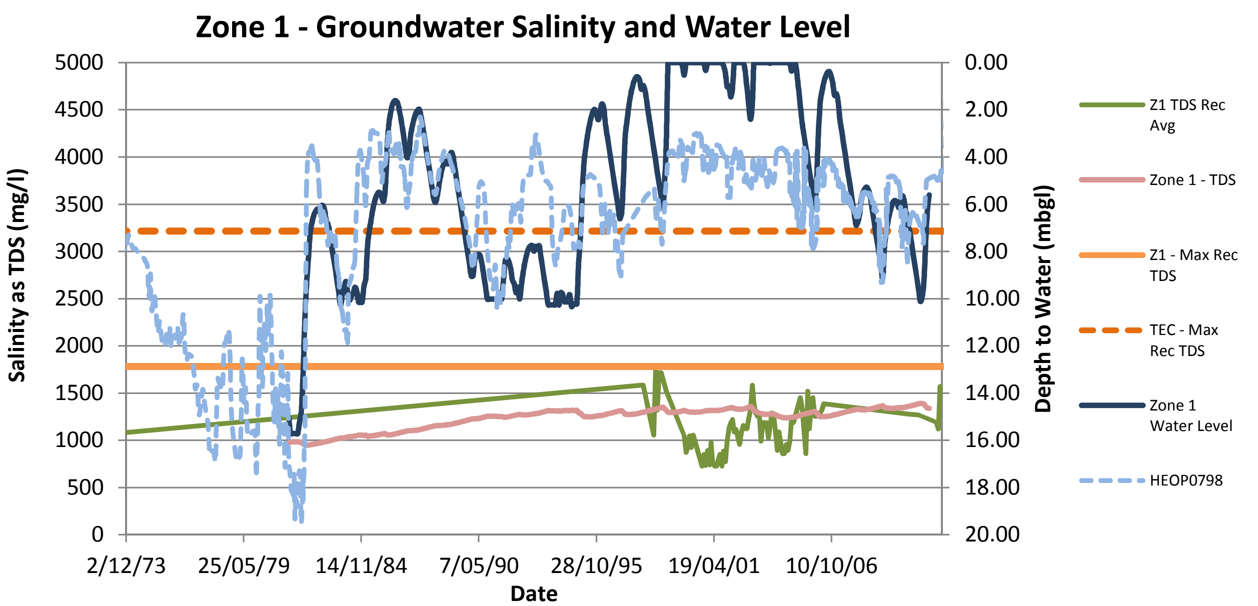


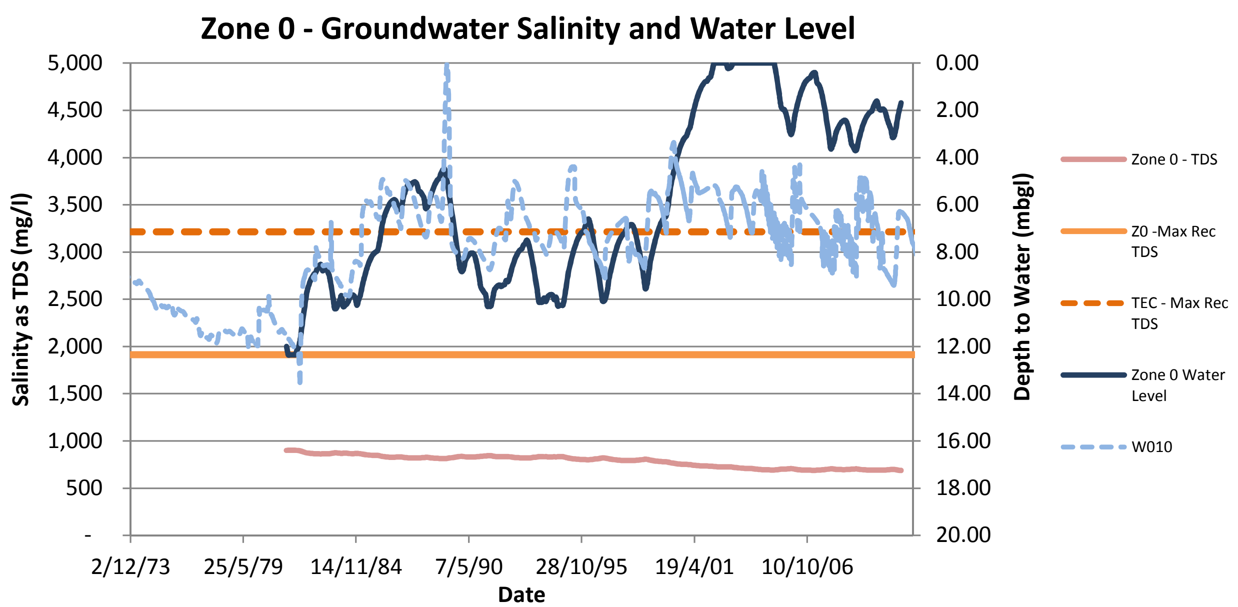
RPS

ZONE 3, 4 AND 5 - GROUNDWATER SALINITY - WITH DAM (CURRENT) ANNEX 1A

F:\Jobs\1703B\B4\300\New Salt Models_July_Aug\SEA Predictions\[Groundwater Balance and Salt Model_rev3.xlsx]Annex 1A



