Hydrogeological Assessment for Cloudbreak Water Management Scheme

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EXECUTIVE SUMMARY

Fortescue Metals Group Ltd (Fortescue) owns and operates the Cloudbreak Iron Ore Mine (Cloudbreak) located in the Pilbara region of Western Australia. Cloudbreak has been operating since mid 2008 and is currently producing approximately 35 mtpa of iron ore. Since mid 2008 the Cloudbreak water management scheme (WMS) has developed to a scale where approximately 25 GL/a is currently dewatered, supplying mine water requirements of approximately 7 GL/a, and injecting excess water of approximately 18 GL/a.

As a result the net draw from the aquifer is approximately 7 GL/a. Further expansion of the Cloudbreak WMS is required to support the Cloudbreak life of mine (LOM) plan. This document has been prepared to support approval of the expansion. The document outlines the current knowledge of the groundwater system and details the development of a numerical model and the results of LOM simulations.

The hydrogeological setting of Cloudbreak has been characterised based on field investigations, borefield developments and extensive groundwater monitoring since 2006. This includes the period since mid 2008 when Cloudbreak has been operating a significant groundwater management scheme. These works form the basis for the conceptual hydrogeological model of the Cloudbreak project area described in this report.

The Marra Mamba Formation (MMF) ore body is an important part of the present day groundwater system being the most significant brackish aquifer in the area. The aquifer is elongated along the strike of the Chichester Ranges. The aquifer receives recharge from rainfall infiltration in the Chichester Ranges which subsequently flows to the south towards the Fortescue Marsh. The MMF is overlain by a sequence of alluvial sediments which thicken towards the Marsh and result in the MMF aquifer becoming increasingly confined down dip.

It is also recognised that the Marsh environment is a dominant feature of the hydrogeological system. The Marsh is a closed basin and periodically experiences flooding in response to runoff from the surrounding surface water catchment. Significant rainfall in the catchment can generate runoff in the order of 500 to 1,000 GL, which forms a broad shallow lake over the Marsh. Infiltration results in saturation of the unsaturated zone, which even after a prolonged dry period where the water level may fall to 1.5 m below ground level is not expected to exceed 90 GL.

The lake water then proceeds to evaporate and if no significant rainfall events occur within the next 12 months will be completely evaporated and the watertable will start to fall below ground level again as the process of evaporation continues to remove water from the sub surface storage under the extremely dry and hot climatic conditions. This cycle of flooding and evaporation, over time, has resulted

in development of a hypersaline body of groundwater beneath the Marsh which is an important part of the present day flow system.

The hypersaline groundwater beneath the Marsh and the brackish groundwater flowing southward meet in a broad transition zone where the less dense brackish groundwater flows up and over the hypersaline via low permeability alluvial sediments, eventually discharging via evaporation and evapotranspiration in the vicinity of the Marsh floor.

A density-driven flow and transport numerical groundwater model was developed in the FEFLOW groundwater modelling system for the Cloudbreak project and adjacent Fortescue Marsh region. The model has been successfully calibrated against steady state and transient piezometric and salinity data including twenty years of inferred Marsh flood levels and two years of significant dewatering and injection operations. The calibrated groundwater model was subsequently used to simulate the water management plan for the Cloudbreak Life of Mine Strategic Plan.

The Cloudbreak water management strategy is designed to meet multiple needs; those of the business, the environment and stakeholders. The project involves large scale dewatering which exceeds the mine water demand by a considerable quantity annually. Recognising the need to maintain as much as possible the equilibrium of the hydrogeological system in order to satisfy environmental and stakeholder needs, a significant proportion of the abstracted water is returned to compatable aquifers by injection. Brackish groundwater is returned to brackish aquifers along strike from the active mine area and saline groundwater is returned to the saline (Oakover) aquifer located to the south of the mining operation.

The Cloudbreak water management strategy was assessed via numerical simulation. Over the Life of mine (14 years) abstraction is predicted to be at an average rate of 58 GL/a and injection is predicted to be at an average rate of 47 GL/a. The net abstraction from the operation, which is the balance of total abstraction and total injection is approximately 11 GL/a, which represents approximately 20% of abstraction. In other words, 80% of the water abstracted during dewatering is returned to the aquifer system from which it is drawn.

The resulting drawdown from dewatering is localised to the mining area and shifts focus over the life of the operation. Drawdown occurring at the perimeter of the Marsh is approximately 1 m or less. Localised mounding is predicted to develop in the brackish injection areas in response to injection. The simulated mounding is generally less than 5 m above the natural water levels. Watertable rise of generally less than 2 m may develop in the saline injection area however this is typically of short duration. No surface expression of groundwater is expected as a result of injection.

Uncertainty analysis was undertaken with respect to a range of rainfall conditions and hydraulic parameters. The resulting water levels for synthetic wet and dry

rainfall sequences show small variability being generally less than 1m. This is largely due to the dampening effect of evaporation, which is high when the watertable is elevated and low when the watertable is lower.

Dewatering volumes are sensitive to the hydraulic conductivity of the mineralised MMF, however there is a good understanding of the hydraulic conductivity distribution in this aquifer. Water levels do show some sensitivity to the range of hydraulic conductivities of both Oakover Formation and mineralised MMF explored in the assessment.

Groundwater level recovery occurs relatively rapidly following the completion of mining and dewatering. Water levels recover to within two meters locally around some mine pits after approximately 20 years recovery under average rainfall conditions. Water level adjacent to the Marsh recover rapidly also, in response to Marsh flooding events.

A 2-d model was developed to enable more accurate simulated results of salinity change in response to the water management plan. In particular the potential influence on the salinity of the watertable zone (where of existing brackish or fresher water quality), which represents the zone of highest potential beneficial use (vegetation and pastoral use) was assessed. The results of this assessment indicate that the shallow watertable zone may be marginally influenced but will generally be maintained within the natural brackish range.

A comprehensive description of infrastructure requirements and management systems is presented in accompanying document:

Fortescue 2010, Cloudbreak Water Management Scheme, CB-RP-HY0014.

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1. INTRODUCTION

1.1 BACKGROUND

Fortescue Metals Group Ltd (Fortescue) owns and operates the Cloudbreak Iron Ore Mine (Cloudbreak) located in the Pilbara region of Western Australia (Figure 1). Cloudbreak has been operating since mid 2008 and is currently producing approximately 35 mtpa of iron ore, which is transported by rail to the Herb Elliot Port Facility at Port Hedland prior to shipping overseas.

Water is an integral element in the Cloudbreak operation. Dewatering, water supply and disposal of excess water are all managed to ensure the needs of the operation, environment and stakeholders are met. A cornerstone of Cloudbreak's water management strategy is Managed Aquifer Recharge (MAR). This strategy involves returning the majority of excess water (from dewatering) to the aquifer system resulting in a significantly smaller net draw from the aquifer and reducing impacts associated with abstraction.

Since mid 2008 the water management operation of Cloudbreak has developed to a scale where approximately 25 GL/a is currently dewatered, supplying mine water requirements of approximately 7 GL/a, and injecting excess water of approximately 18 GL/a. As a result the net draw from the aquifer is approximately 7 GL/a.

Fortescue has prepared this technical document to support expansion of the current Cloudbreak Water Management Scheme (WMS). The expansion is required to support the Cloudbreak life of mine (LOM) plan.

1.2 OBJECTIVES

The objectives of the report are to:

- Document and demonstrate suitable and appropriate knowledge of the hydrogeological system and related aspects of the hydrological cycle with respect to the project.
- Provide detailed description and demonstrate the appropriateness of the numerical groundwater model that has been developed to simulate the system and the forward predictions of water management activities proposed at Cloudbreak.
- Present and describe the results of predictive simulations, including an assessment of the sensitivity of the results.
- Provide a factual document for use in regulatory processes and to support applications for increased abstraction and re-injection requirements.

1.3 SCOPE

Given the objectives outlined above, this document seeks to present the following:

- Provide a brief historical overview of hydrogeological activities undertaken in the project area.
- Provide a description of the existing hydrogeological and hydrological system, including social and environmental factors which have potential links to these systems.
- Describe the current operation in terms of water movements and impacts.
- Describe a conceptual model for the system as the basis for the numerical model.
- Provide a description of the numerical model developed for simulation of the system, including calibration results
- Describe the proposed water management system and present the results of predictions, including discussion regarding uncertainty.
- Present conclusions and make recommendations for future works.

This document does not include description of the WMS infrastructure or management systems, which are presented in:

Fortescue, 2010. Cloudbreak Water Management Scheme, CB-RP-HY-0014.

2. PREVIOUS WORK

A number of phases of hydrogeological works including test production bores, modelling assessments, geophysical surveys, geochemical assessments, borefield developments and aquifer reviews have been ongoing since 2005. These programs have been implemented to support both approval and operational requirements. As a result of these works significant knowledge of the hydrogeological system has been gained. A summary of previous works is outlined in Table 1.

Table 1: Hydrogeological activities undertaken for Cloudbreak

Project	Scope	Outcomes	Reference
Hydrogeological Compilations	Cloudbreak PER (2005) • 2 test production bores • Groundwater model developed • Dewatering assessment conducted	Conceptual model and numerical model utilising 'average' Pilbara hydraulic parameters Predicted dewatering requirements of up to 12 GL/a over life of mine	Aquaterra, 2005
	Cloudbreak Hydrogeological Assessment to support change to Ministerial Statement - Increase dewatering to 25 GL/a and injection to 18 GL/a. Included: • Significant revision of conceptual model based on further drilling and test works (see below); • Significant revision of numerical hydrogeological model; • Review of short term dewatering and injection requirements; and • Hydrological Impact assessment.	Updated status quo with regards to conceptual hydrogeology and short term dewatering requirements. Key updates include significant increase of hydraulic conductivity parameters and inclusion of density coupling in groundwater flow modelling.	FMGL, 2009c

Project	Scope	Outcomes	Reference
Aquifer Reviews	As part of licencing conditions for the Cloudbreak 5C Licence, aquifer reviews are prepared. During the mine construction phase annual aquifer reviews were prepared for the 2006 and 2007 licence periods. Since groundwater licensing of the dewatering operation commenced in mid 2008 both annual and quarterly reporting has been required, two annual aquifer reviews have been completed as well as 6 quarterly aquifer reviews, a triennial annual aquifer review is in production for the 2009 – 2010 period. The aquifer reviews describe and comment on volumetric data (abstraction, injection, mine water use), water level data and water quality data recorded for the period.		FMGL, 2010e; FMGL, 2010d; FMGL, 2010c; FMGL, 2009i; FMGL, 2009h; FMGL, 2009f; FMGL, 2009e; FMGL, 2009d; FMGL, 2007b; FMGL, 2009a

Project	Scope	Outcomes	Reference
Dewatering and Injection Borefield Development	Numerous phase of bore installation (dewatering and injection bores) and yield assessment (aquifer tests) have been conducted across the approximately 50 km strike that the Cloudbreak WMS is developed. These works commenced prior to dewatering operations began and are undertaken on an ongoing basis to support new pit developments and injection borefields.	A significant knowledge base of the of hydraulic properties across the project area has been developed	Aquaterra 2006a; Aquaterra 2006b; FMGL, 2008a; FMGL, 2008b; FMGL, 2008c; FMGL, 2009b; FMGL, 2009f; FMGL, 2010a; FMGL, 2010b FMGL, 2010g; FMGL, 2010h; FMGL, 2010i; FMGL, 2010j; FMGL, 2010k;
Geochemical Assessment	Measurement of groundwater quality parameters and sampling of groundwater from proposed mine dewatering Borefield. Chemical analysis of groundwater samples Assessment of likely changes to groundwater composition and mineral precipitation due to mixing of water types, using aqueous geochemical modelling software PHREEQC. Documentation of methodologies, results, conclusions and recommendations.	Provide information on the borefield and aquifer geochemistry: Precipitation of secondary minerals in the injection well and the receiving aquifer is unlikely to be significant: calcite and dolomite were already oversaturated in the receiving aquifer. The saturation index (SI) is unchanged, Gypsum was and remains after mixing with the injected water undersaturated in the aquifer. The potential for bio-fouling to occur is low	FMGL, 2007a

Project	Scope	Outcomes	Reference
		due to the presence of iron-precipitating bacteria, oxygen and ferrous iron.	
	Predicted geochemical interactions for re-injection of saline abstraction water into the saline Oakover Formation and in surface storage facilities Assessment of the potential for mineral precipitation with the PHREEQC geochemical model using 3 different scenarios	The degrees of saturation with respect to potential mineral precipitates are approximately the same for both the abstraction and injection zone groundwater. The most likely mineral precipitates for the South Transfer Pond are Ca-Mg carbonates, amorphous silica, and ferric oxyhydroxide according to geochemical modeling results. Geochemical model calculations for three scenarios predict that mixing of abstraction water with injection zone water (except brackish water) generally reduces the potential for precipitation of most carbonate, sulfate, and silica minerals (except Mn and Fe oxyhydroxides) and therefore limits potential for geochemical fouling	MWH, 2009
Geophysical surveys	A SkyTEM survey was conducted in 2010. The SkyTEM survey involved flying over 1500 line kilometres of data, covering an area of about 80 kilometres by 10 kilometres. SkyTEM is a helicopter-mounted, time domain electromagnetic (TDEM) system, where a dual TDEM moment, 24 metre wide (311 m2) electromagnetic loop was towed at a nominal 30 metre terrain	These data have assisted in mapping the position of the saline interface and in determining: The heterogeneity of the salt interface, with saline zones often aligned with	FMGL, 2010n

Project	Scope	Outcomes	Reference
	height along regularly-spaced grid lines. Data-inversion was carried out using the Laterally-Constrained Inversion (LCI) method, whereby field data were filtered and then modeled against a subsurface layer structure constrained laterally on a number of chosen model parameters (including layer conductivity and layer thickness).	structural lineaments and other preferential flow paths; The surface drainage and brackish groundwater flow patterns via inverse conductivity (resistivity) data; That saline zones beneath the ore zone may be disconnected from principle flow mechanisms ('fossil' groundwater); and That the extremely high electrical conductivity of saline aquifer zones is such that saline strata may mask the responses from deeper hydrogeological units.	
Saline Injection Trial	Assessment of a 6-months saline injection trial : Summary of the operations, groundwater levels, water quality data, and vegetation monitoring. Hydrogeological assessment of these data, hydrogeological characterisation of the saline injection area, numerical model assessment. Commitments assessment, Compliance assessment.	Proof of concept has been achieved. Environmental impact consistent with predictions, Injection of saline water has not impacted the upper, fresher aquifers except in isolated sites thought to relate to bore construction. Telemetry system control being developed. Hydrogeological characterisation of the saline injection area and validation of the model in this area were limited due to	FMGL, 2010f

Project	Scope	Outcomes	Reference
		limited aquifer response. Progress in the assessment of clogging potential of saline reinjection.	

3. EXISTING ENVIRONMENT

This section outlines the knowledge base regarding elements of the hydrological environment significant to the project. The majority of the information has been developed over the period that the Cloudbreak project has been under development (see Table 1).

3.1 LOCATION

Cloudbreak is located in the eastern Pilbara region, approximately 120 km north west of Newman and 240 km south east of Port Hedland (Figure 2).

3.2 TOPOGRAPHY

The eastern Pilbara regional topography is dominated by the Hamersley Plateau in the south and the Chichester Ranges in the north with the two features separated by the Fortescue Valley. The main drainage is the Fortescue River, which flows northwards on Ethel Creek Station and then northwest on Roy Hill Station into the Fortescue Marsh.

Within the Chichester Ranges the topography can be described as gently undulating, with a maximum relief from the Fortescue Valley (400 to 450 mRL) to the Chichester Ranges (500 to 600 mRL) of approximately 50 to 200 m. The Chichester Ranges and the major drainage system of the Fortescue Valley to the south both trend towards west-north-west.

The Fortescue Marsh forms an extensive intermittent wetland on the valley floor. The eastern section immediately adjacent to the Cloudbreak operation mine occupies an area about 100 km long by typically 10 km wide, at an elevation of around 400 to 405m ASL (SWC, 2008).

Between the raised relief of the Chichester ranges and the Fortescue Marsh Basin a transitional zone exists, characterised by fluvial deposition and formation of a series of alluvial fans, which for the most part overlie the Cloudbreak mine mineralisation.

3.3 CLIMATE

The inland Pilbara region is classified as arid, with weather patterns characterised by hot and wet summer and warm dry winter periods. Climatic statistics from the Bureau of Meteorology weather station at Newman (118 km from Cloudbreak) are presented in Table 2 and average monthly rainfall is presented in Figure 3.

The normal maximum temperature range in summer is 35 to 40 degrees Celsius (^{o}C). Winter maximum temperatures are mild/warm with temperatures in the 24 to 28 degrees ^{o}C range.

Most of the summer rain comes from scattered thunderstorms and occasional tropical cyclones. The long-term average annual rainfall is approximately 310 mm; however, this can vary dramatically due to the influence of tropical cyclones as illustrated by the highest monthly and daily records and the 2008 to 2009 records for Cloudbreak. In the last 10 years (1999 to 2009) the annual rainfall recorded at Newman was in excess of 400mm for 6 of those years and above 500 mm for three years. For these periods, over half the annual rainfall typically fell within a one to two month period. Further analysis of rainfall and its influence on the hydrological system is presented in subsequent chapters.

Evaporation greatly exceeds mean annual rainfall. The average annual pan evaporation rates recorded at Wittenoom (112 km from Cloudbreak) exceed 3000 mm.

Table 2: Climatic Data for Newman and Cloudbreak

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean daily max. temp (°C)[1]	39.5	37.0	35.0	31.7	27.3	23.1	23.0	25.8	30.5	35.0	37.4	38.9	32.0
Mean daily min. temp (°C)[1]	25.0	23.9	21.5	17.3	11.6	6.8	5.9	7.5	11.8	17.2	20.6	23.6	16.1
Highest monthly rainfall (mm)[1]	239.8	305.6	214.2	89.6	110.3	77.8	139.8	79.6	35.6	34.8	65.2	236.0	619.2
Highest recorded daily rainfall (mm)[1]	137.7	117.0	101.0	64.0	57.0	36.0	72.4	36.2	24.8	18.8	46.4	214.0	214.0
Newman mean monthly rainfall (mm)[2]	57.2	77.0	40.7	19.6	18.1	14.2	14.9	7.7	3.4	4.9	10.5	37.4	310.1
Cloudbreak 2008 rainfall (mm)[2]	50.0	56.0	66.0	2.0	0.0	49.0	0.0	0.0	3.0	11.0	1.0	73.0	310.0
Cloudbreak 2009 rainfall (mm)[2]	31.0	165.5	23.0	0	3.0	7.5	2.0	0	0	0	8.0	21.0	261.0
Wittenoom Mean monthly evaporation (mm)	356.5	274.4	282.1	231	179.8	138	151.9	189.1	255	344.1	372	387.5	3175.5

Source: Bureau of Meteorology (www.bom.gov.au)

[1] Rainfall data for Newman from 1971 to 2010

[2] Cloudbreak rainfall data recorded onsite

3.4 SURFACE WATER

3.4.1 Regional surface hydrology

Cloudbreak lies within the area of the Chichester Range which drains in a southerly direction towards the Fortescue Marsh. Over time, the larger catchments draining the Chichester Ranges have formed a series of floodplains, alluvial fans and sheet flow zones that form a band of low relief terrain between ranges and the Fortescue Marsh. This band runs along the northern edge of the marsh, between 5 and 10 km from the base of the Chichester Ranges and sloping at around 0.3%. Infrastructure associated with Cloudbreak is sited on this band south of the ranges and within the foothills of the ranges themselves (Worley Parsons, 2010).

The Fortescue Marsh lies in the upper Fortescue River catchment, which is effectively disconnected from the Lower Fortescue River catchment by the Goodiadarrie Hills, 50 km west from Cloudbreak. West from the Goodiadarrie Hills, the Lower Fortescue River catchment drains to the coast, whereas east of the hills the Fortescue Marsh receives its runoff from the Upper Fortescue River catchment. The Fortescue Marsh is an extensive, intermittent wetland, bound by the Chichester Range to the north and the Hamersley Range to the south, occupying an area of approximately 1,000 km^2 when in flood (Department of Environment, Heritage, Water and the Arts (DEHWA) 2008).

In common with other areas in the Pilbara Region, the Fortescue Valley is subjected to localised thunderstorm and cyclonic rainfall events. Typically these events occur during the period of December through to April and can produce very large runoff events. The period July to November typically has relatively low rainfall (Table 2), although significant runoff during this time can occur. Following significant rainfall events, runoff from the Upper Fortescue River catchment (approximately 31,000 km^2) drains to the Fortescue Marsh. For the smaller runoff events, isolated pools form on the Fortescue Marsh at the main drainage inlets, whereas for the larger events the whole Marsh area may flood.

3.4.2 Marsh surface water levels and water quality

Based on Water and Rivers Commission (WRC) internal records, the flood storage level in the Fortescue Marsh would need to exceed 413 mASL to overspill westwards past the Goodiadarrie Hills. Although no published flood level data are available for the Fortescue Marsh, WRC internal records show a Fortescue Marsh flood level near the BHP Billiton Iron Ore (BHPBIO) railway in March 1980 of around 406.5 mASL as a result of rainfall from consecutive cyclones Dean and Enid. Enquires with BHPBIO indicate that flood levels have never overtopped the railway where it crosses the Fortescue Marsh, although large floods in the early 1970s are reported to have caused inundation up to the existing railway track level (G. Liddell, BHPBIO, pers. comm.). At the eastern end of the Fortescue Marsh, an indication of flood levels can be obtained from data from the Roy Hill stream flow gauging station (S708008) established on the Upper Fortescue River. This gauging

station, used to monitor stream flows entering the Fortescue Marsh, was located just downstream from the Roy Hill Homestead and was operational from September 1973 to September 1986. At the gauging station, the level of the main flow channel bed was around 405.5 mASL and during the 13 years of records, the maximum level of stream flow was 408.75 mASL (February 1980). The corresponding level of peak flood storage in the downstream Fortescue Marsh would have been less than this gauge level, as indicated by the above WRC internal data (i.e. 406.5 mASL in March 1980).

Historical satellite imagery of the region between 1999 and present was reviewed to estimate the elevation of flooding, surface area and volume. A summary of this data is presented in Appendix A. The study indicates that flood water levels reached approximately 407 m in response to a flooding event(s) in 2000. At this time the entire Marsh, approximately 853 km^2 was in flood, which represented a volume of approximately 794 GL. Flooding events in 2001, 2002 and 2003 subsequently resulted in accumulated runoff in excess of 500 GL. A number of smaller events have also occurred in this timeframe.

Surface water runoff to the Fortescue Marsh is typically of low salinity and turbidity, though the runoff turbidity significantly increases during peak periods of flooding (WRC, 2000).

Water stored on the Fortescue Marsh slowly dissipates through the processes of seepage and evaporation. During the evaporation process, the water salinity has been recorded to increase from 6,500 to 11,370 mg/L as the pond areas recede and dry up (Fortescue 2007b).

3.4.3 Fortescue Marsh Surface Water Balance

Building on sheet flow and catchment water balance modelling conducted for the Chichester Ranges (Worley Parsons, 2010), a simple water balance for the Fortescue Marsh was developed. The catchment area that Cloudbreak occupies, including all pit developments, associated infrastructure and upstream areas comprises a 1070 km^2 area of the Chichester Ranges and a 700 km^2 area of flat terrain north of the Marsh. This compares to a total catchment area for the Marsh of 26,000 km^2 above Goodiadarrie Hills and below Opthalmia Dam.

The proposed mines and infrastructure make up a very small proportion of the catchment area and only a smaller proportion of the total developed area would be under development at any one point in time. However mine developments may result in crossings, diversions, storage or ponding of some of the flows from these combined areas. Based on a runoff coefficient of 22%, the total average annual runoff from the potentially impacted area is 150 GL, or 7% of the total 2,150 GL for the entire Marsh catchment (Worley Parsons, 2010). The mine development will not prevent a large proportion of these flows from reaching the Marsh each year because:

- Only a small part of the mine developments are active in any single year.
- “Impacts” include ponding, temporary storage, diversions and changes in water quality. Over a typical year, the average water quantity reaching the marsh would not change.

3.4.4 Cultural Significance

Semi-permanent water bodies or “Yintas” on the shores of the Fortescue Marsh have been identified as culturally significant areas. The Yintas are located at low points in the Marsh surface topography. Each of the Yintas is associated with large catchments draining the Chichester Ranges. These include large streams like Goman Creek (Worley Parsons, 2010) and Christmas Creek which may distribute across 2 Yintas (Worley Parsons, 2010) during large floods.

3.4.5 Site hydrology

Surface water flow in and around the mine area takes several different forms, covering different areas, each requiring a unique management approach. In a hydrological sense, the catchment of the study area and surrounds can be divided into several zones based on runoff generating mechanisms and the different types of runoff listed below (Worley Parsons, 2010b):

- Hillslope Runoff - Hillslope runoff zones are located in the portion of catchments where the majority of runoff is contained within small creeks, broad swales or gullies. Flows are generally convergent by nature, which concentrate flows, increases velocities, promotes scour and enhances channel formation. Catchment sizes are usually small but can be larger in cases where the terrain is flat and velocities are insufficient to maintain well defined channels.
- Channel Flow - Channel flow zones are located in the portion of catchments with large channels and adjacent floodplains. These zones are associated with large catchments that predominantly drain the steep areas of the Chichester Range rather than the low relief terrain closer to the Marsh. Large convergent flows, high velocities and large, well defined channels are typical of these creeks. Smaller, more frequent flows are mostly confined to the channel while larger and less frequent flood flows break out onto the adjacent floodplain. These zones can be identified using topographic information and vegetation patterns in aerial photos. Channels are usually devoid of vegetation due to bed load movement during flood events. Vegetation on the adjacent floodplains is maintained either by periodic inundation or has rooting depths sufficient to access the surficial aquifer replenished by more frequent smaller flows.
- Diverging Flow - Diverging flow zones areas are located in the portion of catchments where channel flow has become dispersed, leading to a loss of channel form. The

transition from channel flow to diverging flow normally occurs on the low relief terrain after large rivers have discharged from the Chichester Ranges. The distance that the channel form is maintained is proportional to the size of the flows generated by a catchment (i.e. the greater the flow, the more well defined the channel is further downstream). Sandy Creek is an example where channel form is maintained all the way to the Marsh shoreline at which point the flow diverges and the channel reduces in size and the flow disperses. The width of the Sandy Creek channel reduces from 50 m upstream to around 5 m at the Marsh.

- Sheet flow - Sheet flow zones form in areas where overland flow moves down slope while maintaining a broad shallow front. This is the initial hillslope response to infiltration excess prior to channel initiation. Channel initiation is dependent on a threshold level of stream power, controlled in part by the extent of flow convergence and gradient. There are many examples in the study area where the terrain has been formed by remnant alluvial fans. These areas do not promote convergence of flows and are relatively flat, meaning that sheet flow zones are maintained over large areas.

Some areas including those closer to the shore of the Marsh may exhibit one or more of these characteristics.

3.5 GEOLOGY

3.5.1 Regional Geology

The Mt Bruce Supergroup of Western Australia was laid down between *ca* 2.8 Ga and *ca* 2.2 Ga in the Hamersley Basin, unconformably over a basement of the older, granite–greenstone, component of the Pilbara Craton. The Mt Bruce Supergroup consists of three groups: the Fortescue Group, Hamersley Group and Turee Creek Group in upward sequence. The Hamersley Group, which is divided into a series of formations, has a general thickness of 2.5 km, and is characterised by major banded iron-formation (BIF) units (Trendall et al, 2005). The Hamersley Group includes the economically important Brockman and Marra Mamba Iron Formations. The Marra Mamba Formation (MMF) is the lower most formation of the Hamersley Group (Table 3).

The Cloudbreak deposits are hosted by the MMF, which outcrops on the northern side of the Fortescue Valley in the Chichester Ranges. The Chichester Ranges mark the northernmost extent of the Hamersley Group. Some stratigraphic variation occurs between the southern Hamersley Basin and Northern Hamersley Basin (Chichester Ranges) as illustrated in Figure 4.

The MMF dips gently to the south beneath the Fortescue Valley. Colluvial and alluvial deposits form a thin mantle over the upper flanks of the Chichester Ranges and thicken towards the Fortescue Valley, transitioning from colluvial slopes to alluvial outwash deposits and valley-fill sediments. The following sections describe the main stratigraphic units present in the project area.

Table 3: Stratigraphic Summary of Project Area

Group	Formation/Unit	Lithology
Tertiary Detritals	Tertiary Detritals 3[2]	Colluvial and alluvial sediments, ranging from proximal cobble to pebble, alluvial/colluvial fans to distal silty and clayey valley fills and playa deposits. Basal layers can have well-rounded hematite and maghemite pisoliths
	Tertiary Detritals 2[2]	Fluvial and lacusterine sediments dominated by bleached and mottled clays and micritic limestones (including the Oakover Formation). Includes CID[3] deposits in constrained palaeovalleys.
Hamersley Group	Weeli Wolli Formation[4]	BIF[5], pelite and metadolerite sills
	Brockman Iron Formation[4]	BIF, chert and pelite
	Mount McRae Shale[4]	Pelite, chert and pelite
	Wittenoom Dolomite	Meta-dolomite
	Marra Mamba Formation (MMF)	Mount Newman Member: BIF, minor thin shales bands
		MacLeod Member: Shales, chert and BIF
		Nammuldi Member: Chert and iron-formation
Fortescue Formation	Jeerinah Formation	Roy Hill Shale Member: Bleached white shale
Pilbara Craton		Granitic Rocks

[2] After Kepert, 2005
[3] Channel Iron Deposit
[4] Not present in Northern Hamersley Basin (Chichester Ranges)
[5] Banded Iron Formation

3.5.2 Project Geology

Fortescue Group

The Roy Hill Shale (RHS) Member of the Jeerinah Formation (JF) conformably underlies the MMF and consists mainly of pyritic black shales and minor chert bands. Upper parts of the RHS can be weathered to pale coloured clays.

Hamersley Group

Regionally the MMF is divided into three members (Nammuldi, McLeod and Mt Newman) but only part of the Lower Nammuldi member is present in the project area, which typically consists of cherty BIF (U7 – U4), shale units and underlying ferruginous chert (U3 – U1).

The Nammuldi Member's regional dip is overprinted by low amplitude (<20 m), long wavelength (200 to 800 m), north-south to northeast-southwest trending folds. Folding is likely to be the result of waning phases of deformation in the underlying Pilbara Craton (or alternatively may represent the waning phases of post-Fortescue Group gravity-driven tectonics). Faulting is difficult to distinguish in the MMF, due to the degree of mineralisation and/or hard capping and the paucity of outcrop. North-south to northeast-southwest faulting (that is, sub-parallel to folding) is more readily apparent in the Fortescue Group to the north.

Post depositional geomechanical and geochemical processes include faulting (significant NE-SW faults) and folding, hypogene fluid intrusion and geochemical alteration (hematite ore formation), erosion, shallow supergene geochemical alteration (goethite and goethite-martite ores). These processes have resulted in the present characteristics of the Nammuldi Member, including the formation of the economically important micro-platey hematite, martite-goethite, ocherous geothite and secondary goethite ores, and massive manganese replacement. This complex geochemical evolution has resulted in significant mineralogical and textural overprinting of the original depositional sequence (Clout, 2005).Typical vertical zonation and textural characteristics are discussed below:

- Hardcap: Represents recent intense weathering of iron ore, consisting of highly porous or coarse cellular – textured brown or vitreous goethite. Interpreted to have developed by dissolution of iron minerals (goethite and hematite) and re-precipitation further down in the hydrated or dehydrated zone. The hardcap zone is interpreted to be between 3 and 15 m thick in the Cloudbreak area.
- Hydrated and dehydrated zone: In the hydrated zone, micropores and cavities tend to be infilled with colloform secondary goethite and hematite. The ore is denser and with low porosity. In the dehydrated zone colloform secondary goethite and primary brown or ocherous goethite have largely dehydrated to hematite. Dehydrated zones typically sit above shale bands or faults.

- Primary ore zone: The primary ore zone at Cloudbreak is generally of two main types: micro-platey hematite or martite-goethite ore. Micro-platey hematite ore is porous and occurs in pods located along cross-cutting faults. Primary martite-goethite ore zones are identifiable by an absence of goethite infill textures.

- Ocherous Goethite zone: Beneath the interpreted palaeo-watertable, yellow ocherous goethite predominates over brown goethite.

- Unmineralised BIF and Chert: Typically unaltered and retaining primary texture. It can be very hard and massive but also fractured with micro-platey hematite formed along fracture planes associated with fault zones.

Small amplitude folds along the Chichester Range have affected the mineralisation in both the development and preservation of mineralisation. Synclines appear to have focused supergene fluids, resulting in their preferential mineralisation compared with adjacent anticlines. Subsequent erosion, in part controlled by the structure, lead to the broad stripping of anticlines and also the local stripping of synclines along the drainage. Poorly mineralised, large, high relief mesa tops (for example, Mt Lewin) commonly occur in anticline hinge positions.

The regional development of mineralisation along the Chichester Range was initially Proterozoic and structurally controlled (hypogene), which is in part overprinted and modified by a subsequent phase of supergene mineralisation. The two phases of mineralisation are not genetically related, but may be focused by the same structural and stratigraphic controls.

In general, iron enrichment includes the following components:

1. An iron-rich strata, both as a source of iron and a target for enrichment;
2. Impermeable shale layers, above and below, acting as aquicludes;
3. Favourable structures such as a plunging fold axis or a fractured fault zone, to provide access for fluid circulation;
4. Specific geochemical conditions, including the exposure of BIF to the atmosphere;
5. Suitable electrochemical conditions (including suitable ore porosity to enable groundwater through flow); and
6. Tectonic stability for long periods.

The Wittenoom Formation (WF) overlies the MMF; however, the WF is only present south of the resource area, towards the Fortescue Marsh. Both the MMF and WF are overlain and concealed below tertiary deposits (though at some locations, especially in the north, the MMF outcrops).

Tertiary Detritals

The sequence of sediments that have developed between the outcrop of the MMF and the Fortescue valley are collectively referred to as Tertiary Detritals (Kepert, 2005). A system of classification for the Tertiary sediments has been developed which can largely be applied across the Hamersley province due to similar depositional control factors occurring across the province (Morris, 1985; Kepert, 2005). The system used to describe the Tertiary sequence in the project area is based on the BHPB system (Kepert, 2005), which divides the Tertiary depositional sequence into the following categories:

- Tertiary Detritals 1 (TD1)
- Tertiary Detritals 2 (TD2)
- Tertiary Detritals 3 (TD3)

The depth and complexity of the Tertiary sequence ranges from thin proximal gravels (TD3) adjacent to outcrop to over 100m of distal gravely soils (TD3) overlying clays and chemical sediments (TD2). TD1 sediments have not been intersected to date in the Chichester Ranges (Kepert, 2005). The Tertiary Detritals in the Cloudbreak Area are discussed further below. A schematic cross section is presented in Figure 5.

Tertiary Detritals 3 (TD3)

TD3 generally consist of alluvial and fluvial deposits. Two broad categories are defined: an upper immature and lower-mature sediment (Kepert, 2005). Both groups of sediment have proximal and distal facies and display varying degrees of cementation.

Upper TD3 sediments are described as immature because they have undergone little reworking in their transport and deposition. Clasts are typically pebble to cobble sized, sub-angular to sub-rounded, primarily of unmineralised Nammuldi chert and BIF (mineralised clasts occur also but are diluted away from mineralised zones) and locally Roy Hill shale and chert. The matrix is generally pale buff brown to red brown sandy silt. Proximal deposits tend to be clast supported while more distal facies also have matrix supported layers. Discontinuous, weakly developed pedogenic cementation is present in the upper part of these deposits. TD3 sediments can be up to 30 m thick.

Lower TD3 sediments are described as a mature to very mature sediment typified by pebble size maghemite pisolites. Clasts of this nature indicate a large degree of chemical weathering/alteration during erosion, transportation and deposition.

The clasts are generally pisolitic maghemite and hematite, and their diameter range in size between 2 and 5 mm. The matrix is typically red-brown and clayey. Matrix ranges from being totally absent to 50%. More distal facies become increasingly matrix

dominated with only trace clasts. This unit is typically uncemented and can be up to 30 m thick.

Tertiary detritals 2 (TD2)

The Tertiary Detritals 2 (TD2) consist of a complex sequence of fluvial and lacustrine sediment that in part includes the Oakover Formation, which is developed along major drainage systems throughout the Pilbara Region. Based on the geological setting and mode of deposition, two main broad categories of TD2 sediments can be defined (Kepert, 2005). These categories include confined fluvial facies and open fluvial facies.

Confined Fluvial Facies occur in palaeochannels that are typically incised into bedrock and include lacusterine limestones and economically important channel iron deposits (CID). The sediments are generally constrained to the palaeochannel and are rapidly diluted once the palaeochannel enters into a broad valley. The exception to this is the Oakover Formation, a lacusterine limestone, which can also occur as large sheet deposits in broader valleys. Lacusterine limestones occurring in this facies are typically sheet deposits of very fine grained, white limestone. In many areas, secondary calcite dissolution and precipitation has resulted in the formation of hard calcrete horizons that can be vuggy and cavernous. In this facies lacusterine limestones often develop overlying CID. CID occur as sinuous oolitic to pisolitic goethite with varying clayey matrix composition. CID are generally completely cemented having undergone several stages of iron and silica re-mobilisation, which can result in high secondary porosity.

Open Fluvial Facies deposits occur in major palaeovalleys of the Hamersley Formation. The entire sequence may be considered the lateral equivalent of the Oakover Formation. The sedimentary sequence is typically overprinted by a weathering profile consisting of ferruginous duricrust (up to 5 m thick), ferruginous nodular duricrust (up to 5 m thick), mottled ocherous goethitic (up to 5 m thick) clay and leached clays (up to 50 m thick). lenses and sheets of calcrete are present and typically have associated silcretes overlying and underlying the calcrete horizon. The calcretes are lithologically equivalent to the Oakover Formation, occurring in the confined fluvial facies, but it is uncertain if they were formed at the same time.

3.6 HYDROGEOLOGY

A conceptual hydrogeological cross section showing the general characteristics and processes that characterise the hydrogeological system is provided in Figure 23 and discussed below.

3.6.1 Hydro-stratigraphy

A summary of the hydrostratigraphy in the project area is presented in Table 4 and is described as follows.

Tertiary Detritals

The sediments that form the Tertiary detrital have variable hydraulic characteristics. Within the colluvial and alluvial deposits derived from the Chichester Range, areas of low to moderate yield and storage include chert and BIF gravels deposited proximal to source (Upper TD3) and clayey (variable) maghemite pisolitic gravels (Lower TD3). More distal Lower TD3 deposits tend to be rich in clay and have low permeability, potentially forming a aquitard over the more southerly part of the MMF and Oakover Formation.

Channel Iron Deposits (TD2) also form laterally-constrained but linear areas of moderate to high permeability and storage. These features are small compared to their counterparts in the Hamersley Ranges.

Lithological and hydrogeological data for the open fluvial facies (TD2) in the Fortescue Valley is restricted to the area beneath the lower slopes of the Fortescue Valley Plain, between the mine and the perimeter of the Fortescue Marsh. In this region very high permeability is associated with calcretes and silcretes, elsewhere referred to as the Oakover Formation. This aquifer appears to be largely uniformly present at between approximately 40 and 60 m below ground level across the strike of the project area beneath clay dominated TD3 sediments. At its northern limit this formation overlies cherty BIF (unmineralised) and ferruginous chert of the lower MMF. Further south the Oakover Formation overlies the Wittenoom Dolomite. Importantly, the high permeability zone within the Oakover Formation does not directly overlie or connect with the high permeability zones of the mineralised MMF.

The aquifer zones are associated with primary granular permeability and porosity in clayey gravels (Tertiary pisolite, gravel and clay-rich detritals) and with secondary weathering features within the calcretes (that is, Oakover Formation). Local perched aquifers may also develop where gravely/sandy creek bed deposits are saturated during creek flow events and before leakage to the deeper watertable. Higher transmissivity tends to be associated with greater thicknesses of high permeability lithologies (pisolites and gravels) within the sedimentary profile. Spatial variations in transmissivity within the Tertiary horizons are a result of the heterogeneous deposition.

Hamersley Group

The MMF forms an integral component of present-day groundwater throughflow and storage across the full strike length of the Chichester Range that is targeted for mining (including Christmas Creek deposits). It represents a semi-continuous aquifer of low to high transmissivity and contains fresh to brackish groundwater. Groundwater flow is in a south-south-westerly direction towards the Fortescue Valley. The MMF can be divided into two main hydrogeological units; an upper mineralised unit and a lower unmineralised unit.

The upper MMF (including hardcap zone) is characterised by high permeability and storage, which has been enhanced by the same secondary geochemical weathering processes that created the mineralisation. Areas of lower permeability are associated with lesser secondary supergene alteration (and less mineralisation), and increased thickness of interbedded shales. The high permeability aquifer zone is elongated along the east-west strike of the Nammuldi Member, however it becomes disconnected where anticlinal features have been eroded by weathering and displaced along structural features. To the north the aquifer outcrops and becomes unsaturated. To the south the alteration and associated permeability (and mineralisation) diminishes. As such, the high permeability of the upper MMF is not necessarily in direct connection with the highly permeable Oakover Formation. This aquifer is characteristically underlain by a shale band which creates a level of hydraulic disconnection from underlying aquifers.

The lower MMF consists of laminated BIF and ferruginous chert. This part of the MMF is largely unaltered geochemically. The permeability of this unit is enhanced along fracture zones and frequently at the contact zone with the underlying Roy Hill Shale.

Where sub-cropping and partially saturated, the mineralised MMF is unconfined. The mineralised MMF becomes partially confined to the south as the thickness of Tertiary sequence thickens and changes facies.

Abstraction (from fracture zones) in the lower MMF typically respond like a confined aquifer, perhaps due to its laminar form and the shale horizon separating the upper MMF from the lower MMF. Storage is considered to be low and limited to discrete fracture zones.

The Wittenoom Formation (WF), which stratigraphically overlies the MMF, is thought to form the bedrock below the Tertiary sequence in the Fortescue Valley. Lithological logging of the Wittenoom Dolomite below the valley plain indicates that where fresh, it is crystalline and of massive nature and has poor intergranular porosity and permeability. Secondary permeability associated with faulting may be developed locally. Weathering has resulted in a clay-dominated zone with low permeability forming the upper profile of the Wittenoom Dolomite.

Fortescue Group

The Jeerinah Formation (JF) conformably underlies the MMF. The Roy Hill Shale (RHS) is the upper most unit of the JF. The RHS generally has low permeability, although some zones of relatively enhanced hydraulic conductivities associated with fracturing and weathering are present. Additionally, a number of stratigraphic horizons within the RHS (located north of the MMF outcrop) have been found to have moderate hydraulic conductivities and are capable of low to moderate yields. These permeable zones are typically associated with chert dominated lithologies.

Table 4: Summary of Geological and Hydro-Stratigraphic Framework

Geological & Hydro-stratigraphy	Description	Hydrogeological Unit	Hydrogeological Characteristics/ Classification[6]
TD3	Colluvial and alluvial sediments, ranging from proximal cobble to pebble, alluvial/colluvial fans to distal silty and clayey valley fills and playa deposits. Basal layers can have well-rounded hematite and maghemite pisoliths.	Immature Upper – proximal facies	Partially saturated, poorly sorted deposits ranging from silt to cobbles, may have moderate permeability where proximal deposits are saturated, though not laterally extensive below the watertable.
		Immature Upper – distal facies	Increasing fines content, generally low permeability.
		Mature Lower – proximal facies	Mainly consists of moderately well sorted pisoliths with high storage and moderate permeability.
		Mature Lower – distal facies	Distal deposits are increasingly rich in fines with low permeability, forms semi-confining aquitard.
TD2	Fluvial and lacustrine sediments dominated by bleached and mottled clays and micritic limestones (including the Oakover Formation). Includes CID (4) deposits in	Generally unconsolidated clays, silts and minor sandy gravely layers, semi continuous distribution.	Alluvial and lacustrine sediments present in broader Fortescue Valley. Generally low permeability. Semi-continuous and semi-confining layers, leaky.
		Oakover Formation Aquifer – Vuggy to cavernous. Semi-continuous distribution in discrete palaeochannels and broader Fortescue Valley.	Zones of re-precipitated calcium carbonate and silica. Can be very vuggy creating zones of high permeability. May be present in laterally constrained settings overlying CID and also as more continuous sheets in the broader Fortescue Valley. Presumably semi-confined by overlying clays and silts.

[6] Note: Many of the formations described here have layering at various scales and can be expected to demonstrate strongly anisotropic permeability, with vertical permeability lower than horizontal permeability.

Geological & Hydro-stratigraphy	Description	Hydrogeological Unit	Hydrogeological Characteristics/ Classification[6]
	constrained palaeovalleys.	CID	Locally developed deposits, laterally constrained to channels incised into MMF, generally represents zones of high permeability.
Wittenoom Dolomite	Crystalline dolomite	WD	Generally massive, localised permeability associated with fault zones. Upper zone generally weathered and clay-dominant. Only present beneath south of the mineralised MMF
Nummuldi Member (MMF)	Nummuldi Member: Cherty BIF shale and ferruginous chert, intrusive hypogene hematite deposits and post-depositional supergene geochemical alteration and iron enrichment zones.	Hardcap - Physical and chemical weathering product of MMF. Abundant large solution cavities.	Noticeably vuggy and porous, high porosity and permeability. Generally thin and discontinuous unit. Generally in good connection with MMF.
		MMF – Hypogene Hematite zones; massive, friable, foliated, intrusion and precipitation of iron rich fluids along fault zones.	Interpreted to have high porosity (micro-scale), but tends to have low to moderate permeability.
		MMF upper (supergene mineralisation) – Goethite, martite and hematite zones; secondary alteration and mineralisation. Complex overprinting of primary deposits by secondary physical and geochemical processes.	Geochemical alteration (iron mineralogy transformations) resulting in iron enrichment zone, related to hydration and dehydration. Enhanced 'secondary' porosity and moderate to high permeability. Very high permeability zones generally only semi-continuous.
		MMF upper (supergene mineralisation) and shale – as above with significant shale units.	As above, transmissivity reduced by presence of shale units.
		MMF upper (non-mineralised) – cherty BIF and shales.	Stratigraphic sequence is dominated by shales, limited physical deformation and geochemical alteration; generally low permeability.

Geological & Hydro-stratigraphy	Description	Hydrogeological Unit	Hydrogeological Characteristics/ Classification[6]
		MMF lower (non-mineralised) – ferruginous chert and faulting. Primary unmineralised chert and iron formation.	Bedded chert and iron formation, generally low storage and moderate to high permeability related to regional scale fracture systems.
		MMF lower (non-mineralised) – Ferruginous chert and no faulting.	Bedded chert and iron formation, generally very low storage and low permeability with only local scale fractures.
Roy Hill Shale (Jeerinah Formation)		Upper Weathered Roy Hill Shale/ transition zone.	Can have moderate permeability.
		Lower, fresh Roy Hill Shale.	Thick unit with generally low permeability. Can have enhanced permeability zones associated with cross cutting fractures and cherty interbeds.

3.6.2 Hydrostratigraphic Connectivity

For the current study the aquifer connectivity between several hydro-stratigraphic units is considered of particular importance. The significance and interpreted nature of the connectivity between these units is described below:

- TD2 (Oakover Formation) and MMF hydro-stratigraphic units
- TD3 and MMF hydro-stratigraphic units
- TD2 and TD3 hydro-stratigraphic units
- Lower and Upper MMF (Mineralised MMF)

Due to the relatively high permeability of the mineralised MMF and the Oakover Formation, direct connectivity between these two units potentially forms a pathway linking hypersaline water in the valley basin and the fresh water aquifer system located along the flank of the Chichester Ranges. Investigations to date have found no direct hydraulic connection between the TD2 and the MMF.

The hydraulic connection between the TD3 units and the MMF is significant to the project because the TD3 units, whilst generally having lower permeability do have significant groundwater storage properties. Leakage from the TD3 units increases the sustainability of the fresh water resource in the project area by limiting the extent of drawdown associated with abstraction from the MMF and therefore reducing saline water intrusion. The ability for leakage indicates that the overburden can be dewatered by indirect abstraction from the MMF.

In general, hydraulic connection is likely to be well developed where proximal TD3 facies overly the MMF and less well developed where distal TD3 facies overly the MMF. Vertical leakage between the TD3 units and the MMF has been observed to occur in the project area, illustrating that direct abstraction from the MMF induces drawdown in the overlying TD3 unit.

TD2 valley-fill sediments are likely to inter-finger with TD3 distal sediments, however, due to the generally low permeability of the TD3 distal facies sediments, transmissivity between these units is likely to be low. TD2 closed channel sediments may have good hydraulic connection with more permeable TD3 proximal facies sediments and provide a pathway for saline water migration.

The level of hydraulic connection between the Upper MMF (mineralised MMF) and fractured Lower MMF is important with regards to geotechnical issues whilst mining and the potential for up-welling of saline water. Data from the current operation indicate that solute migration is mainly observed within fracture zones of the lower MMF (section 4.4.2).

3.6.3 Hydraulic properties

Step-rate tests and constant-rate tests have been performed for most bores installed at Cloudbreak. Test durations typically range between 12 and 48 hours depending on data requirements. In some cases test durations are shorter, such as in the saline aquifer where yields are high and storage capacity is relatively low (as discharge must be contained on the drill site). A summary of aquifer testing results are presented in Table 5. These results and other less quantitative information are discussed below.

Tertiary Detritals

Aquifer testing focused specifically on the TD3 sequence is limited, however observations of lithology and yield are routinely made. As described previously the TD3 sequence is typically clay rich, though localised zones of well sorted pisolites do occur. This is reflected in observation of low yield and the results of hydraulic tests which have indicated that aquifer transmissivity and hydraulic conductivity is in the order of 100 m^2/day and 4 m/day respectively. Aquifer responses are unconfined.

With regards to the TD2 sequence, a significant number of bores have been constructed specifically targeting the Oakover Formation. Test durations were constrained to between 3 and 12 hours due to limited disposal capacity (storage pond capacity). Aquifer response is generally typical of a confined aquifer, which is consistent with the observed stratigraphy in this domain. With some exceptions, all the tested saline bores intersected aquifer zones with very high yields. The average transmissivity and hydraulic conductivity were in the order of 6000 m^2/day and 300 m/day respectively. Measurements of aquifer (bulk) specific storage are considered less accurate but are typically in the range of 10^{-2} to 10^{-4}.

Marra Mamba Formation

Numerous bores have been installed across a strike of approximately 50 km of the MMF, primarily in mineral resource areas. Dewatering bores are typically screened across the Tertiary Detritals, upper MMF (mineralised zone) and part of the lower MMF. Yields are generally moderate to high and dominantly from the upper MMF. Yields can be high from the lower MMF associated with compartmentalised fracture zones.

Test durations have typically been between 12 and 48 hours with some tests up to ten days. Aquifer responses have typically been leaky and have ranged from unconfined to confined. Transmissivity of the aquifer is typically high, with the average transmissivity and hydraulic conductivity in many areas exceeding 1,000 m^2/day and 100 m/day respectively. Measurements of aquifer (bulk) specific storage are considered less accurate but are usually in the order of 10^{-3}.

Jeerinah Formation

Water exploration in the Jeerinah Formation, in areas to the north of the Cloudbreak resource area has historically taken place for water supply purposes. While these records are not well documented, the information suggests that yields are very low across significant parts of this formation. Anecdotal information suggests numerous ‘dry’ holes were drilled in this region. Moderate yields (2 to 8 L/s) are associated with constrained fracture zones which have been visually identified from aerial photography.

Table 5: Summary of test pumping analysis for Cloudbreak

Aquifer	Area	B[7] (m)	K[8]		T[9]		S[10]		Number of bores tested	Test Duration Range (mins)	Source
			Range (m/d)	Average (m/d)	Range (m^2/d)	Average (m^2/d)	Range	Average			
Marra Mamba Formation	Hillside West	2 to 40	2 to 1055	140	70 to 20000	3115	6.2e-04 to 1.8e-01	4.53e-02	37	360 to 2880	FMGL, 2008b; FMGL, 2010a
	Hillside East	12 to 48	2 to 214	37	33 to 8145	1101	1.2e-04 to 5e-04	6.52e-2	22	90 to 2880	FMGL, 2010i
	Brampton	10 to 36	2 to 770	100	14 to 10500	1887	2.4E-04 to 8.9E-02	8.66e-03	50	60 to 2880	FMGL, 2008c ; FMGL, 2009b ; FMGL, 2010b
	Hook Pit	11 to 36	2 to 333	39	7 to 5988	652	1.48E-10 to 8E-2	6.1E-3	60	150 to 14400	FMGL, 2008a ; FMGL, 2009b ; FMGL, 2009f ; FMGL, 2010j ;
	Hayman Pit	8 to 28	4 to 113	29	7 to 2767	428	7.9e-07 to 6.3e-03	2.5e-03	26	360 to 1440	FMGL, 2008a ; FMGL, 2008c ; FMGL, 2009b ; FMGL, 2009f ; FMGL, 2010a ; FMGL, 2010k
	Hamilton	9 to 26	2 to 38	10	11 to 875	138	-	3.85e-05	25	720 to 2880	FMGL, 2010
	Gnarloo Pit (Long Pit)	9 to 36	2 to 500	130	30 to 10000	2760	1.4E-4 to 4.2E-1	3.45E-2	37	180 to 2880	FMGL, 2009b ; FMGL, 2009f
Tertiary Detritals (TD3)	Regional	5 to 20	0.2 to 8	4	1 to 210	130	-	-	3	1440	Aquaterra, 2005, FMGL, 2010l
Oakover Formation (TD2)	Saline reinjection area	8 to 48	81 to 1333	380	2480 to 20000	6805	1.7e-4 to 8.0e-2	2.11e-4	20	120 to 720	FMGL, 2010g ; FMGL, 2010h ; FMGL, 2008f ; FMGL, 2008b ;

[7] Aquifer thickness
[8] Hydraulic Conductivity
[9] Transmissivity
[10] Storativity, only calculated where appropriate monitoring bore is available for the test.

3.6.4 Groundwater Levels and Topographic Driven Flow

Most groundwater systems are driven by a component of rainfall infiltrating the soil profile and reaching the watertable. Water flows from higher-elevation recharge areas, of higher hydraulic head to lower-elevation discharge areas of lower hydraulic head. This type of flow regime is often referred to as a topographic-driven flow system. This section describes topographic driven groundwater flow dynamics in the project area.

Chichester Ranges Area

In a regional sense, groundwater movement within the shallow groundwater system is driven by episodic rainfall infiltration on the elevated flanks of the Fortescue Valley and surrounding plateau. The high hydraulic head in this part of the system drives groundwater movement towards the valley, to areas of lower hydraulic head. The regional groundwater levels within the phreatic aquifer, measured in December 2007 are presented in Figure 6. The general recharge component is estimated to be about three percent of rainfall but this will vary depending on the intensity and duration of the rainfall events and season. Water level trends for a number of sites in the project area are presented in Appendix B and Figure 7. Rainfall recorded at both Newman and Cloudbreak are presented graphically also. Though the time period for these records is relatively short and some of the records are influenced by operational activities (commenced in mid 2008), trends are evidently related to natural hydrological patterns which can indicate the scale of variability under natural conditions.

Water levels recorded at sites at some distance from the Marsh (>1 km) have generally displayed a linear recession trend since early 2006 (CBX06, CCF02, CCF07, SCX03, SCX06), resulting in a decline of between 1.5 to 2m, which is interpreted to be in response to prolonged low rainfall conditions.

Fortescue Marsh and Fringing Area

Significant rainfall events result in large volumes of water ponding on the Fortescue Marsh (see section 3.4.1). This water recharges the shallow groundwater system (see section 3.6.5) and can result in localised and temporal reversal of the shallow groundwater gradient.

The groundwater elevation for a number of bores in the area near the Marsh, including records for two University of Western Australia Research sites, which are located within the Marsh are presented in Appendix B. The location of these sites is shown in Figure 7, which also shows the region of the Marsh over which ponding occurred following a significant rainfall event in late February 2009 (taken from Landsat Imagery). The data records for these sites typically range from late 2006 to present.

The first part of the data record for all sites typically displays a declining water level trend. When viewed in the context of recent rainfall records and Marsh flooding (Section 3.4.1) it is likely that this groundwater level recession is subsequent to a significant rainfall and flooding of the Marsh between January and March 2006, in which period approximately 380 mm of rainfall was recorded at Newman. The water level recession is punctuated by a small water level rise in relation to rainfall (130mm) between March and April 2007. Ponding on the Marsh was observed to occur in relation to this event. Notably, water level rise is only observed in bores located adjacent to the Marsh.

Although water levels were not recorded at the time of the 2006 flooding event, back-extrapolating the water level back to early 2006, it is probable that water level change between the 2006 and 2007 events was in the order of 1m in areas adjacent to the Marsh.

From 2007, water levels decline over the subsequent two years to early 2009. Adjacent to the Marsh this equates to water level decline of approximately 0.5 m, in addition to the 1m decline recorded between 2006 and 2007. Interestingly, a similar amount of rain fell in early 2008 as did in early 2007, however the rainfall did not result in significant ponding on the Marsh and no noticeable water level rise.

Water levels adjacent to the Marsh responded to rainfall in early 2009. The rainfall event was of high intensity (105 mm in one day) and resulted in significant ponding on the Marsh. This ponding event was recorded at two research sites within the margin of the Marsh (see Appendix B). The western most site (Site B) recorded ponding of approximately 0.5 m above ground level (406.8 mAHD) and eastern most site (Site A) recorded ponding of approximately 0.2 m above ground level (405.8 mAHD). The ponding in this region of the Marsh is localised and appears related to discharge from catchments in the Chichester ranges. Water level rise adjacent to the Marsh was in the order of 0.5m and similarly to the water level rise in 2007 was not noticeable further away from the Marsh. No significant rainfall events have occurred since early 2009 and water levels have been subsequently declining to where they are approximately 0.2 m below the rise in early 2009.

In summary, since early 2006 it is estimated that water levels adjacent to the Marsh have declined under natural hydrological conditions by between 1.5 and 2m. Annual watertable fluctuations can vary by up to approximately 1m. The data indicates that years which experience average rainfall conditions (2007 and 2009) can result in water level recovery in the order of 0.5 m adjacent to the Marsh, however the development of ponding on the Marsh related to high intensity rainfall is an important factor. Years with above average rainfall can result in water level rise in the order of 1m across a much broader region. Water level rise related to these events may be greater if the water levels prior to an above average rainfall season are low. Conversely, water level fall of up to a meter can occur annually. The annual rate of decline diminishes with increasing depth to watertable.

3.6.5 Groundwater Salinity and Density Driven Flow

Groundwater salinity plays an important role both in driving the groundwater flow dynamics in the lower topographic levels within the valley and in determining strategies adopted for dewatering, water supply and water disposal.

Groundwater Salinity

Groundwater in the Cloudbreak region typically ranges in salinity from marginal (> 500 milligrams per litre [mg/L] Total Dissolved Solids [TDS]) in upslope recharge areas to hyper-saline beneath the Fortescue Marsh and some fracture zones below the mineralised Marra Mamba Formation (>50,000 mg/L TDS). The groundwater salinity (measured as TDS [mg/L]) within the Upper Tertiary Detritals is shown in Figure 8, within the Oakover Formation and Upper MMF is shown in Figure 9; and within the Wittenoom Dolomite (Upper) and Lower MMF is shown in Figure 10. Salinity can be seen to increases with proximity to the Marsh and with depth.

The groundwater salinity distribution in vertical profile between the Chichester ranges and the Fortescue Marsh is illustrated in Figures 11 to 13. Within hydrogeological units, stratification is generally gradual. Between stratigraphic units the stratification can be very sharp. In the southern extents of the resource area, the salinity can increase sharply between the upper MMF and the lower MMF over one to two orders of magnitude.

Hydrochemistry

The composition of 135 groundwater samples have been plotted on a Piper diagram (Figure 14) for classification of water types (Frankcombe, 2010). It illustrates two dominant water types and a definite mixing trend. The majority of waters plot in the high Na-Cl-SO4 window with variability between end members, resulting in two predominant types:

- Na-Cl-SO4
- Na-Cl

The Na-Cl and Na-Cl-SO4 typically correlate with the higher salinity groundwater located proximal to the Fortescue Marsh or at greater depth. The influence of the density driven saline groundwater system is evident at distance from the Marsh with almost all groundwater signatures from the Tertiary sequence and upper MMF closer to the Chichester Ranges displaying elevated proportions of Cl-SO4. At further distances from the Marsh into the Chichester Ranges catchment, the water type in the Roy Hill Shale member is noted as Ca-Mg-Na-K.

Geophysical Assessment of Groundwater Salinity

The spatial distribution of groundwater salinity was further investigated via a SkyTEM airborne conductivity survey. The SkyTEM survey involved flying over 1500 line kilometres of data, covering an area of about 80 kilometres by 10 kilometres. SkyTEM is a helicopter-mounted, time domain electromagnetic (TDEM) system, where a dual TDEM moment, 24 metre wide (311 m2) electromagnetic loop is towed at a nominal 30 metre terrain height along regularly-spaced grid lines. The SkyTEM survey was conducted by Geoforce Pty Ltd over an eight-day field program in September 2009. The surveyed area extended from the marsh boundary in the south to the northern limit of saturated ore, from Christmas Creek in the east to Cloudbreak in the west.

Data-inversion was carried out using the Laterally-Constrained Inversion (LCI) method, whereby field data were filtered and then modeled against a subsurface layer structure constrained laterally on a number of chosen model parameters (including layer conductivity and layer thickness). The 3D inversion data were displayed as slices through specific hydrogeological surfaces, including five metres below the watertable surface (Figure 15) and along the top of the ore zone (Figure 16).

These data have assisted in mapping the position of the salt interface and in determining:

- The heterogeneity of the salt interface, with saline zones often aligned with structural lineaments and other preferential flow paths;
- The surface drainage and brackish groundwater flow patterns via inverse conductivity (resistivity) data;
- That saline zones beneath the ore zone may be disconnected from principal flow mechanisms (‘fossil’ groundwater); and
- That the extremely high electrical conductivity of saline aquifer zones at Christmas Creek is such that saline strata may mask the responses from deeper hydrogeological units.

Density-Driven Flow

Studies of similar ‘closed basin’ settings (for which the Fortescue Valley is analogous) have observed density driven flow systems occurring beneath the basin surface (Fan et al, 1996; Holzbecher, 2004; Thornton and Wilson, 2007). The mechanism that drives these flow systems is referred to as free convection. Free convection occurs when a denser fluid is placed on top of a less dense fluid. The former may sink and displace the latter in order to achieve stability. This type of flow is driven by the density gradient in a fluid (Fan et al, 1996). The free convection system is initiated by evaporation of shallow groundwater and water that has ponded in the basin. Evaporation leads to concentration of the groundwater and the increasing density of the fluid causes it to migrate downward,

in time, reaching the bottom of the aquifer (or a partially confining bed). The lateral density gradient then induces lateral flow of the saline water, which encounters and mixes with the fresh water. Mixing causes diffusion dilution of the saline water, which decreases its density and causes it to flow upwards and return to the valley surface. This zone of interaction is referred to as the transition zone. The shape, size and positioning of the wedge are controlled by a number of factors including the magnitude of the density contrast, the hydraulic and dispersive properties of the aquifer, stratigraphy, structures, the groundwater head in the freshwater regime.

Hydraulic head measurements in variable density groundwater environments can be corrected for density to allow interpretation of horizontal and vertical flow patterns (Post et al, 2007). Figure 17 presents the interpreted corrected head distribution for observed heads within the MMF, which illustrates that density driven convective flow beneath the Marsh results in lateral flow adjacent to the Marsh in deeper aquifers.

The density contrast between saline groundwater and fresh groundwater leads to a wedge-shaped transitional zone beneath the fresh groundwater in the aquifers flanking the Chichester Range. Within the MMF, the saline transition zone has been recorded to be in direct hydraulic connection with fresh water. The saline interface may move seasonally due to changes in recharge. Limited intrusion of saline water into the TD3 sediments is mainly due to the significantly lower permeability of these sediments (compared with underlying TD2 and Marra Mamba Formation).

3.6.6 Recharge

Aquifers within the Tertiary Detritals and MMF are recharged via rainfall infiltration. With regards to the Upper MMF aquifer, direct rainfall recharge occurs in areas of outcrop, indirect recharge occurs via leakage from overlying Tertiary aquifers and throughflow from the RHS (the RHS is recharged by rainfall in the Chichester Ranges catchment). Recharge via the direct rainfall recharge method is expected to be low reflecting the generally low rainfall of the region (see Section 3.3).

Recharge is expected to be enhanced in outcrop and subcrop zones near (and south of) the Chichester Range’s break of slope, where the Chichester Range’s hilly zones transition to alluvial fan systems extending to the Fortescue Marsh. These zones break-of-slope regions include outcrop/subcrop with drainage-incisions such that there is direct connection between surface water permeable lithologies.

The Fortescue Marsh is alternately an important recharge or discharge mechanism for the Tertiary sequence beneath and adjacent to the Marsh (see Section 3.6.3). Seasonal rainfall runoff from the catchment can result in large volumes of water accumulating on the Marsh. Ponding can range from formation of localised ponds at the discharge points of the main catchments to whole scale inundation of the Marsh depending on the scale of the rainfall/runoff event (see Section 3.4.2). Infiltration of water causes the shallow

watertable to rise and temporarily be represented by the pond surface. The elevated head of the shallow groundwater in the Marsh can create a localised reversal of the watertable gradient causing water to flow laterally away from the Marsh.

3.6.7 Discharge

The presence of hypersaline groundwater in aquifers beneath the Marsh means that topographic-driven groundwater flow in the shallow Tertiary aquifer system and MMF is likely to discharge towards the Fortescue Valley floor and be removed from the groundwater system evaporation and evapotranspiration processes. Discharge is expected to be at a limited rate due to the low permeability of the Tertiary Detritals (TD3) fringing the Marsh and through which groundwater must flow.

3.7 FLORA AND FAUNA

3.7.1 Flora

The vegetation was mapped across the entire northern edge of the Marsh and extending up the flanks of the Chichester Range. A total of 29 vegetation communities were delineated within this area, including 15 samphire flats communities associated with the Fortescue Marsh (Mattiske Consulting 2007). Based on inspection of the vegetation mapping boundaries, the most prevalent communities extending into the Marsh (in order of progression from the edge of the Marsh) include community types 13, 22 and 26.

The samphire vegetation types are locally restricted to the Marsh and unique in the central Pilbara region. The distribution of community types appears to be a function of site heterogeneity within the Marsh. Mattiske (2005) noted that "occurrence of these different communities on the fringes of the Marsh is largely controlled by the local site conditions and the seasonal inundation of some of the areas". A similar observation was made by Payne & Mitchell (1999) in the eastern portion of the Marsh, who found that "the saline flood plains (occupying a large proportion of the floodplain) included very scattered to moderately close shrublands of samphire often with distinct zonation of species". Factors suggested as contributing to the zonation patterns included flood heights, duration of flooding and soil salinity. More recently, the distribution patterns of major samphire species have been linked to site elevation by Barrett and Associates (2009) who observed that "communities dominated by Tecticornia auriculata occur at the lowest elevations, T. halocnemoides subsp. tennis and T. indica subsp. leiostachya occur at slightly higher elevations with T. indica subsp. bidens occurring at the higher elevations".

Outside the Marsh, other important vegetation types are discussed as follows:

- Acacia *aneura* (Mulga) is abundant in low open woodlands bordering the Marsh and extending up the flanks of the uplands. The Chichester Range marks the northern extent of this species. Mulga is characterised by having shallow root systems and a strong reliance on sheet flow to sustain its physiological moisture requirements;
- Open Woodland of *Eucalyptus victrix* and Eucalyptus *camaldulensis* occur in and around the creeklines entering the Marsh from the Chichester Range. These species are suspected to have at least a partial dependence on groundwater to meet their physiological moisture requirements. Eucalyptus *camaldulensis* in particular is recognised as having deep, aggressive root systems.

The Marsh is not recorded to contain any Declared Rare Flora (DRF) listed under the *Wildlife Conservation Act* 1950, or threatened plant species listed under the EPBC Act.

3.7.2 Fauna

Surveys conducted for earlier project approvals identified a range of species with conservation significance that occur, or have the potential to occur, in the vicinity of the Fortescue Marsh. Three species were identified as potentially having a special reliance on the habitat provided by the Marsh: namely the Night Parrot, Bilby and Australian Bustard.

The importance of the Fortescue Marsh in supporting large breeding populations of waterbirds in flood years is widely recognized.

Stygofauna species have been detected in the Cloudbreak project area; however, these species are non-unique to the area having a far wider occurrence (Bennelongia, 2007).

3.8 ABORIGINAL HERITAGE

There is a long history of Aboriginal occupation of land in the vicinity of the Fortescue Marsh. FMGL has detected a number of ethno-archaeological sites (mainly stone artefact scatters) in the course of exploration and mine development activities associated with the Chichester Operations. Aboriginal heritage surveys associated with the Cloudbreak mine commenced in late 2003.

During the Ethnosciences survey, two Yinta areas in the Cloudbreak project area at the Marsh were visited and were partially recorded as possible Aboriginal Sites under the Aboriginal Heritage Act 1972:

- Sandy Creek (Jitumpulpa)
- Goman's Creek/Pool (Nguwarna)

3.9 PASTORAL USE

Cloudbreak is located on Hillside and Mulga Downs pastoral leases. These pastoral stations operate beef cattle production enterprises. Station infrastructure is minimal but includes multiple stock watering points derived from shallow bores. The details of operational pastoral bores in the vicinity of the project area is summarised in Table 6. Future water requirements in terms of volumes and draw points are not expected to increase as the current supply is based on the stock numbers that the area can sustainably support, however further water sources have been made available by Fortescue at Cloudbreak and ongoing provision of this infrastructure will be as agreed between relevant parties.

Additionally, two pastoral bores; Mulga Bore and Cooks Bore are no longer in use having been subject to rising salinity levels. It is understood that the salinity levels in these bores

exceeded acceptable limits between 10 to 15 years ago, which has anecdotally been attributed to the upstream development of Opthalmia Dam.

Table 6: Operational Pastoral Bores

Bore Name	Pastoral Station	Location	Water Quality (TDS in mg/L)
Walla Bore	Mulga Downs	710020E; 7534549N	Unknown
Kardardarrie Bore	Mulga Downs	714520E; 7534070N	5,000 mg/L
Thieves Bore	Mulga Downs	722537E; 7534269N	2,500 mg/L
Moojari Bore	Mulga Downs	727900E; 7531200N	2,000 to 2,500 mg/L
Minga Well	Mulga Downs	733719E; 7529737N	1,100 to 1,700 mg/L
Outcamp Well	Hillside	760711E; 7521638N	Unknown
Mulinyury Bore	Hillside	756803E; 7522730N	Unknown

4. CURRENT OPERATIONAL OVERVIEW

Construction commenced at Cloudbreak in 2006 and the mine came into operation in mid 2008. This section gives an overview of the Cloudbreak water management strategy, water use and groundwater impacts to date.

4.1 CLOUDBREAK GROUNDWATER MANAGEMENT STRATEGY

The water management strategy employed for the project has been developed to meet the needs of the business, the environment and stakeholders. In most cases the components of the water management strategy address multiple needs. A key component of the strategy is Managed Aquifer Recharge (MAR), which involves returning excess groundwater directly to the groundwater system. Brackish and saline waters are segregated and returned to compatible aquifers, so that the brackish water resource is preserved for future use. A summary of the water management strategy is presented in Table 7 and illustrated in Figure 18.

Table 7: Cloudbreak Water Management Objectives and Strategies

Objectives	Water Management Strategies
Business • Prevent disruption to mining due to water • Conservation of groundwater resource • Cost-efficient operation ***Environment*** • Minimisation of impacts associated with discharge of excess water to environment • Minimisation of GDE impact due to operational groundwater level change • Prevention of aquifer contamination • Sustainable use of groundwater resource • Carbon-efficient construction and operation • Minimisation of clearing	***Planning*** • Inclusion of water management as a key parameter in a 'total' mine planning process. ***Hydrological*** • Aquifer injection as principal excess water management method. • Separate water management streams for brackish and saline water • 'Banking' of brackish groundwater for future recovery • Targeted injection of excess water to reduce drawdown footprint • Injection of saline groundwater into compatible saline quality aquifer(s). • Preservation of most surface and groundwater flow through the Operations to the Fortescue Marshes • Development of a structured

requirements • Minimisation of closure legacy ***Social*** • Minimal impact to cultural values • Minimal impacts to pastoralists • Minimal impact to other users	groundwater management (monitoring and response) system. ***Infrastructure*** • Optimal, efficient conveyance system. • Flexible water conveyance system enabling redistribution of water as • required to manage potential impacts ***Operation*** • Develop highly skilled workforce implement groundwater management system

4.2 SUMMARY OF GROUNDWATER USE AT CLOUDBREAK

Water use at Cloudbreak is summarised chronologically below and presented in Table 8.

- August 2006 – July 2008: Prior to mid 2008 groundwater was abstracted for construction purposes, largely dust suppression.
- August 2008 – July 2009: Dewatering commenced in mid 2008 and is reflected in the significant increase in abstraction to approximately 15 GL/a for the period. The Ore Processing Facility (OPF) came into operation at this time resulting in an increase in mine water consumption to approximately 1.7 GL/a. The primary disposal method for excess groundwater was injection into compatible aquifers. Approximately 7 GL/a was returned to the aquifer system by this method; however, approval restrictions prevented development of sufficient infrastructure to manage injection of all excess groundwater in this period. The remaining excess water (approximately 2.3 GL) was disposed of by approved surface discharge.
- August 2009 – July 2010: Dewatering requirements to support mine requirements for this period were predicted to be approximately 25 GL/a. Additional approval was sought and granted to increase the scale of the dewatering operation to this level, this also included approval to inject 20 GL/a. The approval enabled expansion of the injection infrastructure to meet the predicted requirement. In the period dewatering was approximately 24 GL, injection was approximately 19 GL; mine use was approximately 3.5 GL; and surface discharge was approximately 0.5 GL which occurred in the first two months during construction and commissioning.

At present, Cloudbreak currently operates a water management system that comprises approximately 70 dewatering bores (operational at any one time), 80 injection bores (in

both brackish and saline injection areas), 200 km of pipelines, multiple settlement dams, transfer ponds and supply points. The operational workforce consists of approximately 30 fulltime staff which can reach up to 70 personnel during periods of construction. The operational team is supported by a team of Perth-based water resource professionals and specialist groundwater modellers.

Table 8: Summary of Abstraction, Disposal and Mine Water Use

Annual Period	Abstraction	Injection	Surface discharge	Mine Use	
				OPF	Dust Suppression
Aug 06 - Jul 07	330,047	0	0	0	330,047
Aug 07 - Jul 08	769,730	13,409	0	36,935	719,386
Aug 08 - Jul 09	15,636,321	7,020,081	2,297,262	959,190	694,232
Aug 09 - Jul 10	23,112,689	18,600,281	567,355	2,387,442	1,172,787

4.3 SALINE INJECTION TRIAL

A saline injection trial was established at Cloudbreak to prepare the Chichester operations for full-scale saline water injection. The trial commenced on 17 October 2009 and is currently operated with an injection rate of 10 ML/d. The objectives of the trial have been to:

- Establish whether reinjection is a feasible management strategy for excess saline dewatering (proof of concept);
- Understand the fate of injected saline water and particularly whether it will impact naturally brackish aquifers;
- Refine best operating practices and infrastructure configuration for full-scale implementation;
- Develop the hydrogeological characterisation in the saline injection areas, where test-pumping is limited by discharge restrictions on saline water;
- Validate the numerical model in the saline injection area to improve confidence in numerical predictions; and
- Assess the potential for bore and aquifer clogging during saline injection.

The operation of the trial to date has been successful, with the following outcomes being achieved:

- Proof of concept has been achieved; in that it has been demonstrated that reinjection to the south of mining operations is a feasible management method for excess saline water.
- The environmental impacts of the trial have been consistent with those predicted. Vegetation monitoring has indicated that no degradation of vegetation health has occurred as a result of the trial.
- Injected saline water has not impacted the upper, fresher aquifers.
- The trial has enabled experience and expertise to be developed in operating complex telemetry systems.
- The hydrogeological characterisation of the saline injection area has been extended and the trial has provided a valuable validation dataset for the numerical model.
- The low clogging potential predicted by geochemical modelling has been confirmed by the trial. The indications to date are that the required redevelopment frequency may be similar to that of Cloudbreak's brackish injection bores, i.e. varying between two to twelve months.

The trial is ongoing, it is expected that further learning and operational experience will be gained prior to full scale operation.

4.4 GROUNDWATER IMPACTS

Groundwater monitoring and aquifer reviews are an important requirement and function of the Cloudbreak water management scheme. Key Indicators of groundwater impact, including water level and salinity change, have been recorded and reported on a regular basis (FMGL, 2010e; FMGL, 2010d; FMGL, 2010c; FMGL, 2009i; FMGL, 2009h; FMGL, 2009f; FMGL, 2009e; FMGL, 2009d; FMGL, 2007b; FMGL, 2009a) and are briefly summarised below.

4.4.1 Water level change

Dewatering and injection do influence groundwater levels by respectively lowering (drawdown) or raising (mounding) the water level. Drawdown and mounding are a measure of the operations impact on the groundwater system.

The change in the watertable from mid 2008 to August 2010 is presented in Figure 19. For the upper MMF and the Oakover Formation (to the south) this change is shown in Figure 20. The water level change due to natural water level fluctuations (see section 3.6.3) has been removed to enable focus on the impacts of the operation.

Drawdown in the range of 20 to 30 m has occurred in the immediate vicinity of active pits (Brampton, Hook, Hayman and Hamilton pits). At the perimeter of the Marsh, watertable drawdown has been negligible. Drawdown is relatively localised due to the compartmentalisation of high permeability in the Upper MMF (mineralised zone) and Oakover Formation, and the generally low permeability of Tertiary Detrital units.

Mounding of up to 4m has occurred in the Hillside West brackish injection borefield. No mounding associated with this borefield is observed at the perimeter of the Marsh.

4.4.2 Salinity change

Ingress of saline groundwater in response to dewatering has been observed in some parts of the groundwater system. Electrical conductivity (EC) measured from monitoring bores in the Brampton Pit area (bores are referenced on cross section in Figure 13) is presented in Figure 21. This data illustrates the migration of saline groundwater through different parts of the flow system and is discussed below.

This saline ingress has been most prominently observed in the lower MMF. Initial values of EC in this unit have typically been greater than overlying units by one to two orders of magnitude[11] and indicate that this unit is more connected to the hypersaline groundwater regime than overlying hydrogeological units. This unit is characterised by relatively high hydraulic conductivity in discrete fractures and low effective porosity. Under these conditions flow velocity may be high and likewise transport of solute could be rapid; however, the volume of water transmitted is considered low. Migration of saline water is observed underneath mining resource areas within this unit.

Within the upper MMF (mineralised zone) migration of saline groundwater is less apparent. The mineralised zone is generally compartmentalised from the saline groundwater system by intervening shale units and low permeability Tertiary units. Movement of saline water into this aquifer unit is generally via the lower MMF and the volume of saline groundwater moving into this unit is low. Coupled with the relatively high effective porosity of this unit, it is expected that salinity increases will be slower to develop. Increasing trends are observed at the southern perimeter of the mineralised zone (BRM03_S).

Migration of saline groundwater through the Tertiary Detritals appears to be very limited. The low hydraulic conductivity of this unit is an impediment to flow; therefore, it is expected that increasing salinity trends will be very slow to develop.

[11] EC records at HSMB10A_D and HSMB12_D between early October 2008 and late October 2009 have been artificially lowered due to adjacent injection of brackish groundwater.

5. CONCEPTUAL MODEL

Site specific data and relevant literature were detailed in Section 3 to develop a description of the hydrogeological framework and hydrological processes relevant to the project area. In this section, this understanding is consolidated in to a conceptual model and a quantified water balance is presented. Together these form the basis of the computer-based numerical model.

5.1 FORTESCUE MARSH

The flanks of the Chichester Ranges and the margins of the Fortescue Marsh have been the subject of extensive drilling and aquifer testing investigations. Whilst direct information on the lithological profile of the Fortescue Marsh is limited by restricted drilling access for FMGL and others, it is likely that the geology of the Marsh valley infill is broadly an extension of the geological units and structures occurring on the margin of the Marsh, with a higher proportion of low-energy fines in the upper sequence and possible evaporite deposits such as gypsite and halite. Tertiary detritals comprising silty and clayey playa deposits overlie calcrete of the Oakover Formation, with weathered and crystalline dolomite of the Wittenoom Formation at depth. See Section 3.5 for more information on these hydrostratigraphic units and Section 3.6.2 for more on their hydraulic relationships.

Additionally it is postulated that a unit of low permeability and/or high storage may occur within the upper two metres of the Marsh sediments. Supporting the presence of such a unit is the low response to rainfall in monitoring bores (see sites A2 and B2 in Appendix B), and observations of gypsite hardcap in the upper metre of the shallow UWA borings on the margin of the Marsh. This unit remains to be verified, but if present it would be hydraulically significant in limiting watertable recharge and perhaps directing recharge flows laterally.

Under the range of natural conditions the Fortescue Marsh may function as either a recharge, discharge, or static storage zone. Figure 22 demonstrates the flow regimes in each of these circumstances and Section 3.6.4 describes the observations of the rainfall, Marsh water levels and groundwater levels.

When ponding occurs on the Marsh during “Flood” conditions, recharge occurs to the watertable beneath the Marsh. Prolonged ponding is interpreted to fully saturate the aquifer beneath the surface expression of the ponds and create downward and lateral recharge flows. Density contrast between the fresh rain waters and the underlying evapo-concentrated aquifer may preferentially encourage lateral migration of recharge; alternatively dissolution of salts stored in the unsaturated soil profile may cause the density of recharge waters to equilibrate quite rapidly with underlying waters. The observable recharge influence of the Marsh is restricted to the watertable aquifer and within only approximately one kilometre of the Marsh margin sediments (see records in

Appendix B for bores shown in Figure 22 – February 2009 Marsh ponding event). Beyond this distance, even large recharge events do not observably influence water level heads.

The flow regime between ponding events on the Marsh is shown as “Interflood” in Figure 22 and represents the most common state of the Marsh. Periodic rainfall events that do not cause pond formation do not generate observable recharge in monitoring bores as noted above. Rainfall in these events is intercepted before the watertable by a combination of evaporation from the surface, soil storage (with associated soil moisture increase) and evapotranspiration from the unsaturated profile. Evaporation (and possibly transpiration) also occurs from the watertable, and as a result the Marsh functions as a net discharge zone in these conditions.

Following an extended period of low rainfall the Marsh may reach the state shown as “Prolonged dry” in Figure 22. In this state the watertable is lowered to the extinction depth for evaporation and discharge from the Marsh no longer occurs. The piezometric gradient between the Chichester recharge zones and the Marsh will gradually flatten and water levels distal from the Marsh will slowly decline toward the elevation of the Marsh evaporation extinction level.

It is expected that in all conditions the convection flow cell will be maintained by the density profile throughout the aquifer units.

5.2 CONCEPTUAL ELEMENTS AND APPROACH

Elements of the natural and anthropogenic environment discussed in preceding chapters which are to be represented in the numerical groundwater study are summarised in Table 9 and presented diagrammatically in Figure 23.

Table 9: Summary of Conceptual Model

Elements of conceptual model	Description
Model framework and hydraulic properties	
Domain	The model domain covers an area of approximately 3,100 km^2.
Hydrogeological Units	See Table 4
Hydraulic properties	See Table 5
Salinity	Groundwater salinity ranges between fresh (<500 mg/L) and hypersaline (150,000 mg/L)
Model Boundaries	*Northern boundary* – Though the MMF is truncated where it outcrops in the Chichester Ranges, this does not represent the northern boundary of the hydrogeological system. Groundwater occurrence within the Jeerinah Formation (Roy Hill Shale) is interpreted to be in connection with the MMF, though the through-flow is likely to be variable depending on cross cutting fracture development and weathering as shales typically have low hydraulic properties. As the through-flow from the Jeerinah Formation is considered important to the hydrogeological system, the northern boundary has been selected to represent a surface water and interpreted groundwater divide within the Jeerinah Formation. *Southern boundary* – The southern boundary is located to the south of the Fortescue Marsh, it is partly arbitrary but is considered to be outside the influence of the operation *Eastern boundary* – the eastern boundary is beyond the eastern extent of the operation, groundwater flow is considered to be parallel to this boundary. *Western boundary* – the western boundary is beyond the western extent of the operation, groundwater flow is considered to be parallel to this boundary. *Model base* – is at an arbitrary depth within generally impermeable formations . *Model top* – represents the watertable. *Solute Concentration Boundary* - Salt accumulates at shallow depth below the Marsh and saline water continues to

Elements of conceptual model	Description
	recharge the shallow aquifer system beneath the Fortescue Marsh.
Groundwater Recharge	
Catchment Recharge	Recharge due to infiltration of rainfall in the catchment area (excluding Fortescue Marsh) is estimated to range between 0.2 to 3% of rainfall. For the northern area of the domain this results in recharge of approximately 8 GL/a
Fortescue Marsh Flooding	Total runoff to the Marsh in response to significant rainfall (above 100mm recorded in one month) in the catchment can be in the order of 500 to 1000 GL. After a prolonged dry period in which water levels below the Marsh decline to 3m below the occurrence of a significant ponding event (over 600 km^2) could recharge the groundwater system by approximately 200 GL of water (based on a storage of 10%) Recharge related to flooding can be predicted based on correlation between observed flooding and rainfall records. Both subsurface recharge and surface water are considered in the water balance.
Groundwater Discharge	
Evaporation and evapotranspiration	Evaporation and evapotranspiration principally occur in the Marsh area, where the depth to watertable is shallowest. Potential evapotranspiration rates in the region are as high as 3,000mm/year though 75% of this rate is commonly adopted and is expected to exponentially decline as depth to watertable increases (to a maximum depth of 3 meters). When the marsh is not in flood the loss from the system through evaporation and evapotranspiration is expected to be equivalent to the catchment recharge (approximately 8 GL/a). When the Marsh is in flood and water levels are elevated beneath the Marsh evapotranspiration will be greater.
Groundwater Flow	
Hydraulic gradient and throughflow (topographic-driven flow)	Groundwater flow through the aquifer system is considered to be equivalent to recharge in the upper (non-Marsh) catchment. Groundwater flow is low, being constrained by the presence of dense water beneath the Marsh, which forces fresher water flowing towards the Marsh to flow upwards through relatively low permeability sediments towards the Marsh through the upper layer which consists of relatively low permeable sediments

Elements of conceptual model	Description
Salinity and density gradient Density-driven flow)	High salinity water has a higher density than fresh water. The resulting density gradient has an important influence on groundwater flow. The density value at 150,000 mg/l is 1.117kg/l.
Anthropogenic	
Pastoral bores	Several pastoral bores and wells are located in the project area. The draw from these bores and wells is very low and drawn from the watertable.
Cloudbreak Dewatering	Mining pits are located at areas with mineralised MMF and dewatering is required to lower the watertable to target depths.
Cloudbreak Injection	Injection of brackish groundwater is laterally into MMF; injection of saline groundwater is to the south into the Oakover Formation
Christmas Creek Operation	Christmas Creek operation located to the east of Cloudbreak and some Water Management activities at Christmas Creek require consideration by Cloudbreak.

6. GROUNDWATER MODELLING ASSESSMENT

6.1 MODEL OBJECTIVES

The regional aquifer system in the Cloudbreak area has been simulated using a numerical groundwater flow and transport model. The model was constructed based on the conceptual model and by using available information and observational data.

The objective of this groundwater modelling study is to predict dewatering requirements of mine operations and the aquifer's response to mine dewatering (groundwater pumping) and water management plans (water injection).

6.2 NUMERICAL MODEL CONSTRUCTION

6.2.1 Numerical Model Complexity

Within the context of the Murray-Darling Basin Guidelines (Murray-Darling Basin Commission, 2000) the numerical model is considered to be of moderate complexity as an 'Impact Assessment' model. Within this approach, where understanding or data is lacking, it is possible to design the associated model aspects to be conservative with respect to their intended use.

6.2.2 Model Software and Code Settings

Based on the characteristics of the hydrogeological system described in Section 3.6, principally the density-driven flow, the modelling assessment was undertaken using FEFLOW software, version 5.412. FEFLOW has a 30-year history of development and is now owned by DHI-WASY, a division of the Danish Hydraulic Institute. The code uses the finite element method, which allows highly flexible discretisations of the model domain, and can simulate density-driven flow and transport (that is, with flow controlled by both hydraulic gradients [caused by differences in groundwater heads] and density gradients [caused by differences in salinity]).

The following general solver and code settings were adopted:

- The default iterative non-symmetrical equation solver 'preconditioned Lanczos-type BICGSTAPB' was used for all simulations;
- the default convergent form transport equations were adopted;
- the non-Fickian dispersion law was utilised;
- the non-Boussinesq equation was applied;
- fluid viscosity effects on conductivity were incorporated;

- the predictor – corrector automatic time stepping system utilising the Forward Adams-Bashford/backward trapezoid rule was applied;
- the default Euclidean L2 intergral Root Mean Square (RMS) error norm with a convergence criteria of 0.001; and
- no 'upwinding' techniques (Galerkin FEM option) were applied to dampen solution error.

6.2.3 Numerical Mesh and Numerical Layers Design

The model domain is approximately 65 km long in the East/West direction and 42 km wide in the South/North direction. The domain covers an area of 3140 km^2 between the Chichester Ranges and the Fortescue Valley Floor (Figure 24).

The model consists of eleven numerical layers, largely consistent with the hydro-stratigraphy. However, each layer may contain more than one geological formation. The hydro-stratigraphy/layer relationship developed for the model is outlined in Table 10 and presented in Figure 25. The unspecified layer condition allows the layer to be treated as confined or unconfined depending on the relationship between the slice elevation and the associated head. The elevation details of specific layers are presented in Appendix C.

Table 10: Model Layering and Hydro-Stratigraphic Relationship

Layer (from top)	Hydro-stratigraphy	FEFLOW Layer Setting
1	TD3 – Upper and artificial hollow domain[12]	Free and movable
2	TD3 – Upper	Unspecified
3 and 4	TD3 – Lower	Unspecified
5 and 6	TD2 (Oakover) and TD3 Lower	Unspecified
7	Wittenoom Dolomite and Hardcap	Unspecified
8 and 9	Mineralised MMF, un-mineralised MMF, and	Unspecified
10	MMF (Lower)	Unspecified
11	Roy Hill Shale	Unspecified

[12] The middle part (covering the Fortescue Marsh and its surrounding low elevation areas, bounded in the vertical direction by the ground surface and the elevation of 410 m) of the top numerical layer is filled with artificial material that has porosity of 1 and conductivity of 1000 m/day. This part of model domain was used to simulate surface water flooding over the Marsh.

Each numerical layer was divided into about 560,000 triangles. The average elemental area is about 5600 m^2 (the side length of an average triangle is about 105 m). However, the numerical mesh is not uniform. It is denser inside and around the designed mining pits (about 100 m in the side length of triangles), in the transient zone between the salt water brackish water and along the Weeli-Wolli Creek (about 500 m in the side length of triangles) than in other regions (about 1000 m in the side length of triangles). In addition, the density of the numerical mesh was automatically increased around pumping/injection wells.

6.2.4 Model Parameters

Hydraulic properties

The groundwater flow equations utilised by FEFLOW require input of hydraulic parameters for the model domain. For density-coupled flow, the ratio of the maximum density to the 'ambient' density is required. A density ratio of 0.0912 has been applied to the model domain. For the various hydrogeological units, the hydraulic parameters defined in the conceptual model can be directly assigned in the FEFLOW pre-processor environment.

The hydraulic parameters assigned to the numerical model were optimised during model calibrations as detailed in Table 11. Hydraulic properties for individual layers can be found in Appendix D. The mineralised MMF has a spatially variable hydraulic parameter distribution that has been determined by extensive aquifer testing.

Table 11: Hydraulic Parameterisation of Numerical Model

Hydrogeological Unit	Layer	K[1] (x & y direction)	K (z direction)	Sy[2]	Ss[3]
TD3 Upper	1 & 2	0.6	0.08	0.1	5e-4
TD3 Upper: High K Zone	2	6	0.8	0.1	5e-4
TD3 Lower	3 to 7	1.7	0.08	0.1	5e-4
TD2 – Oakover Formation	5 & 6	302	8.6	0.05	5e-5
Wittenoom Dolomite	7	3.0	0.2	0.025	1e-5
Mineralised MMF Upper	8 & 9	6.5 -259	0.015 – 0.02	0.015-0.075	5e-4

[1] Hydraulic conductivity (m/d)
[2] Specific yield
[3] Specific Storage

Hydrogeological Unit	Layer	K[1] (x & y direction)	K (z direction)	Sy[2]	Ss[3]
Un-mineralised MMF Upper & Lower MMF	8 to 10	4.3	0.09	0.005	1e-5
RHS	11	0.02	0.02	0.002	1e-5

Mass transport properties

Whereas classical groundwater flow modelling solves a water balance equation, ensuring that any change in storage is balanced by the difference between inflows and outflows to a particular region, solute transport modelling solves a solute balance equation, whereby the change in mass of solute in any region is balanced by the difference between mass input and output to that region.

The transport of mass occurs in two ways, by advection and hydrodynamic dispersion (Bear, 1972). Advection is the process by which a volume of water is transported through the ground, carrying with it its own concentration of solutes (dissolved mass). Hydrodynamic dispersion consists of diffusion and mechanical dispersion. Diffusion is a process whereby spatial variations in concentration lead to movement of solutes, even when the water itself is motionless. Simultaneously occurring with advection and diffusion is mechanical dispersion, which is due to spatial variations in velocity at various scales caused by the tortuosity of porous media and heterogeneity of hydraulic conductivity. Hydrodynamic dispersion is quantitatively described using the dispersion coefficient. The dispersion coefficient is a complex tensor. In practice, it is simply represented by the longitudinal and transverse dispersivities. It is well known that dispersivities are scale dependent (Gelhar, 2003). Dissolved salts at low concentrations have little effect on flow processes. However, it has been shown that a concentration difference as small as several thousand mg/L may cause enough density effect that significantly affects groundwater flow, especially in situations where hydraulic gradients are small. In the Cloudbreak area, hydraulic gradient is only 0.1 to 0.2% (head differences of 1 or 2 m over a horizontal distance of 10 km). In such circumstances, small density differences may cause groundwater flow due to the “natural convection”. Given that the salinity gradient is much larger than several thousand mg/L in the area, density driven flow would be the dominating process.

Solute transport and density driven flow have been included in the numerical model presented here. Key solute transport parameters are listed in Table 12.

Due to the high salinity of the solution, the non-linear dispersion law (non-Fickian law) has been applied, which has been shown to achieve a better agreement with

measurements than the linear dispersion law for problems involving high concentration solute transport (Diersch & Kolditz, 2002).

Table 12: Solute Transport Parameters

Parameter	Value
Reference concentration (Co)	0 mg/L
Maximum concentration (Cs)	150,000 mg/L
Density Ratio[13]	0.116
Molecular diffusion coefficient	10–9 m^2/s
Longitudinal dispersivity (□L)	500 m
Transverse dispersivity (□T)	50 m
Porosity	Sy (for purposes of computing velocities in the transport equation)

6.2.5 Boundary Conditions

The boundary conditions applied to the numerical model are summarised in Table 13.

Table 13: Model Boundary Conditions

Boundary Location	Applied to Slices	Numerical Boundary Description
Flow Boundaries		
North	All slices	No flow boundary located in impermeable Roy Hill Shale
South	All slices	Specified Head boundary located far away from the mining site
East	All slices	No flow boundary along groundwater flow direction
West	All slices	No flow boundary along groundwater flow direction
Bottom	Top slice	No flow boundary inside the impermeable layer of Roy Hill Shale
Top	Bottom slice	Free and movable watertable (or free water surface during ponding) with rainfall recharge and groundwater

[13] Is the difference between the density of water at highest salinity and lowest salinity, divided by the density of water at the lowest salinity.

Boundary Location	Applied to Slices	Numerical Boundary Description
		evapotranspiration
Solute Transport Boundaries		
Fortescue Marsh	All slices	Groundwater underneath the Fortescue Marsh is highly saline. A specified concentration of 150,000 mg/L was assigned to all numerical nodes inside the saline water body.
Other area	All outer boundaries not covered by the Marsh	Zero-flux boundary condition was applied due to that either no water or very low concentration water flows across these boundaries.

6.2.6 Model Stressors

Model stressors refer to those elements of the model that apply a stress and include recharge, evaporation, anthropogenic inputs and outputs. Application of these stressors typically involves defining rates of input or output, which can be defined as a constant rate or a time-varying sequence. Constraints can usually be applied also which limit input or output depending on some predefined constraint such as depth to watertable from surface. The stressor can be applied to a single node as in the case of a well function or an array of nodes such as for a recharge zone. Further details of numerical of stressors are provided below.

Catchment Recharge

Rainfall falling on the catchment that infiltrates to the watertable is referred to as catchment recharge. The model does not include unsaturated flow and therefore groundwater recharge is first calculated (based on rainfall) and applied direct to the watertable (top of the model). For steady state models recharge is based on a long term average and for transient models is time-varying on a weekly or monthly basis. Catchment recharge is zoned according to recharge potential of the geological materials. On the northern side of the Marsh individual recharge rates have been applied over the RHS, MMF and TD3 lithologies. These zones are presented in plan view in Appendix D.

Marsh Flooding

Marsh flooding refers to the flux of water applied to the model during flooding events. The flux includes water that recharges the unsaturated zone below the Marsh and the water stored above the Marsh surface in response to a flooding event. In the absence of stream flow gauging data for the Marsh flooding the correlation between rainfall and observed flooding has been analysed to understand the magnitude of rainfall required to cause flooding. In this way the

rainfall record can be used to predict and develop a record of Marsh flooding events. The amount of water flowing into the Marsh area through surface runoff was assumed to be proportional to rainfall rate and was determined through model calibration. The Marsh area was divided into three zones based on ground elevations, which directly relates to the occurrence of ponding. Zone 1, where ground elevations are below 405.5 m, receives highest flux. Zone 3, where ground elevations are above 406.0 m, receives lowest flux. The flux is in a range between the highest and the lowest over Zone 2, where ground elevations are between 405.5 and 406.0 m. These flux rates were determined through model calibrations. These zones are presented in plan view in Appendix D.

Evaporation and Evapotranspiration

Losses from the groundwater and surface water system due to evaporation and evapotranspiration were also assigned to the top of the model. It was assumed that evapotranspiration is only important over the Fortescue Marsh, where the watertable is shallow and ponding occurs. Evaporation was applied at 75% of average monthly pan evaporation rates when the water level is at or above the Fortescue Marsh land surface. Below the land surface, the evaporation rate declines exponentially (as described in Shah et al, 2007). At a depth of 1.5 m below the Fortescue Marsh elevation, zero evapotranspiration is applied.

Anthropogenic

Anthropogenic stressors include functions that represent dewatering and injection. These activities are represented in the model as either ‘well functions’ or specified head functions. Well functions closely represent bores and have an assigned rate of water in or out of the model. The rate can be fixed or time varying and applied to specific aquifers of the model. Specified head functions can also be used to replicate dewatering or injection. To replicate dewatering the specified head function is assigned a head that replicates the level to which dewatering is required and water is removed from the model at a rate based on flow from surrounding areas to that specified head.

6.3 STEADY-STATE MODEL CALIBRATION

6.3.1 Methodology

The model was initially calibrated by applying a set of steady state boundary conditions (representing recent history) to a transient model with a simulation time of 1000 years. This long term simulation modelled the evolution of an initially fresh aquifer system by applying a constant concentration boundary condition set at 150,000 mg/L at Fortescue Marsh. The actual historical evolution of the current salinity distribution is unknown; however, the process applied enables the derivation of a reasonable spatial distribution of salinity to be used as the initial condition for the transient calibration period. The steady state model represents the long-term groundwater flow state without considering Fortescue Marsh flooding events, which are highly dynamic and could not simulated in a state-steady model.

A manual calibration methodology was employed, whereby values of recharge, evapotranspiration and hydraulic properties were manually adjusted to minimise the discrepancy between observed and simulated groundwater levels.

The evaluation criteria for the model included:

- Residuals between observed and simulated groundwater levels at monitoring wells,
- Consistency between modelled water balance and estimated water balance in the model conceptualisation stage, and
- The agreement between simulated and observed salinity distribution in the model area.

A summary of the steady state model details and specific settings, including initial conditions, model stressors and calibration data sets is presented in Table 14.

Table 14: Steady State Calibration Settings, Inputs and Calibration Datasets

Item	Description
Model Settings	
Simulation duration	1000 years
Time steps	0.1 to 100 days
Maximum iterations	12
Convergence Criteria	0.001 m
Mesh and layering	As outlined in Section 6.2.3
Hydraulic properties	As outlined in Section 6.2.4
Boundary conditions	As outlined in Section 6.2.5

Item	Description
Stressors	
Catchment Recharge (non-Marsh)	0.2 to 5% of rainfall
Marsh flooding	No flux applied
Evapotranspiration	A uniform evapotranspiration rate over the whole Marsh was obtained through calibration
Groundwater pumping	none
Groundwater injection	none
Calibration datasets	
Water levels	Average pre-mining groundwater levels between 2006 and 2008
Salinity	Average observed salinity distribution between 2006 and 2008

6.3.2 Results

Simulated vs Observed Water Levels and Groundwater Salinity

The comparison between simulated and measured groundwater levels is shown in Figure 26. The residual between simulated and measured groundwater levels is in the range of -6.25 to to 9.05 m. The average absolute residual is 1.33 m. Scaled Root Mean Squared error of the calibration is 4.6%, which is smaller than the value of 5% recommended by the MDBC Groundwater Flow Modelling Guideline (MDBC, 2000).

Simulated steady-state watertable level contours are compared with measured groundwater levels in Appendix E. The contours show reasonable agreement through important areas of the domain.

Simulated steady-state salinity contours are compared with interpreted salinity contours for the Oakover Formation levels in Appendix E. Simulated groundwater salinity distribution is reasonably in agreement with measured groundwater salinity distribution at pre-mining conditions, which was generated from a limited number of observational bores.

Water Balance

The calibrated total groundwater recharge over the whole model domain is about 9 GL/a, of which 8.1 GL/a is from rainfall recharge and 0.9 GL/a is from Southern boundary inflow. Groundwater discharge is through evaporation over the Fortescue

Marsh and equals to the recharge. The model imbalance is about 0.0019 GL/a, which is only 0.02% of the total recharge.

Calibrated rainfall recharge and evapotranspiration rates are shown in Table 15.

Table 15: Calibrated Rainfall Recharge and Evapotranspiration Rates

Zone ID	Description	Rainfall Recharge Rate	
		m/day	% of Rainfall
1	Alluvial zone to the south of the Marsh	1.7e-5	1
2	Weeli-Wolli Creek zone	4.25e-5	5
3	Fortescue Marsh	-3.8e-5	Evapotranspiration
4	Southern exposed bedrock zone	3.4e-6	0.2
5	Alluvial zone to the north of the Marsh	8.49e-6	1
6	Northern exposed bedrock zone	3.4e-6	0.2
7	Exposed MMF zone	5.1e-5	3

6.4 TRANSIENT MODEL CALIBRATION

6.4.1 Methodology

Following steady state calibration, the model was calibrated to a time series of observations between 1997 and 2010. In addition to the natural stressors on the system, the calibration period included a period of significant anthropogenic influence in the form of the Cloudbreak water management operation (see Section 4.0).

As discussed previously (see Section 3.6 & 6.2.6), flooding and evaporation processes occurring in the Marsh represent large stressors in the model. Further explanation of the method of simulating flooding and evaporation in the Marsh area is presented as below:

Marsh flooding was applied only when monthly rainfall is over 100 mm. The flux applied to the Marsh was assumed to be proportional to rainfall rate. The Marsh area was divided into three zones based on ground elevations, which directly relates to the occurrence of ponding. Zone 1, where ground elevations are below 405.5 m, receives highest flux. Zone 3, where ground elevations are above 406.0 m, receives lowest flux. The flux is in a range between the highest and the lowest over Zone 2, where ground elevations are between 405.5 and 406.0 m. These flux rates were determined through model calibrations.

Model calibrations were conducted by varying key model parameters and boundary conditions. Key model parameters considered in model calibrations include conductivity of mineralised MMF and Oakover Formation, specific yield of mineralised MMF and specific storage of Oakover Formation. Calibrated important boundary conditions are recharge and evapotranspiration over the Fortescue Marsh, catchment rainfall recharge and salinity of groundwater underneath the Marsh.

The evaluation criteria for model performance included:

- Residuals between observed and simulated groundwater levels at monitoring wells as quantified by scaled RMS (Root Mean Squared) of residuals;
- The agreement between simulated and measured hydrographs (representing groundwater hydraulic dynamics at selected key locations (such as monitoring bores inside the Fortescue Marsh and on the Northern edge of the Marsh;
- Consistency between modelled water balance and estimated water balance in the model conceptualisation stage: and
- The agreement between simulated and observed salinity distribution in the model area.

A summary of the transient model details and settings specific settings, including initial conditions, model stressors and calibration data sets is presented in Table 16.

Table 16: Transient Calibration Settings, Inputs and Calibration Datasets

Item	Description
Model Settings	
Model Duration	From 01/01/1997 to 31/05/2010
Time steps	Automatically determined by FEFLOW with the maximum time step of 5 days
Maximum iterations	12
Convergence criteria	0.001 m
Initial Conditions	
Groundwater heads	From steady state model
Salinity distribution	From steady state model
Stressors	
Catchment Recharge (non-Marsh)	Based on monthly rainfall from 1997 – 2010 Measured data at the Newman station were imported to FEFLOW as a time-varying power function
Marsh flooding	Based on rainfall record as above. Flux applied when rainfall greater than 100 mm/month, except February 2008 (the monthly rainfall of 124 mm didn't cause significant Marsh flooding as evidenced by measured GWL at monitoring bores)
Potential Evapotranspiration	Average monthly data
Groundwater pumping	Weekly data from 2007 to 2010 at 111 pumping wells and a number of sumps operating during the model calibration period
Groundwater injection	99 injection wells operating during the model calibration period. Weekly data from 2008 to 2010
Calibration datasets	
Ground water levels	13069 observed groundwater levels at 275 wells.
Marsh flood water levels	Non-regular water levels between 1999 and 2010 inferred from Landsat images and UWA observed groundwater levels at two bore holes in the period of 17/09/2008 to 25/05/2010.
Salinity	Salinity contour maps generated from observed data.

6.4.2 Results

By adjusting those key model parameters and boundary conditions described above, the best overall agreement between simulated and measured groundwater levels was achieved by using:

- Model parameters shown in Table 11.
- The flux applied to the three Marsh zones being at rates of 2, 3 and 4 times of rainfall, respectively (the threshold rainfall for Marsh recharge is 100 mm/month);
- The same catchment rainfall recharge rates as obtained from steady state model calibration with threshold monthly rainfall of 50 mm for recharge, and
- The groundwater salinity under the Marsh at 150, 000 mg/L.

Simulated vs Observed water levels

Simulated groundwater levels are compared with measured ones in Figure 28. The error between observed and simulated groundwater levels is in the range of -21.95 to 11.04 m. The average absolute error is 1.87 m, which is about 3% of the maximum difference in observed groundwater levels. Typically, an error less than 5% is indicative of an acceptable calibration, since it means that the error is only a small part of natural groundwater level variations. The normalised Root Mean Squared error of the calibration is 5.3%, which is slightly larger than the value of 5% recommended by the MDBC Groundwater Flow Modelling.

Hydrographs showing simulated and observed water levels are presented in Appendix F. The agreement between measured and simulated hydrographs at key locations is reasonably well, implying that the calibrated model has included the major processes and is representative of the groundwater system.

Water balance

The groundwater balance of the calibrated model is shown in Table 17. Catchment recharge which refers to groundwater recharge in the Chichester ranges and flanking areas (to the TD3, MMF and RHS) is approximately 8 GL/a.

The water balance is dominated by fluxes in and out of the model occurring in the Marsh area of the domain. It is important to note that a significant portion of these fluxes are occurring above ground level in the zone of surface water ponding. Water levels in the zone immediately beneath the marsh surface only fluctuate by 1 to 2 m and represent a smaller store of water relative to the above ground ponding.

Groundwater pumping in the mining area is significant only in the later stage of the calibration period. The simulated total groundwater injection and pumping are 23.6 GL and 33.6 GL, respectively, which are close to measured groundwater injection

and pumping (24.3 and 37.8 GL, respectively). Storage change represents the balance of inputs and outputs in the groundwater system.

Table 17: Groundwater balance for the calibrated transient model

INPUT/OUTPUT		Calibrated Annual Quantity (GL/a)
Input	Catchment Recharge	7.8
	Marsh Flooding	297.0
	Groundwater Injection	1.8
	Boundary recharge	0.3
	Total	306.9
Output	Evapotranspiration	345.8
	Groundwater Pumping	2.5
	Total	348.3
Storage Change		-41.4

6.5 MODEL PREDICTION

6.5.1 Methodology

Cloudbreak Life of Mine (LOM) Plan

The basis for the model prediction is the Cloudbreak Life of Mine (LOM) Plan, which provides a strategy for Fortescue to produce 35 Mtpa (wet rocket product) from the Cloudbreak mine site (FMGL, 2010m). The plan defines a mining sequence which if mined accordingly will enable production of required tonnes of ore at suitable product grade over LOM. The plan therefore is the basis for developing the mine dewatering scenario.

Water Management Strategy

The model simulation is in line with the water management strategy outlined in Section 4.1, as such, the following key elements will be represented in the model:

- Dewatering of below watertable resource areas in accordance with the mine sequence outlined in the LOM plan;
- Provision of approximately 10 GL/a of brackish water for mine requirements, with additional requirements later in the mine life as described in Section xxx;
- Injection of remaining excess brackish water to brackish MMF aquifer along strike from active mining area(s);
- Injection of saline groundwater into saline Oakover aquifer located south of the mining area.

Assessment Approach

The assessment approach has three key stages, as follows:

- In the first stage the model is run with no anthropogenic activities, which provides data on water level for the average climatic sequence (discussed further below). This information is important for estimation of the impact of mine operation, which is quantitied by groundwater level differences between these baseline scenarios and the scenarios under mine operations.
- In the second stage, an initial mining simulation is conducted with only abstraction and no injection. The annual abstraction volume is calculated for each year of the prediction period and then used to determine subsequent well injection rates and locations.
- In the third stage the calculated injection rates are then applied in a combined dewatering and injection scenario. This second dewatering simulation usually results in higher dewatering volumes due to re-circulation of the injected water back to the mine pits and requires several iterations to optimise required

injection volumes and impacts. The distribution of groundwater drawdown and mounding from the final simulation is used to assess potential environmental impacts of mine dewatering and water injection.

Average Rainfall Sequence

For the prediction, rainfall model inputs were generated from rainfall data in the period 1972 to 2008. Only 31 years in the period have complete rainfall records. These years were ranked based on the annual rainfall. The five years (1980, 1983, 2006, 2007 and 2008) with rainfall closest to the median annual rainfall in the 31 years were selected for generating rainfall data for the base case. A fourteen year time series was randomly generated using the five year data. The result is a sequence of 2008, 2006, 2008, 2007, 1983, 2008, 2008, 1983, 2007, 1983, 2007, 1983, 2007, 1980). Using 100 mm/month as the threshold value for Marsh flooding, these are nine flooding events in the 14 years prediction period. The rainfall for each event is 122.8, 122.8, 124.6, 122.8, 122.8, 124.6, 124.6, 124.6 and 112.9 mm.

Additional details regarding the simulation are presented in Table 18.

Table 18: Prediction Model settings, inputs and calibration datasets

Item	Description
Model Settings	
Simulation duration	14 years
Time steps	5 day maximum
Maximum iterations	12
Convergence criteria	0.001 m
Initial Conditions	
Groundwater heads	Results at the end of May 2010 predicted by the Transient Calibration Model
Salinity distribution	Results at the end of May 2010 predicted by the Transient Calibration Model
Stressors	
Catchment Recharge	Based on average 14 year rainfall sequence.
Marsh Flooding	As above, flux applied when greater than 100 mm/month rainfall is recorded. Nine Marsh flooding events occur in the sequence
Potential Evapotranspiration	Average monthly data
Groundwater pumping	Simulated by assigning specified heads over numerical nodes inside mine pits, specified head is maintained for the annual duration that the mining area is identified for mining.

Item	Description
Groundwater injection	Well functions apply flux to MMF (for brackish injection) and to OF (for saline injection). Individual flux based on aquifer testing and current operational rates

6.5.2 Results

The results presented in this section include the following:

- Volumetric description of total water movements;
- Description of baseline water levels (non-operational simulation);
- Description of the water level change from baseline (due to dewatering and injection); and
- Results of depth to watertable assessment (from ground level).

Volumetric Abstraction and Injection Summary

The annualised rates of dewatering and injection are presented in Table 19 and described below.

Total abstraction for the life of the project is predicted to be 811 GL of which 664 GL will be injected to the groundwater system. The net abstraction from the operation, which is the balance of total abstraction and total injection, represents approximately 21% of the total abstraction over the life of the operation. In other words, 80% of the water abstracted during dewatering is returned to the aquifer system from which it is drawn.

Table 19: Dewatering, Injection and Mine Water Use Summary

Simulation Year	Dewatering Summary			Injection Summary				Mine Water Summary	
	Stage 1[14] Dewatering Simulation (GL)	Stage 2[15] Dewatering Simulation (GL)	Increased Dewatering Due to Injection (%)	Total Injection (GL)	Brackish Injection (GL)	Saline Injection (GL)	Ratio of Brackish Injection	Mine Water Use (GL)	Ratio of Mine Water Use to Dewatering (%)
1	38	38	1%	26	8	18	30%	12	32%
2	30	31	4%	22	6	16	28%	9	30%
3	43	43	1%	35	9	26	25%	8	19%
4	59	66	13%	55	12	43	23%	11	17%
5	48	55	14%	45	9	36	20%	10	18%
6	53	58	9%	48	8	40	18%	10	17%
7	75	79	5%	73	11	62	15%	6	7%
8	40	44	12%	34	4	30	13%	10	23%
9	88	91	4%	80	8	72	10%	11	12%
10	52	58	10%	45	4	41	9%	13	22%
11	83	90	8%	81	6	75	8%	9	10%
12	36	42	16%	29	2	27	7%	13	31%

[14] Dewatering only simulation (no injection)

[15] Dewatering and injection simulation

Simulation Year	Dewatering Summary			Injection Summary				Mine Water Summary	
	Stage 1[14] Dewatering Simulation (GL)	Stage 2[15] Dewatering Simulation (GL)	Increased Dewatering Due to Injection (%)	Total Injection (GL)	Brackish Injection (GL)	Saline Injection (GL)	Ratio of Brackish Injection	Mine Water Use (GL)	Ratio of Mine Water Use to Dewatering (%)
13	29	32	10%	20	1	19	6%	12	37%
14	74	84	14%	71	4	67	5%	13	16%
Average (GL)	**53**	**58**	**9%**	**47**	**7**	**41**	**15%**	**11**	**21%**
Total (GL)	**747**	**811**	**-**	**664**	**93**	**571**	**-**	**147**	

Baseline Water Level Condition

The results of the baseline water level simulation (stage 1) for selected locations along the perimeter of the Marsh are presented in Figures 44 to 52, along with simulated operational water levels that are discussed below. The figures also show the range of measured and inferred water levels since January 2006. The locations of these bores are shown in Figure 29 to 43. The figures show a fluctuating trend of water level rise and fall, which is primarily driven by the cycle of flooding, and evaporation occurring in the Marsh.

The average water level fluctuations at reference bores inside the perimeter of the Marsh (A2 and B2) is approximately 1.5 m and at reference sites adjacent to the Marsh the average fluctuation is approximately 0.5 m

Change in Water Level from Baseline

The difference between the results of the baseline simulation and the results from the simulation involving dewatering only (stage 2) have not been presented in this report as they present an intermediate stage, which informs the injection strategy. Results from this simulation show drawdown in excess of 1m extending into the Marsh area, highlighting the importance of targeted injection to minimise the dewatering footprint.

The difference between the results of the baseline simulation and the results from the simulation involving dewatering and injection (stage 3) is shown in plan view for each year in the Figures 30 to 43 and discussed below.

In general, significant water level change due to the operation is focused on the active mining area and of short duration in any particular locality due to the ‘migratory’ nature of the mining front. The cone of depression resulting from the dewatering operation shifts focus throughout the life of the operation in alignment with the active mining area.

With respect to predicted drawdown, the water levels in the immediate resource area subject to mining may be lowered by up to 75 m. However, the shape of the drawdown cone is generally quite steep (represented by the tightly spaced contour lines around the pit) and the drawdown becomes significantly less away from the immediate pit area Drawdown occurring at the perimeter of the Marsh is approximately 1 m or less.

The drawdown footprint is significantly reduced by the injection strategy, which returns brackish water to compatible aquifer(s) located to the east and west of the active mine pits and saline water to compatible aquifer(s) located to the south of the active mine pits. In the brackish groundwater injection areas the water levels are predicted to rise by up to 5 m, however in these areas the depth to groundwater is typically in excess of 15 m. In the saline injection area groundwater levels are

predicted to rise by up to 2 m, which generally remains within the historically observed water level range water level.

The predicted water levels at selected sites along the perimeter of the Marsh for both the baseline simulation and the dewatering and injection simulation are presented in Figures 44 to 52. Consistent with the plan view of drawdown and mounding the hydrographs show that the water level change due to the operation is relatively small in areas adjacent to the Marsh and water levels generally remain within the range of observed water levels.

Depth to Watertable Analysis

The depth to watertable has been considered due to both drawdown and water level rise having the potential to cause impacts to vegetation. Figures 30 to 43 show in plan view the depth to the watertable across the project area at the end of each year. The ground surface elevation for selected locations along the Marsh is shown in Figures 44 to 52.

The results show that at locations where water level changedue to the operation is predicted that there will be no springs or other surface expression of the watertable as a result of water injection in the Hillside injection borefield areas or the saline injection borefield area. Adjacent to the Marsh the depth to watertable generally remains within its natural range and where water level rise occurs, the peaks are generally of low magnitude and short duration. The hydrograph (Figure 51) for the reference site ‘Artificial West’ shows water levels to be approximately 2 m below ground level preceding operations in this area. The water level at this site is predicted to rise to within 1 m of ground level for a period of approximately 200 days. It is expected that water levels will not in fact rise to this level as the initial water level is expected to be lower than that in the model by 1 to 2 m. In addition, the model does not currently consider evapotranspiration in this area as water levels away from the Marsh are generally low. Evapotranspiration has a significant dampening effect on shallow aquifer water level rise and would restrict mounding more than represented.

Water Balance

The average annual groundwater balance over the prediction period is shown in Table 20.

As shown previously in the transient calibration (Section 6.4.2) flooding (input) and evaporation (output) occurring in the Marsh area (including a large surface water component) represent large fluxes in the model.

Under mining conditions groundwater the balance of abstraction (output) and injection (input) result in a net loss of approximately 10 GL/a.

Table 20: Groundwater balance of the Average Rainfall Sequence Scenario

INPUT/OUTPUT		Annual Quantity (GL/a)		
		Dry Rainfall Sequence	Average Rainfall Sequence	Wet Rainfall Sequence
Input	Catchment Recharge	2.6	4.2	10.2
	Marsh flooding	40	116	418
	Groundwater Injection	47.4	47.4	47.4
	Boundary recharge	0.5	0.3	-0.8
	Total	90.5	167.9	474.8
Output	Evapotranspiration	51.6	124.2	403.6
	Mine Dewatering	57.5	57.9	61.0
	Total	109.1	182.1	464.6
Storage Change		-19.0	-14.5	9.6

6.6 MODEL SENSITIVITY AND UNCERTAINTY ANALYSIS

6.6.1 Methodology

In this section uncertainty with regards to hydraulic parameters and recharge are discussed. The method in which the potential range of these elements is determined is further discussed below.

Rainfall Variability

A stochastic method was used to generate one thousand realisations of rainfall data for the 38 year Newman rainfall record. Stochastic climate data are random numbers that are modified so that they have the same statistical characteristics (in terms of mean, variance, skew, long-term persistency, etc…) as the historical data from which they are based. Each stochastic replicate (sequence) is different and has different characteristics compared to the historical data, but the average of each characteristic from all the stochastic replicates is the same as the historical data.

The 1000 realisations were ranked from the driest realisation to the wettest realisation based on their total rainfall over the period. The realisation at 5% ranking was used to generate the dry scenario. The driest continuous 14 years in the realisation was used for the dry scenario, which had two flood events in the prediction period. The realisation at 95% ranking was used to generate the wet scenario. The wettest continuous 14 years in this realisation was used for the wet scenario, which has 19 flood events (using the 100 mm monthly rainfall threshold).

A comparison of the frequency of flood events for the dry, average and wet sequence is presented in Table 21.

Table 21: Comparison of Simulated Marsh Flooding Sequences

Years	Marsh Flooding Frequency		
	Dry Sequence	Average Sequence	Wet Sequence
1	0	1	2
2	0	0	2
3	1	1	1
4	0	1	2
5	0	0	1
6	0	1	1
7	0	1	0
8	0	0	1

Years	Marsh Flooding Frequency		
	Dry Sequence	Average Sequence	Wet Sequence
9	0	1	2
10	0	0	2
11	0	1	1
12	1	0	2
13	0	1	1
14	0	1	1
Total number of Flooding	2	9	19

Hydraulic Parameters

The results described in the preceding section may vary in direct response to varying hydraulic parameters. The variables explored in this study are presented in Table 22. The parameters included in the assessment are those that were observed during model calibration to be the most influential on model results. The ranges adopted represent the reasonable upper and lower bound values of each parameter, based on results from field investigations.

Table 22: Hydraulic parameter values used in sensitivity study

Parameters	Sensitivity Range			
	Base case	Upper Limit	Lower Limit	Pump Test Results
Oakover Formation				
Kxy[16] (m/day)	302	432	173	380 (81-1333)
Kz[17] (m/day)	8.6	12.4	8.6	
Ss[18]	5.00E-05	1.00E-04	1.00E-05	1e-5
Upper Marra Mamba formation (Mineralised)[19]				
Kxy (m/d)	4.3-173	6.48-259	2.16-86.4	69 (2-1055)

[16] Hydraulic conductivity – horizontal
[17] Hydraulic conductivity –vertical
[18] Specific storage
[19] For the upper MMF values of Kxy and Ss are spatially variable

Parameters	Sensitivity Range			
	Base case	Upper Limit	Lower Limit	Pump Test Results
Sy[20]	0.01-0.05	0.015-0.075	0.005-0.025	NA

Other model details are presented in Table 23.

Table 23: Sensitivity model settings, inputs and calibration datasets

Item	Description
Model Settings	
Time steps	Automatically determined by FEFLOW with the maximum time step of 5 days
Maximum iterations	12
Convergence criteria	0.001 m
Initial Conditions	
Groundwater heads	Same as those used in the baseline simulation
Salinity distribution	Same as those used in the baseline simulation
Stressors	
Rainfall	Monthly 14 year average rainfall sequence data were imported to FEFLOW as a time-varying power function used to calculate rainfall recharge rate.
Potential Evapotranspiration	Average monthly data
Groundwater pumping	Same as that used in the baseline simulation
Groundwater injection	Same as that used in the baseline simulation

6.6.2 Sensitivity and Uncertainty Analysis Results

The results of this analysis are presented in Appendix G and discussed below.

Baseline Water Level Condition for Wet and Dry Sequences

The results of the sensitivity analysis are presented in Appendix G. The baseline water level simulation for the wet and dry sequences (stage 1) for selected locations along the perimeter of the Marsh show that the baseline water level for the wet and dry sequences can vary by up to 1.5 m. At reference bores A2 and B2

[20] Specific yield

located inside the perimeter of the Marsh, baseline water level display a difference of up to approximately 2 m.

Change in Water Level from Baseline for Wet and Dry Sequences

As for the average rainfall sequence, the difference between the results of the baseline simulation and the results from the simulation involving dewatering only (stage 2) have not been presented in this report as they present an intermediate stage, which informs the injection strategy. It is worth noting however that the results from this simulation for both the wet and dry sequences show drawdown in excess of 1m extending into the Marsh area.

The difference between the results of the baseline simulation and the results from the simulation involving dewatering and injection (stage 3) for both wet and dry sequences is shown in plan view for each year in Appendix G. In general the drawdown and mounding distributions between the two sequences vary by only a small magnitude.

For the wet and dry sequences (and average sequence) the predicted water levels at selected sites along the perimeter of the Marsh for both the baseline simulation and the dewatering and injection simulation are presented in Appendix G. The drawdown difference between the wet and dry sequences can be up to 2 m and the difference in water level rise is generally less than 1m.

Depth to Watertable Analysis for Wet and Dry Sequences

As for the average rainfall sequence the depth to watertable has been considered for the wet and dry sequence due to both drawdown and water level rise having the potential to cause impacts to vegetation. Results are presnetd in Appendix G in the form of plans showing depth to watertable and hydrographs.

The results show that at locations where groundwater impact (water level change from baseline) is predicted there will be no springs or other surface expression of the watertable as a result of water injection in the Hillside injection borefield areas or the saline injection borefield area. Adjacent to the Marsh the depth to watertable generally remains within its natural range and where water level rise occurs, the peaks are generally of low magnitude and short duration.

Water Balance for Wet and Dry Sequences

Model water balances for the Dry and Wet scenarios were presented at Table 20. Additional, annual abstraction data for the three scenarios is presented in Table 24.

As to be expected, in the dry scenario, catchment recharge, marsh flooding and evaporation are all reduced significantly from the average scenario and vice versa for the wet scenario.

The sensitivity of abstraction and injection volumes to the wet and dry rainfall sequences is low (Table 24). Based on the sensitivity analysis the maximum annual abstraction for the wet scenario is 94 GL in year 9.

Table 24: Comparison of Abstraction for Wet, Dry and Average Scenarios

Year	Dry Scenario	Average Scenario	Wet Scenario
1	38	40	37
2	31	32	33
3	43	45	47
4	66	65	68
5	55	54	57
6	58	58	61
7	79	77	81
8	44	44	45
9	91	89	94
10	58	57	60
11	91	91	92
12	41	40	43
13	32	32	33
14	83	83	89
Average	**58**	**58**	**60**
Total	**811**	**806**	**840**

Hydraulic Parameter Sensitivity Analysis

The sensitivity of dewatering volumes to hydraulic properties of the mineralised MMF and Oakover Formation is summarised at Table 25. Generally the dewatering volume is not sensitive to hydraulic properties of either Oakover Formation or the mineralised MMF.

Based on the change in dewatering volume from the base scenario, the dewatering is most sensitive to hydraulic conductivity of the mineralised MMF, then to specific yield of mineralised MMF and hydraulic conductivity of Oakover Formation, least sensitive to specific storage of Oakover Formation.

The influence of the hydraulic properties on water levels at the selected locations is presented in Appendix H. It is evident that these hydrographs are sensitive to hydraulic conductivities of both Oakover Formation and mineralised MMF, but not sensitive to specific yield of mineralised MMF or specific storage of Oakover Formation.

Table 25: Comparison of Abstraction for Parameter Sensitivity Analysis

Year	Base	High K MMF	High K OF	High Sy MMF	High Ss OF	Low Ss OF	Low K OF	Low Sy MMF	Low K MMF
1	38.2	46.4	38.70	39.4	37.7	40.1	40.1	40.2	37
2	31.3	30.2	31.70	31.8	31.6	30.5	30.3	30.5	33
3	43.3	50.3	44.30	45.8	44.0	43.1	41.8	44.7	47
4	66.3	74.2	67.50	66.5	65.7	66.1	63.1	65.6	68
5	54.9	62.2	55.40	54.3	54.9	54.1	51.9	54.5	57
6	58.1	65.9	60.30	60.2	58.7	58.8	56.5	56.7	61
7	78.7	89.3	88.40	80.5	81.8	76.4	78.6	76.4	81
8	44.3	48.5	44.30	44.8	43.6	44.5	44.6	42.8	45
9	91.1	102.1	93.80	97.6	90.2	89.8	96.1	90.1	94
10	57.5	62.0	59.60	59.4	57.8	57.9	52.3	56.4	60
11	91.1	104.7	92.60	93.0	92.8	91.1	89.0	86.5	92
12	41.3	41.6	41.40	41.2	41.0	41.6	42.0	41.1	43
13	31.6	33.2	31.80	31.9	31.8	32.2	31.6	30.9	33
14	82.9	89.2	84.90	86.5	83.5	83.3	81.2	82.2	89
Average	57.9	64.3	59.6	59.5	58.2	57.8	57.1	57.0	50.8
Total	810.6	899.8	834.7	832.9	815.1	809.5	799.1	798.6	711.5
Change in total DW Volume from Base Scenario		11%	3%	2.8%	0.6%	-0.1%	-1.4%	-1.5%	-12.2

6.7 SIMULATION OF POST-MINING GROUNDWATER LEVEL RECOVERY

Groundwater level recovery trends after mine closure was simulated by the numerical model. Groundwater drawdown distributions at the end of one, five, ten, twenty, thirty and forty years following mine closure for the average rainfall scenario are shown in Appendix I. The largest groundwater drawdown in the mining area decreases from over 40 m at the end of mining to about 4 m after ten years recovery and to about 2 m after 20 years following the mine closure. Drawdown in the vicinity of the Marsh also diminishes over a short period of time.

These results demonstrate that the proposed water management (groundwater abstraction and injection) would introduce minimum long-term effect in terms of groundwater levels (and storage).

6.8 CUMULATIVE IMPACTS

A number of other water management projects including Fortescue's Christmas Creek project are proposed in the vicinity of the Fortescue Marsh. The influence of these projects in terms of drawdown and or mounding is presented in Figure 53. The relationship between these impacts is discussed below.

The Hancock 'Roy Hill' project (Hancock, 2009) is located to the east of the Christmas Creek project, some 60 km from Cloudbreak. The project requires dewatering and therefore development of a drawdown cone results. There is no overlap between the drawdown impacts associated with the Roy Hill Project and groundwater impacts associated with the Cloudbreak project.

The Brockman Resources Project is located on the southern side of the Fortescue Marsh. The proposed water management for the project includes dewatering and injection. Dewatering results in a drawdown cone which is limited to the southern side of the Fortescue Marsh (Aquaterra, 2010). On this basis there is expected to be negligible overlap between the drawdown impacts associated with the Roy Hill Project and groundwater impacts associated with the Cloudbreak project.

Fortescues Christmas Creek project is located to the east of Cloudbreak. A five year water management plan involving dewatering and injection has been developed for the project (FMGL, 2010n). The overlap of these impacts is presented in Figure 53. For the period assessed minor overlap occurs in the brackish injection area to the east of Cloudbreak and west of Christmas Creek. Resulting in water level rise in the order of 1m above the Cloudbreak impact alone. This cumulative affect remains well below a level that has potential to cause impact in this area and is localised to a future mining region.

6.9 ASSESSMENT OF VERTICAL SALINITY MOVEMENT

6.9.1 Objectives

The preceding section describes a three-dimensional (3-d) density driven flow and transport modelling assessment. The model is able to reasonably predict groundwater dewatering volumes and bulk water salinity of mining water. However computational limitations mean that it is impossible to use very fine numerical meshes for a regional flow and transport model such as this one. Therefore, the model may introduce numerical dispersion and undermine its accuracy in predicting groundwater salinity changes caused by mine dewatering and saline water injection in parts of the domain that have low existing salinity but are adjacent to zones that have higher salinities.

To compliment the 3-d modelling work, a two dimensional (2-d) density driven flow and transport model was constructed to investigate the impact of the operation on shallow groundwater zones that are naturally lower in salinity (less than 6,000 mg/L).

6.9.2 Model Assumptions and Construction

The 2-d model simulates flow and transport in a representative slice of the 3-d model domain along the general flow direction from the Fortescue Marsh to the mining area. Employing a finer numerical mesh in the 2-d model ensures that groundwater salinity changes caused by mine dewatering can be confidently predicted.

Major characteristics and assumptions are summarised as below:

- Density-driven flow is considered since salt concentrations of groundwater in deep geological formations are over 100,000 mg/L, which may significantly affect groundwater flow dynamics.
- Unsaturated flow is considered in the model, since the FEFLOW 2-d saturated flow model can only simulate groundwater flow in confined aquifers and groundwater flow under mine dewatering is unconfined.
- The principal component of groundwater flow is from the Marsh to the to the pit.
- The boundary at the south end of the model has constant heads due to the large distance between the boundary and mining pit.
- The boundary condition at the northern end of the model is no-flow.
- The top of the model has an average rainfall recharge rate applied. The bottom of the model is a no-flow boundary.

- The base of the mining pit is located on the base of the mineralised MMF. Numerical nodes over the pit bottom are assigned as boundary nodes with specified heads.
- Saline groundwater from mining pits is injected to the Oakover Formation through injection wells.

A two-dimensional vertical cross-section FEFLOW model was constructed to investigate whether groundwater salinity in the shallow alluvial layer would be significantly affected by mine dewatering and saline injection. Both southern and northern boundaries of the model were located at groundwater divides where no-flow boundary conditions can be applied. Water flux on the land surface was not considered. Mine dewatering was simulated by applying constant heads to the pit base.

The model domain (Figure 54) is 32 km long in the horizontal direction and extends from the land surface to the level of 210 m (a.s.l) in the vertical profile. The model is aligned through the current Hook Pit area. The domain was divided into 279057 numerical elements (triangles) with an average area of 26 m2.

Model parameters were obtained from the 3-d model calibration (refer to Table 11 & 12). Initial groundwater levels were obtained by running a model for a 20 years period with specified groundwater heads (based on measurements) at boundaries and in the middle of the Marsh. It is assumed that the obtained groundwater levels would represent mean groundwater flow under the natural condition. Initial salt concentrations were also obtained through running the above described model with the middle part of the Marsh as a concentration specified boundary and initial model concentrations being specified based on measured concentrations.

6.9.3 Calibration

Two scenarios of simulations were designed to investigate the effect of dewatering on the salinity of groundwater in the shallow alluvials:

- Scenario 1: no water injection was applied.
- Scenario 2: 50% of predicted dewatering water in Scenario 1 was injected into the Oakover Formation and concentration of injected water was 10,000 mg/L (the predicted maximum concentration of the bulk pit water is 9000 mg/L).
- Scenario 3: 50% of predicted dewatering water in Scenario 1 was injected into the Oakover formation. The concentration of injected water was 50,000 mg/L to represent a worst-case scenario in terms of the effect of saline water injection on groundwater quality in the shallow alluvial layer.

All simulations were run for a period of four years. This is a conservative timeframe as dewatering is not likley to occur in one particular location for this length of time.

Predicted dewatering volumes are shown in Table 26. Since a 2-d model simulates a slice along the groundwater flow direction, the length of mine pits perpendicular to the flow direction is required to convert this dewatering volume into a total dewatering volume. Pit lengths obtained from the 3-d model were used to calculate total dewatering volumes (also shown in Table 26).

In scenario 1, total dewatering volume was 50 GL/a in the first year, and decreased to between 33 and 25 GL/a in the following years (assuming maintaining dewatering of the same pit). Due to saline water injection, the total dewatering volume in the four year period was 20% larger in Scenarios 2&3 than in Scenario 1. The increased dewatering volume is about 40% of the injected water.

Table 26: Predicted Dewatering Volumes from 2-d flow and transport model

Dewatering year (assumes constant location)	Pit Length (m)	Dewatering Volume (Scenario 1)		Dewatering Volume (Scenarios 2&3)	
		2-d Results (m3/m/Year)	Converted Volume[21] (GL/a)	2-d Results (m3/m/Year)	Converted Volume (GL/a)
1	4800	10416	50	10325	50
2	4800	6876	33	8678	42
3	4800	6087	29	7998	38
4	4800	5252	25	7523	36
Total		28631	123	34525	148

For the 2-d model to be used for predicting the effect of mine dewatering and saline water injection, groundwater flow in the 2-d model should be representative of groundwater flow in the 3-d model. This can be done by comparing the total dewatering volume between 2-d and 3-d models. If it predicts similar amount of dewatering water as that predicted by the 3-d model, then the 2-d model can be used to predict groundwater salinity under the condition of dewatering and saline water injection.

The comparison of dewatering estimates for the 2-d model and 3-d model are presented in Table 27. Dewatering volumes from the 2-d model have been adjusted to reflect a moving mine sequence (this involves adjustment of pit length to reflect mine plan for each year and adjustment of dewatering rate to reflect additional new areas being dewatered). Dewatering volumes predicted by the 2-d model and 3-d model are quite similar. The difference is about 20% in the case without saline water injection and only 3% in the case with saline water injection. Therefore, it can

[21] Converted volume calculated by multiplying 2-D results with pit length

be concluded that the 2-d model is reasonably representative of the 3-d model and may be used to predict the effect of mine dewatering and saline water injection on shallow groundwater salinity.

Table 27: Comparison between dewatering volume predicted by the 2-D model and the 3-D Model

Dewatering Year (assumes moving pit sequence)	Dewatering Volume (Scenario 1)		Dewatering Volume (Scenarios 2&3)	
	2-d Results (GL/a)	3-d Results (GL/a)	2-d Results GL/a	3-d Results (GL/a)
1	50	38	50	38
2	24	30	29	31
3	35	43	43	45
4	46	59	60	65
Total	155	170	182	179

6.9.4 Results

Simulated groundwater salinity breakthrough curves at selected locations (Figure 55) in the shallow alluvial layer are shown in Figures 56a-c. Figure 56a shows that shallow groundwater salinity doesn't change with time suggesting that mine dewatering would not affect groundwater quality in the shallow aquifer. Injecting 50% of the dewatering water predicted in Scenario 1 slightly increased shallow groundwater salinity (Figure 56b) when the injected water has the salinity (10,000 mg/L) just above the maximum salinity of dewatering water predicted in Scenario 1. In the Scenario 3, where the injected water has a high salinity of 50,000 mg/L, shallow groundwater salinity increased (Figure 56c), but still below the brackish water salinity standard (6,000 mg/L) in all observational wells.

Density driven flow and transport were simulated by a 2-d vertical FEFLOW model. The effect of mine dewatering and saline water injection on shallow groundwater quality was investigated through numerical simulations. Major findings of this investigation are:

- The dewatering estimates made by the 2-d model are broadly consistent with those of the 3-d model.
- Injecting 50% of the dewatering water predicted in Scenario 1 slightly increased shallow groundwater salinity when the injected water salinity (10,000 mg/L) was just above the maximum salinity of dewatering water predicted in Scenario 1.

If injected water has a high salinity of 50,000 mg/L, shallow groundwater salinity would increase but still be maintained below the brackish water salinity standard (6000 mg/L) in all observational wells.

6.10 LIMITATIONS

All numerical groundwater modelling is subject to limitations in the conceptualisation and representation of the natural system. The following limitations of the Cloudbreak model are noted.

The hydraulic parameters in the Marra Mamba Formation and Oakover Formation aquifers and the connectivity between these aquifers have been extensively explored over large parts of the domain. These findings have been extrapolated to areas that have not been defined by drilling and testing activities.

The monitoring bore dataset for Cloudbreak covers the period 2006 to 2010, which is sufficient for a solid characterisation but does not capture the full range of natural variation. A aquifer response to moderate Marsh flooding events has been captured however, the response to significant flooding events identified in historical Landsat imagery is not available.

The monitoring bore network extends to the Fortescue Marsh fringe but not to the Fortescue Marsh surface. Though the marsh's response to flooding and evaporation has been simulated using other datasets such as historical Landsat records, this is a limitation in that the assessment is not based on measured groundwater responses.

The simulation of the salinity distribution has been undertaken to provide a broad scale representation of the density driven flow mechanism. Salinity is not modelled with sufficient resolution to accurately represent salinity change during the project duration. This has however been explored via a 2-d modelling approach.

Simulation of the groundwater recovery after dewatering finished was carried out assuming the pre-mining hydraulic characteristics were maintained. The hydraulic properties of the material inside the mine pit were not changed to the hydraulic properties of the pit back filling materials as (1) hydraulic properties of back filling materials are not known and likely to be spatially and temporally variable; and (2) much more effort is required to include temporally variable material properties in the FEFLOW model.

The likely effect of this simplifying assumption is that dewatering volumes will be slightly over predicted. Backfill materials are likely to be of lower permeability and specific yield than the orebody, even given the bulking effect of backfill, as all overburden and waste materials have significantly lower permeability and specific yield than the orebody. As a result the actual inflow into closed mine pits is likely lower than simulated.

The proposed water management scheme is designed for the supplied mine plan, which is the best available information at the time of assessment. Modifications to the mine plan will result in different water management outcomes. This limitation is

addressed through an adaptive management approach to water management, whereby mining, abstraction and injection are tailored to the mining sequence such that water management objectives can be achieved.

6.11 FUTURE WORK

Recommendations to further improve the hydrogeological characterisation and predicted outcomes of the Cloudbreak Water Management Scheme are outlined below.

- The heterogeneity of aquifer properties and associated uncertainties should continue to be assessed through additional drilling and aquifer testing. This should target the following key aquifer units: mineralised Marra Mamba Formation and Oakover Formation.
- Drilling and aquifer testing should include further assessments of the hydraulic connection between mineralised Marra Mamba Formation and the Oakover Formation.
- A drilling program should be undertaken on the Fortescue Marsh to assess the Marsh's lithological and hydraulic properties, and to provide monitoring bores for long-term groundwater response assessments. Installation of bores on the Marsh is subject to access restrictions.
- Model calibration should remain an ongoing process whereby operational data are used effectively for hydrogeological refinement.
- Cloudbreak operations should continue to exploit opportunities for mutually-beneficial water management with Christmas Creek (and possibly other surrounding minesites).

7. CONCLUSIONS

The hydrogeological setting of Cloudbreak has been characterised based on field investigations, borefield developments and extensive groundwater monitoring since 2006. This includes the period since mid 2008 where Cloudbreak has been operating a significant groundwater management scheme including dewatering and injection of approximately 25 GL/a and 18 GL/a respectively.

The field investigations and borefield developments form the basis for the conceptual hydrogeological model of the Cloudbreak project area described in this report.

The Marra Mamba Formation ore body is an important part of the present day groundwater system being the most significant brackish aquifer in the area. The aquifer is elongated along the strike of the Chichester Ranges. The aquifer receives recharge from rainfall infiltration in the Chichester Ranges which subsequently flows to the south towards the Fortescue Marsh. The MMF is overlain by a sequence of alluvial sediments which thicken towards the Marsh and result in the MMF aquifer becoming increasingly confined down dip.

It is also recognised that the Marsh environment is a dominant feature of the hydrogeological system. The Marsh is a closed basin and periodically experiences flooding in response to runoff from the surrounding surface water catchment. Significant rainfall in the catchment can generate runoff in the order of 500 to 1,000 GL, which forms a broad shallow lake over the Marsh. Infiltration results in saturation of the unsaturated zone, which even after a prolonged dry period where the water level may fall to 1.5 m below ground level is not expected to exceed 90 GL.

The lake water then proceeds to evaporate and if no significant rainfall events occur within the next 12 months will be completely evaporated and the watertable will start to fall below ground level again as the process of evaporation continues to remove water from the sub surface storage under the extremely dry and hot climatic conditions. This cycle of flooding and evaporation, over time, has resulted in development of a hypersaline body of groundwater beneath the Marsh which is an important part of the present day flow system.

The hypersaline groundwater beneath the Marsh and the brackish groundwater flowing southward meet in a broad transition zone where the less dense brackish groundwater flows up and over the hypersaline via low permeability alluvial sediments, eventually discharging via evaporation and evapotranspiration in the vicinity of the Marsh floor.

A density-driven flow and transport numerical groundwater model was developed in the FEFLOW groundwater modelling system for the Cloudbreak project and

adjacent Fortescue Marsh region. The model has been successfully calibrated against steady state and transient piezometric and salinity data including twenty years of inferred Marsh flood levels and two years of significant dewatering and injection operations. The calibrated groundwater model was subsequently used to simulate the water management plan for the Cloudbreak Life of Mine Strategic Plan.

The Cloudbreak water management strategy is designed to meet multiple needs; those of the business, the environment and stakeholders. The project involves large scale dewatering which exceeds the mine water demand by a considerable quantity annually. Recognising the need to maintain as much as possible the equilibrium of the hydrogeological system in order to satisfy environmental and stakeholder needs, a significant proportion of the abstracted water is returned to compatable aquifers by injection. Brackish groundwater is returned to brackish aquifers along strike from the active mine area and saline groundwater is returned to the saline (Oakover) aquifer located to the south of the mining operation.

The Cloudbreak water management strategy was assessed via numerical simulation. Over the Life of mine (14 years) abstraction is predicted to be at an average rate of 58 GL/a and injection is predicted to be at an average rate of 47 GL/a. The net abstraction from the operation, which is the balance of total abstraction and total injection is approximately 11 GL/a, which represents approximately 20% of abstraction. In other words, 80% of the water abstracted during dewatering is returned to the aquifer system from which it is drawn.

The resulting drawdown from dewatering is localised to the mining area and shifts focus over the life of the operation. Drawdown occurring at the perimeter of the Marsh is approximately 1 m or less.

Localised mounding is predicted to develop in the brackish injection areas in response to injection. The simulated mounding is generally less than 5 m above the natural water levels. Watertable rise of generally less than 2 m may develop in the saline injection area however this is typically of short duration. No surface expression of groundwater is expected as a result of injection.

Uncertainty analysis was undertaken with respect to a range of rainfall conditions and hydraulic parameters. The resulting water levels for synthetic wet and dry rainfall sequences show small variability being generally less than 1 m. This is largely due to the dampening effect of evaporation, which is high when the watertable is elevated and low when the watertable is lower.

Dewatering volume are sensitive to the hydraulic conductivity of the mineralised MMF, however there is a good understanding of the hydraulic conductivity distribution in this aquifer. Water levels do show some sensitivity to the range of hydraulic conductivities of both Oakover Formation and mineralised MMF explored in the assessment.

Groundwater level recovery occurs relatively rapidly following the completion of mining and dewatering. Water levels recover to within two meters locally around some mine pits after approximately 20 years recovery under average rainfall conditions. Water level adjacent to the Marsh recover rapidly also, n response to Marsh flooding events.

A 2-d model was developed to enable more accurate simulated results of salinity change in response to the water management plan. In particular the potential influence on the salinity of the watertable zone (where of existing brackish or fresher water quality), which represents the zone of highest potential beneficial use (vegetation and pastoral use) was assessed. The results of this assessment indicate that the shallow watertable zone may be marginally influenced but will generally be maintained within the natural brackish range.

A comprehensive description of infrastructure requirements and management systems is presented in accompanying document:

Fortescue 2010, Cloudbreak Water Management Scheme, CB-RP-HY0014.

8. REFERENCES

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Figures

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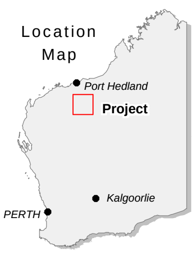
Figure 1.

Regional Locality Plan



Mine Sites

Towns

FMG Railway

Other Railways

Roads

Major Creek/Drainage

N

0 25 50

kilometres

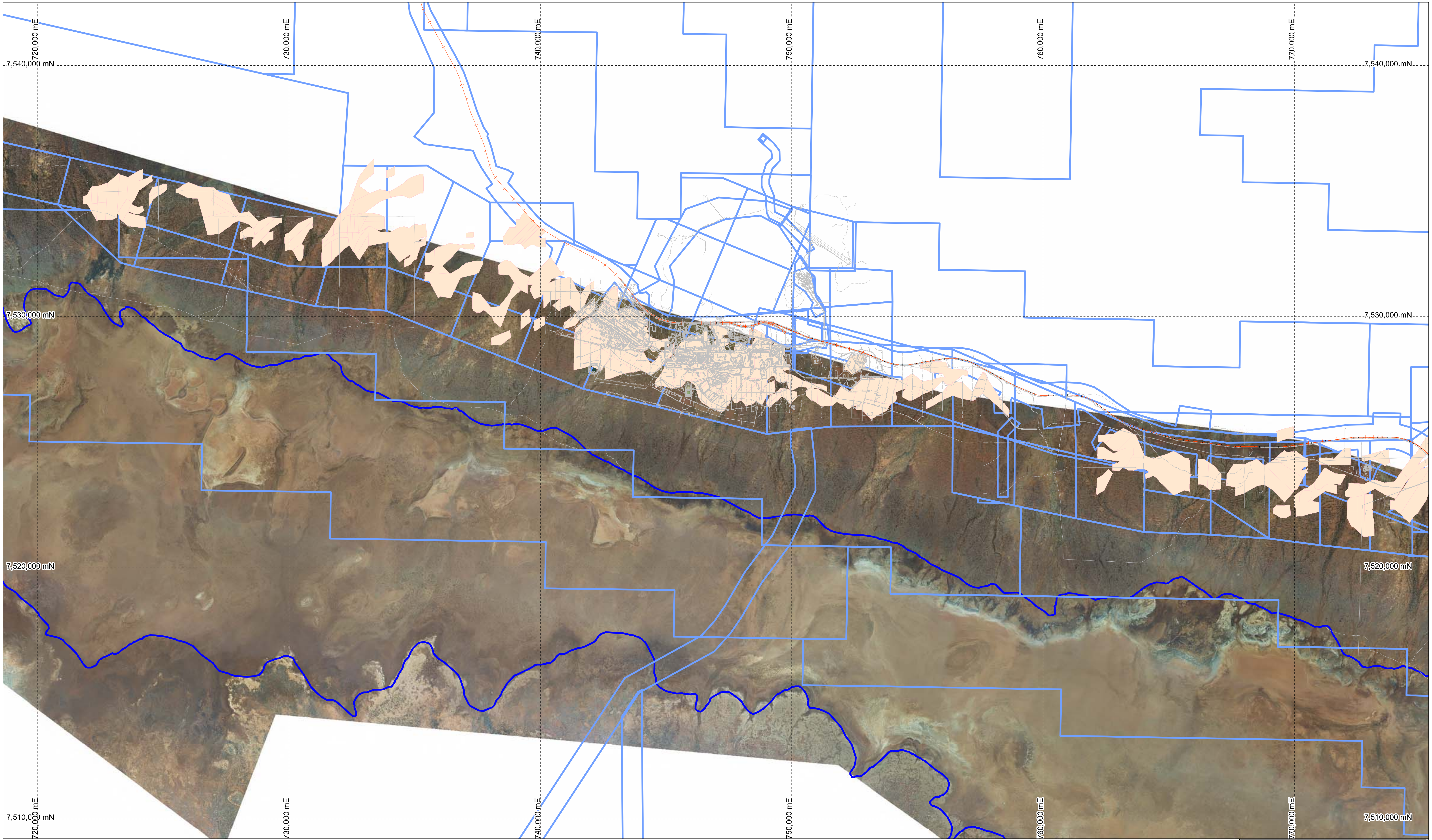
Fortescue Metals Group Ltd

Regional Locality Plan

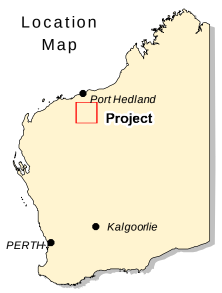
Author: B. Willis-Jones	Date: 9/09/2010
Drawn By: SH	Revision: 0
Doc No: CB_MP_HY_0044	Confidentiality: 1
Projection: Longitude / Latitude (WGS 84)	Scale: 1:1750000

Figure 2.

Site Location Plan



Location Map



FMG Tenements

Mine Sequence

Fortescue Marsh Boundary

Infrastructure

FMG Rail

N

0 1.25 2.5 5
kilometres

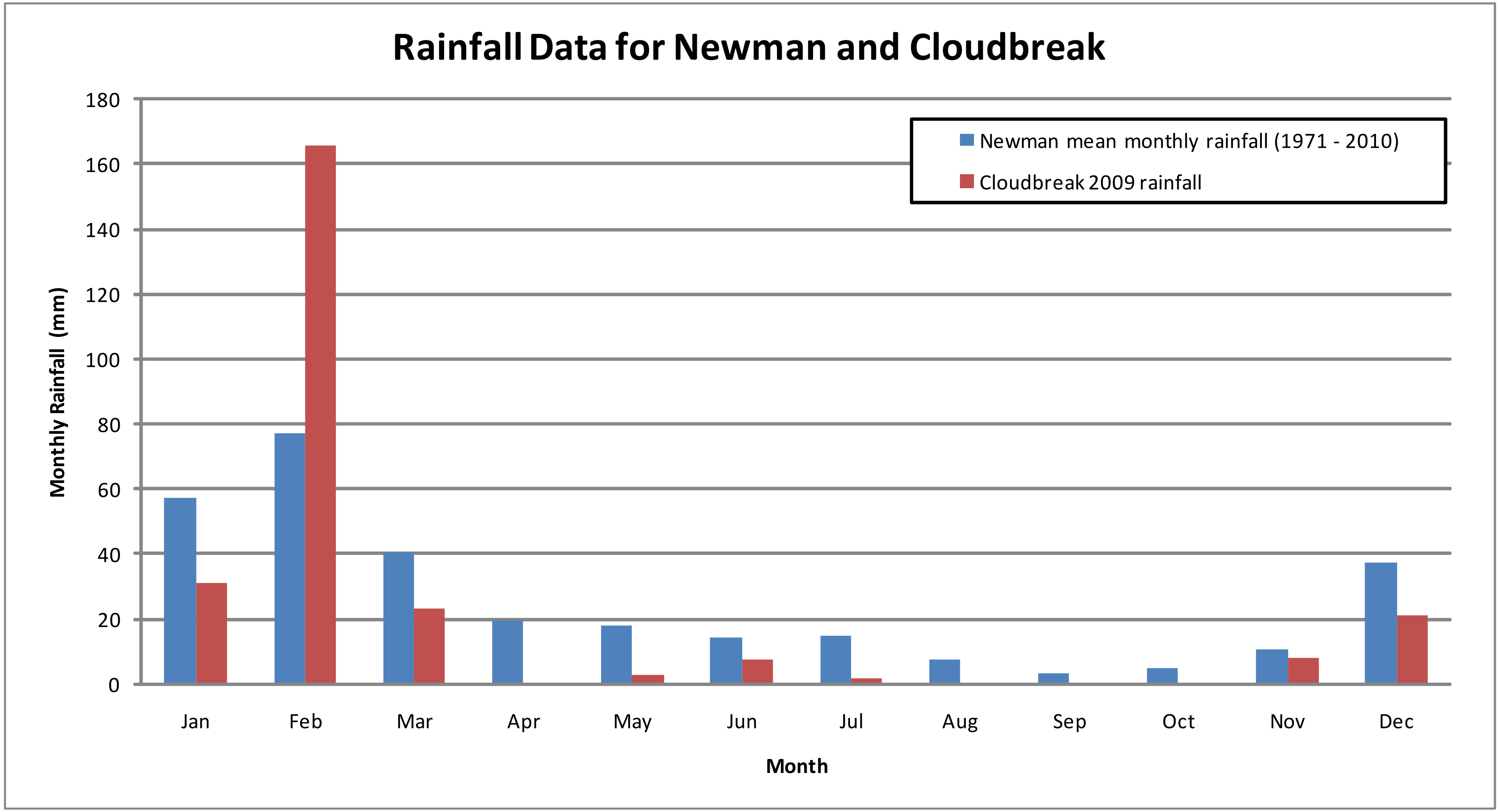
Fortescue Metals Group Ltd

Site Location Plan

Author: B. Willis-Jones	Date:8/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000

Figure 3.

Rainfall Data for Newman and Cloudbreak



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Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 3

Figure 4.

Hamersley Basin and Chichester Ranges Stratigraphy

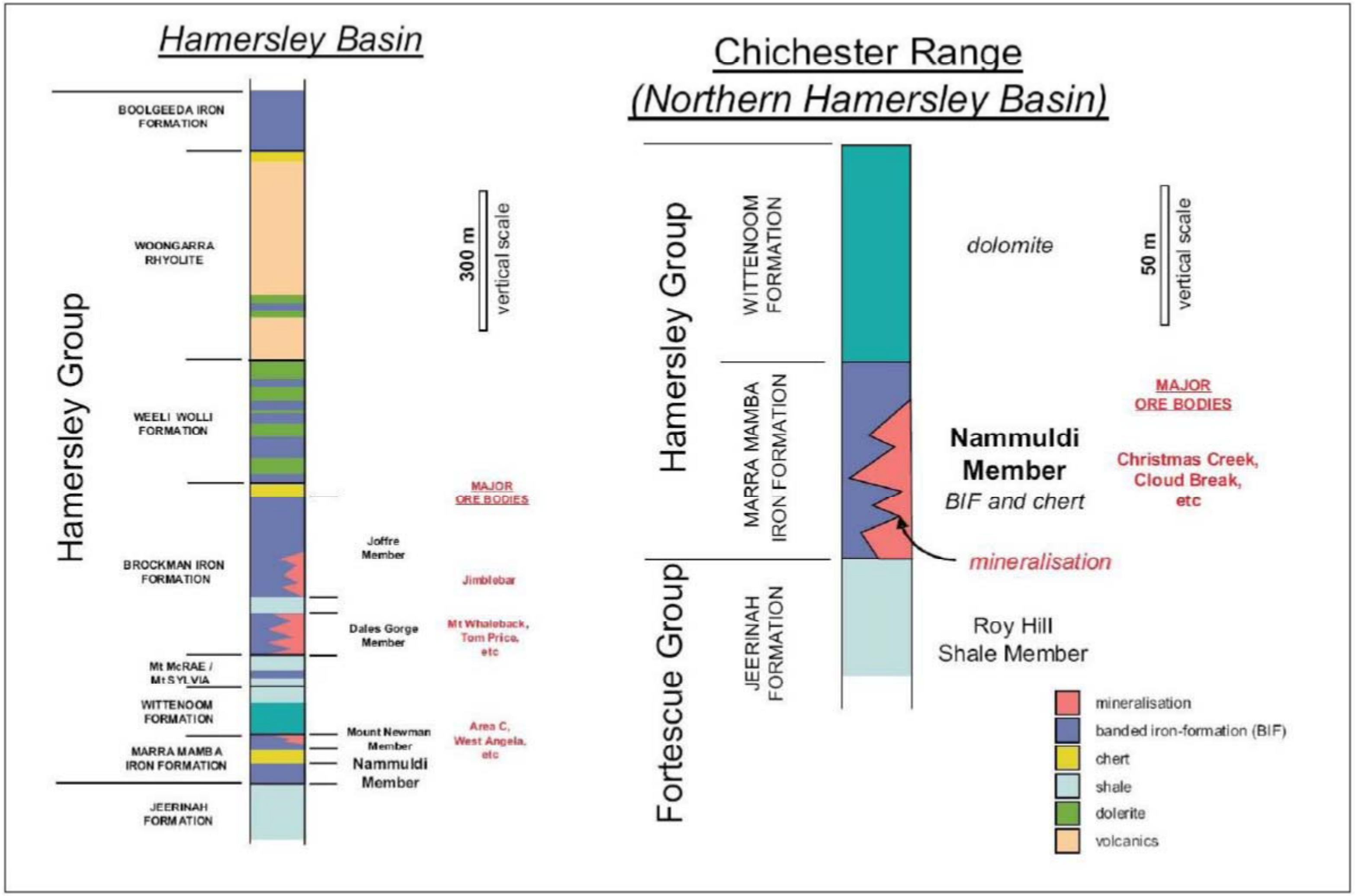


Figure Title: Hamersley and Chichester Ranges Stratigraphy	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 4

Figure 5.

Tertiary Stratigraphy

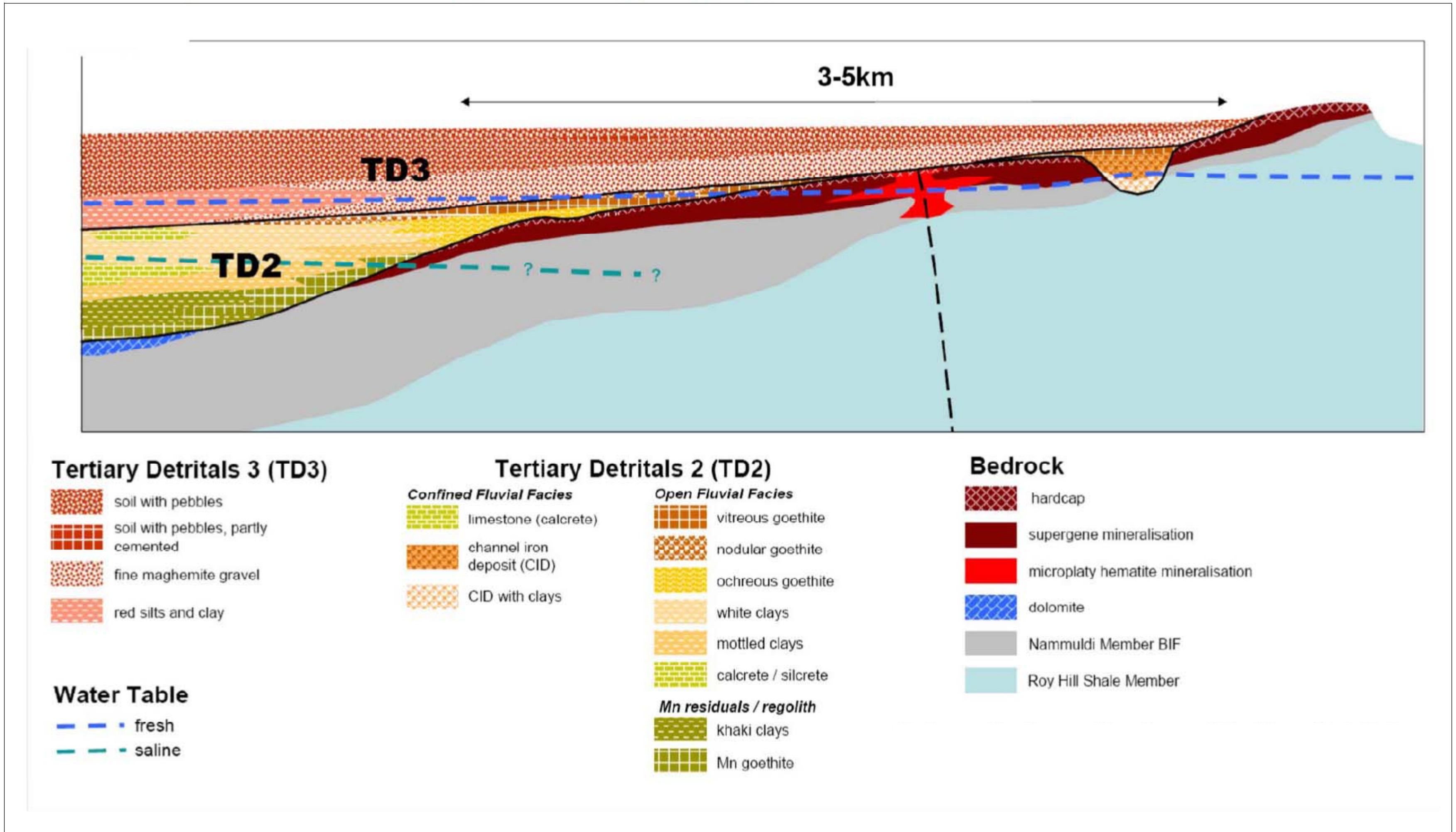


Figure Title: Schematic Cross Section of Tertiary Detritals for Cloudbreak	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 5

Figure 6.

Watertable Elevation Contours (December 2007)

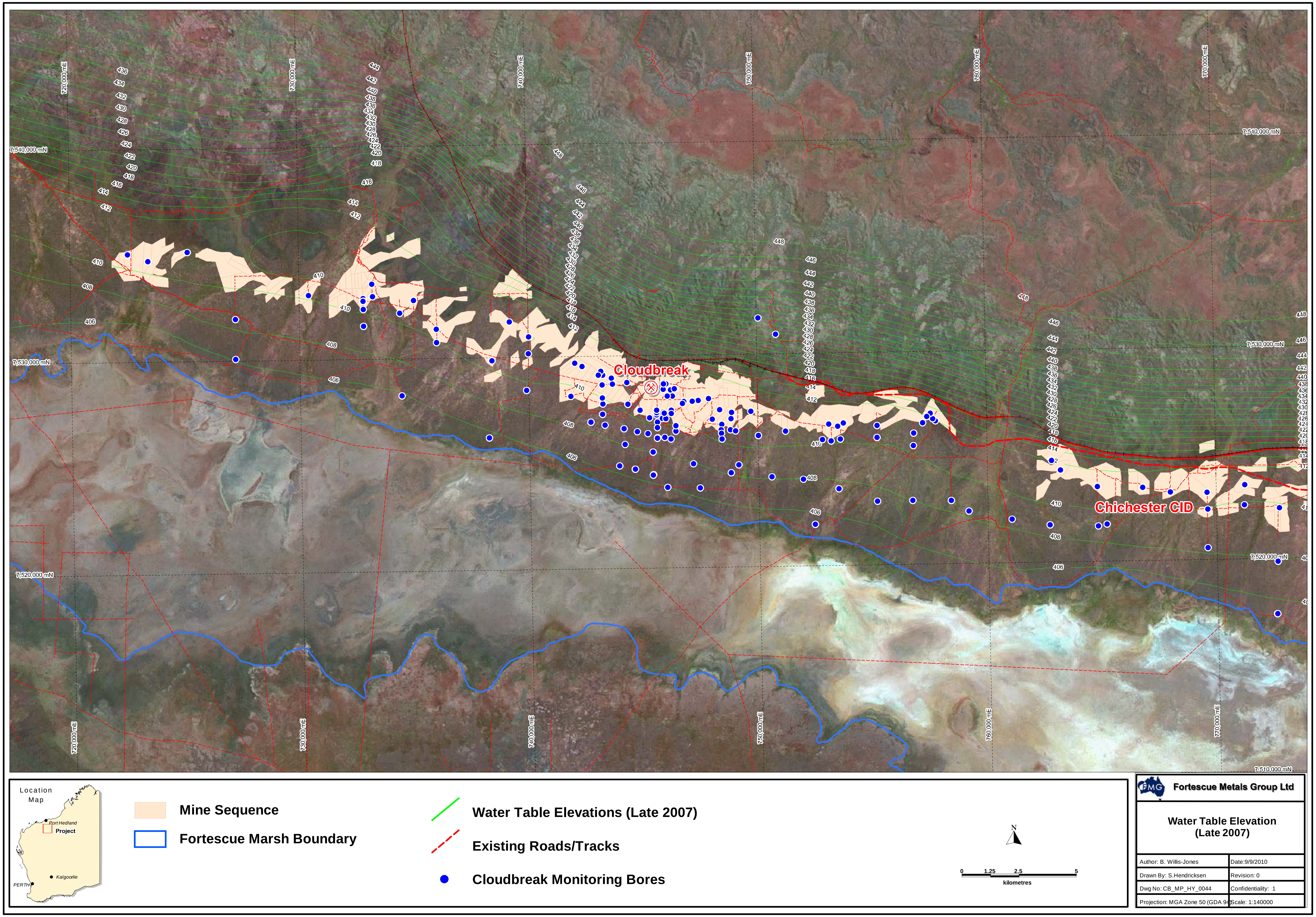

Cloudbreak
Chichester CID
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,510,000 mN
7,520,000 mN
7,530,000 mN
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Sequence
Fortescue Marsh Boundary
Water Table Elevations (Late 2007)
Existing Roads/Tracks
Cloudbreak Monitoring Bores
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Water Table Elevation (Late 2007)
Author: B. Willis-Jones
Date: 9/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000

Figure 7.

February 2009 Flooding Event

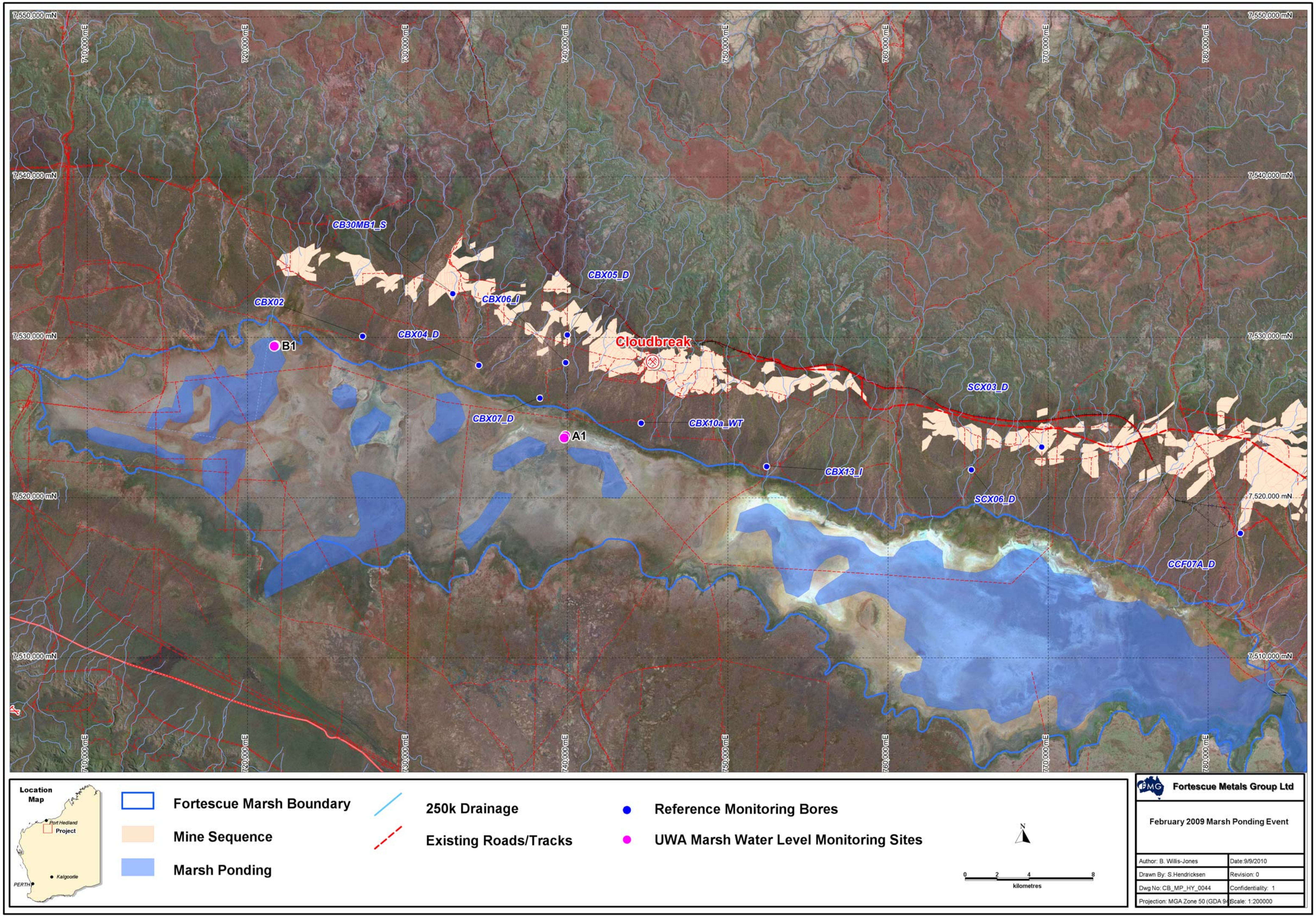
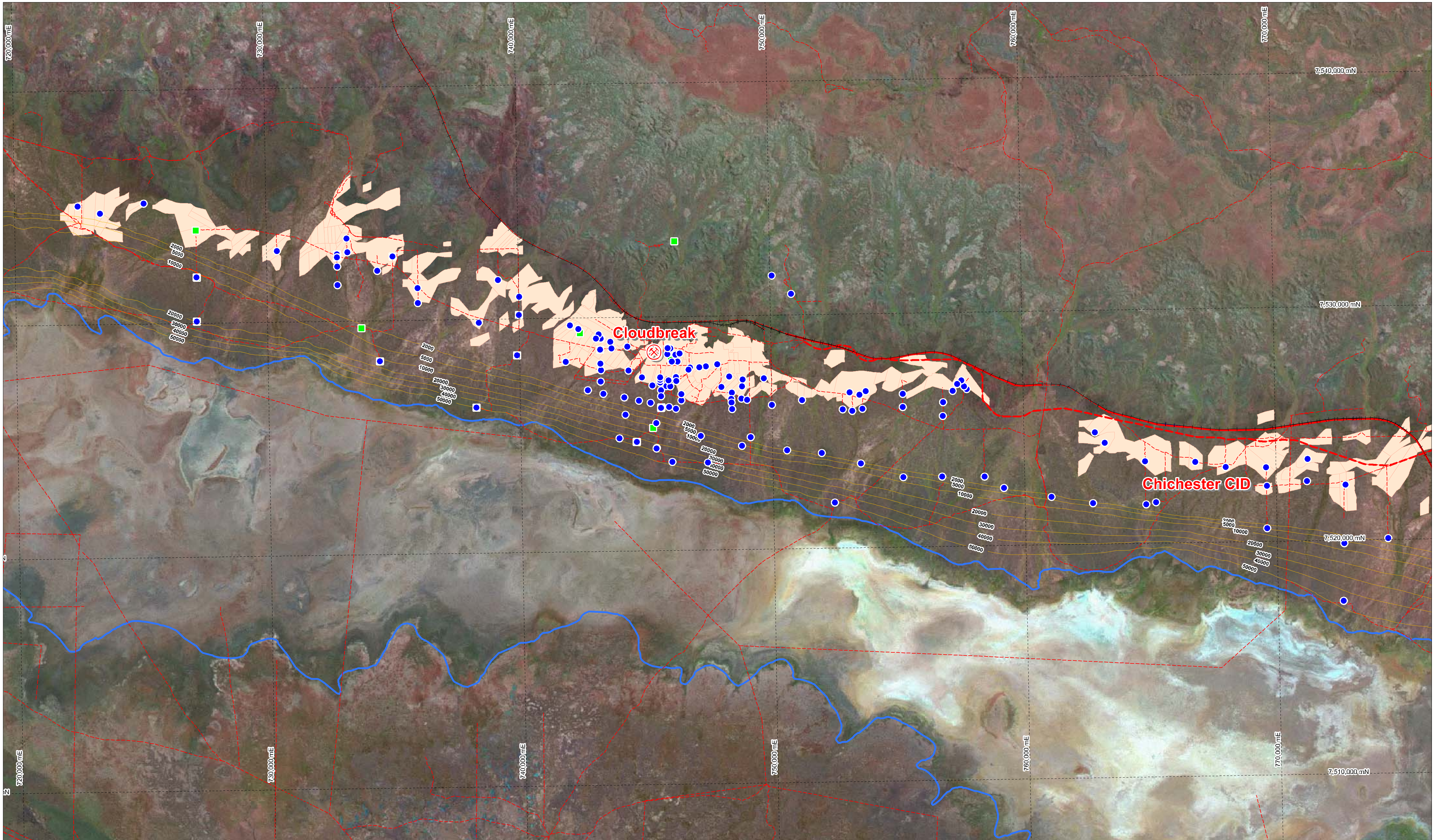
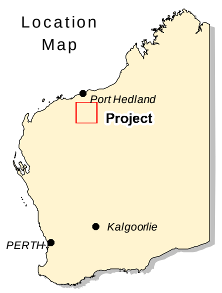

7,550,000 mN
7,540,000 mN
7,530,000 mN
7,520,000 mN
7,510,000 mN
710,000 mE
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
780,000 mE
CB30MB1_S
CBX05_D
CBX02
CBX06_I
CBX04_D
B1
Cloudbreak
SCX03_D
CBX07_D
CBX10a_WT
A1
CBX13_I
SCX06_D
CCF07A_D
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Fortescue Marsh Boundary
Mine Sequence
Marsh Ponding
250k Drainage
Existing Roads/Tracks
Reference Monitoring Bores
UWA Marsh Water Level Monitoring Sites
N
0 2 4 8
kilometres
Fortescue Metals Group Ltd
February 2009 Marsh Ponding Event
Author: B. Willis-Jones
Date:9/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:200000

Figure 8.

Salinity Distribution in Upper Tertiary Detritals





- Mine Sequence
- Fortescue Marsh Boundary
- Salinity Upper TD3
- Existing Roads/Tracks
- Cloudbreak Monitoring Bores
- Sampling Points

N

0 1.25 2.5 5
kilometres

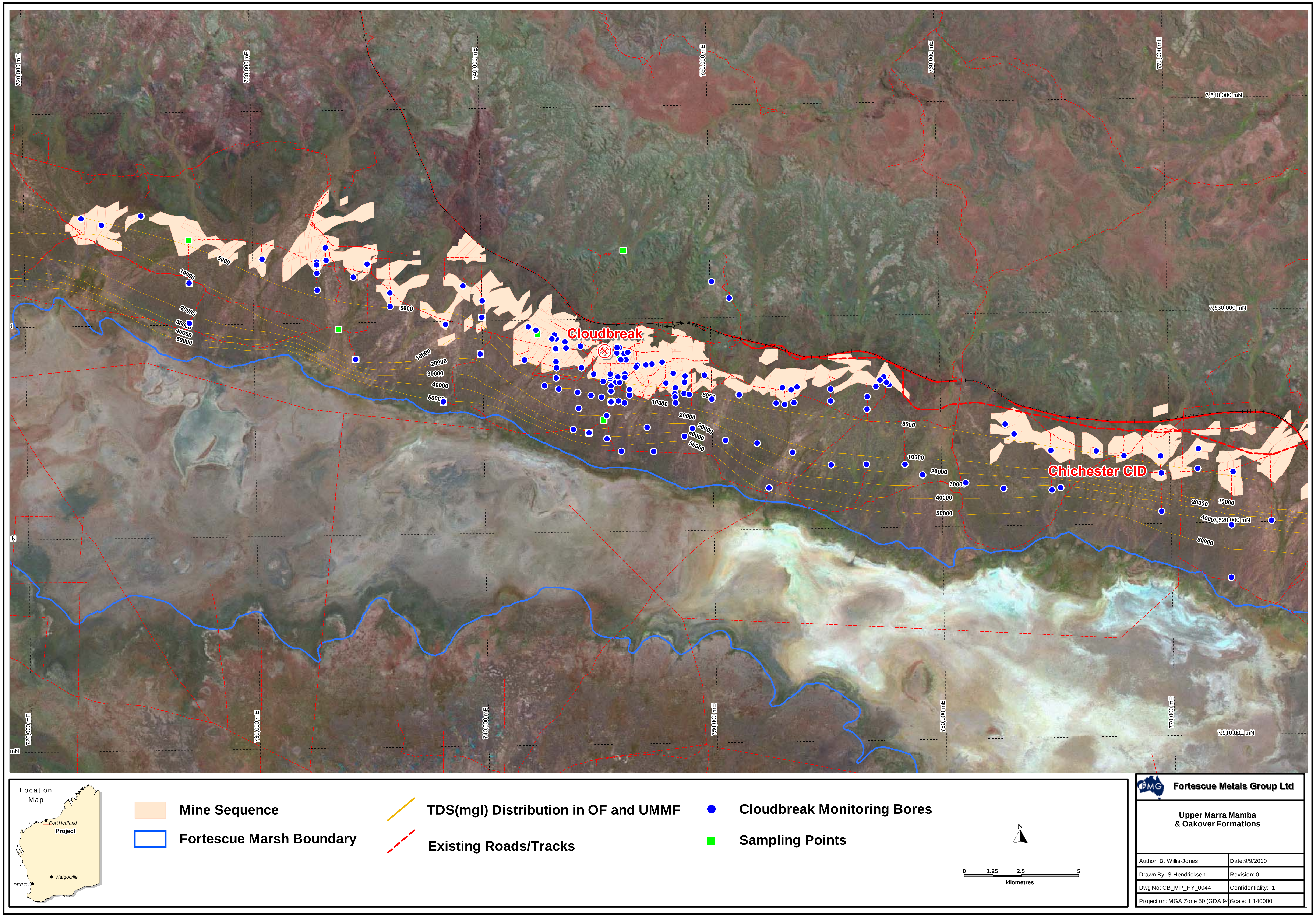
Fortescue Metals Group Ltd

Salinity Distribution in Upper Teriary Detritals (TD3) in mg/L

Author: B. Willis-Jones	Date:9/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000

Figure 9.

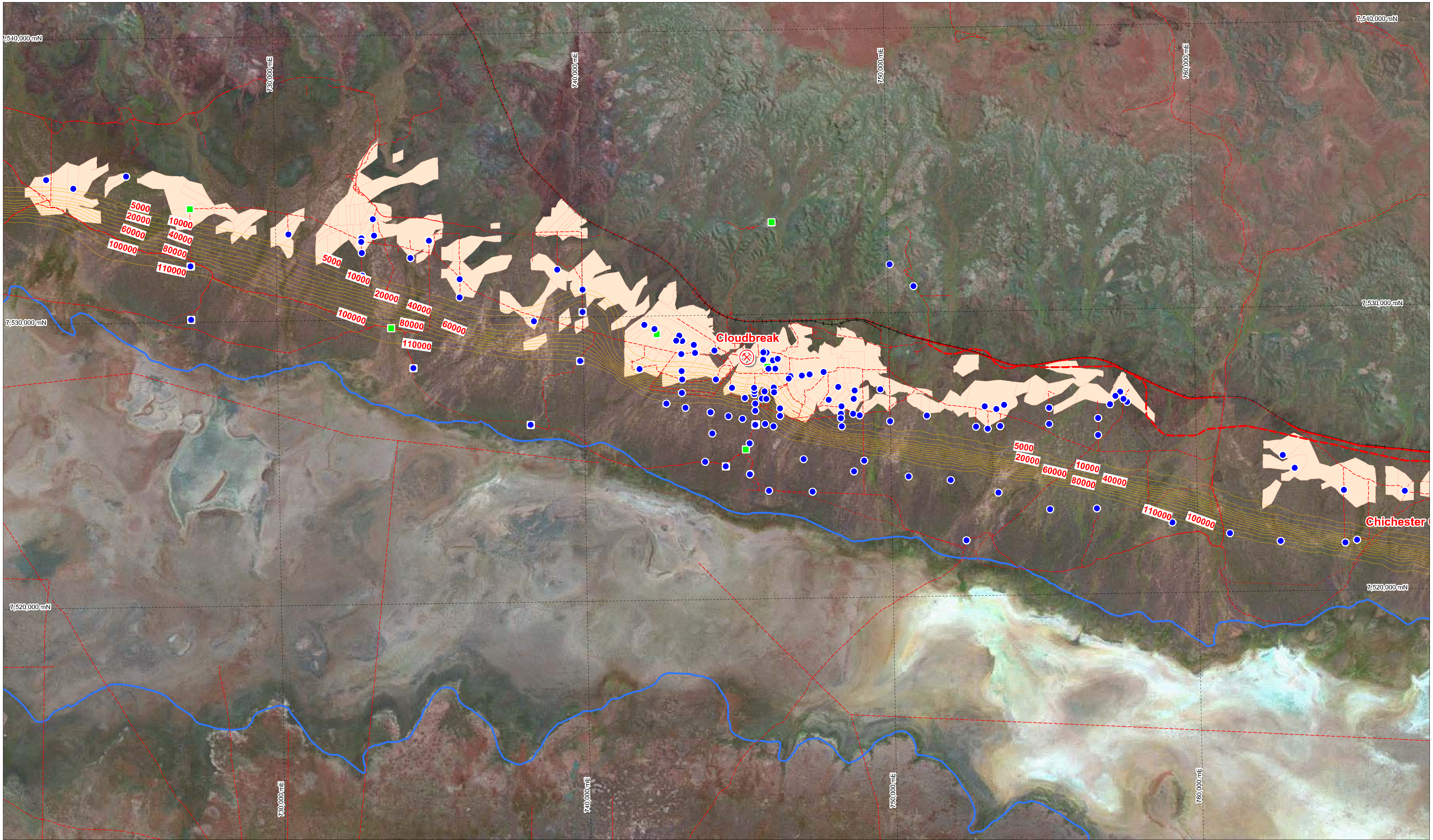
Salinity Distribution in Upper Marra Mamba Formation and Oakover Formation



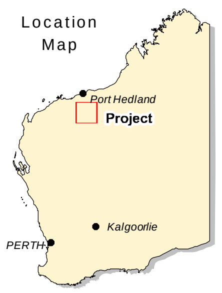
Cloudbreak
Chichester CID
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
7,510,000 mN
5000
10000
20000
30000
40000
50000
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Sequence
Fortescue Marsh Boundary
TDS(mgl) Distribution in OF and UMMF
Existing Roads/Tracks
Cloudbreak Monitoring Bores
Sampling Points
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Upper Marra Mamba
& Oakover Formations
Author: B. Willis-Jones
Date:9/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000

Figure 10.

Salinity Distribution in Lower Marra Mamba Formation and Wittenoom Formation



Location Map



Mine Sequence

Fortescue Marsh Boundary

Salinity Distribution (mg/L)

Existing Roads/Tracks

FMG Rail

Cloudbreak Monitoring Bores

Sampling Points

N

0 1 2 4
kilometres

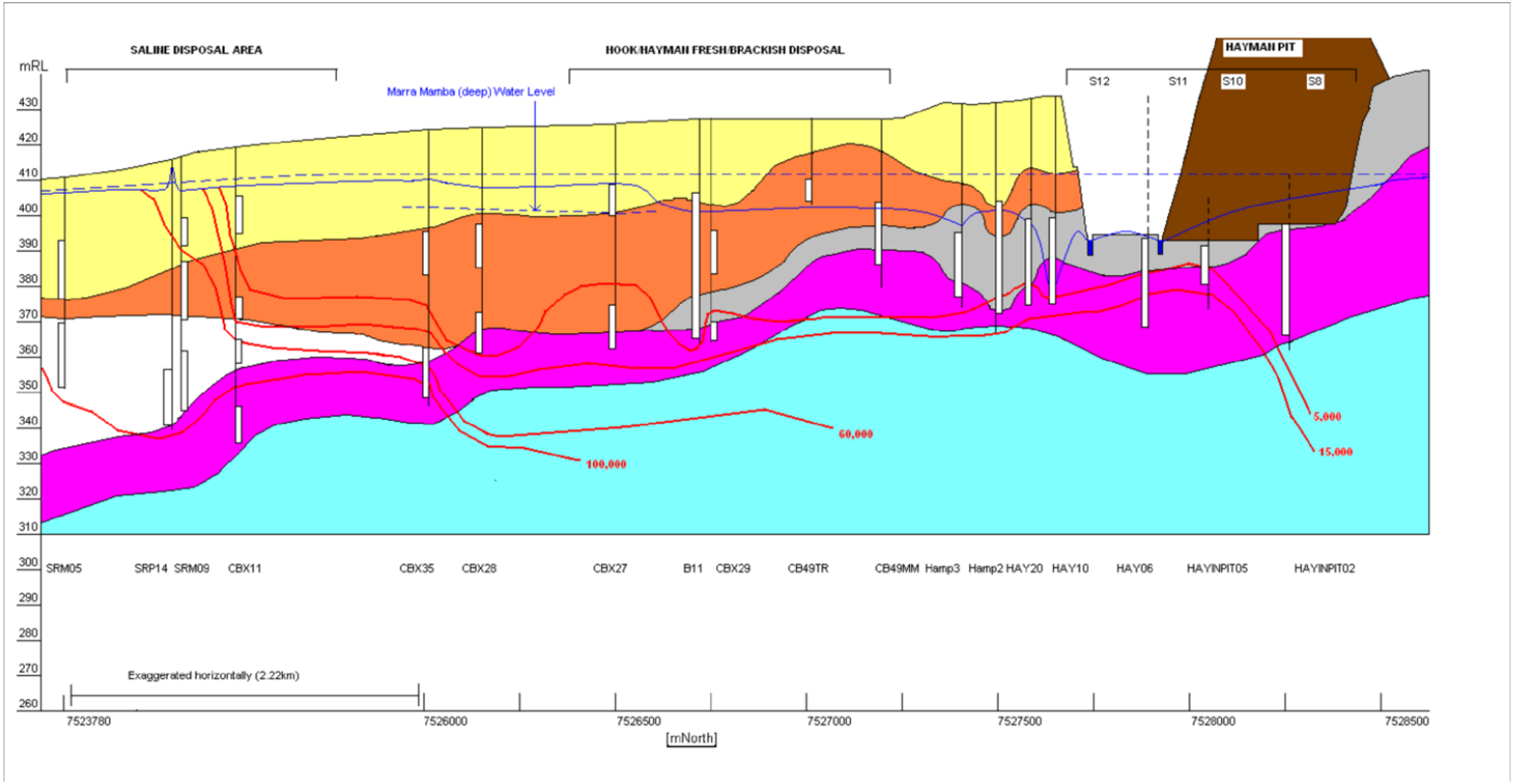
Fortescue Metals Group Ltd

Salinity Distribution in Lower Marra Mamba Formation & Wittenoom Formation in mg/L

Author: B. Willis-Jones	Date:9/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:115000

Figure 11.

Hydrogeological Cross Section – Hayman Pit



Alluvium Ta (gravelly soils)

Tertiary Detritals Tds (including hardcap Hc)

Oakover Formation To (calcrete and silcrete/chalcedony)

Mineralised Marra Mamba MUm/MUh (including transition zone MUt)

Unmineralised Lower Marra Mamba MUb (Cherts/BIF)

Wittenoom Formation (Dolomites and Shales)

Roy Hill Shale Jr (Jeerinah Formation - leached white to fresh black carbonaceous shales)

Original Static Water Level

Equipotential electrical conductivity lines (uS/cm)

Water table level

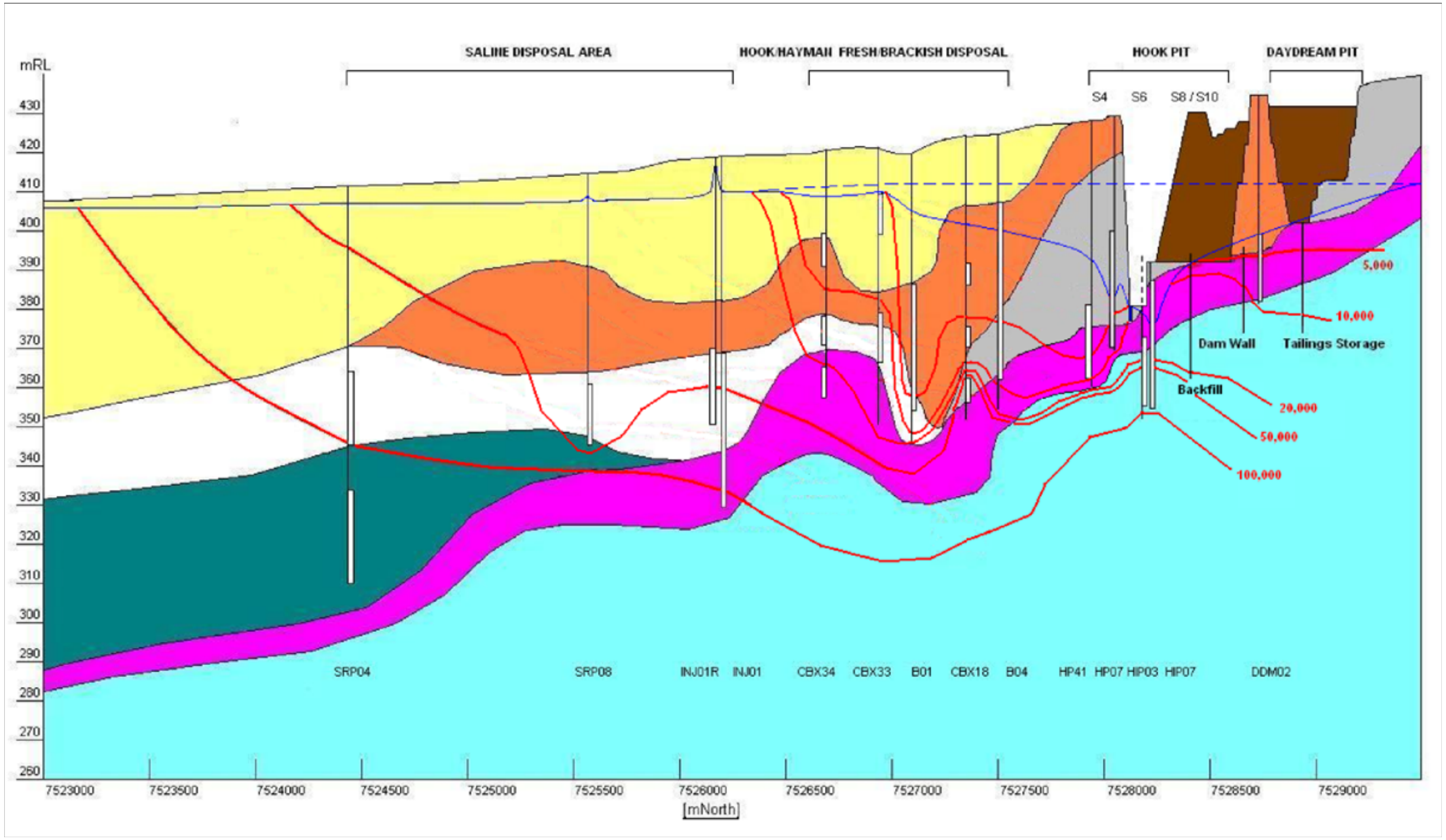
Monitoring/Production bore location and screened interval

SECTION SCALES:
Vertical Scale (all sections): 1:1,250
Horizontal Scale (Hook & Brampton sections): 1:23,810
Horizontal Scale (Gnarloo and Hayman sections): 1:11,905

Figure Title: hydrogeological cross sections showing salinity transition zone - Hayman Pit	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 11

Figure 12.

Hydrogeological Cross Section – Hook Pit



CLOUDBREAK SECTIONS LEGEND

Alluvium Ta (gravelly soils)

Tertiary Detritals Tds (including hardcap Hc)

Oakover Formation To (calcrete and silcrete/chalcedony)

Mineralised Marra Mamba MUm/MUh (including transition zone MUt)

Unmineralised Lower Marra Mamba MUb (Cherts/BIF)

Wittenoom Formation (Dolomites and Shales)

Roy Hill Shale Jr (Jeerinah Formation - leached white to fresh black carbonaceous shales)

Original Static Water Level

Equipotential electrical conductivity lines (uS/cm)

Water table level

Monitoring/Production bore location and screened interval

SECTION SCALES:

Vertical Scale (all sections): 1:1,250

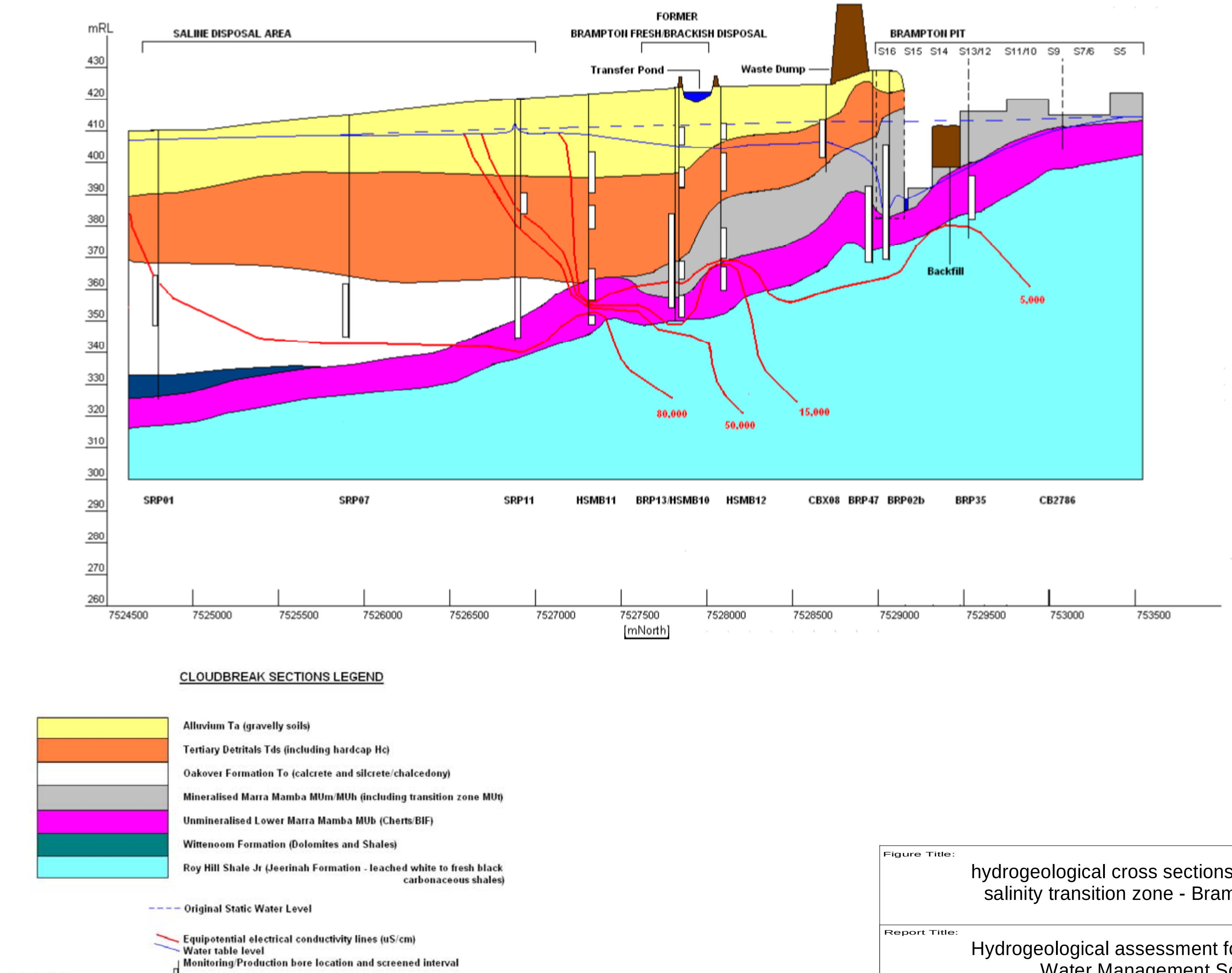
Horizontal Scale (Hook & Brampton sections): 1:23,810

Horizontal Scale (Gnarloo and Hayman sections): 1:11,905

Figure Title: hydrogeological cross sections showing salinity transition zone - Hook Pit	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 12

Figure 13.