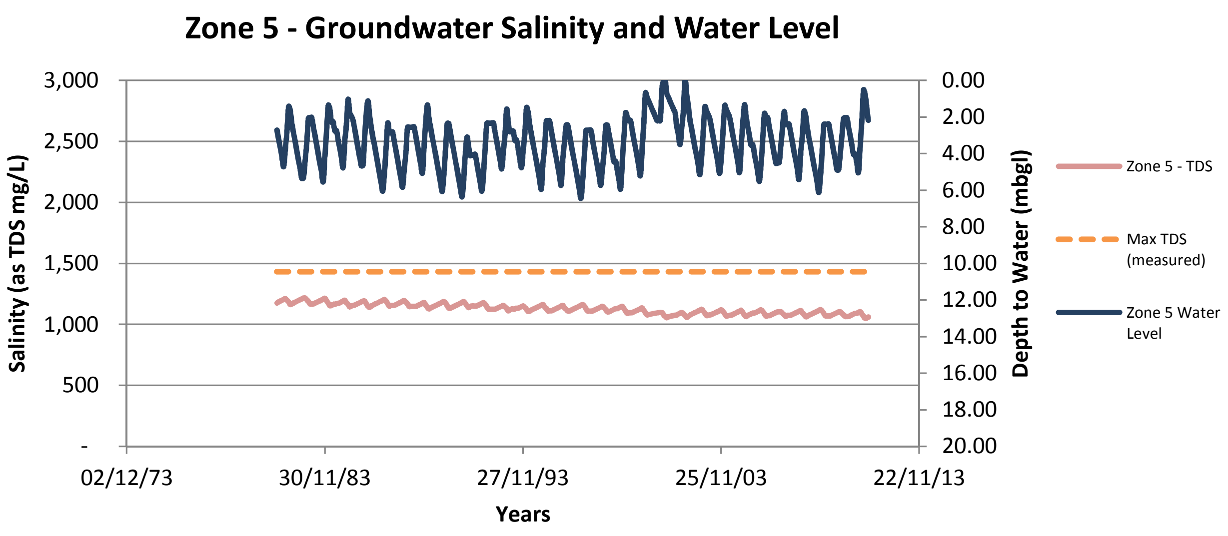


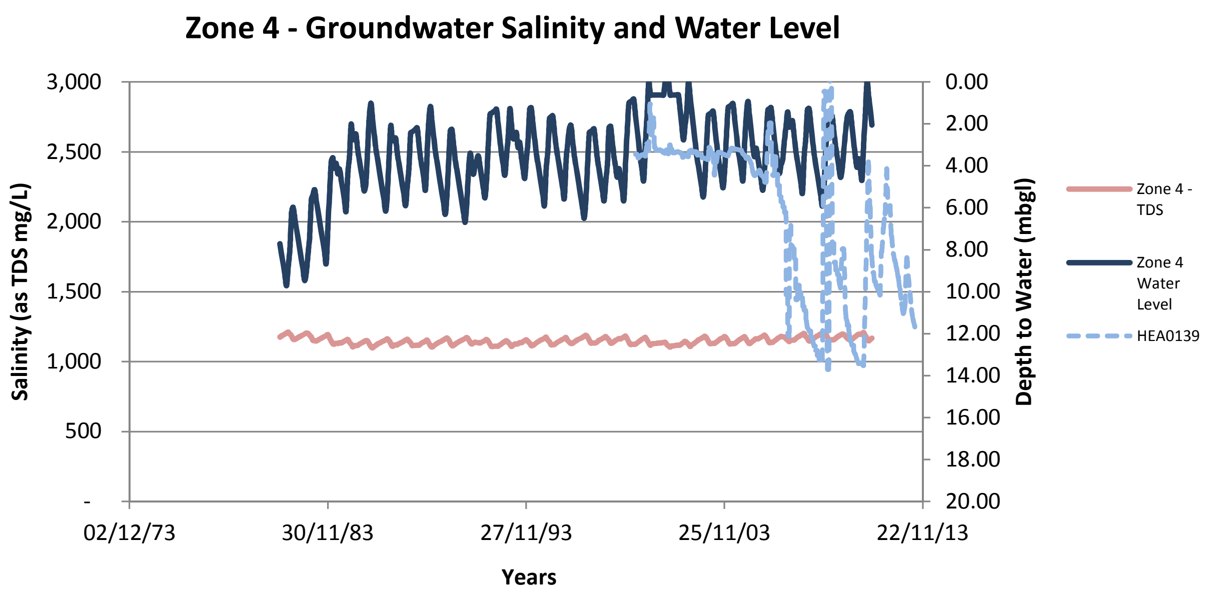


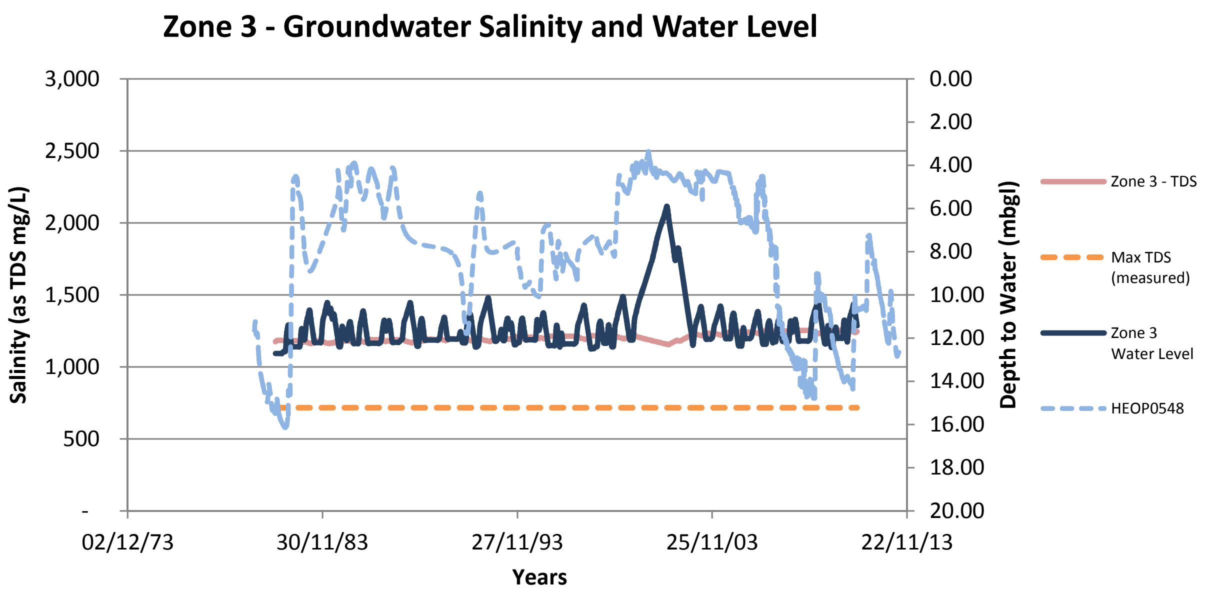
RPS

ZONE 0, 1 AND 2- GROUNDWATER SALINITY - WITH DAM (CURRENT) ANNEX 1B

F:\Jobs\1703B\B4\300\New Salt Models_July_Aug\SEA Predictions\[Groundwater Balance and Salt Model_rev3.xlsx]Annex 1B