Hydrogeological Cross Section – Brampton Pit

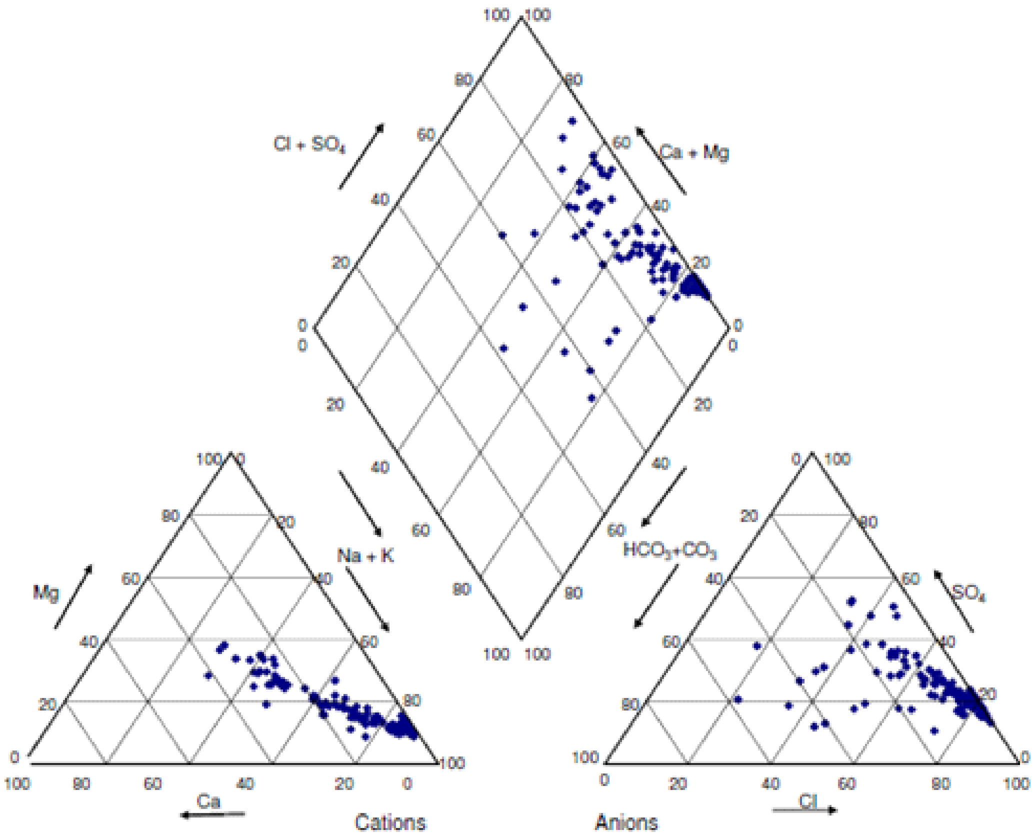


SECTION SCALES:
Vertical Scale (all sections): 1:1,250
Horizontal Scale (Hook & Brampton sections): 1:23,810
Horizontal Scale (Gnarloo and Hayman sections): 1:11,905

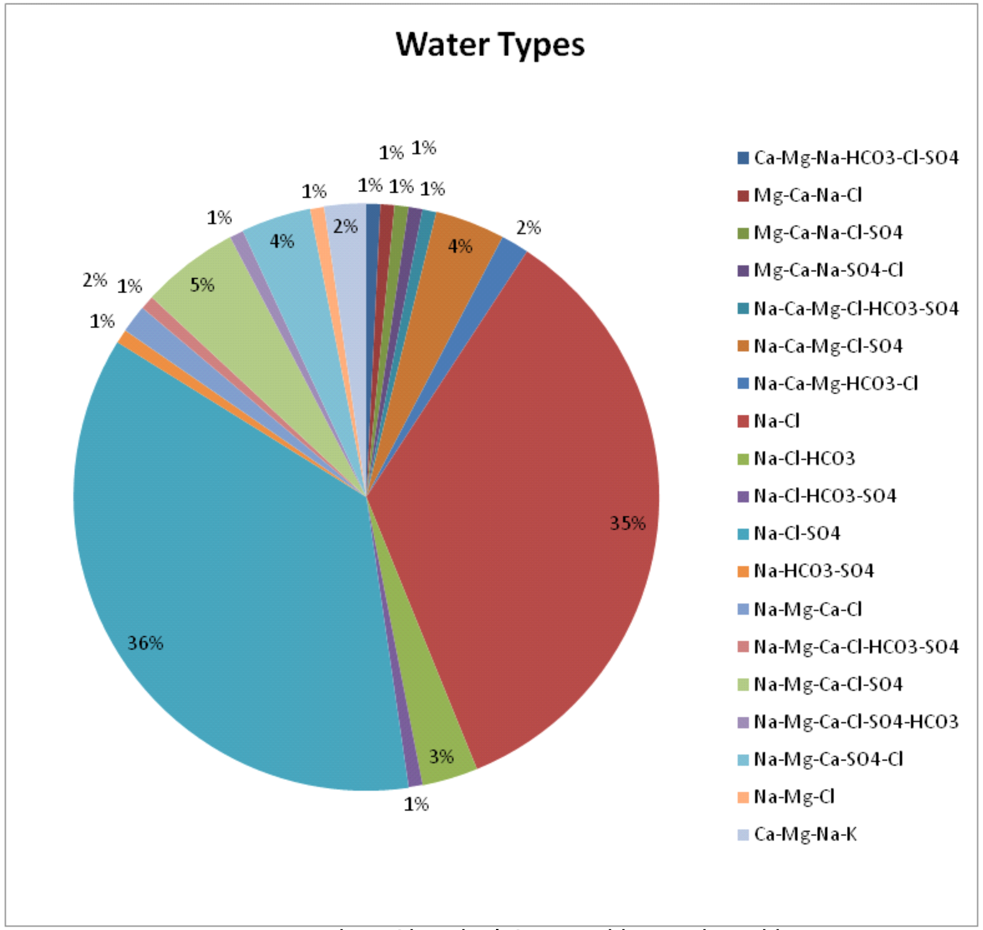
Figure Title: hydrogeological cross sections showing salinity transition zone - Brampton Pit	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 13

Figure 14.

Water Types



Piper Plot of 135 Groundwater Samples Across the Cloudbreak-Christmas Creek Area. Jeerinah Fm samples shown in red.

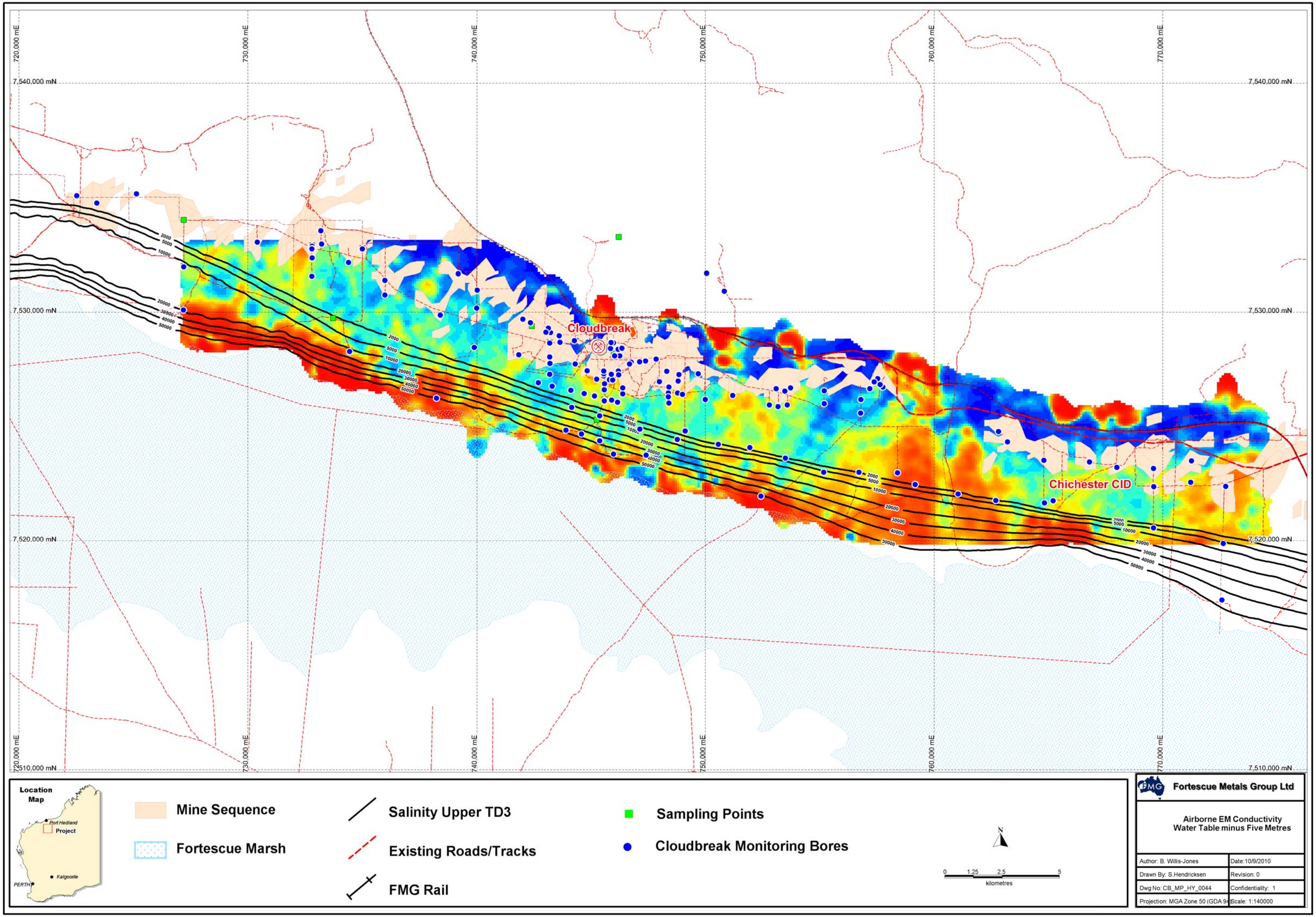


Water Types Based on Chemical Composition and Position on Piper Plot. Dominant Water Types 1) Na-Cl-SO4 (36%), 2) Na-Cl (34%), 3) Na-Mg-Ca-Cl-SO4 (5%), 4) Na-Mg-Ca-SO4-Cl (4%)

Figure Title:	
Water Types	
Report Title:	
Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 14

Figure 15.

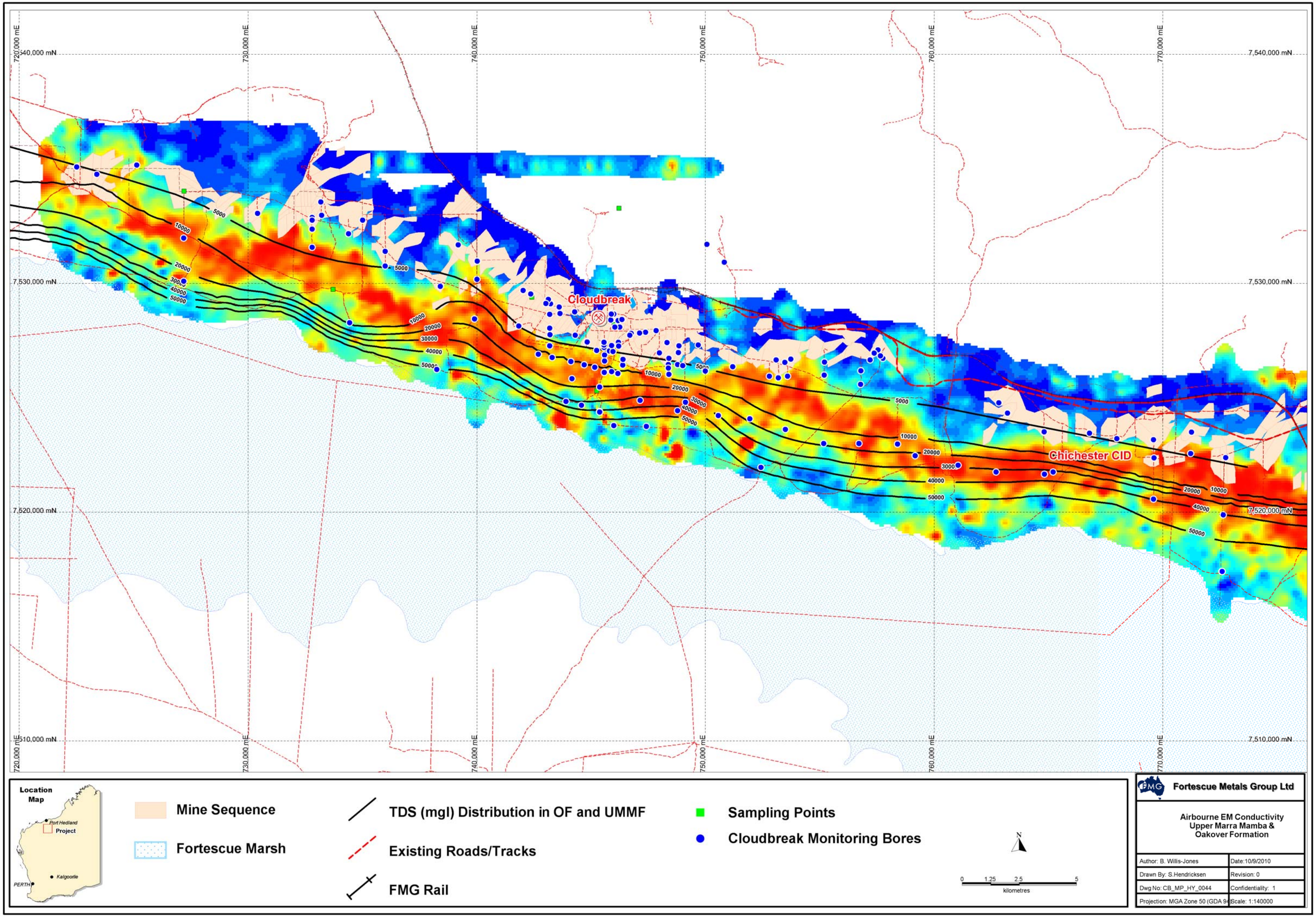
SkyTem Conductivity Response at Watertable



720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
7,510,000 mN
Cloudbreak
Chichester CID
2000
5000
10000
20000
30000
40000
50000
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Sequence
Fortescue Marsh
Salinity Upper TD3
Existing Roads/Tracks
FMG Rail
Sampling Points
Cloudbreak Monitoring Bores
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Airborne EM Conductivity
Water Table minus Five Metres
Author: B. Willis-Jones
Date:10/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000

Figure 16.

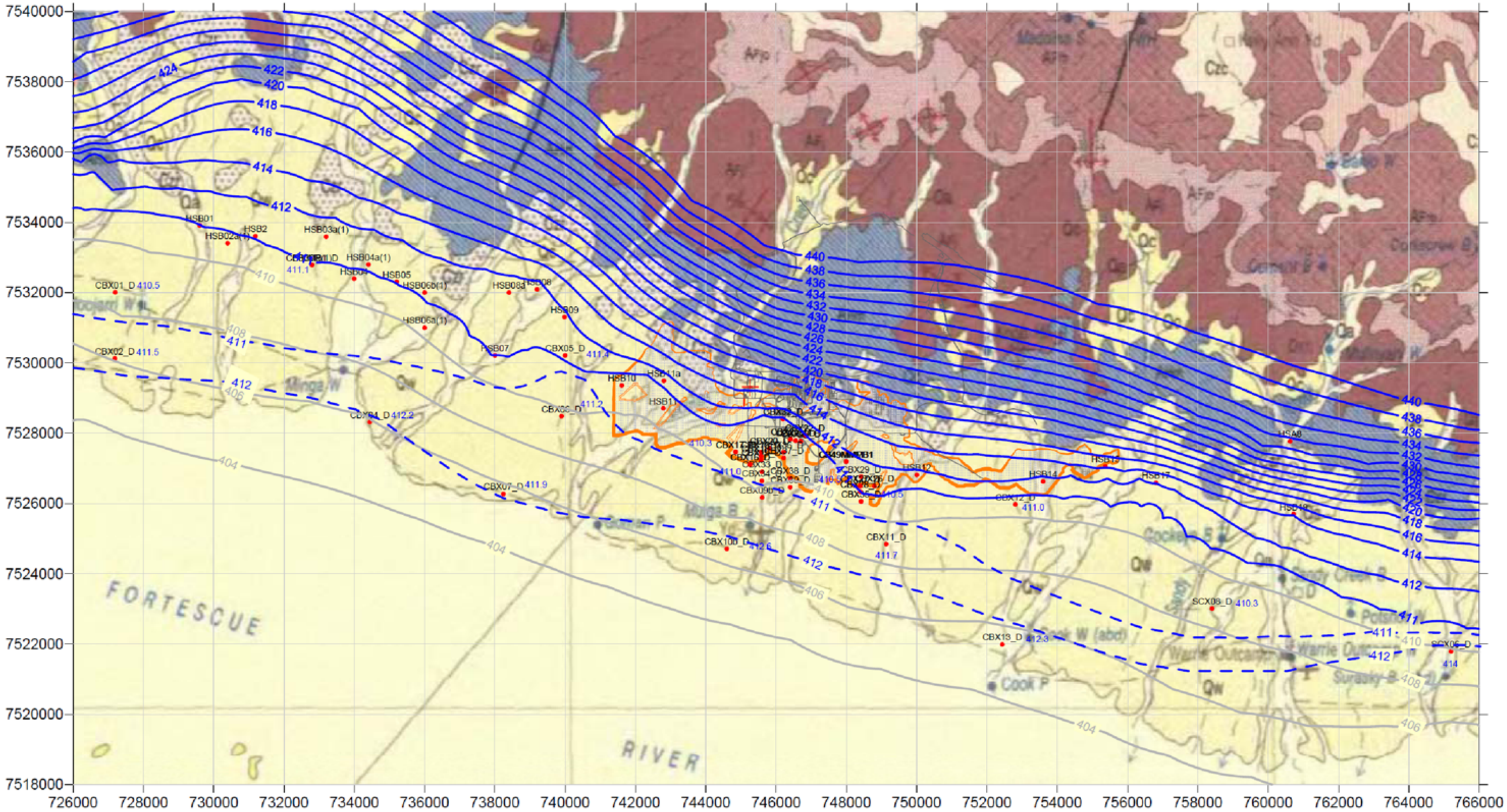
SkyTem Conductivity Response at Upper Marra Mamba Formation and Oakover Formation



Cloudbreak
Chichester CID
7,540,000 mN
7,530,000 mN
7,520,000 mN
7,510,000 mN
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
5000
10000
20000
30000
40000
50000
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Sequence
Fortescue Marsh
TDS (mgl) Distribution in OF and UMMF
Existing Roads/Tracks
FMG Rail
Sampling Points
Cloudbreak Monitoring Bores
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Airbourne EM Conductivity
Upper Marra Mamba &
Oakover Formation
Author: B. Willis-Jones
Date:10/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000

Figure 17.

Freshwater Equivalent Heads in Upper Marra Mamba Formation and Oakover Formation



LEGEND

400	Interpreted Water Level Contours
400	Interpreted Water Level Contours (Non-density Corrected)
400	Interpreted Water Level Contours (Freshwater Equivalent)
CBX01_I	Monitoring Bore Sites

Figure Title:
Fresh water Equivalent Heads in
Marra Mamba Formation and Oakover Formation

Report Title:
Hydrogeological assessment for Cloudbreak
Water Management Scheme

Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 17

Figure 18.

Schematic Cloudbreak Water Management Scheme

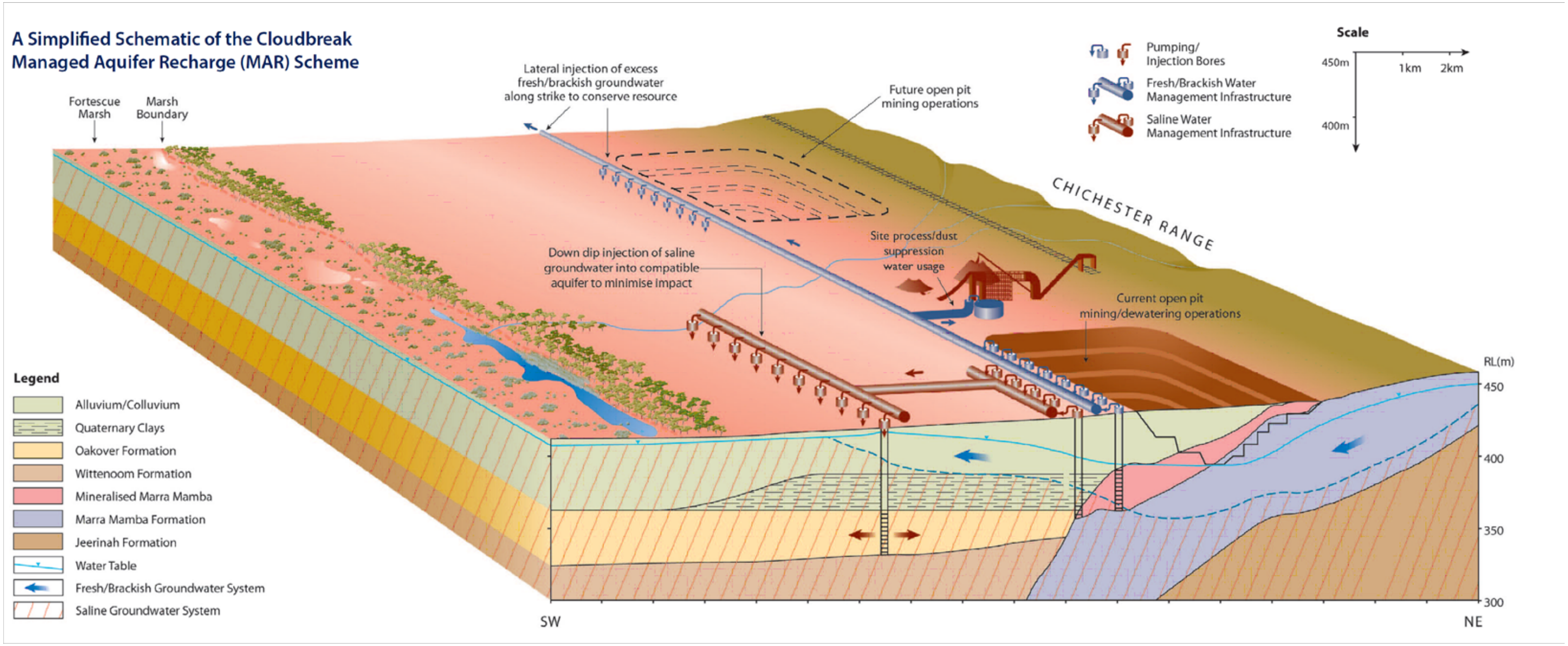


Figure Title: Schematic Cloudbreak Water Management Scheme	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 18

Figure 19.

Operational Related drawdown and Mounding at the Watertable (July 2010)

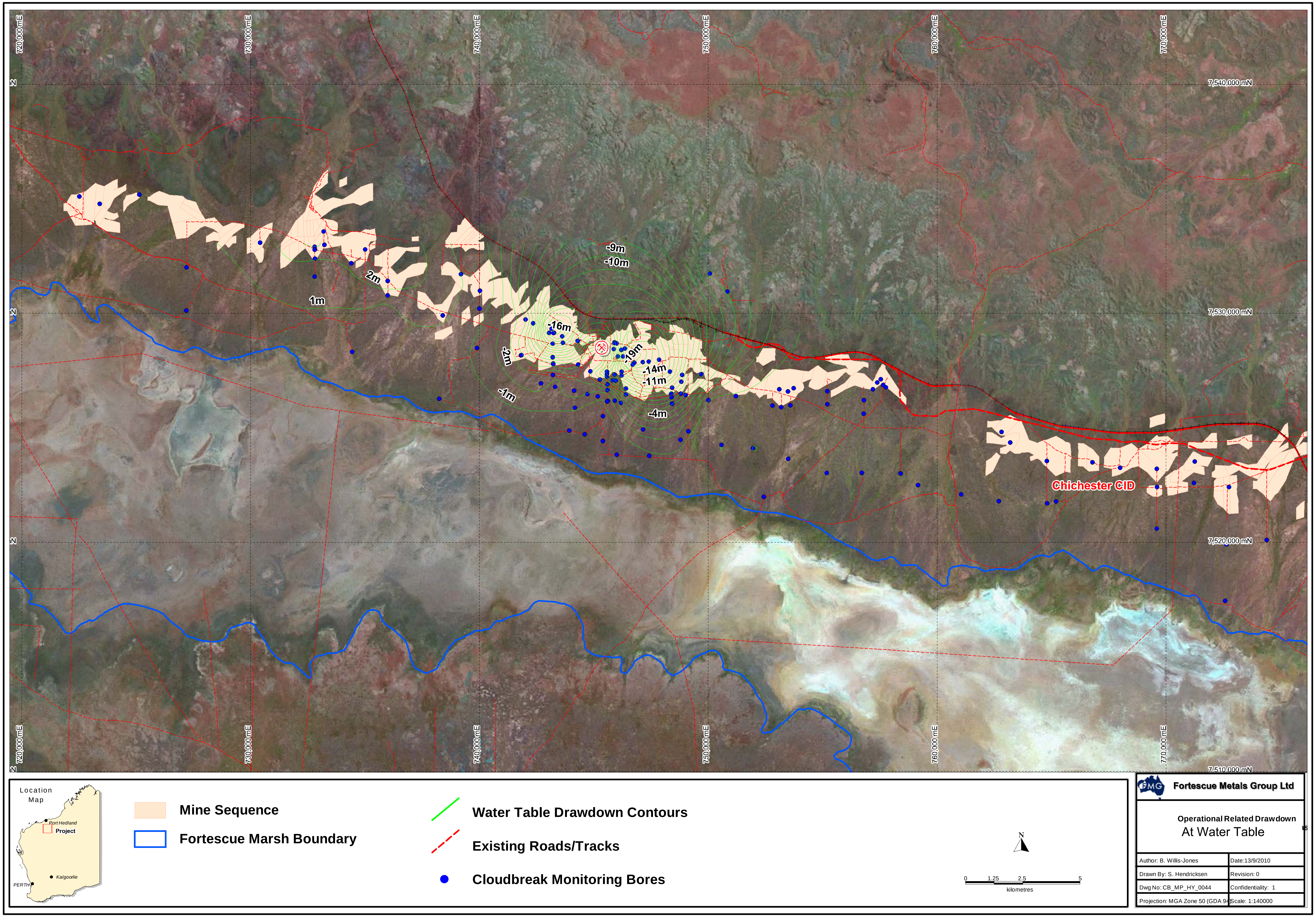
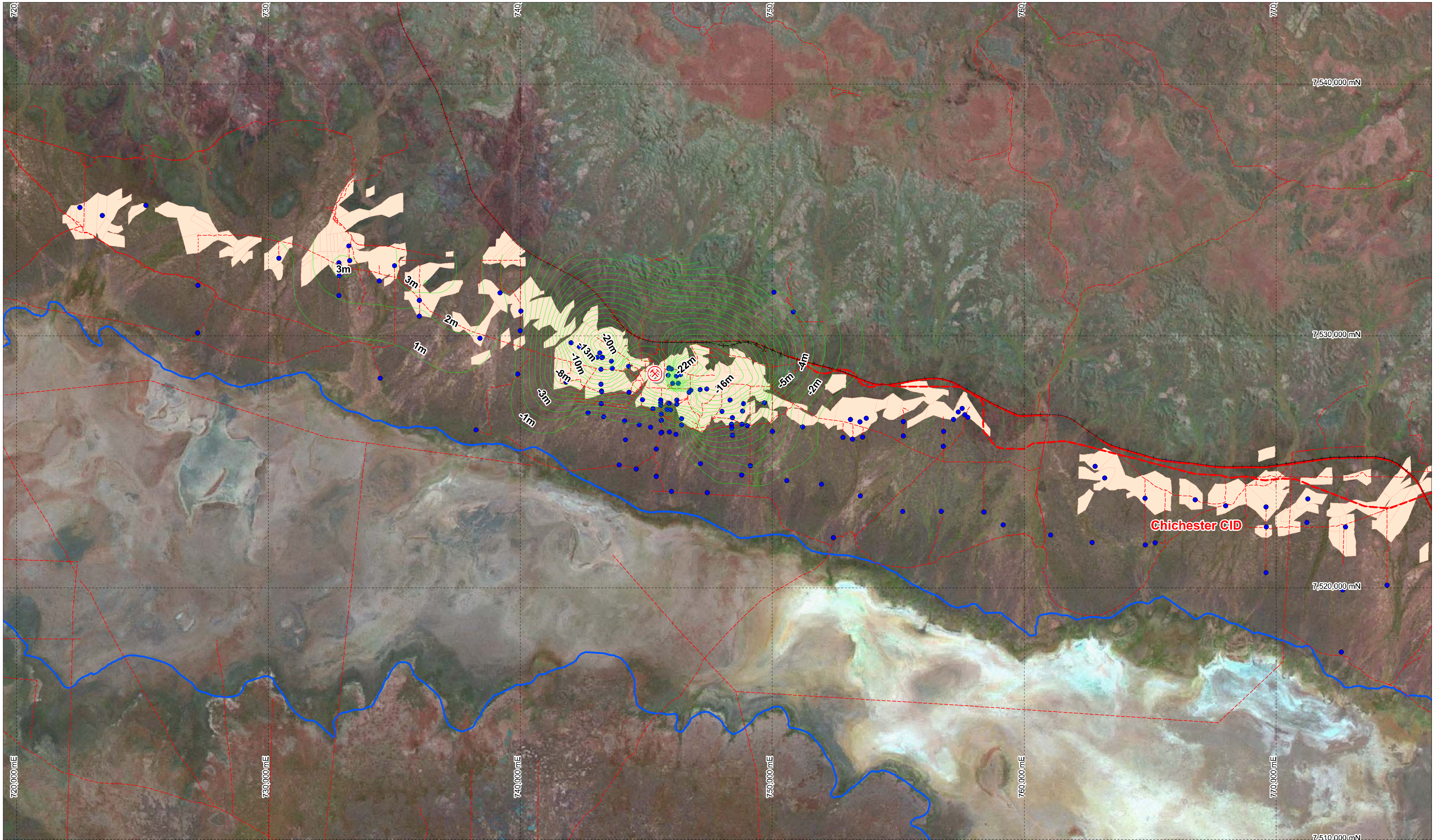

720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
7,510,000 mN
-9m
-10m
2m
1m
-16m
-2m
-19m
-14m
-11m
-1m
-4m
Chichester CID
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Sequence
Fortescue Marsh Boundary
Water Table Drawdown Contours
Existing Roads/Tracks
Cloudbreak Monitoring Bores
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Operational Related Drawdown
At Water Table
Author: B. Willis-Jones
Date:13/9/2010
Drawn By: S. Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000

Figure 20.

Operational Related drawdown and Mounding in Upper Marra Mamba Formation and Oakover Aquifers (July 2010)



Mine Sequence

Fortescue Marsh Boundary

Drawdown (-ve) and Mounding (+ve) impacts (m)

Existing Roads/Tracks

Cloudbreak Monitoring Bores

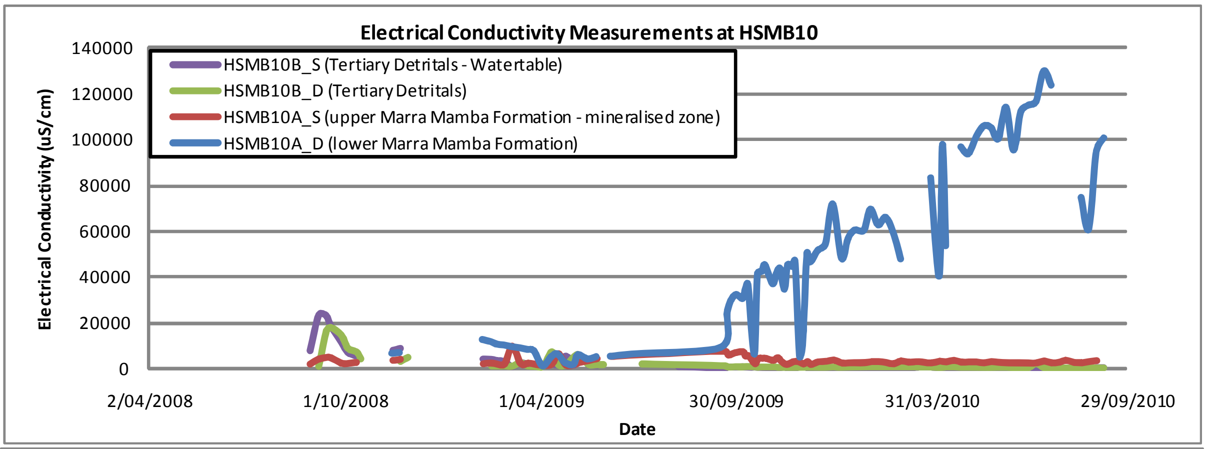
Fortescue Metals Group Ltd

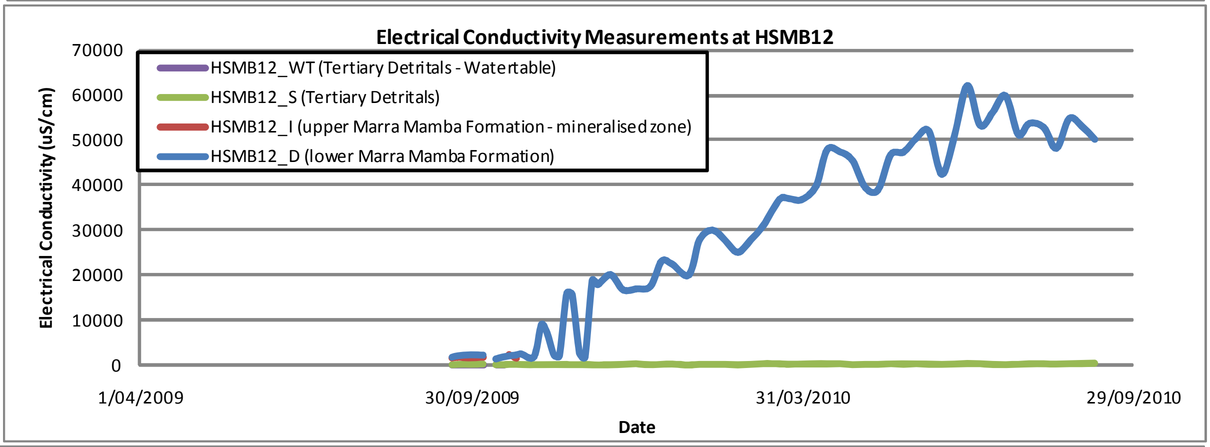
Operational Related Drawdown in Upper MMF & Oakover Formations

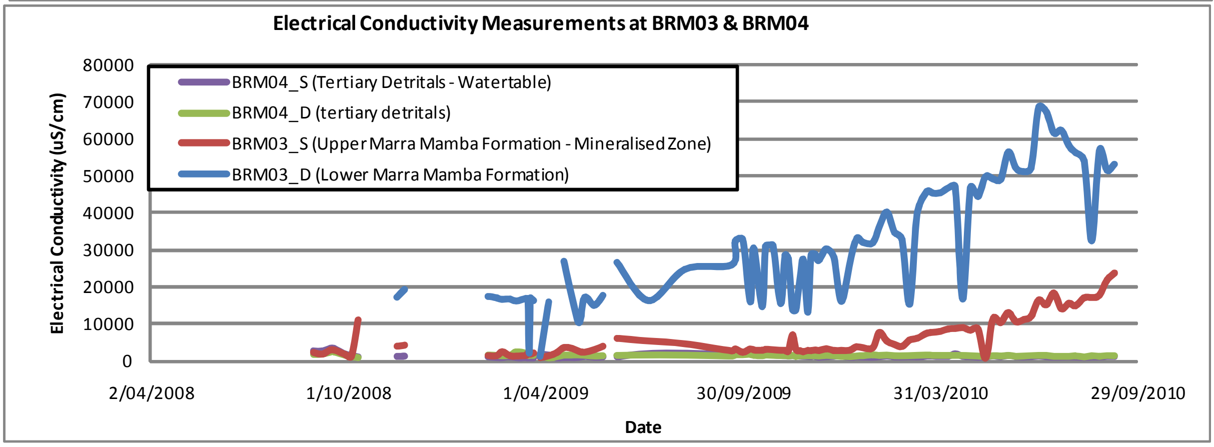
Author: B. Willis-Jones	Date:13/9/2010
Drawn By: S. Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000

Figure 21.

Operational Related Saline water Ingress







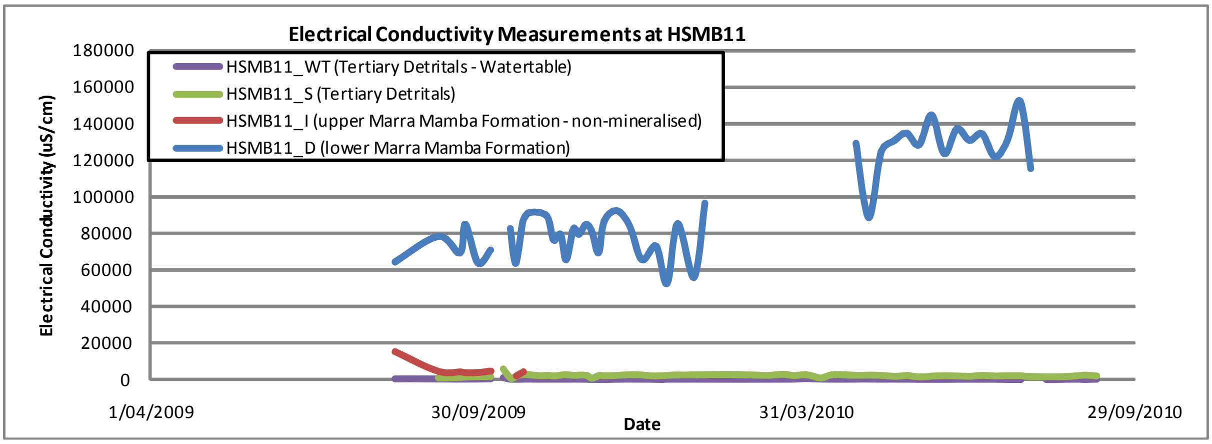


Figure Title:

Saline Groundwater Ingress

Report Title:

Hydrogeological assessment for Cloudbreak Water Management Scheme

Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 21

Figure 22.

Fortescue Marsh Conceptual Model

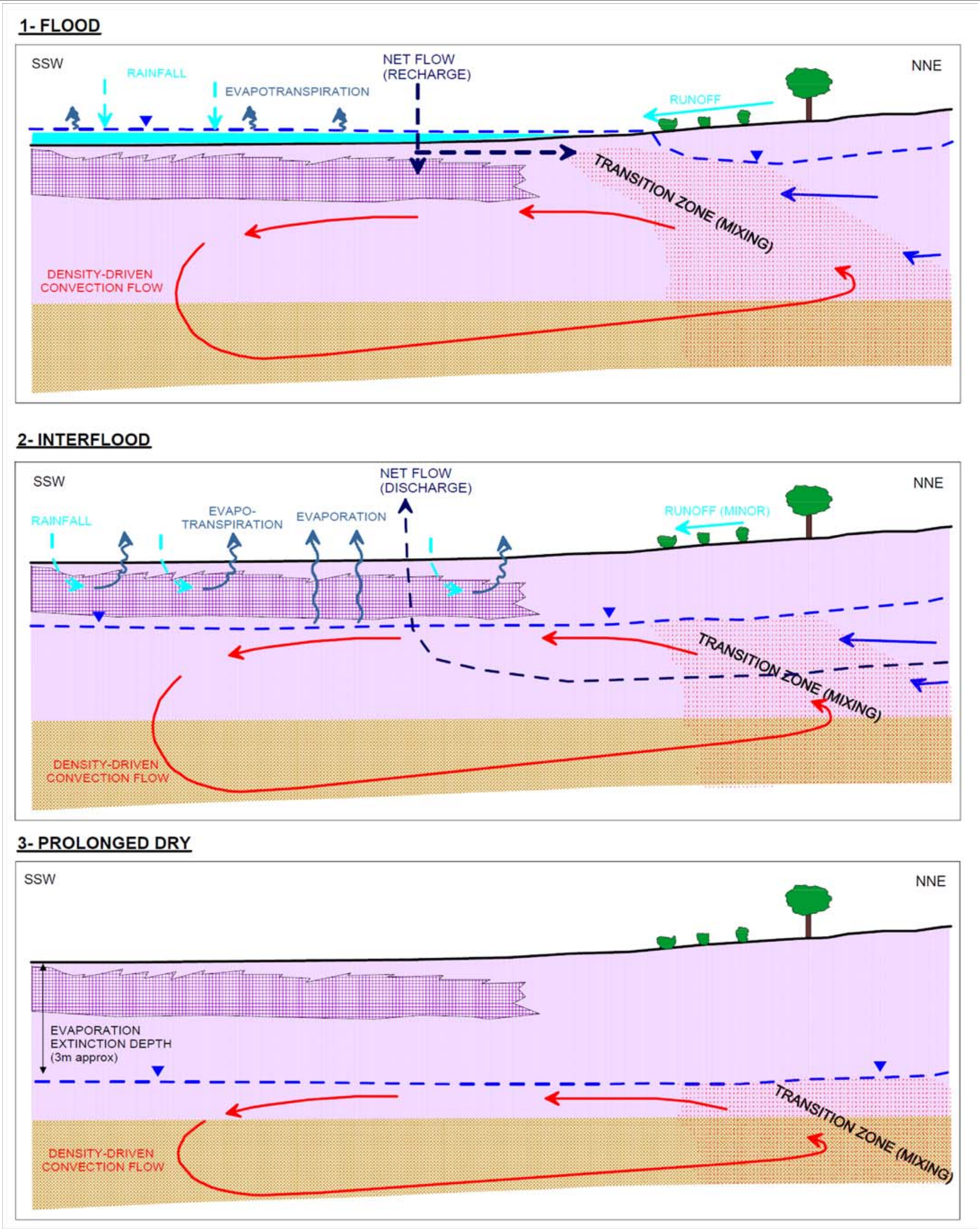
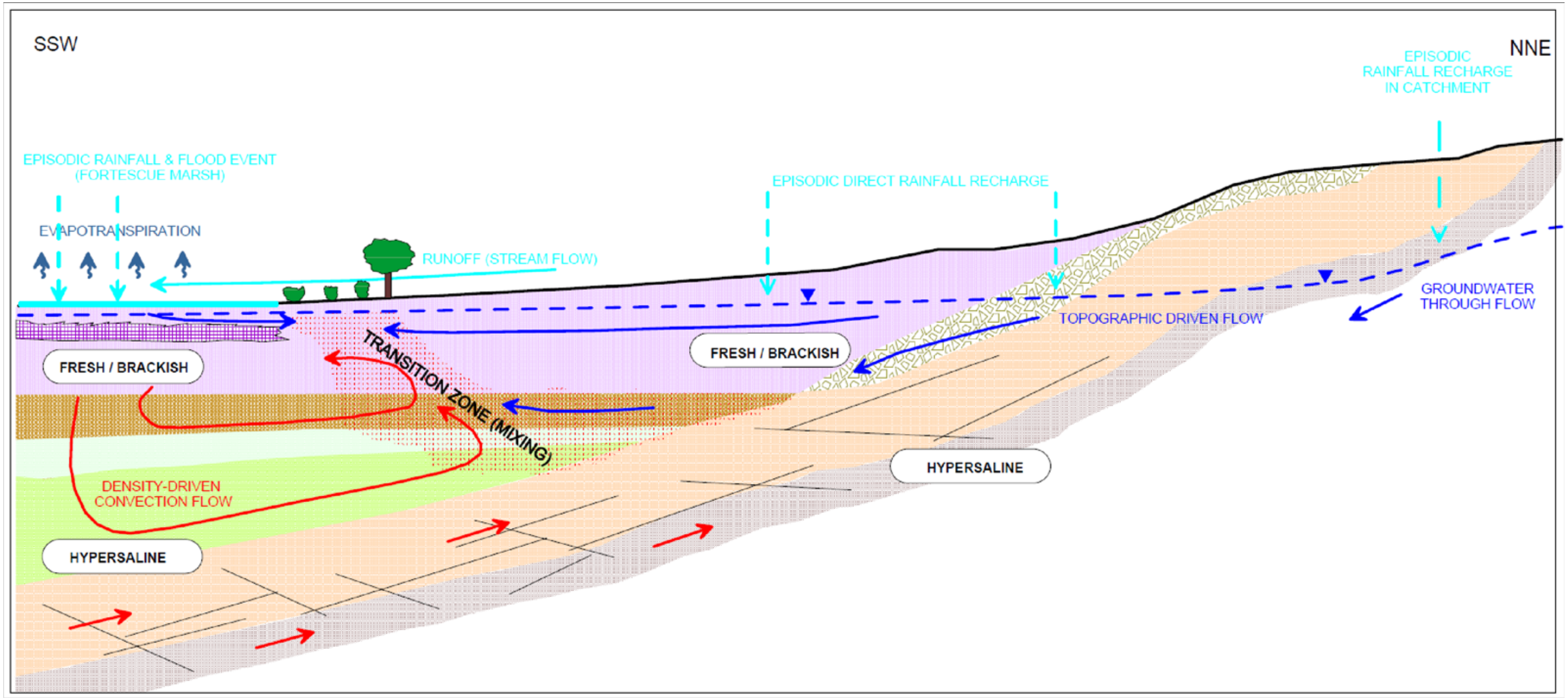


Figure Title: Fortescue Marsh Conceptual Model	FMG
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 22

Figure 23.

Cloudbreak Hydrological Conceptual Model



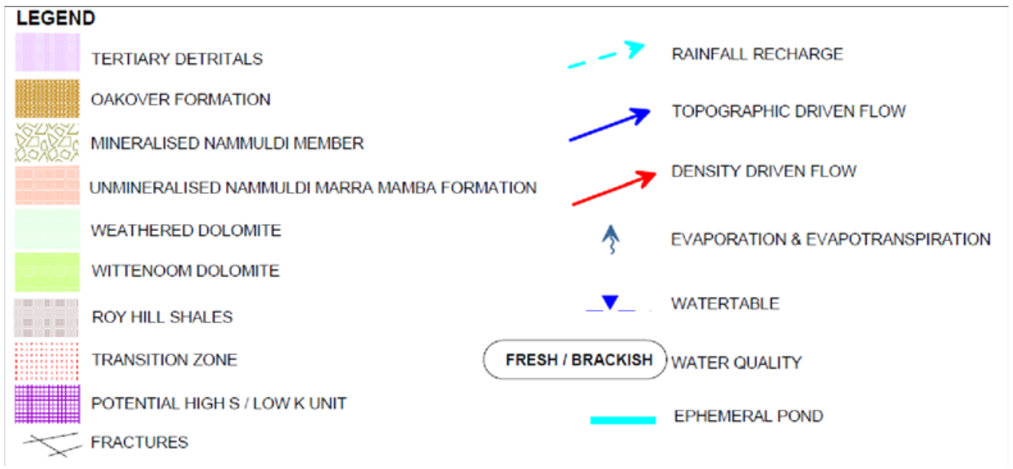


Figure Title: Cloudbreak Project Area Conceptual Model	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 23

Figure 24.

Numerical Model Domain and Mesh

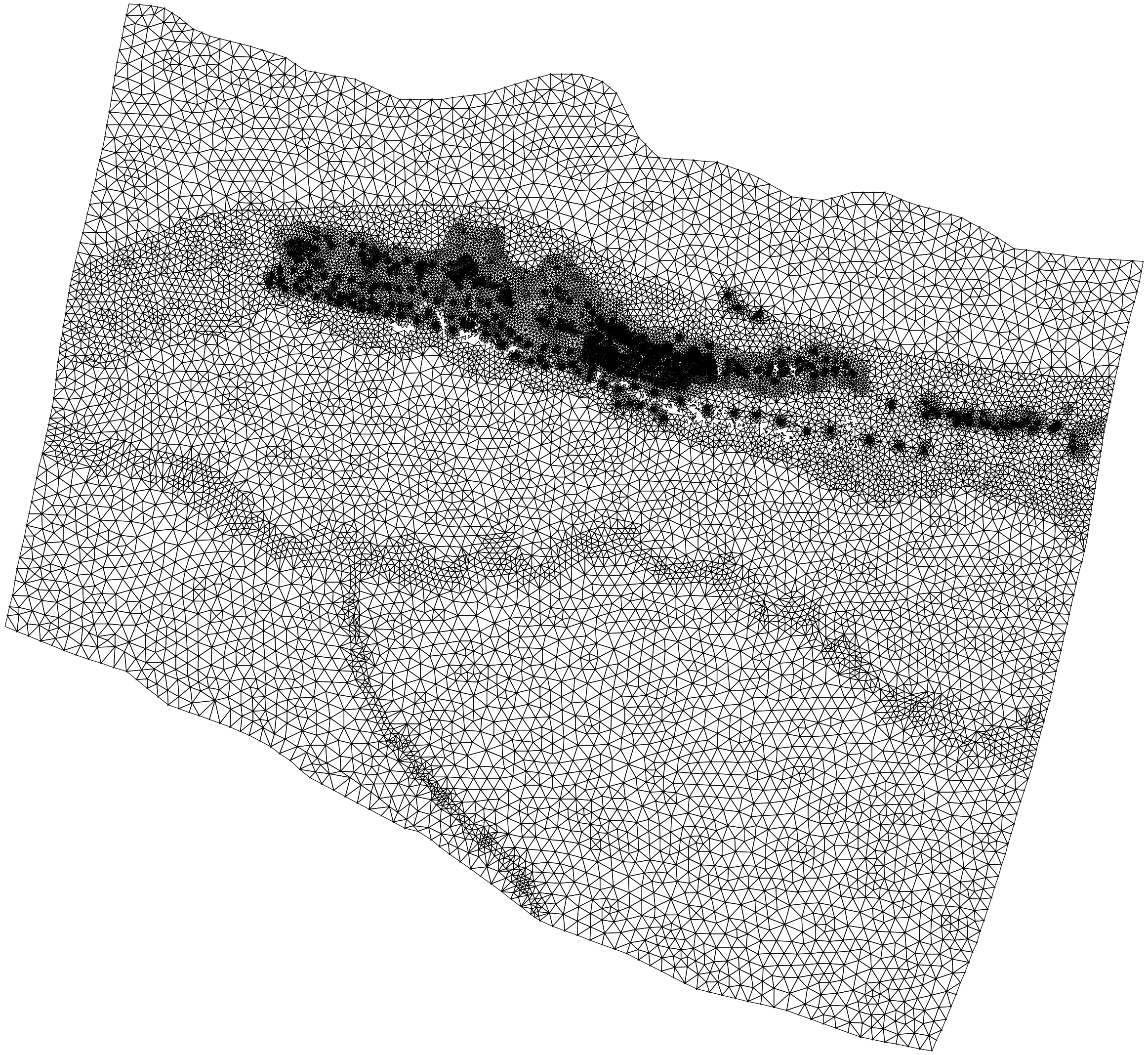
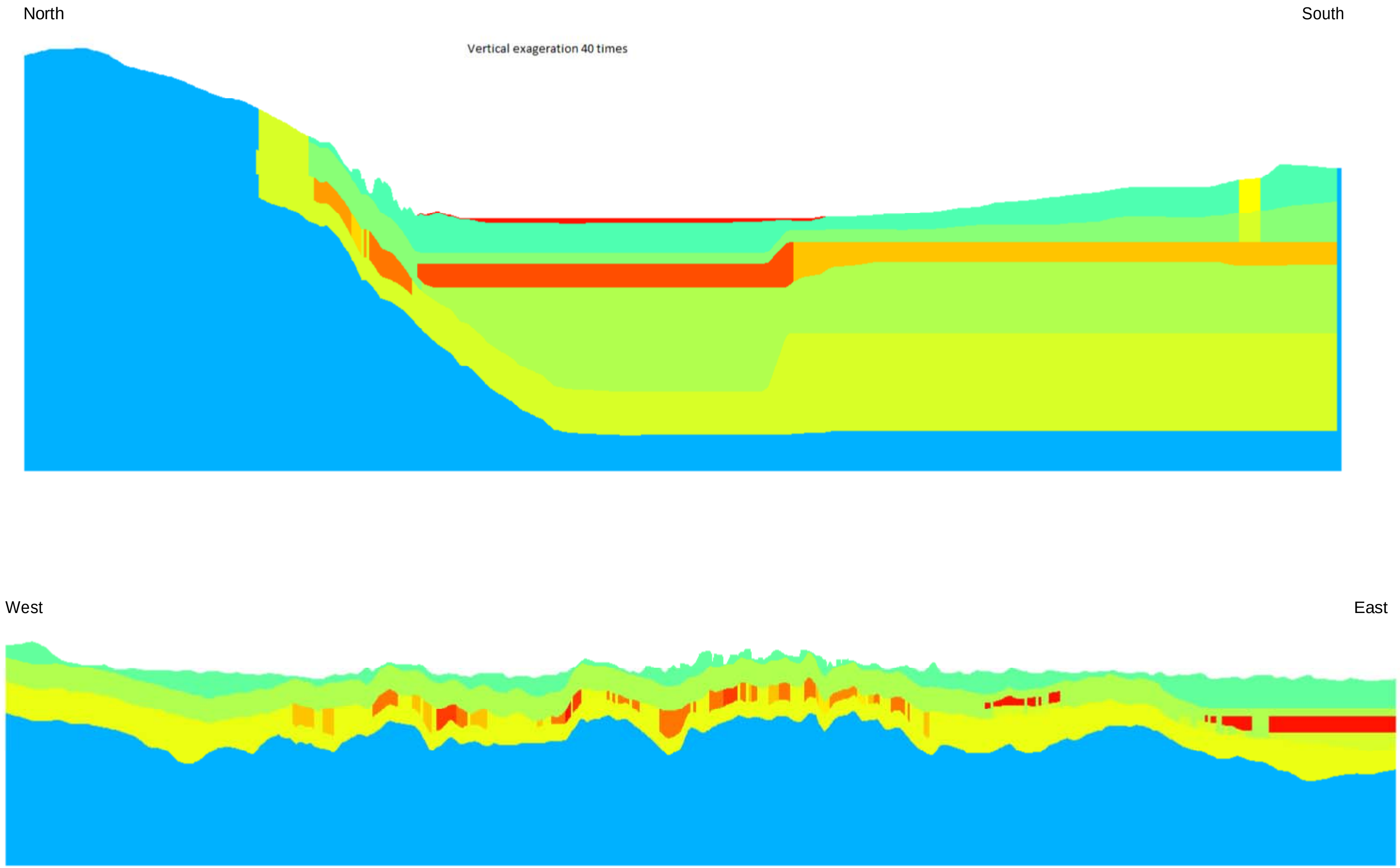


Figure Title: Numerical Model Domain and Mesh	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 24

Figure 25.

Model Layering and Property Distribution



- Hollow layer (Fortescue Marsh)
- Tertiary Detritals (upper TD3)
- Tertiary Detritals (lower TD3)
- Wittenoom Dolomite
- Calcrete
- Oakover Formation
- Un-mineralised Marra Mamba Formation
- Roy Hill Shales
- Mineralised Marra Mamba Formation

Figure Title: Model Layering and Property Distributions	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 25

Figure 26.

Steady State Calculated vs Observed Model Calibration Summary

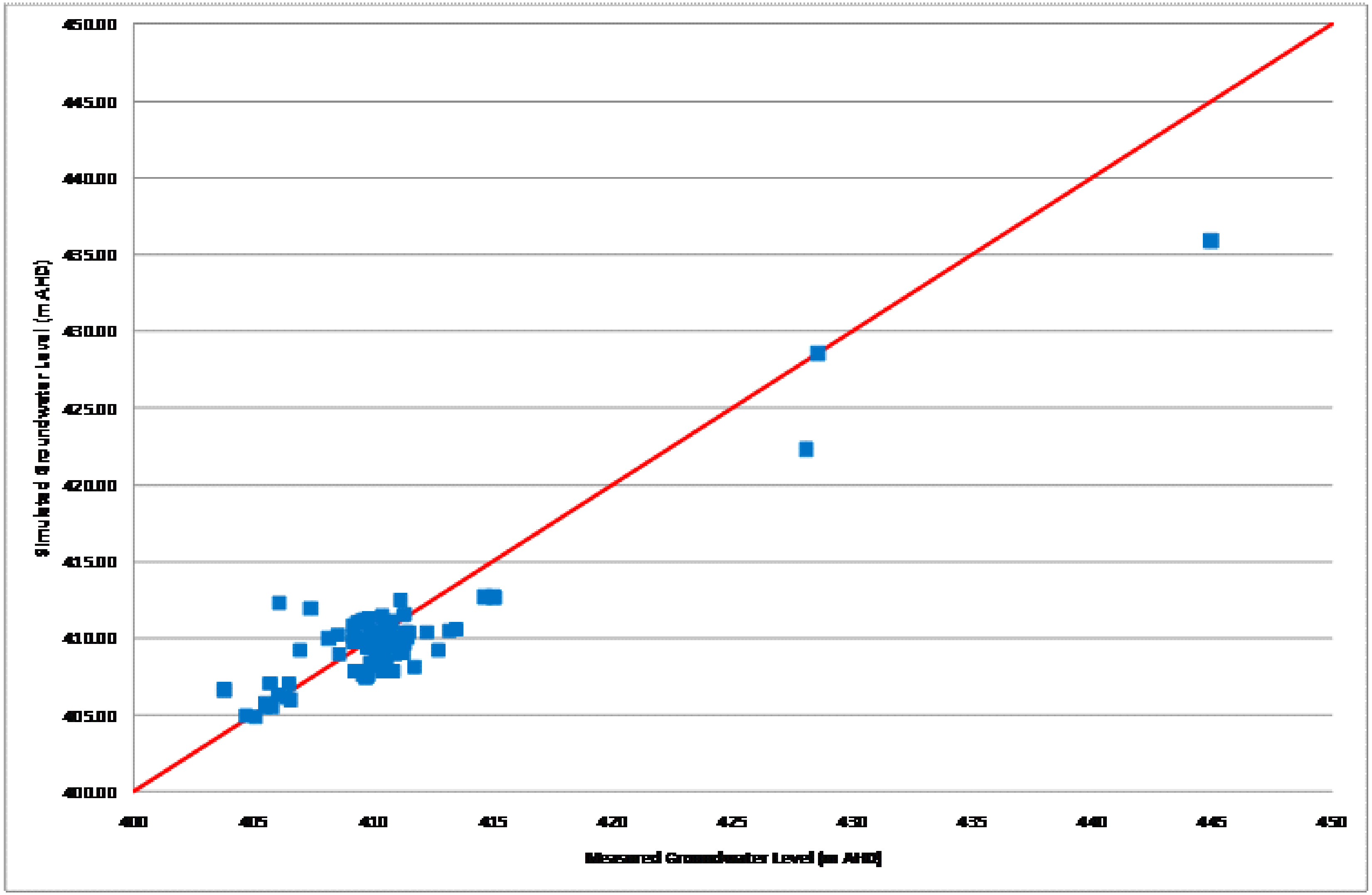


Figure Title:

Steady State Calibration
Observed vs Calculated Heads

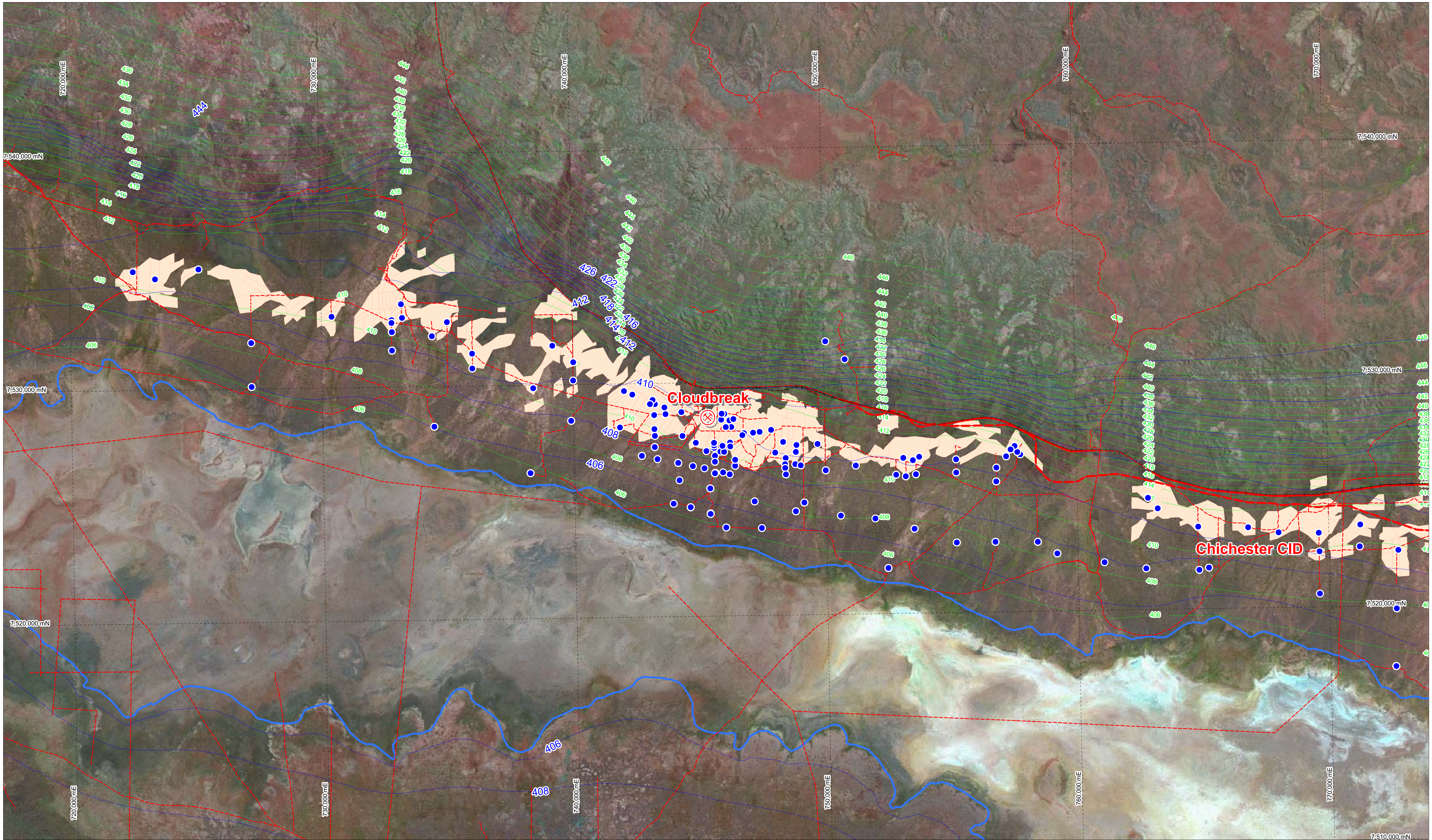
Report Title:

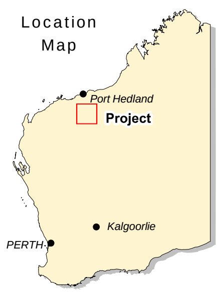
Hydrogeological assessment for Cloudbreak
Water Management Scheme

Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 26

Figure 27.

Steady-State Simulated versus Observed Water Table





Mine Sequence

Fortescue Marsh Boundary

Simulated Pre-Mining Water Table Elevation (mAHD)

Water Table Elevations (Late 2007) in mAHD

Existing Roads/Tracks

Cloudbreak Monitoring Bores

N

0 1.25 2.5 5
kilometres

Fortescue Metals Group Ltd

Comparison of Interpreted Water Table Elevation (Late 2007) and Simulated Pre-mining Water Table Elevation

Author: B. Willis-Jones	Date:9/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000

Figure 28.

Transient Calculated vs Observed Model Calibration Summary

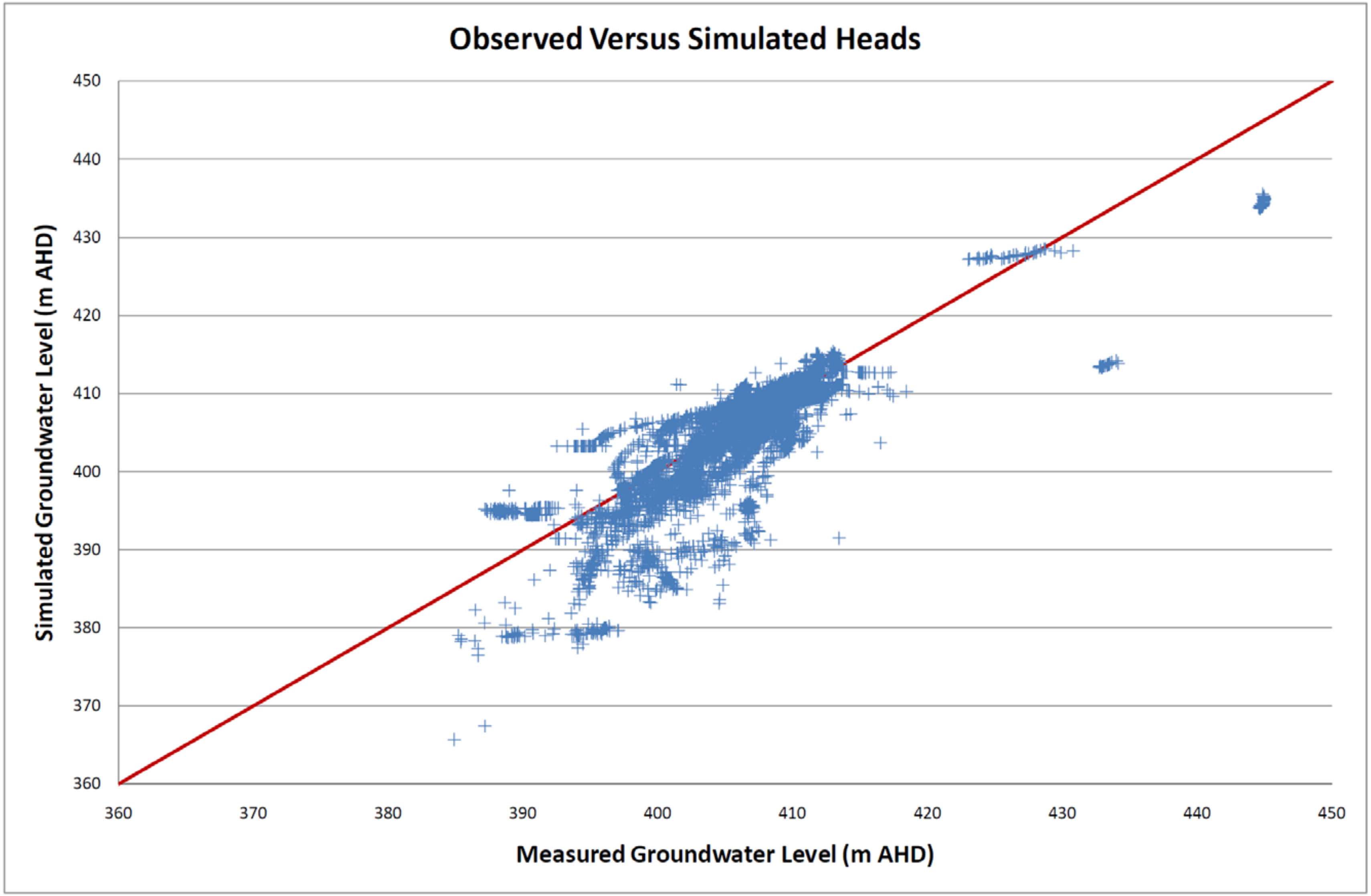
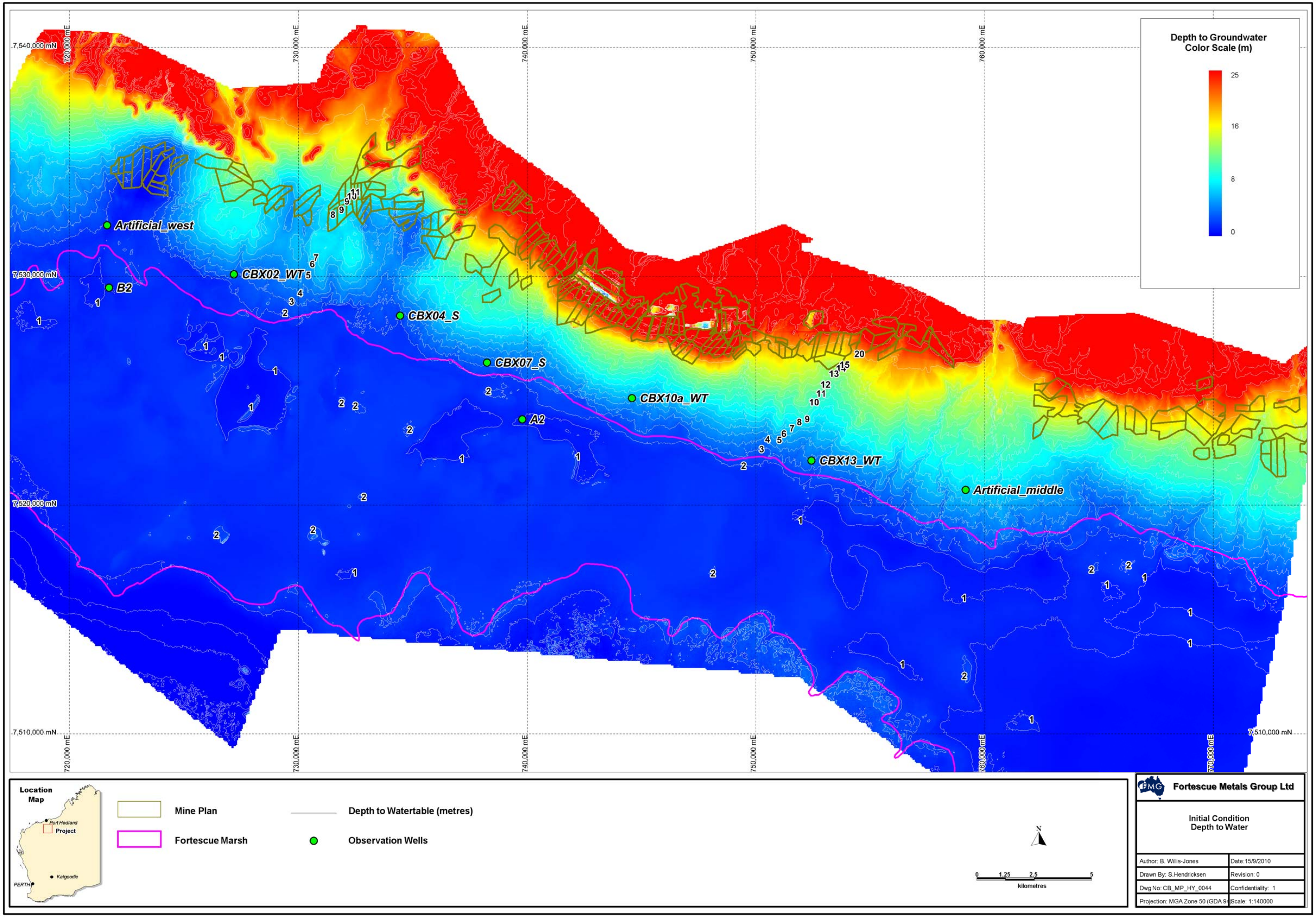


Figure Title: Transient Calibration Observed vs Calculated Heads	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 28

Figure 29.

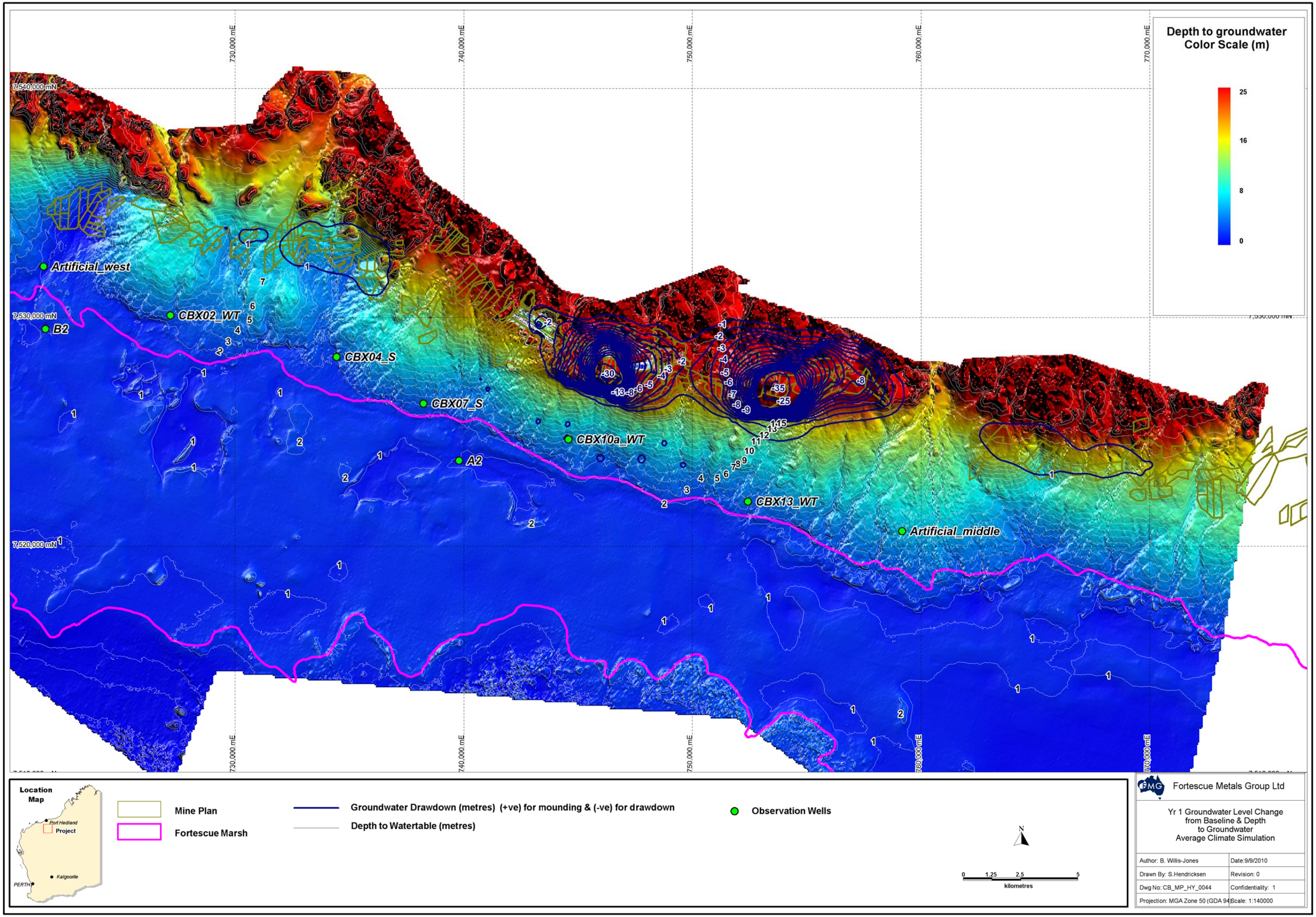
Depth to Watertable Initial Condition



Depth to Groundwater
Color Scale (m)
25
16
8
0
Artificial_west
B2
CBX02_WT
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
7,540,000 mN
7,530,000 mN
7,520,000 mN
7,510,000 mN
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Depth to Watertable (metres)
Observation Wells
N
0
1.25
2.5
5
kilometres
Fortescue Metals Group Ltd
Initial Condition
Depth to Water
Author: B. Willis-Jones
Date:15/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94
Scale: 1:140000

Figure 30.

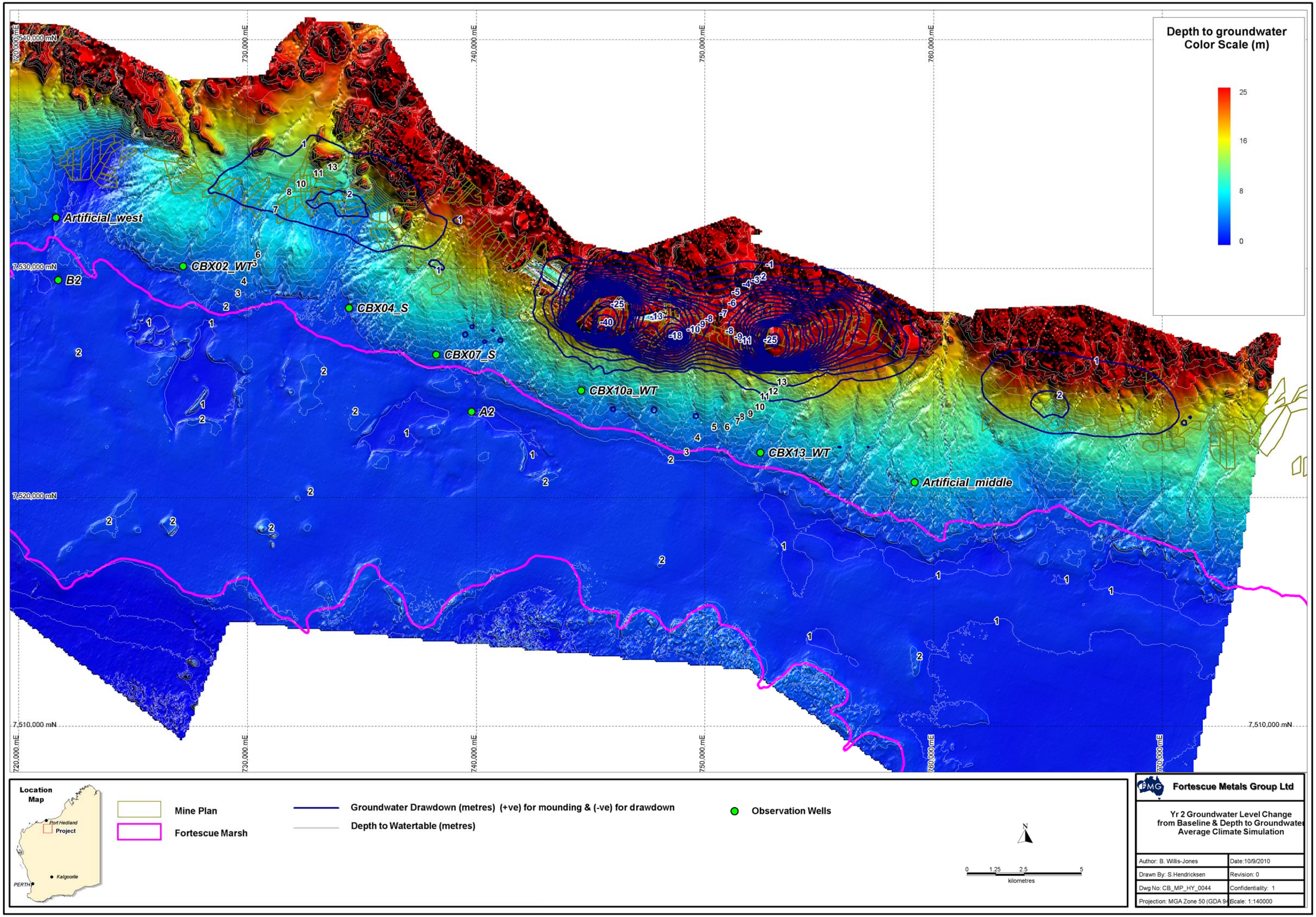
Groundwater Level Change from Baseline and Depth to Water – Year 1



Depth to groundwater Color Scale (m)
25
16
8
0
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Artificial_west
CBX02_WT
B2
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
-30
-35
-25
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0
1.25
2.5
5
kilometres
Fortescue Metals Group Ltd
Yr 1 Groundwater Level Change from Baseline & Depth to Groundwater Average Climate Simulation
Author: B. Willis-Jones
Date:9/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000

Figure 31.

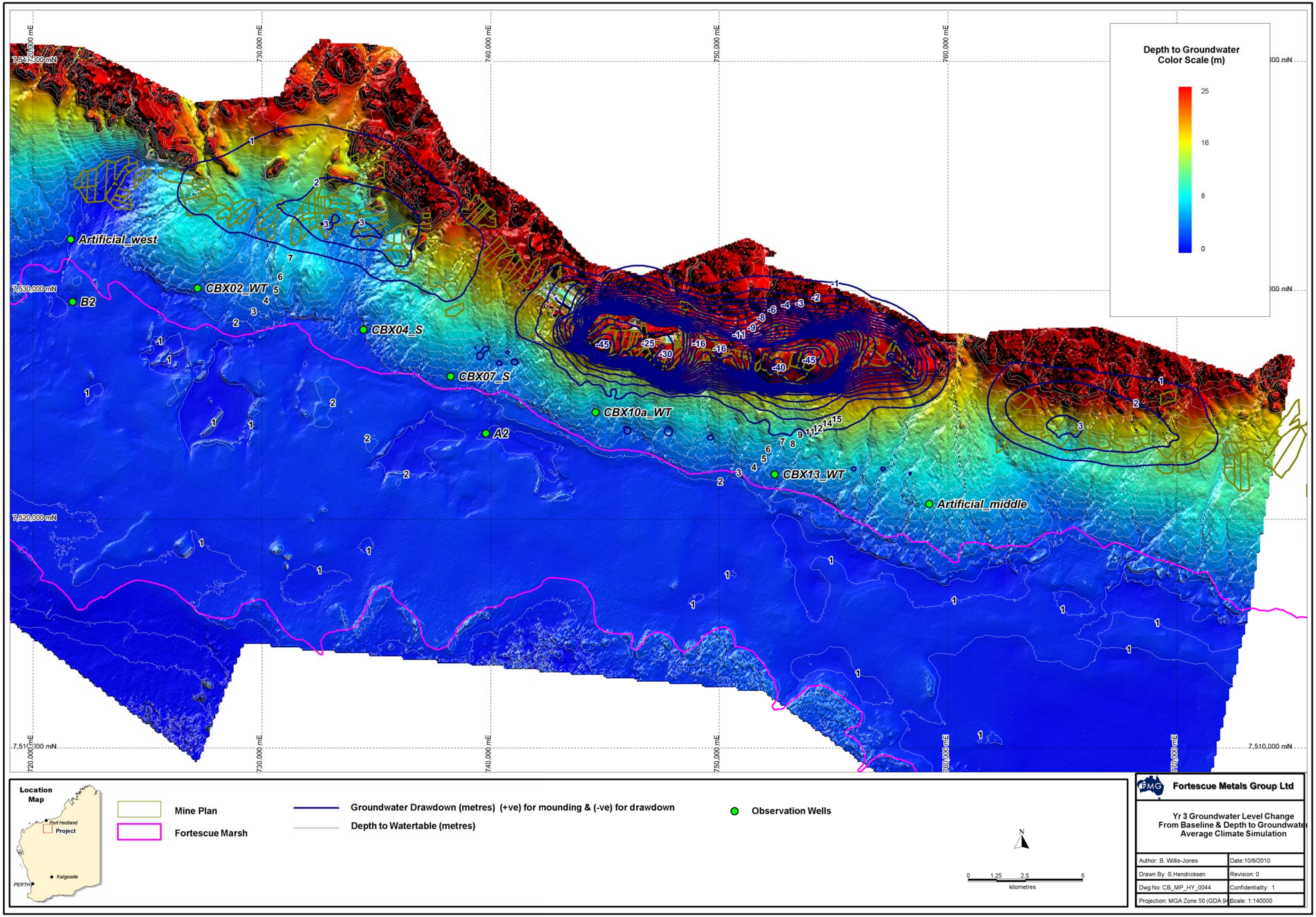
Groundwater Level Change from Baseline and Depth to Water – Year 2



Depth to groundwater Color Scale (m)
25
16
8
0
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
7,510,000 mN
Artificial_west
CBX02_WT
B2
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 2 Groundwater Level Change from Baseline & Depth to Groundwater Average Climate Simulation
Author: B. Willis-Jones
Date:10/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000

Figure 32.

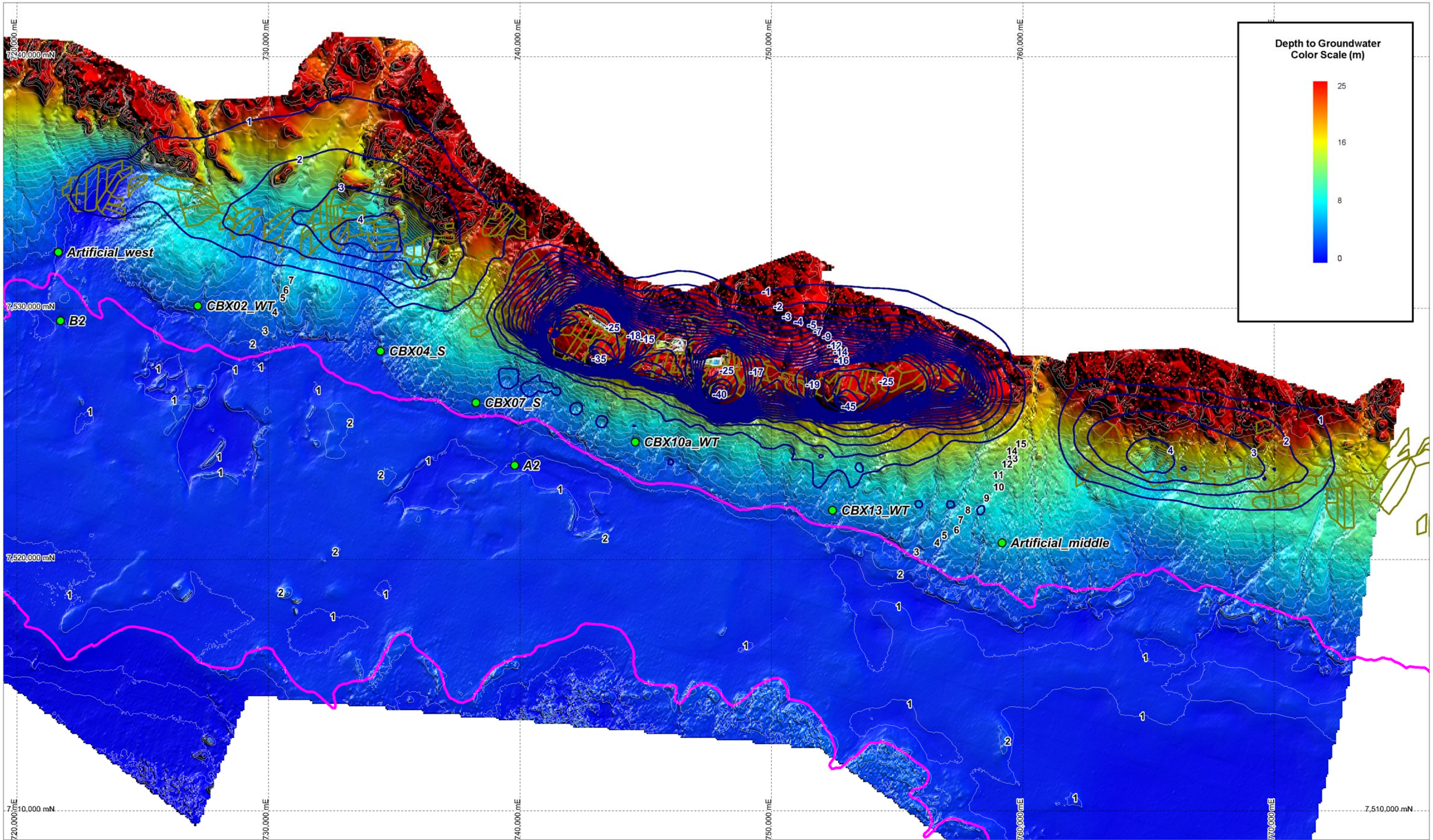
Groundwater Level Change from Baseline and Depth to Water –Year 3



Depth to Groundwater Color Scale (m)
25
16
8
0
Artificial_west
B2
CBX02_WT
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,530,000 mN
7,520,000 mN
7,510,000 mN
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 3 Groundwater Level Change From Baseline & Depth to Groundwater Average Climate Simulation
Author: B. Willis-Jones
Date:10/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000

Figure 33.

Groundwater Level Change from Baseline and Depth to Water – Year 4



Mine Plan

Fortescue Marsh

Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown

Depth to Watertable (metres)

Observation Wells

N

0 1.25 2.5 5
kilometres

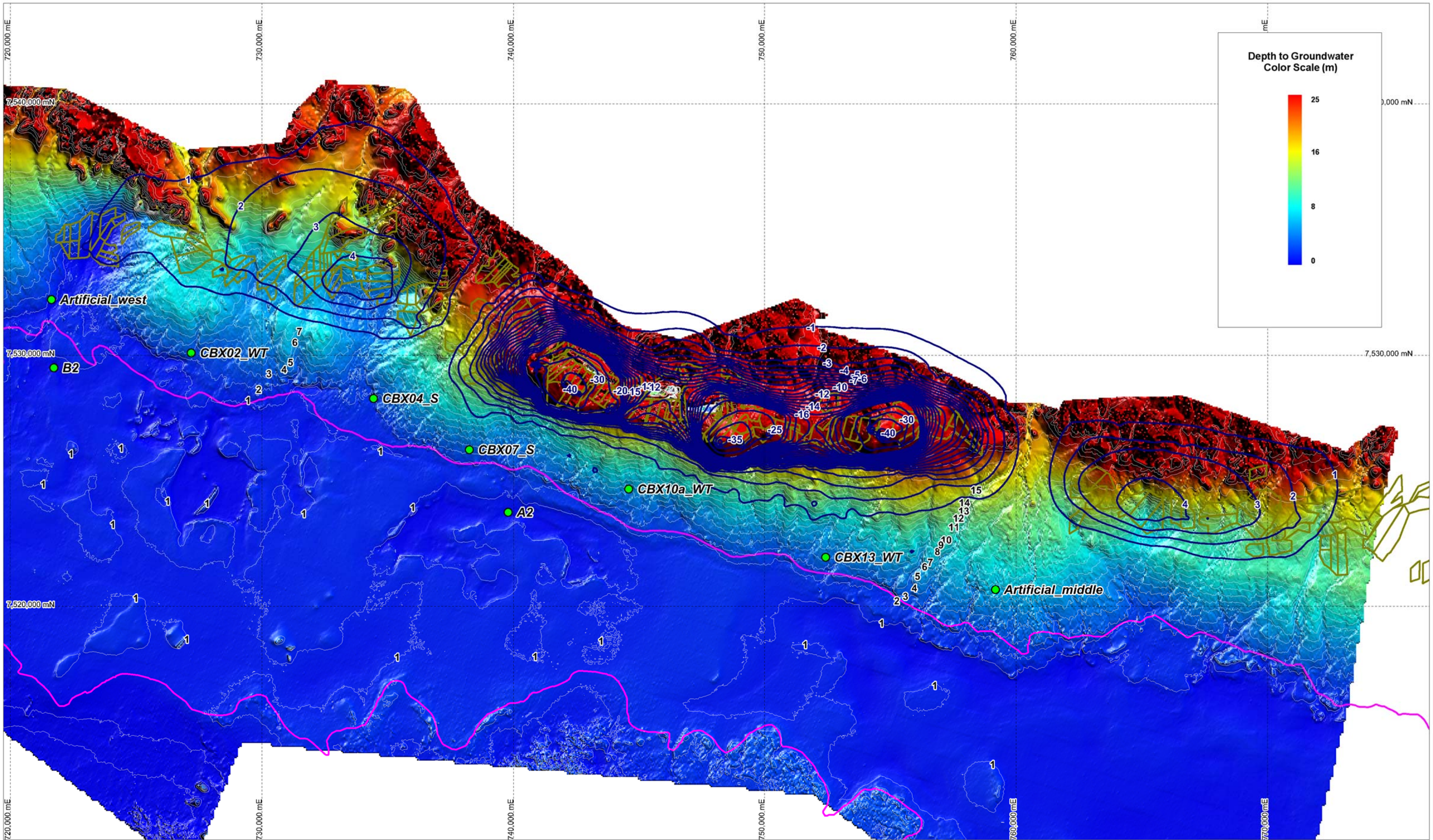
Fortescue Metals Group Ltd

Yr 4 Groundwater Level Change from Baseline & Depth to Groundwater Average Climate Simulation

Author: B. Willis-Jones	Date:15/9/2010
Drawn By: S. Hendricksen	Revision:
Dwg No: CB_MP_HY_0044	Confidentiality:
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000

Figure 34.

Groundwater Level Change from Baseline and Depth to Water – Year 5



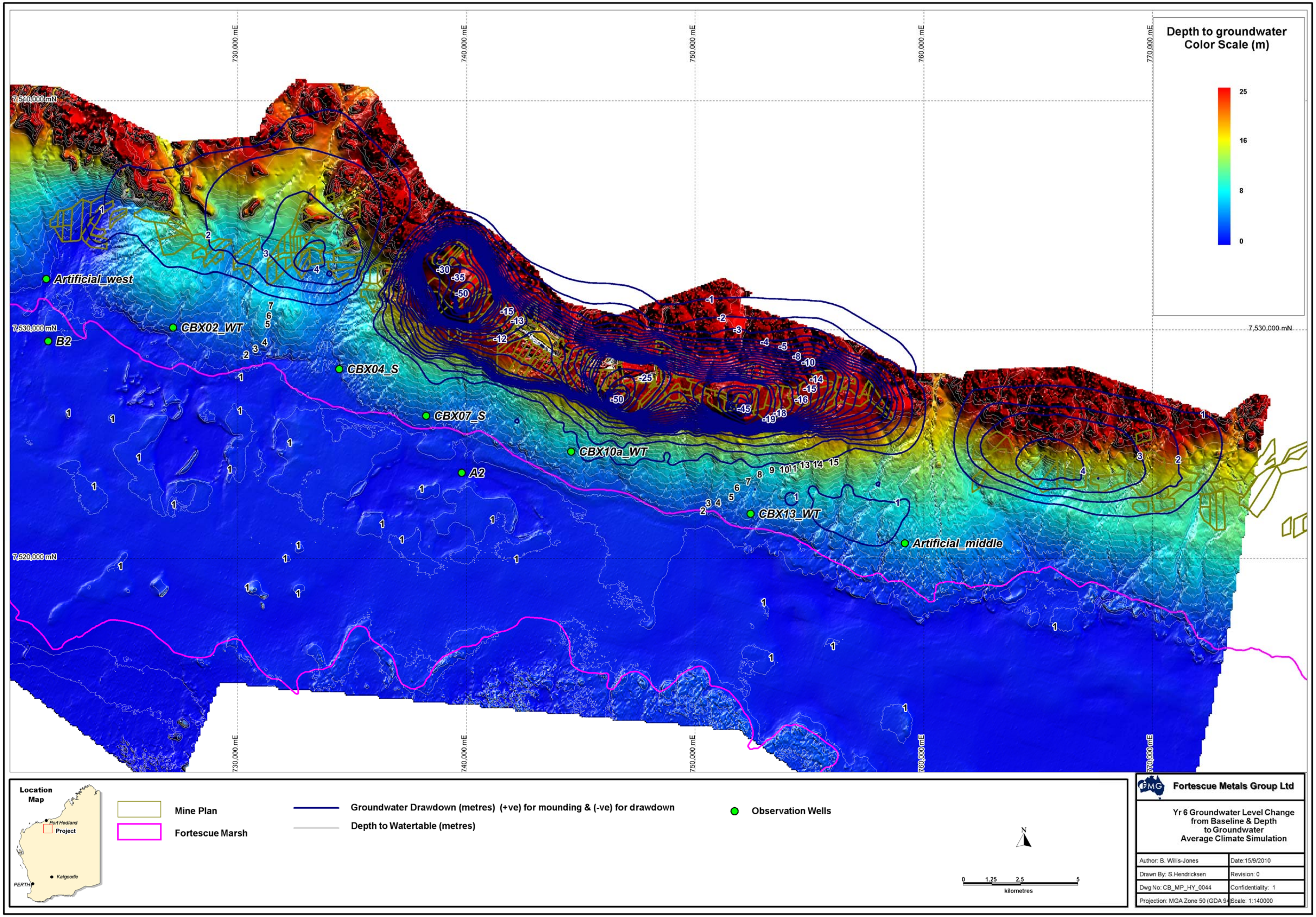
Fortescue Metals Group Ltd

Yr 5 Groundwater Level Change from Baseline & Depth to Groundwater Average Climate Simulation

Author: B. Willis-Jones	Date:15/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000

Figure 35.

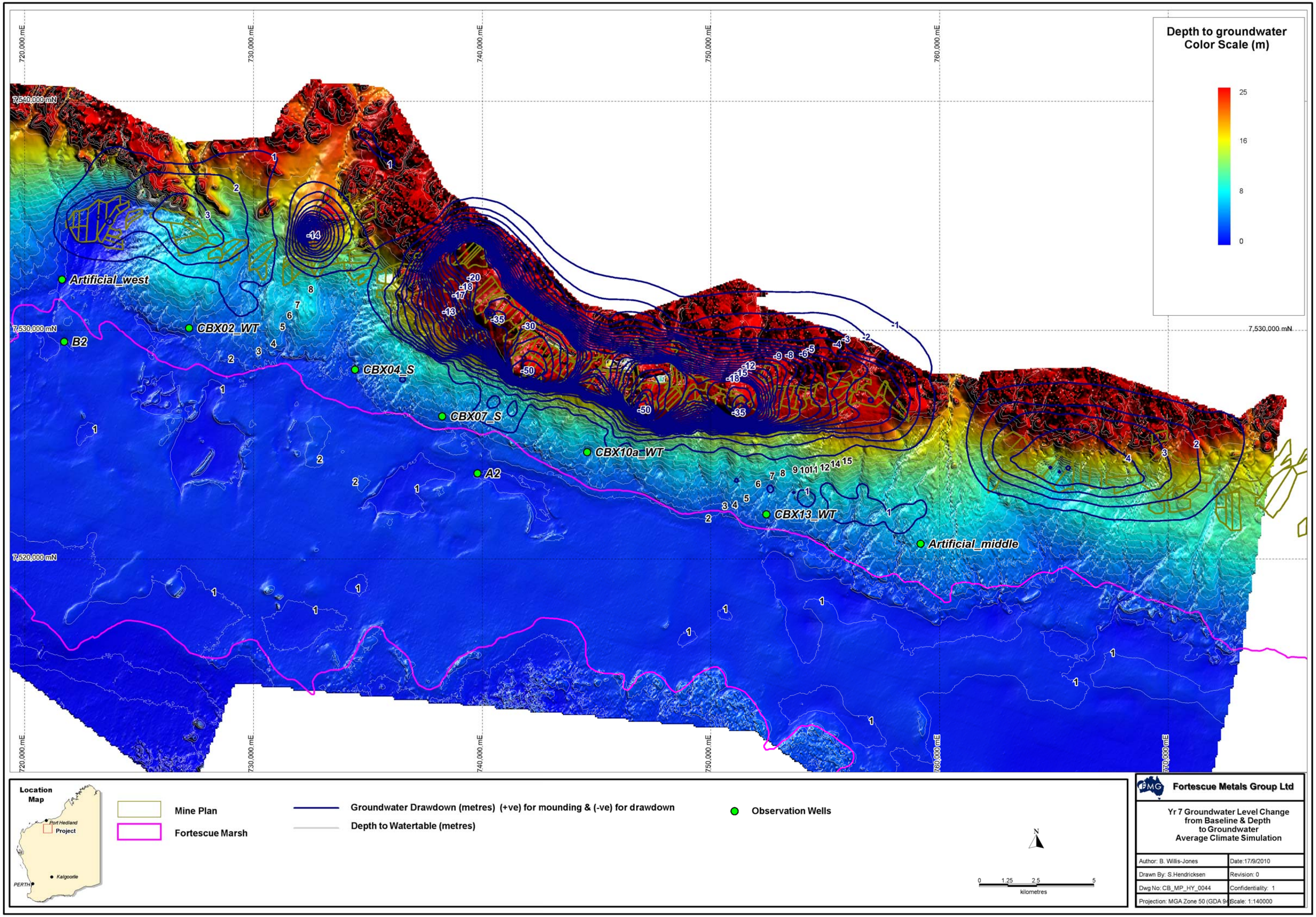
Groundwater Level Change from Baseline and Depth to Water – Year 6



Depth to groundwater Color Scale (m)
25
16
8
0
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Artificial_west
CBX02_WT
B2
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 6 Groundwater Level Change
from Baseline & Depth
to Groundwater
Average Climate Simulation
Author: B. Willis-Jones
Date:15/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000

Figure 36.

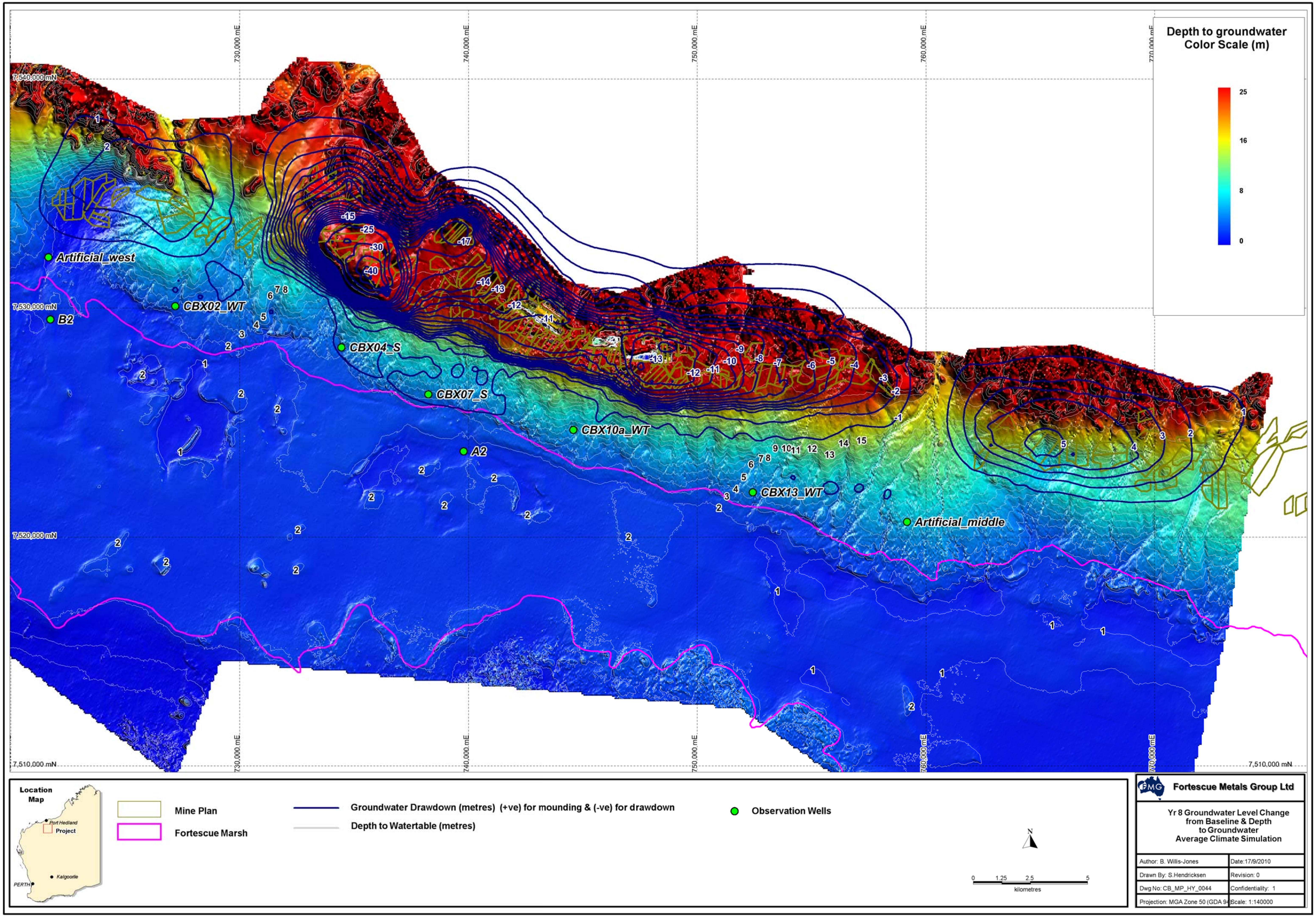
Groundwater Level Change from Baseline and Depth to Water – Year 7



Depth to groundwater Color Scale (m)
25
16
8
0
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Artificial_west
CBX02_WT
B2
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 7 Groundwater Level Change from Baseline & Depth to Groundwater Average Climate Simulation
Author: B. Willis-Jones
Date:17/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94
Scale: 1:140000

Figure 37.

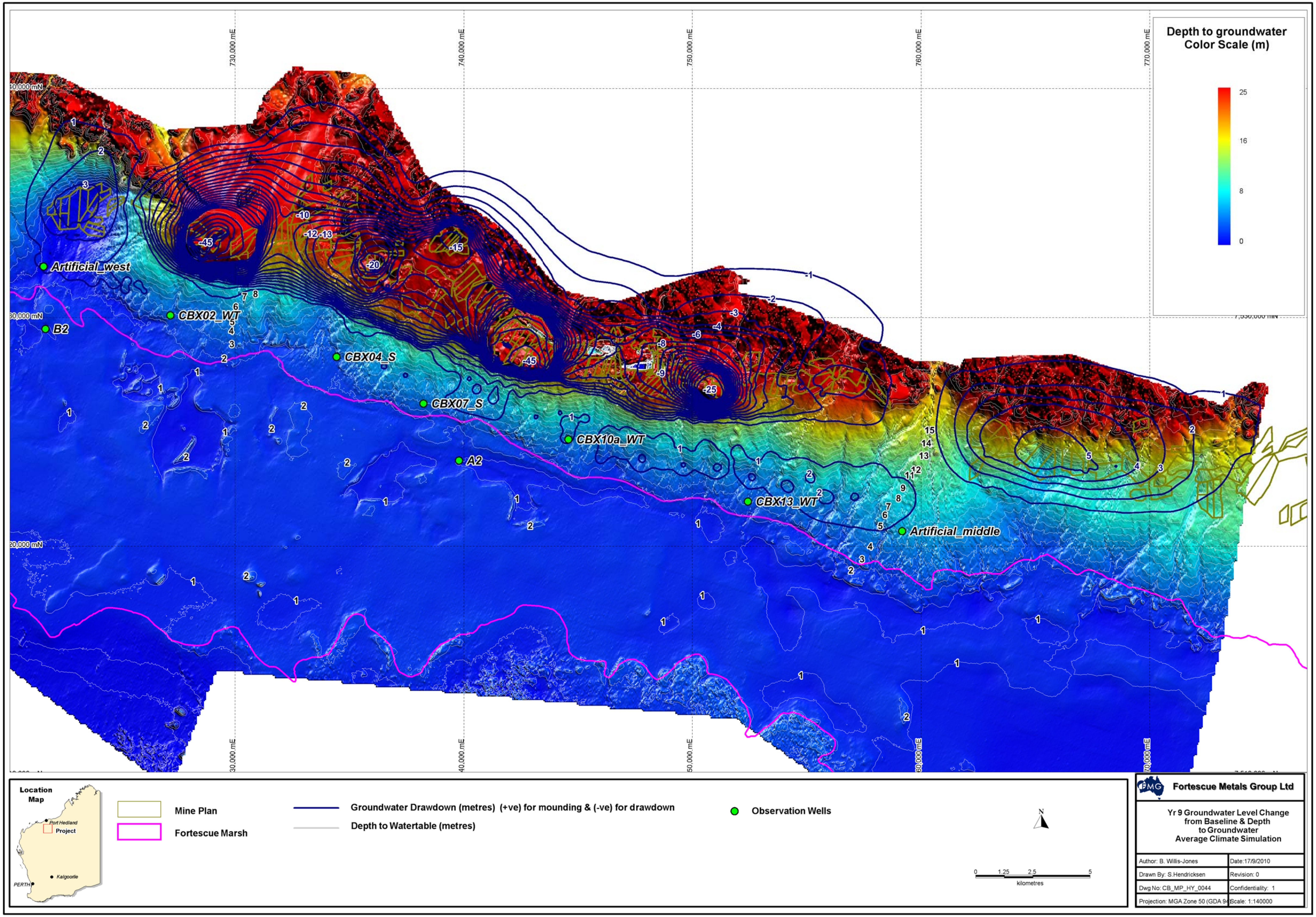
Groundwater Level Change from Baseline and Depth to Water – Year 8



Depth to groundwater
Color Scale (m)
25
16
8
0
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
7,510,000 mN
Artificial_west
CBX02_WT
B2
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 8 Groundwater Level Change
from Baseline & Depth
to Groundwater
Average Climate Simulation
Author: B. Willis-Jones
Date:17/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94
Scale: 1:140000

Figure 38.

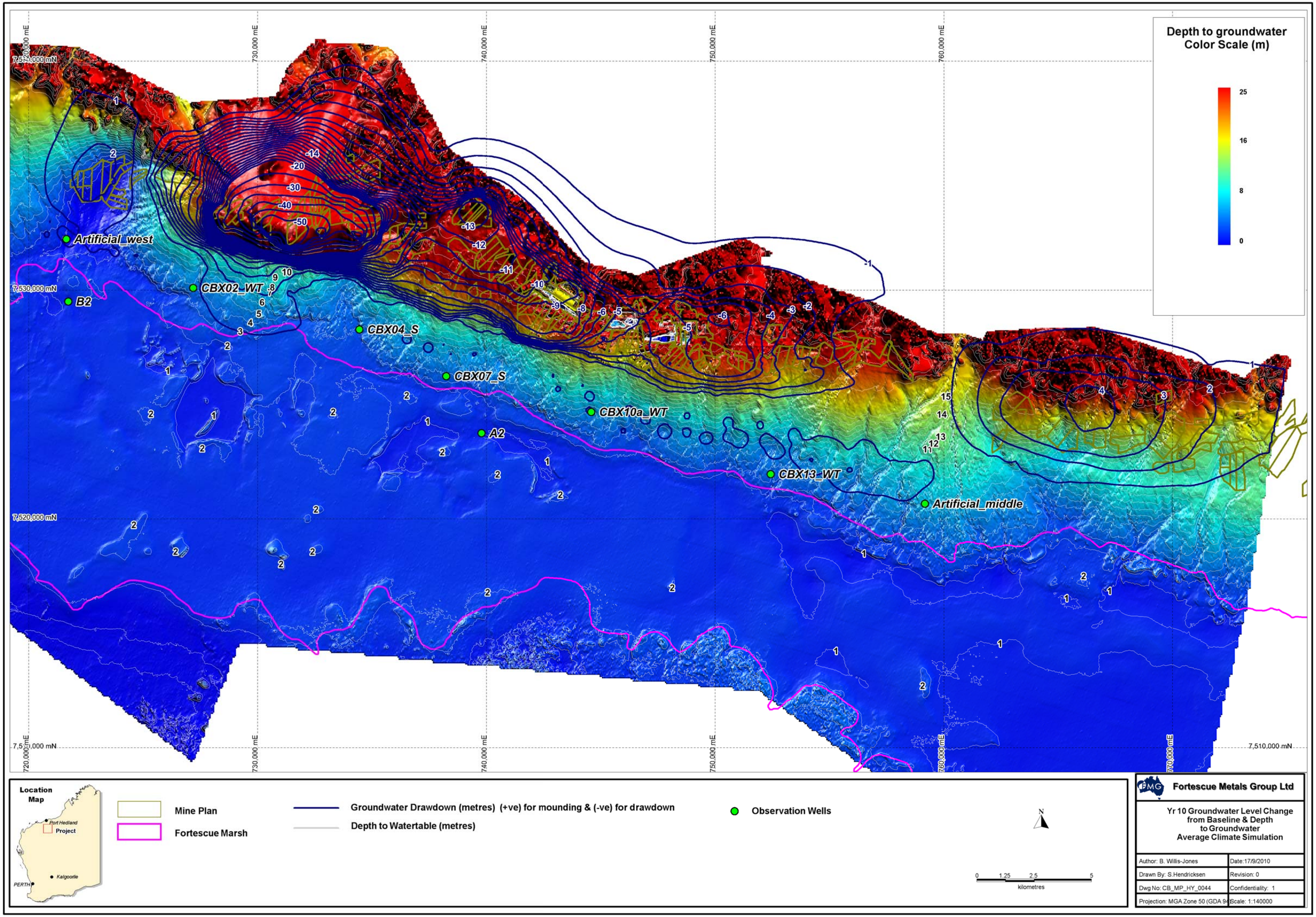
Groundwater Level Change from Baseline and Depth to Water – Year 9



Depth to groundwater
Color Scale (m)
25
16
8
0
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
Artificial_west
B2
CBX02_WT
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
-45
-10
-12
-13
-15
-20
-25
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 9 Groundwater Level Change from Baseline & Depth to Groundwater Average Climate Simulation
Author: B. Willis-Jones
Date:17/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94
Scale: 1:140000

Figure 39.

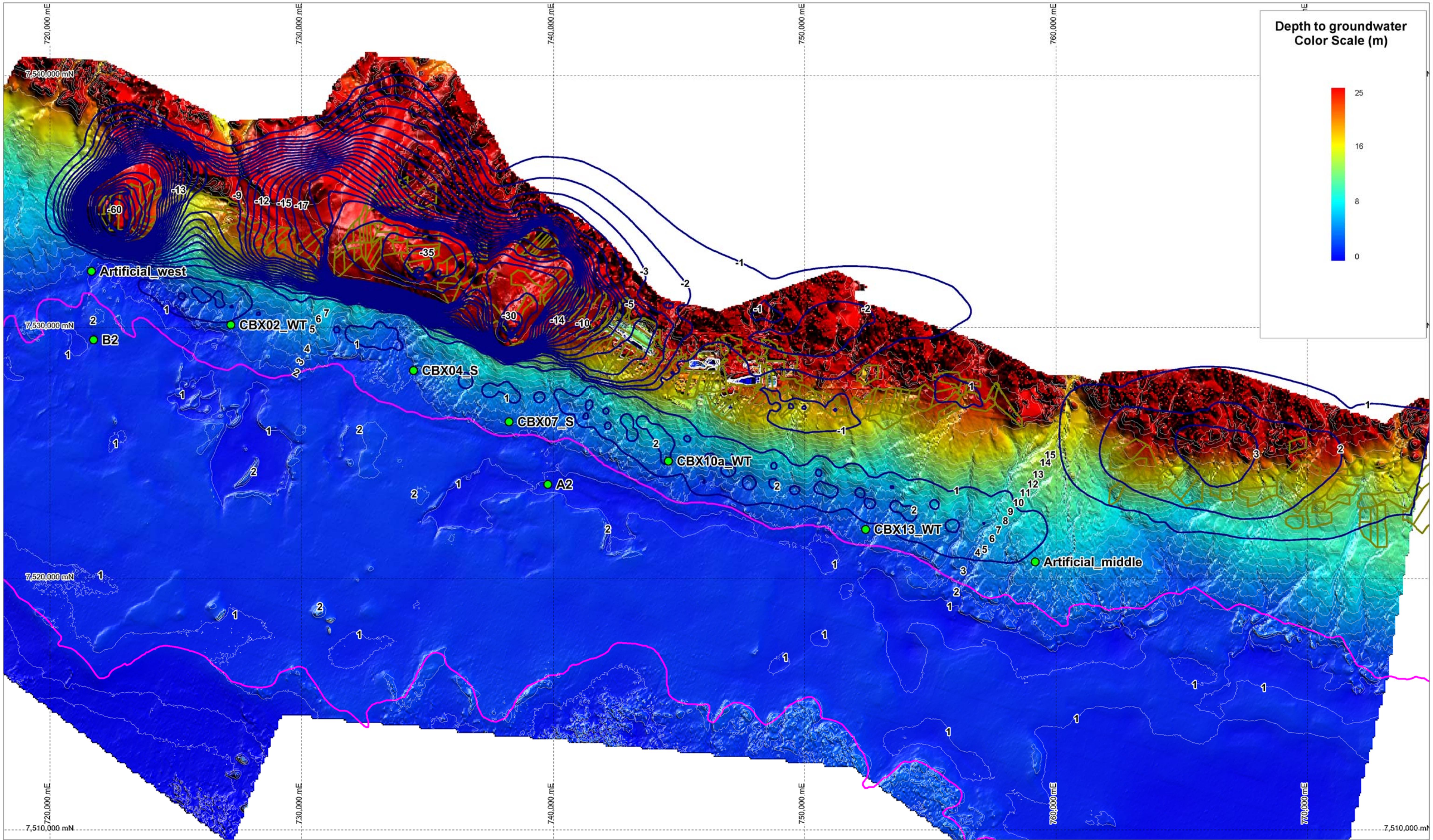
Groundwater Level Change from Baseline and Depth to Water – Year 10



Depth to groundwater
Color Scale (m)
25
16
8
0
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,530,000 mN
7,520,000 mN
7,510,000 mN
Artificial_west
B2
CBX02_WT
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0
1.25
2.5
5
kilometres
Fortescue Metals Group Ltd
Yr 10 Groundwater Level Change from Baseline & Depth to Groundwater Average Climate Simulation
Author: B. Willis-Jones
Date:17/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94
Scale: 1:140000

Figure 40.

Groundwater Level Change from Baseline and Depth to Water – Year 11



Location Map
Port Hedland
Project
Kalgoorlie
PERTH

Mine Plan

Fortescue Marsh

Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown

Depth to Watertable (metres)

Observation Wells

N

0 1.25 2.5 5
kilometres

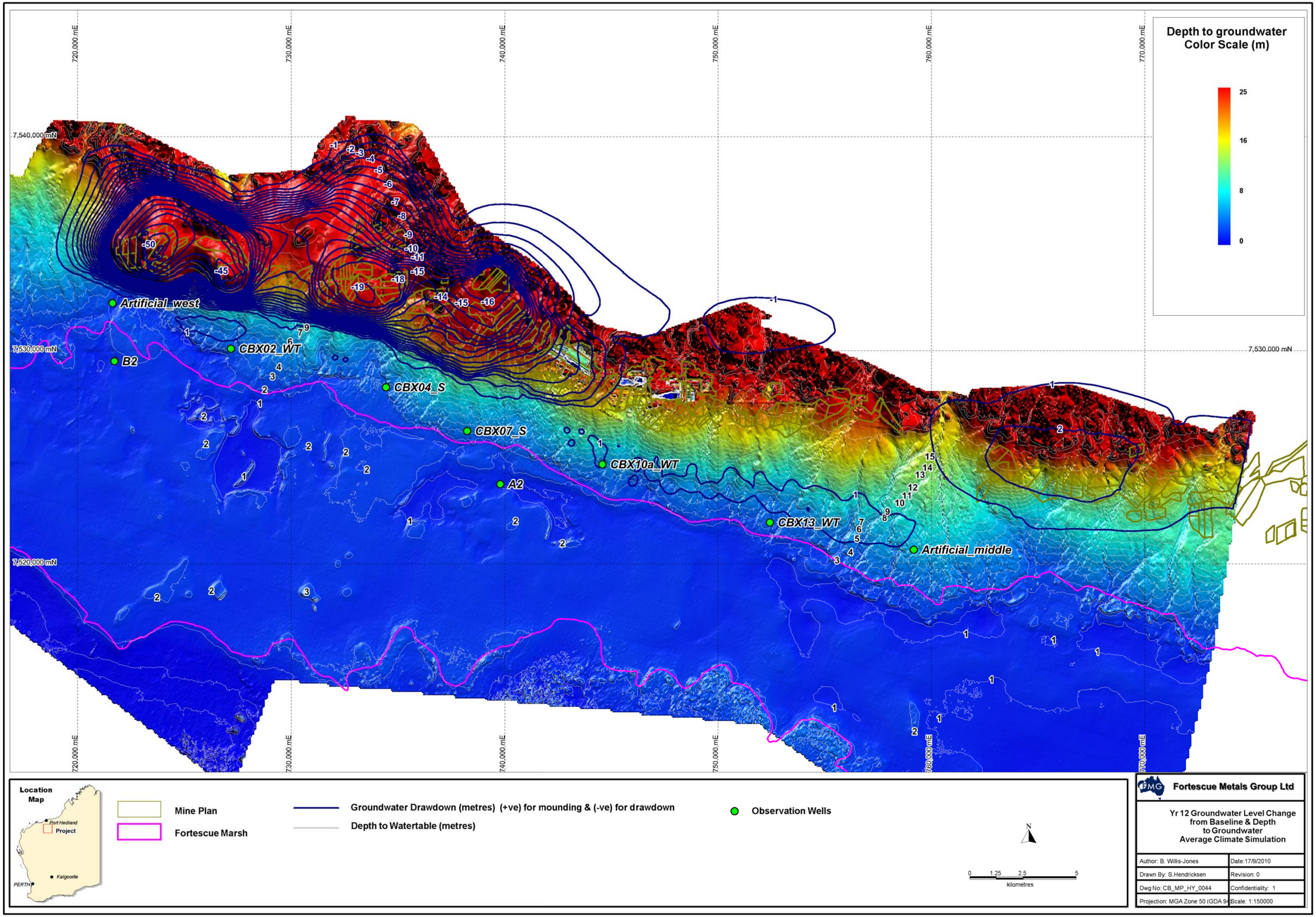
Fortescue Metals Group Ltd

Yr 11 Groundwater Level Change from Baseline & Depth to Groundwater Average Climate Simulation

Author: B. Willis-Jones	Date:17/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94	Scale: 1:140000

Figure 41.

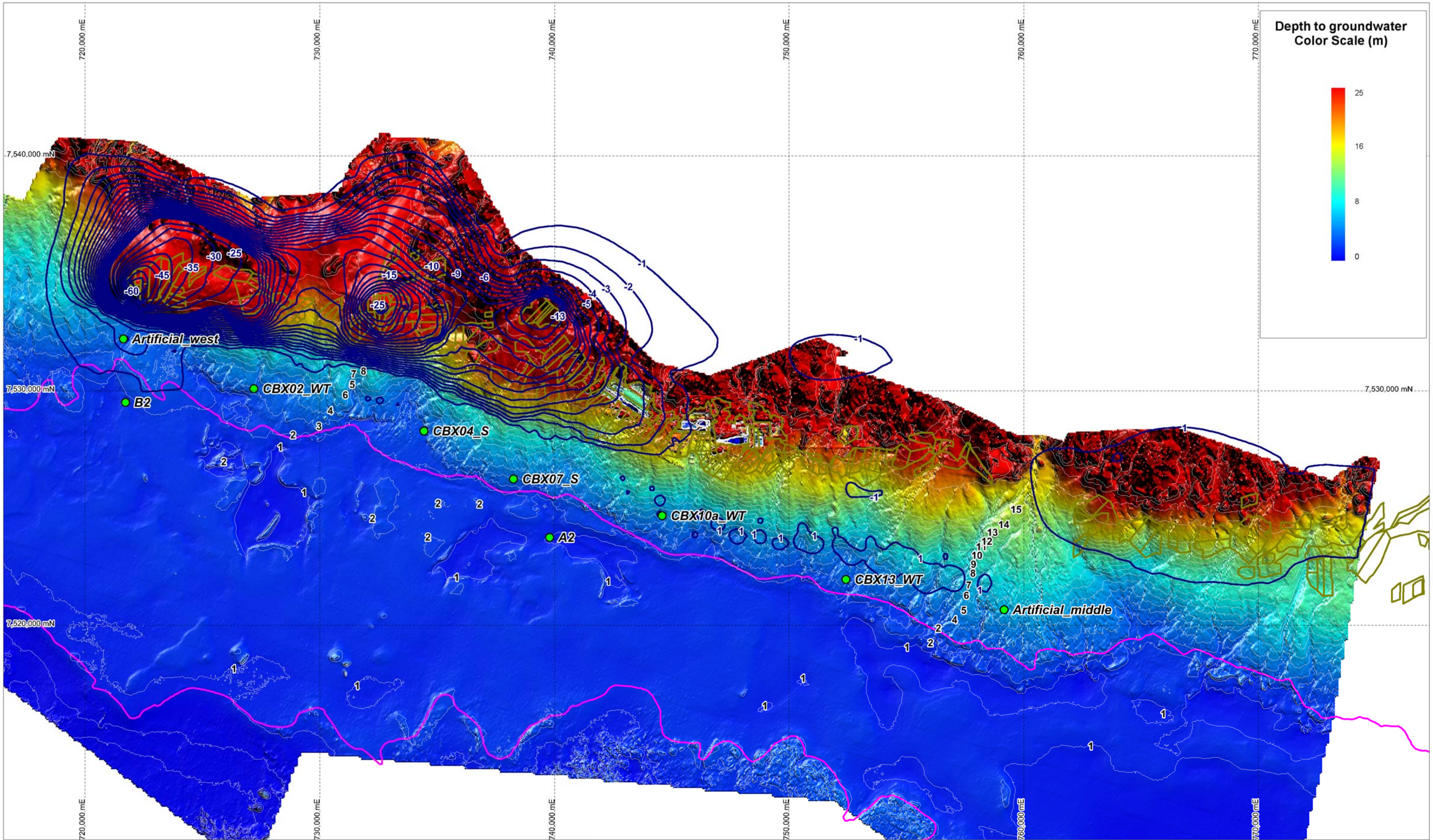
Groundwater Level Change from Baseline and Depth to Water – Year 12



Depth to groundwater
Color Scale (m)
25
16
8
0
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Artificial_west
B2
CBX02_WT
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 12 Groundwater Level Change from Baseline & Depth to Groundwater Average Climate Simulation
Author: B. Willis-Jones
Date:17/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:150000

Figure 42.

Groundwater Level Change from Baseline and Depth to Water – Year 13



Location Map

Port Hedland

Project

Kalgoorlie

PERTH

Mine Plan

Fortescue Marsh

Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown

Depth to Watertable (metres)

Observation Wells

0 1.25 2.5 5

kilometres

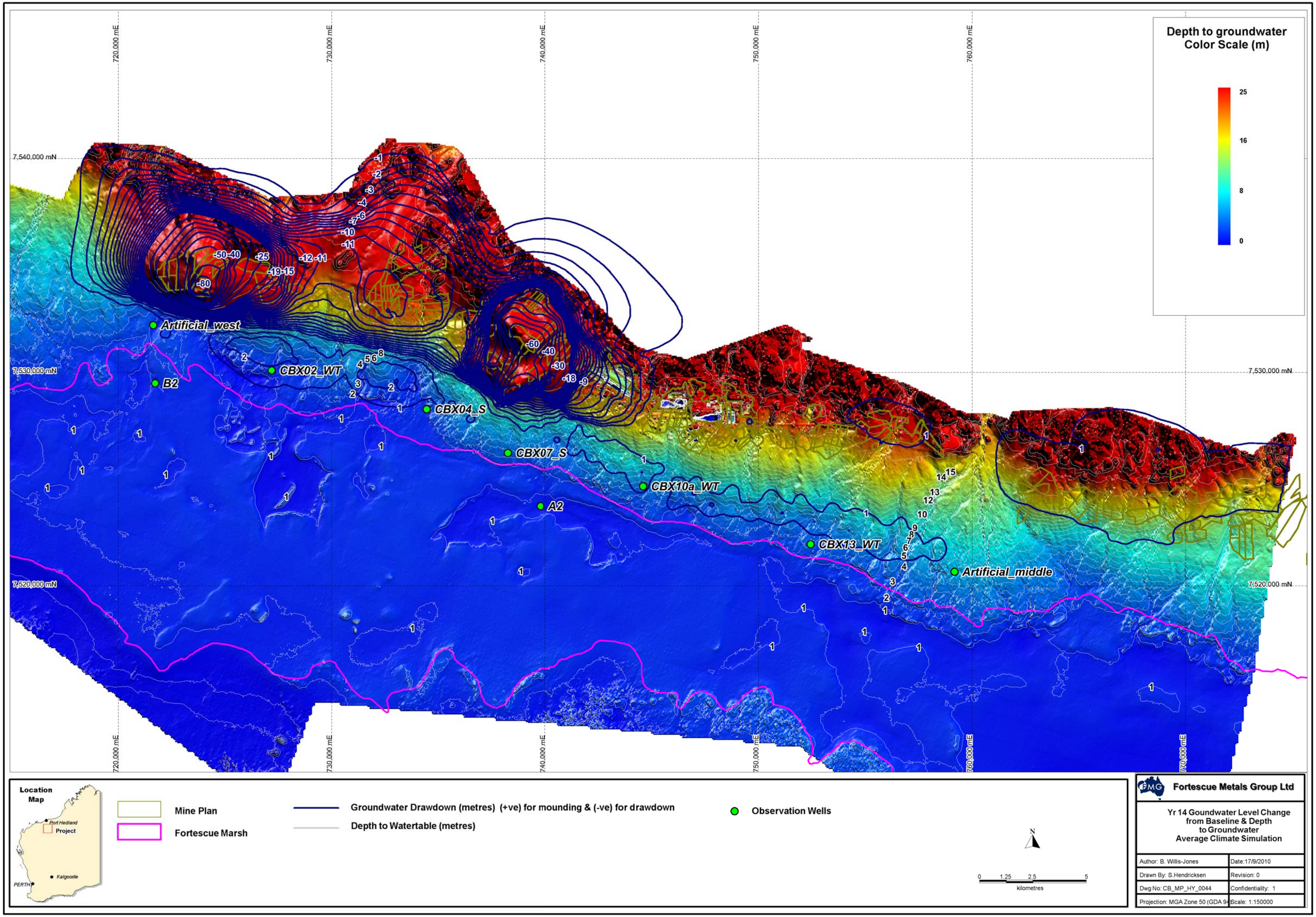
Fortescue Metals Group Ltd

Yr 13 Groundwater Level Change from Baseline & Depth to Groundwater Average Climate Simulation

Author: B. Willis-Jones	Date:17/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:150000

Figure 43.

Groundwater Level Change from Baseline and Depth to Water – Year 14



Depth to groundwater
Color Scale (m)
25
16
8
0
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Artificial_west
B2
CBX02_WT
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
-80
-50 -40
-25
-19 -15
-12 -11
-60
-40
-30
-18
-9
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 14 Goundwater Level Change from Baseline & Depth to Groundwater Average Climate Simulation
Author: B. Willis-Jones
Date:17/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:150000

Figure 44.

Predicted Groundwater Level at Reference Bore CBX02_WT

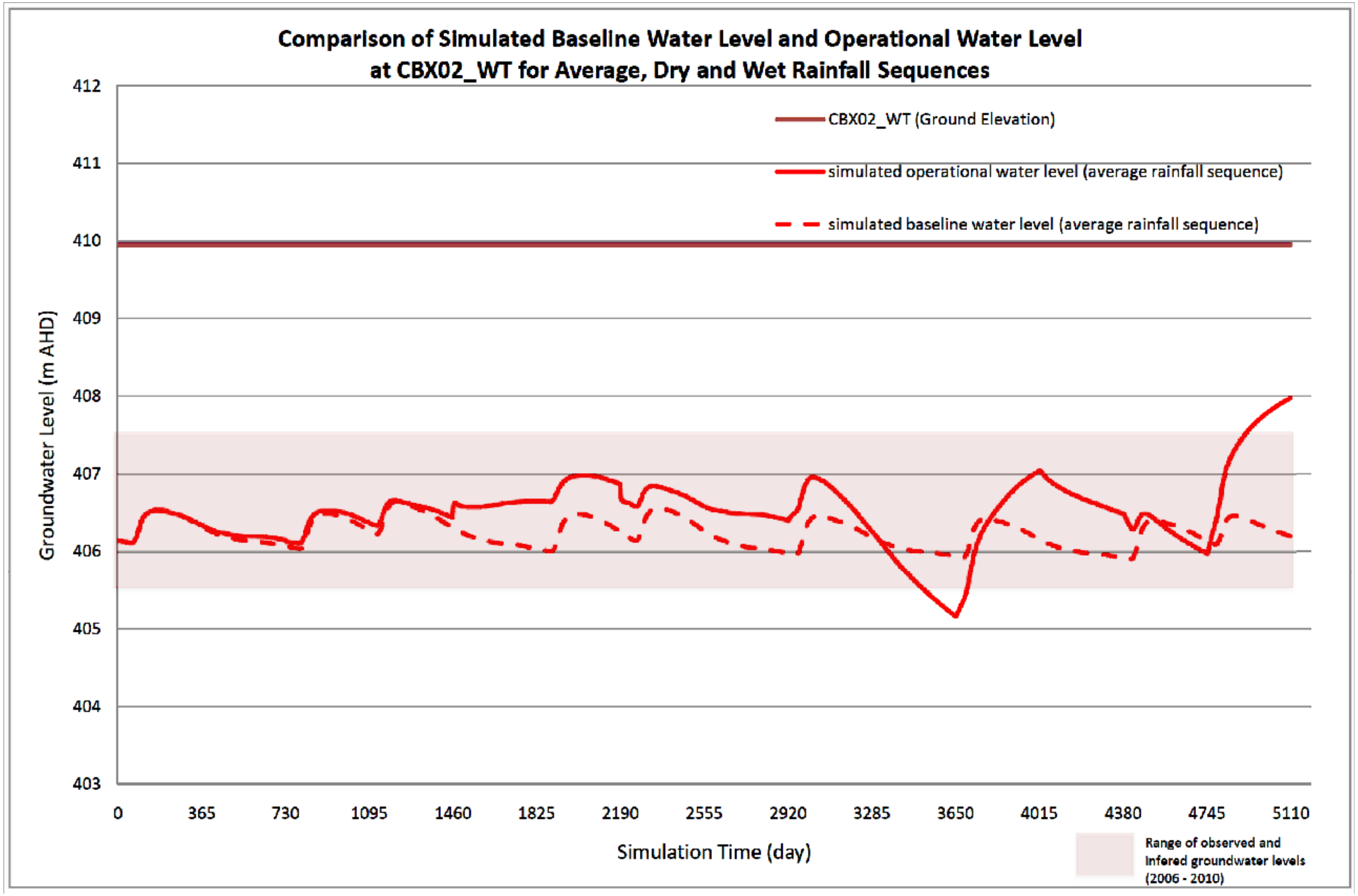


Figure Title: Predicted Water Level at Reference Bore CBX02_WT	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 44

Figure 45.

Predicted Groundwater Level at Reference Bore CBX04_S

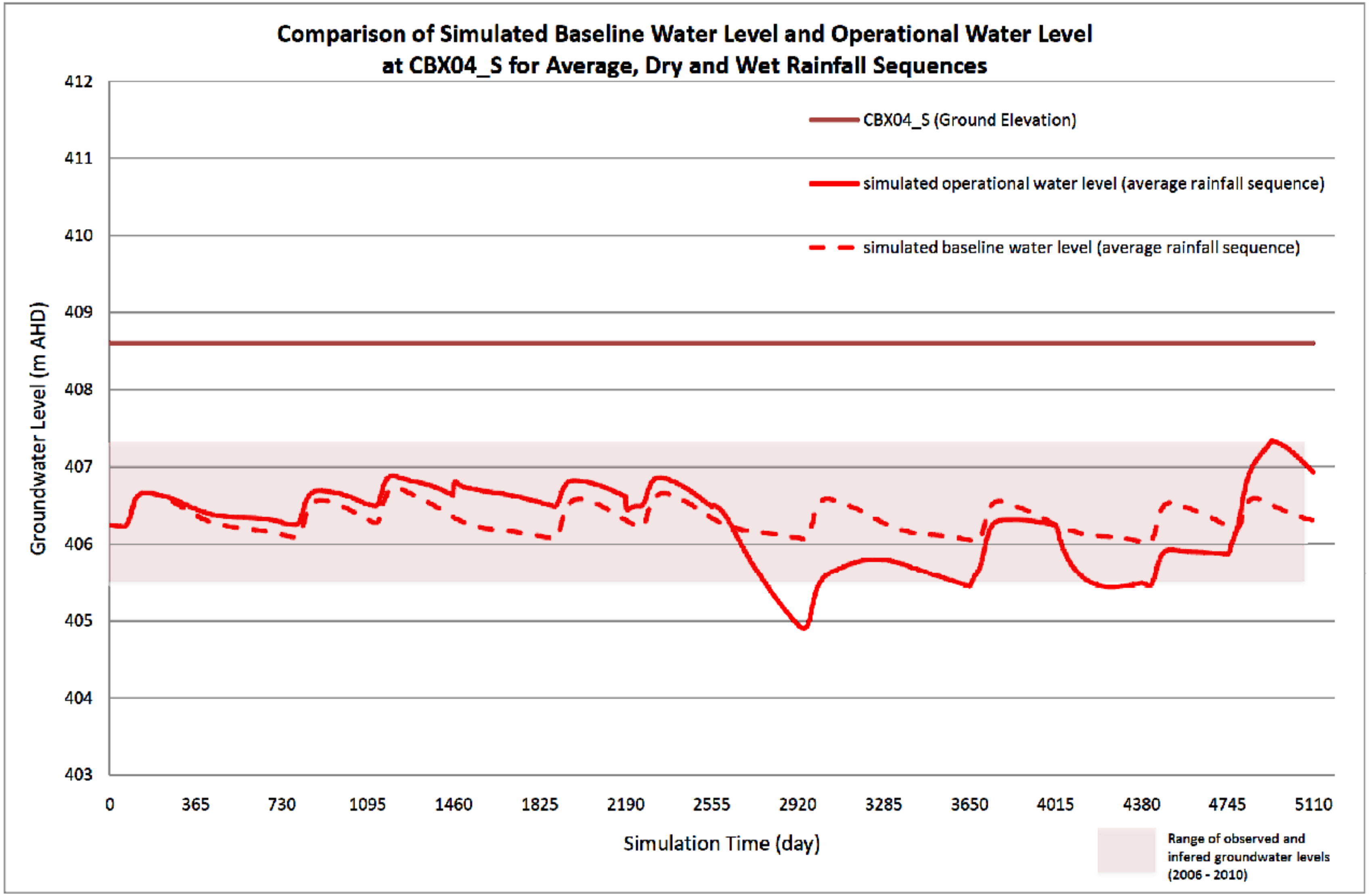


Figure Title: Predicted Water Level at Reference Bore CBX04_S	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 45

Figure 46.

Predicted Groundwater Level at Reference Bore CBX07_S

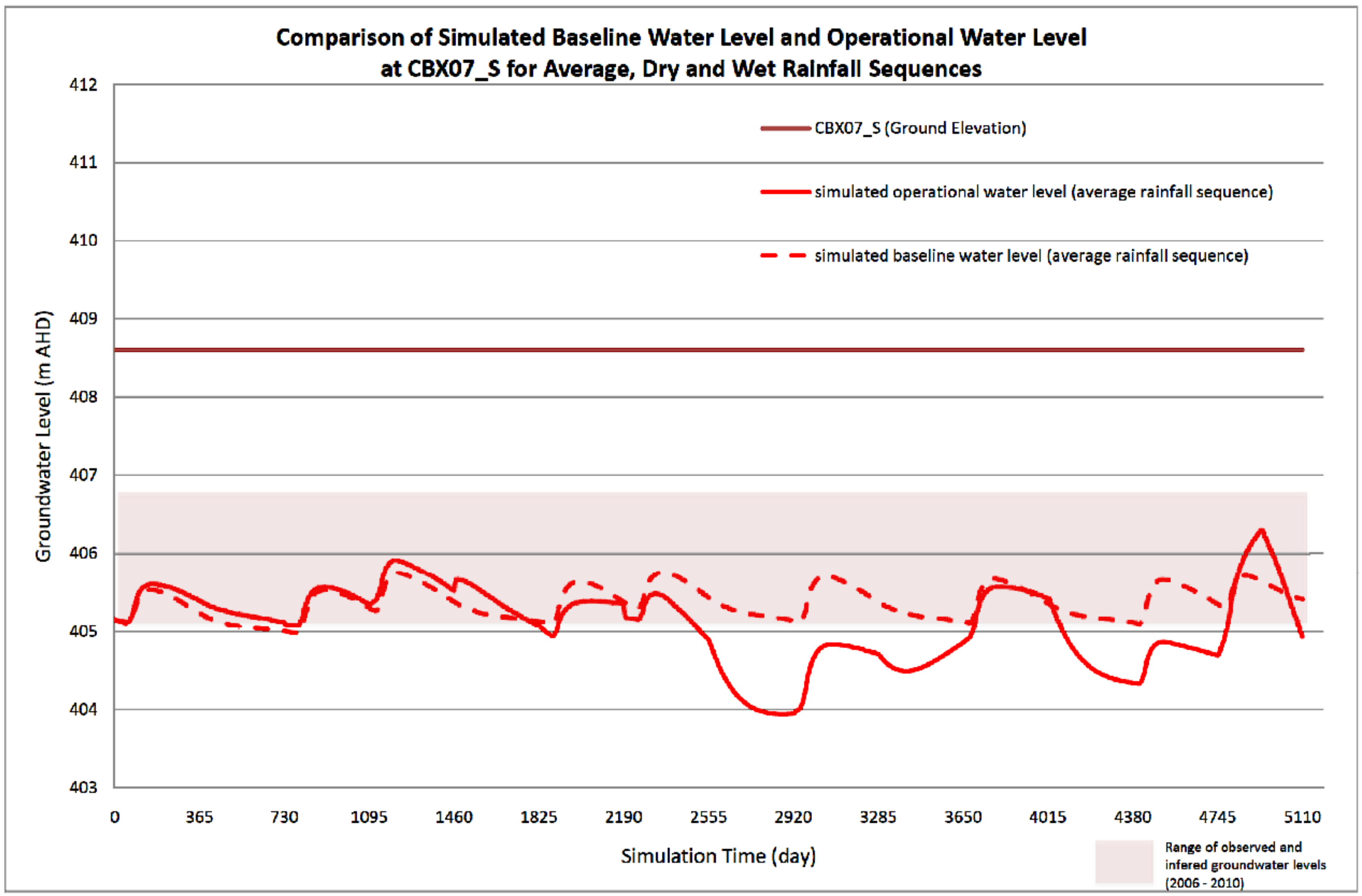


Figure Title: Predicted Water Level at Reference Bore CBX07_S	FMG
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 46

Figure 47.

Predicted Groundwater Level at Reference Bore

CBX10a_WT

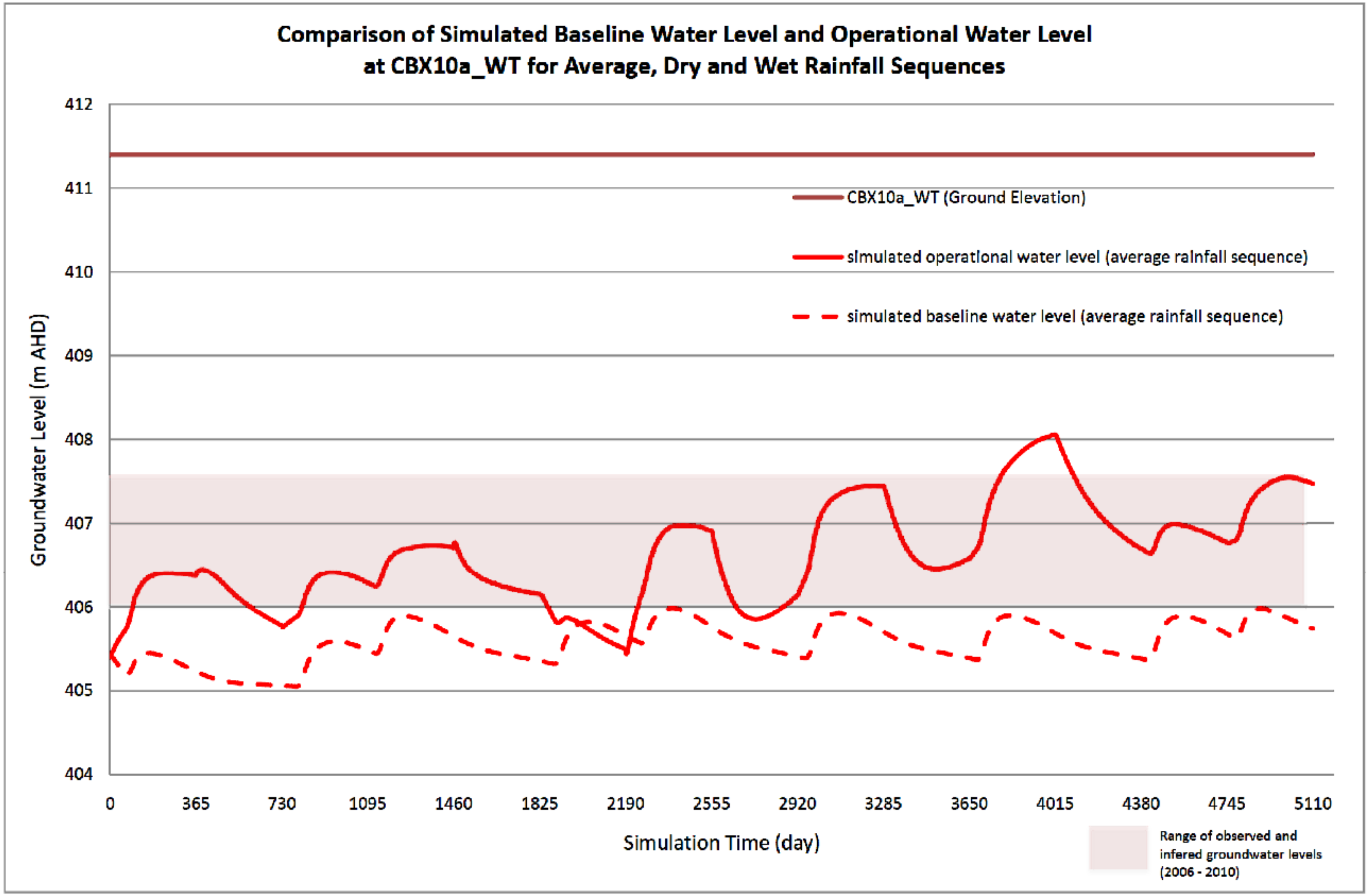


Figure Title: Predicted Water Level at Reference Bore CBX10a_WT	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 47

Figure 48.

Predicted Groundwater Level at Reference Bore CBX13_WT

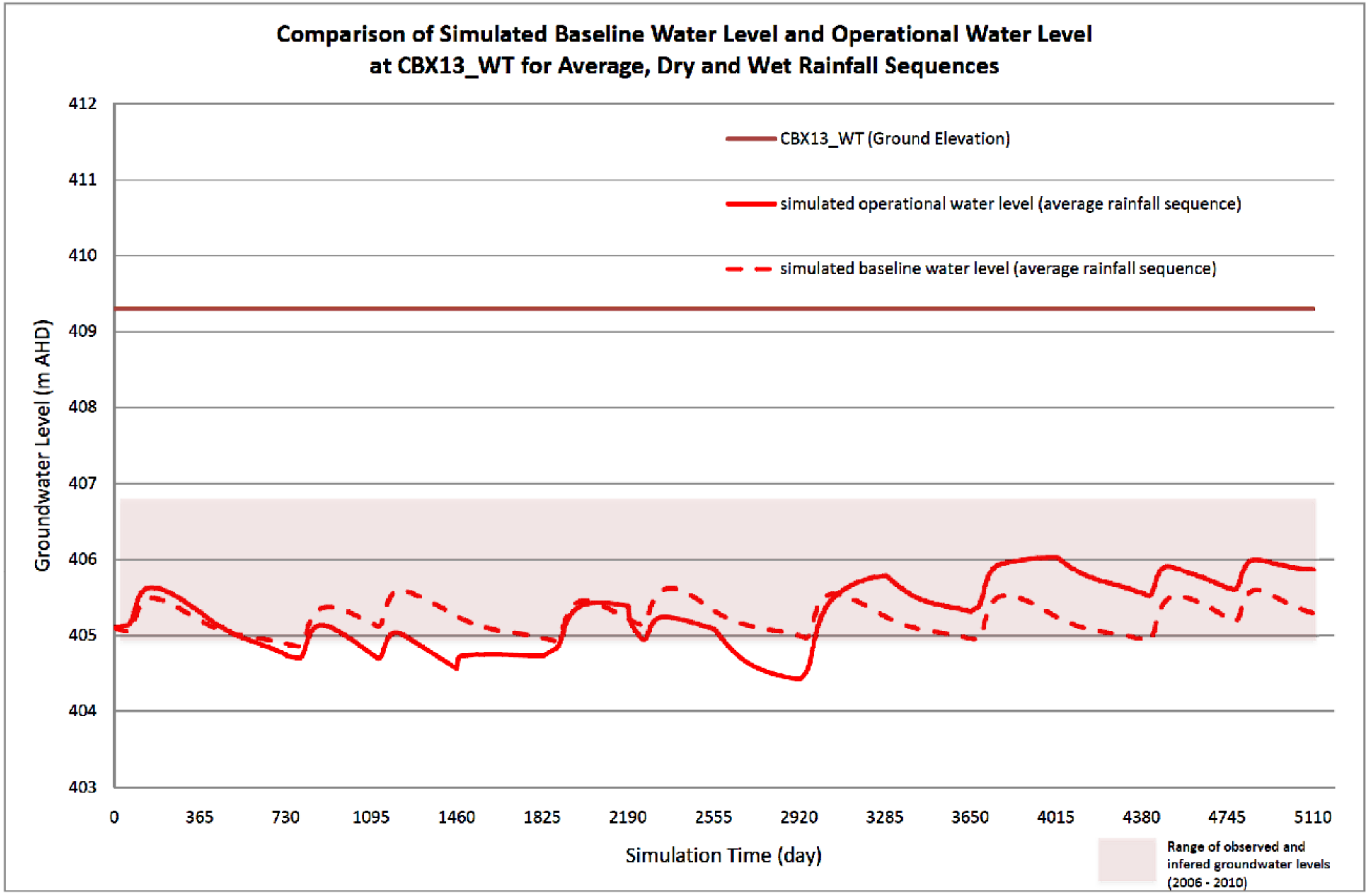


Figure Title: Predicted Water Level at Reference Bore CBX10a_WT	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 48

Figure 49.

Predicted Groundwater Level at Reference Bore A2

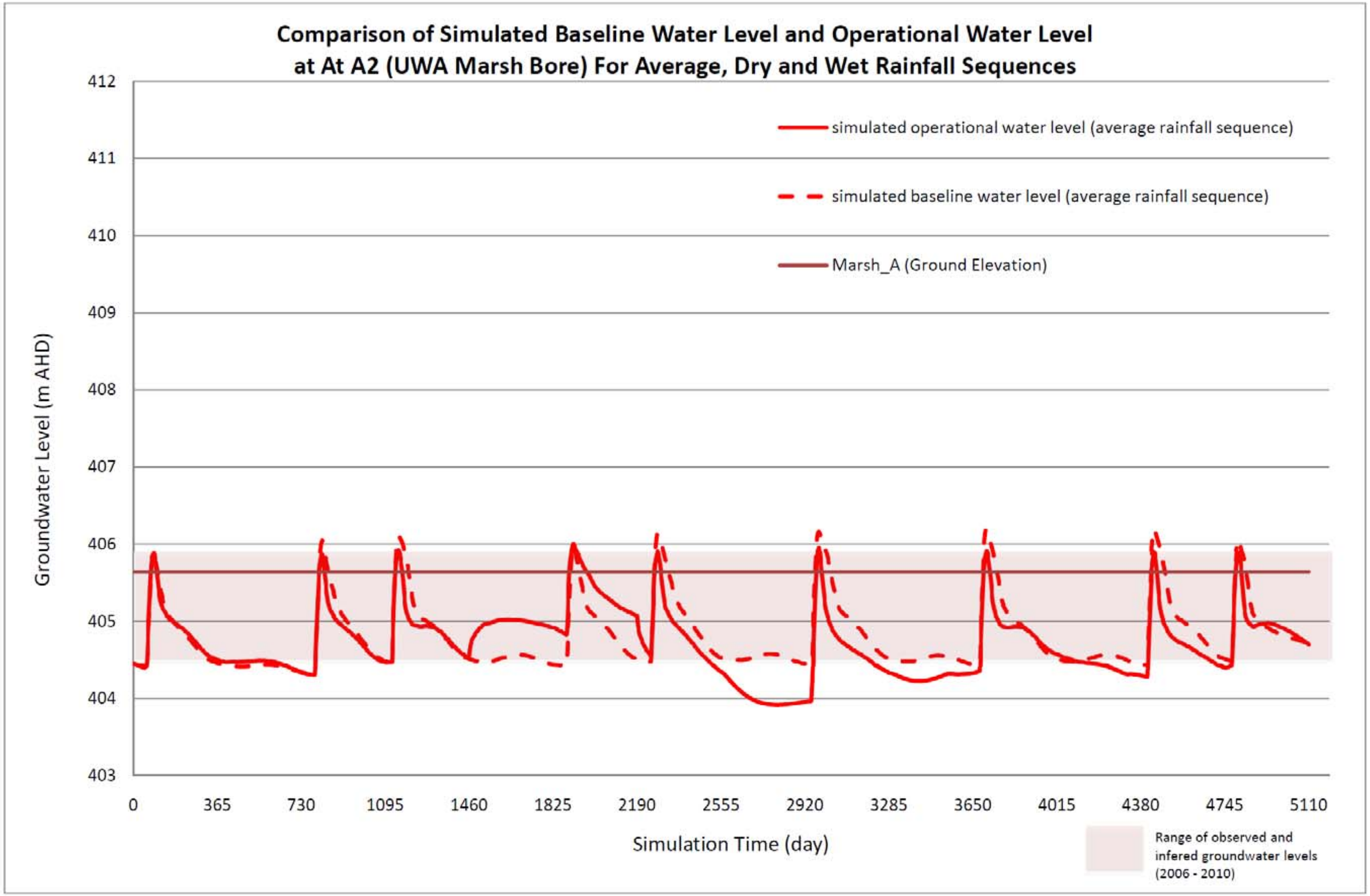


Figure Title: Predicted Water Level at Reference Bore A2	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 49

Figure 50.

Predicted Groundwater Level at Reference Bore B2

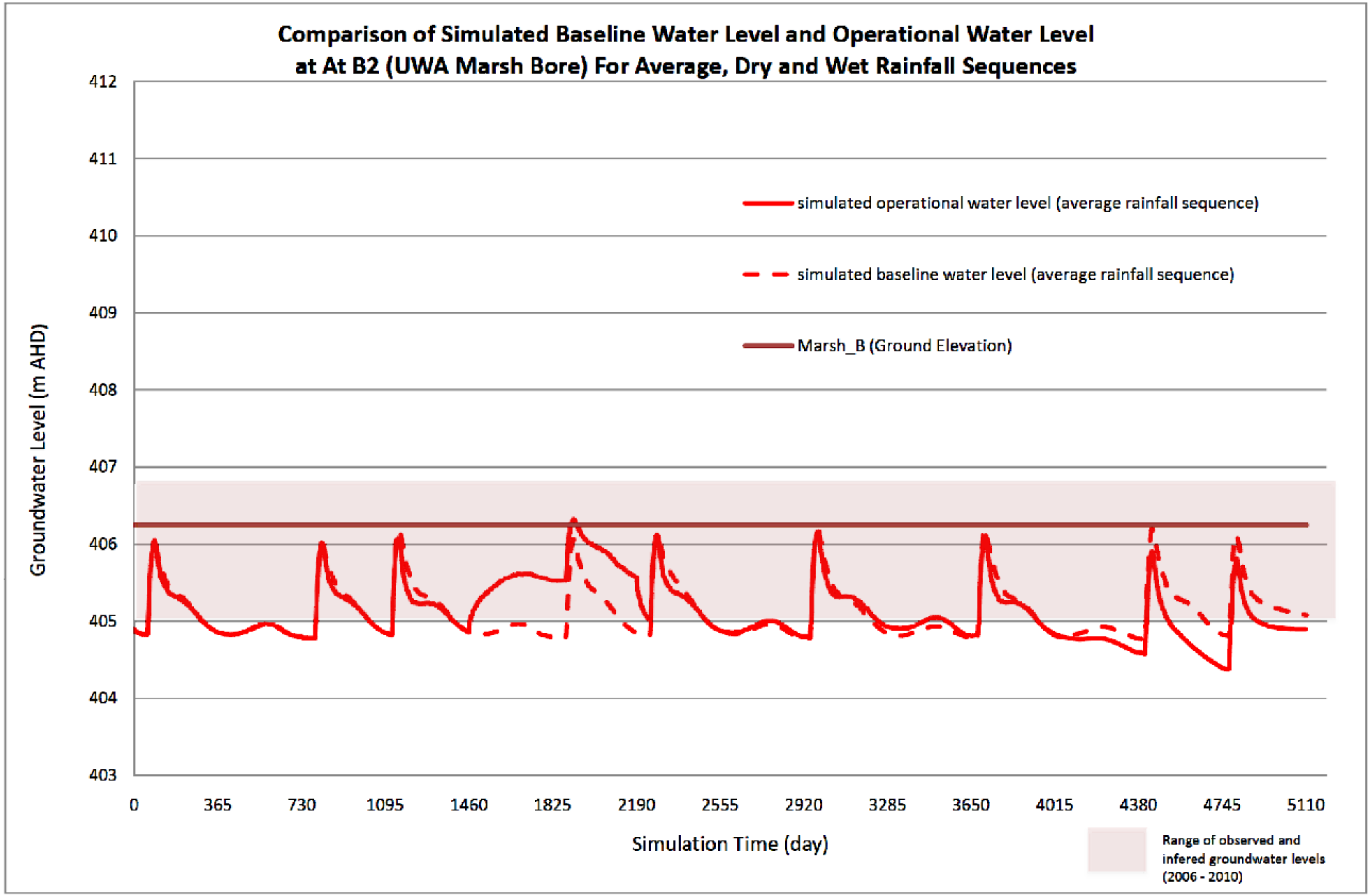


Figure Title: Predicted Water Level at Reference Bore B2	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 50

Figure 51.

Predicted Groundwater Level at Reference Bore
Artificial West

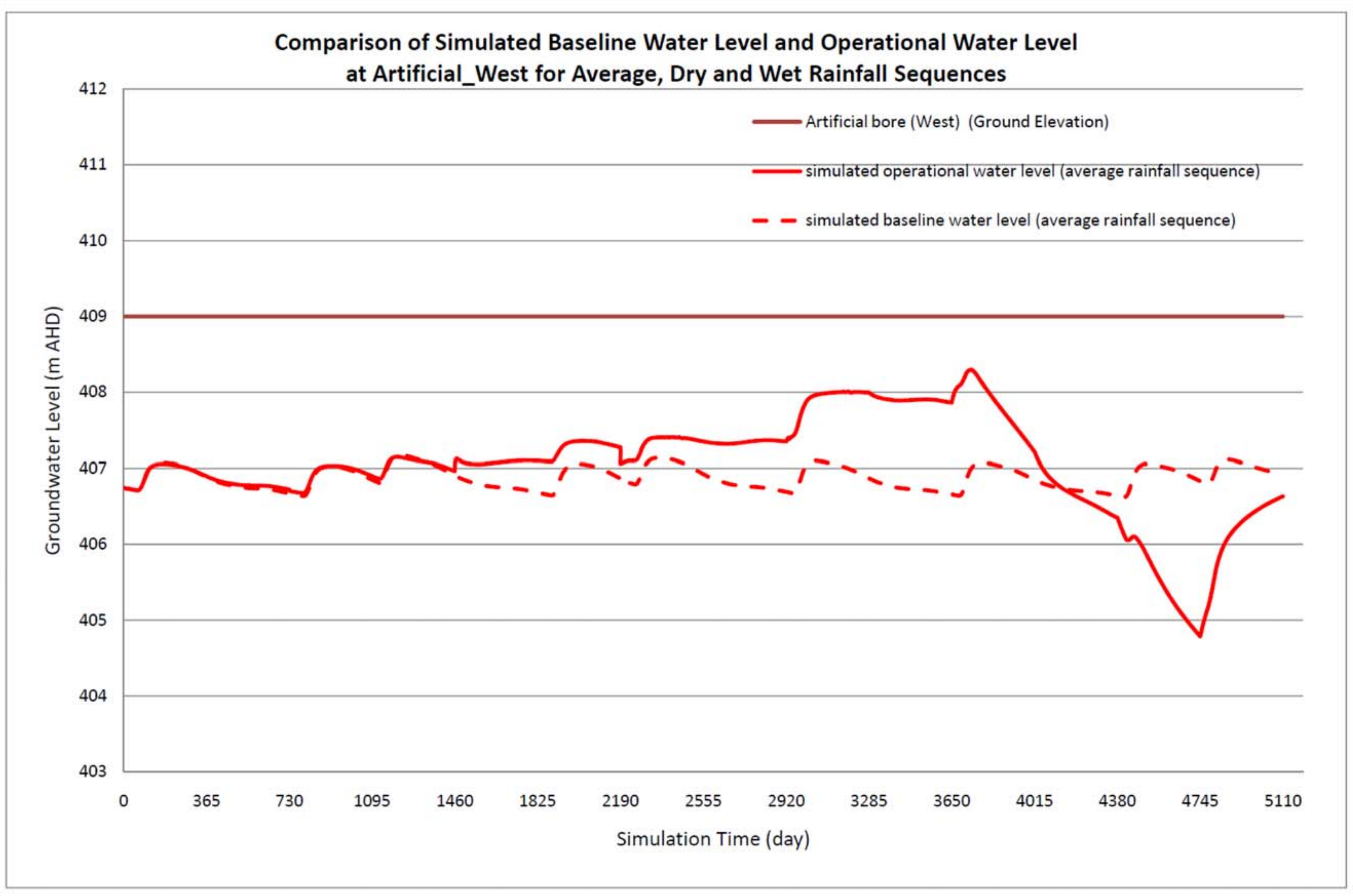


Figure Title: Predicted Water Level at Reference Bore Artifical_West	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 51

Figure 52.

Predicted Groundwater Level at Reference Bore
Artificial Middle

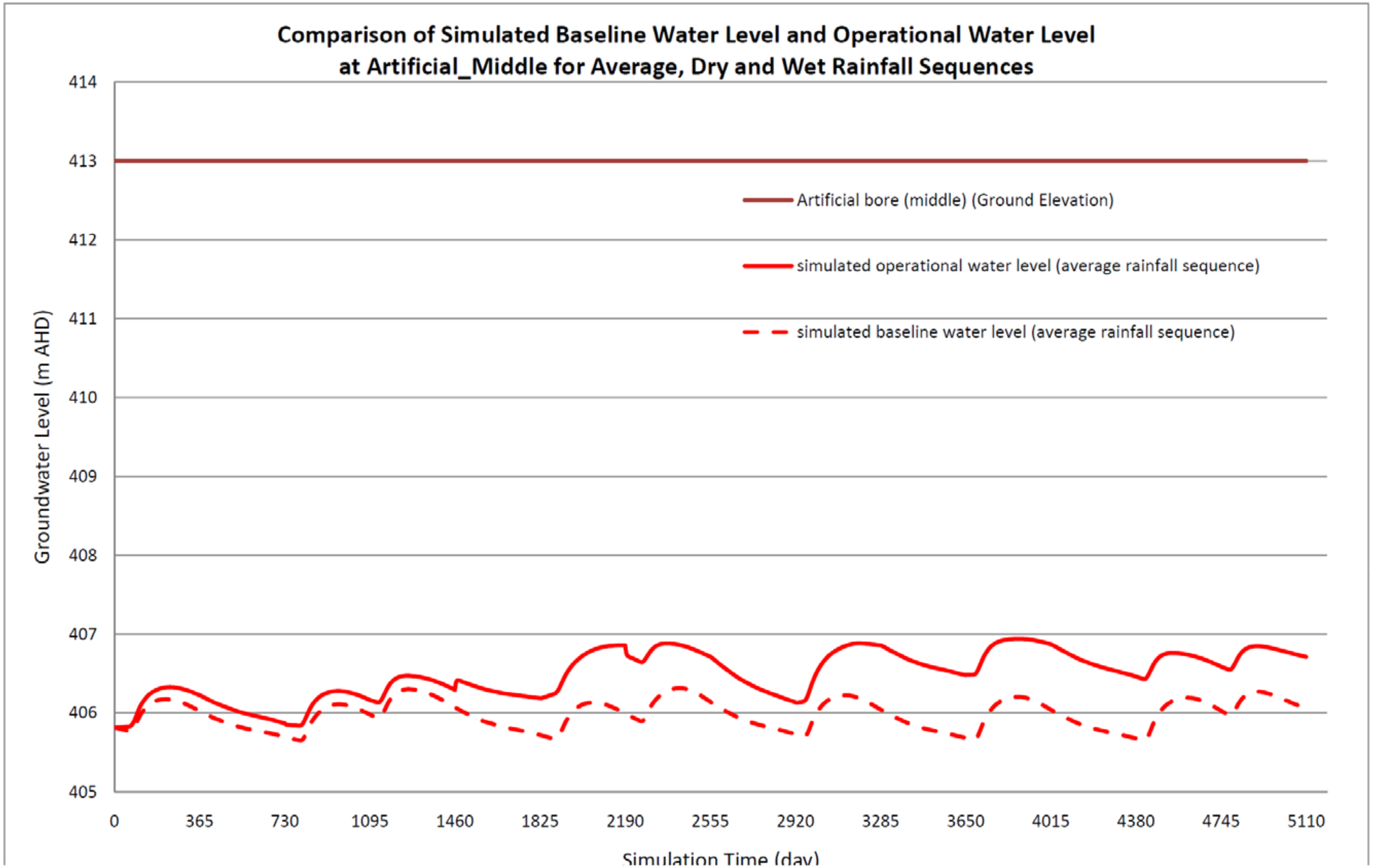


Figure Title: Predicted Water Level at Reference Bore Artifical_Middle	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 52

Figure 53.

Cumulative Impacts

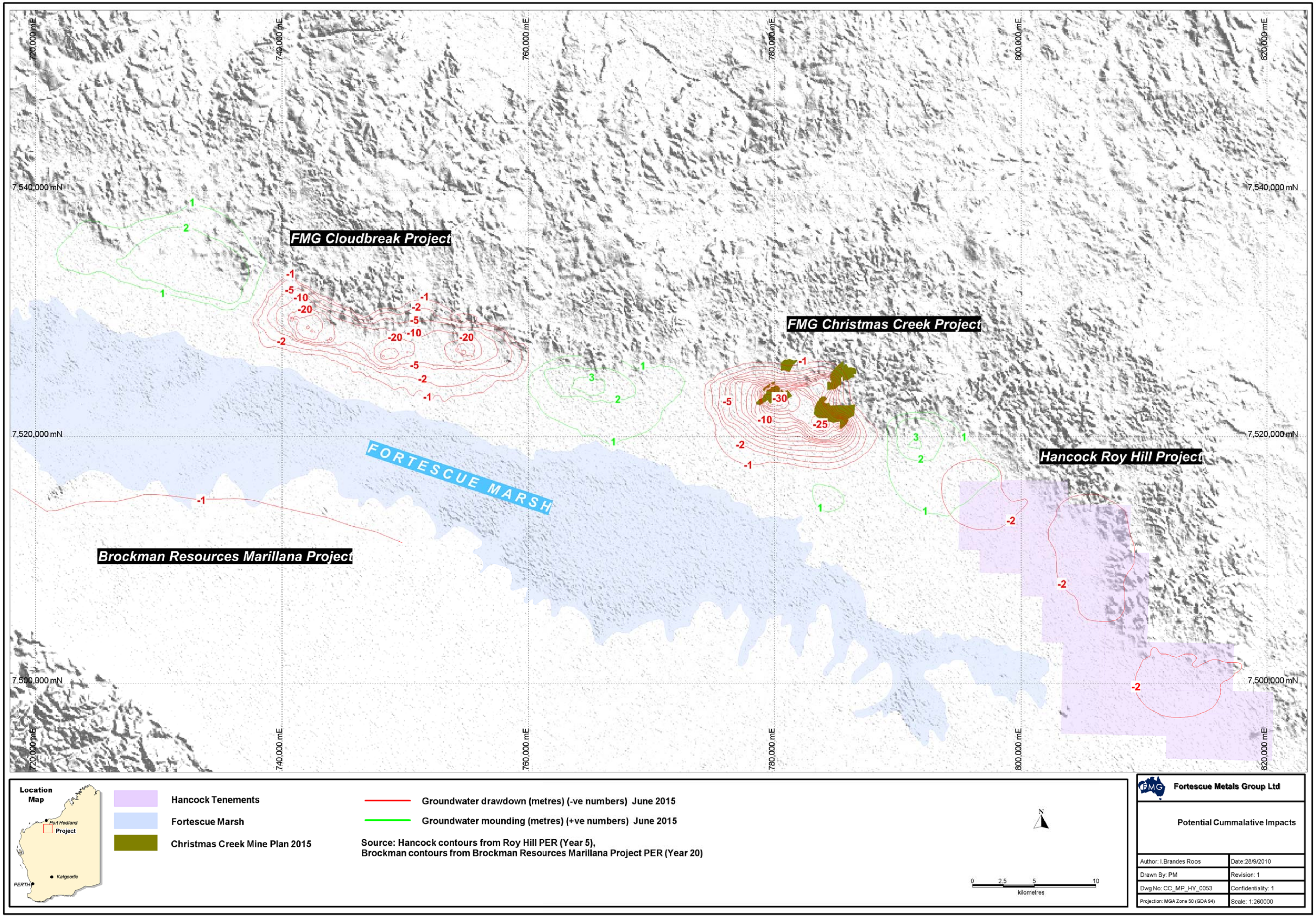

720,000 mE
740,000 mE
760,000 mE
780,000 mE
800,000 mE
820,000 mE
7,540,000 mN
7,520,000 mN
7,500,000 mN
FMG Cloudbreak Project
FMG Christmas Creek Project
Hancock Roy Hill Project
Brockman Resources Marillana Project
FORTESCUE MARSH
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Hancock Tenements
Fortescue Marsh
Christmas Creek Mine Plan 2015
Groundwater drawdown (metres) (-ve numbers) June 2015
Groundwater mounding (metres) (+ve numbers) June 2015
Source: Hancock contours from Roy Hill PER (Year 5),
Brockman contours from Brockman Resources Marillana Project PER (Year 20)
N
0 2.5 5 10
kilometres
Fortescue Metals Group Ltd
Potential Cummalative Impacts
Author: I.Brandes Roos
Date:28/9/2010
Drawn By: PM
Revision: 1
Dwg No: CC_MP_HY_0053
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:260000

Figure 54.

2-d Model Geometry

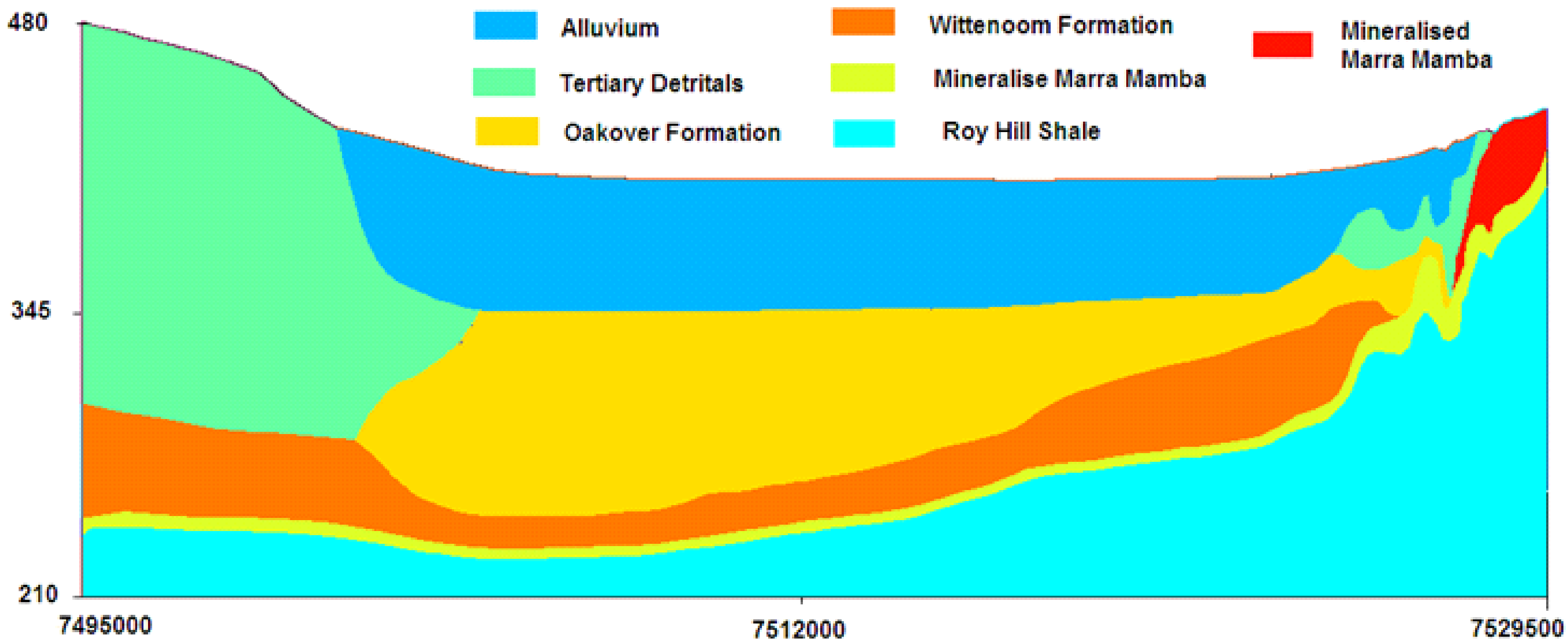


Figure Title: 2-D Model Geometry	
Report Title: Hydrogeological assessment for Cloudbreak Water Management Scheme	
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 54

Figure 55.

2-d Model Shallow Aquifer reference Points

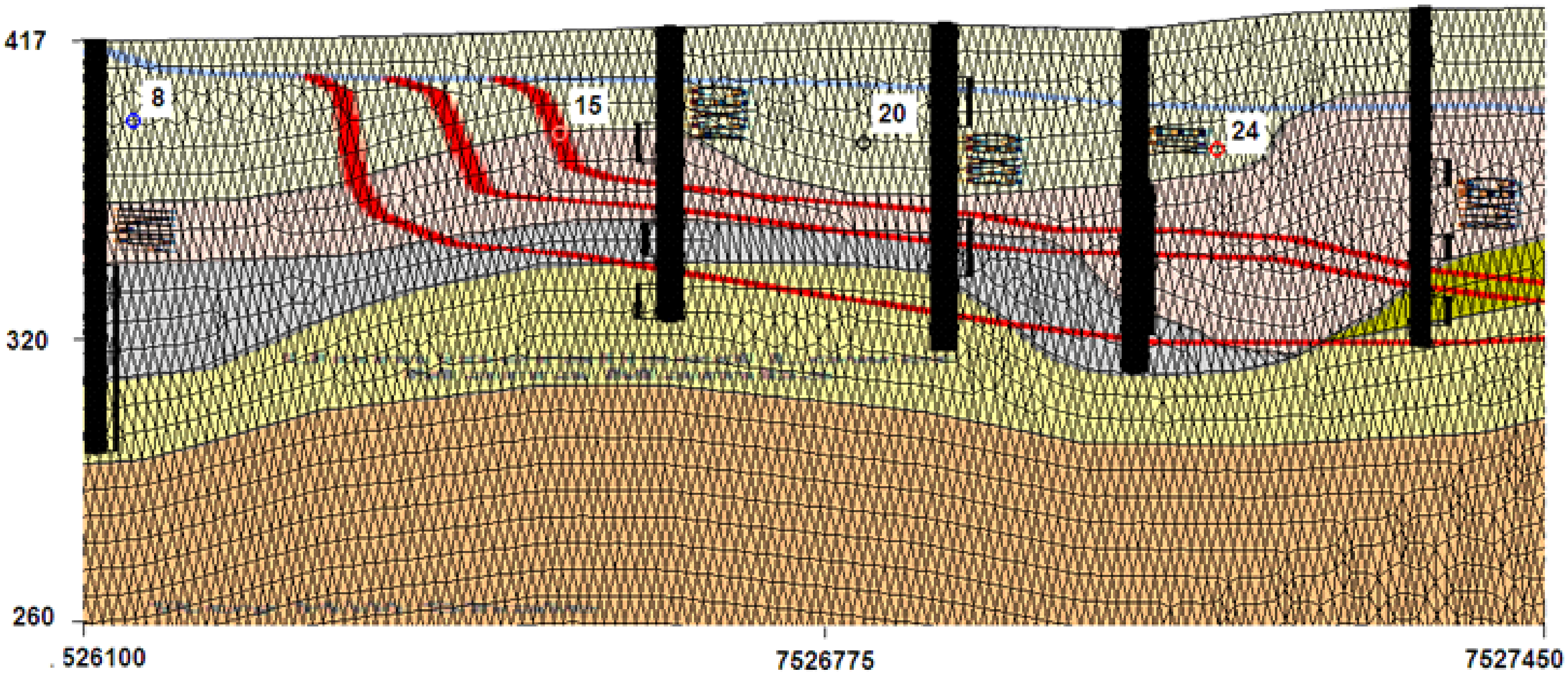


Figure Title:

Salinity Observation Points

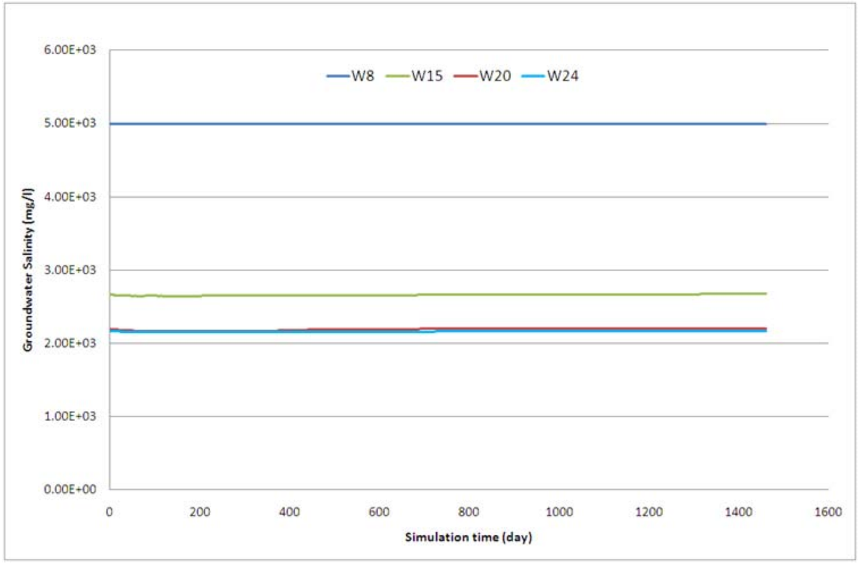
Report Title:

Hydrogeological assessment for Cloudbreak Water Management Scheme

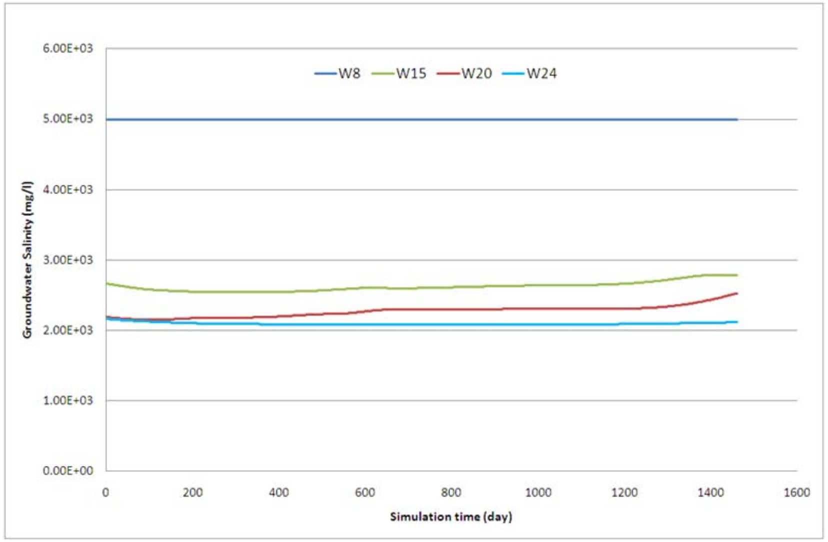
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 55

Figure 56.

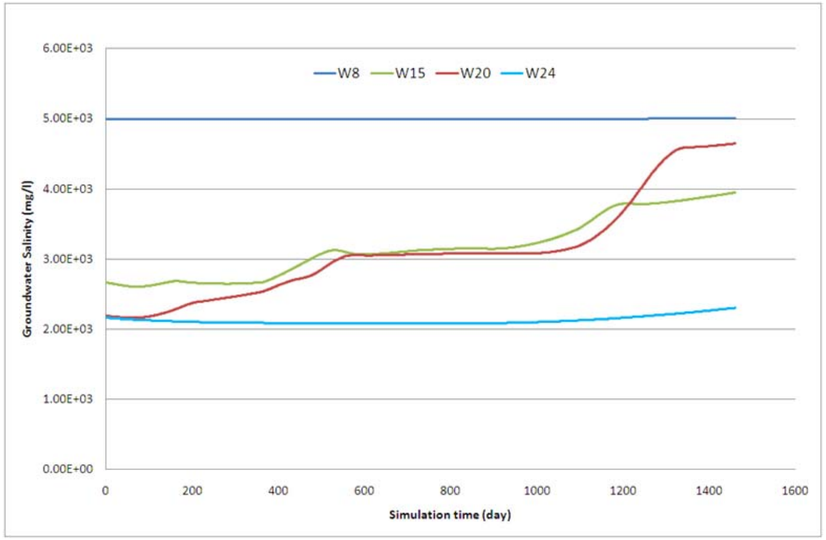
2-d Model Salinity Break through Curves



A: Groundwater salinity breakthrough curves at selected observational wells in the shallow alluvial layer under dewatering conditions without saline water injection.



B: Groundwater salinity breakthrough curves at selected observational wells in the shallow alluvial layer under dewatering and saline water injection conditions (injected water salinity =10000 mg/l).



C: Groundwater salinity breakthrough curves at selected observational wells in the shallow alluvial layer under dewatering and saline water injection conditions (injected water salinity =50000 mg/l).

Figure Title:

Groundwater Salinity Break Through Curves

Report Title:

Hydrogeological assessment for Cloudbreak Water Management Scheme

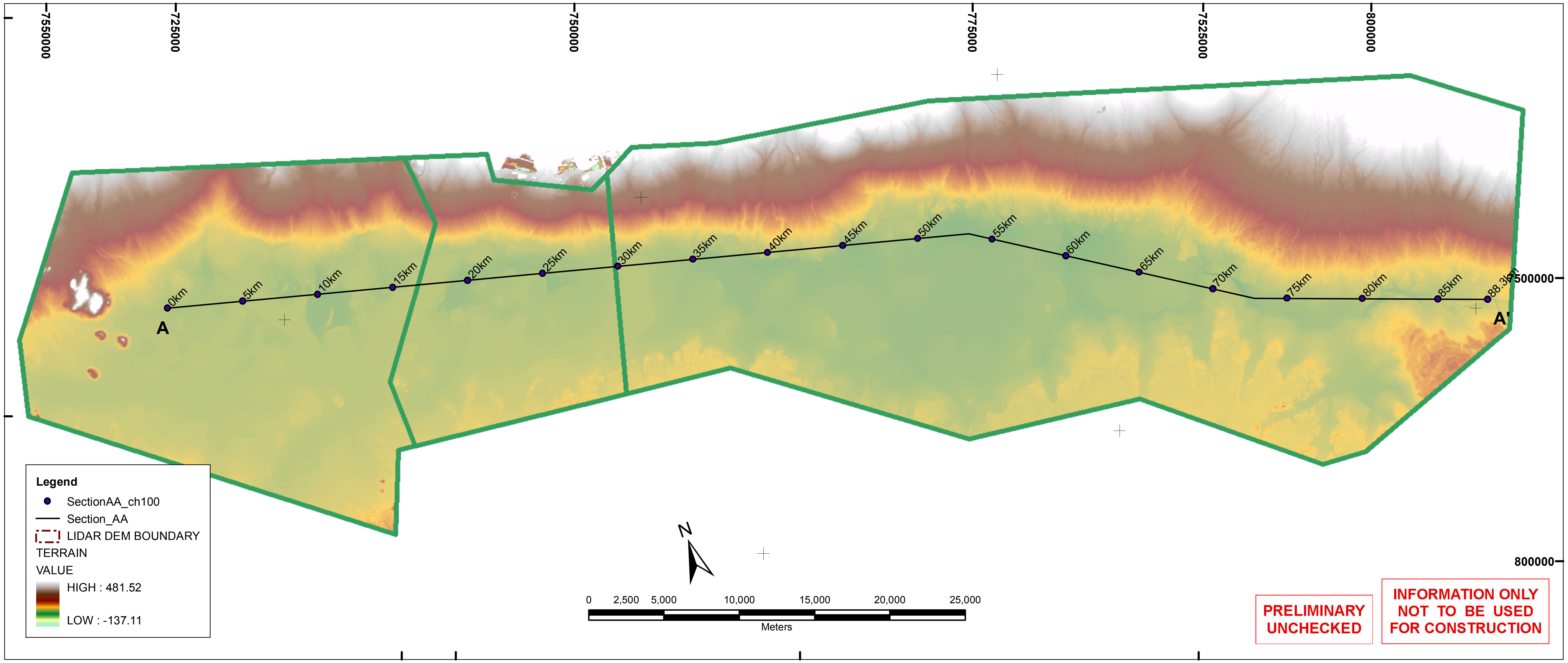
Author:	Date:
Drawn By:	Revision:
Drawing Ref:	Report Ref:
Scale:	Figure No: 56

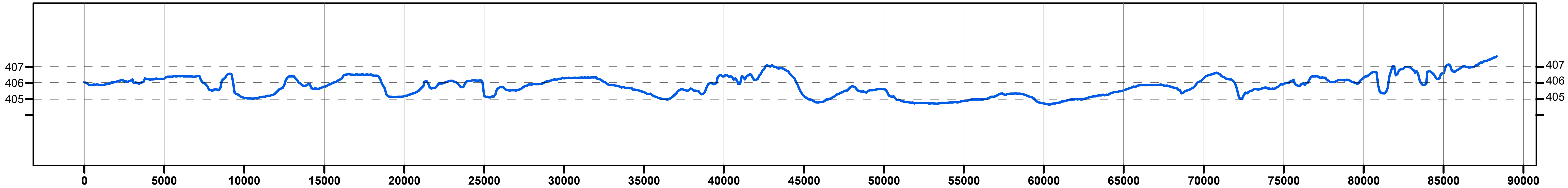
Appendices

Appendix A.