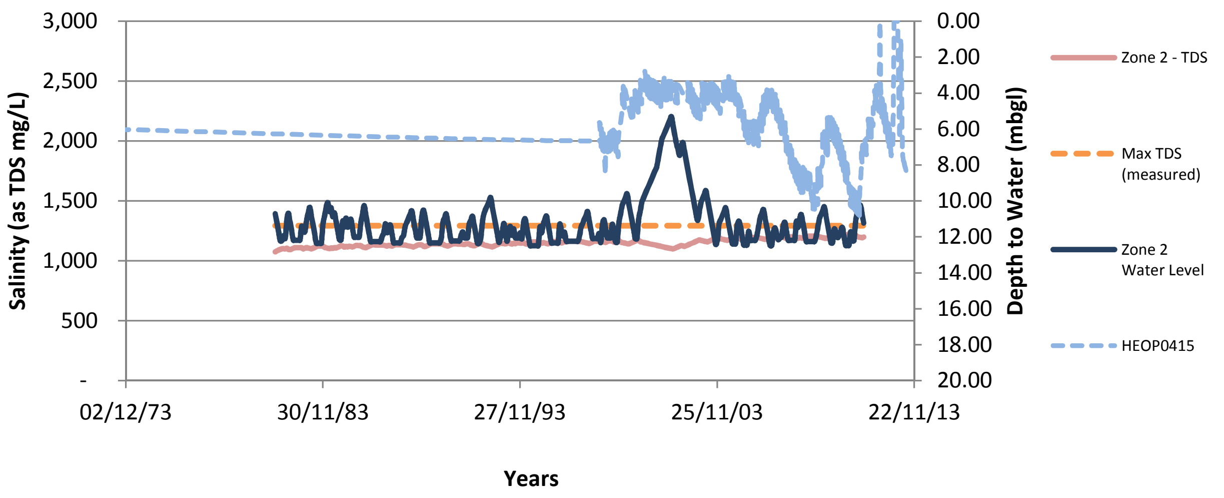


RPS

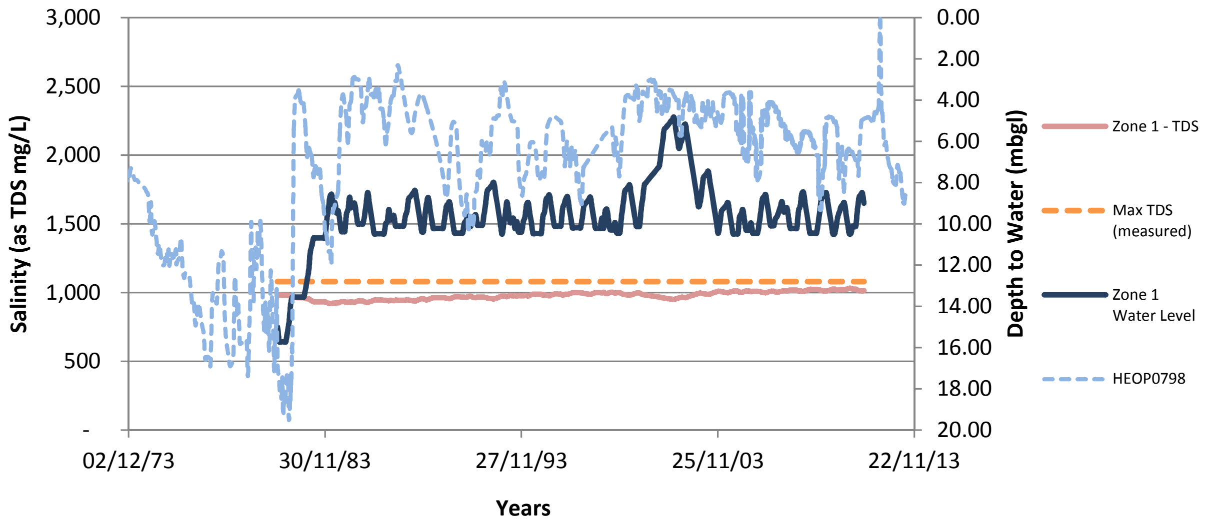
ZONE 3, 4 AND 5 - GROUNDWATER SALINITY PRE DAM ANNEX 2A

F:\Jobs\1703B\B4\300\New Salt Models_July_Aug\SEA Predictions\[Groundwater Balance and Salt Model_preDam_rev3.xlsx]Annex 2A