Fortescue Marsh Flooding Study

LANDSAT INTERPRETATION - Flooding area, volume and water level			
Date	**Area (km2)**	**Volume (GL)**	**Water Level (mAHD)**
Aug-99	322	159	405.9
Nov-99	156	35	405.39
Jun-00	853	794	406.98
Sep-00	807	673	406.83
Dec-00	460	299	406.26
Mar-01	591	396	406.45
Jun-01	347	186	405.98
Sep-01	265	101	405.7
Nov-01	60	10	405.15
Feb-02	764	587	406.72
Apr-02	482	318	406.3
Sep-02	216	63	405.54
Dec-02	20	3	404.95
Mar-03	726	526	406.64
Aug-03	326	163	405.91
Oct-03	169	40	405.42
Jan-04	2	0	404.69
Apr-04	276	113	405.74
Aug-04	145	32	405.37
May-05	0	0	-
Mar-06	259	96	405.68
Jun-06	262	98	405.69
Sep-06	188	48	405.47
Dec-06	105	20	405.27
Jul-07	3	0	404.72
Oct-07	0	0	-
Jun-09	218	65	405.55
Apr-10	0	0	-
Jul-10	0	0	-





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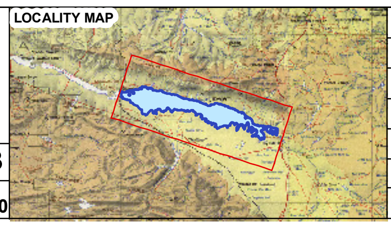

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DATUM: GDA_1994_MGA_Zone_50

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NOTES

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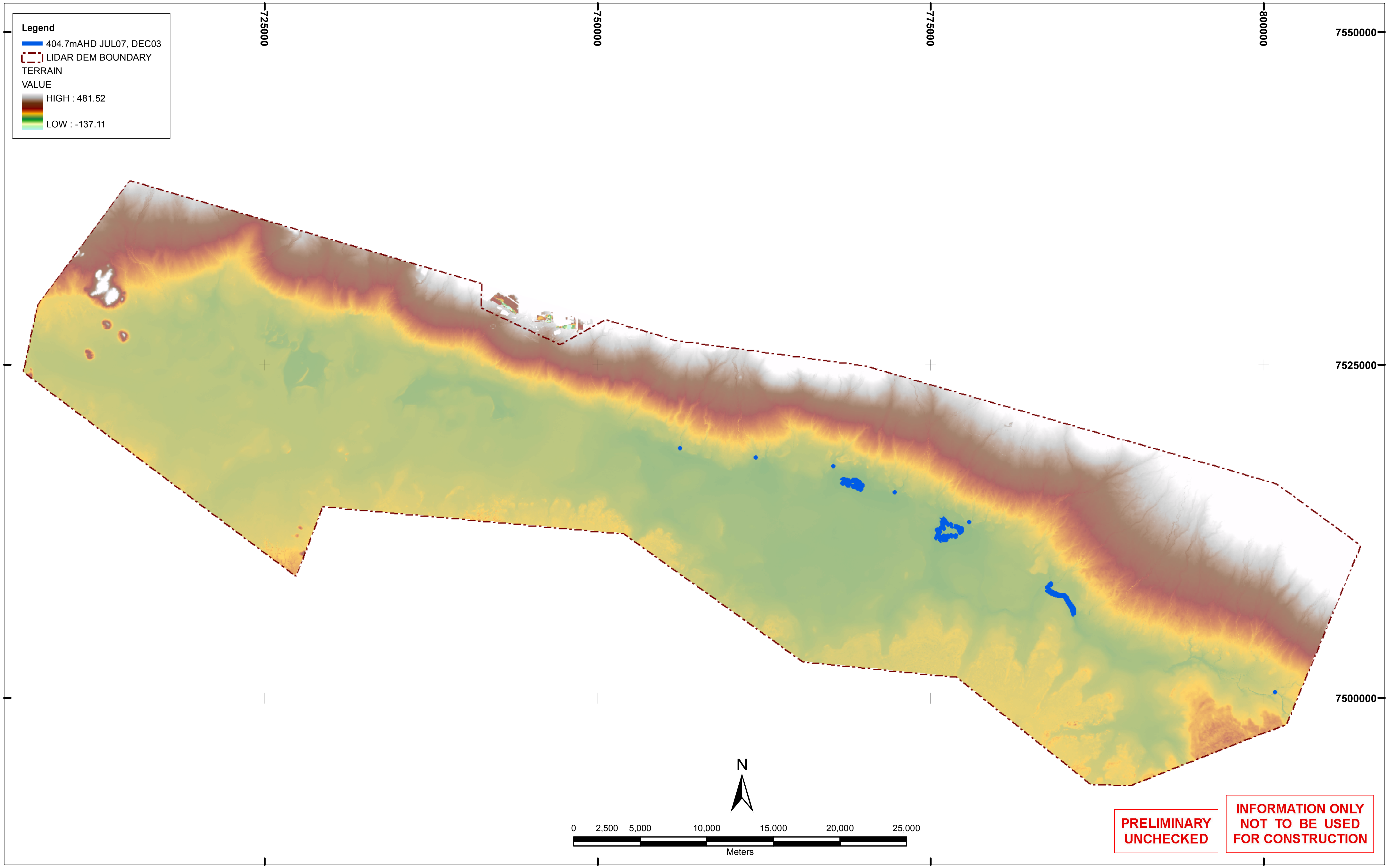

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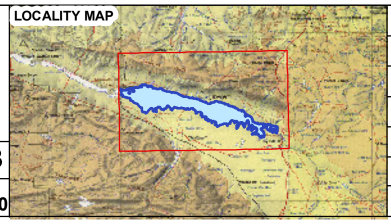
LOCALITY MAP



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SCALE	1:275,000 @ A3
DATUM	GDA_1994_MGA_Zone_50

REV	REVISION DESCRIPTION	DRN	CHK	DATE
A	ISSUED FOR INTERNAL REVIEW			06.10.10

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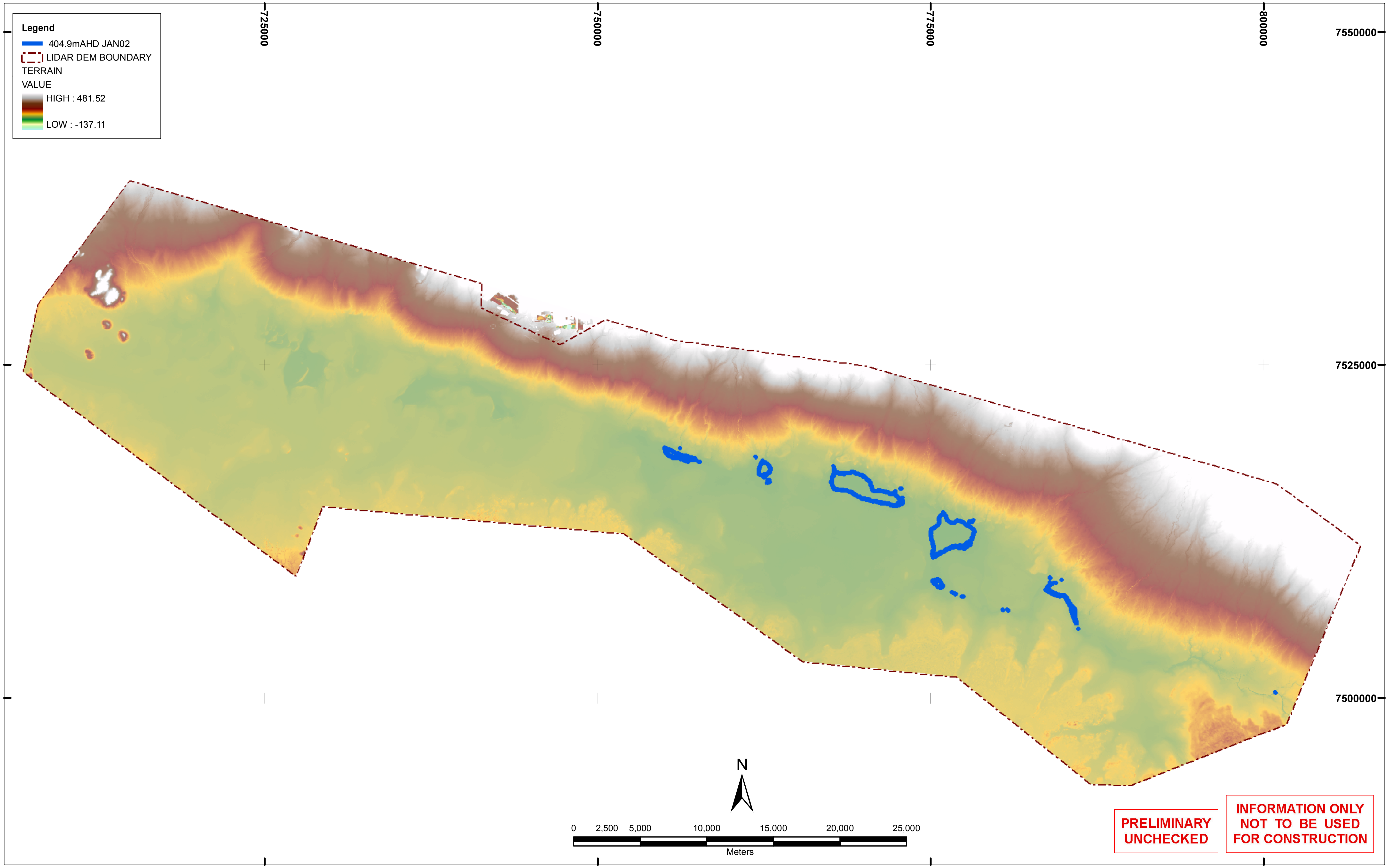

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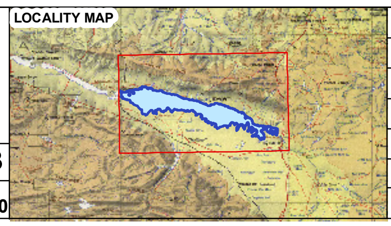

WORLEYPARSONS PROJECT: 201012-00252

SCALE: 1:275,000 @ A3

DATUM: GDA_1994_MGA_Zone_50

REV	REVISION DESCRIPTION	DRN	CHK	DATE
A	ISSUED FOR INTERNAL REVIEW			06.10.10

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TITLE: FORTESCUE MARSH INUNDATION MAPPING 404.9mAHD JAN02

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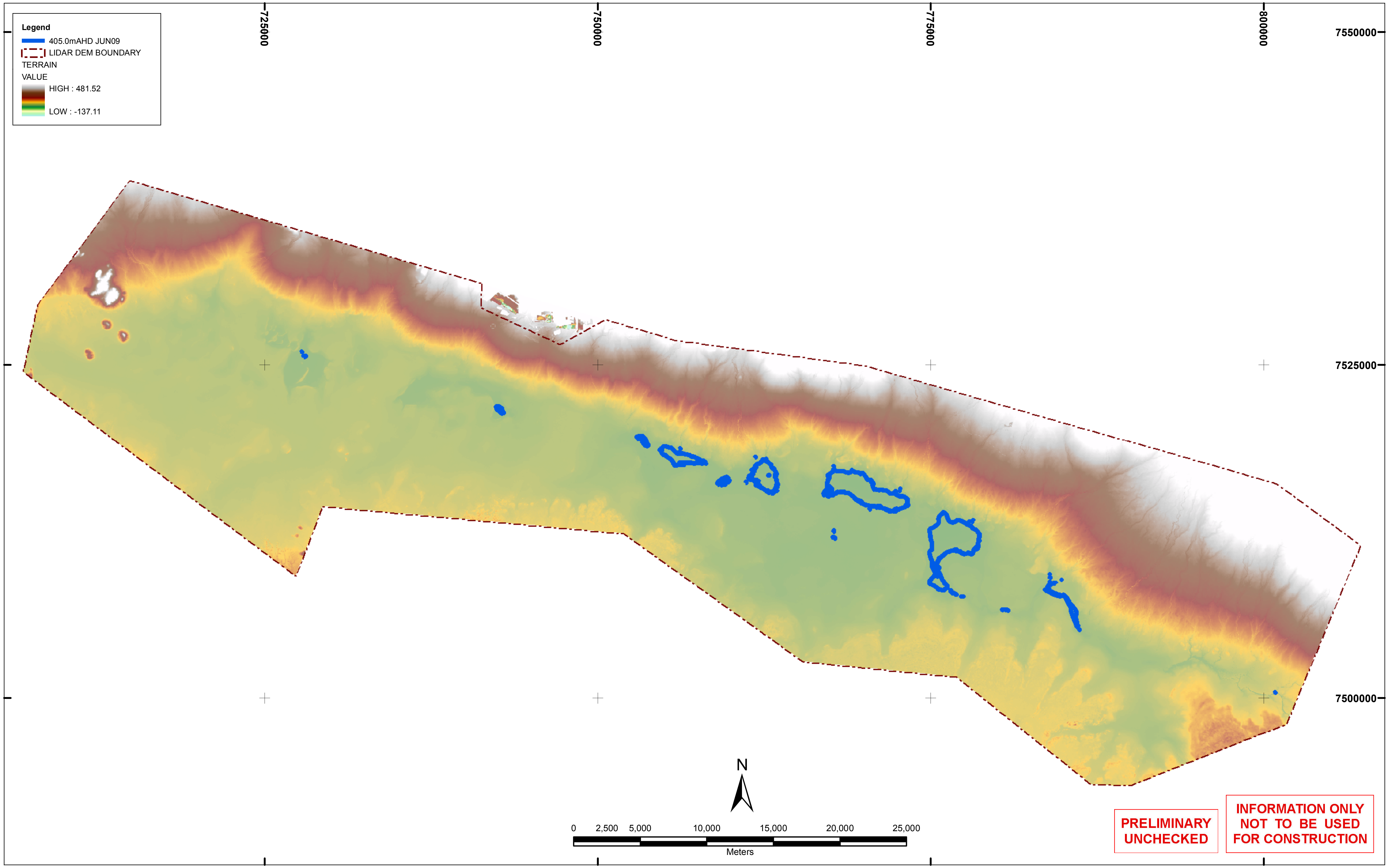

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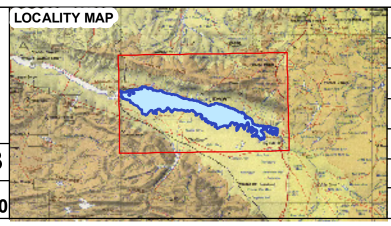

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405.0mAHD JUN09

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DATUM: GDA_1994_MGA_Zone_50

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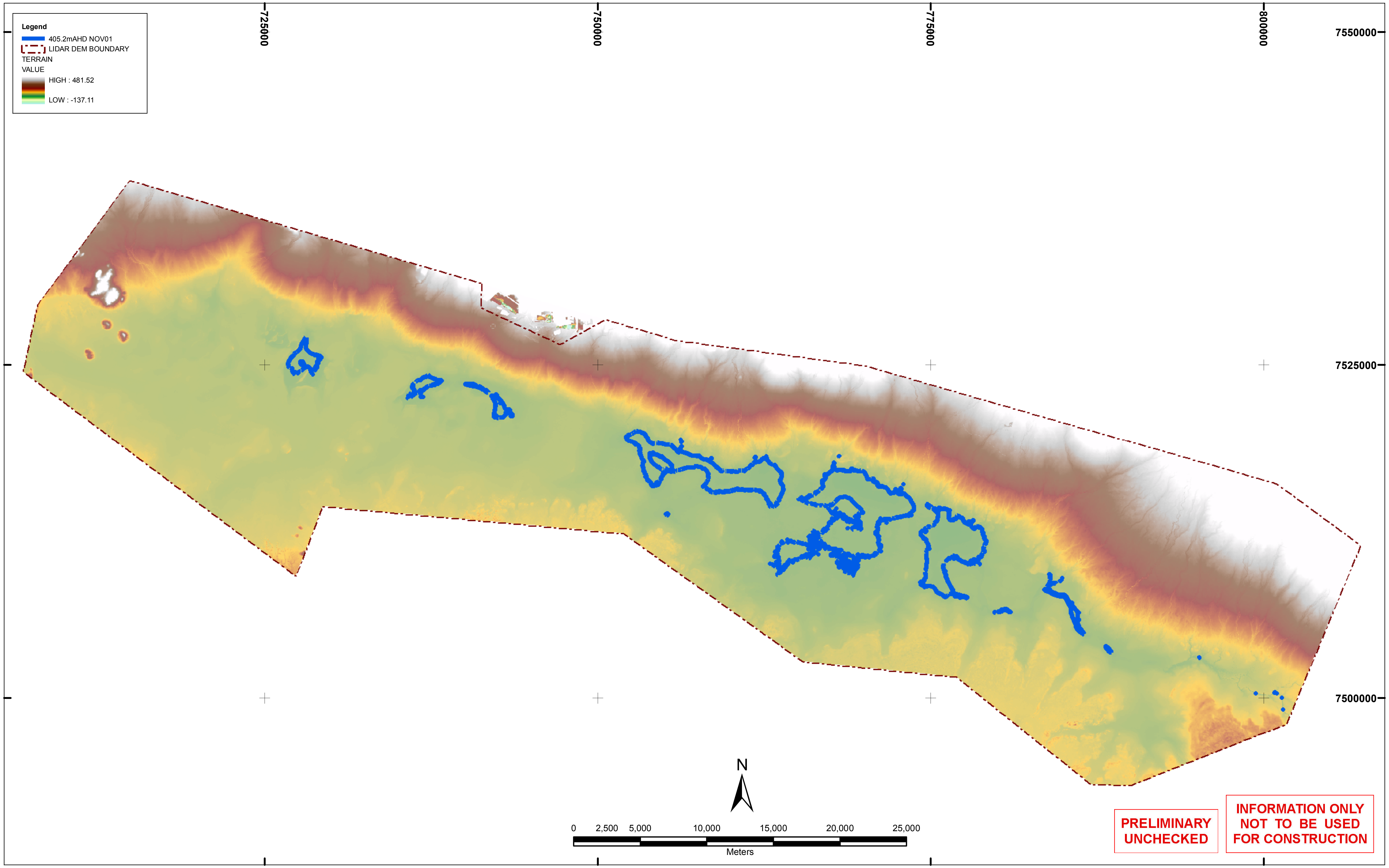

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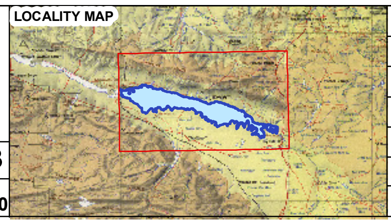

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SCALE: 1:275,000 @ A3

DATUM: GDA_1994_MGA_Zone_50

REV	REVISION DESCRIPTION	DRN	CHK	DATE
A	ISSUED FOR INTERNAL REVIEW			06.10.10

NOTES

CLIENT: FMG

TITLE: FORTESCUE MARSH INUNDATION MAPPING 405.2mAHD NOV01

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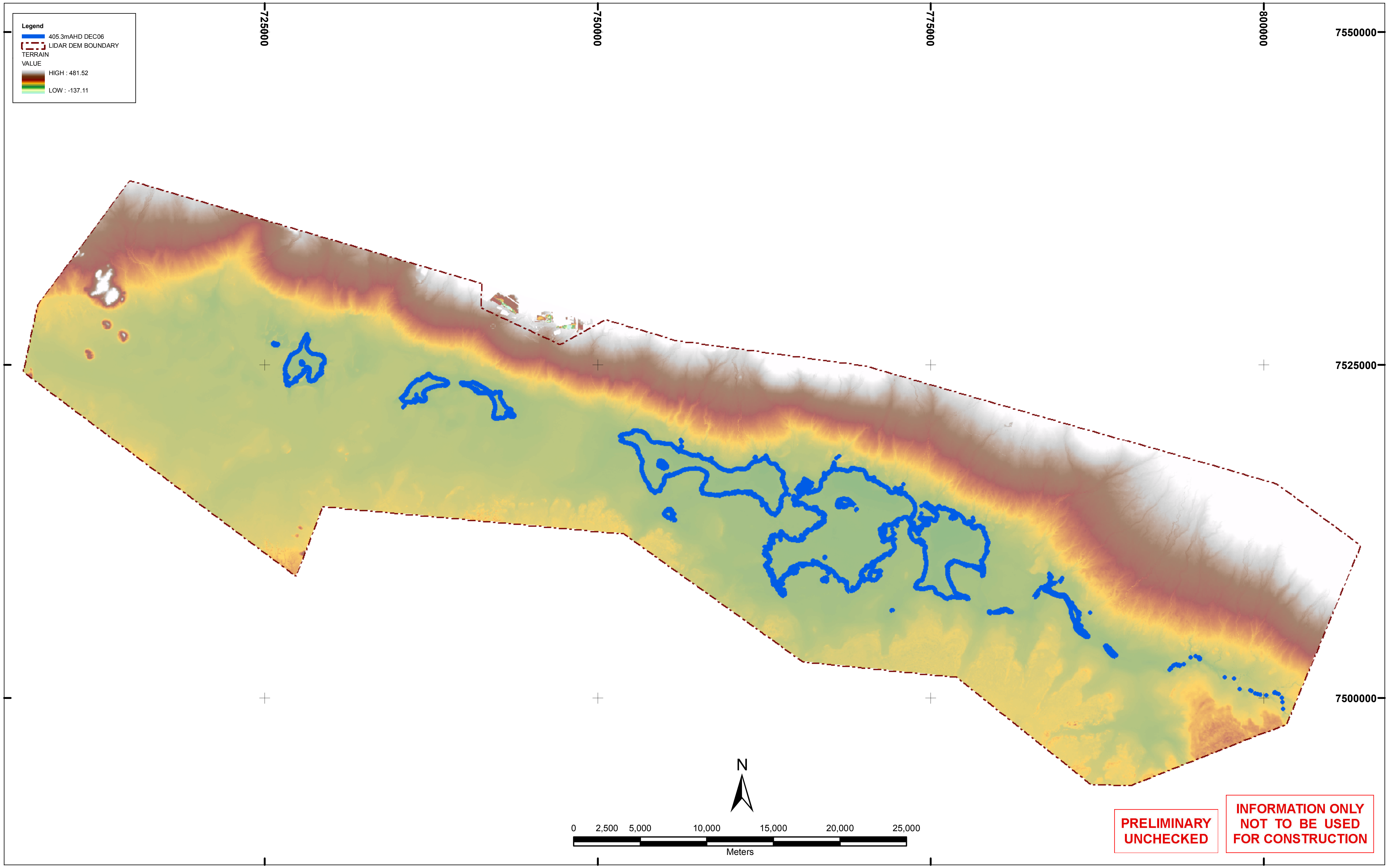

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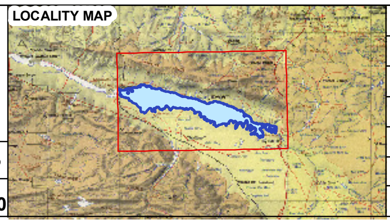
LOCALITY MAP



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	DATUM GDA_1994_MGA_Zone_50				
A	ISSUED FOR INTERNAL REVIEW			06.10.10	
REV	REVISION DESCRIPTION	DRN	CHK	DATE	

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CLIENT
FMG

TITLE
FORTESCUE MARSH
INUNDATION MAPPING
405.3mAHD DEC06

DRG NO 201012-00252-GIS-DSK-002

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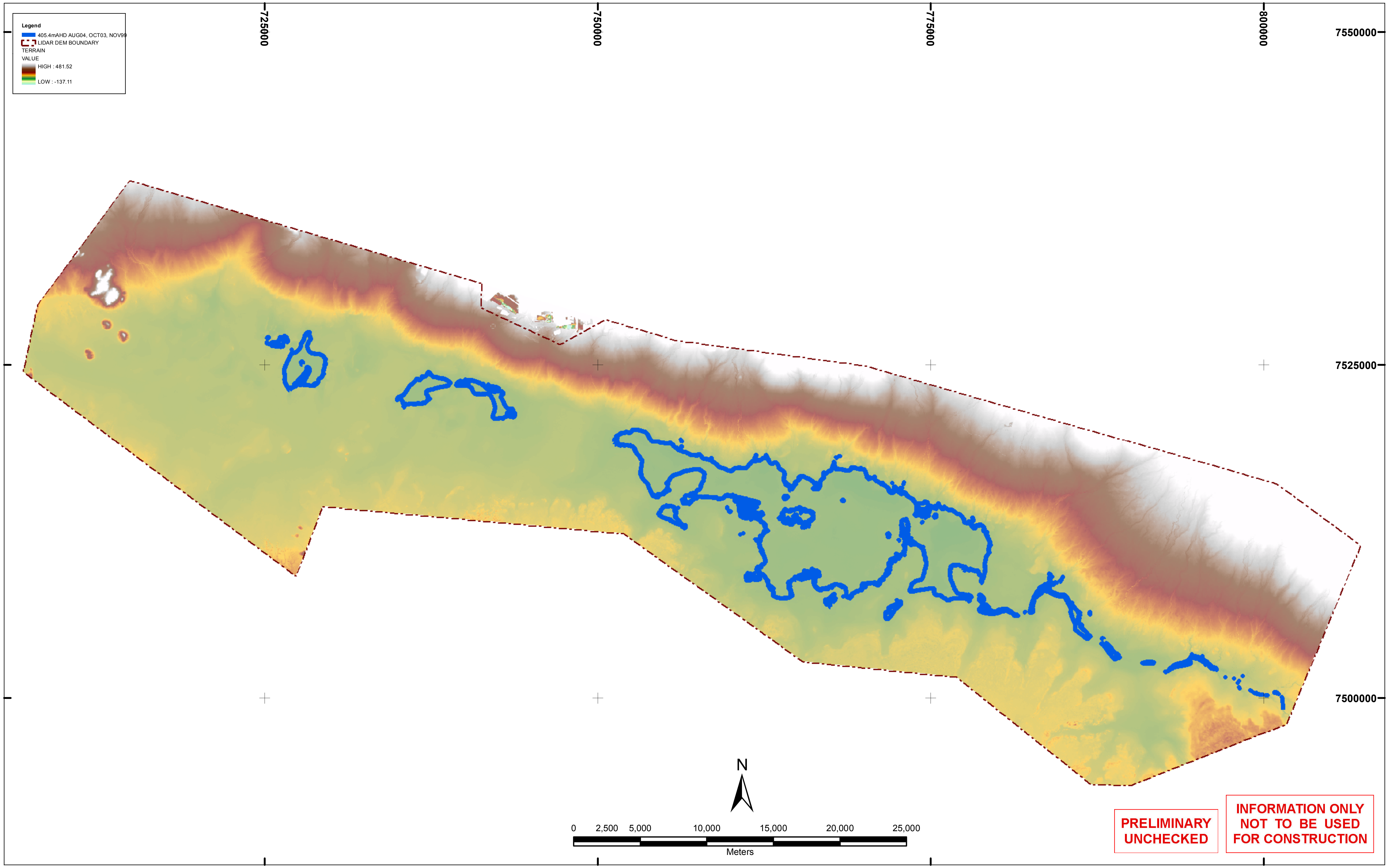

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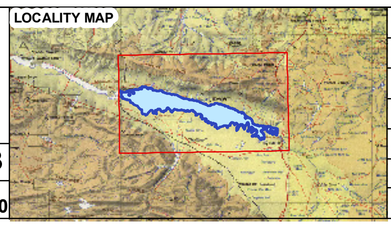

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DATUM: GDA_1994_MGA_Zone_50

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TITLE: FORTESCUE MARSH INUNDATION MAPPING 405.4mAHD AUG04, OCT03, NOV99

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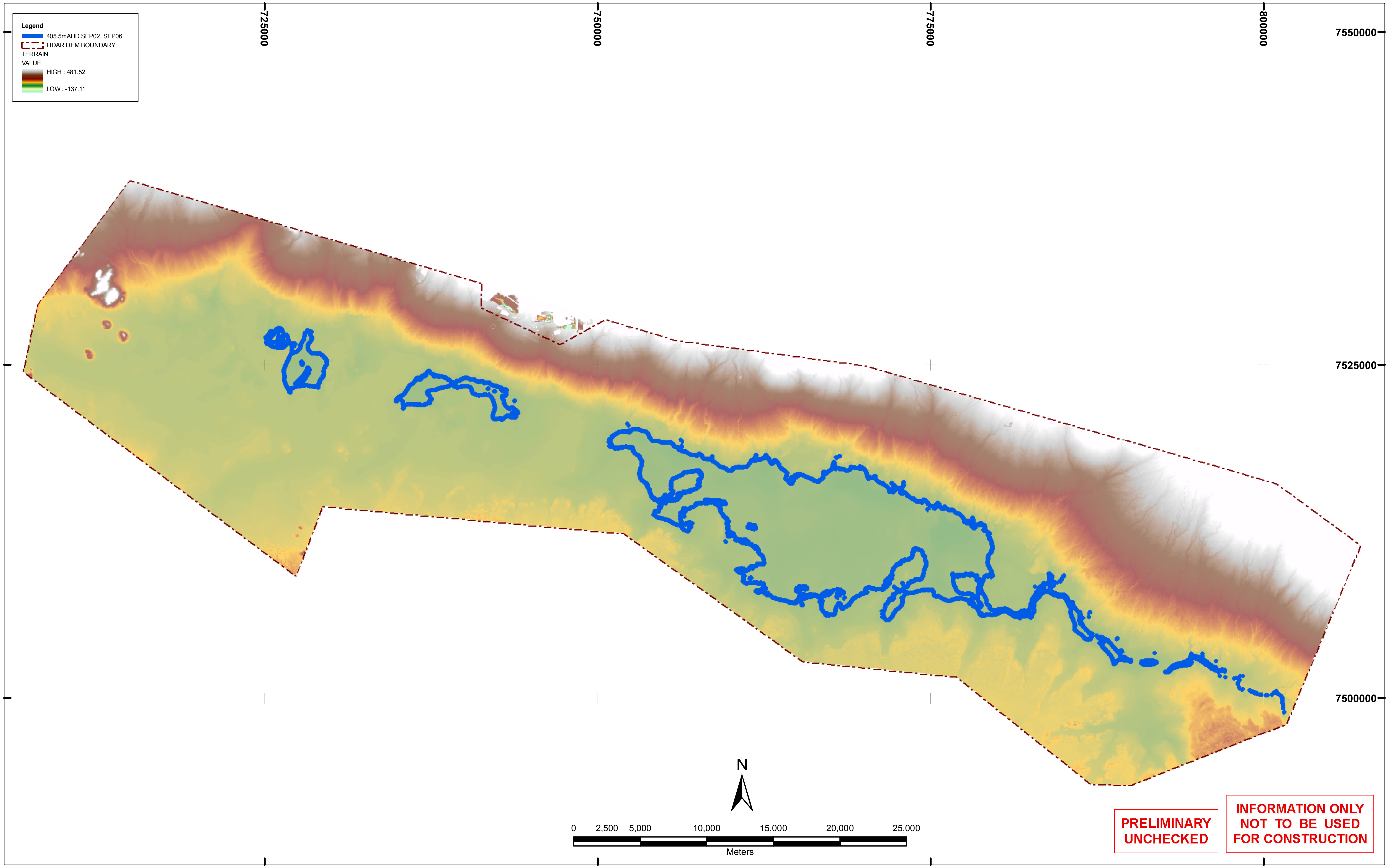
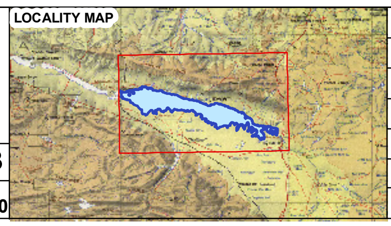


WorleyParsons EcoNomics
resources & energy



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REV	REVISION DESCRIPTION	DRN	CHK	DATE

WORLEYPARSONS PROJECT: 201012-00252

SCALE: 1:275,000 @ A3

DATUM: GDA_1994_MGA_Zone_50

NOTES

CLIENT: FMG

TITLE: FORTESCUE MARSH INUNDATION MAPPING 405.5mAHD SEP02, SEP06

DRG NO: 201012-00252-GIS-DSK-002

REV: A

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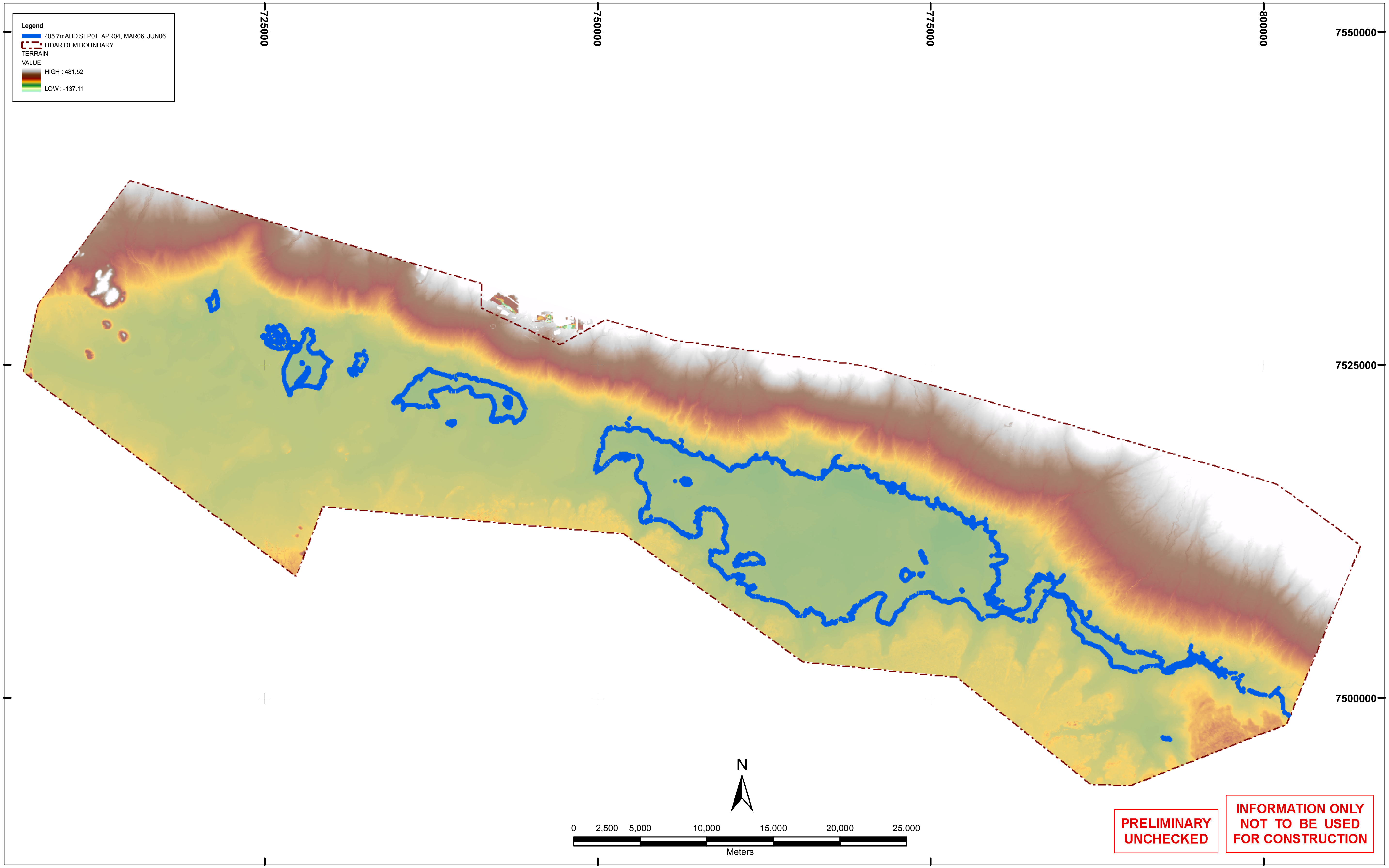

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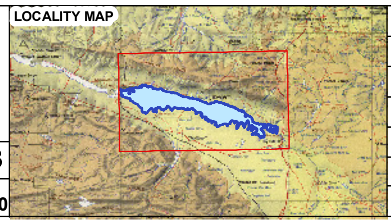
LOCALITY MAP



A	ISSUED FOR INTERNAL REVIEW			06.10.10
REV	REVISION DESCRIPTION	DRN	CHK	DATE

WORLEYPARSONS PROJECT: 201012-00252

SCALE: 1:275,000 @ A3

DATUM: GDA_1994_MGA_Zone_50

NOTES

CLIENT: FMG

TITLE: FORTESCUE MARSH INUNDATION MAPPING 405.7mAHD SEP01, APR04, MAR06, JUN06

DRG NO: 201012-00252-GIS-DSK-002

REV: A

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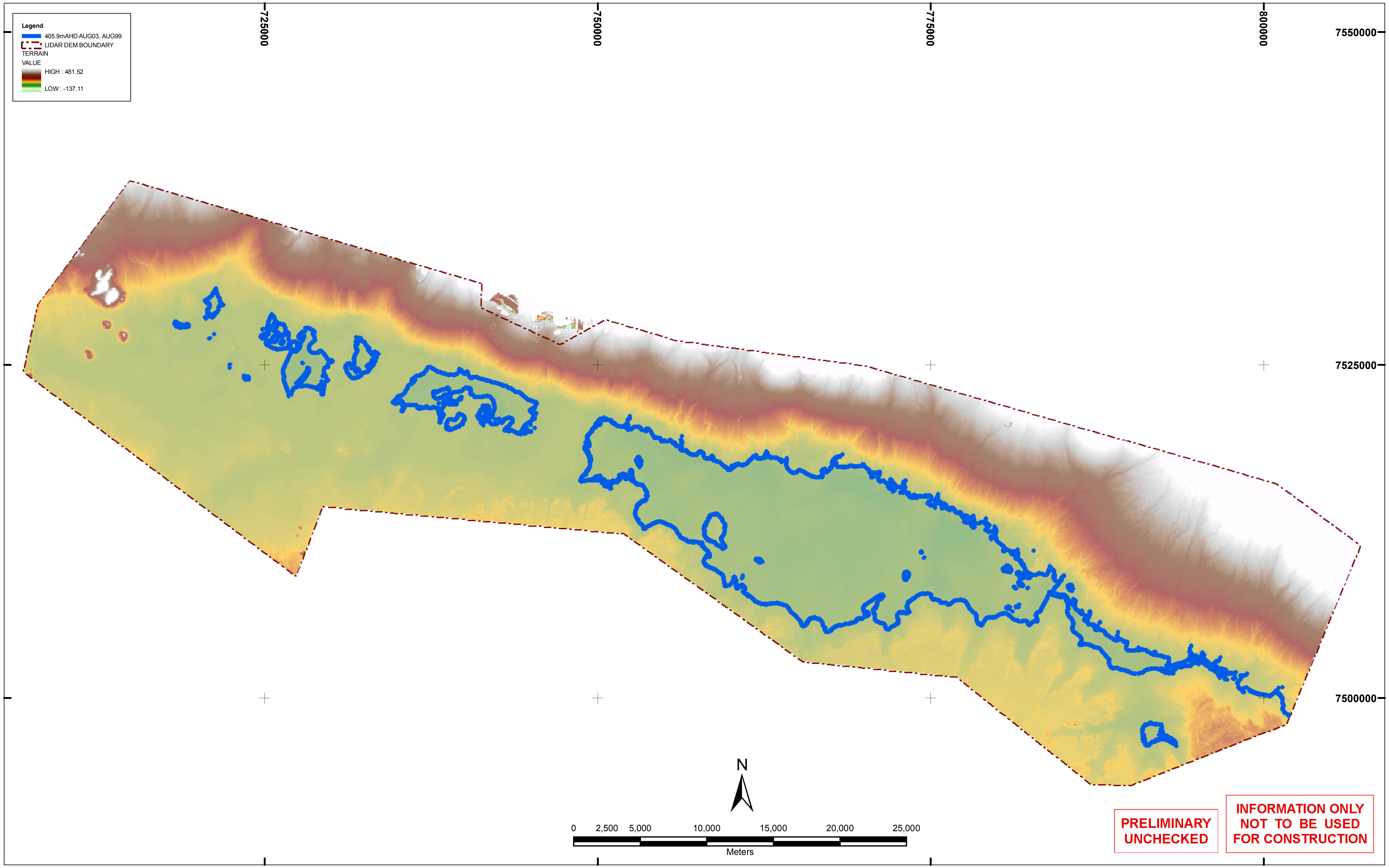

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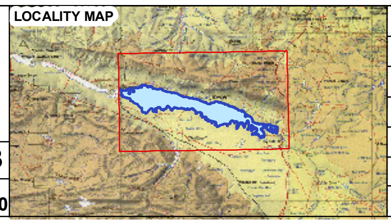
WORLEYPARSONS PROJECT
201012-00252

SCALE 1:275,000 @ A3

DATUM GDA_1994_MGA_Zone_50

LOCALITY MAP



REV	REVISION DESCRIPTION	DRN	CHK	DATE
A	ISSUED FOR INTERNAL REVIEW			06.10.10

NOTES

CLIENT
FMG

TITLE
FORTESCUE MARSH
INUNDATION MAPPING
405.9mAHD AUG03, AUG99

DRG NO 201012-00252-GIS-DSK-002

REV A

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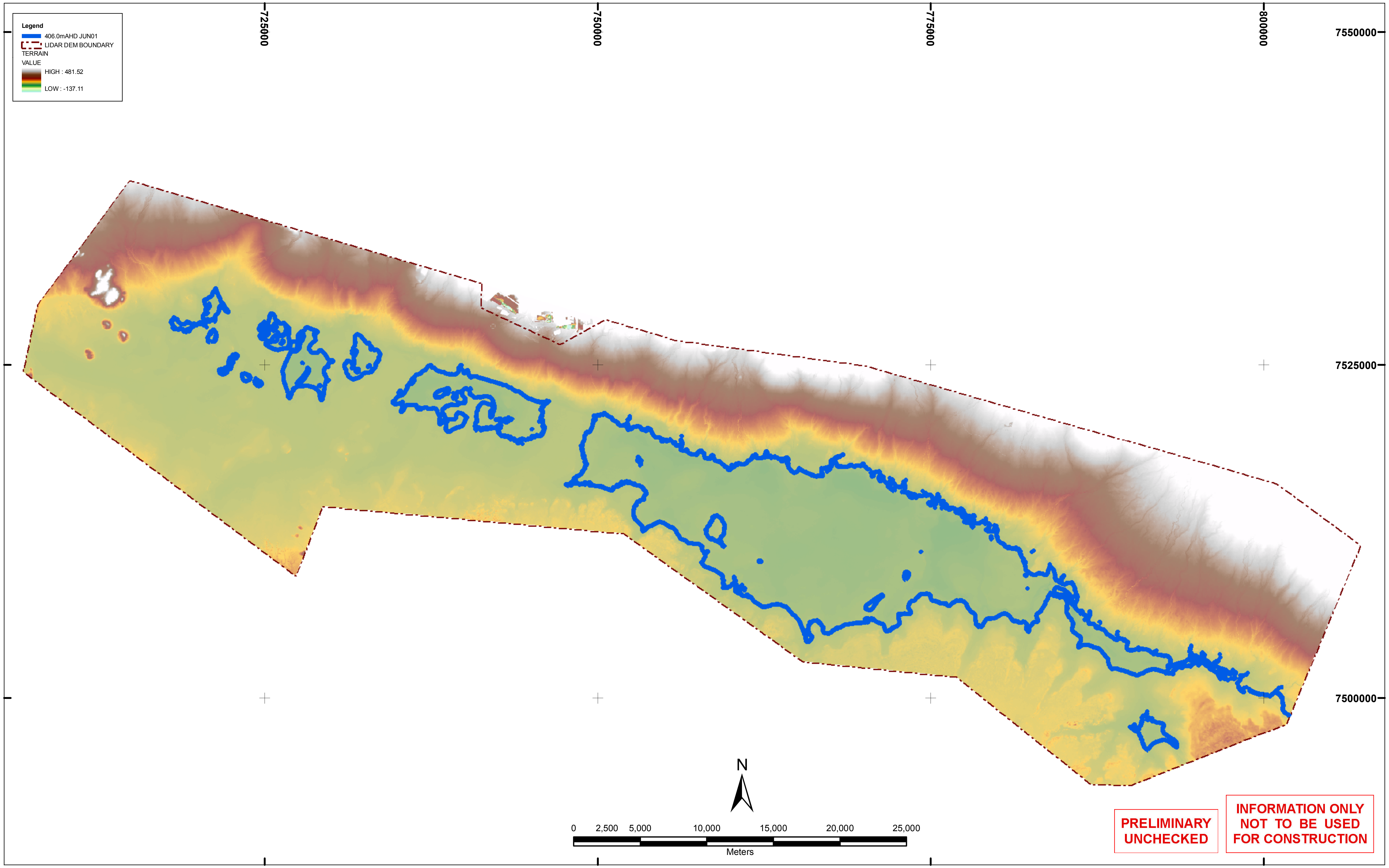

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WORLEYPARSONS PROJECT: 201012-00252

SCALE: 1:275,000 @ A3

DATUM: GDA_1994_MGA_Zone_50

LOCALITY MAP

REV	REVISION DESCRIPTION	DRN	CHK	DATE
A	ISSUED FOR INTERNAL REVIEW			06.10.10

NOTES

CLIENT: FMG

TITLE: FORTESCUE MARSH INUNDATION MAPPING 406.0mAHD JUN01

DRG NO: 201012-00252-GIS-DSK-002

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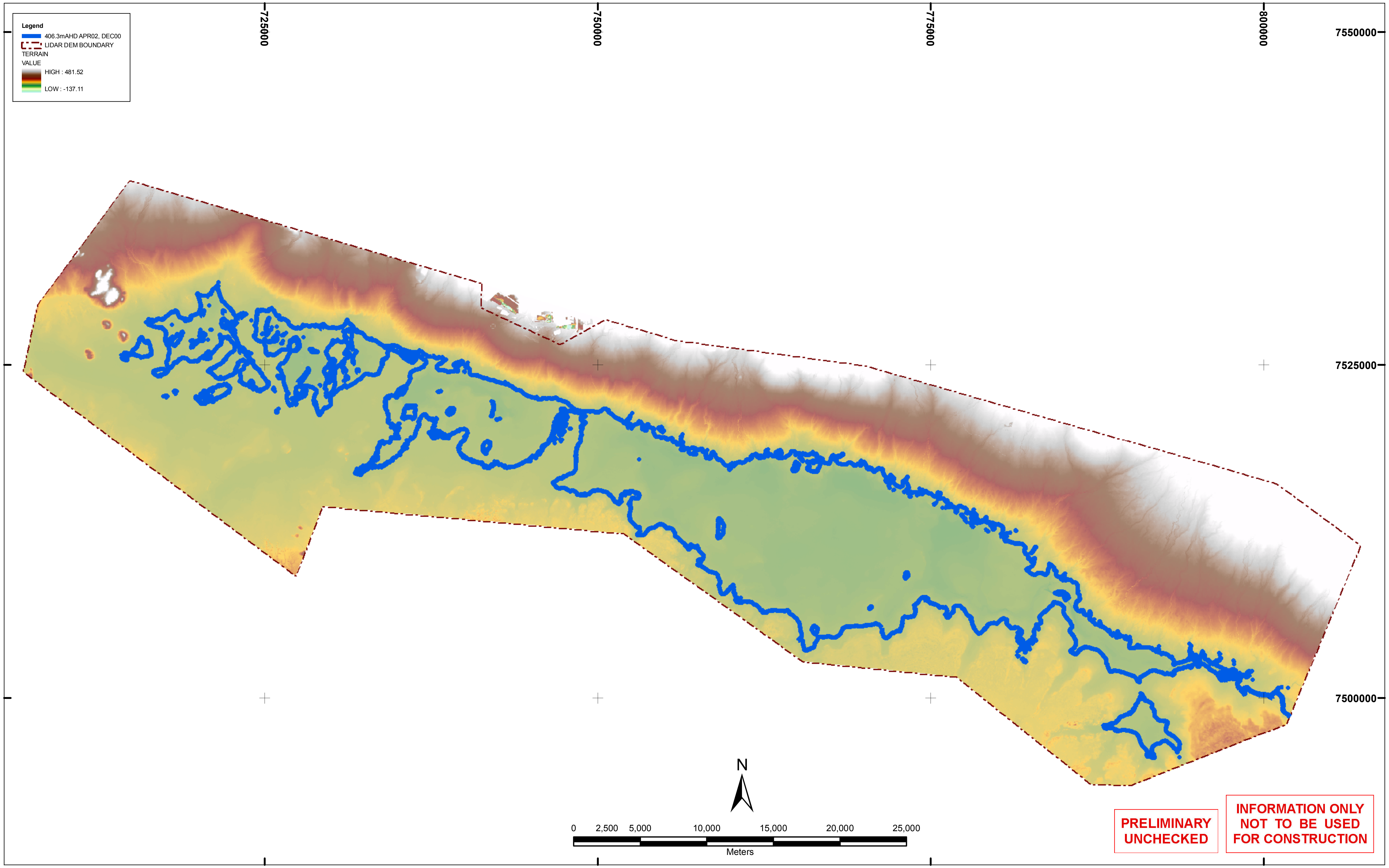

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WORLEYPARSONS PROJECT: 201012-00252

SCALE: 1:275,000 @ A3

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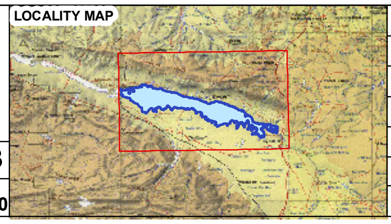

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A	ISSUED FOR INTERNAL REVIEW			06.10.10

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DRG NO: 201012-00252-GIS-DSK-002

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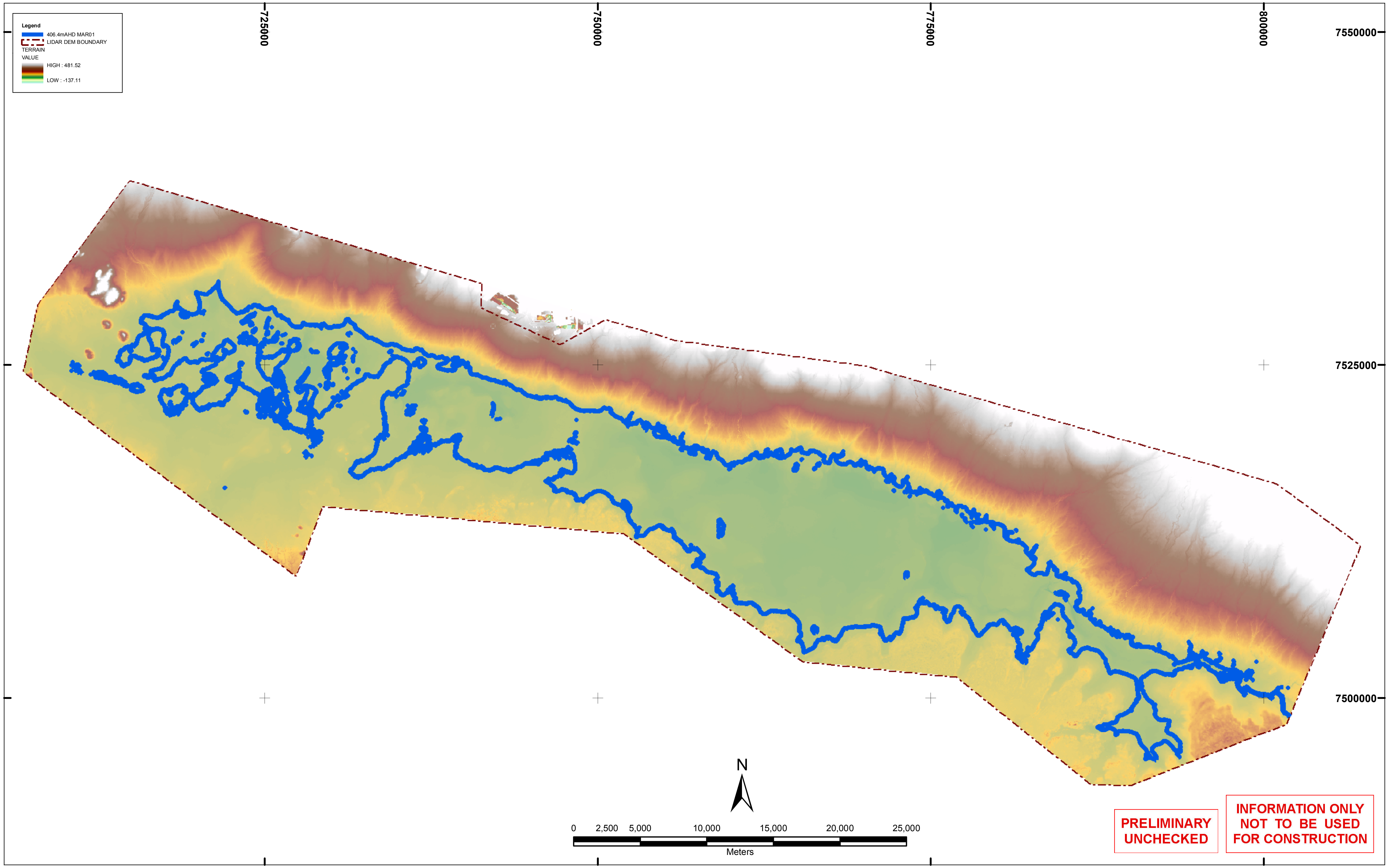

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WORLEYPARSONS PROJECT: 201012-00252

SCALE: 1:275,000 @ A3

DATUM: GDA_1994_MGA_Zone_50

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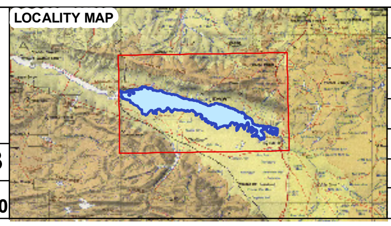

REV	REVISION DESCRIPTION	DRN	CHK	DATE
A	ISSUED FOR INTERNAL REVIEW			06.10.10

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CLIENT: FMG

TITLE: FORTESCUE MARSH INUNDATION MAPPING 406.4mAHD MAR01

DRG NO: 201012-00252-GIS-DSK-002

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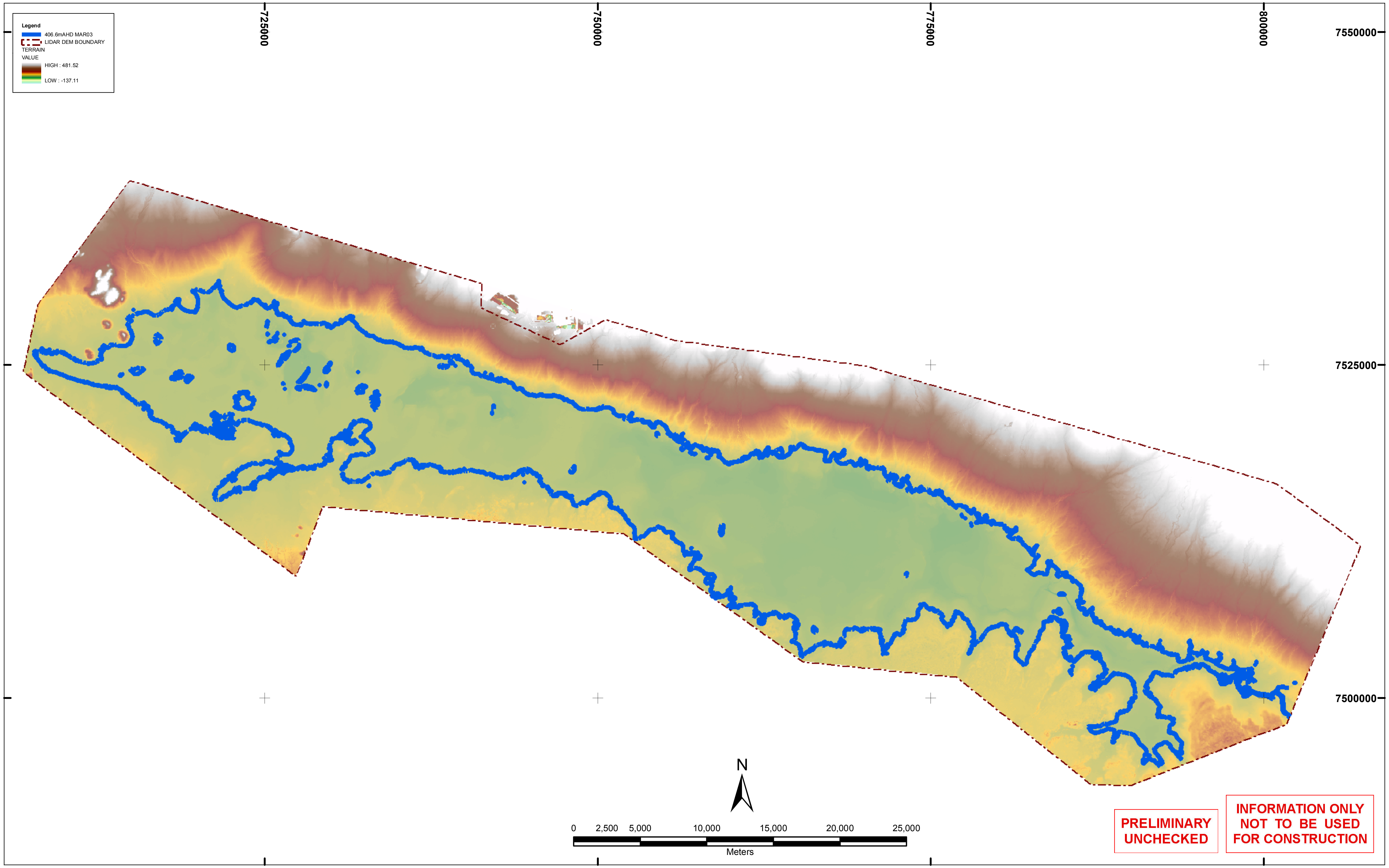

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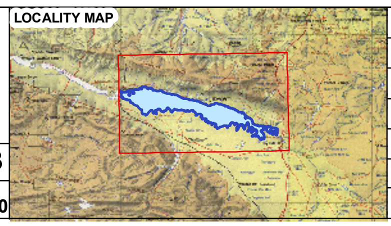

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REV	REVISION DESCRIPTION	DRN	CHK	DATE
A	ISSUED FOR INTERNAL REVIEW			06.10.10

NOTES

CLIENT
FMG

TITLE
FORTESCUE MARSH
INUNDATION MAPPING
406.6mAHD MAR03

DRG NO 201012-00252-GIS-DSK-002

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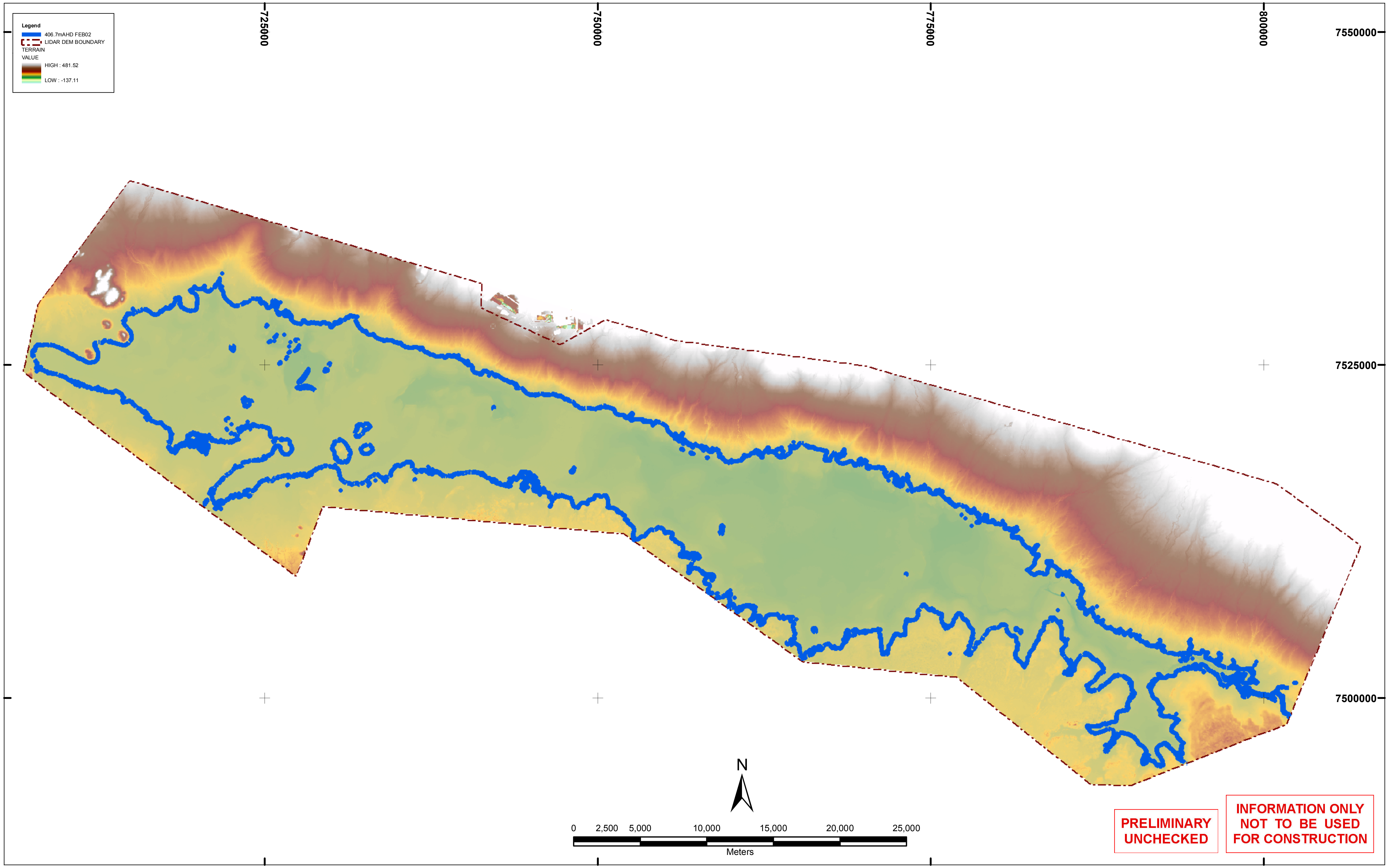

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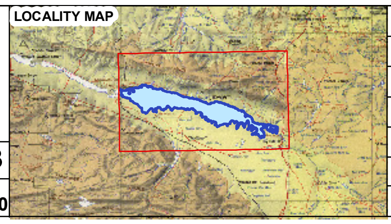

REV	REVISION DESCRIPTION	DRN	CHK	DATE
A	ISSUED FOR INTERNAL REVIEW			06.10.10

WORLEYPARSONS PROJECT: 201012-00252

SCALE: 1:275,000 @ A3

DATUM: GDA_1994_MGA_Zone_50

NOTES

CLIENT: FMG

TITLE: FORTESCUE MARSH INUNDATION MAPPING 406.7mAHD FEB02

DRG NO: 201012-00252-GIS-DSK-002

REV: A

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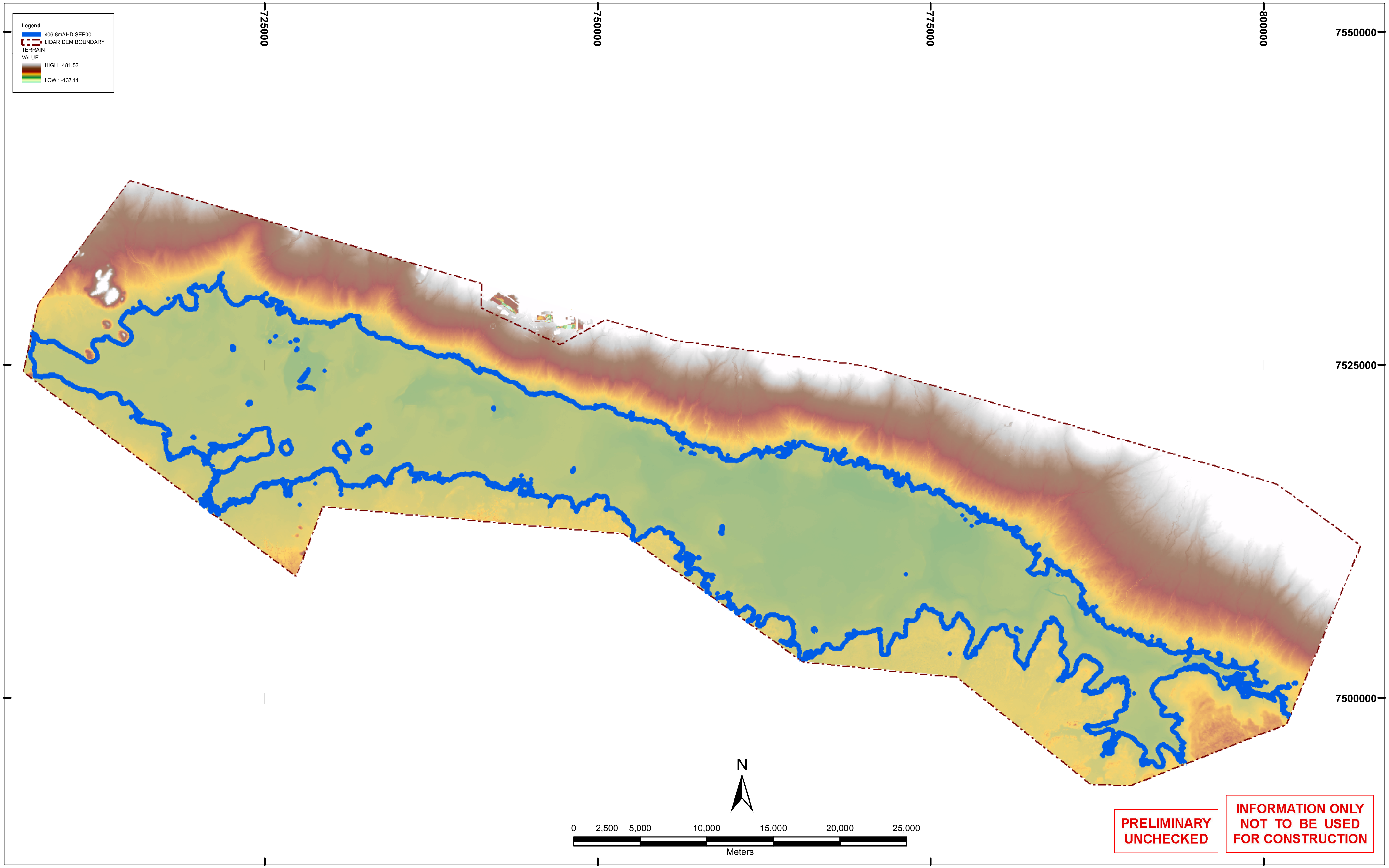

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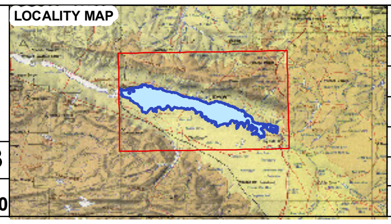
LOCALITY MAP



WORLEYPARSONS PROJECT	SCALE	DATUM
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REV	REVISION DESCRIPTION	DRN	CHK	DATE
A	ISSUED FOR INTERNAL REVIEW			06.10.10

NOTES

CLIENT
FMG

TITLE
FORTESCUE MARSH
INUNDATION MAPPING
406.8mAHD SEP00

DRG NO
201012-00252-GIS-DSK-002

REV
A

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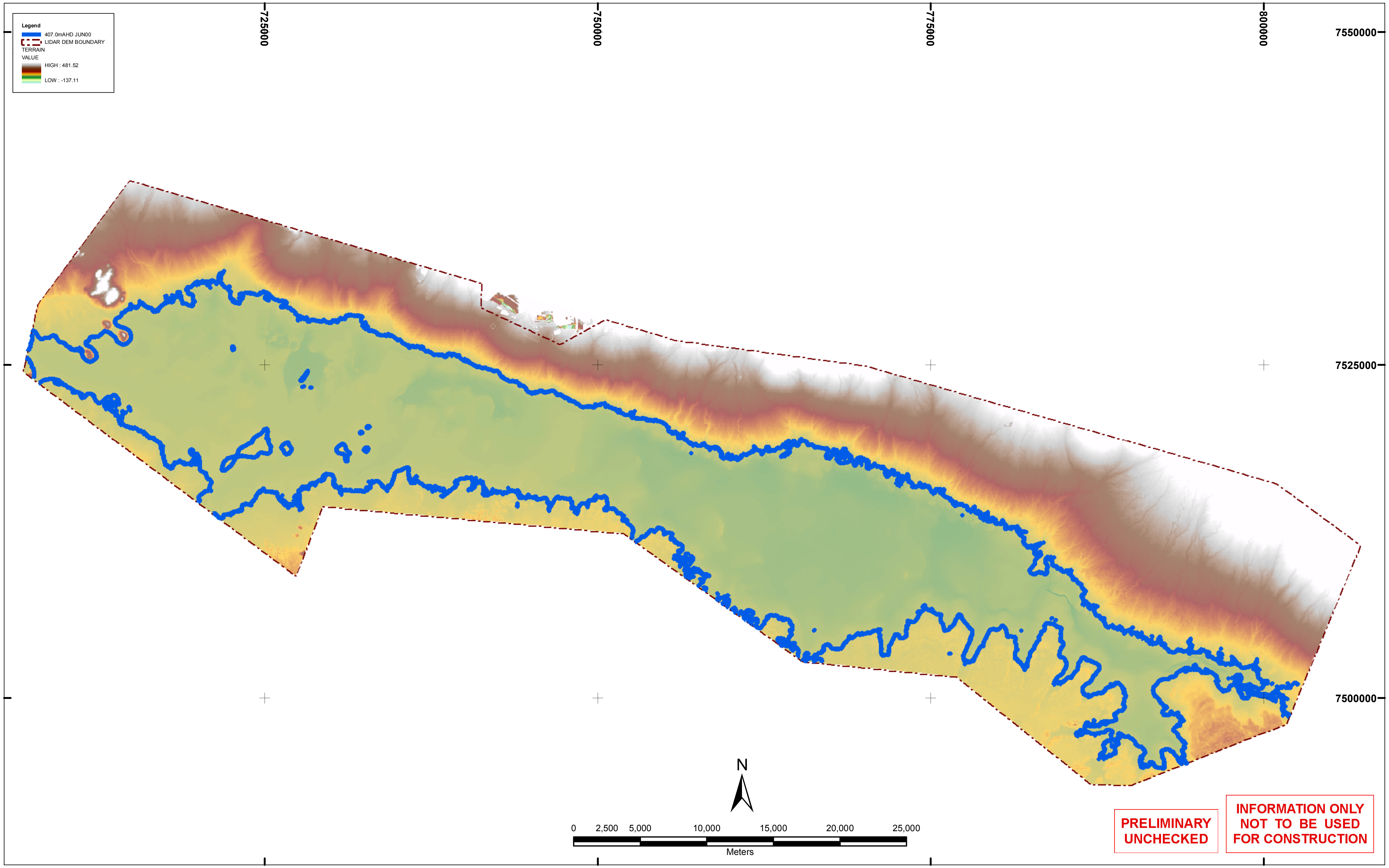

WorleyParsons EcoNomics

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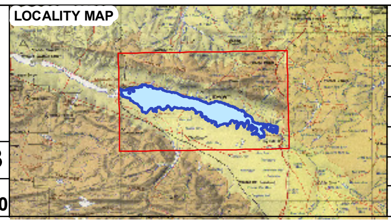
LOCALITY MAP



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REV	REVISION DESCRIPTION	DRN	CHK	DATE
A	ISSUED FOR INTERNAL REVIEW			06.10.10

NOTES

CLIENT: FMG

TITLE: FORTESCUE MARSH INUNDATION MAPPING 407.0mAHD JUN00

DRG NO: 201012-00252-GIS-DSK-002

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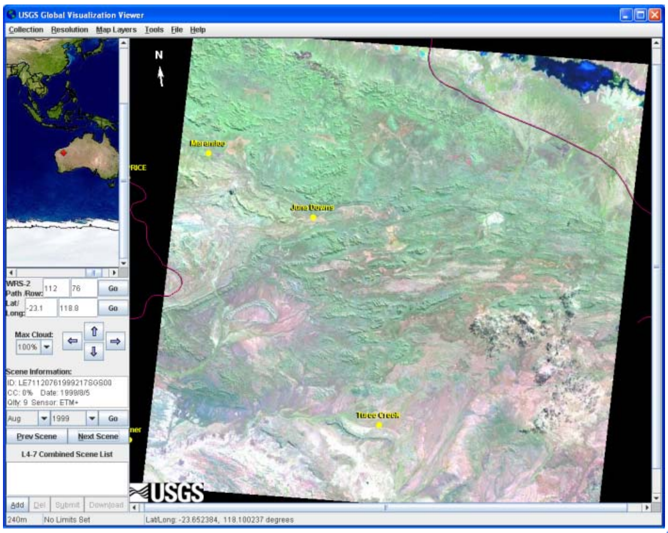
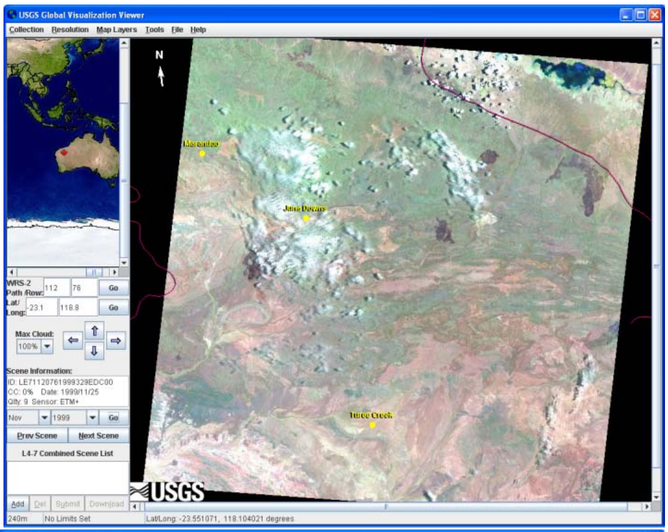
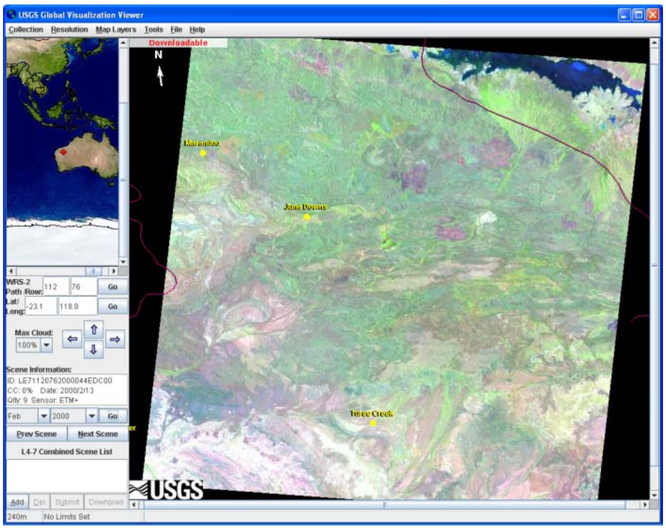
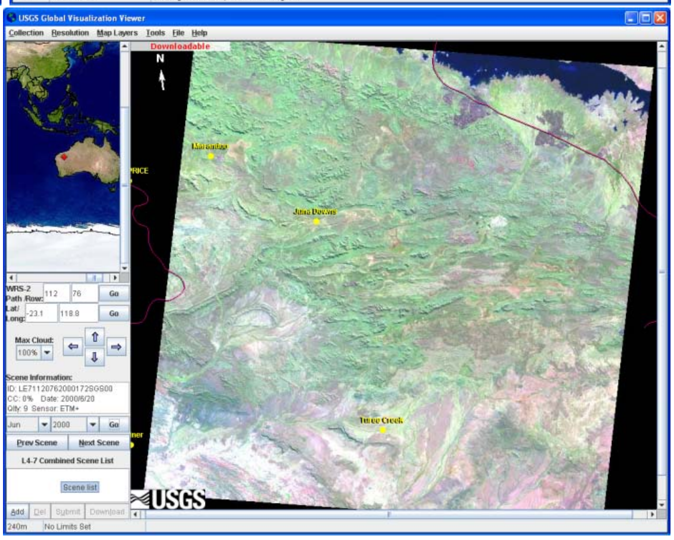
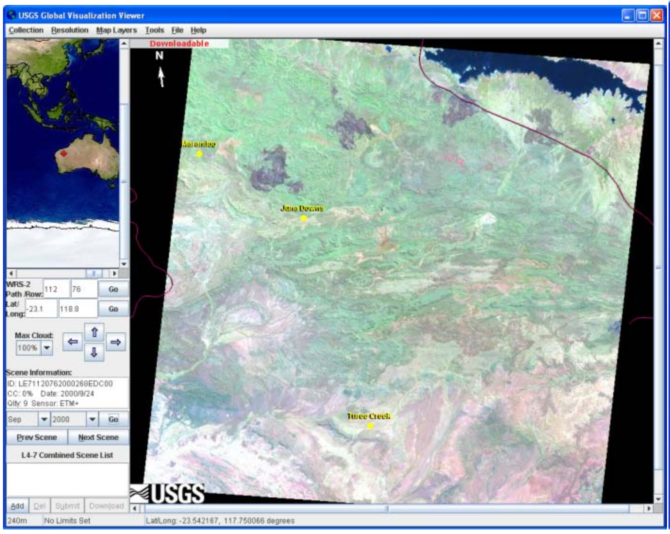
Aug 1999-Dec 2000

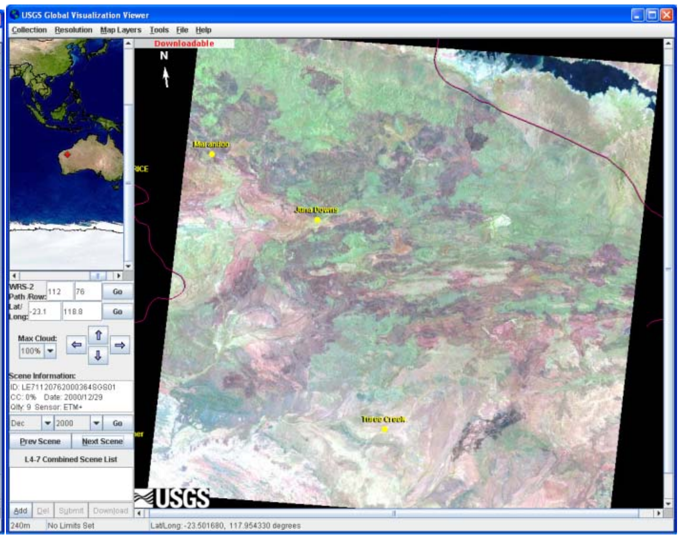












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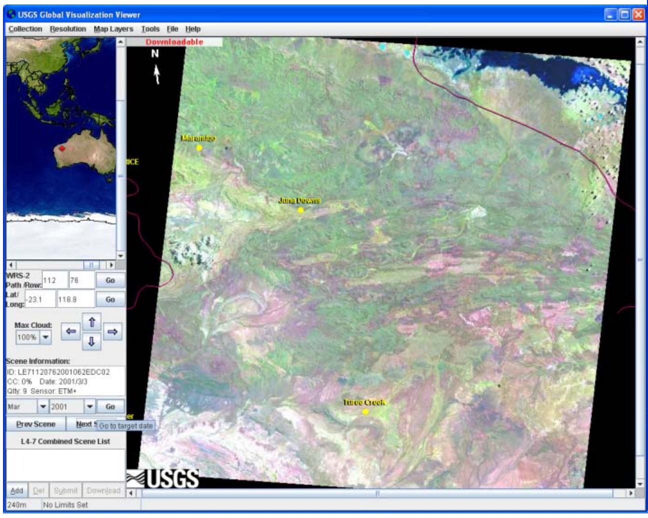

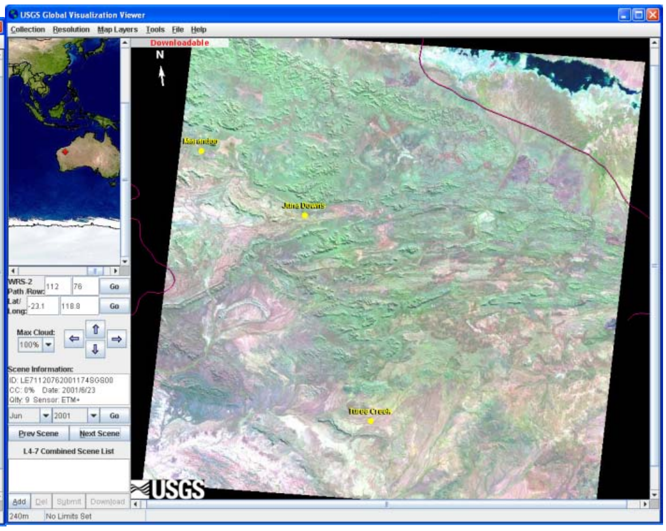

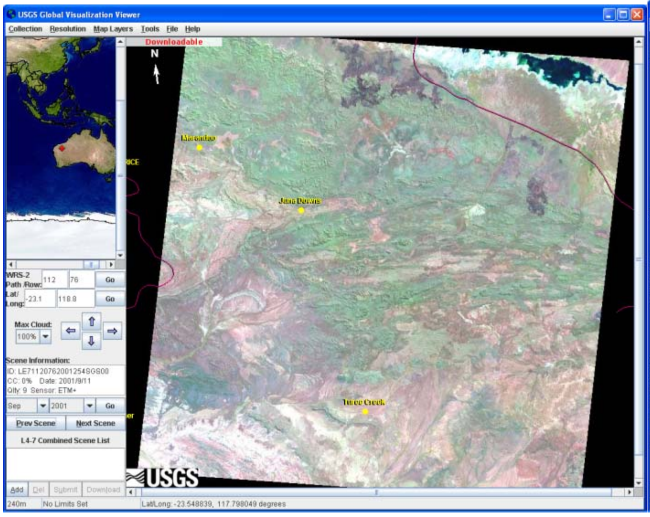

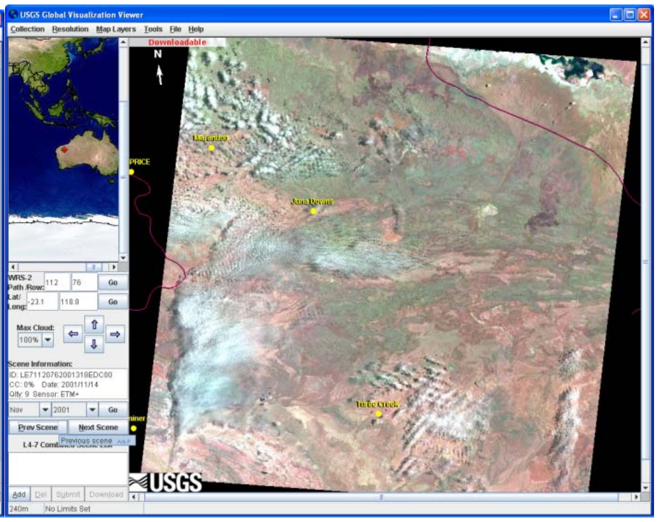

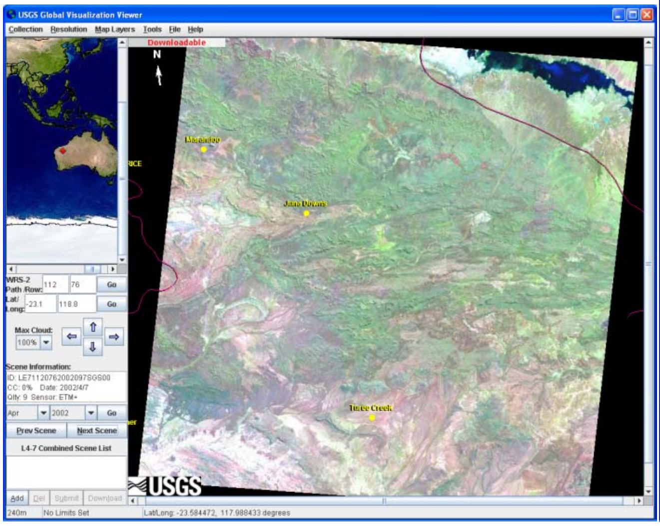

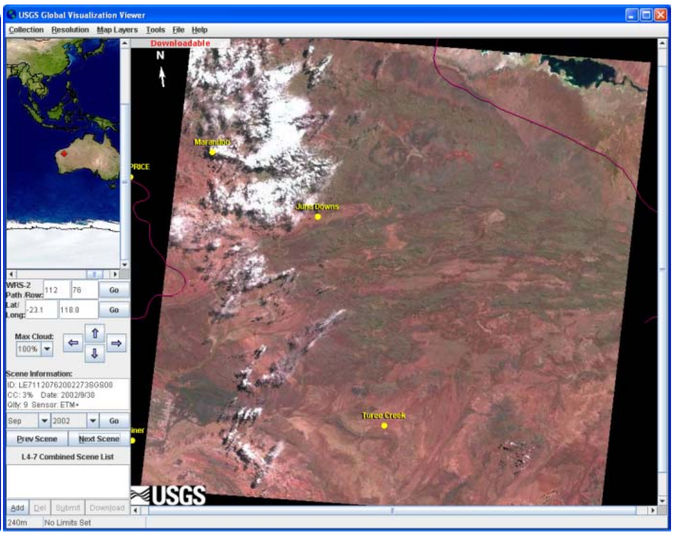

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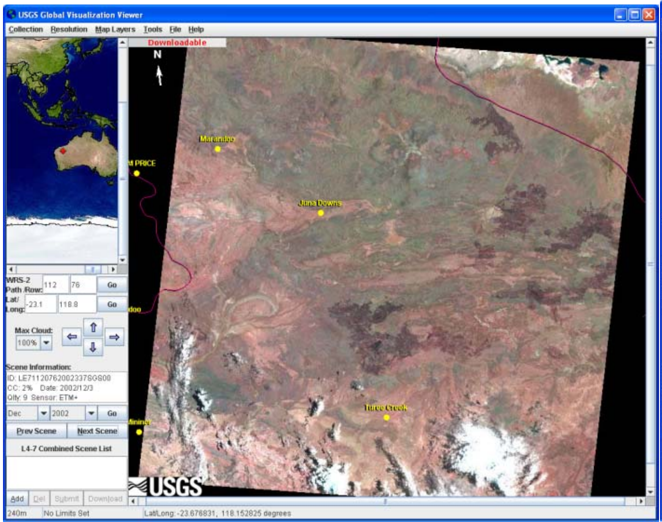
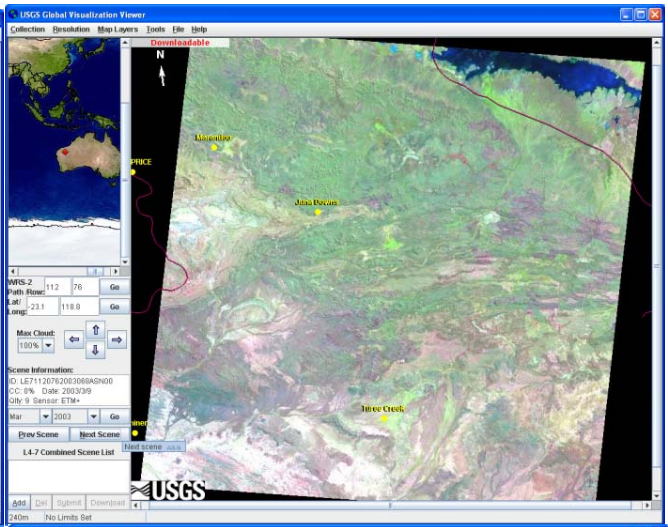
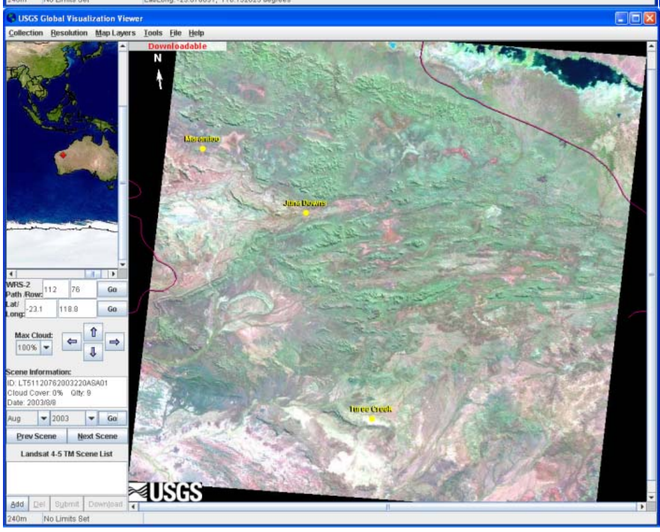
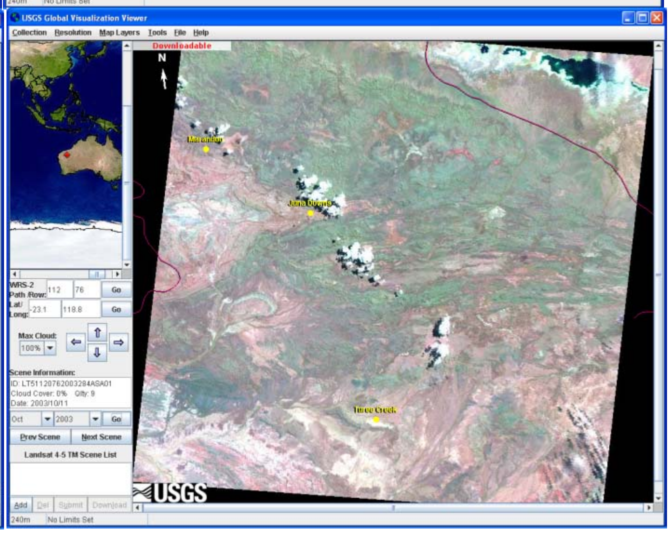
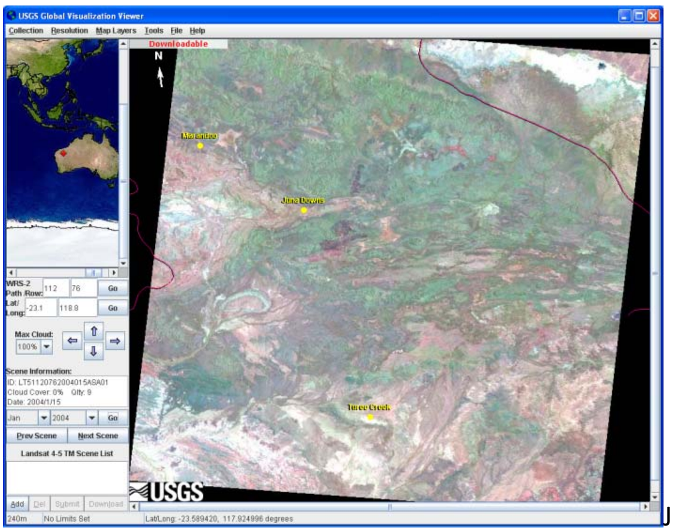
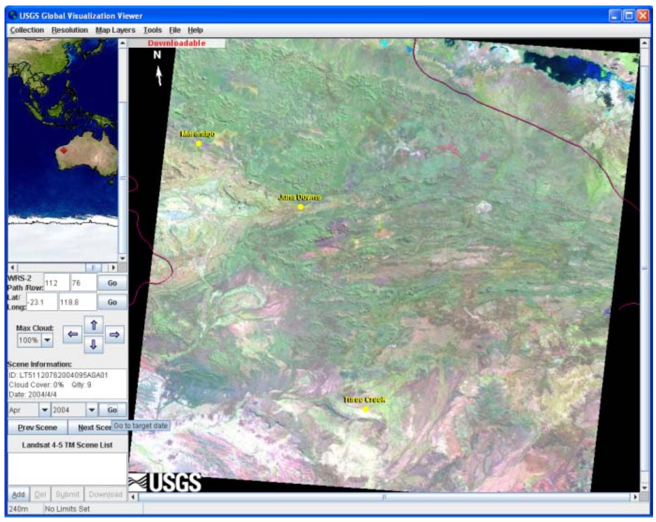




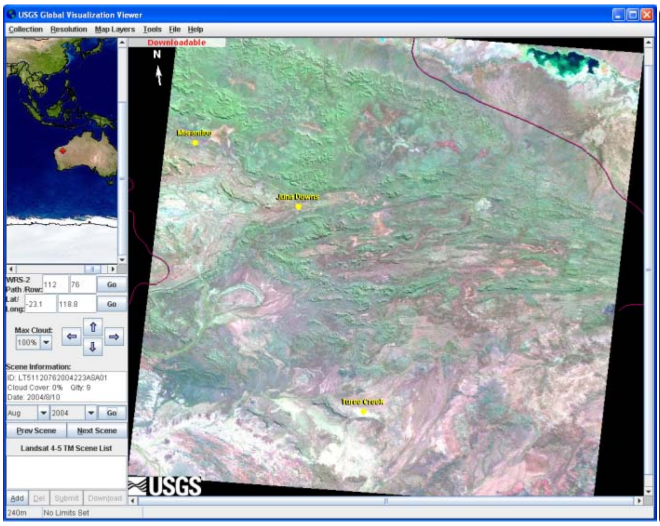


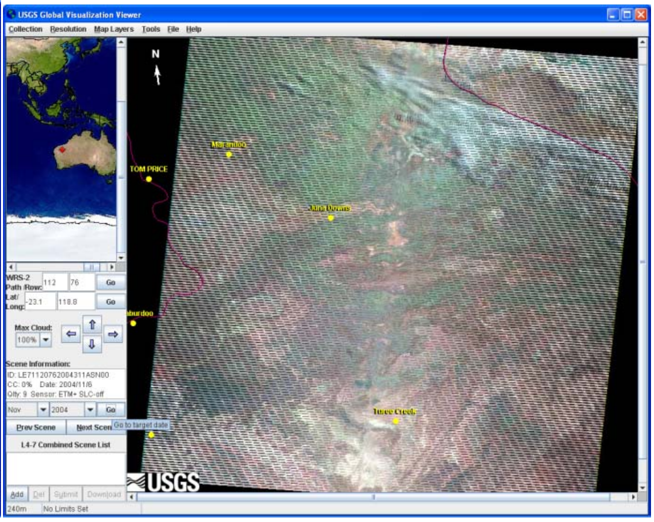


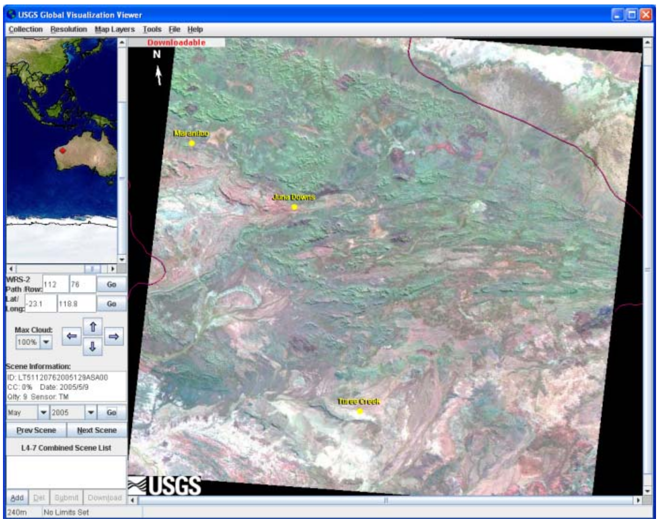


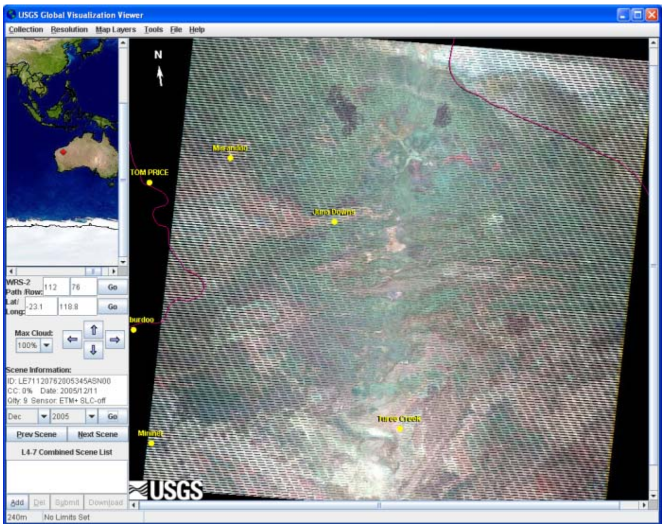


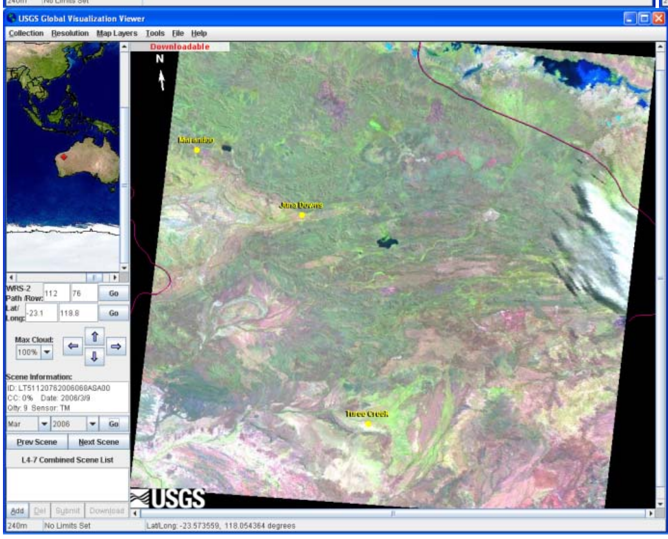
Aug 2004 – June 2006

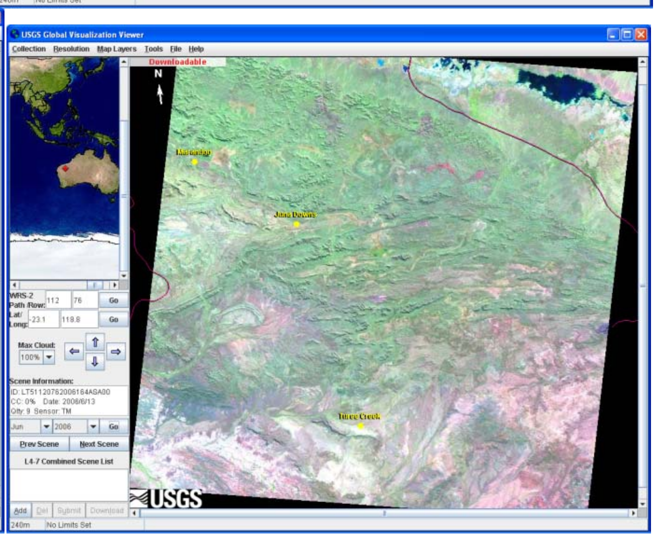












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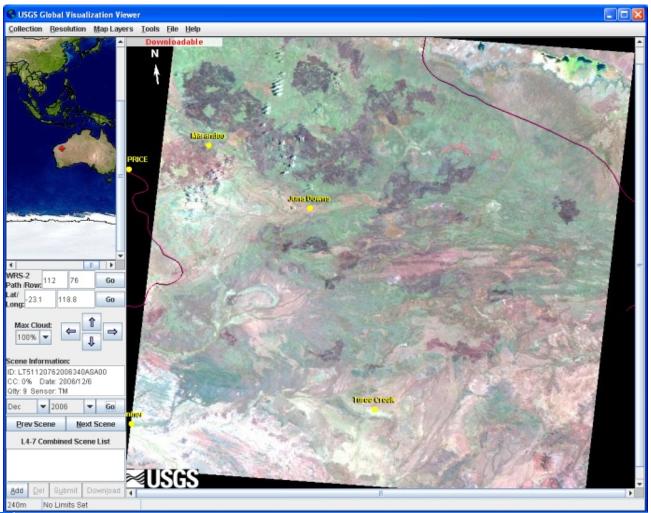
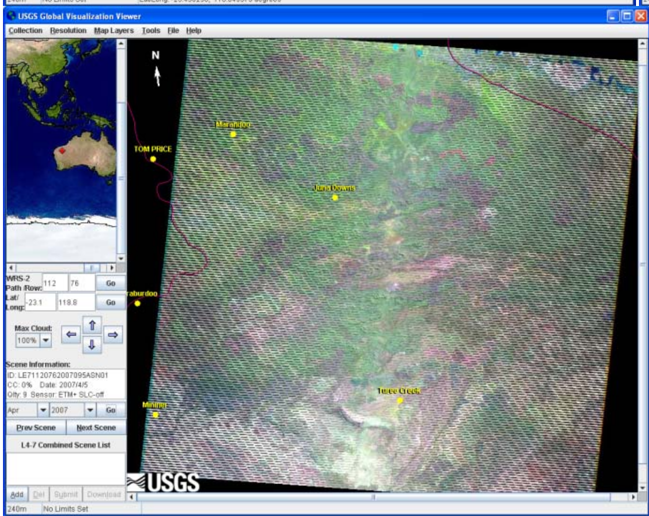
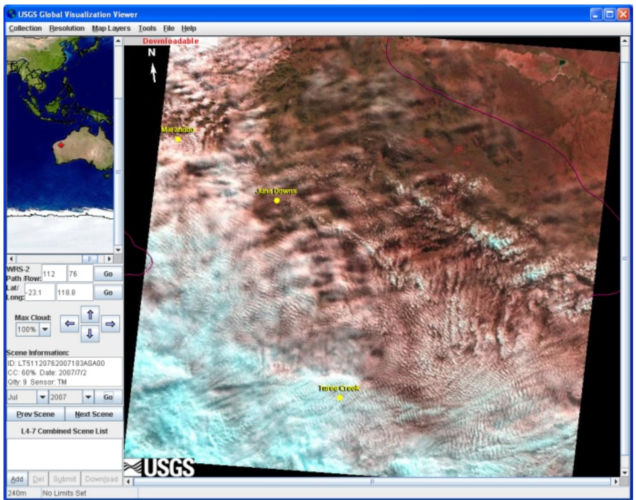
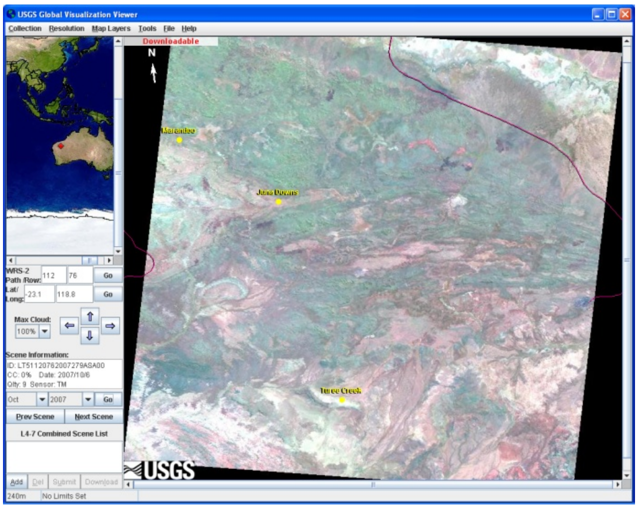
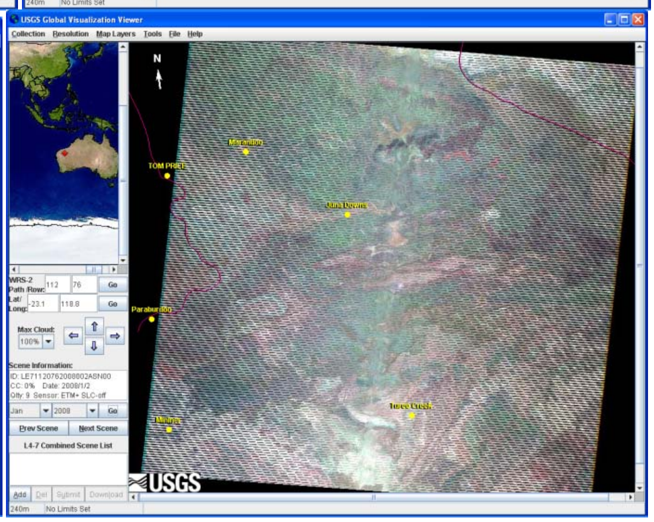


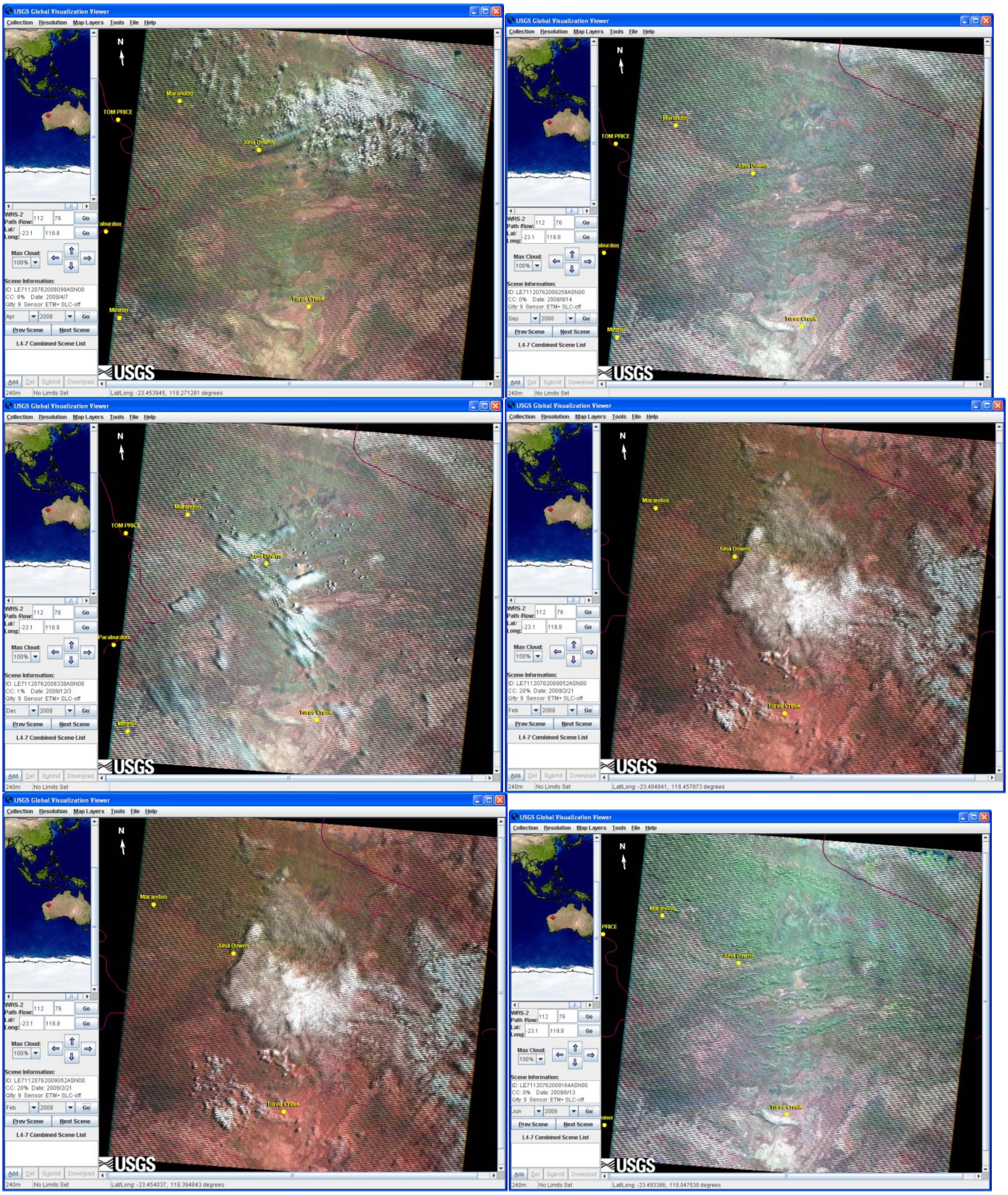








April 2008-June 2009



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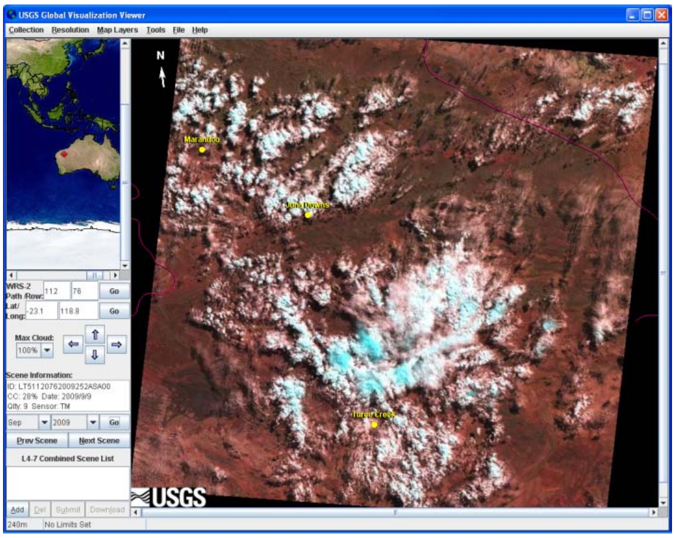
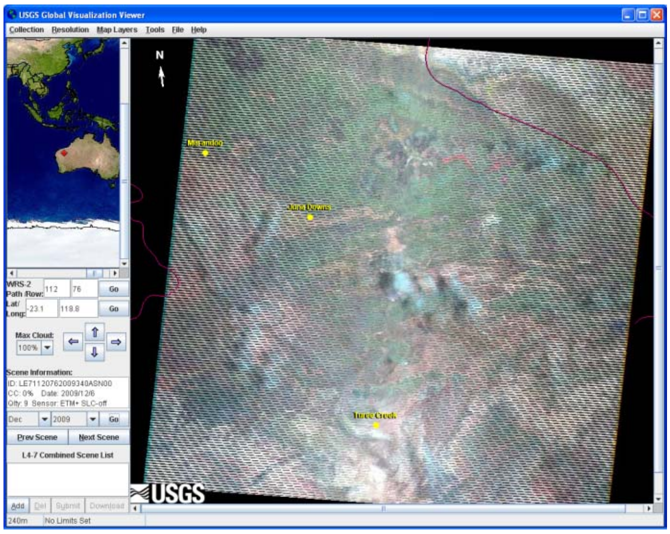
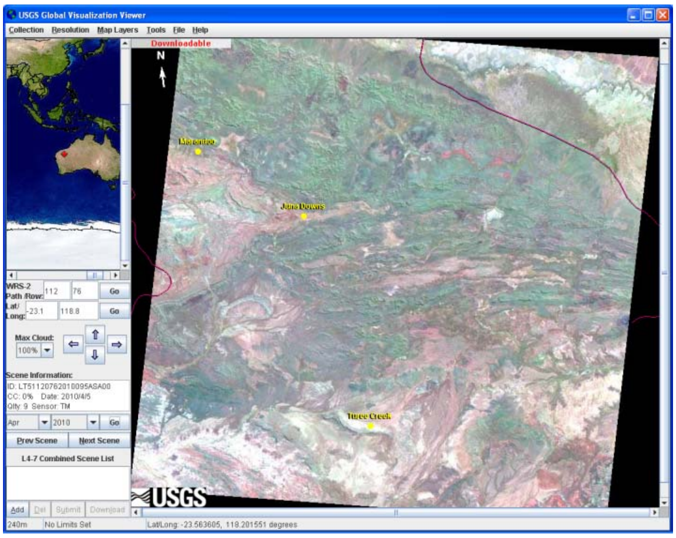
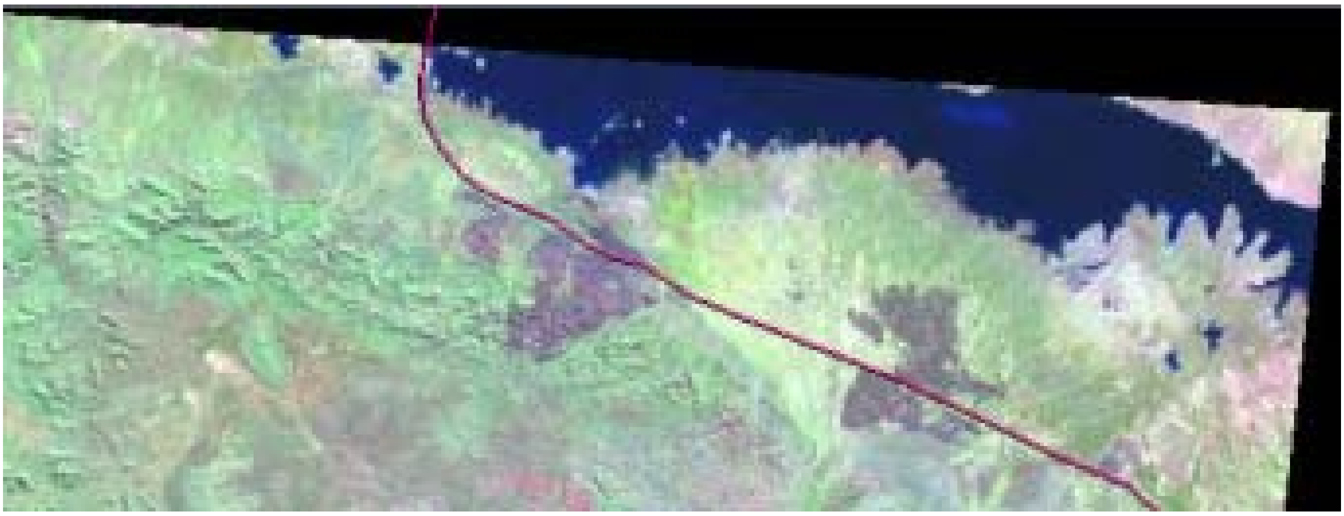






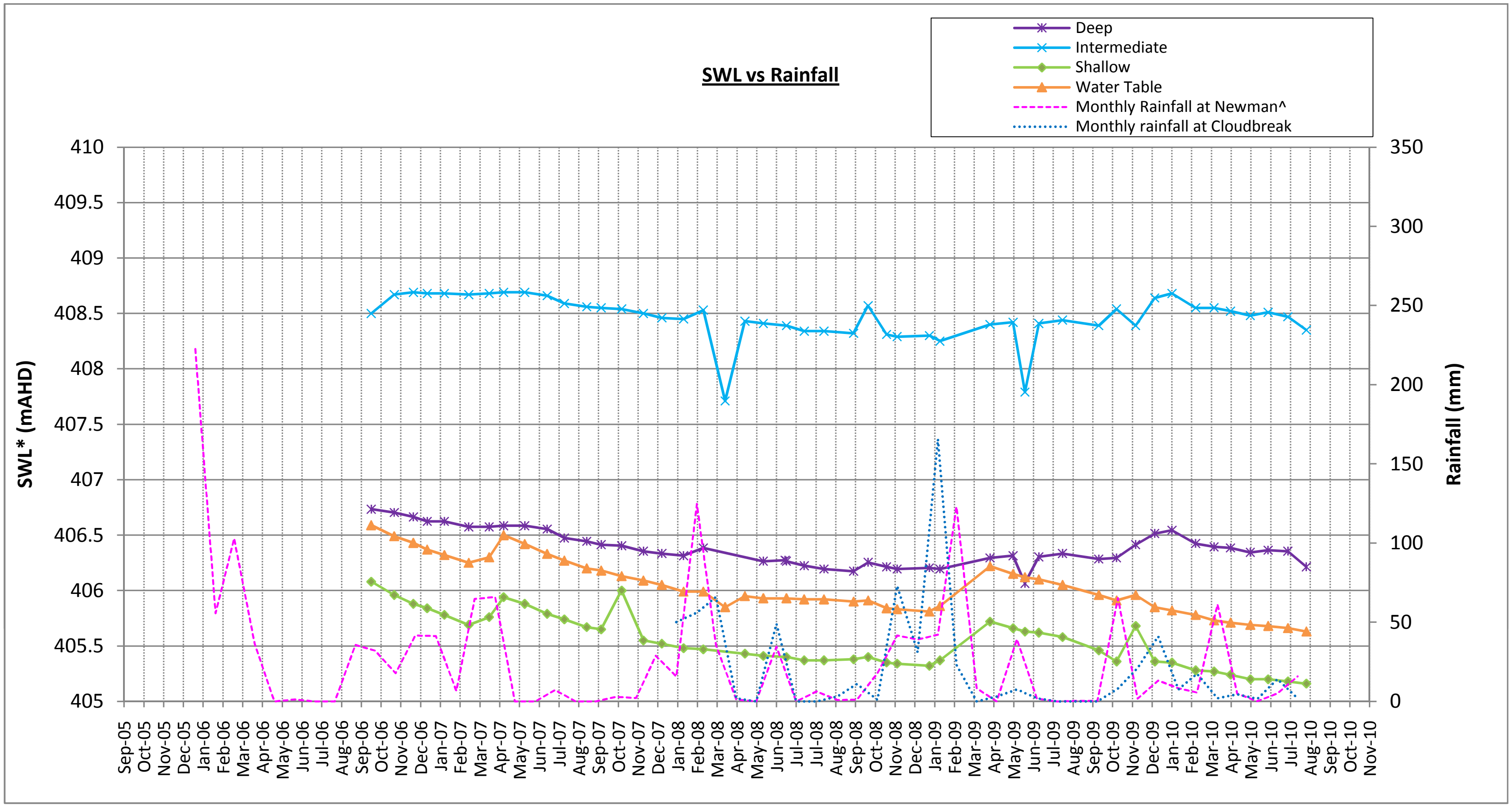


Appendix B.