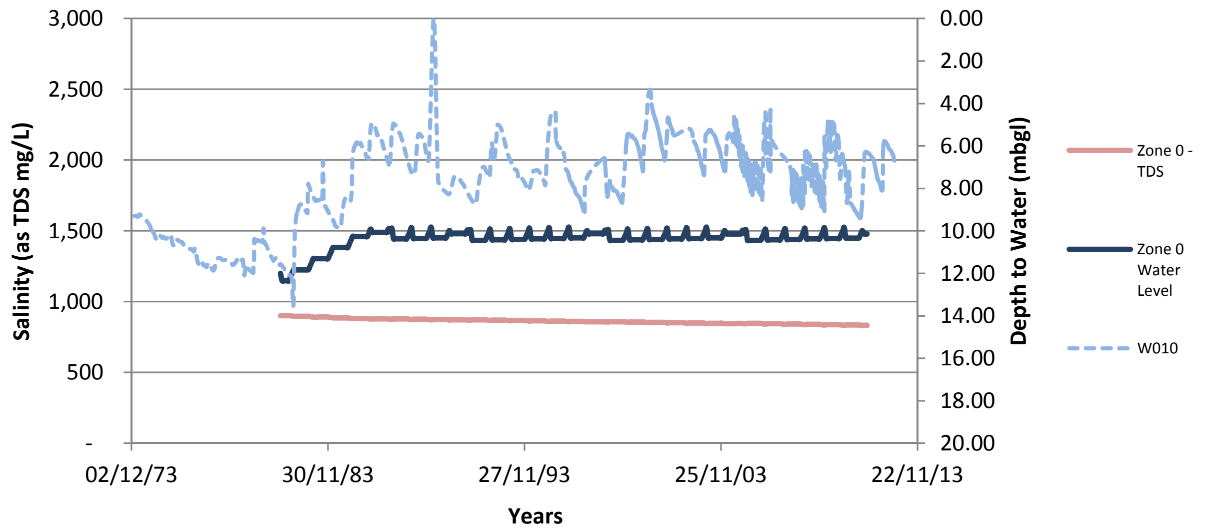
Zone 2 - Groundwater Salinity and Water Level