Observed Water Level trends

Regional Historic Groundwater Trends

Station : CBX02



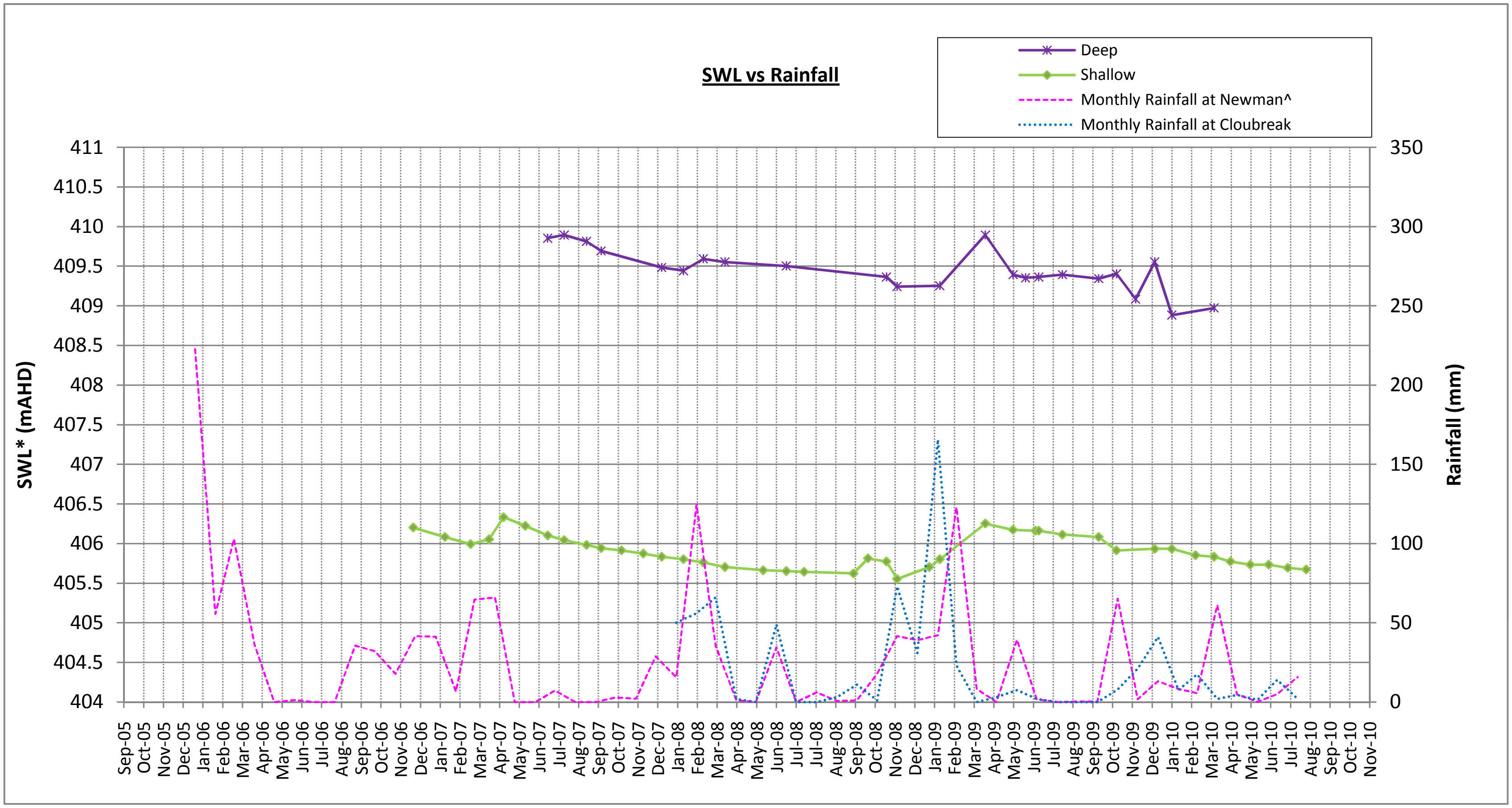
Depth	Bore	Aquifer
Water Table	CBX02_WT	Alluvium
Shallow	CBX02_S	Calcrete
Intermediate	CBX_02_I	Oakover Formation
Deep	CBW02_D	Wittenoom Formation

* Static Water Level

^ Rainfall based on BoM data for the Newman Aero station (Site: 7176)

Regional Historic Groundwater Trends

Station : CBX04



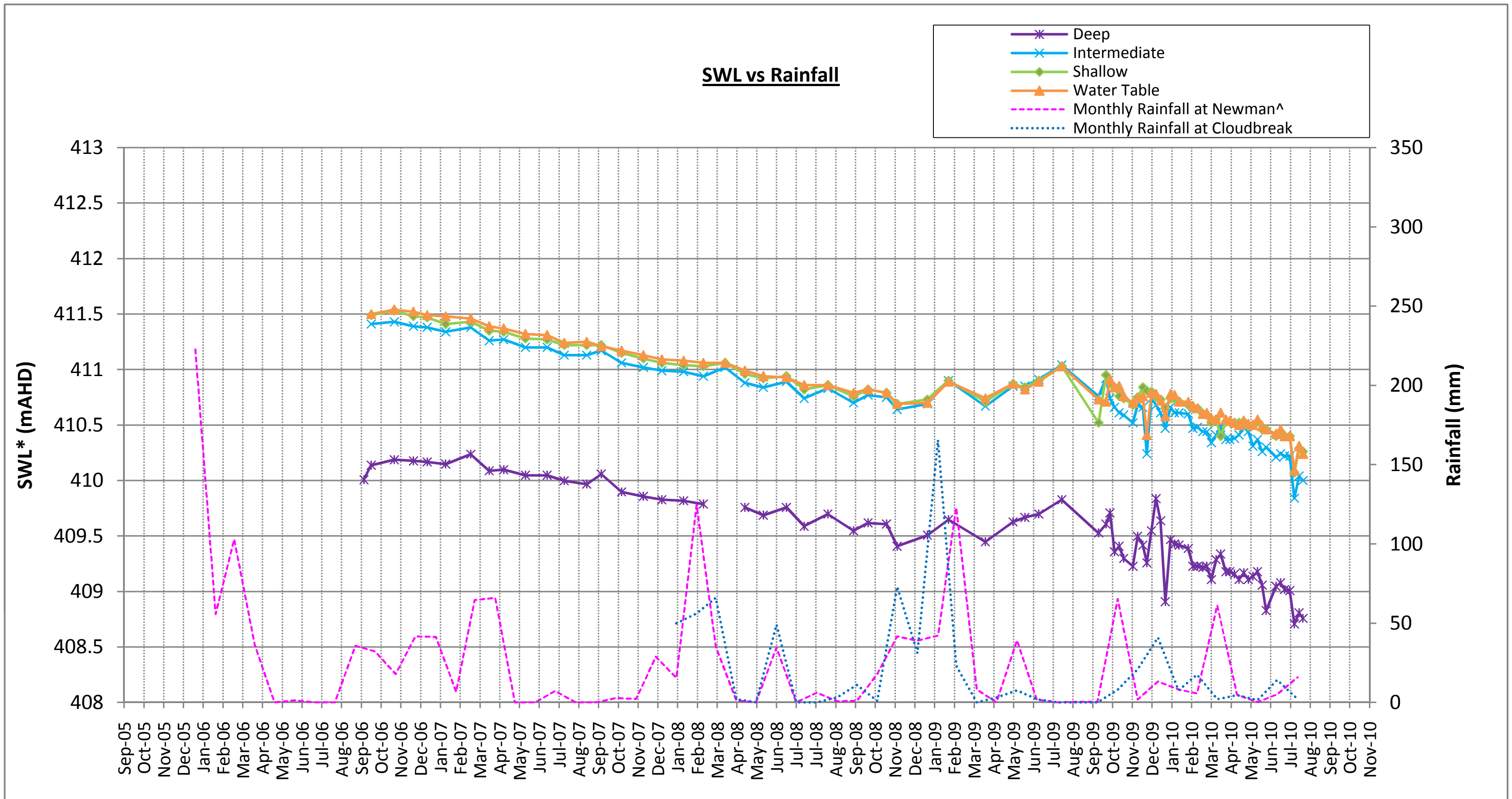
* Static Water Level

^ Rainfall based on BoM data for the Newman Aero station (Site: 7176)

Depth	Bore	Aquifer
Shallow	CBX04_S	Calcrete
Deep	CBW04_D	Oakover Formation

Regional Historic Groundwater Trends

Station : CBX05



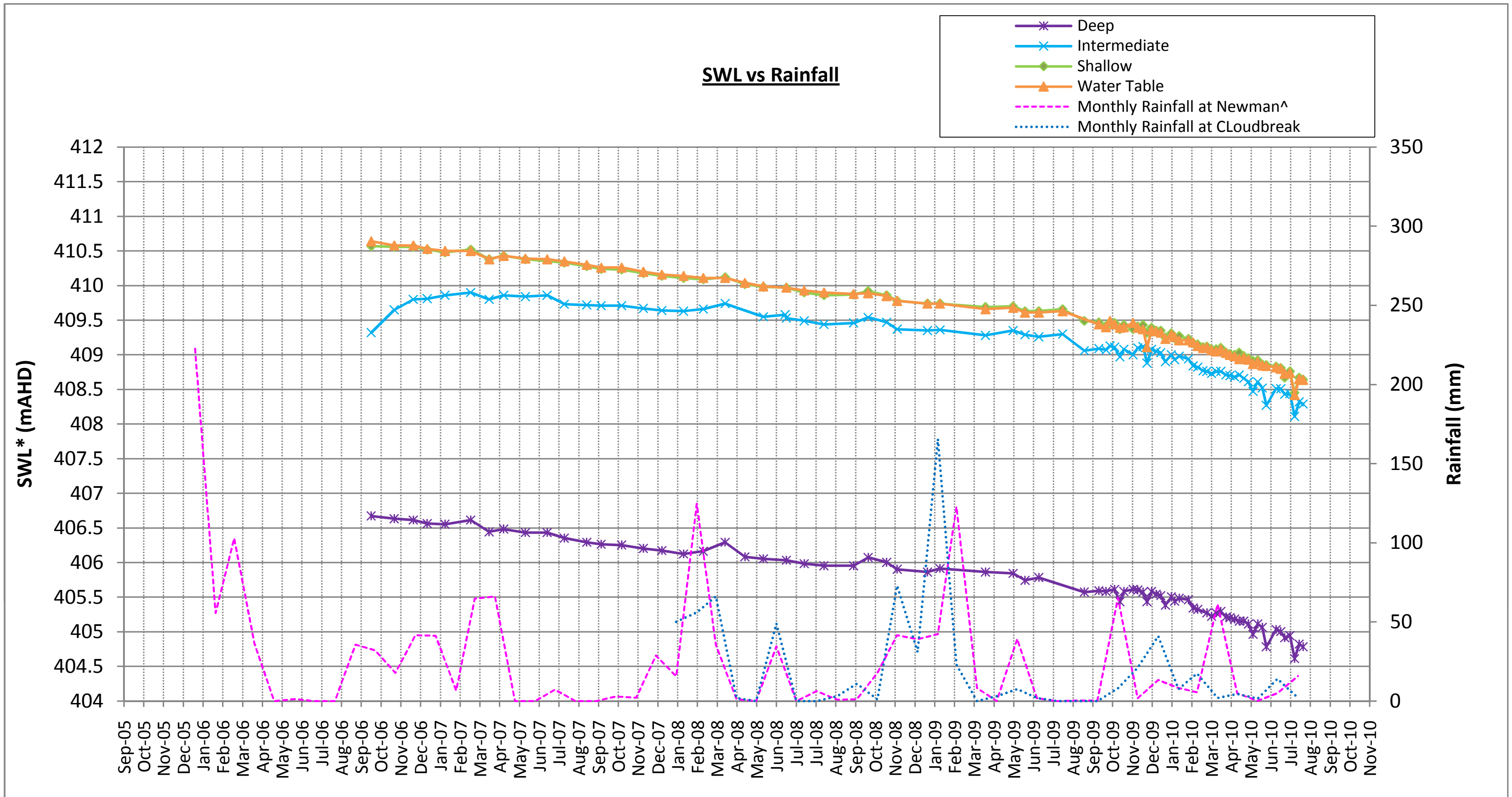
Depth	Bore	Aquifer
Water Table	CBX05_WT	Alluvium
Shallow	CBX05_S	Alluvium
Intermediate	CBX05_I	Mineralised Marra Mamba
Deep	CBW05_D	Non-Mineralised Marra Mamba

* Static Water Level

^ Rainfall based on BoM data for the Newman Aero station (Site: 7176)

Regional Historic Groundwater Trends

Station : CBX06



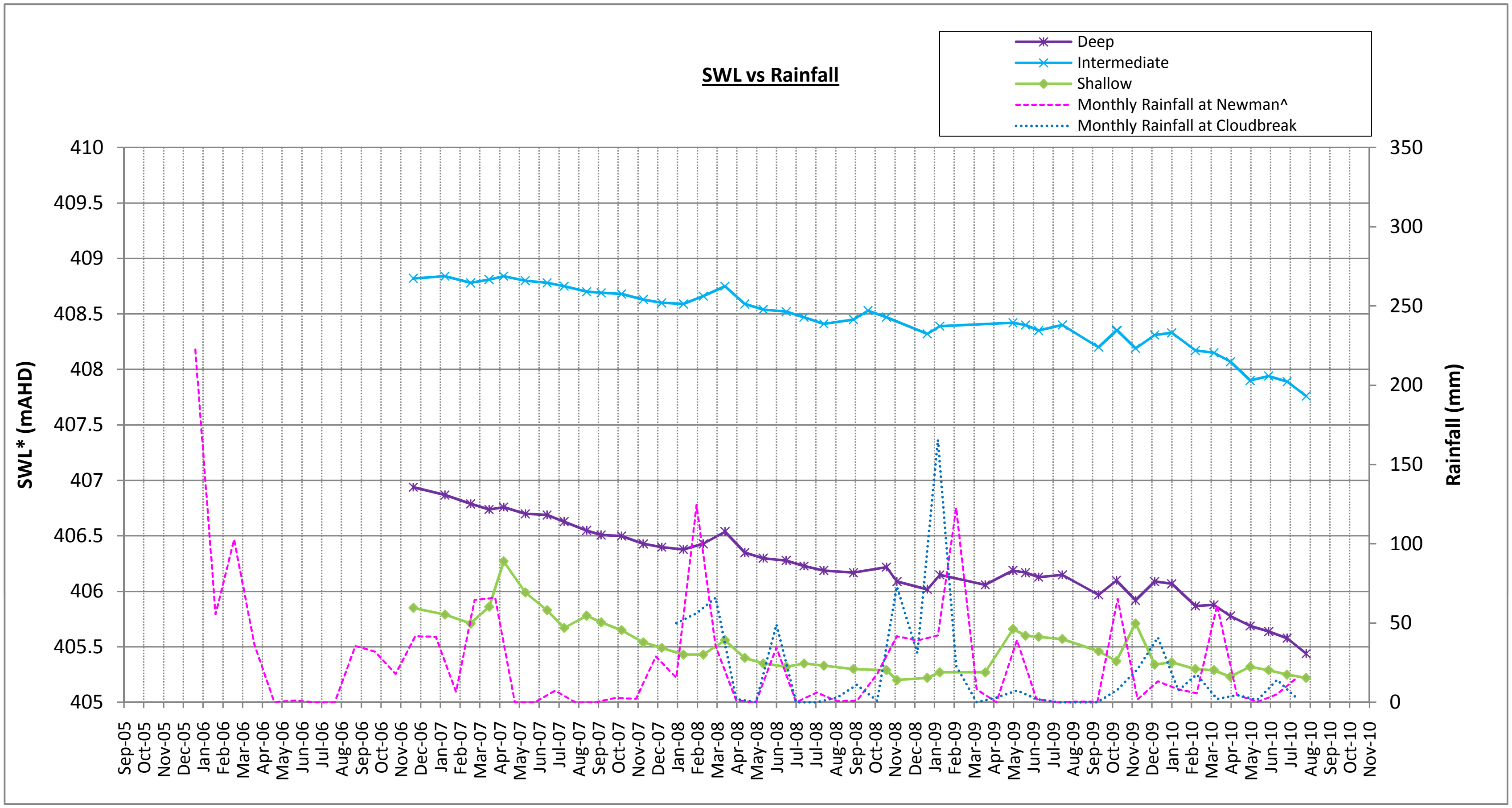
* Static Water Level

^ Rainfall based on BoM data for the Newman Aero station (Site: 7176)

Depth	Bore	Aquifer
Water Table	CBX06_WT	Alluvium
Shallow	CBX06_S	Alluvium
Intermediate	CBX06_I	Oakover Formation
Deep	CBW06_D	Non-Mineralised Marra Mamba

Regional Historic Groundwater Trends

Station : CBX07



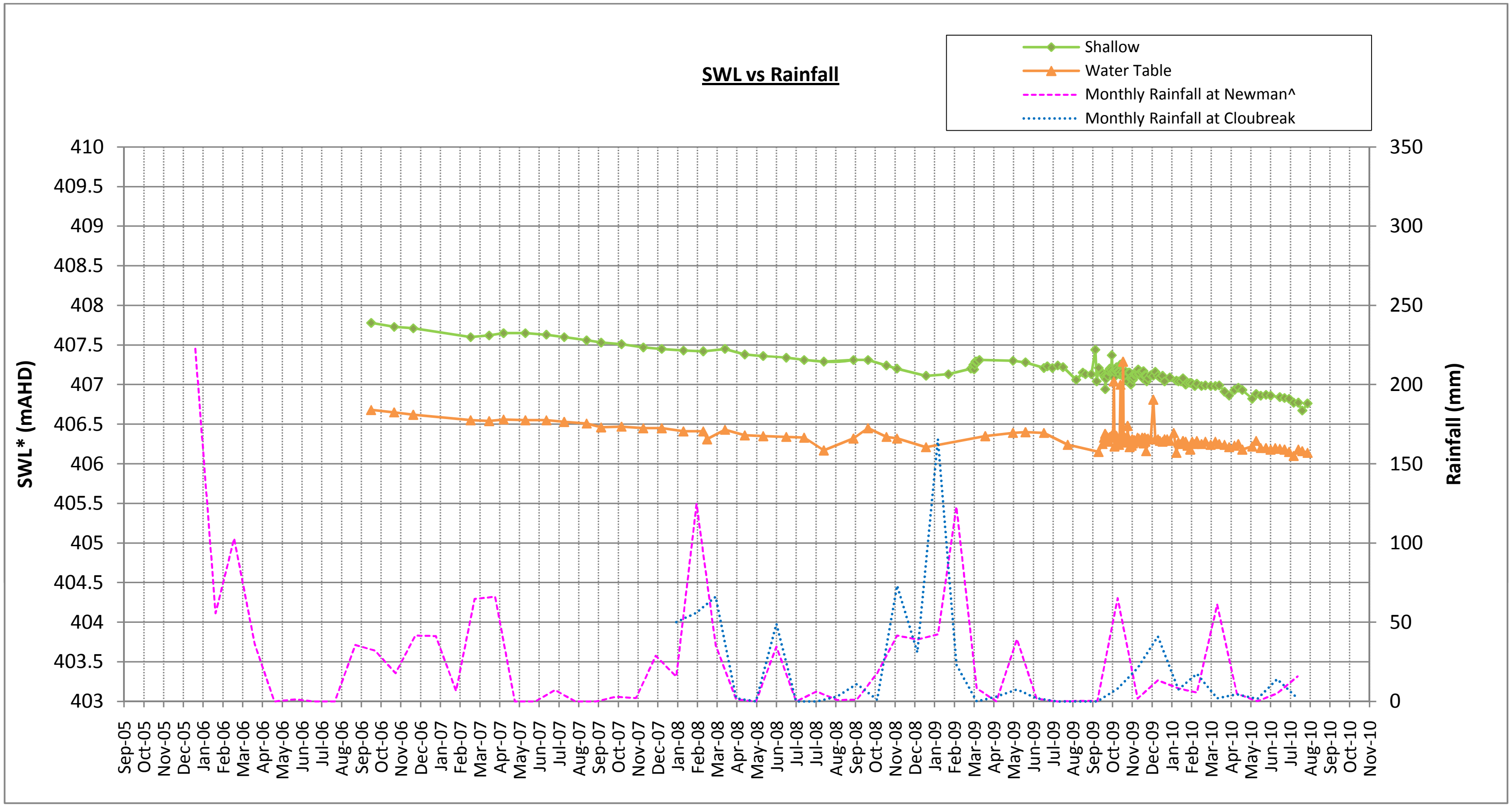
* Static Water Level

^ Rainfall based on BoM data for the Newman Aero station (Site: 7176)

Depth	Bore	Aquifer
Shallow	CBX07_S	Calcrete
Intermediate	CBX07_I	Oakover Formation
Deep	CBW07_D	Mineralised Marra Mamba

Regional Historic Groundwater Trends

Station : CBX10a



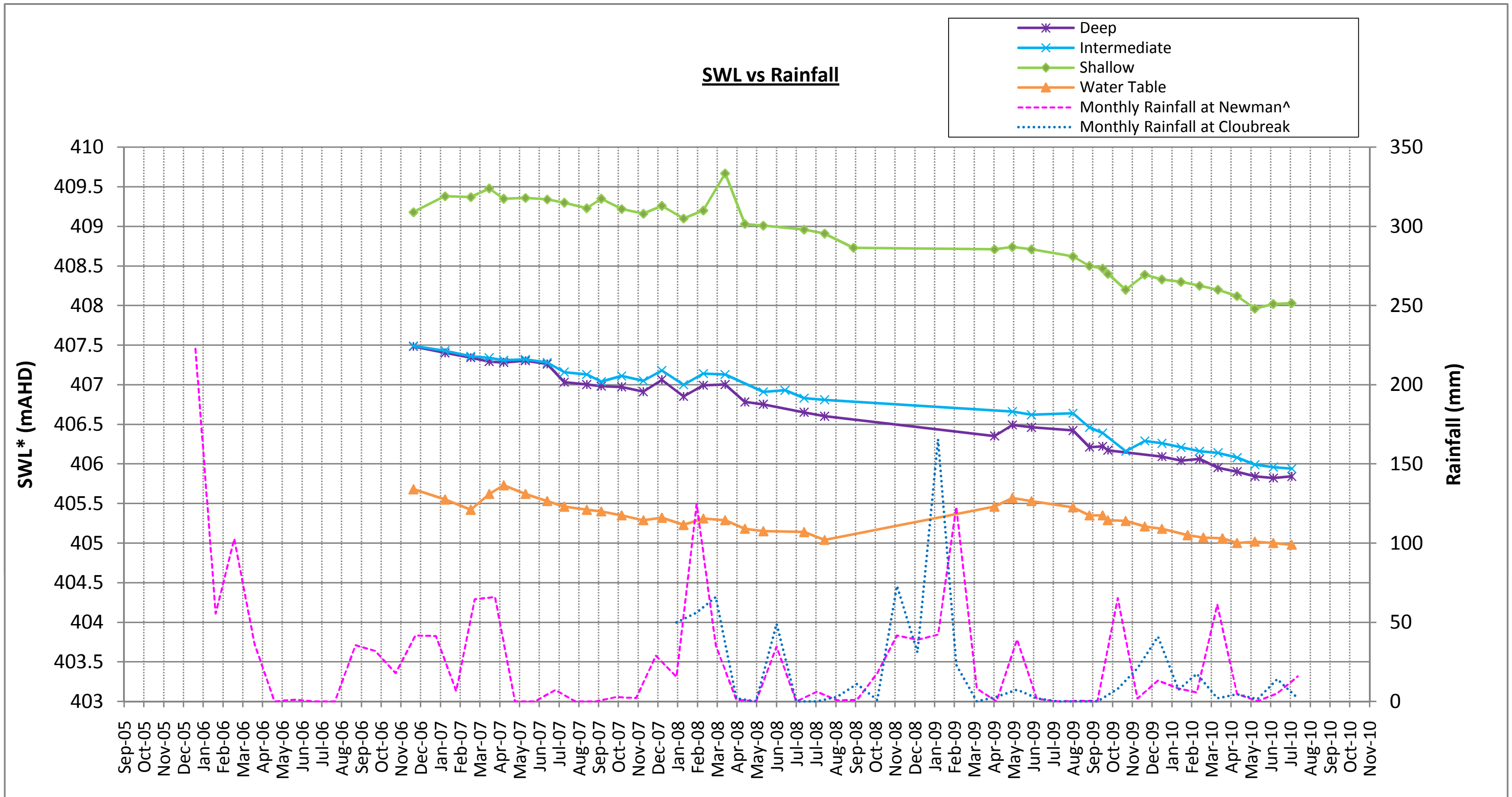
* Static Water Level

^ Rainfall based on BoM data for the Newman Aero station (Site: 7176)

Depth	Bore	Aquifer
Water Table	CX10a_WT	Alluvium
Shallow	CBX10a_S	Alluvium

Regional Historic Groundwater Trends

Station : CBX13



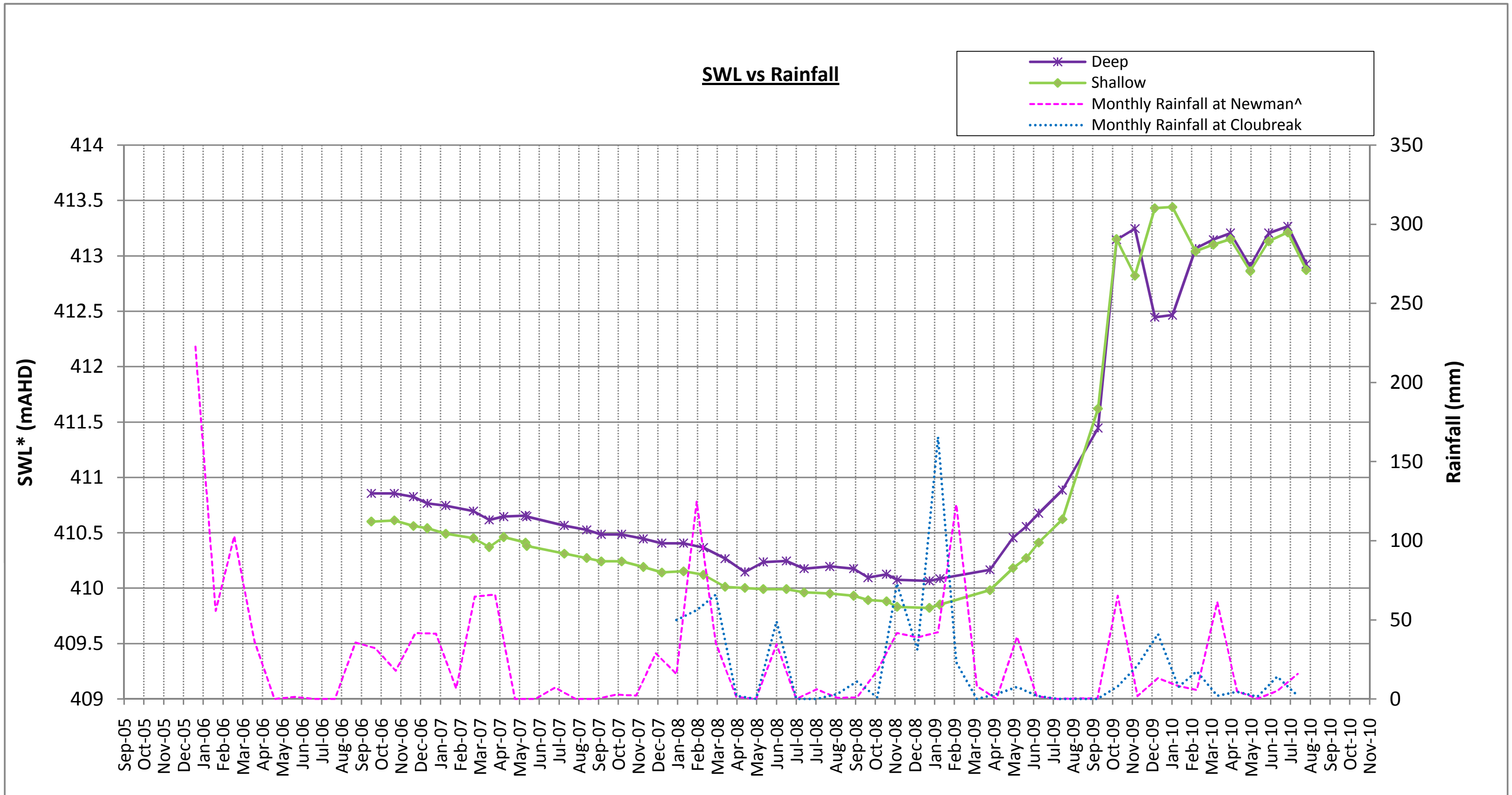
* Static Water Level

^ Rainfall based on BoM data for the Newman Aero station (Site: 7176)

Water Table	CBX13_WT	Alluvium
Shallow	CBX13_S	Calcrete
Intermediate	CBX13_I	Oakover Formation
Deep	CBW13_D	Wittenoom Formation

Regional Historic Groundwater Trends

Station : CB30MB1



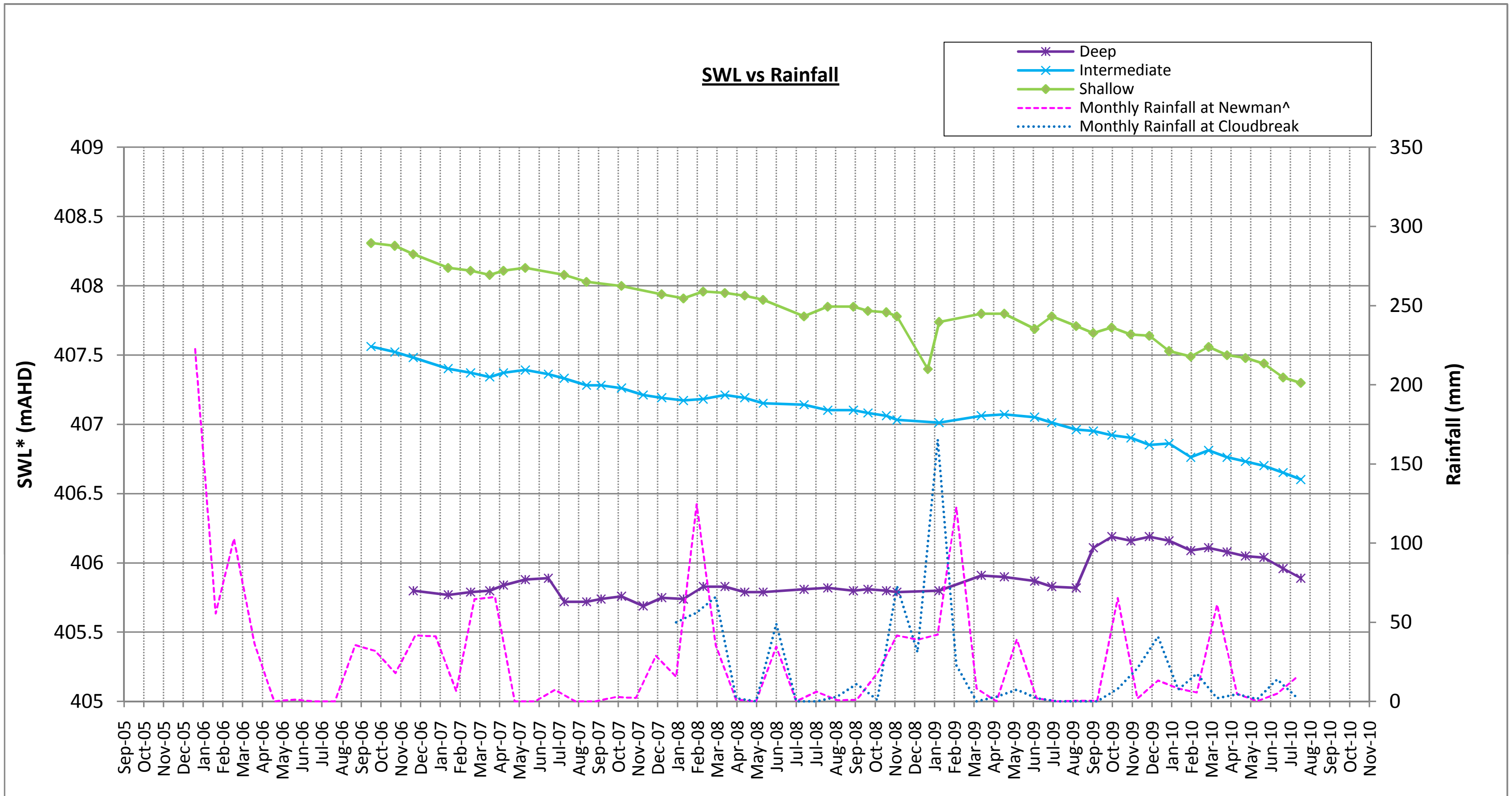
* Static Water Level

^ Rainfall based on BoM data for the Newman Aero station (Site: 7176)

Depth	Bore	Aquifer
Shallow	CB30MB1_S	Detritals
Deep	CB30MB1_D	Mineralised Marra Mamba

Regional Historic Groundwater Trends

Station : CCF02



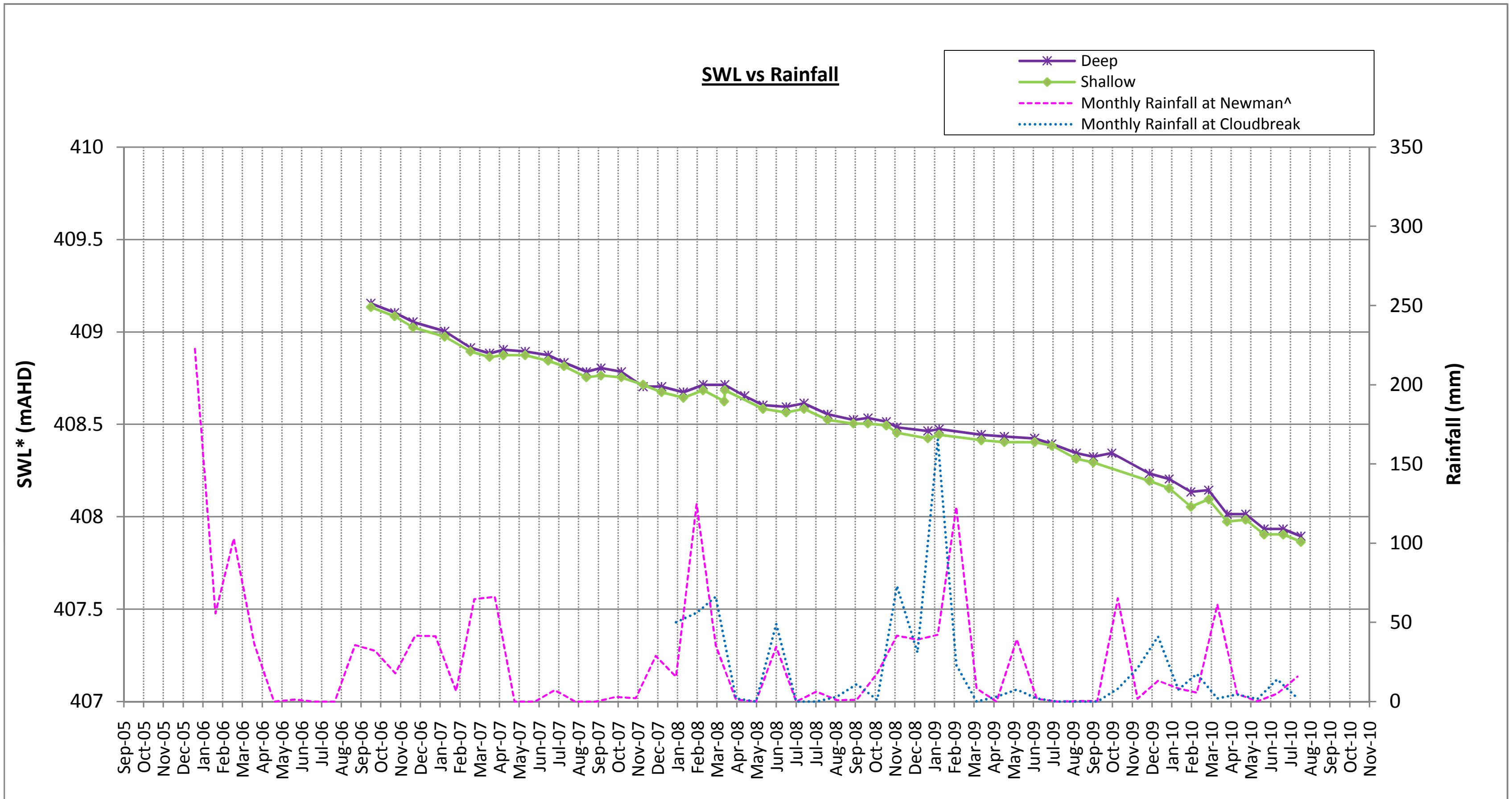
* Static Water Level

^ Rainfall based on BoM data for the Newman Aero station (Site: 7176)

Shallow	CCF02B_S	Calcrete
Intermediate	CCF02_T	Wittenoom Formation
Deep	CCF02A_D	Wittenoom Formation

Regional Historic Groundwater Trends

Station : CCF07

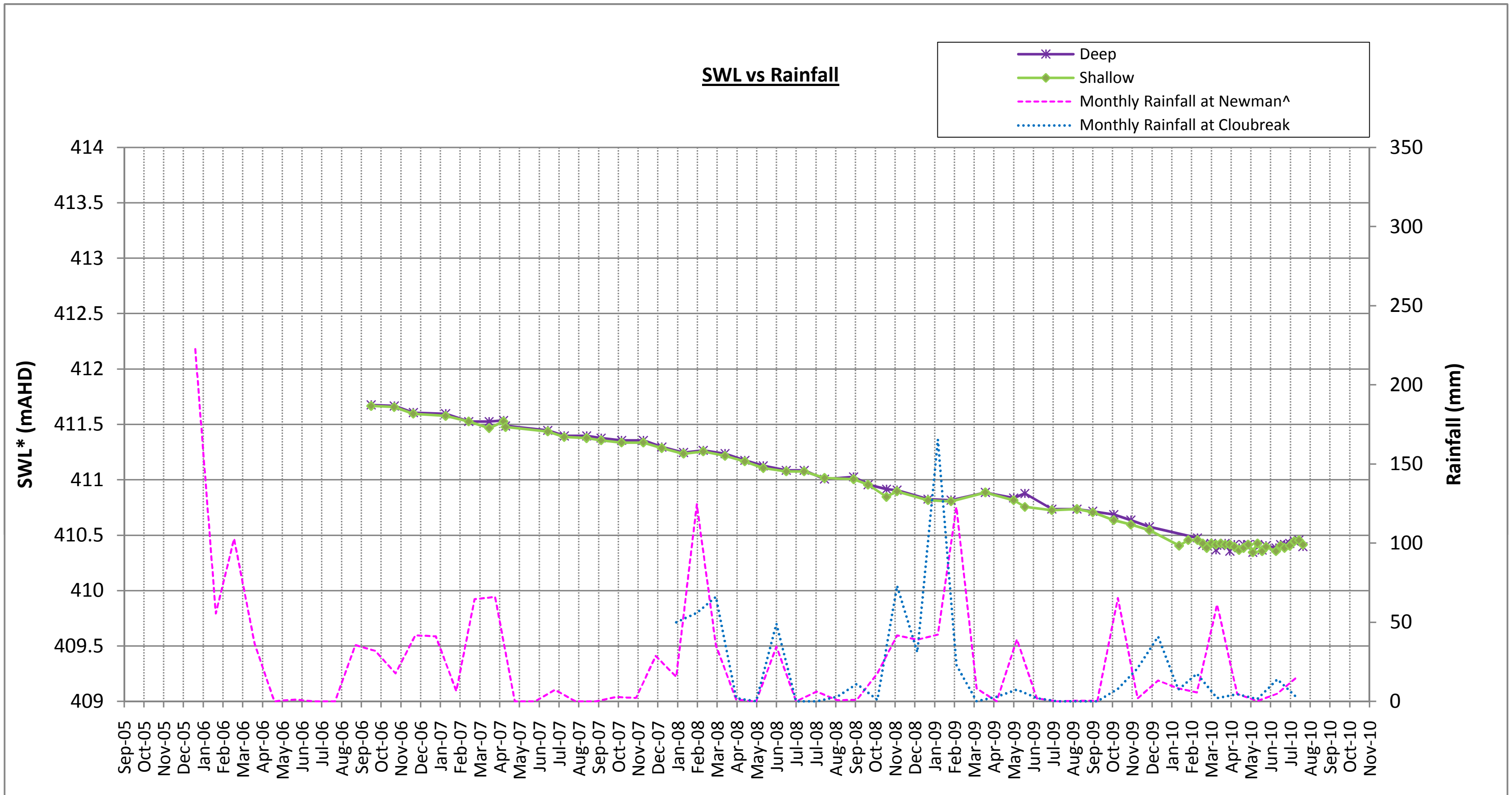


^ Rainfall based on BoM data for the Newman Aero station (Site: 7176)

Shallow	CCF07B_S	Alluvium
Deep	CCF07A_D	Non-Mineralised Marra Mamba

Regional Historic Groundwater Trends

Station : SCX03

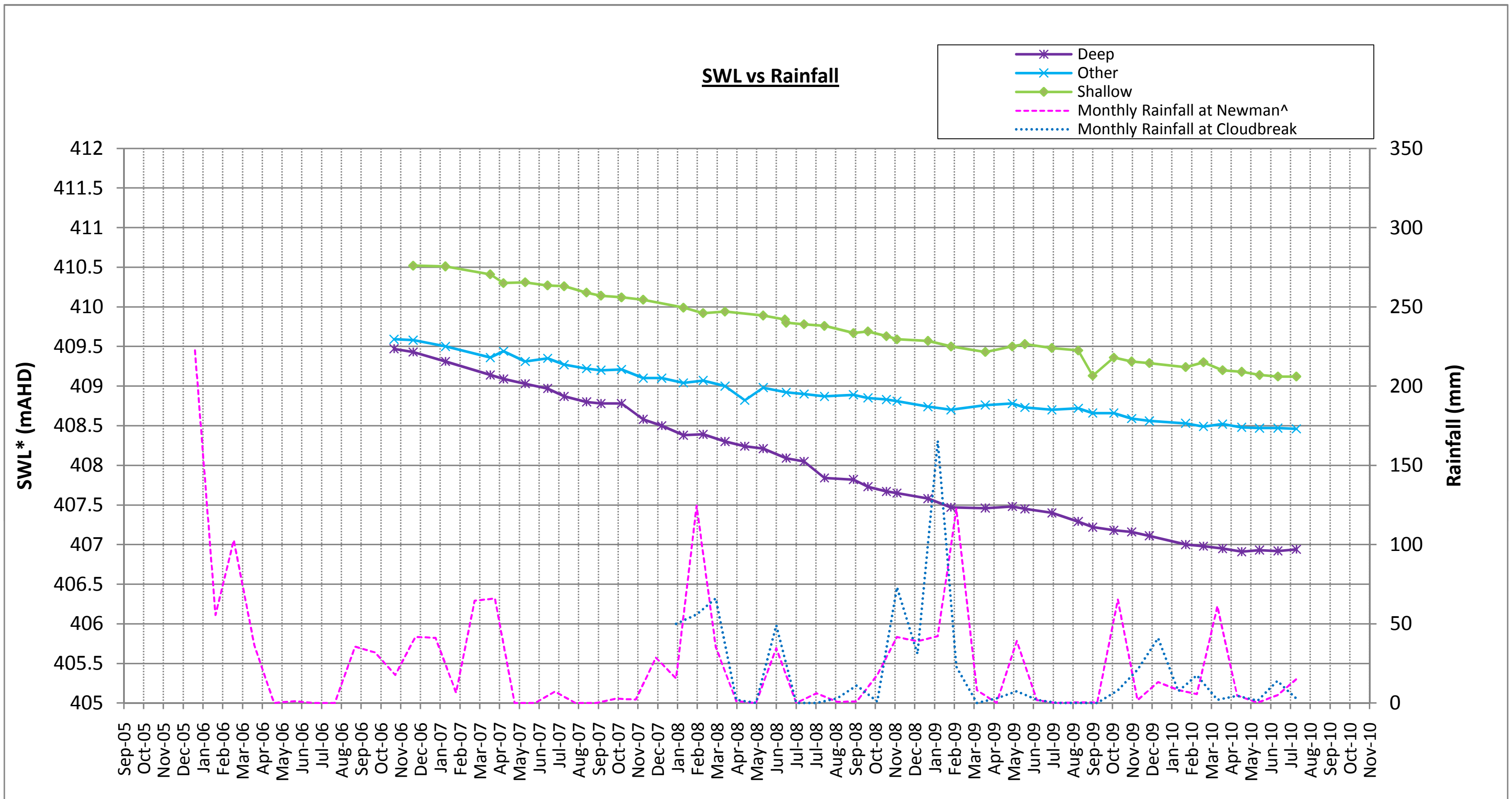


^ Rainfall based on BoM data for the Newman Aero station (Site: 7176)

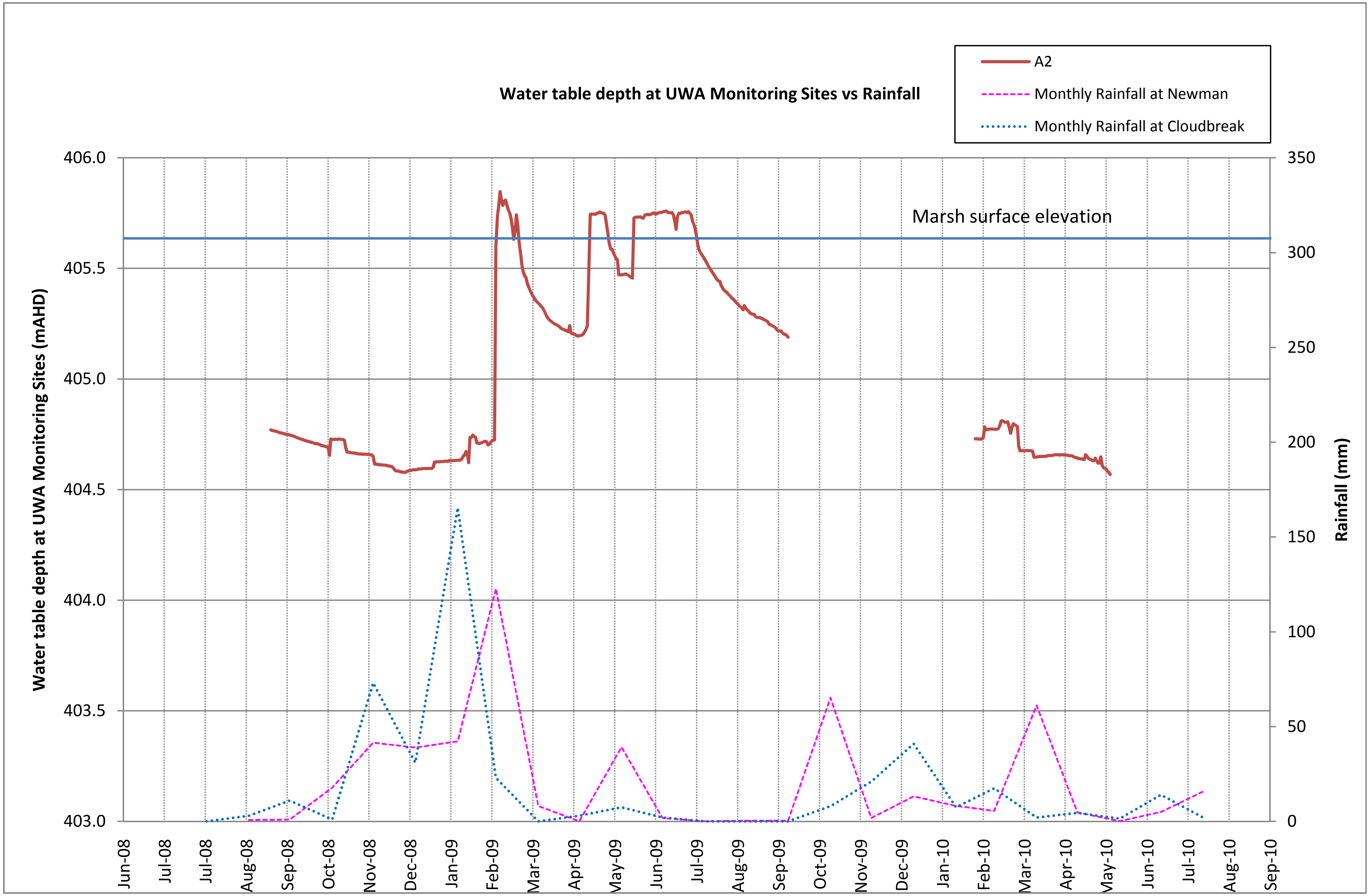
Shallow	SCX03_S	Detritals
Deep	SCX03_D	Mineralised Marra Mamba

Regional Historic Groundwater Trends

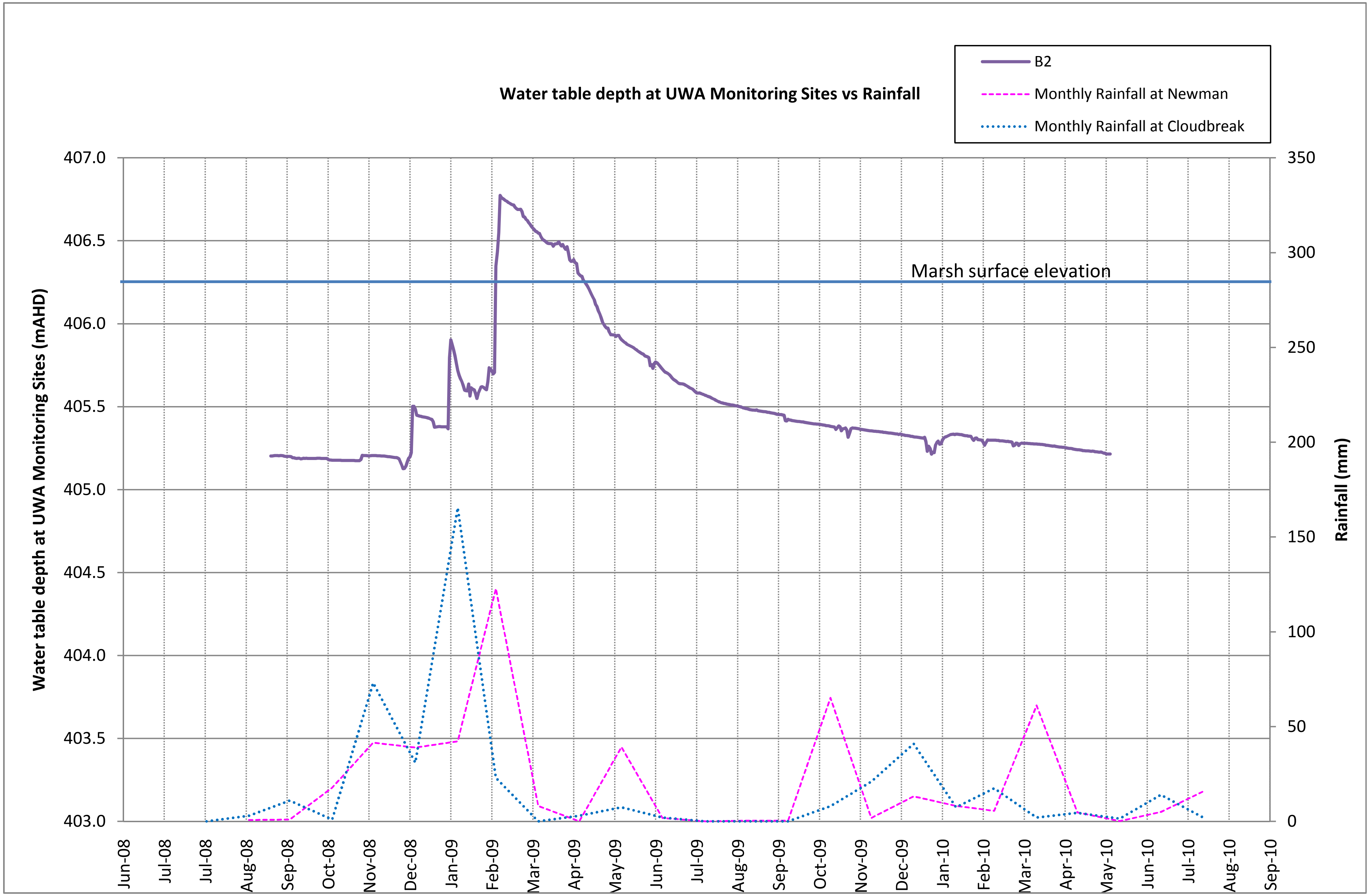
Station : SCX06



Deep	SCX06_D	Mineralised Marra Mamba



Water table depth at UWA Monitoring Sites vs Rainfall
A2
Monthly Rainfall at Newman
Monthly Rainfall at Cloudbreak
Marsh surface elevation
Water table depth at UWA Monitoring Sites (mAHD)
Rainfall (mm)
406.0
405.5
405.0
404.5
404.0
403.5
403.0
350
300
250
200
150
100
50
0
Jun-08
Jul-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09
Jul-09
Aug-09
Sep-09
Oct-09
Nov-09
Dec-09
Jan-10
Feb-10
Mar-10
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10



Water table depth at UWA Monitoring Sites vs Rainfall
B2
Monthly Rainfall at Newman
Monthly Rainfall at Cloudbreak
Marsh surface elevation
Water table depth at UWA Monitoring Sites (mAHD)
Rainfall (mm)
407.0
406.5
406.0
405.5
405.0
404.5
404.0
403.5
403.0
350
300
250
200
150
100
50
0
Jun-08
Jul-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09
Jul-09
Aug-09
Sep-09
Oct-09
Nov-09
Dec-09
Jan-10
Feb-10
Mar-10
Apr-10
May-10
Jun-10
Jul-10
Aug-10
Sep-10

Appendix C.

Model Layer elevations

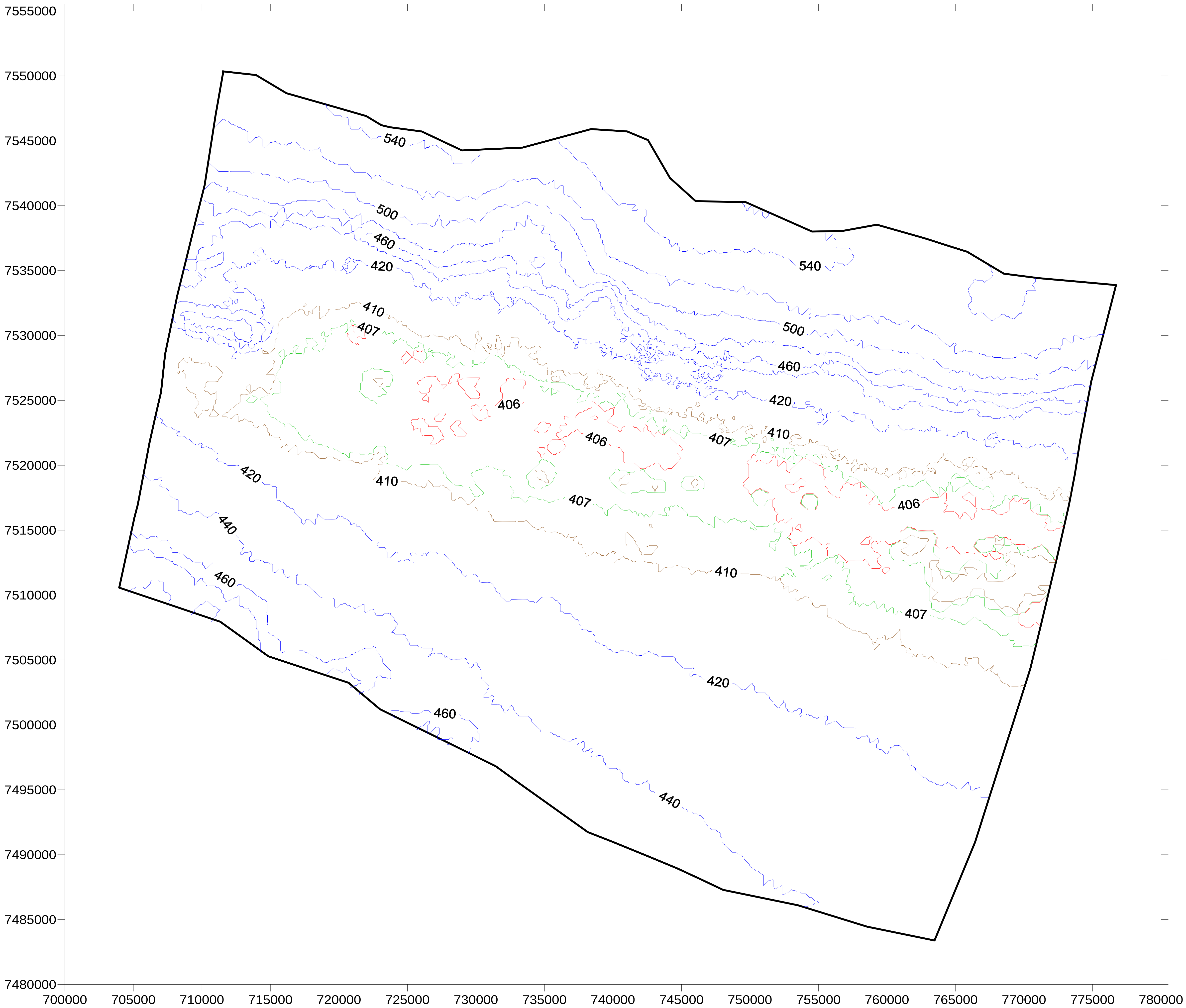


Figure C.1: Ground surface elevation of the model area.

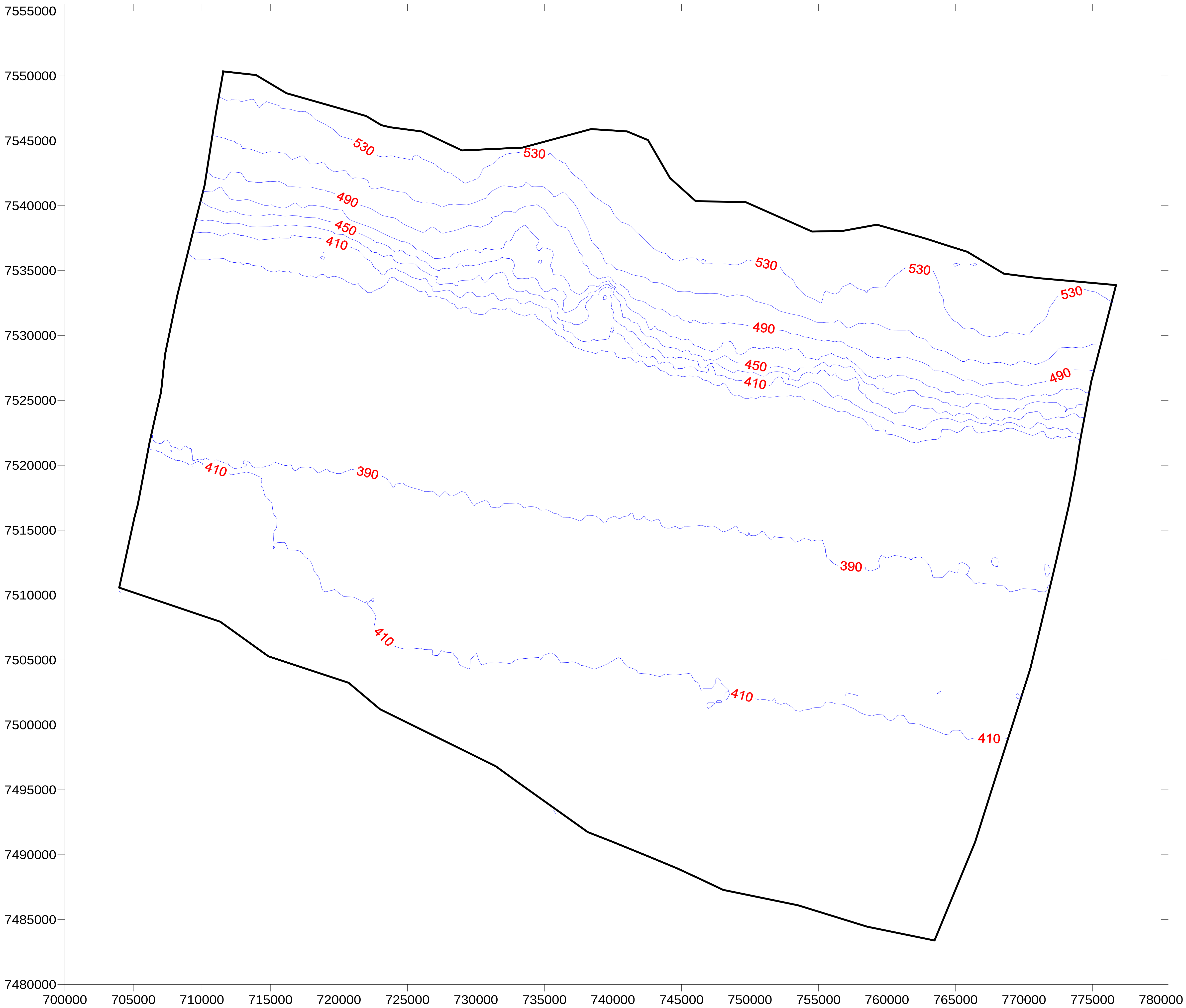


Figure C.2: Elevation of slice 3 of the numerical model (bottom of the Upper TD3 layer).

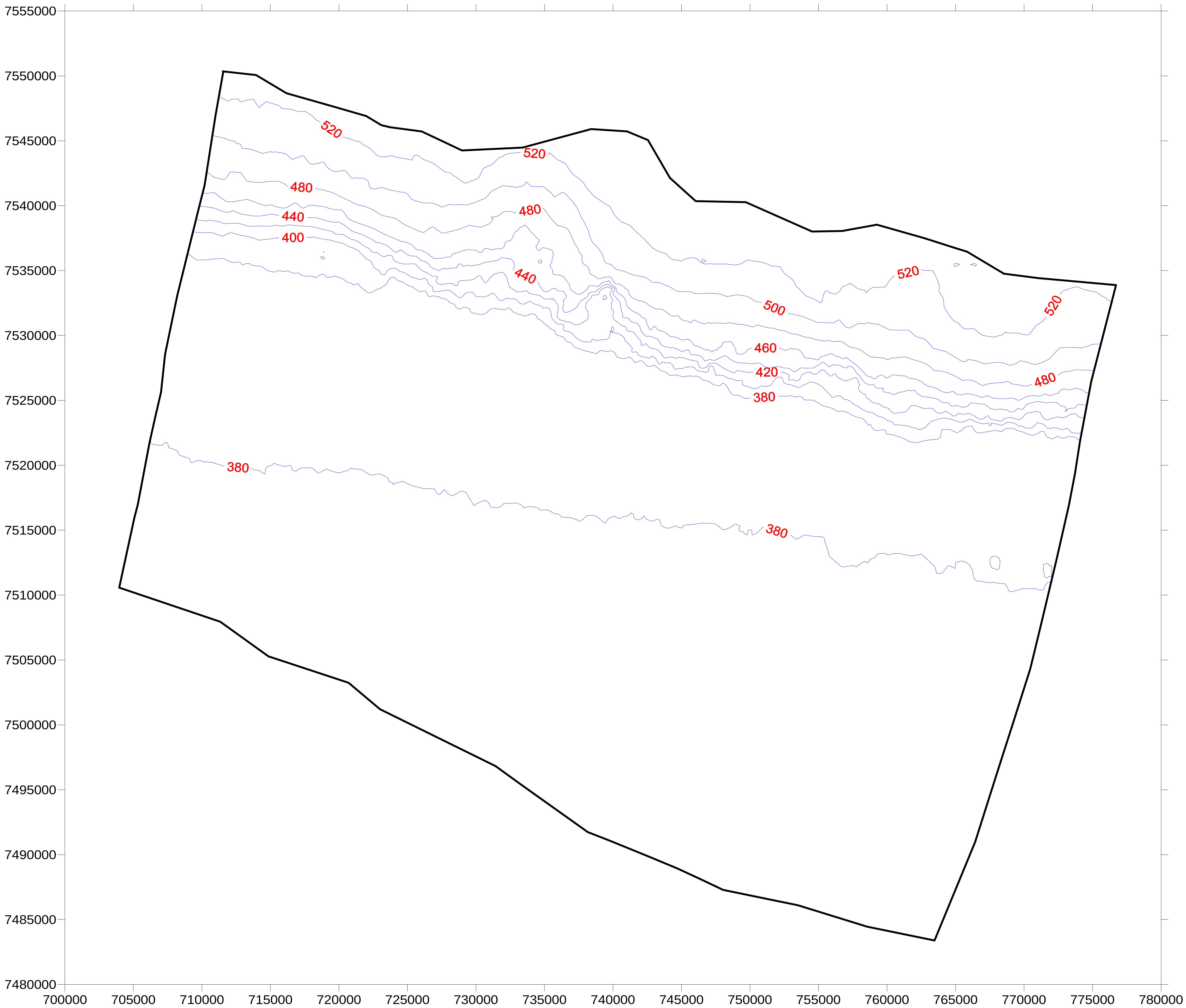


Figure C.3: Elevation of slice 5 of the numerical model (bottom of the Lower TD3 layer).

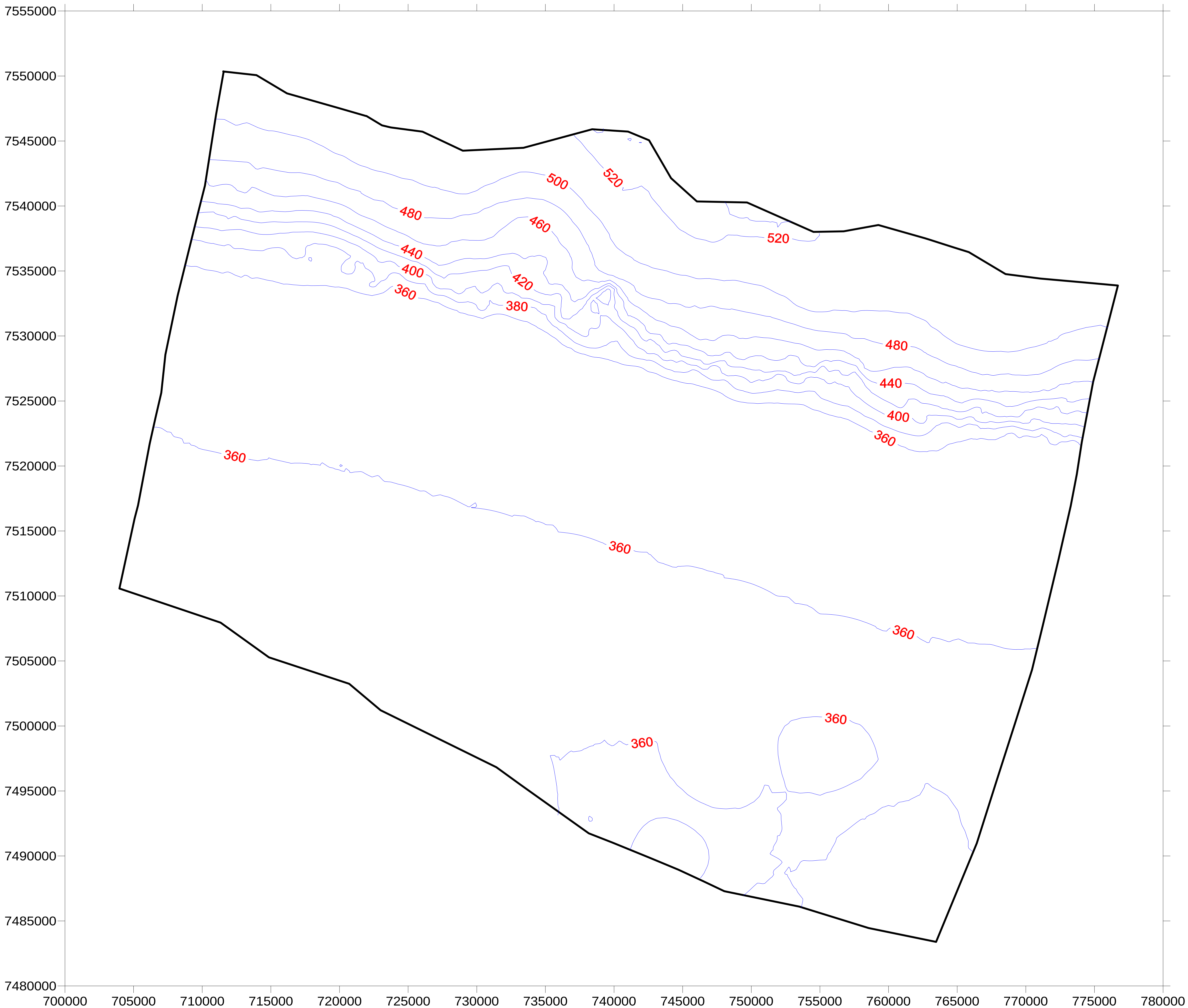


Figure C.4: Elevation of slice 7 of the numerical model (bottom of the Oakover Formation).

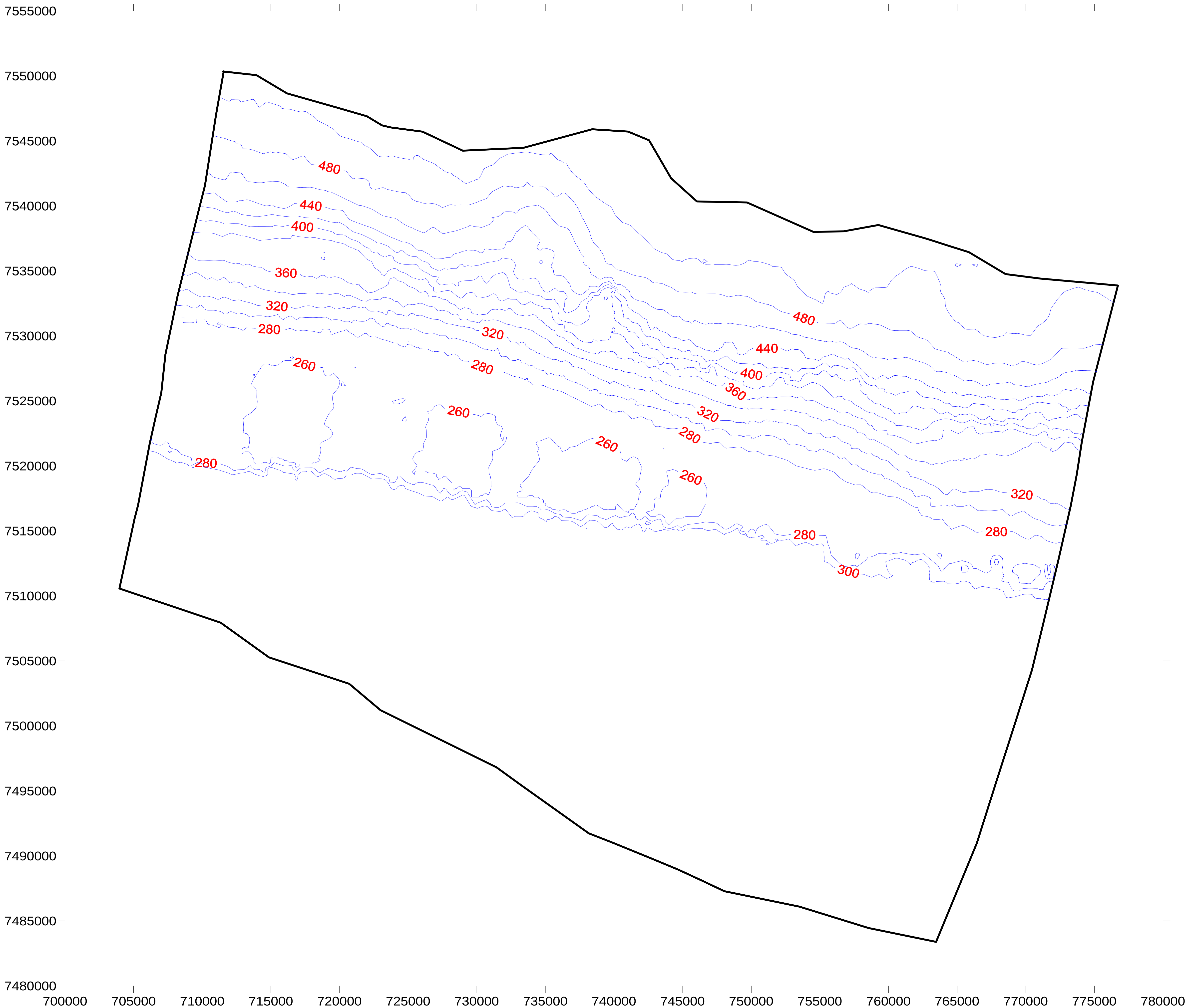


Figure C.5: Elevation of slice 8 of the numerical model (bottom of Wittenoom Dolomite and Hardcap).

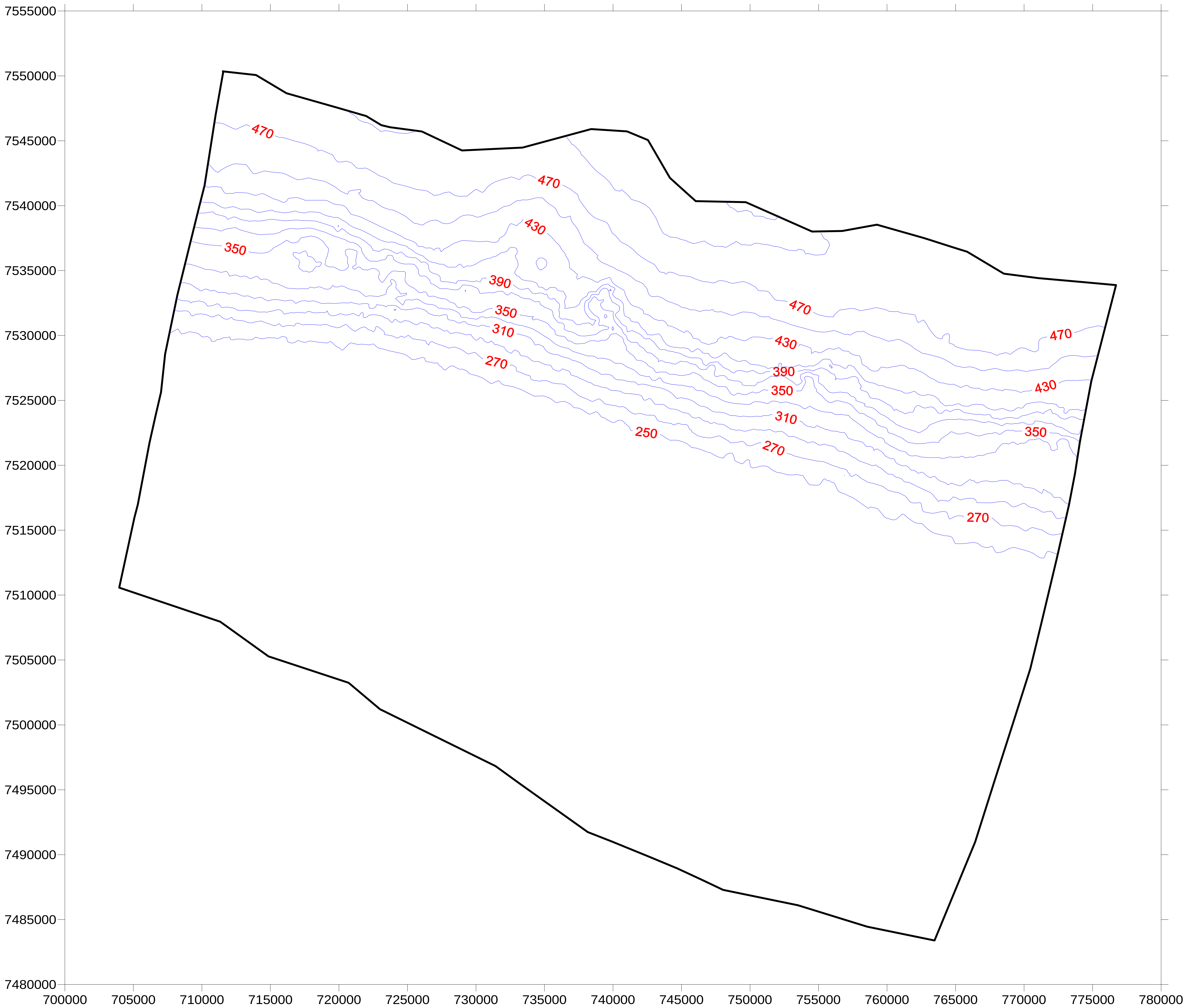


Figure C.6: Elevation of slice 10 of the numerical model (bottom of Mineralised MMF).

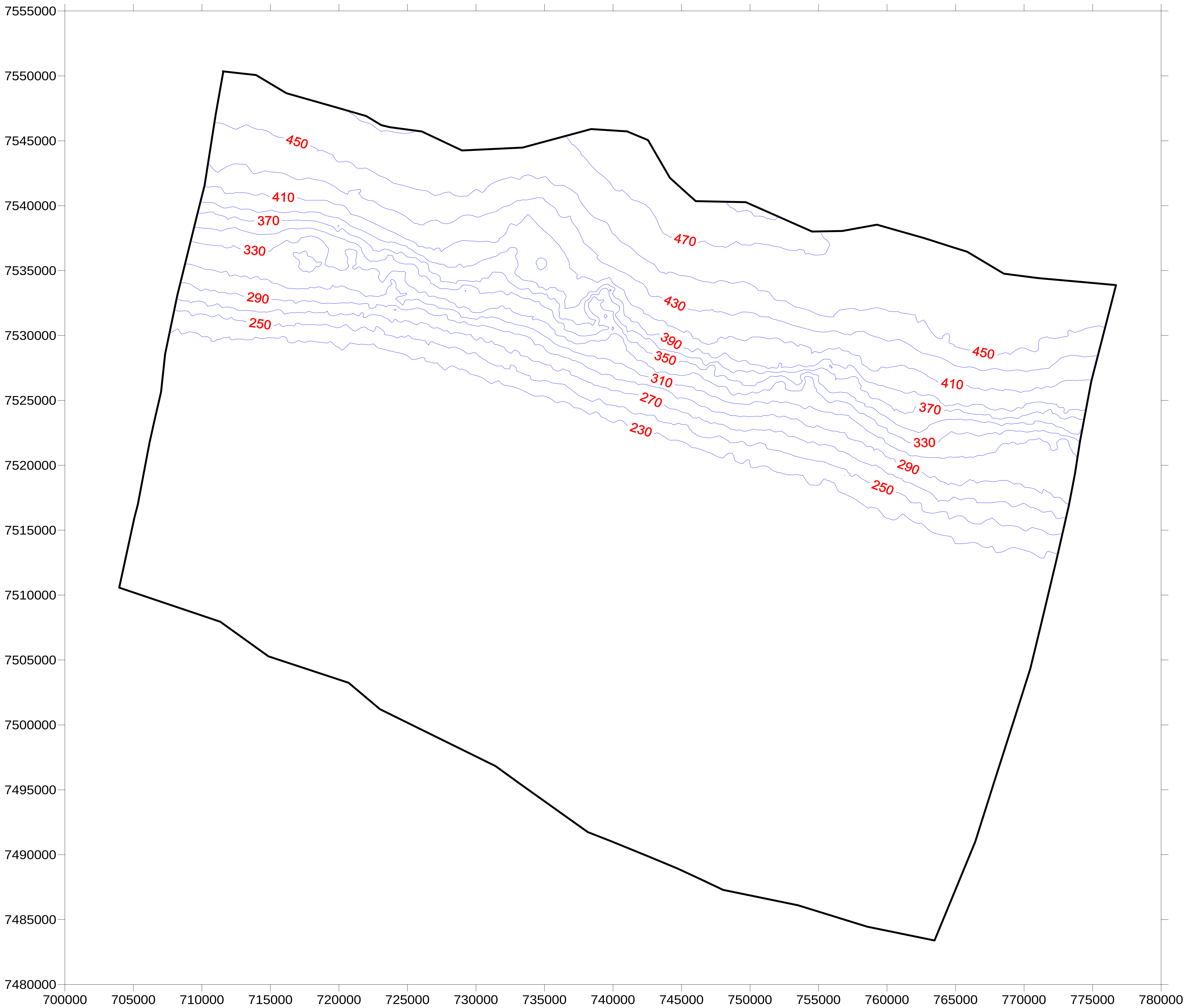
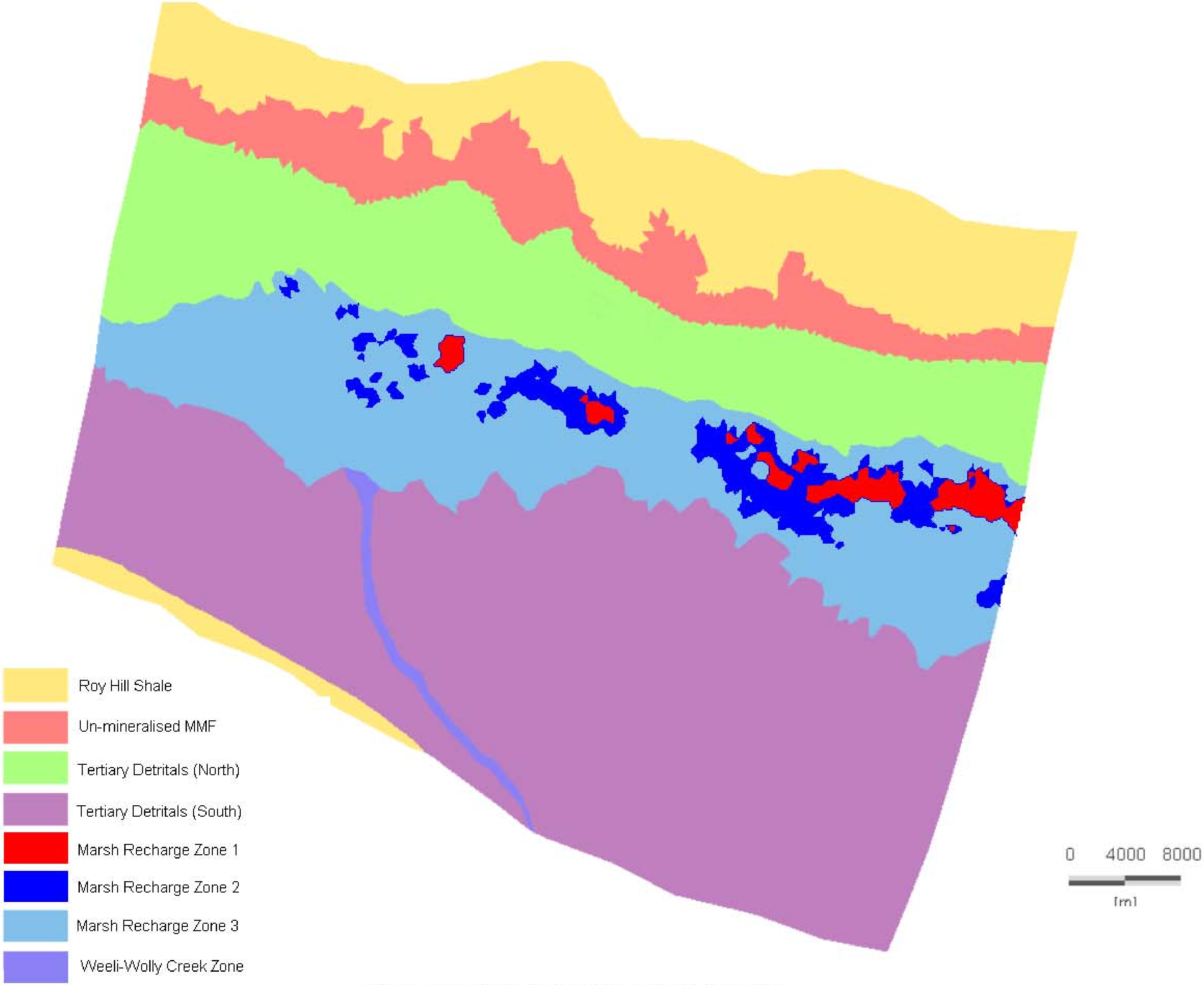


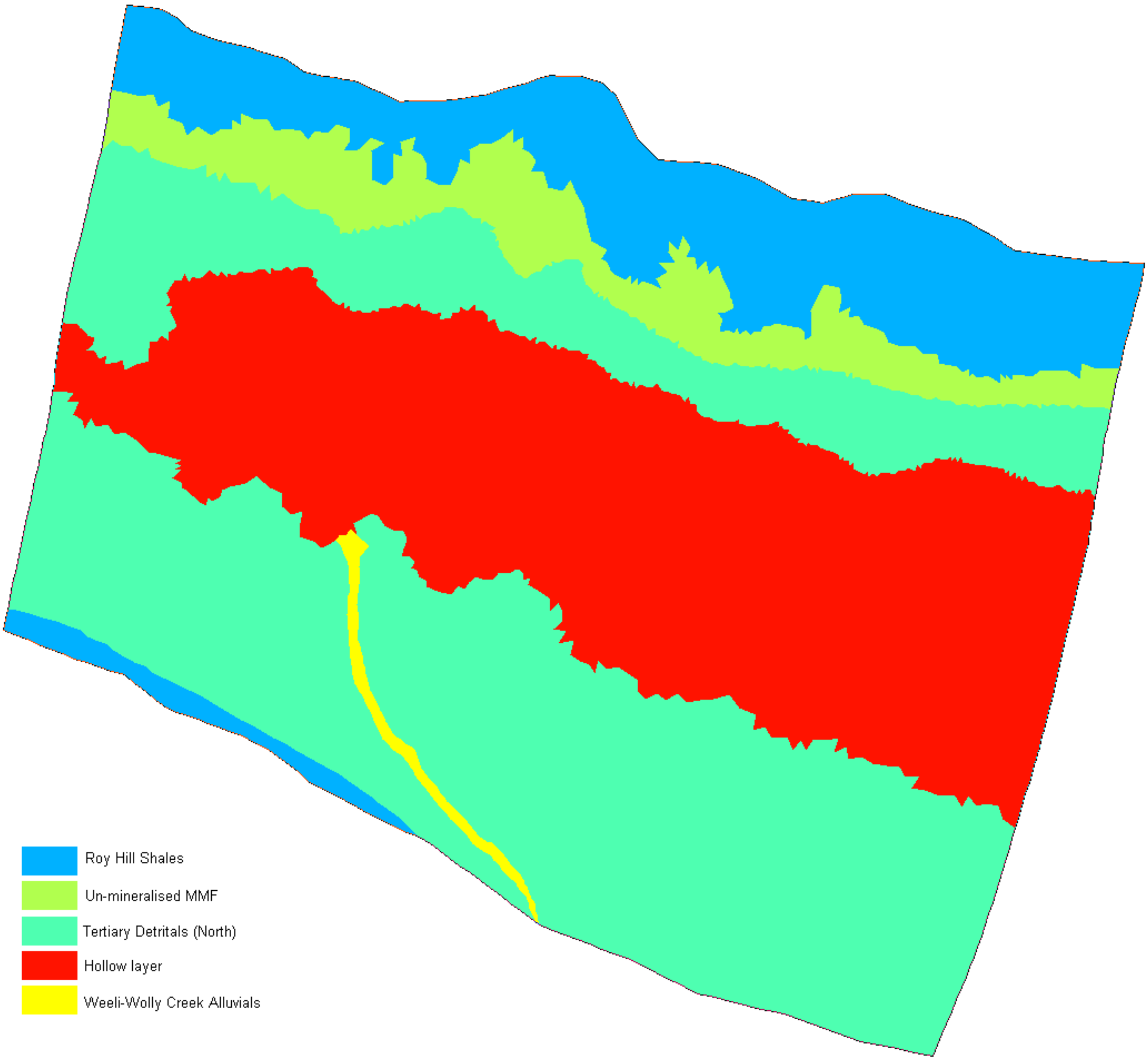
Figure C.7: Elevation of slice 11 of the numerical model (bottom of un-mineralised MMF).

Appendix D.

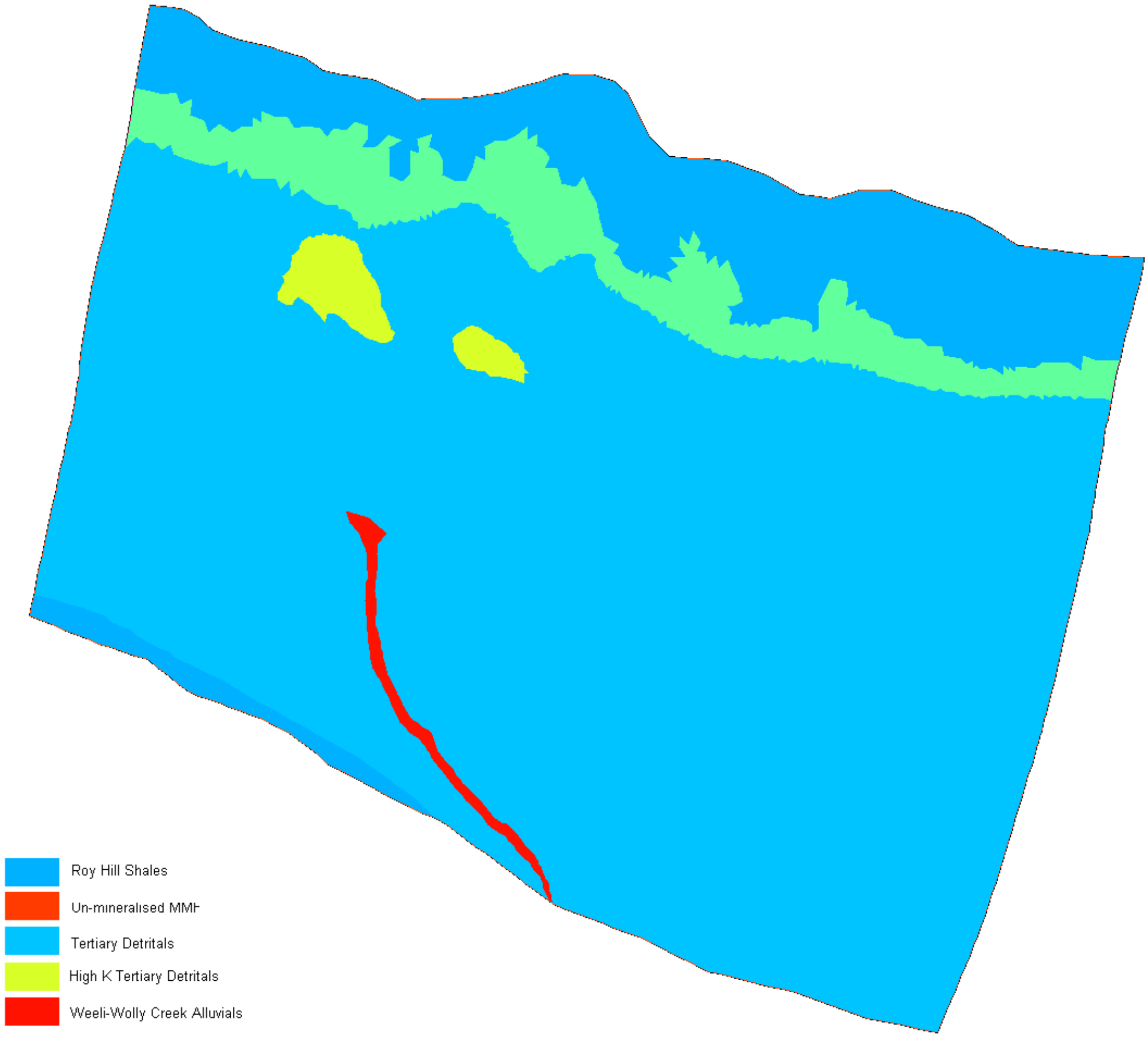
Catchment Recharge Zones, Marsh Flooding Zones and Model Layer Hydraulic Property Distributions



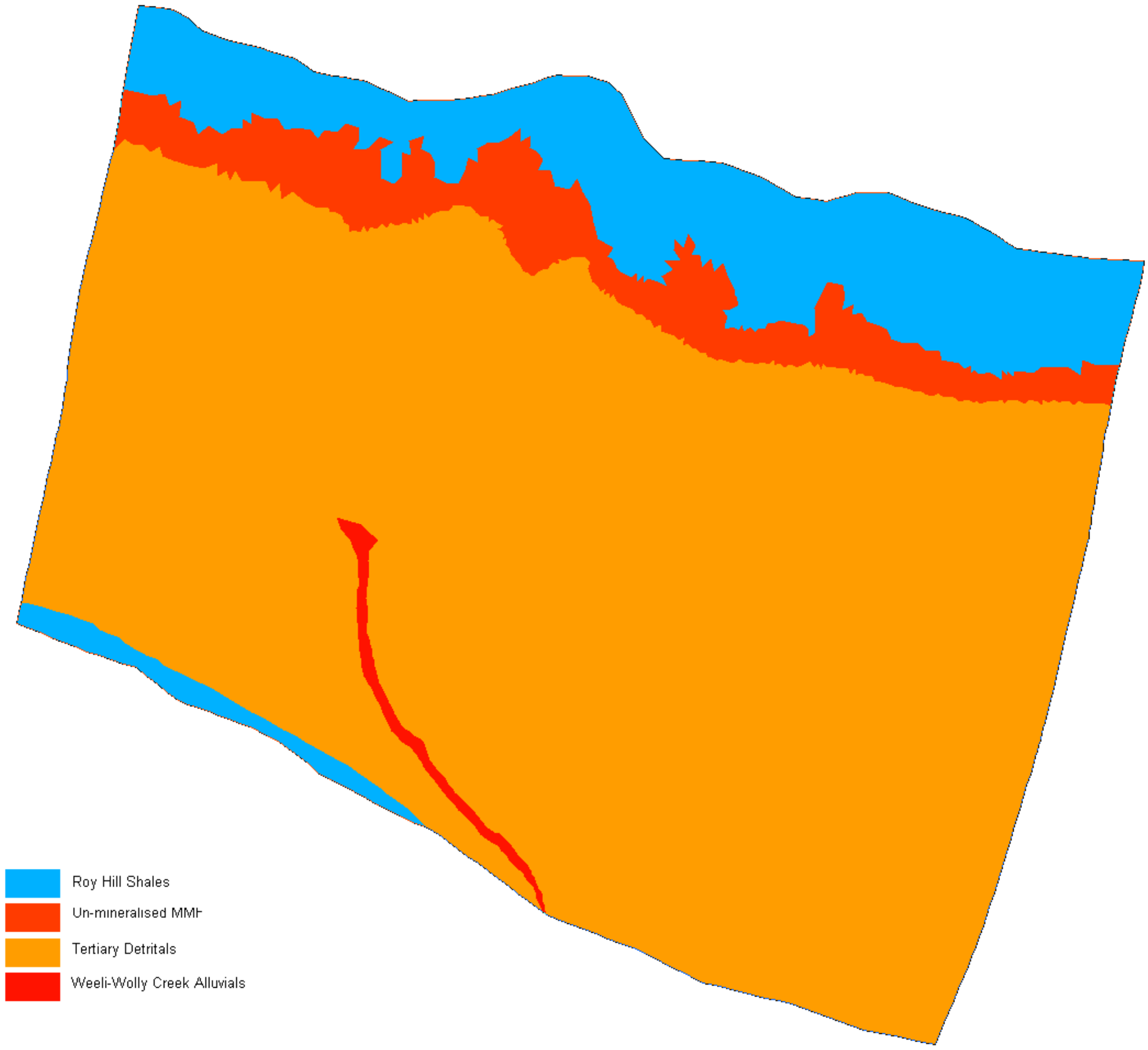
Distribution of groundwater recharge zones



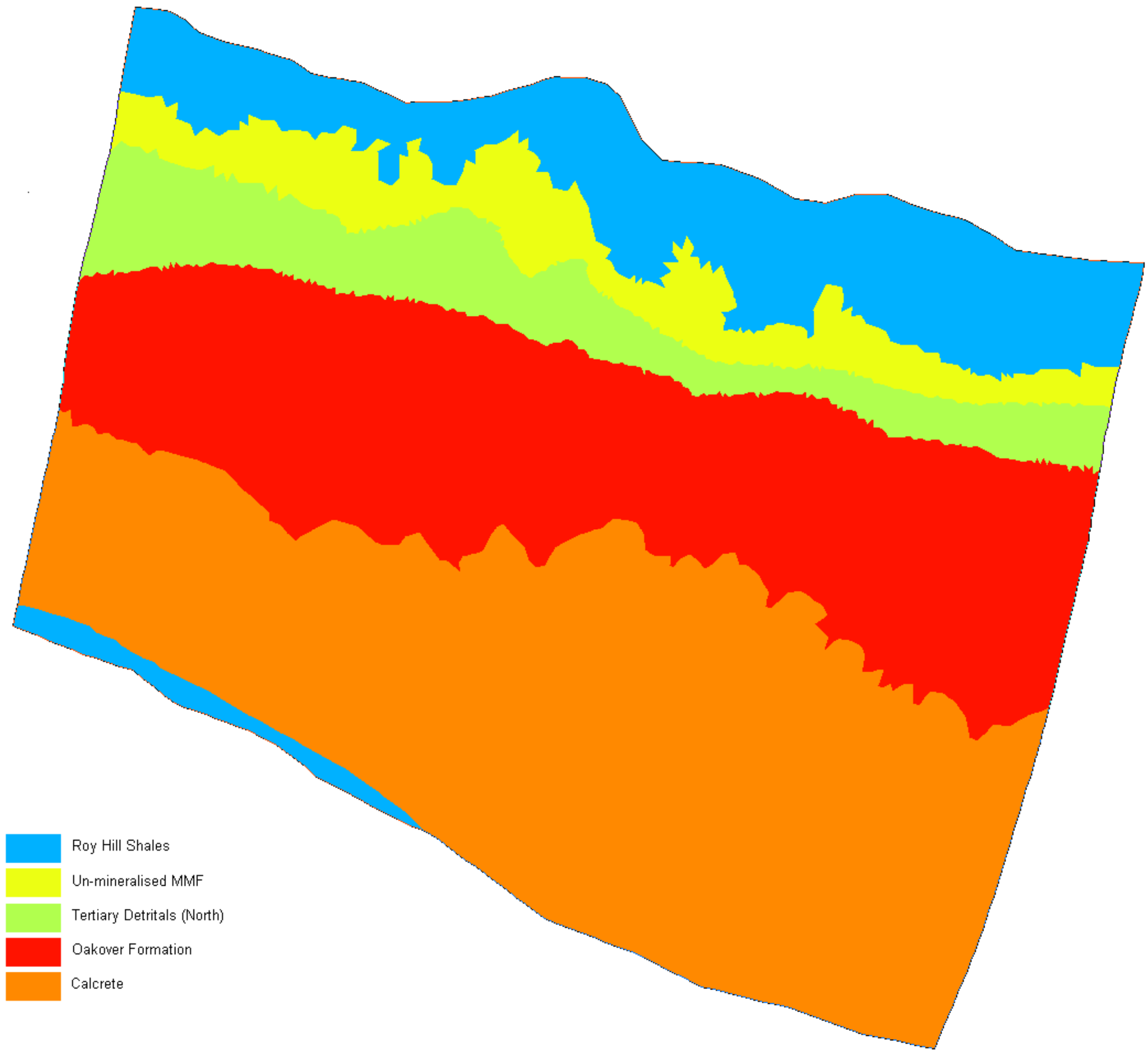
Layer 1 – Hydraulic Conductivity Distribution



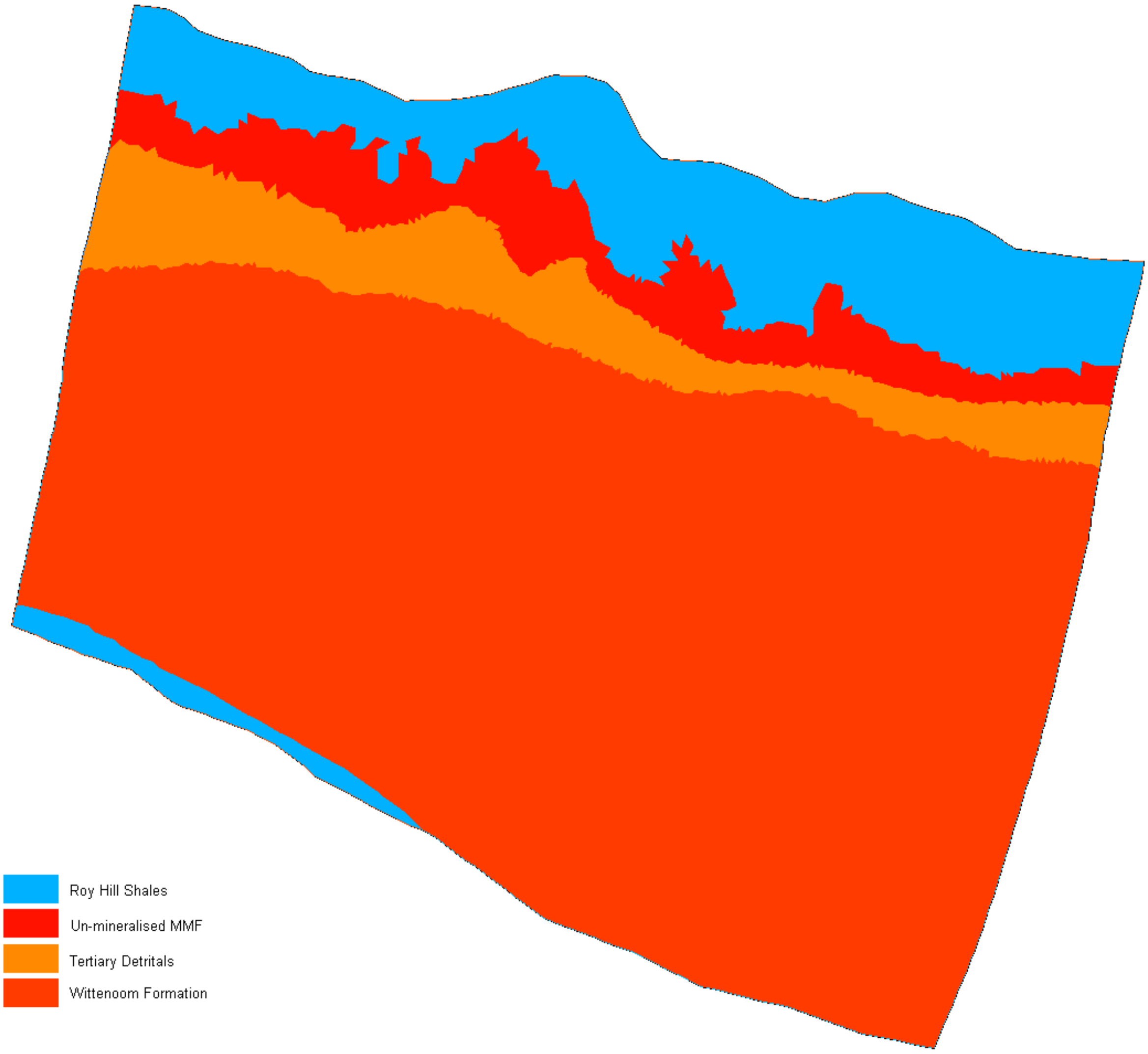
Layer 2 – Hydraulic Conductivity Distribution



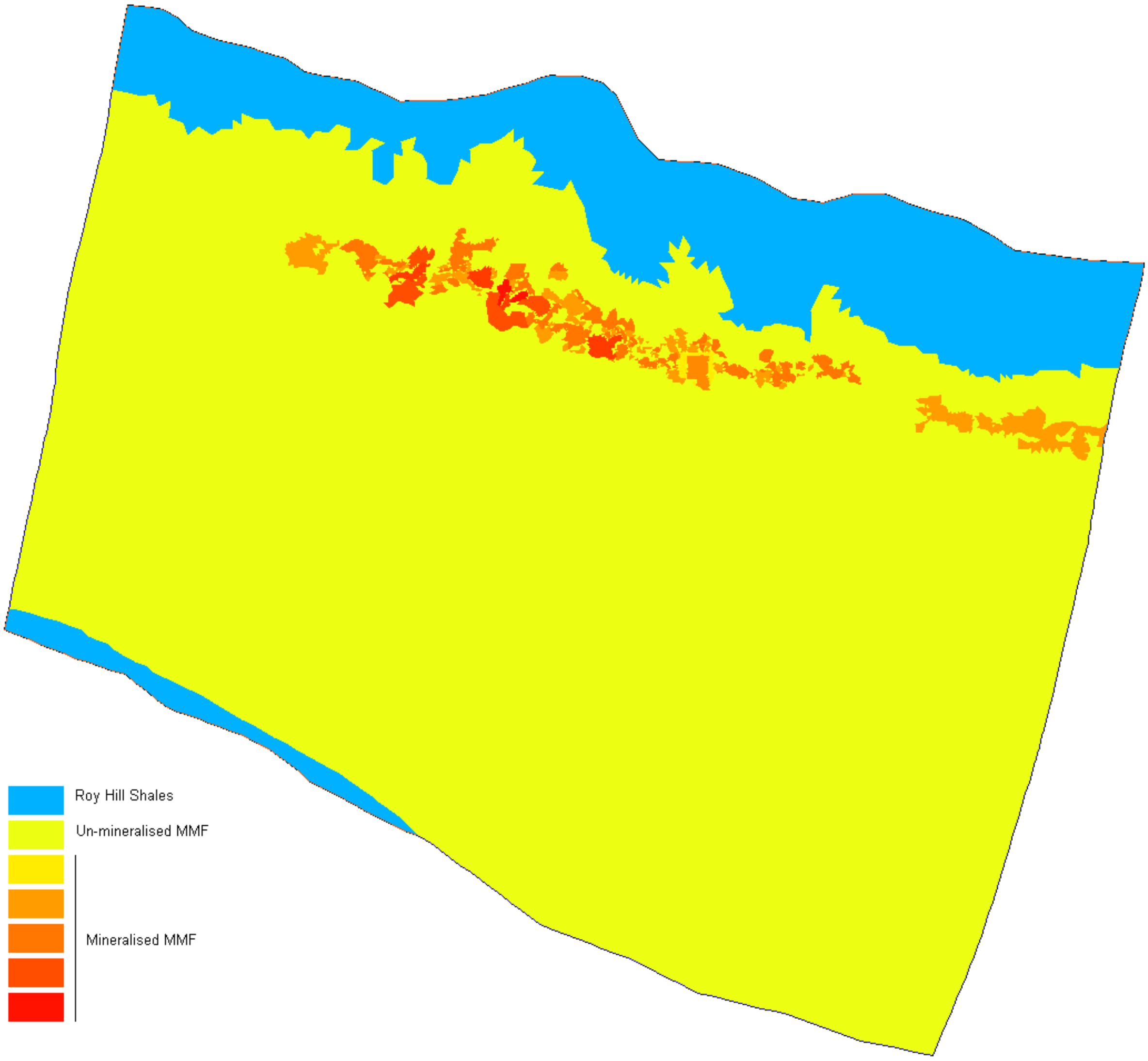
Layer 3 and 4 – Hydraulic Conductivity Distribution



Layer 5 and 6 – Hydraulic Conductivity Distribution

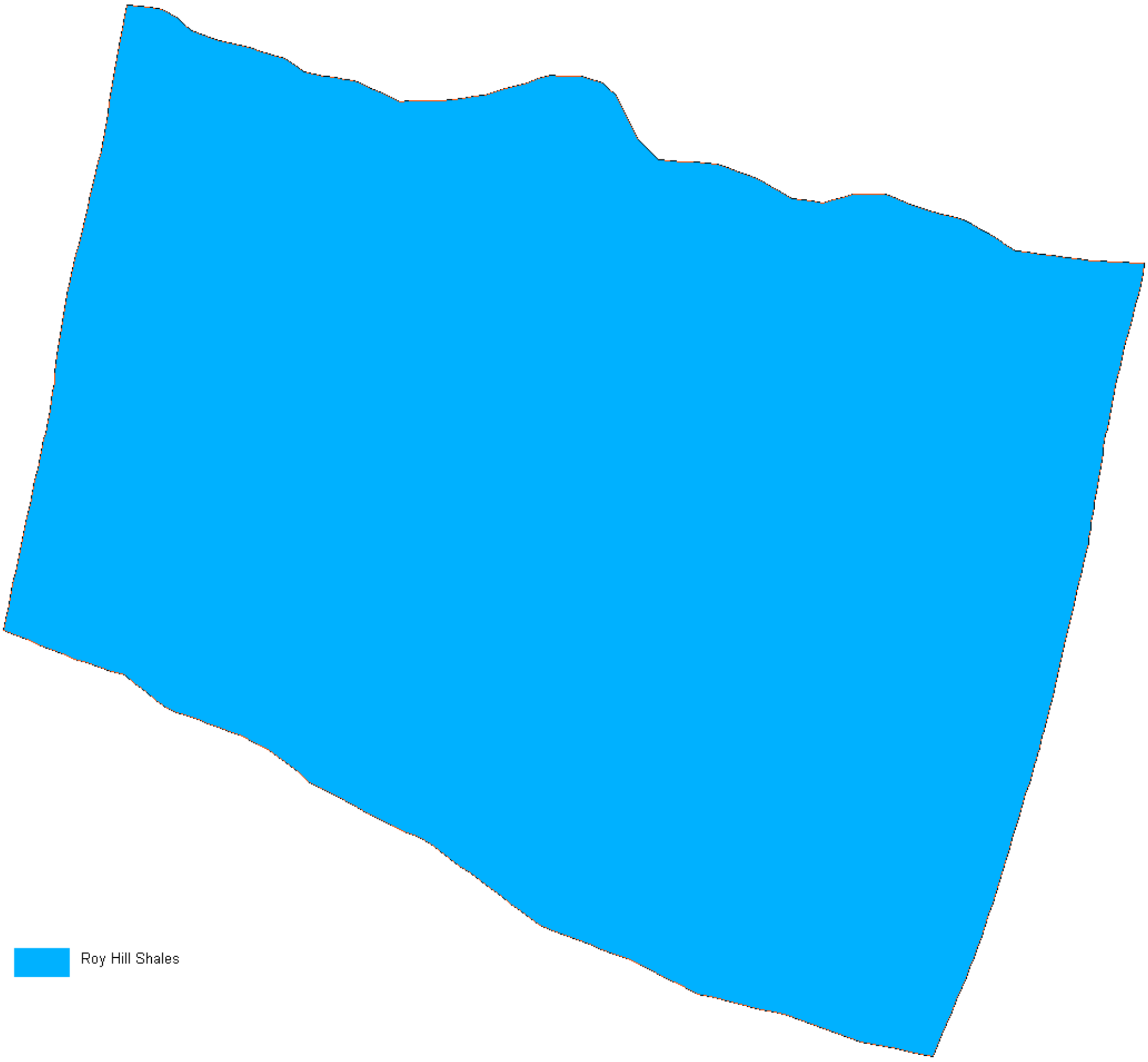


Layer 7 – Hydraulic Conductivity Distribution



Layer 8 and 9 – Hydraulic Conductivity Distribution

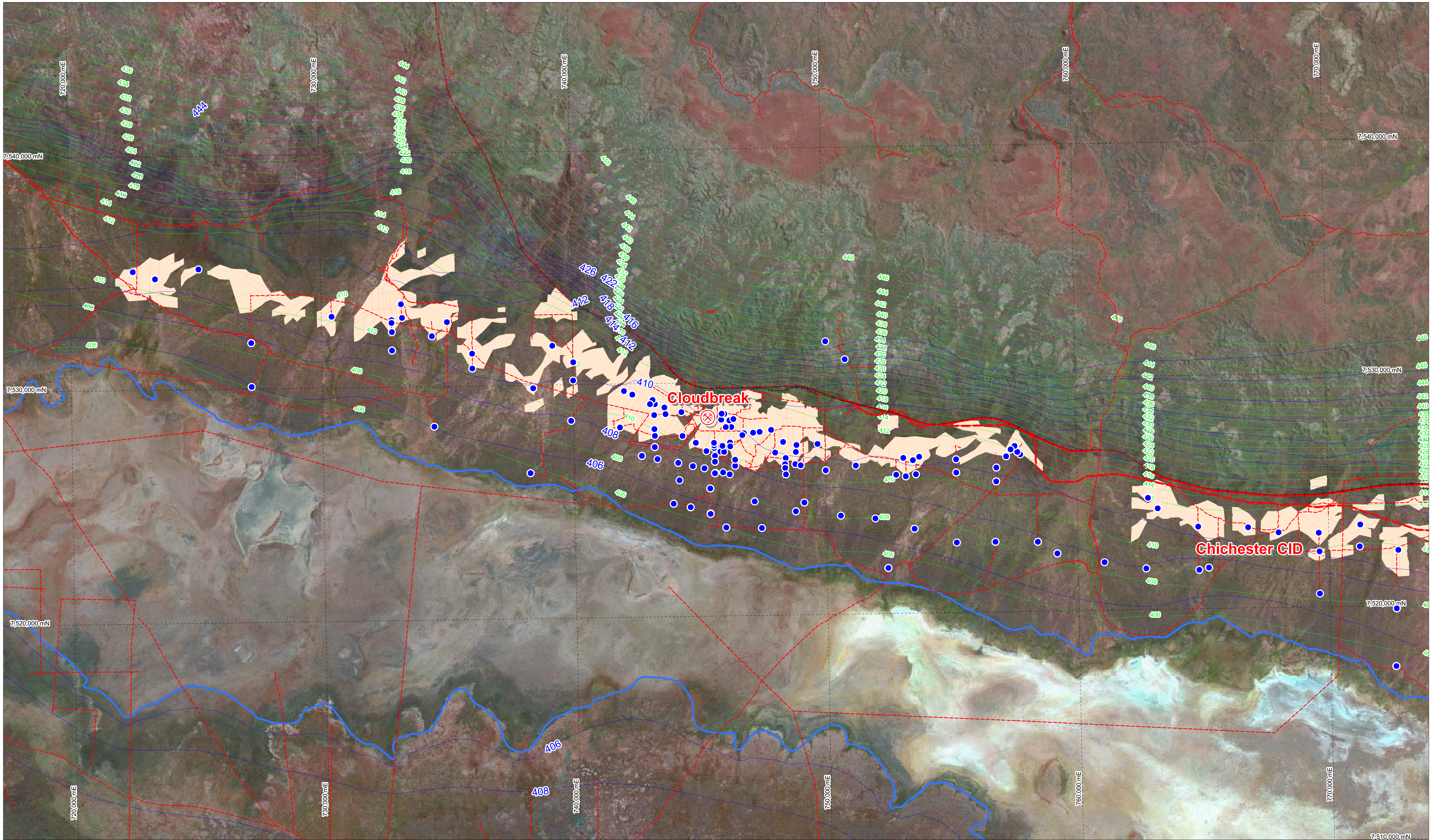
Layer 10 – Hydraulic Conductivity Distribution

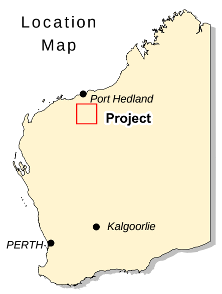


Layer 11 – Hydraulic Conductivity Distribution

Appendix E.

Steady State Calibration Contours





Mine Sequence

Fortescue Marsh Boundary

Simulated Pre-Mining Water Table Elevation (mAHD)

Water Table Elevations (Late 2007) in mAHD

Existing Roads/Tracks

Cloudbreak Monitoring Bores

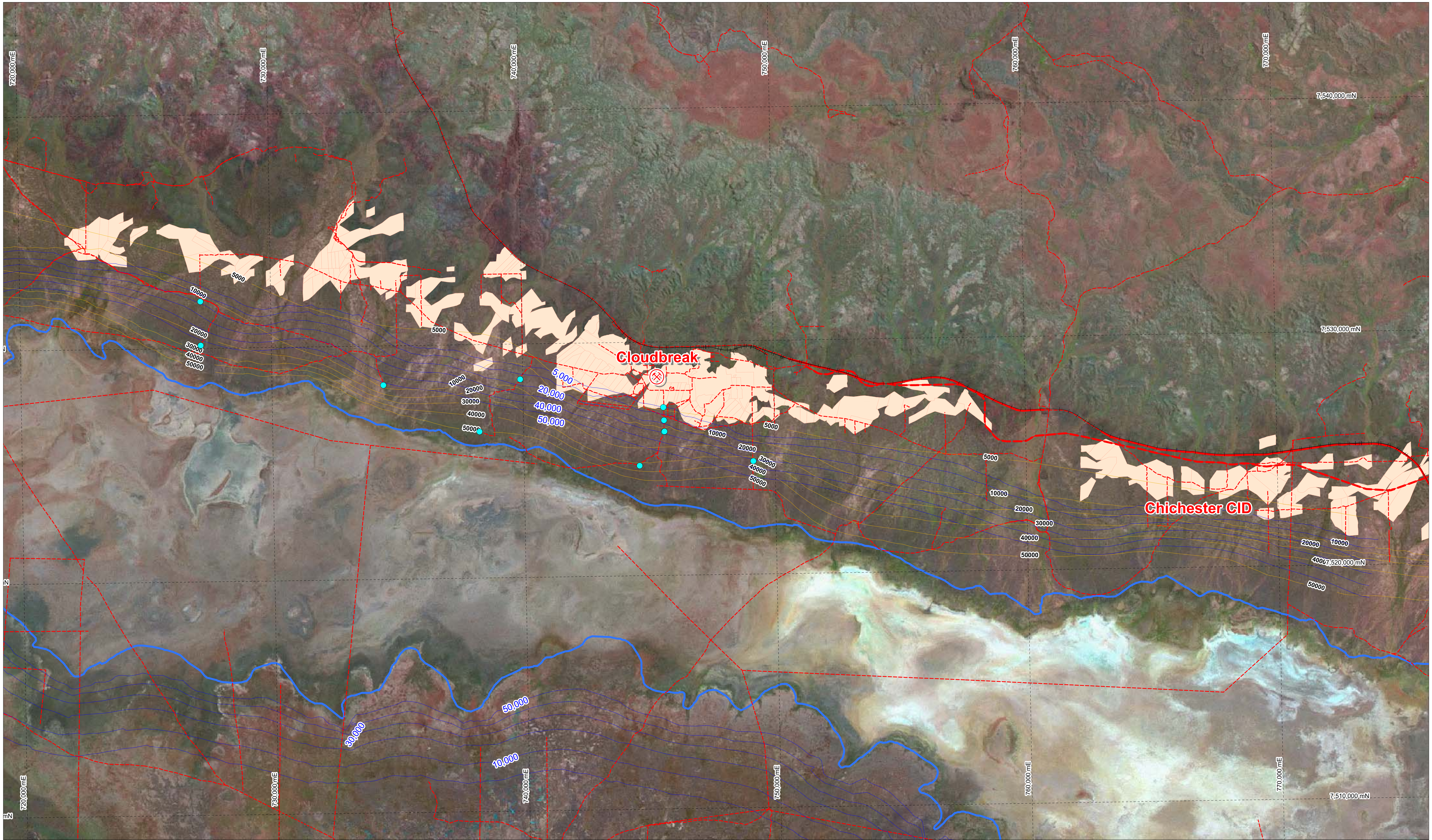
N

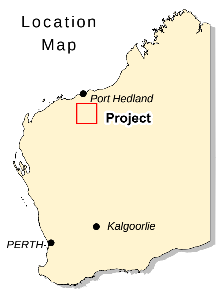
0 1.25 2.5 5
kilometres

Fortescue Metals Group Ltd

Comparison of Interpreted Water Table Elevation (Late 2007) and Simulated Pre-mining Water Table Elevation

Author: B. Willis-Jones	Date:9/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000





Mine Sequence

Fortescue Marsh Boundary

TDS(mgl) Distribution in OF and UMMF

Simulated TDS(mgl) Distribution in OF

Existing Roads/Tracks

Sampling Points

N

0 1.25 2.5 5
kilometres

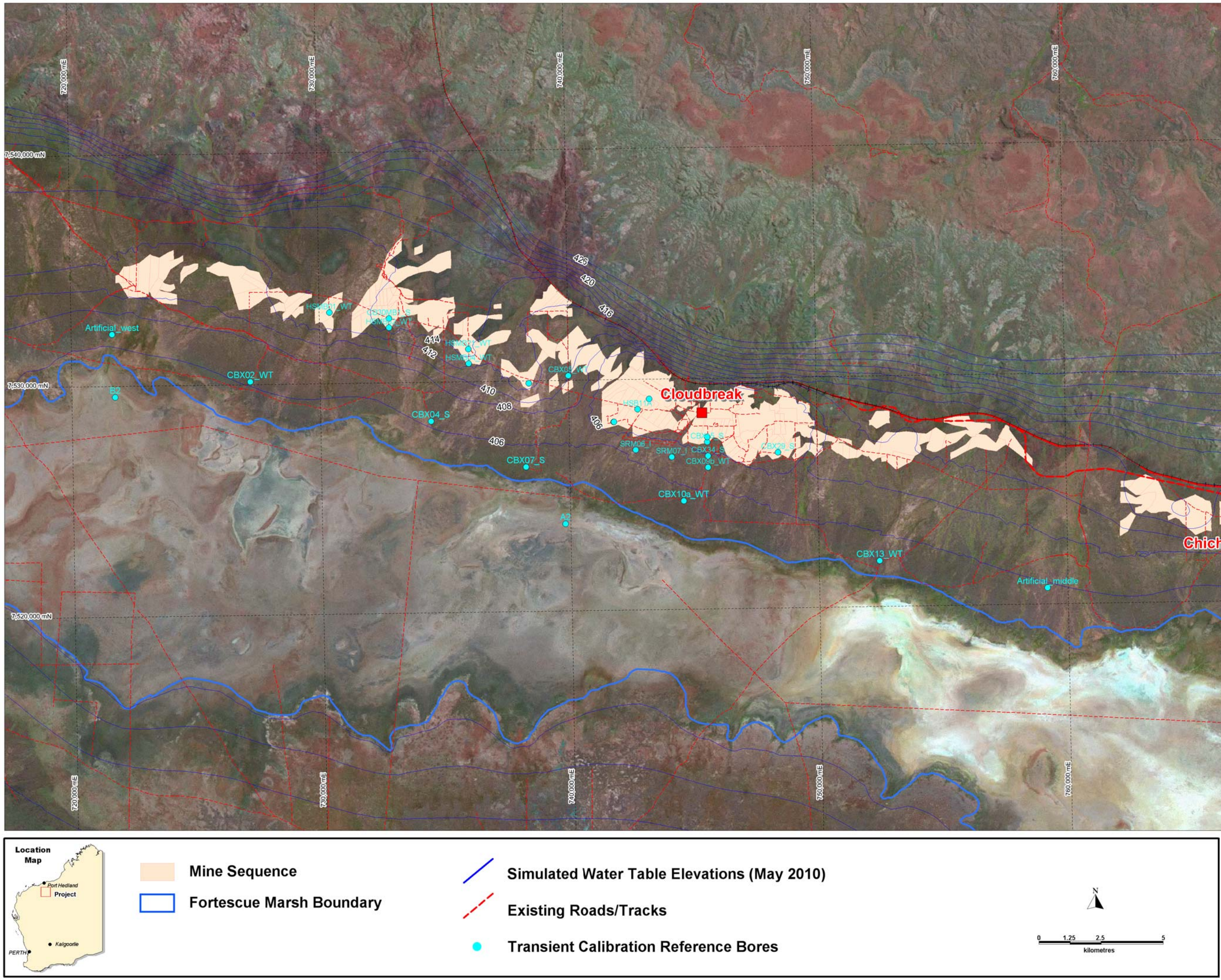
Fortescue Metals Group Ltd

Steady-State Simulated and Observe Salinity Distribution in Oakover Formation and Upper Marra Mamba Formation

Author: B. Willis-Jones	Date: 9/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000

Appendix F.

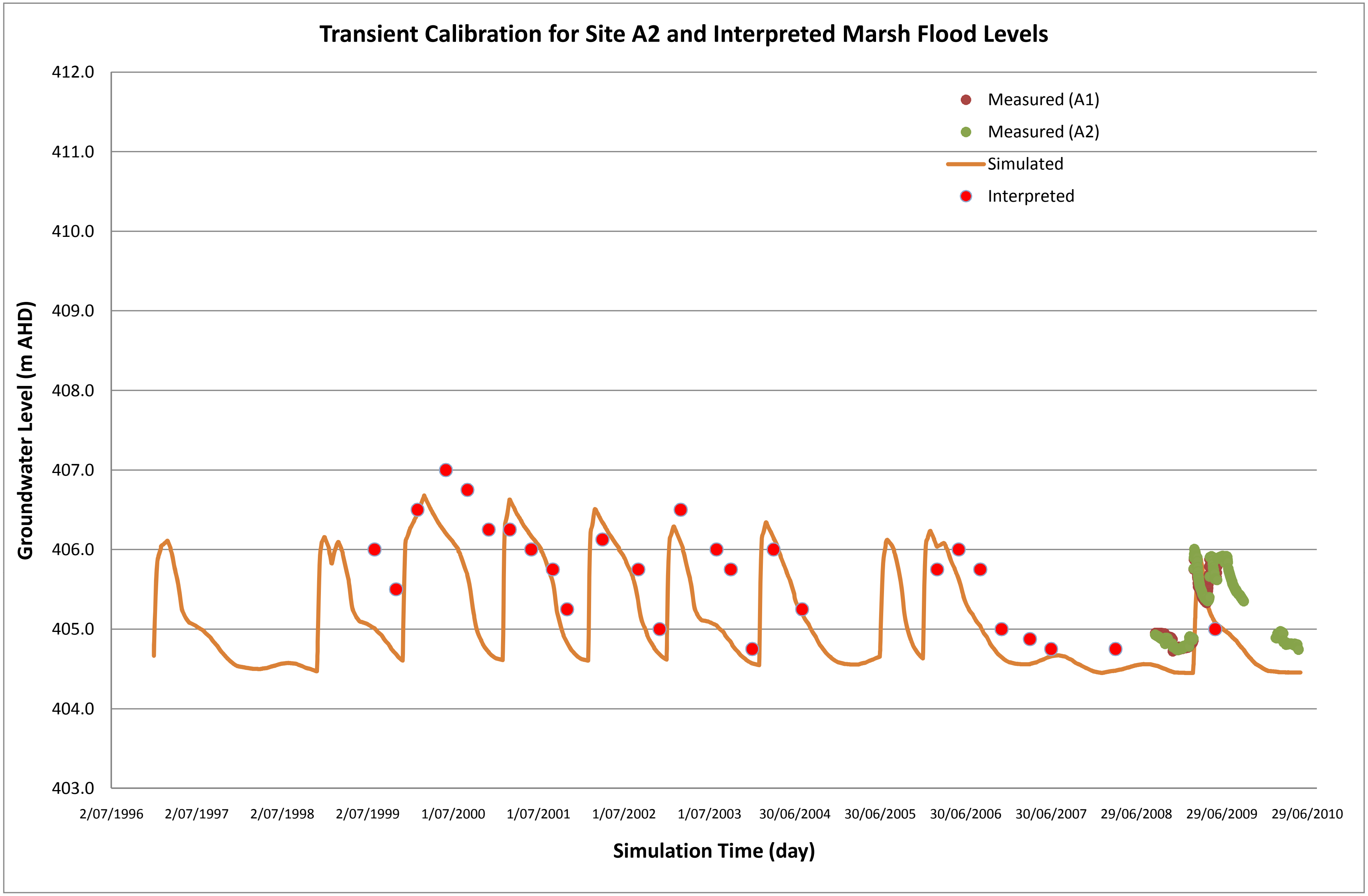
Transient Calibration Hydrographs

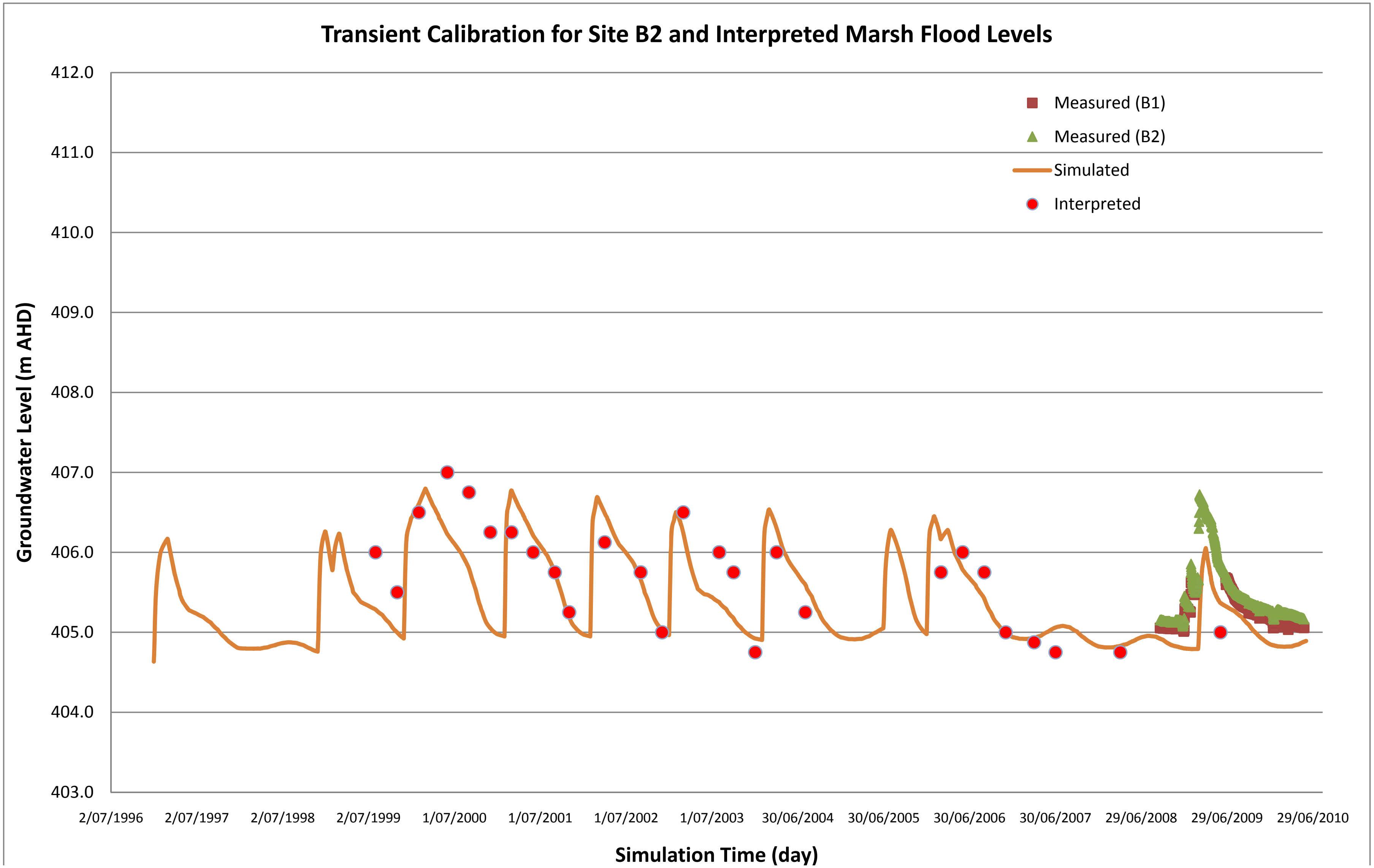


Fortescue Metals Group Ltd

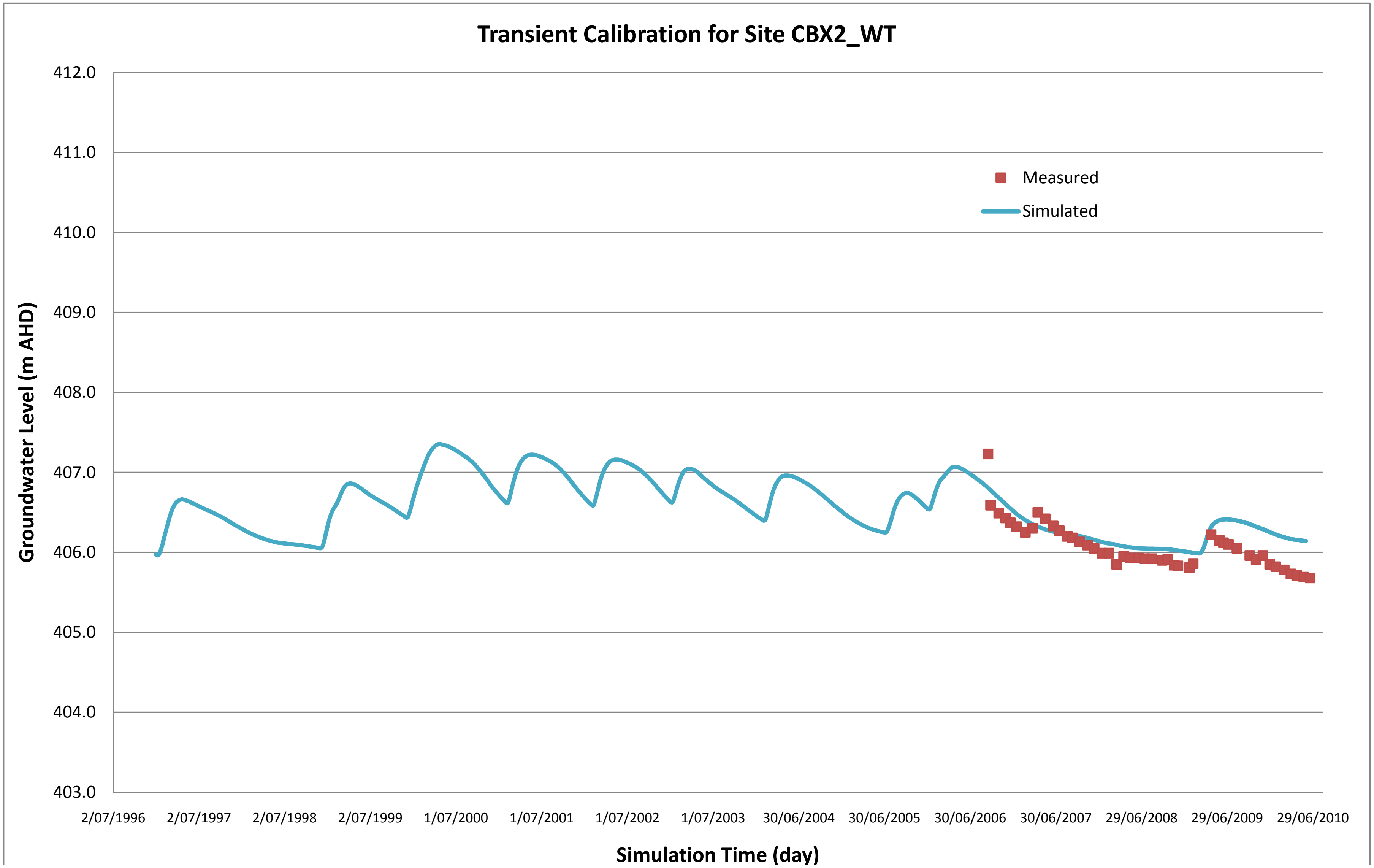
Simulated Water Table Elevation May 2010 and Calibration Reference Points

Author: B. Willis-Jones	Date:9/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000

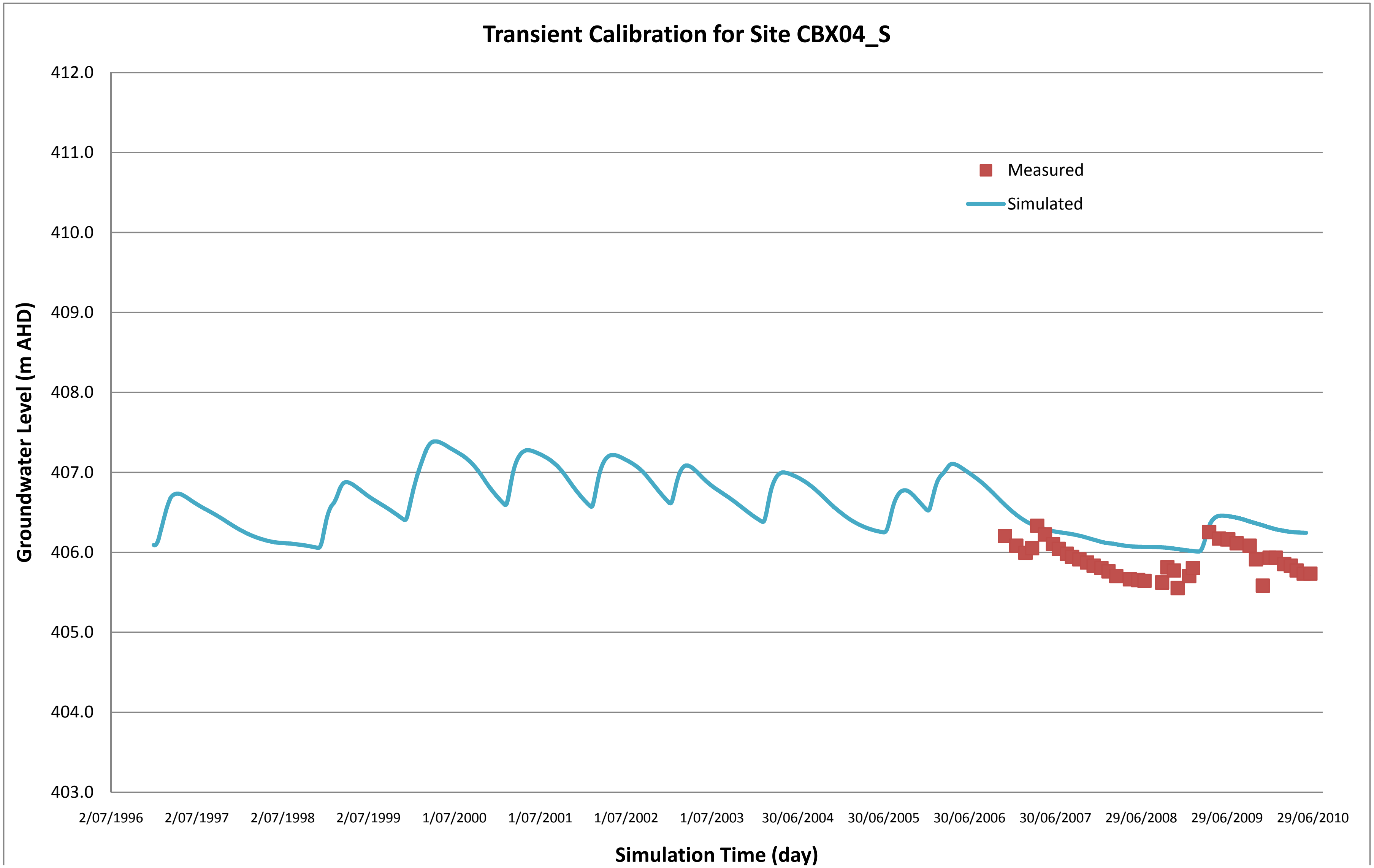

Transient Calibration for Site A2 and Interpreted Marsh Flood Levels
Measured (A1)
Measured (A2)
Simulated
Interpreted
Groundwater Level (m AHD)
412.0
411.0
410.0
409.0
408.0
407.0
406.0
405.0
404.0
403.0
2/07/1996
2/07/1997
2/07/1998
2/07/1999
1/07/2000
1/07/2001
1/07/2002
1/07/2003
30/06/2004
30/06/2005
30/06/2006
30/06/2007
29/06/2008
29/06/2009
29/06/2010
Simulation Time (day)



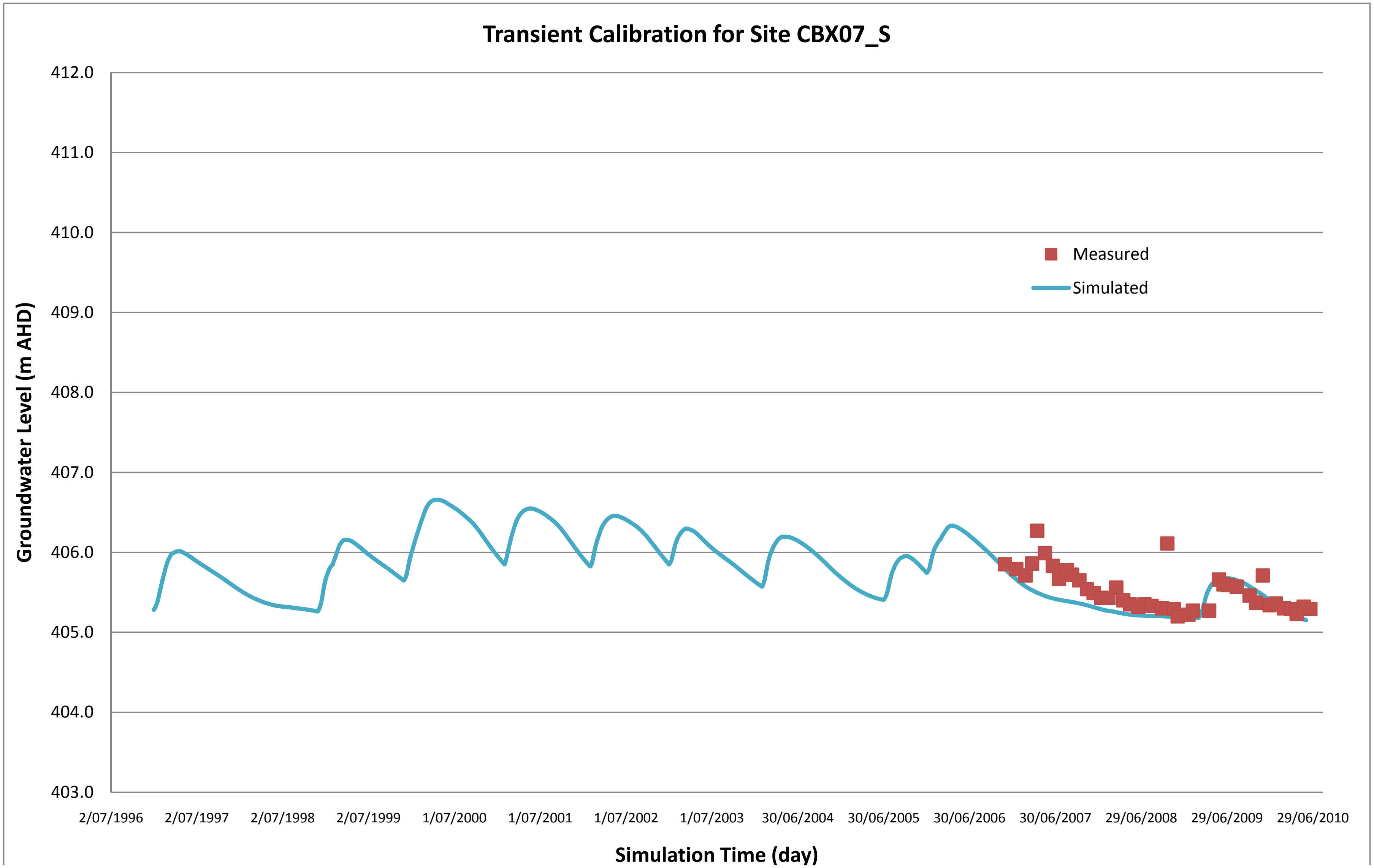
Transient Calibration for Site B2 and Interpreted Marsh Flood Levels
Groundwater Level (m AHD)
412.0
411.0
410.0
409.0
408.0
407.0
406.0
405.0
404.0
403.0
2/07/1996
2/07/1997
2/07/1998
2/07/1999
1/07/2000
1/07/2001
1/07/2002
1/07/2003
30/06/2004
30/06/2005
30/06/2006
30/06/2007
29/06/2008
29/06/2009
29/06/2010
Simulation Time (day)
Measured (B1)
Measured (B2)
Simulated
Interpreted

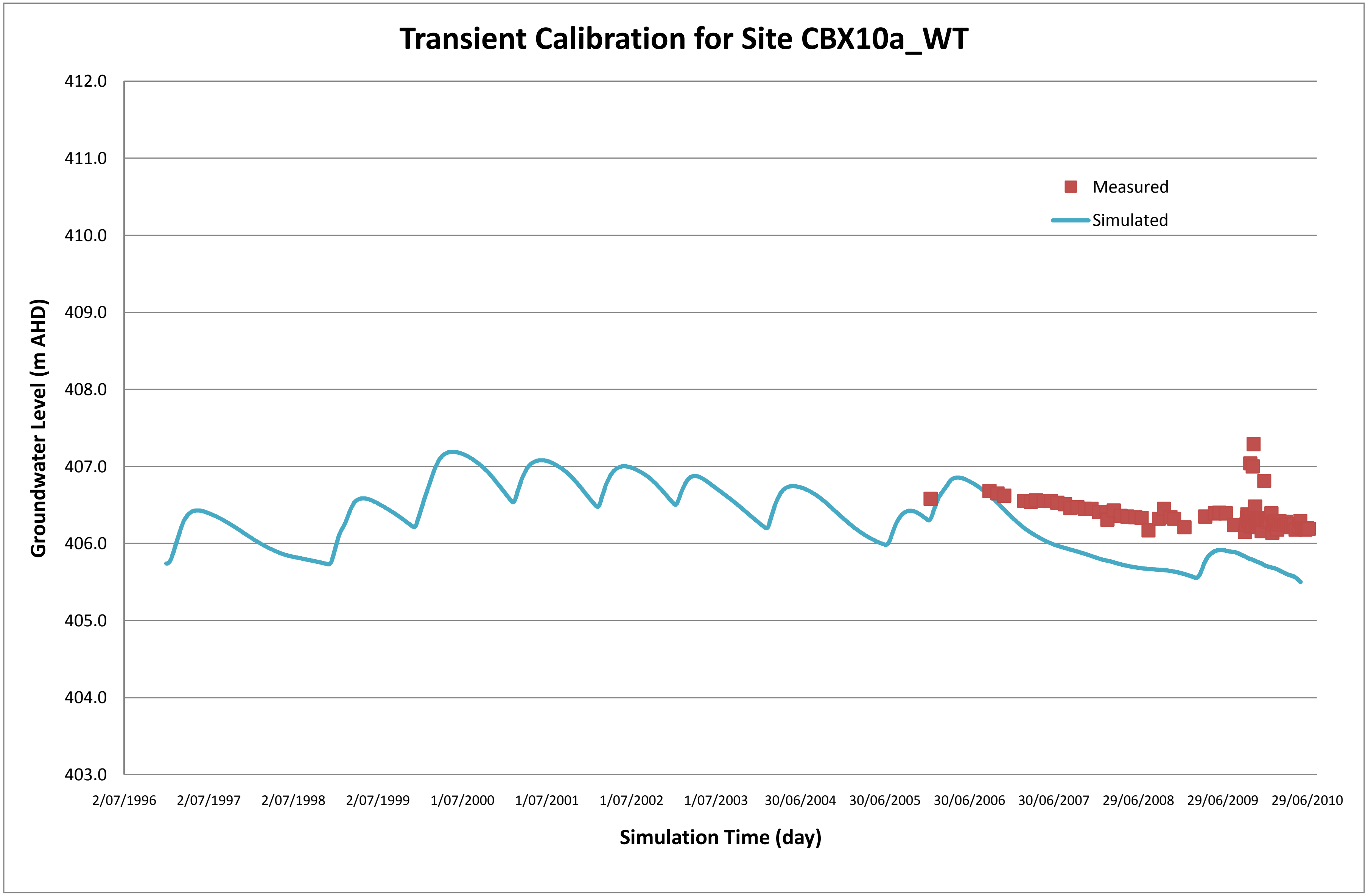


Transient Calibration for Site CBX2_WT
412.0
411.0
410.0
409.0
408.0
407.0
406.0
405.0
404.0
403.0
Groundwater Level (m AHD)
Measured
Simulated
2/07/1996
2/07/1997
2/07/1998
2/07/1999
1/07/2000
1/07/2001
1/07/2002
1/07/2003
30/06/2004
30/06/2005
30/06/2006
30/06/2007
29/06/2008
29/06/2009
29/06/2010
Simulation Time (day)

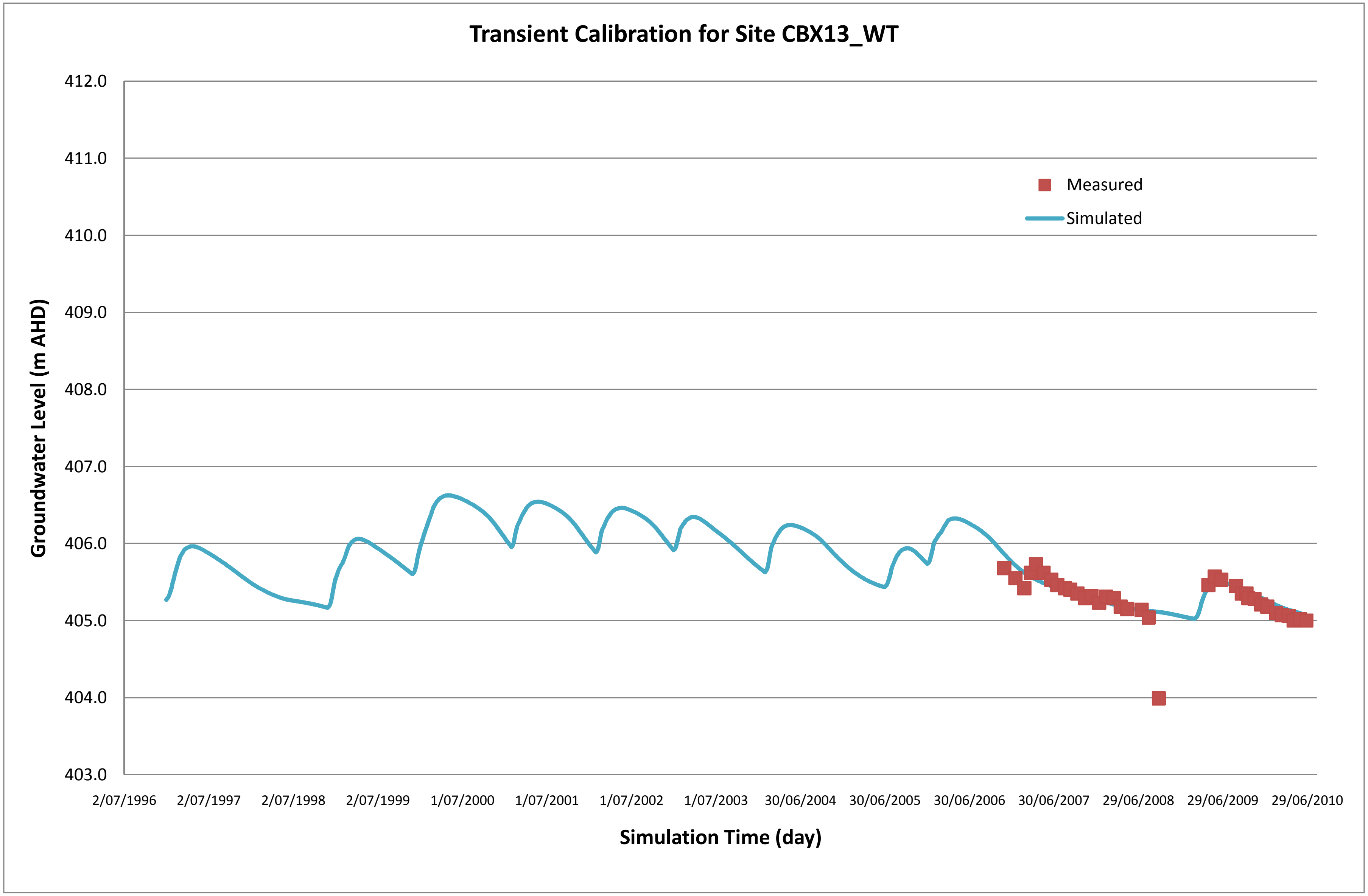


Transient Calibration for Site CBX04_S
Groundwater Level (m AHD)
412.0
411.0
410.0
409.0
408.0
407.0
406.0
405.0
404.0
403.0
Measured
Simulated
2/07/1996
2/07/1997
2/07/1998
2/07/1999
1/07/2000
1/07/2001
1/07/2002
1/07/2003
30/06/2004
30/06/2005
30/06/2006
30/06/2007
29/06/2008
29/06/2009
29/06/2010
Simulation Time (day)

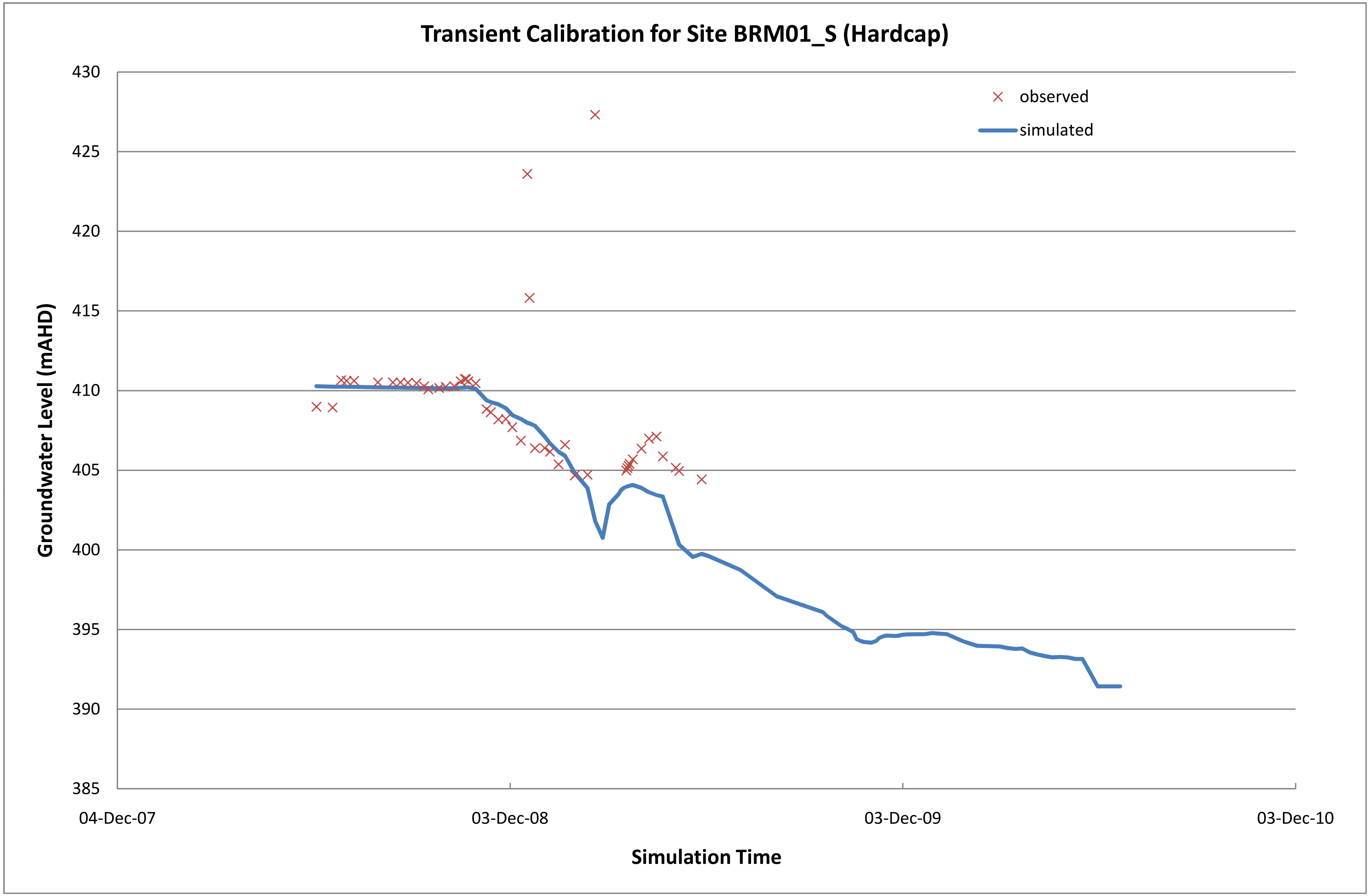

Transient Calibration for Site CBX07_S
Groundwater Level (m AHD)
412.0
411.0
410.0
409.0
408.0
407.0
406.0
405.0
404.0
403.0
Measured
Simulated
2/07/1996
2/07/1997
2/07/1998
2/07/1999
1/07/2000
1/07/2001
1/07/2002
1/07/2003
30/06/2004
30/06/2005
30/06/2006
30/06/2007
29/06/2008
29/06/2009
29/06/2010
Simulation Time (day)



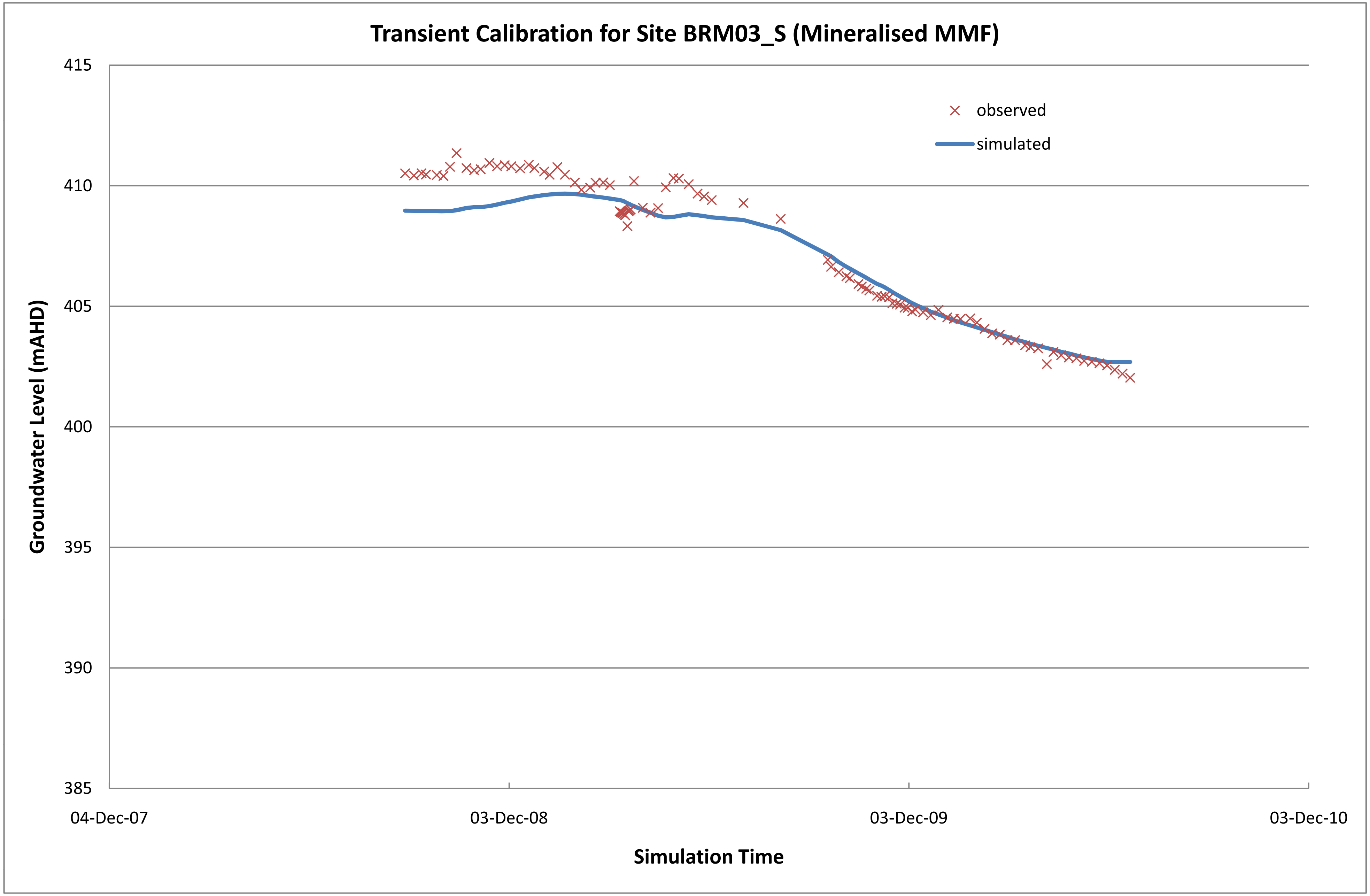
Transient Calibration for Site CBX10a_WT
Groundwater Level (m AHD)
412.0
411.0
410.0
409.0
408.0
407.0
406.0
405.0
404.0
403.0
Measured
Simulated
2/07/1996
2/07/1997
2/07/1998
2/07/1999
1/07/2000
1/07/2001
1/07/2002
1/07/2003
30/06/2004
30/06/2005
30/06/2006
30/06/2007
29/06/2008
29/06/2009
29/06/2010
Simulation Time (day)



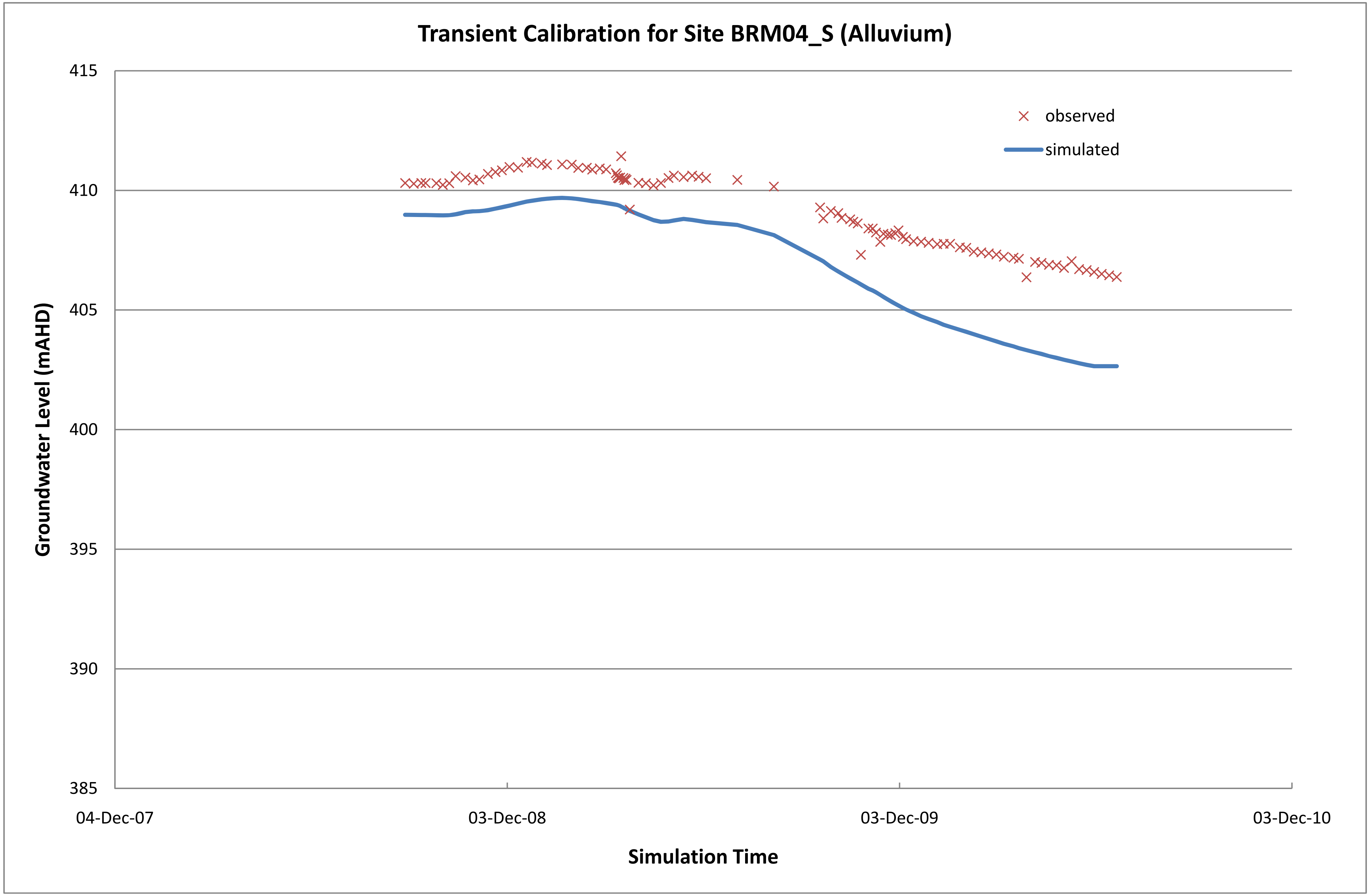
Transient Calibration for Site CBX13_WT
Measured
Simulated
412.0
411.0
410.0
409.0
408.0
407.0
406.0
405.0
404.0
403.0
Groundwater Level (m AHD)
2/07/1996
2/07/1997
2/07/1998
2/07/1999
1/07/2000
1/07/2001
1/07/2002
1/07/2003
30/06/2004
30/06/2005
30/06/2006
30/06/2007
29/06/2008
29/06/2009
29/06/2010
Simulation Time (day)



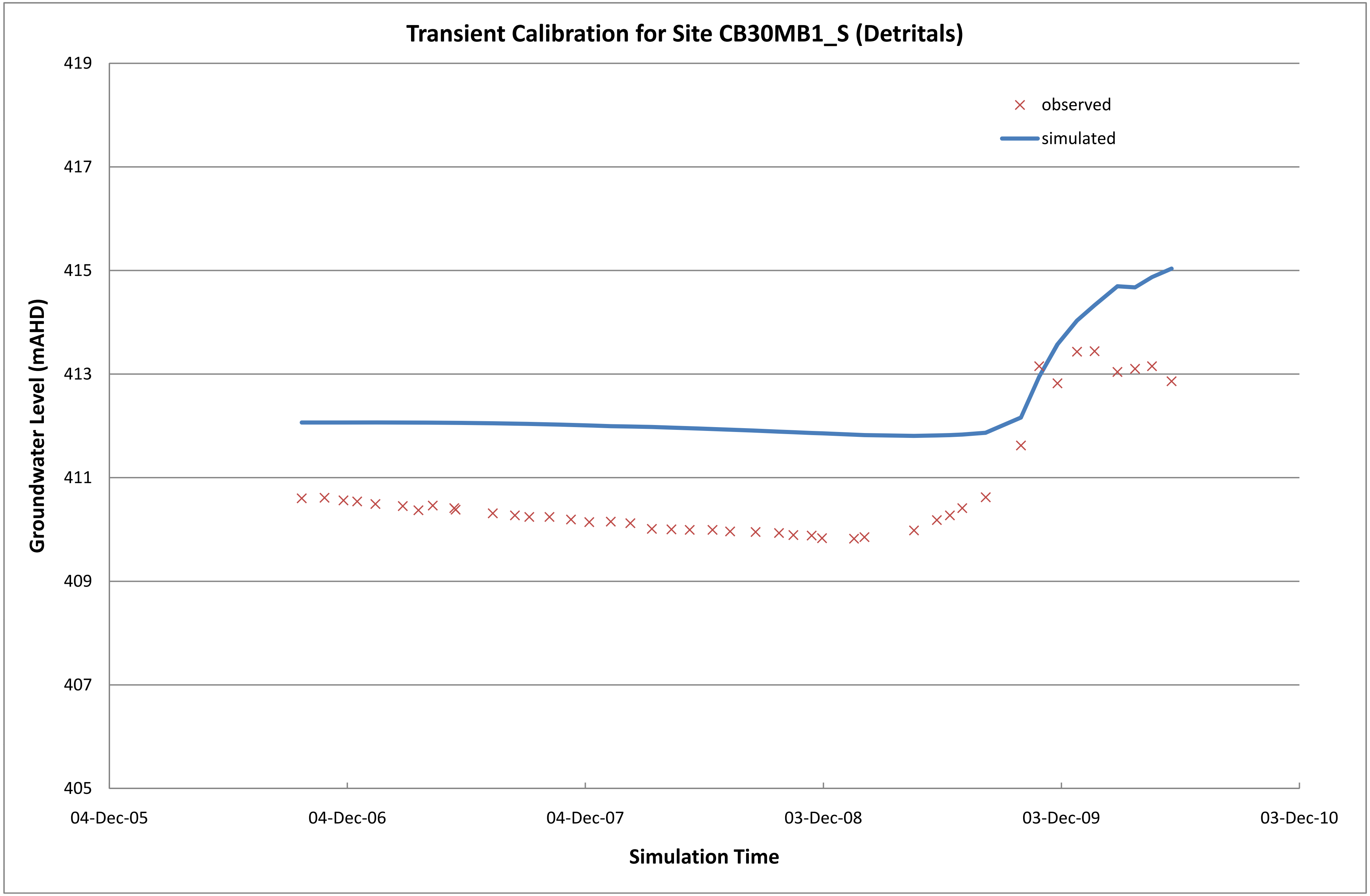
Transient Calibration for Site BRM01_S (Hardcap)
430
425
420
415
410
405
400
395
390
385
Groundwater Level (mAHD)
observed
simulated
04-Dec-07
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time



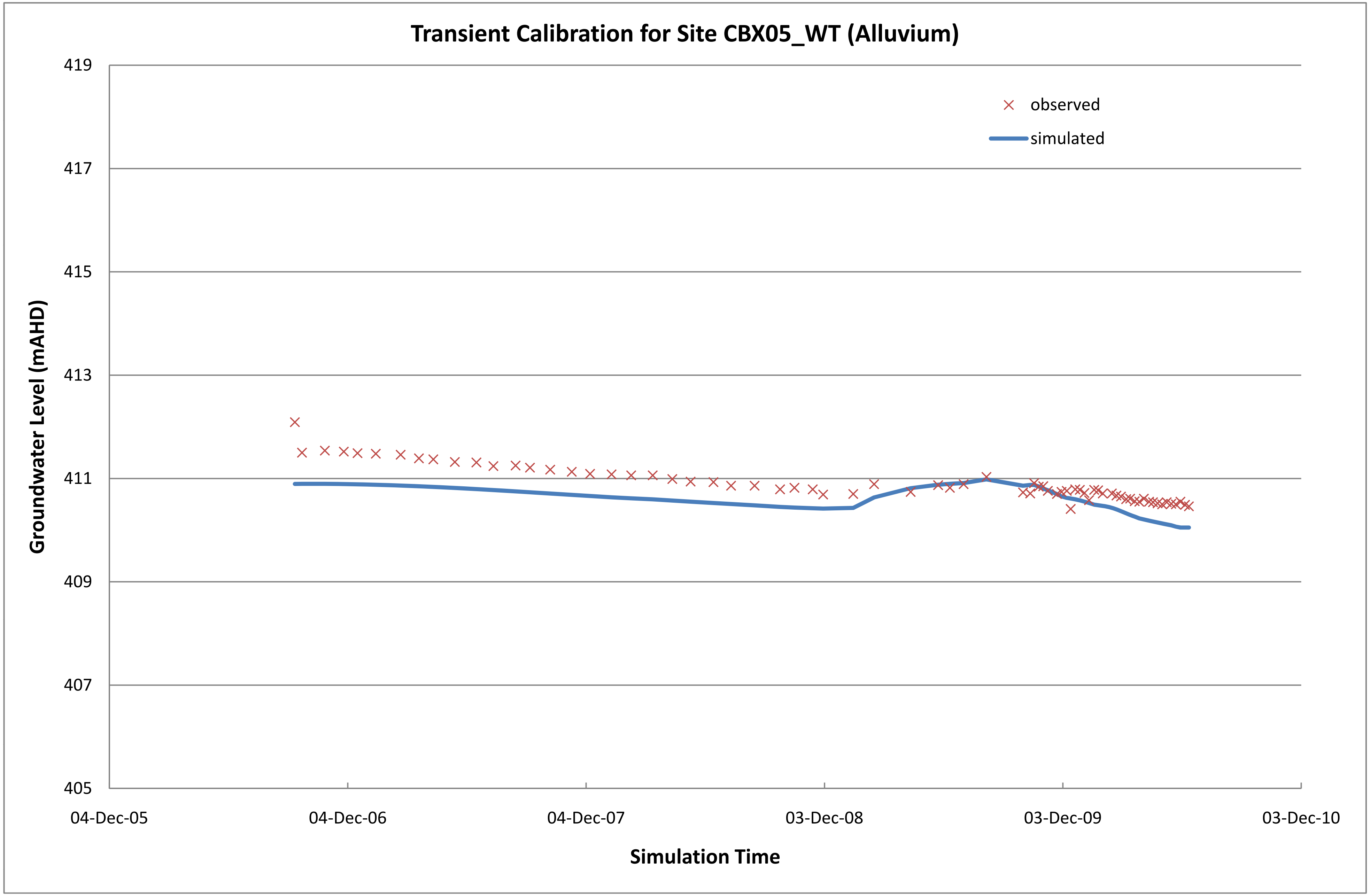
Transient Calibration for Site BRM03_S (Mineralised MMF)
observed
simulated
415
410
405
400
395
390
385
04-Dec-07
03-Dec-08
03-Dec-09
03-Dec-10
Groundwater Level (mAHD)
Simulation Time

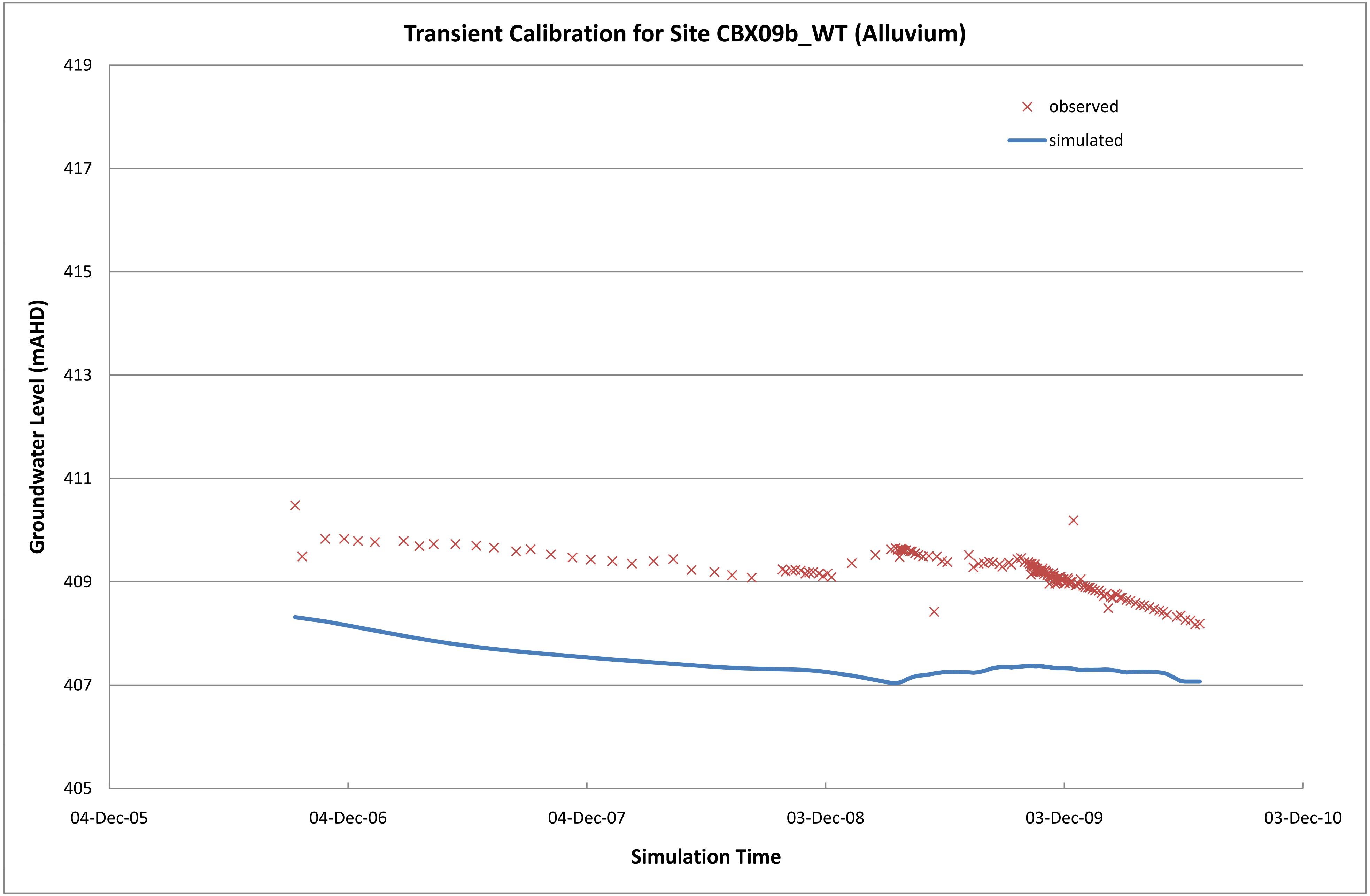


Transient Calibration for Site BRM04_S (Alluvium)
observed
simulated
Groundwater Level (mAHD)
415
410
405
400
395
390
385
04-Dec-07
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time

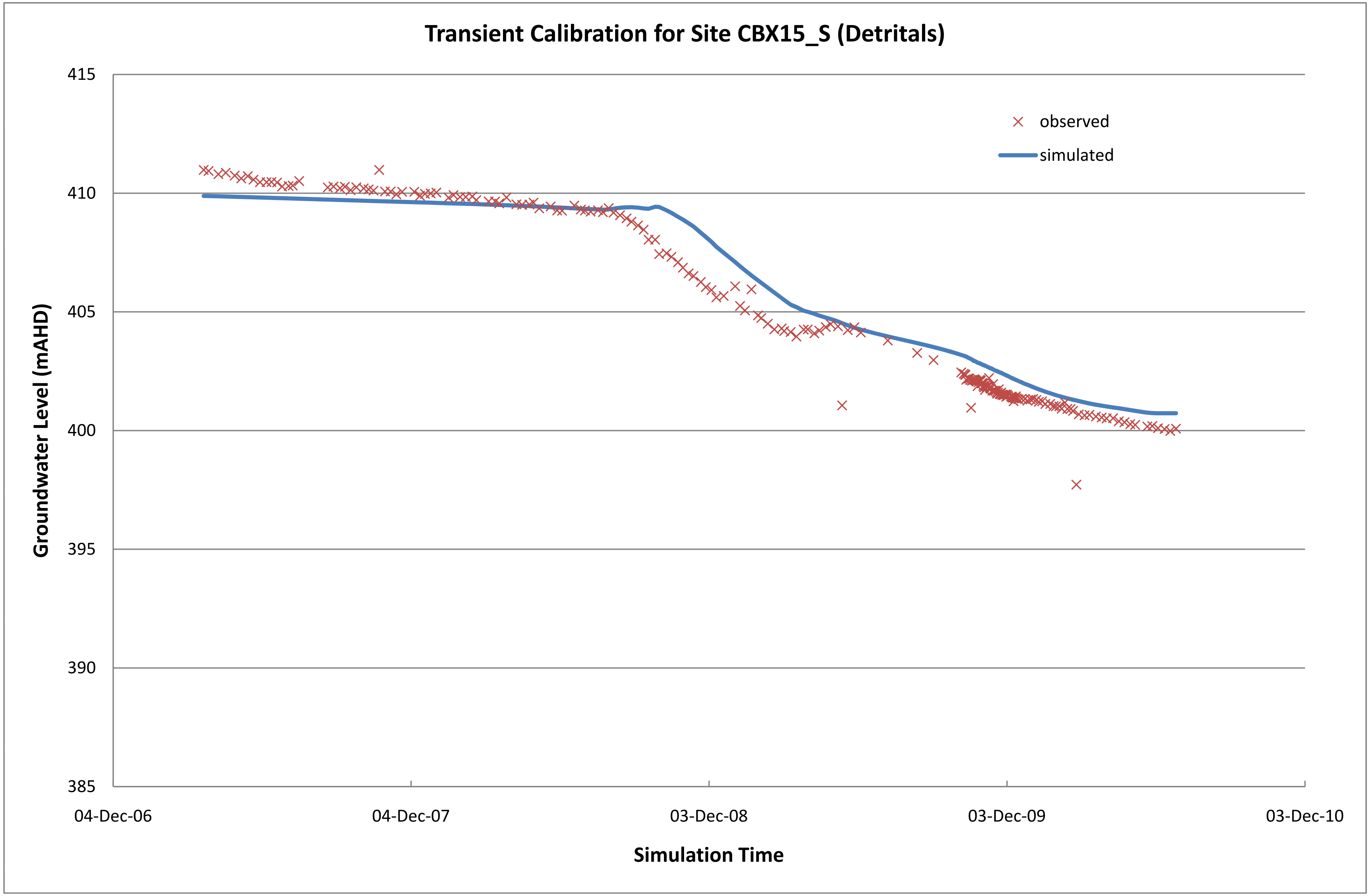


Transient Calibration for Site CB30MB1_S (Detritals)
Groundwater Level (mAHD)
419
417
415
413
411
409
407
405
observed
simulated
04-Dec-05
04-Dec-06
04-Dec-07
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time

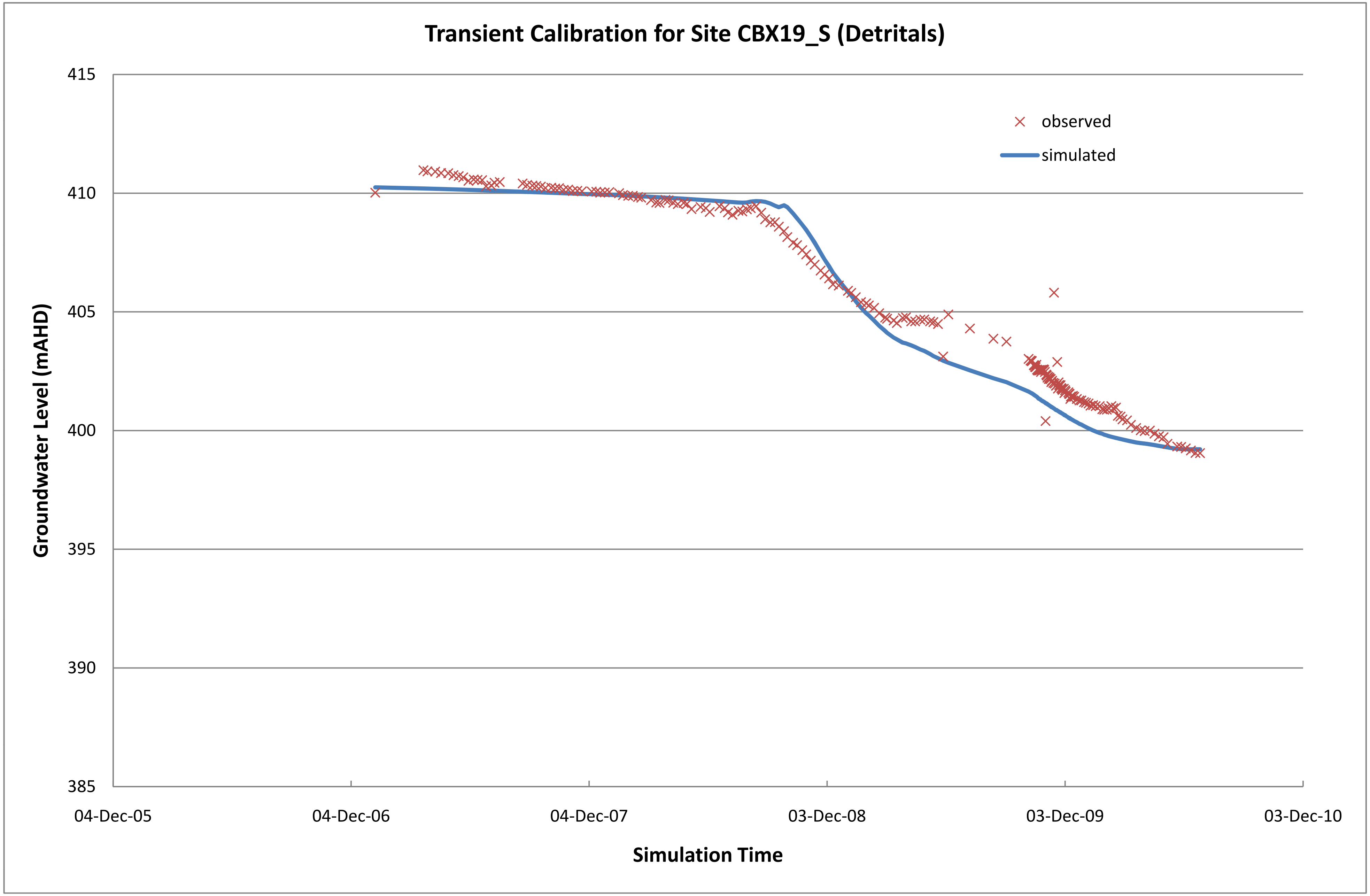

Transient Calibration for Site CBX05_WT (Alluvium)
observed
simulated
Groundwater Level (mAHD)
419
417
415
413
411
409
407
405
04-Dec-05
04-Dec-06
04-Dec-07
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time