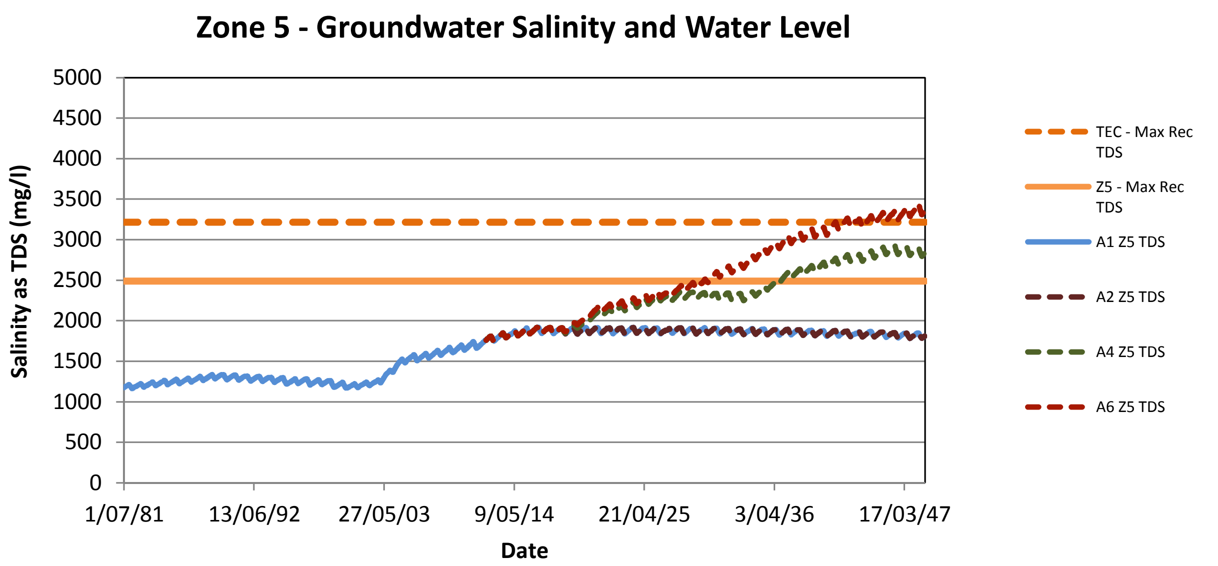


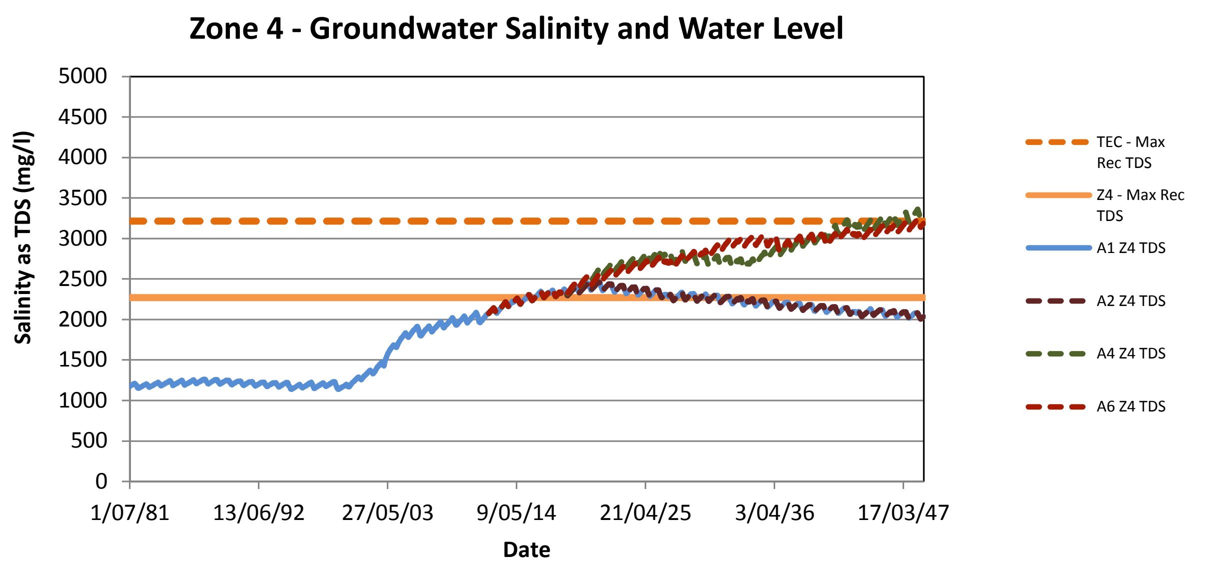
Zone 1 - Groundwater Salinity and Water Level

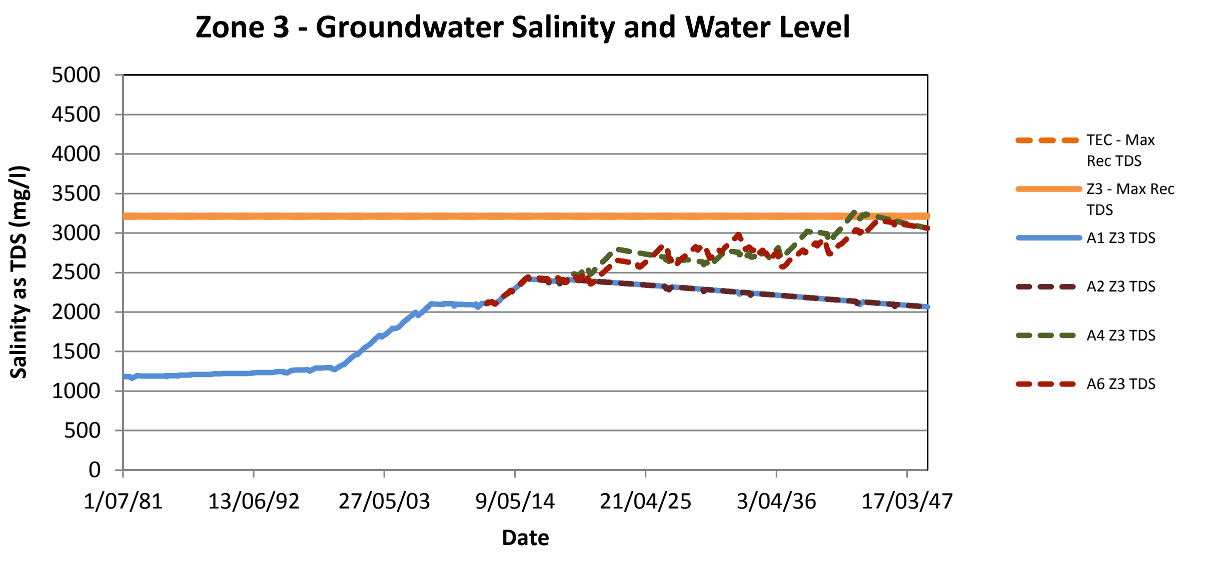


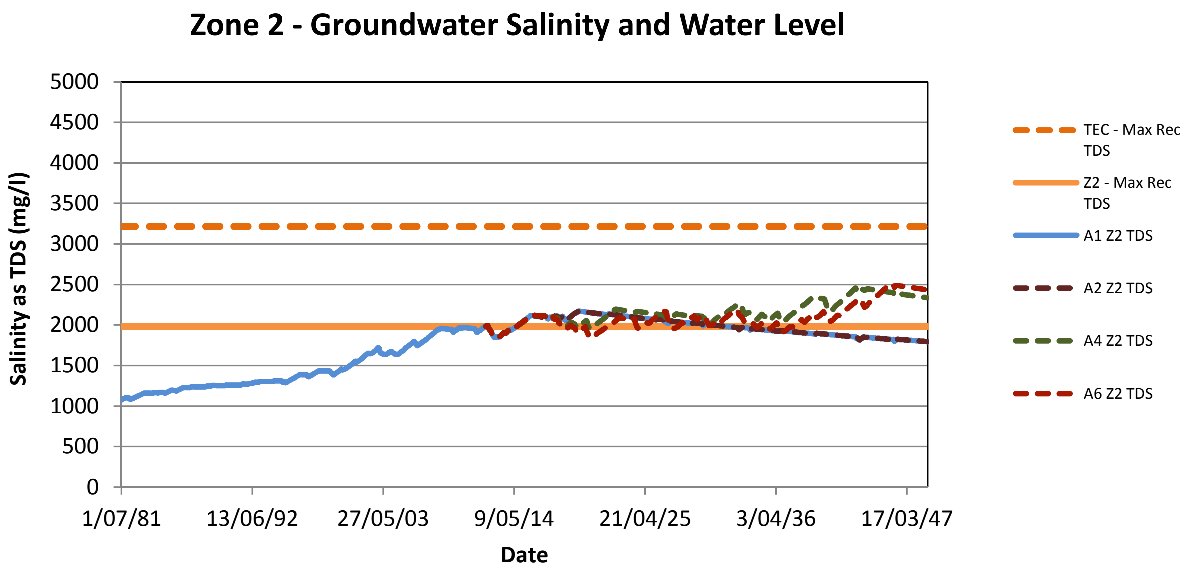
Zone 0 - Groundwater Salinity and Water Level

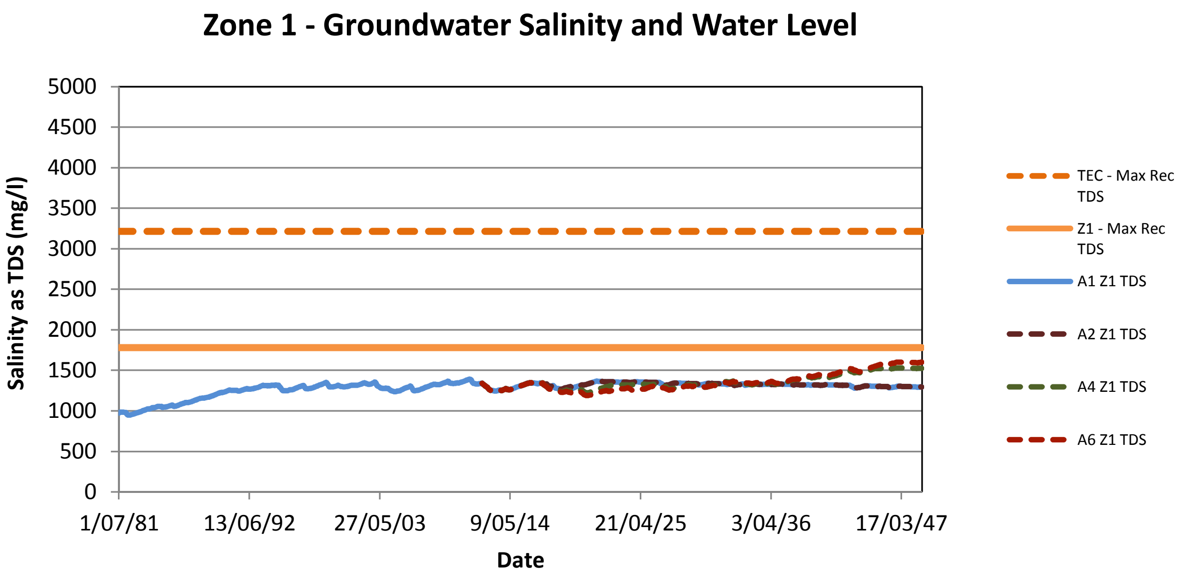



Zone 5 - Groundwater Salinity and Water Level
Salinity as TDS (mg/l)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1/07/81
13/06/92
27/05/03
9/05/14
21/04/25
3/04/36
17/03/47
Date
TEC - Max Rec TDS
Z5 - Max Rec TDS
A1 Z5 TDS
A2 Z5 TDS
A4 Z5 TDS
A6 Z5 TDS


Zone 4 - Groundwater Salinity and Water Level
Salinity as TDS (mg/l)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1/07/81
13/06/92
27/05/03
9/05/14
21/04/25
3/04/36
17/03/47
Date
TEC - Max Rec TDS
Z4 - Max Rec TDS
A1 Z4 TDS
A2 Z4 TDS
A4 Z4 TDS
A6 Z4 TDS


Zone 3 - Groundwater Salinity and Water Level
Salinity as TDS (mg/l)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1/07/81
13/06/92
27/05/03
9/05/14
21/04/25
3/04/36
17/03/47
Date
TEC - Max Rec TDS
Z3 - Max Rec TDS
A1 Z3 TDS
A2 Z3 TDS
A4 Z3 TDS
A6 Z3 TDS


Zone 2 - Groundwater Salinity and Water Level
Salinity as TDS (mg/l)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1/07/81
13/06/92
27/05/03
9/05/14
21/04/25
3/04/36
17/03/47
Date
TEC - Max Rec TDS
Z2 - Max Rec TDS
A1 Z2 TDS
A2 Z2 TDS
A4 Z2 TDS
A6 Z2 TDS


Zone 1 - Groundwater Salinity and Water Level
Salinity as TDS (mg/l)
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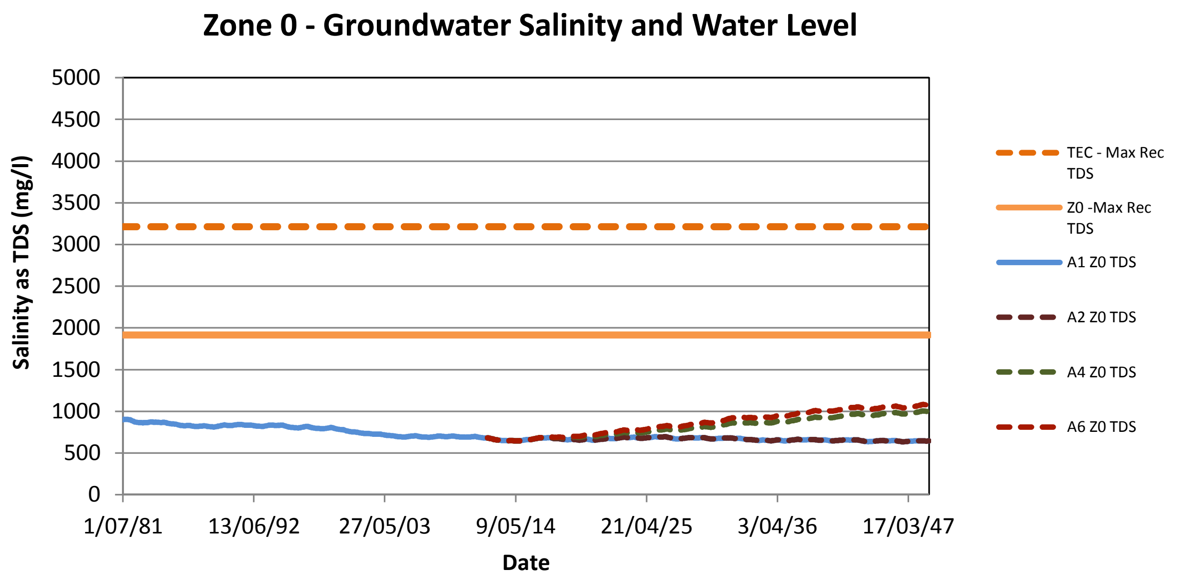
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1/07/81
13/06/92
27/05/03
9/05/14
21/04/25
3/04/36
17/03/47
Date
TEC - Max Rec TDS
Z1 - Max Rec TDS
A1 Z1 TDS
A2 Z1 TDS
A4 Z1 TDS
A6 Z1 TDS


Zone 0 - Groundwater Salinity and Water Level
Salinity as TDS (mg/l)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1/07/81
13/06/92
27/05/03
9/05/14
21/04/25
3/04/36
17/03/47
Date
TEC - Max Rec TDS
Z0 -Max Rec TDS
A1 Z0 TDS
A2 Z0 TDS
A4 Z0 TDS
A6 Z0 TDS