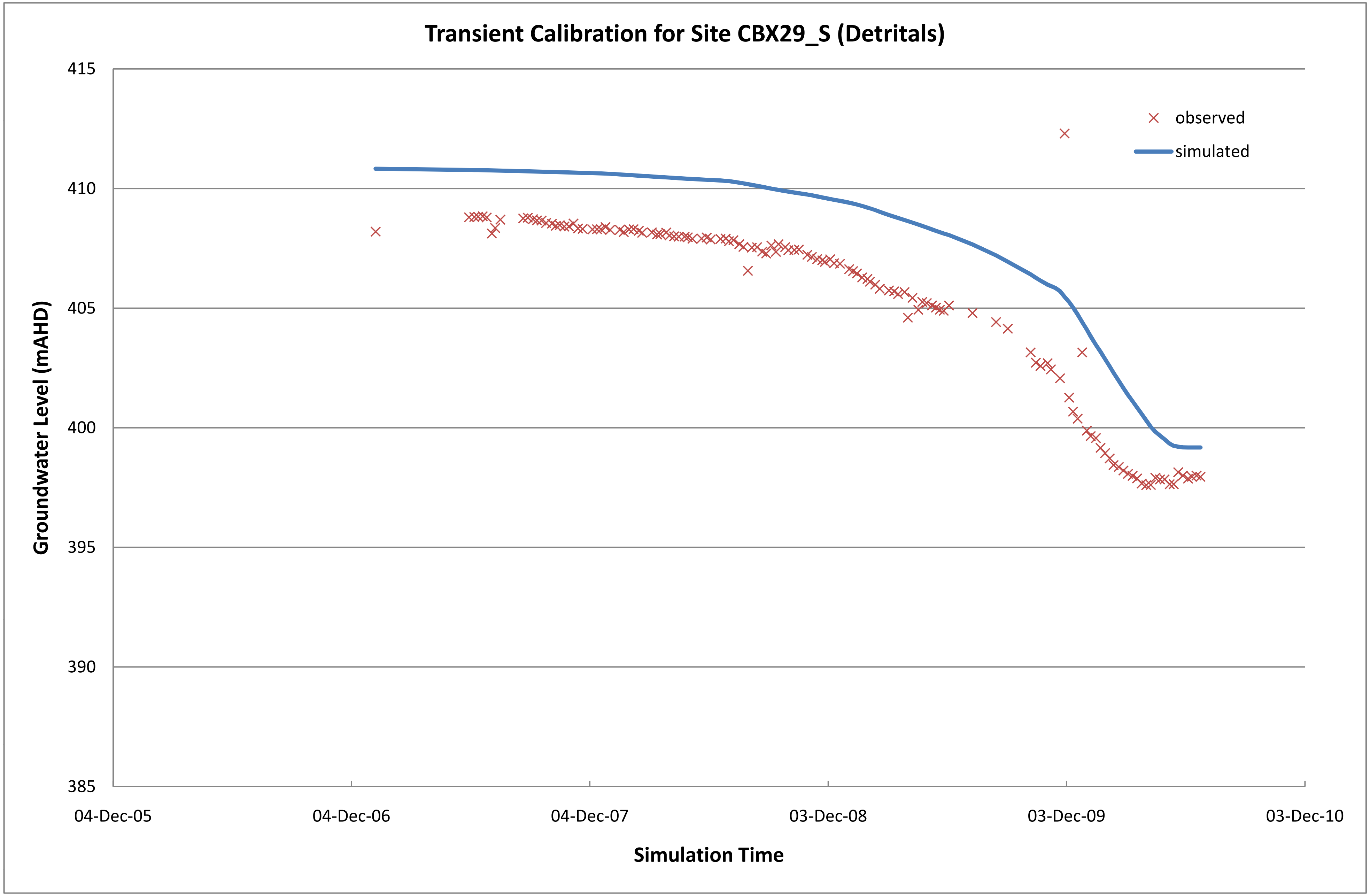
Transient Calibration for Site CBX09b_WT (Alluvium)
observed
simulated
Groundwater Level (mAHD)
419
417
415
413
411
409
407
405
04-Dec-05
04-Dec-06
04-Dec-07
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time



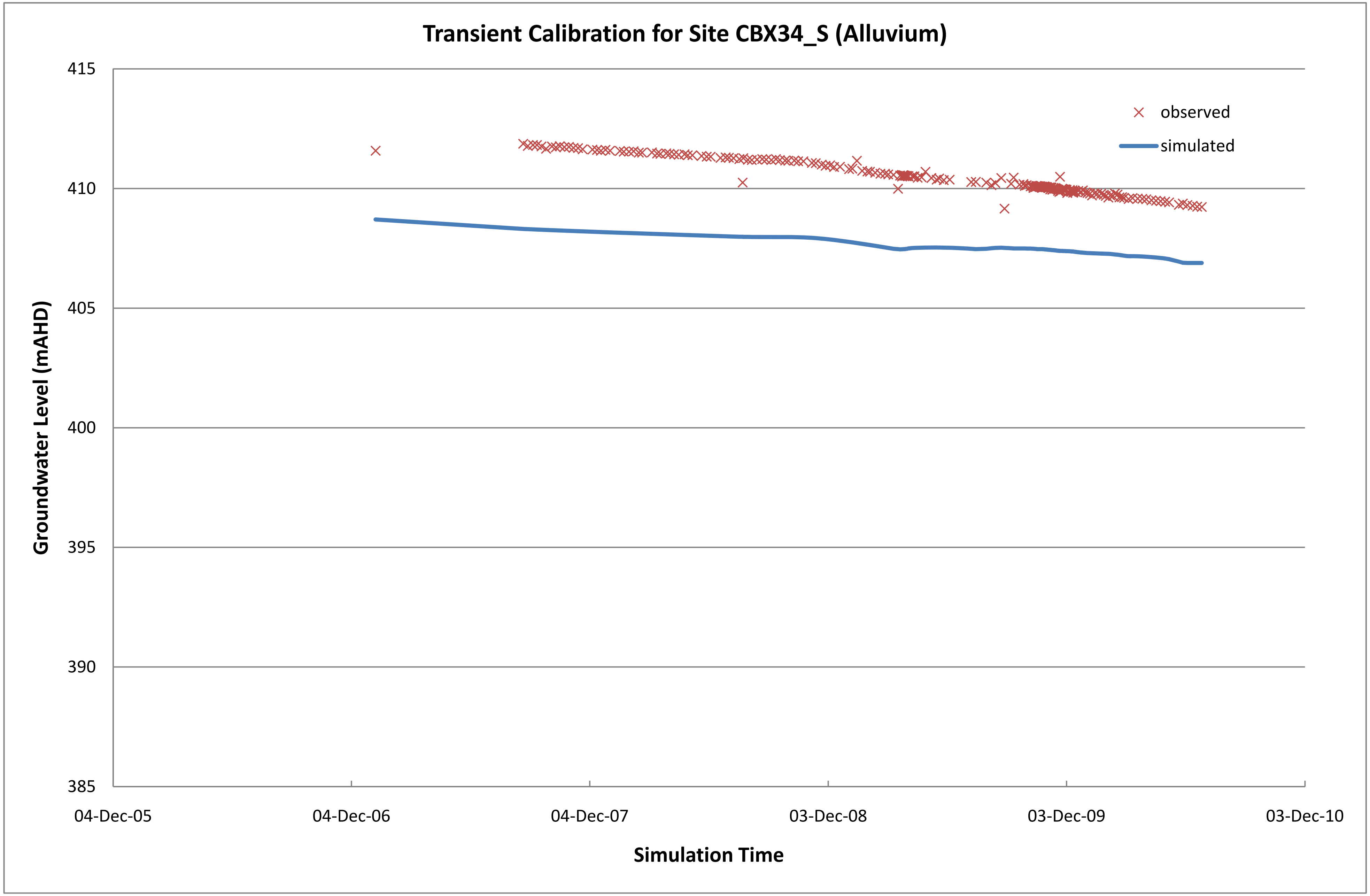
Transient Calibration for Site CBX15_S (Detritals)
415
410
405
400
395
390
385
Groundwater Level (mAHD)
observed
simulated
04-Dec-06
04-Dec-07
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time



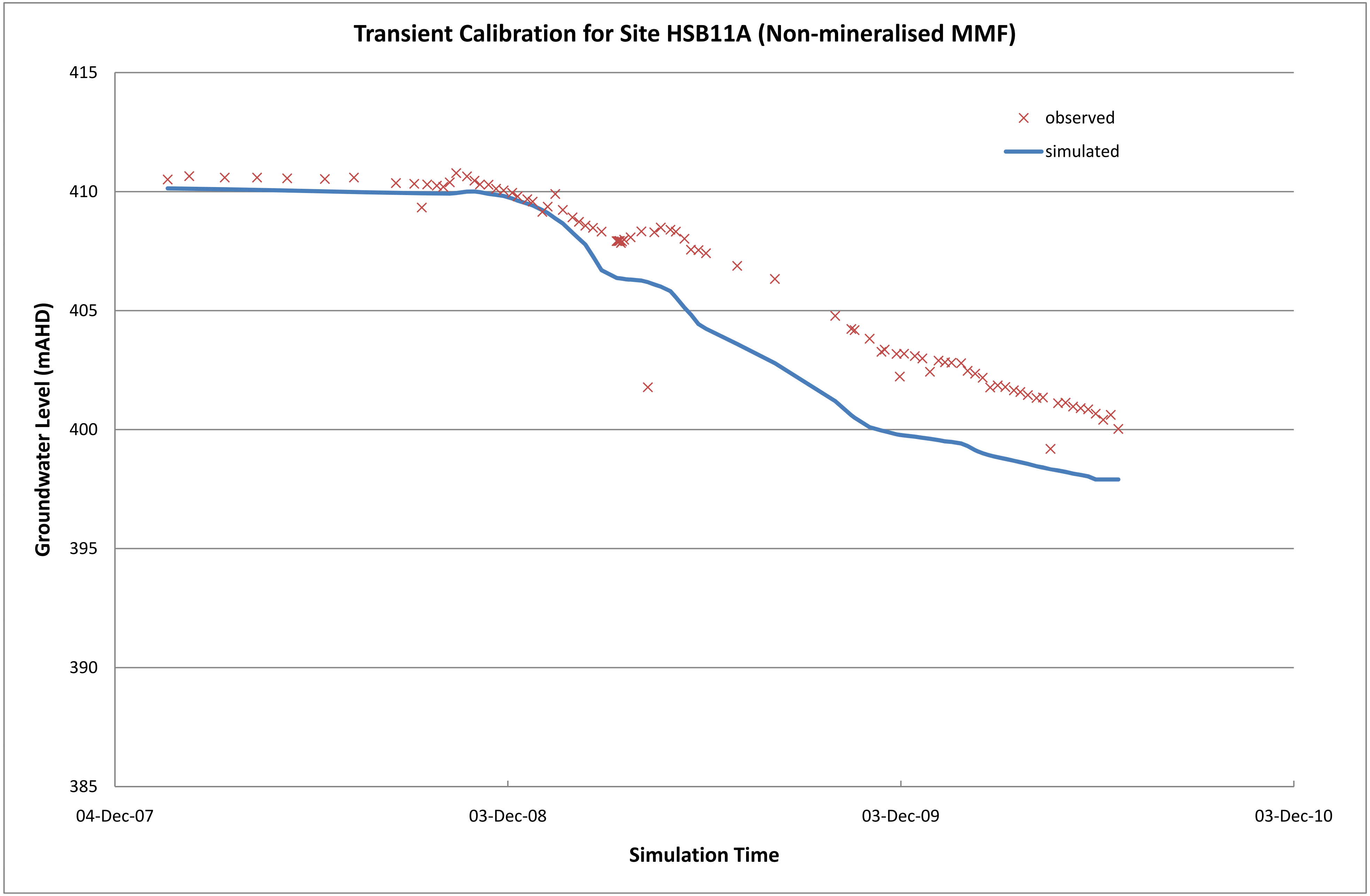
Transient Calibration for Site CBX19_S (Detritals)
observed
simulated
Groundwater Level (mAHD)
415
410
405
400
395
390
385
04-Dec-05
04-Dec-06
04-Dec-07
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time

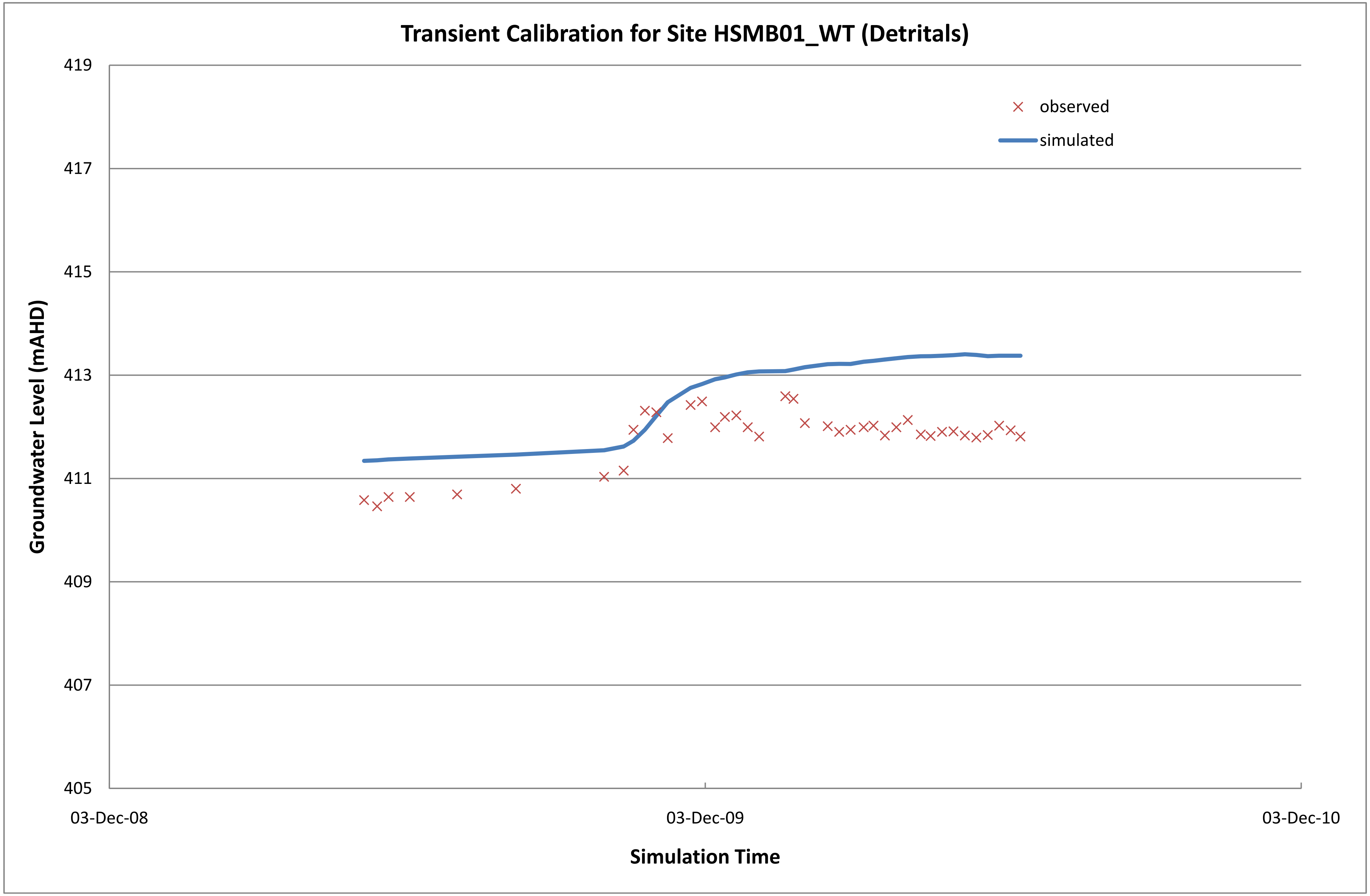


Transient Calibration for Site CBX29_S (Detritals)
observed
simulated
Groundwater Level (mAHD)
415
410
405
400
395
390
385
04-Dec-05
04-Dec-06
04-Dec-07
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time

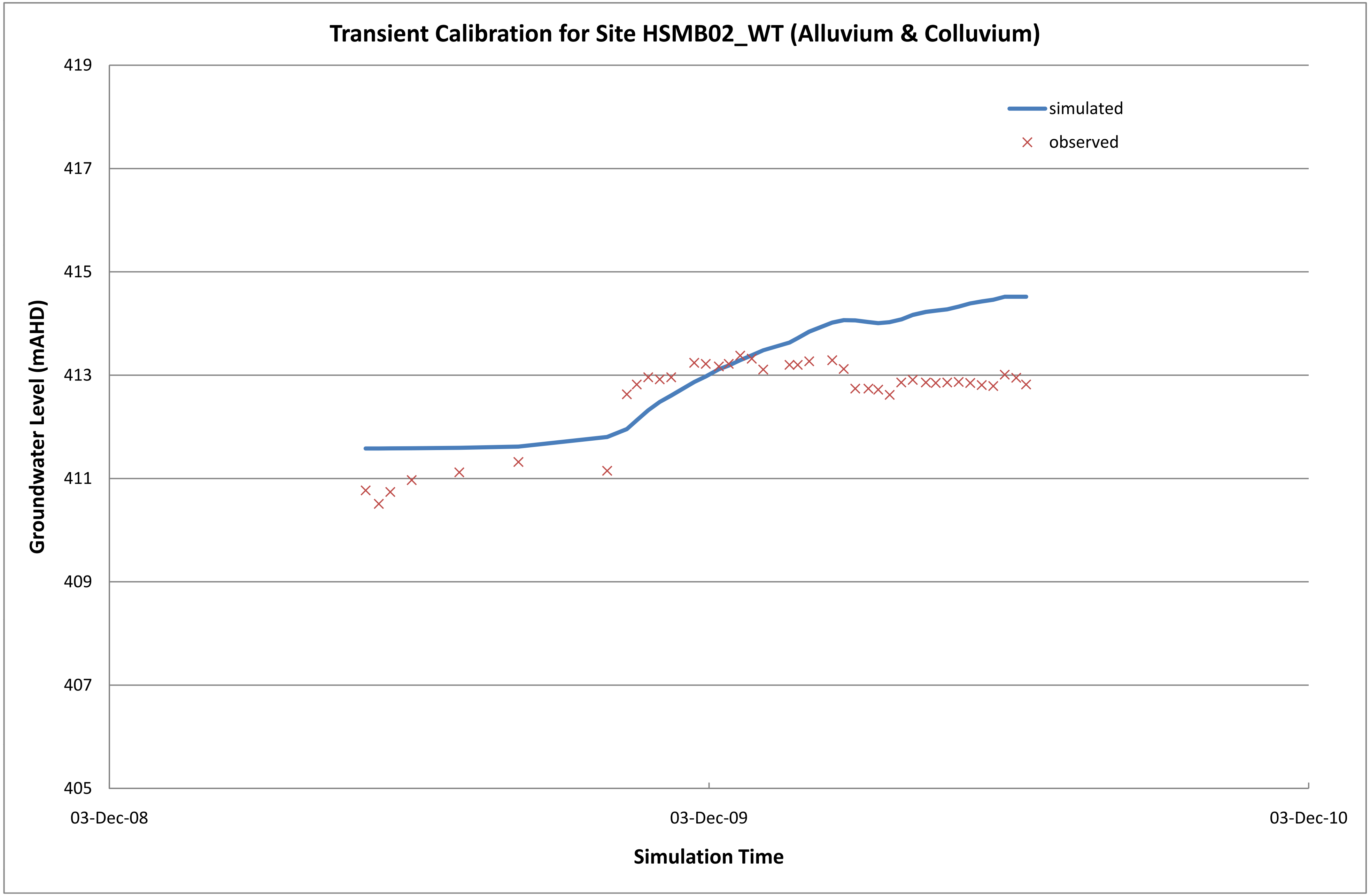


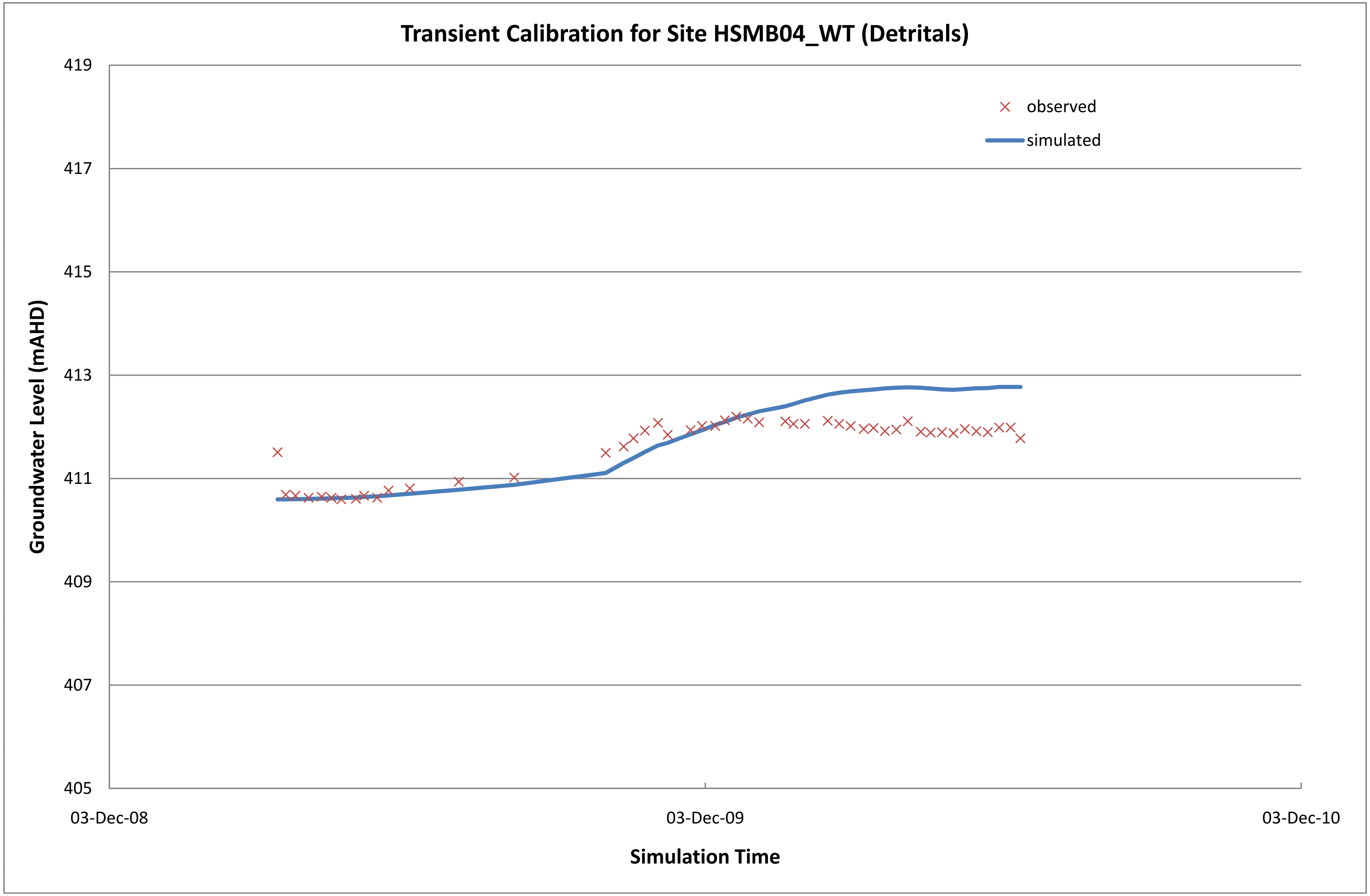
Transient Calibration for Site CBX34_S (Alluvium)
observed
simulated
Groundwater Level (mAHD)
415
410
405
400
395
390
385
04-Dec-05
04-Dec-06
04-Dec-07
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time


Transient Calibration for Site HSB11A (Non-mineralised MMF)
415
410
405
400
395
390
385
Groundwater Level (mAHD)
04-Dec-07
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time
observed
simulated

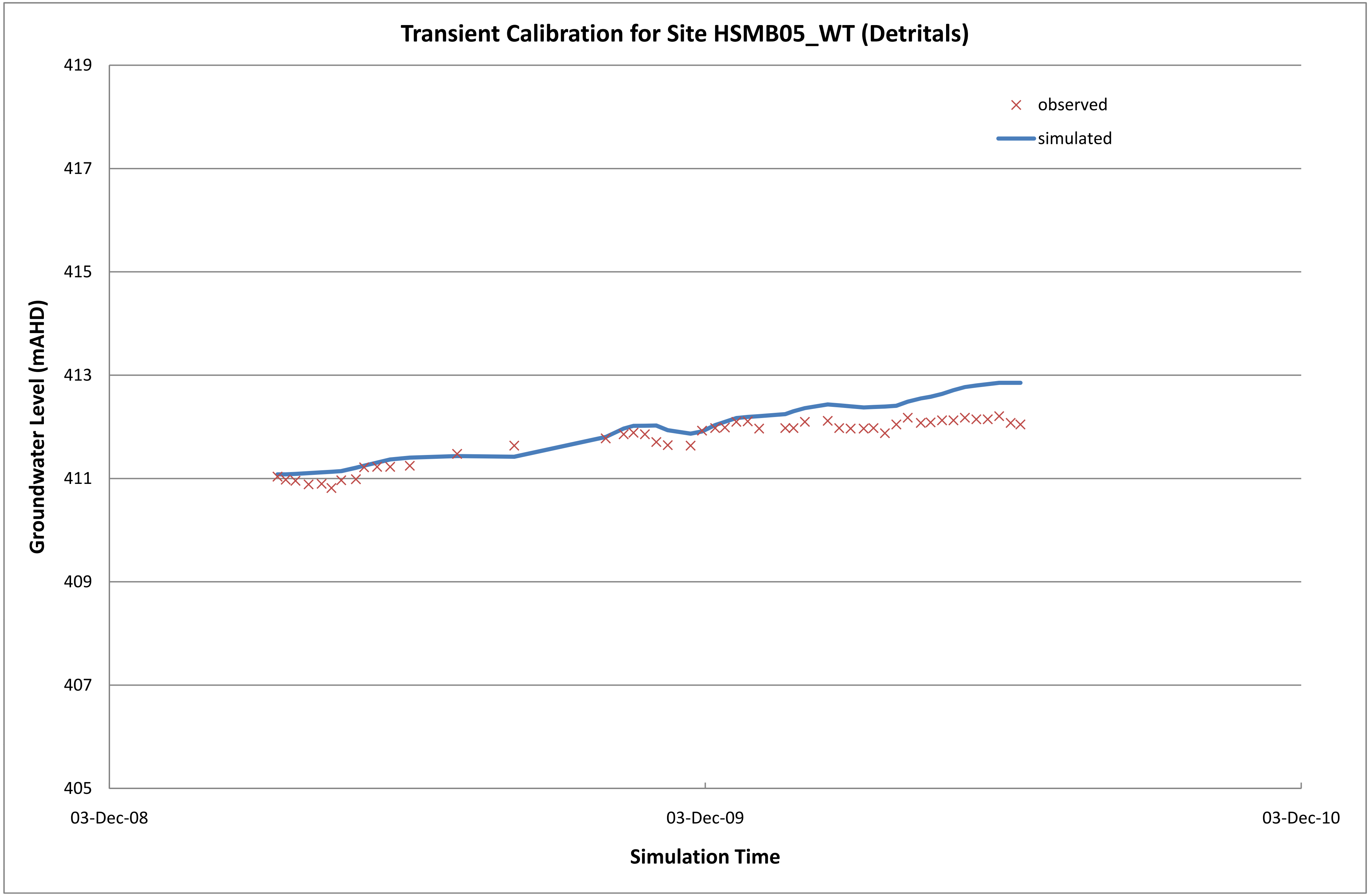


Transient Calibration for Site HSMB01_WT (Detritals)
419
417
415
413
411
409
407
405
Groundwater Level (mAHD)
observed
simulated
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time

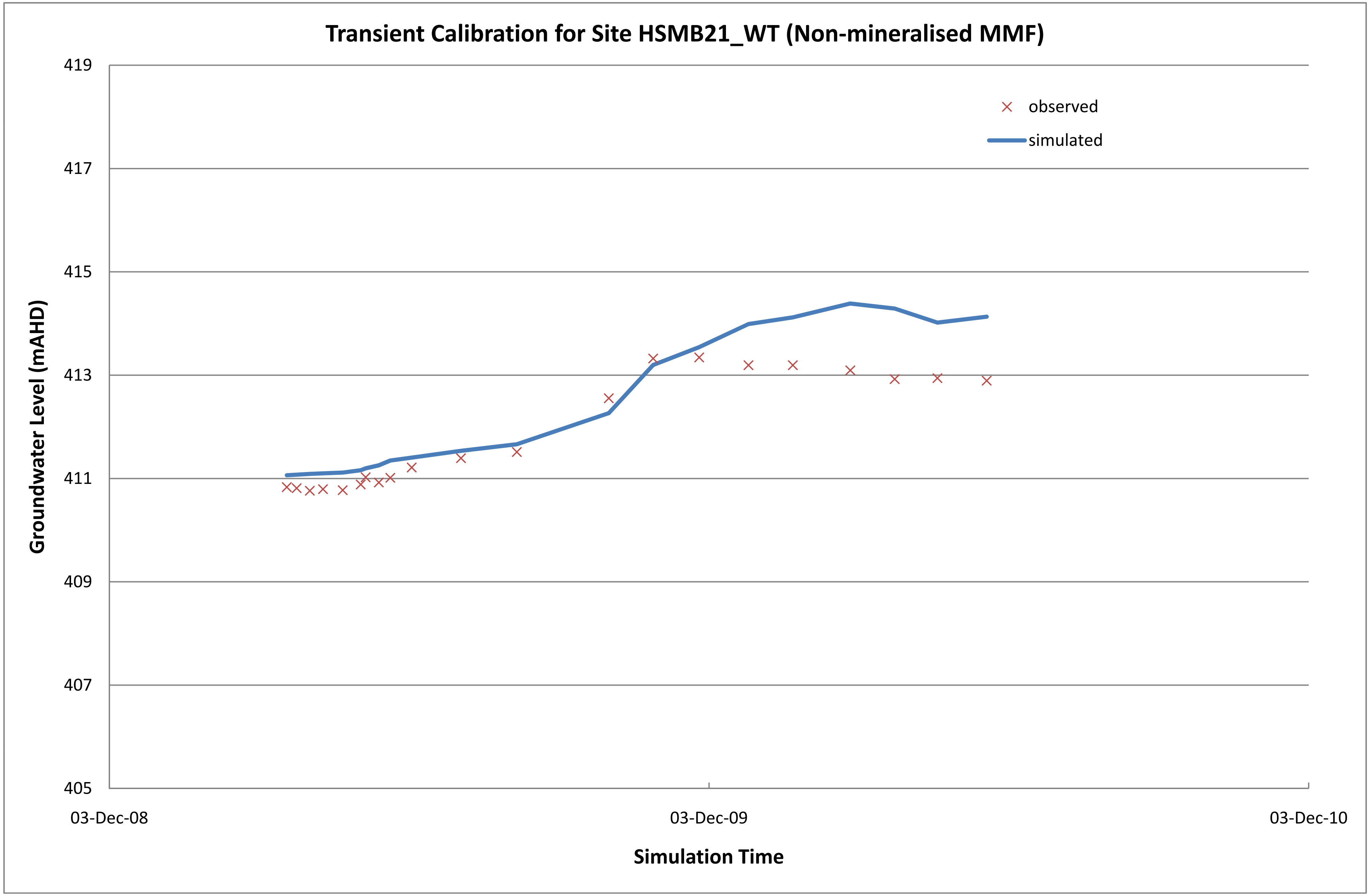

Transient Calibration for Site HSMB02_WT (Alluvium & Colluvium)
simulated
observed
Groundwater Level (mAHD)
419
417
415
413
411
409
407
405
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time



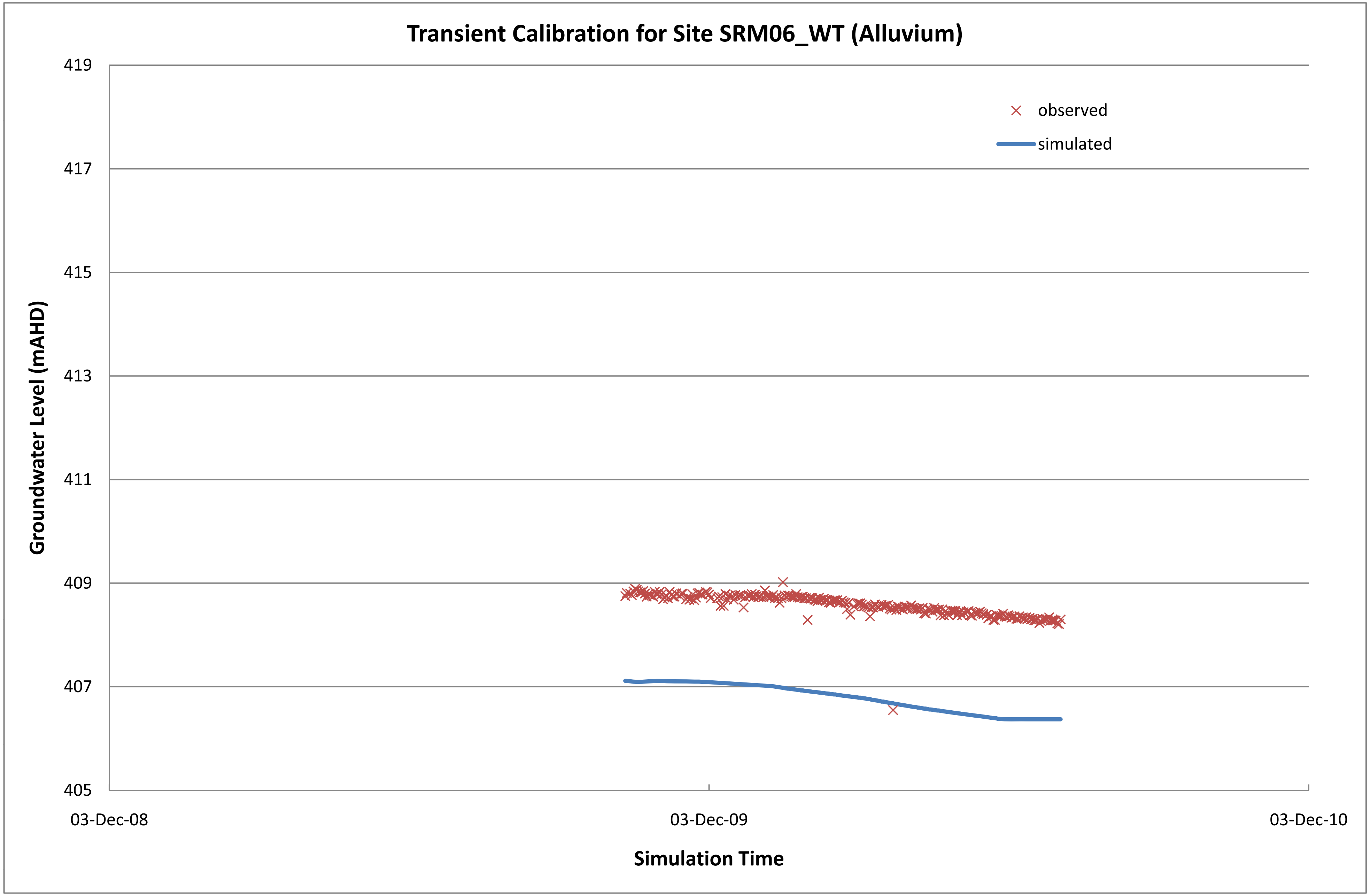
Transient Calibration for Site HSMB04_WT (Detritals)
observed
simulated
Groundwater Level (mAHD)
419
417
415
413
411
409
407
405
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time

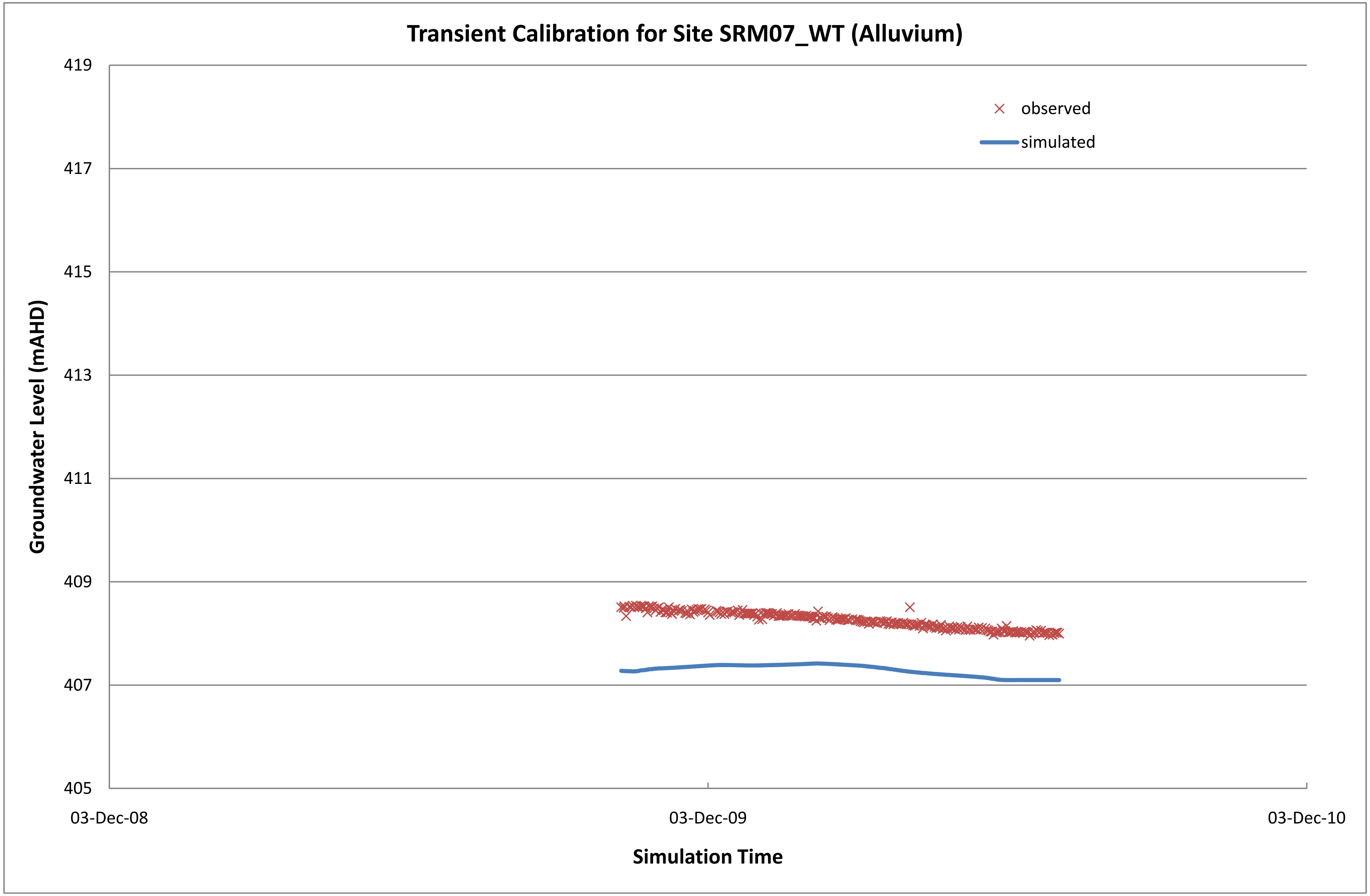


Transient Calibration for Site HSMB05_WT (Detritals)
observed
simulated
419
417
415
413
411
409
407
405
Groundwater Level (mAHD)
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time



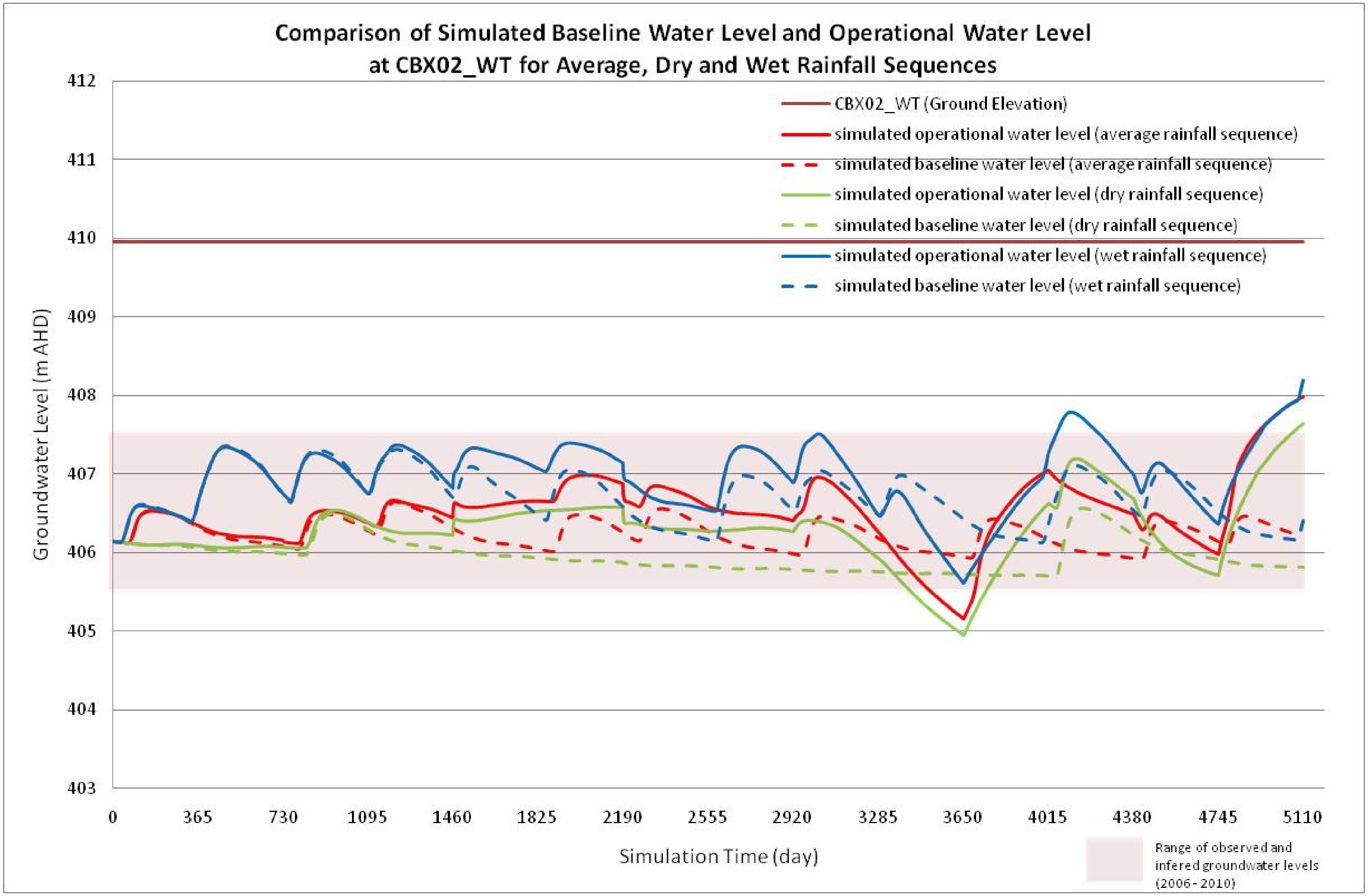
Transient Calibration for Site HSMB21_WT (Non-mineralised MMF)
observed
simulated
419
417
415
413
411
409
407
405
Groundwater Level (mAHD)
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time

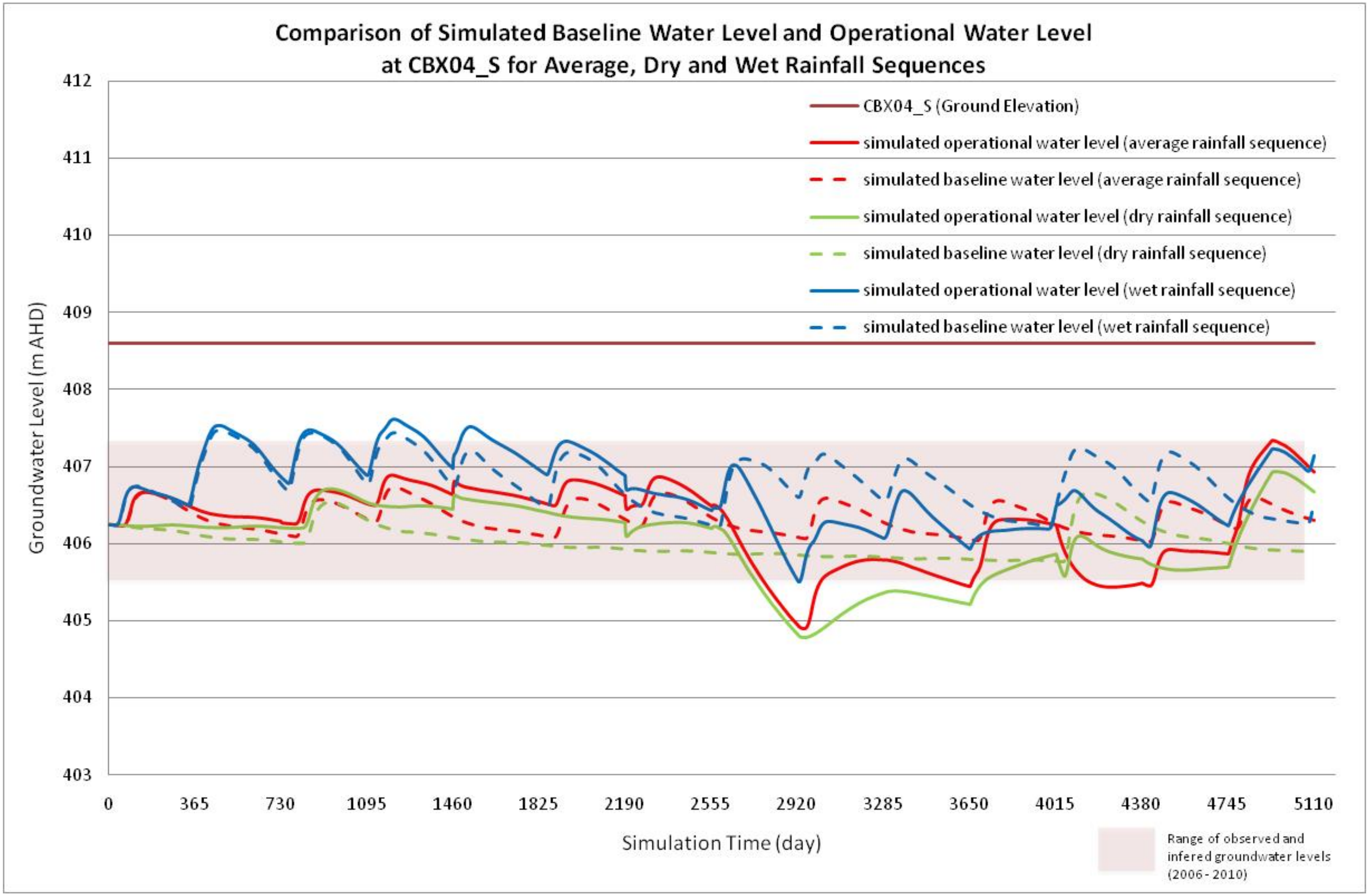

Transient Calibration for Site SRM06_WT (Alluvium)
observed
simulated
Groundwater Level (mAHD)
419
417
415
413
411
409
407
405
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time


Transient Calibration for Site SRM07_WT (Alluvium)
observed
simulated
Groundwater Level (mAHD)
419
417
415
413
411
409
407
405
03-Dec-08
03-Dec-09
03-Dec-10
Simulation Time

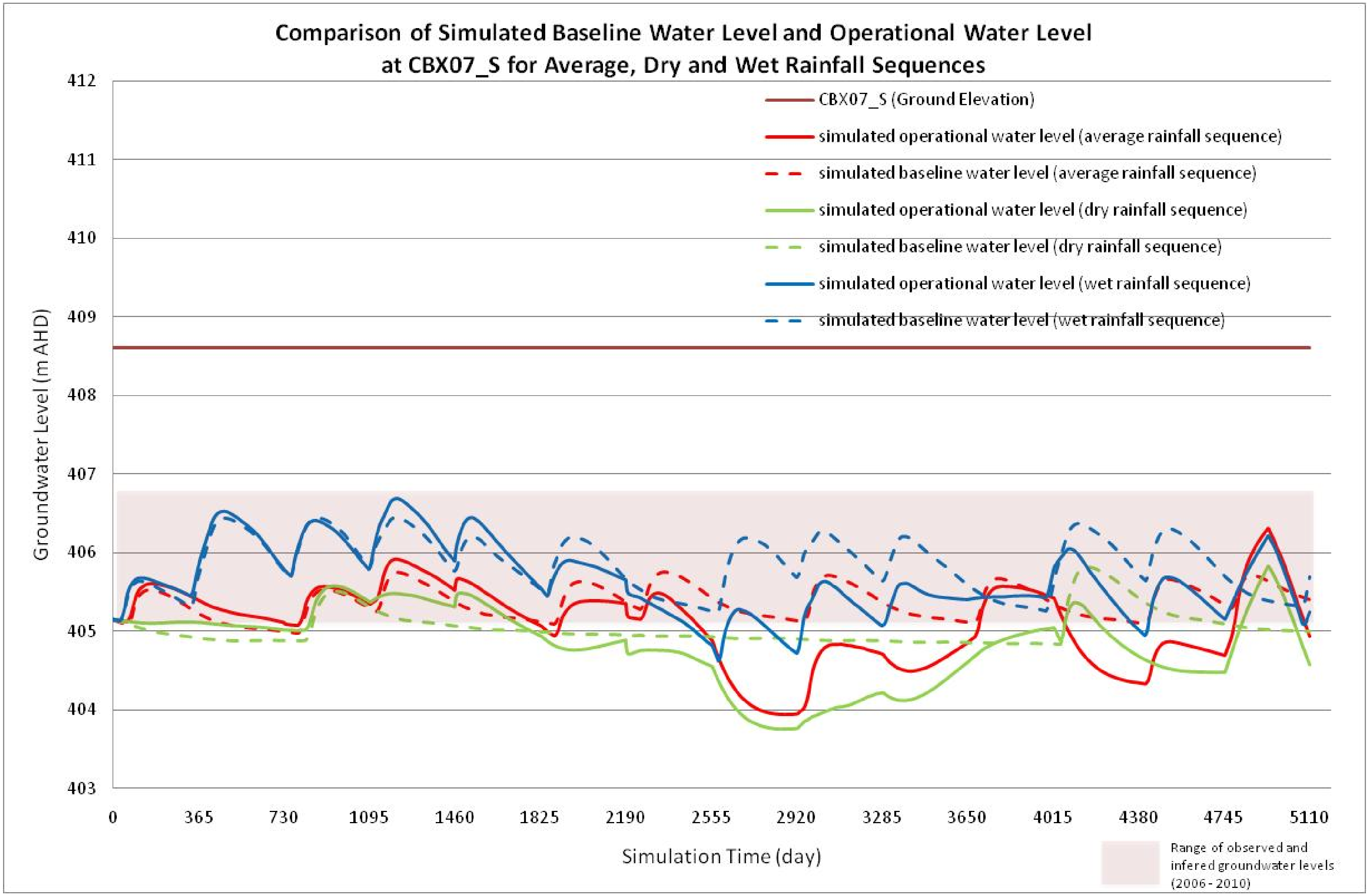
Appendix G.

Sensitivity and Uncertainty Results

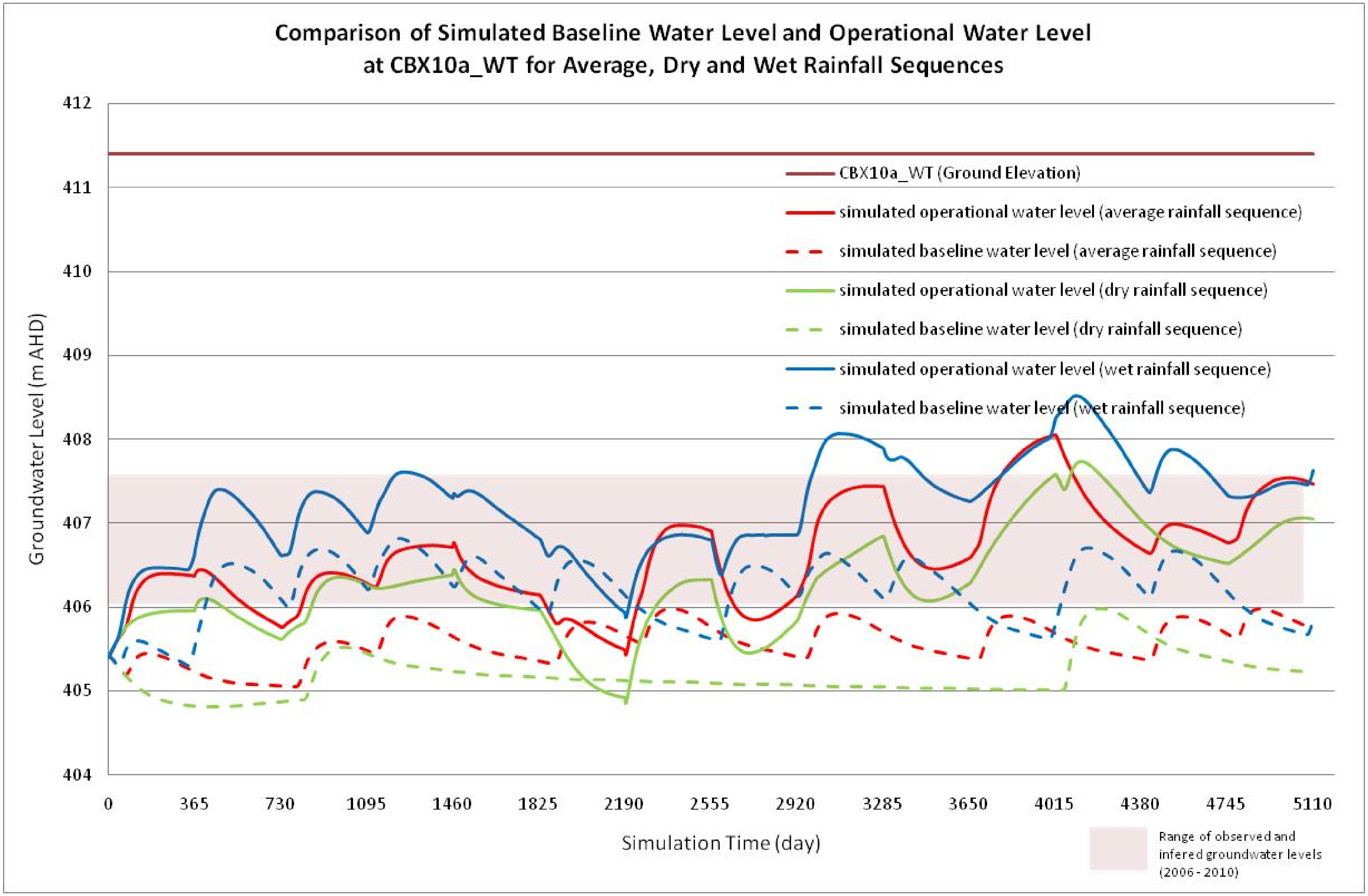

Comparison of Simulated Baseline Water Level and Operational Water Level
at CBX02_WT for Average, Dry and Wet Rainfall Sequences
Groundwater Level (m AHD)
412
411
410
409
408
407
406
405
404
403
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
CBX02_WT (Ground Elevation)
simulated operational water level (average rainfall sequence)
simulated baseline water level (average rainfall sequence)
simulated operational water level (dry rainfall sequence)
simulated baseline water level (dry rainfall sequence)
simulated operational water level (wet rainfall sequence)
simulated baseline water level (wet rainfall sequence)
Range of observed and infered groundwater levels (2006 - 2010)



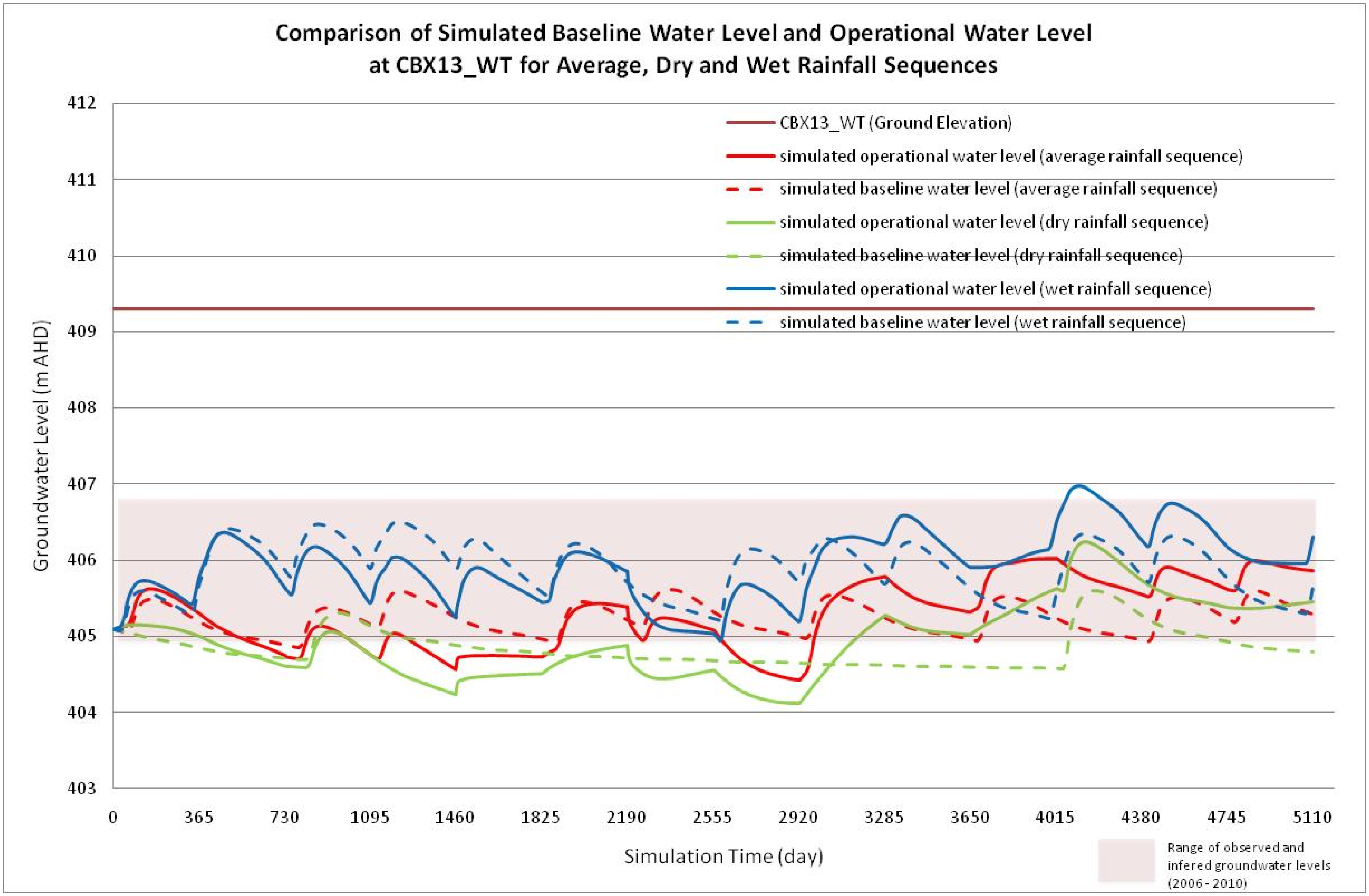
Comparison of Simulated Baseline Water Level and Operational Water Level
at CBX04_S for Average, Dry and Wet Rainfall Sequences
CBX04_S (Ground Elevation)
simulated operational water level (average rainfall sequence)
simulated baseline water level (average rainfall sequence)
simulated operational water level (dry rainfall sequence)
simulated baseline water level (dry rainfall sequence)
simulated operational water level (wet rainfall sequence)
simulated baseline water level (wet rainfall sequence)
Groundwater Level (m AHD)
412
411
410
409
408
407
406
405
404
403
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Range of observed and infered groundwater levels (2006 - 2010)

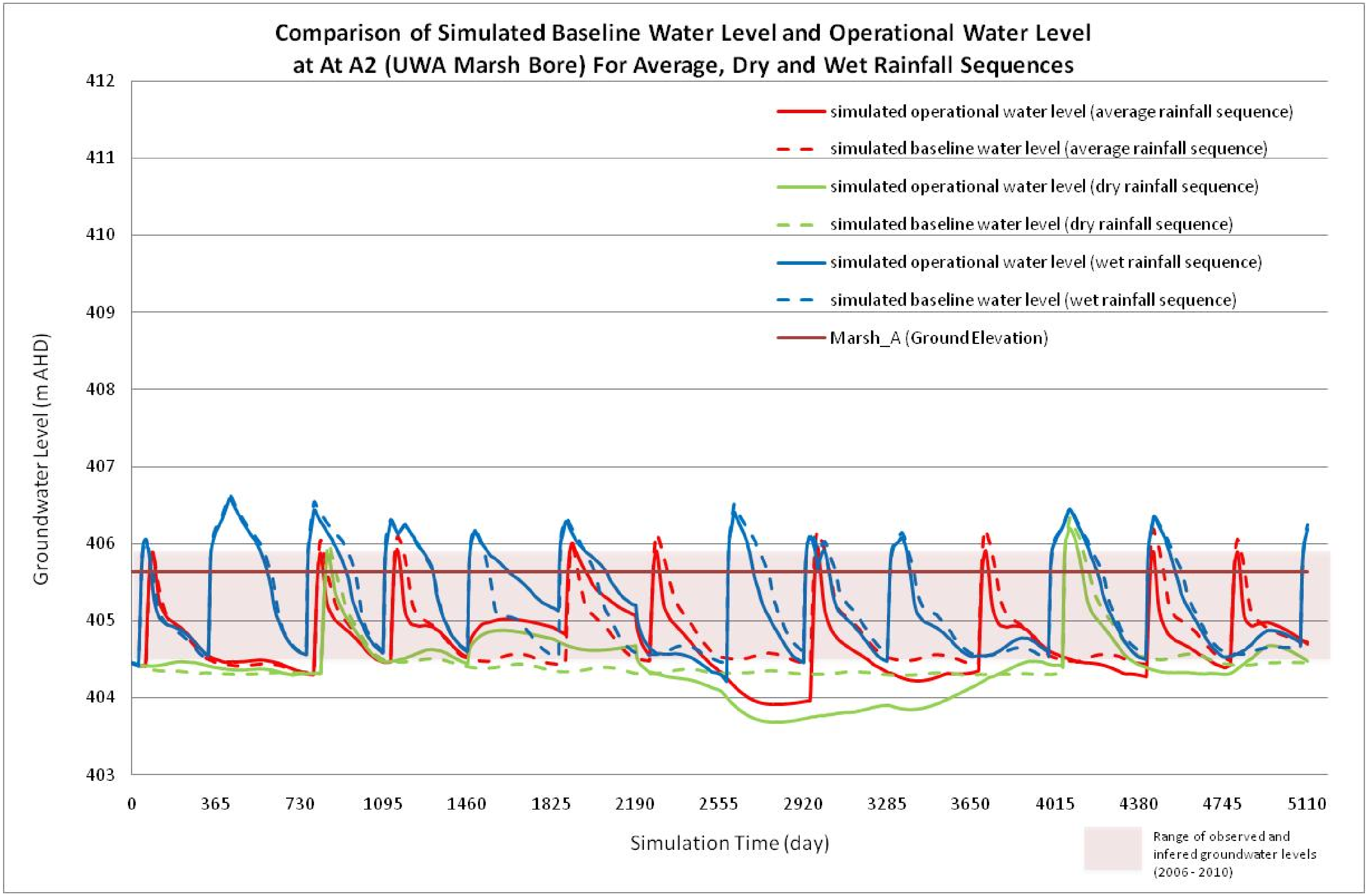


Comparison of Simulated Baseline Water Level and Operational Water Level
at CBX07_S for Average, Dry and Wet Rainfall Sequences
CBX07_S (Ground Elevation)
simulated operational water level (average rainfall sequence)
simulated baseline water level (average rainfall sequence)
simulated operational water level (dry rainfall sequence)
simulated baseline water level (dry rainfall sequence)
simulated operational water level (wet rainfall sequence)
simulated baseline water level (wet rainfall sequence)
Groundwater Level (m AHD)
412
411
410
409
408
407
406
405
404
403
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Range of observed and
infered groundwater levels
(2006 - 2010)

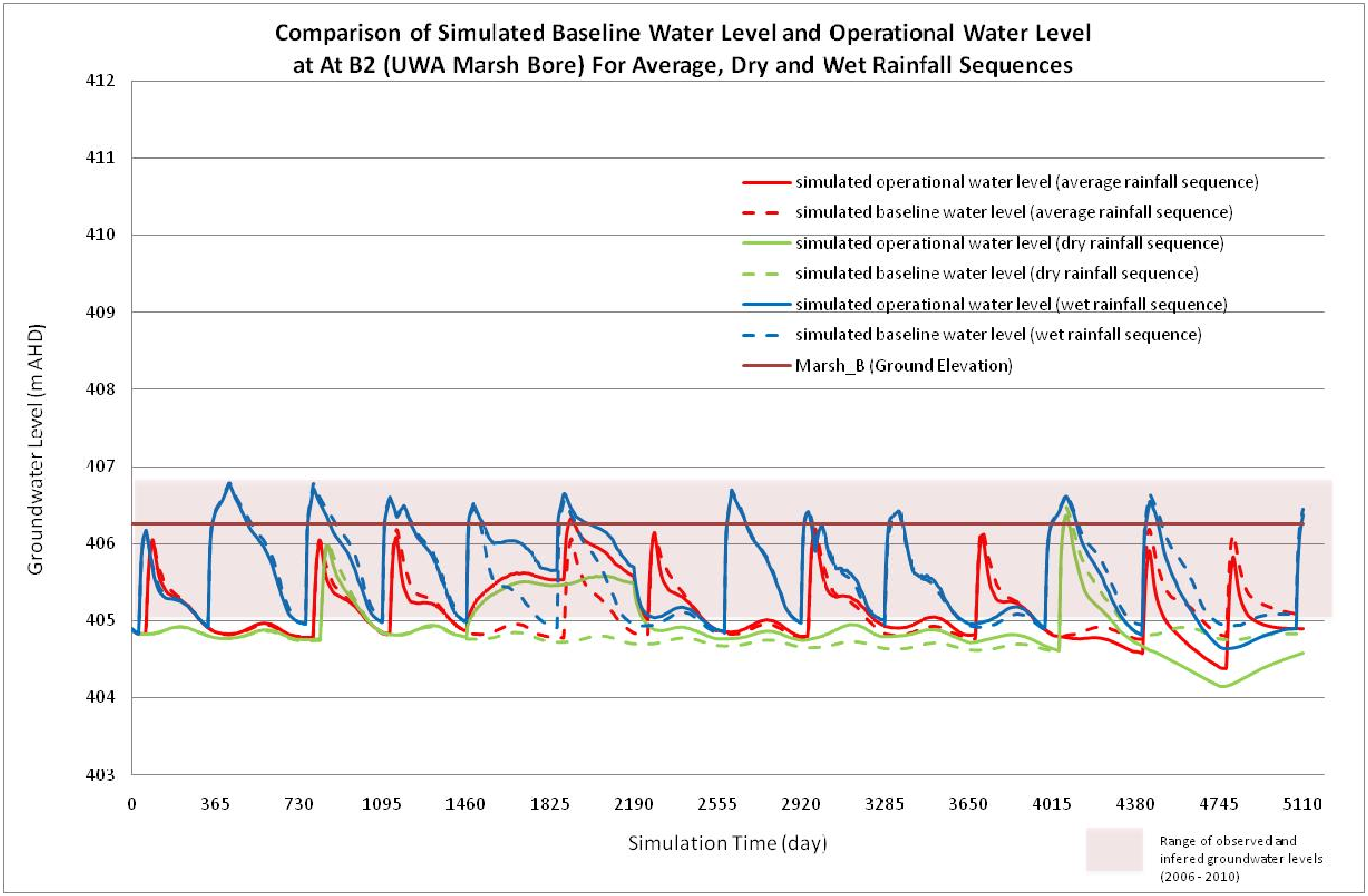


Comparison of Simulated Baseline Water Level and Operational Water Level
at CBX10a_WT for Average, Dry and Wet Rainfall Sequences
Groundwater Level (m AHD)
412
411
410
409
408
407
406
405
404
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
CBX10a_WT (Ground Elevation)
simulated operational water level (average rainfall sequence)
simulated baseline water level (average rainfall sequence)
simulated operational water level (dry rainfall sequence)
simulated baseline water level (dry rainfall sequence)
simulated operational water level (wet rainfall sequence)
simulated baseline water level (wet rainfall sequence)
Range of observed and infered groundwater levels (2006 - 2010)

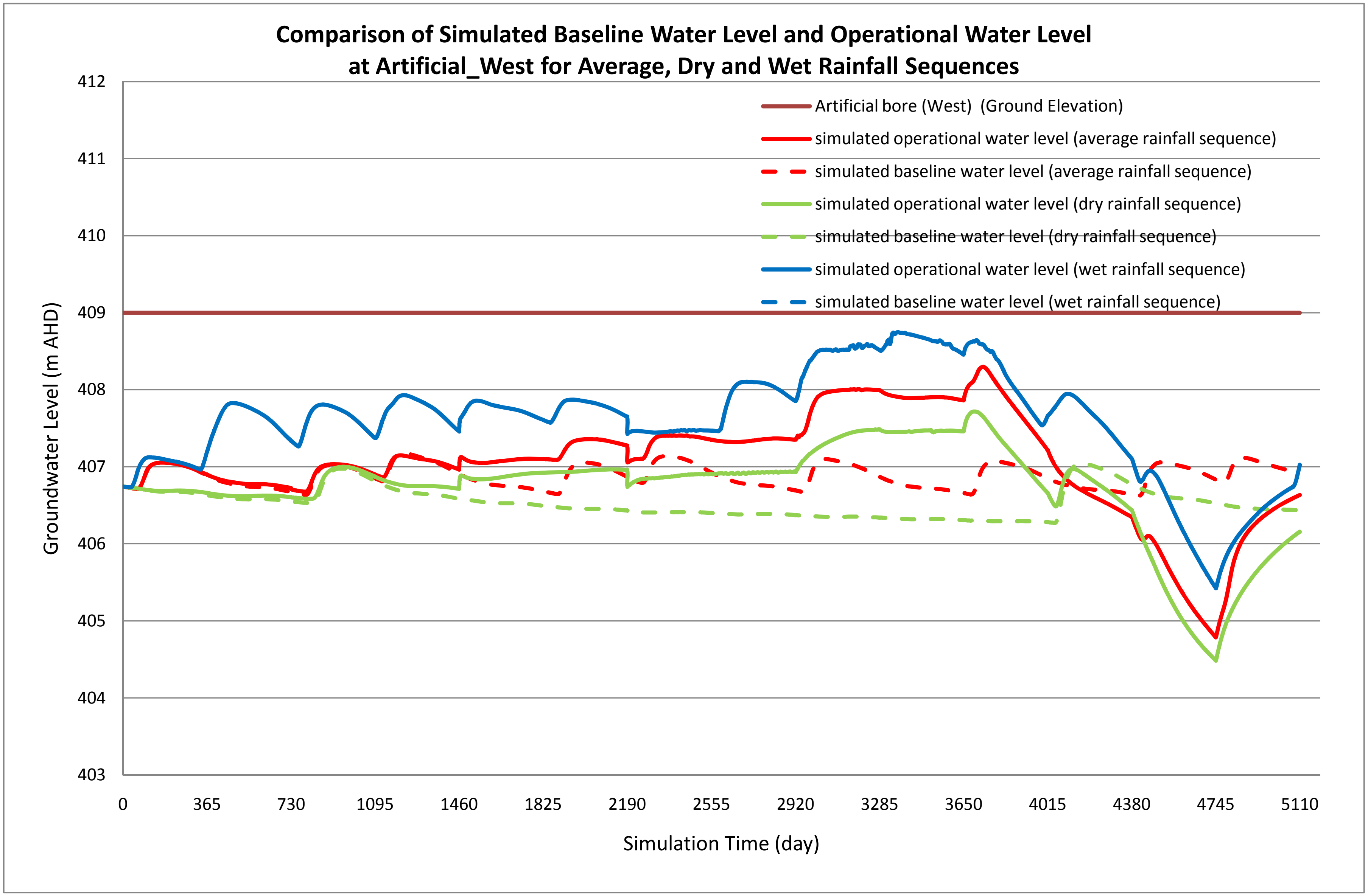

Comparison of Simulated Baseline Water Level and Operational Water Level
at CBX13_WT for Average, Dry and Wet Rainfall Sequences
CBX13_WT (Ground Elevation)
simulated operational water level (average rainfall sequence)
simulated baseline water level (average rainfall sequence)
simulated operational water level (dry rainfall sequence)
simulated baseline water level (dry rainfall sequence)
simulated operational water level (wet rainfall sequence)
simulated baseline water level (wet rainfall sequence)
Groundwater Level (m AHD)
412
411
410
409
408
407
406
405
404
403
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Range of observed and infered groundwater levels (2006 - 2010)



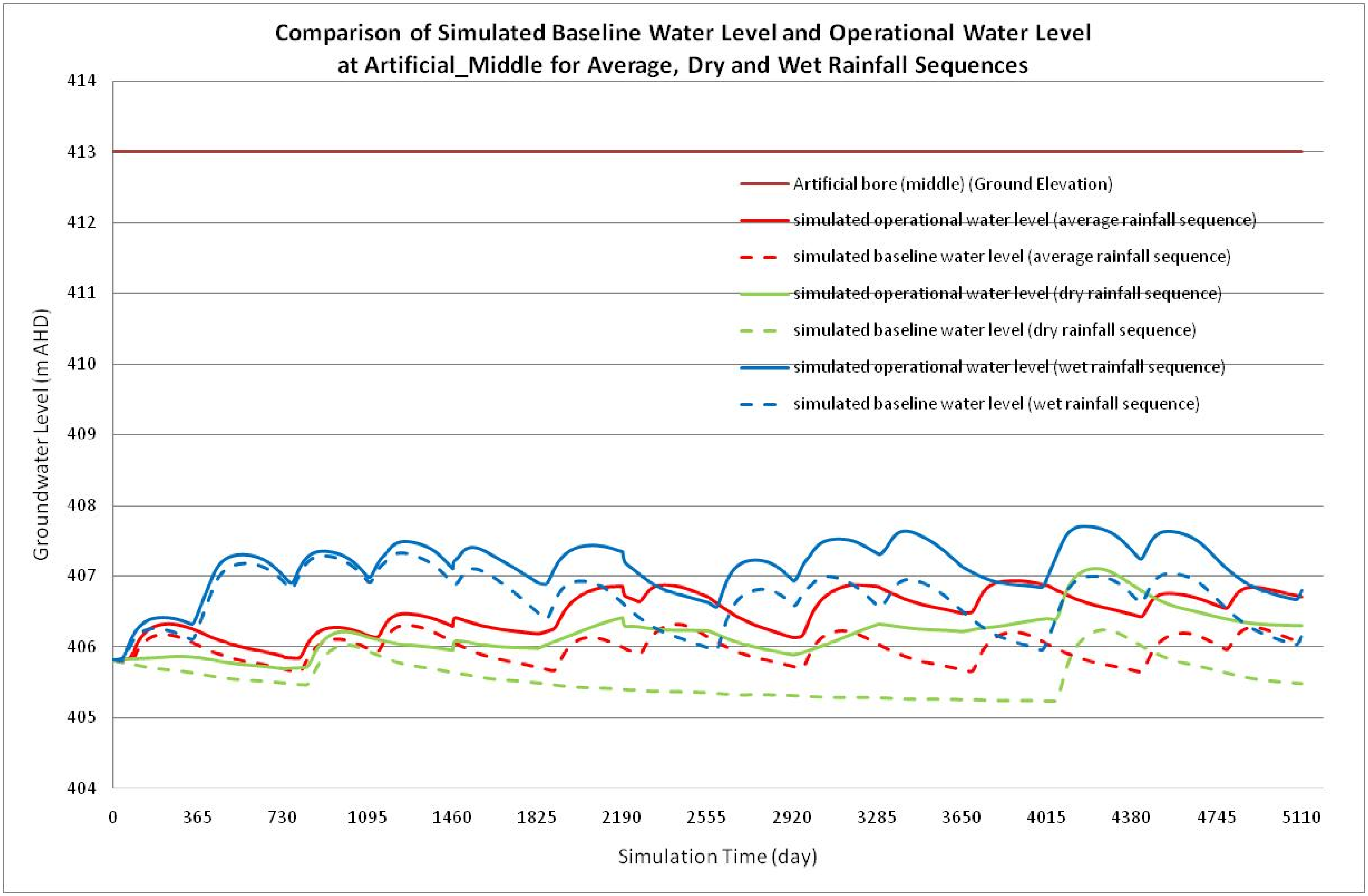
Comparison of Simulated Baseline Water Level and Operational Water Level
at At A2 (UWA Marsh Bore) For Average, Dry and Wet Rainfall Sequences
simulated operational water level (average rainfall sequence)
simulated baseline water level (average rainfall sequence)
simulated operational water level (dry rainfall sequence)
simulated baseline water level (dry rainfall sequence)
simulated operational water level (wet rainfall sequence)
simulated baseline water level (wet rainfall sequence)
Marsh_A (Ground Elevation)
Groundwater Level (m AHD)
412
411
410
409
408
407
406
405
404
403
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Range of observed and infered groundwater levels (2006 - 2010)



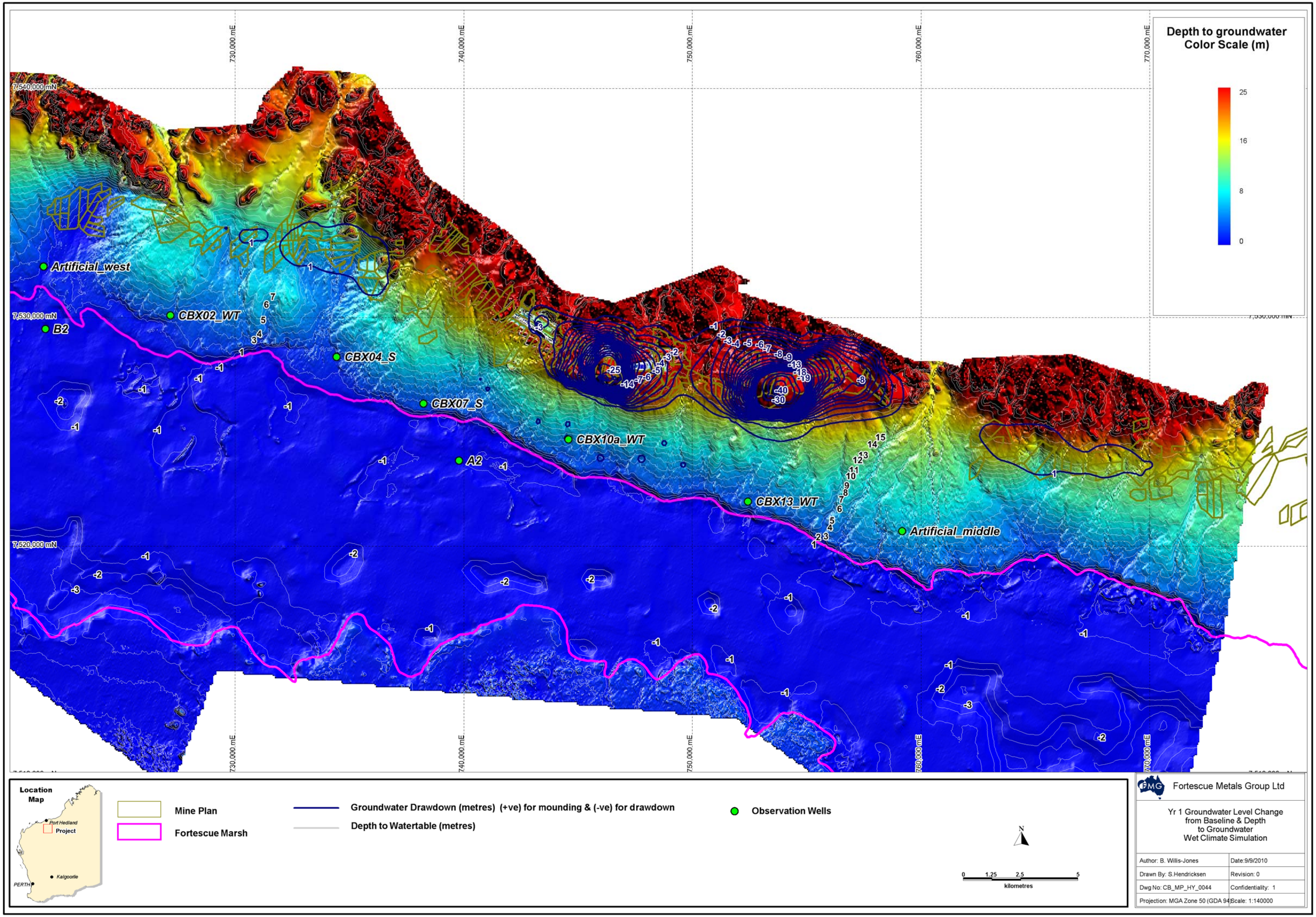
Comparison of Simulated Baseline Water Level and Operational Water Level
at At B2 (UWA Marsh Bore) For Average, Dry and Wet Rainfall Sequences
412
411
410
409
408
407
406
405
404
403
Groundwater Level (m AHD)
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
simulated operational water level (average rainfall sequence)
simulated baseline water level (average rainfall sequence)
simulated operational water level (dry rainfall sequence)
simulated baseline water level (dry rainfall sequence)
simulated operational water level (wet rainfall sequence)
simulated baseline water level (wet rainfall sequence)
Marsh_B (Ground Elevation)
Range of observed and infered groundwater levels (2006 - 2010)



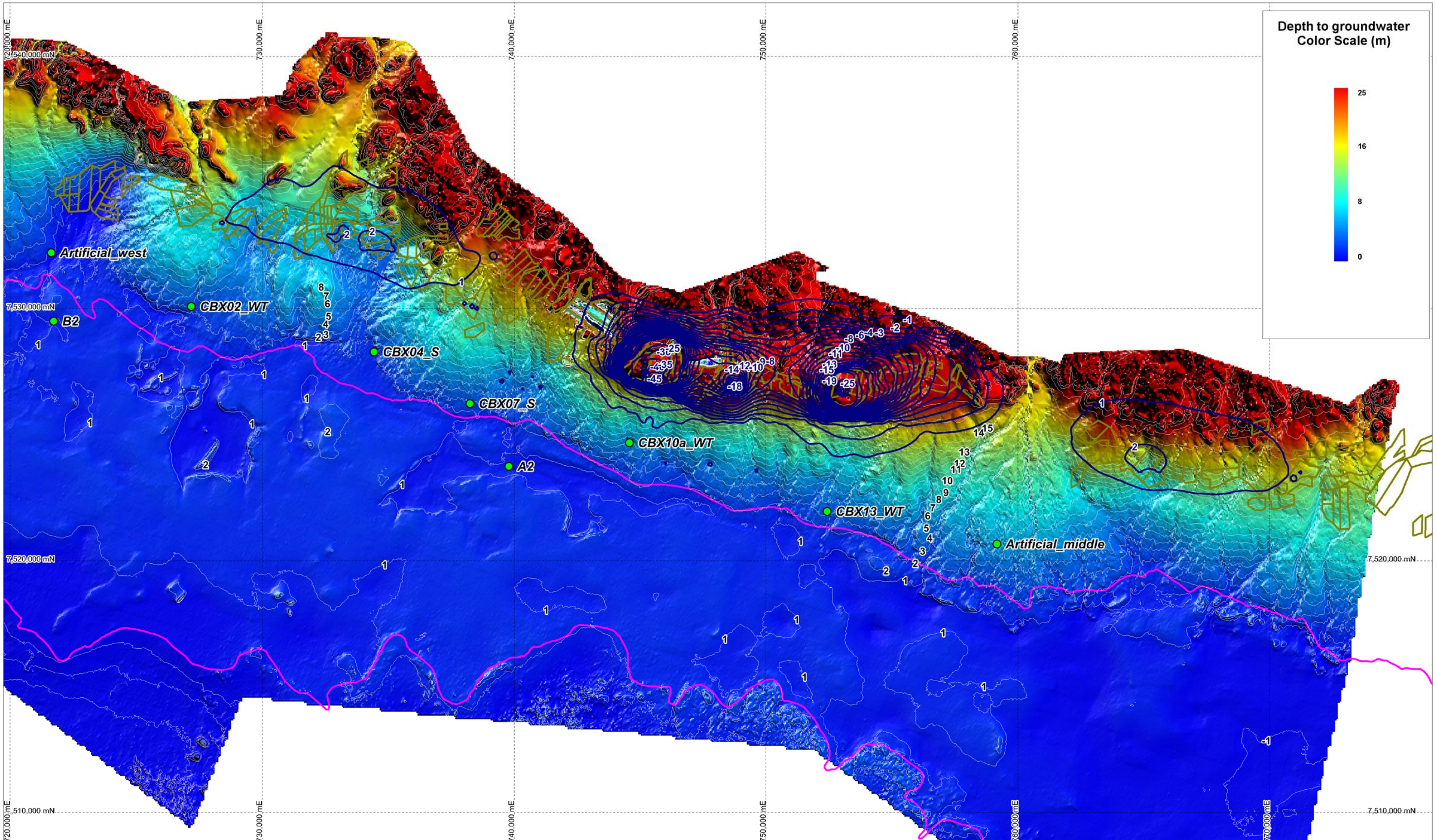
Comparison of Simulated Baseline Water Level and Operational Water Level
at Artificial_West for Average, Dry and Wet Rainfall Sequences
Artificial bore (West) (Ground Elevation)
simulated operational water level (average rainfall sequence)
simulated baseline water level (average rainfall sequence)
simulated operational water level (dry rainfall sequence)
simulated baseline water level (dry rainfall sequence)
simulated operational water level (wet rainfall sequence)
simulated baseline water level (wet rainfall sequence)
Groundwater Level (m AHD)
412
411
410
409
408
407
406
405
404
403
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)



Comparison of Simulated Baseline Water Level and Operational Water Level
at Artificial_Middle for Average, Dry and Wet Rainfall Sequences
Groundwater Level (m AHD)
414
413
412
411
410
409
408
407
406
405
404
Artificial bore (middle) (Ground Elevation)
simulated operational water level (average rainfall sequence)
simulated baseline water level (average rainfall sequence)
simulated operational water level (dry rainfall sequence)
simulated baseline water level (dry rainfall sequence)
simulated operational water level (wet rainfall sequence)
simulated baseline water level (wet rainfall sequence)
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)



Depth to groundwater Color Scale (m)
25
16
8
0
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Artificial_west
CBX02_WT
B2
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 1 Groundwater Level Change from Baseline & Depth to Groundwater Wet Climate Simulation
Author: B. Willis-Jones
Date: 9/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000



Location Map

Port Hedland
Project
Kalgoorlie
PERTH

Mine Plan

Fortescue Marsh

Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown

Depth to Watertable (metres)

Observation Wells

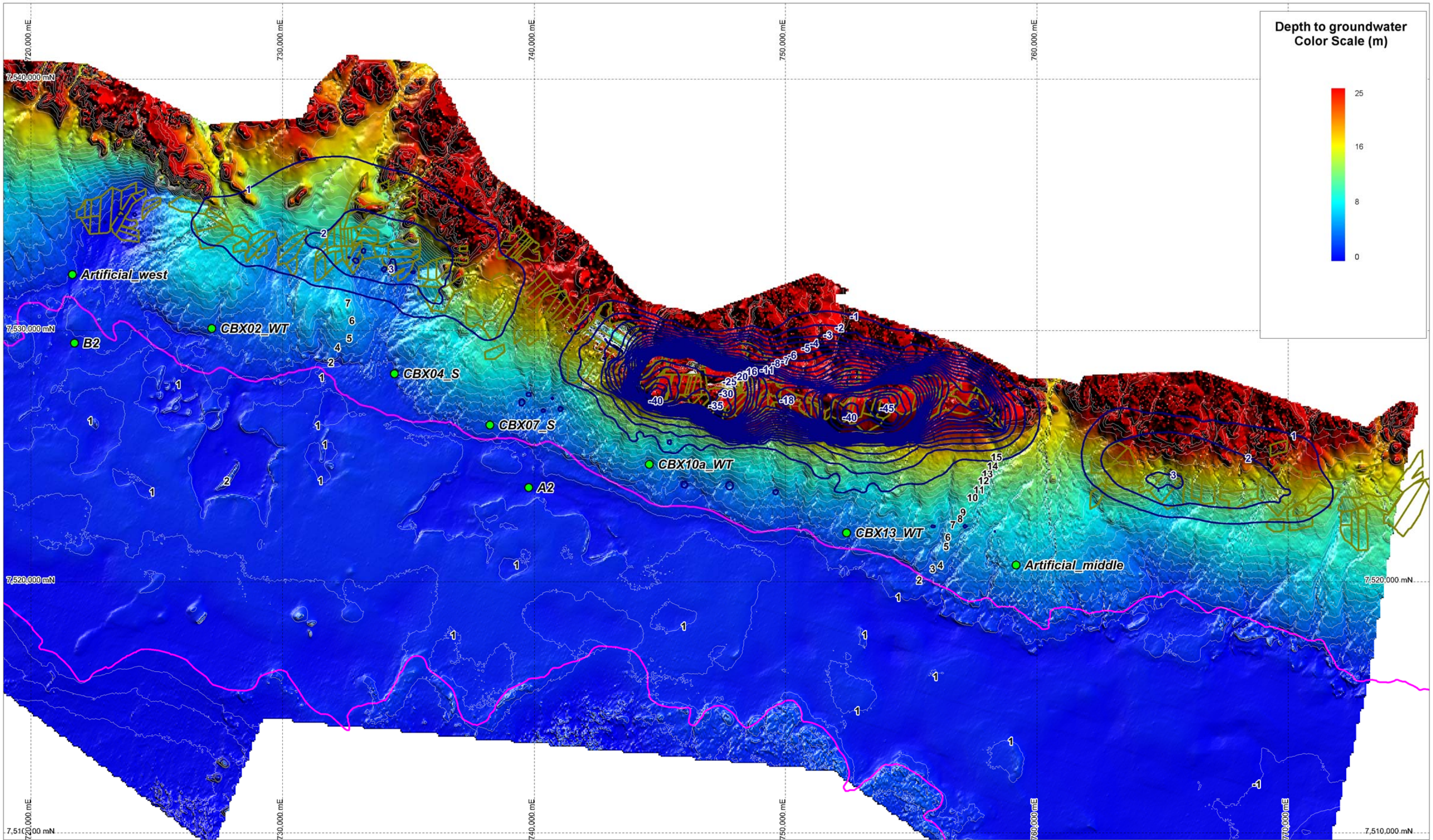
N

0 1.25 2.5 5
kilometres

Fortescue Metals Group Ltd

Yr 2 Groundwater Level Change from Baseline & Depth to Groundwater WET Climate Simulation

Author: B. Willis-Jones	Date:29/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000



Location Map

Port Hedland

Project

Kalgoorlie

PERTH

Mine Plan

Fortescue Marsh

Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown

Depth to Watertable (metres)

Observation Wells

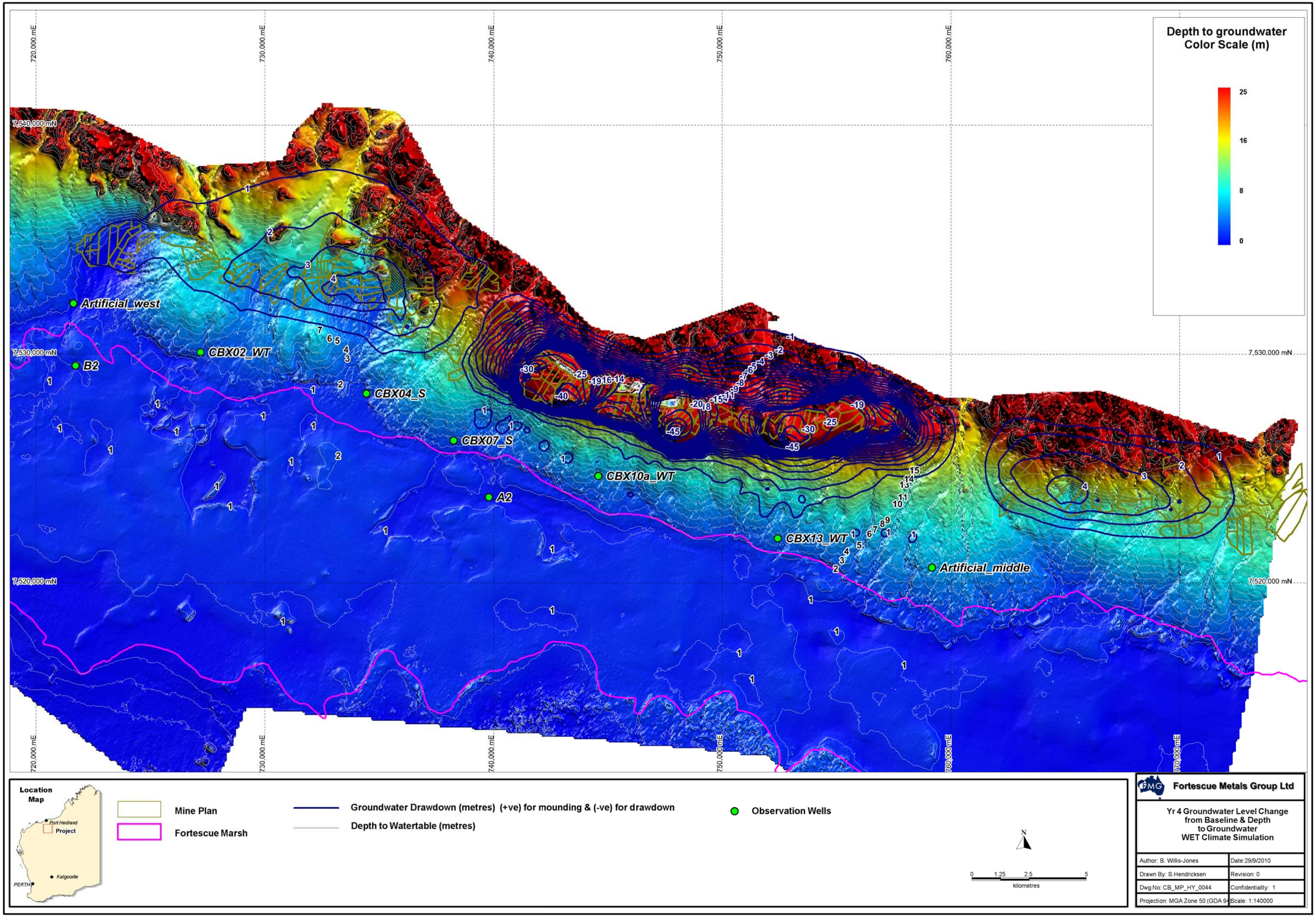
0 1.25 2.5 5

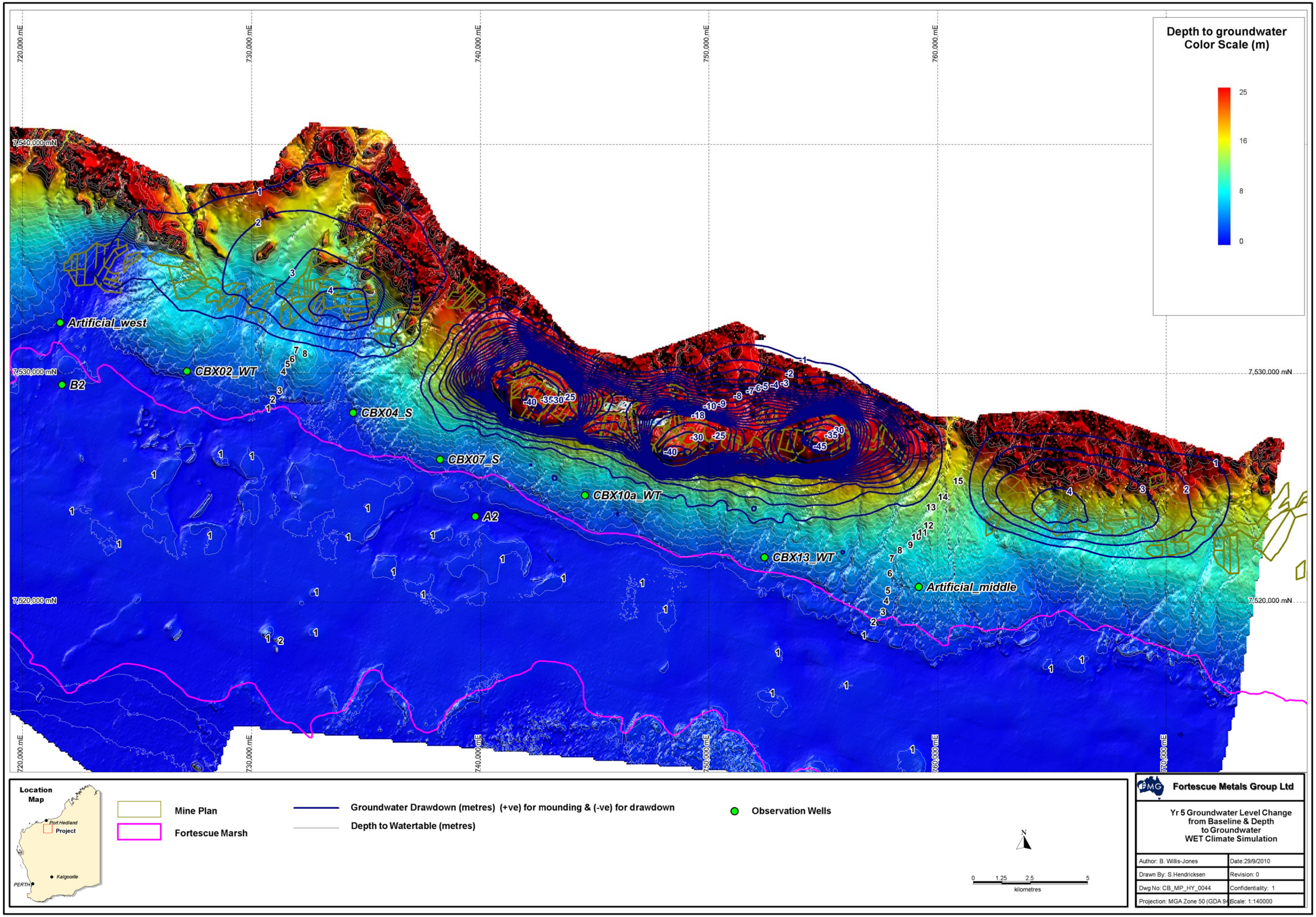
kilometres

Fortescue Metals Group Ltd

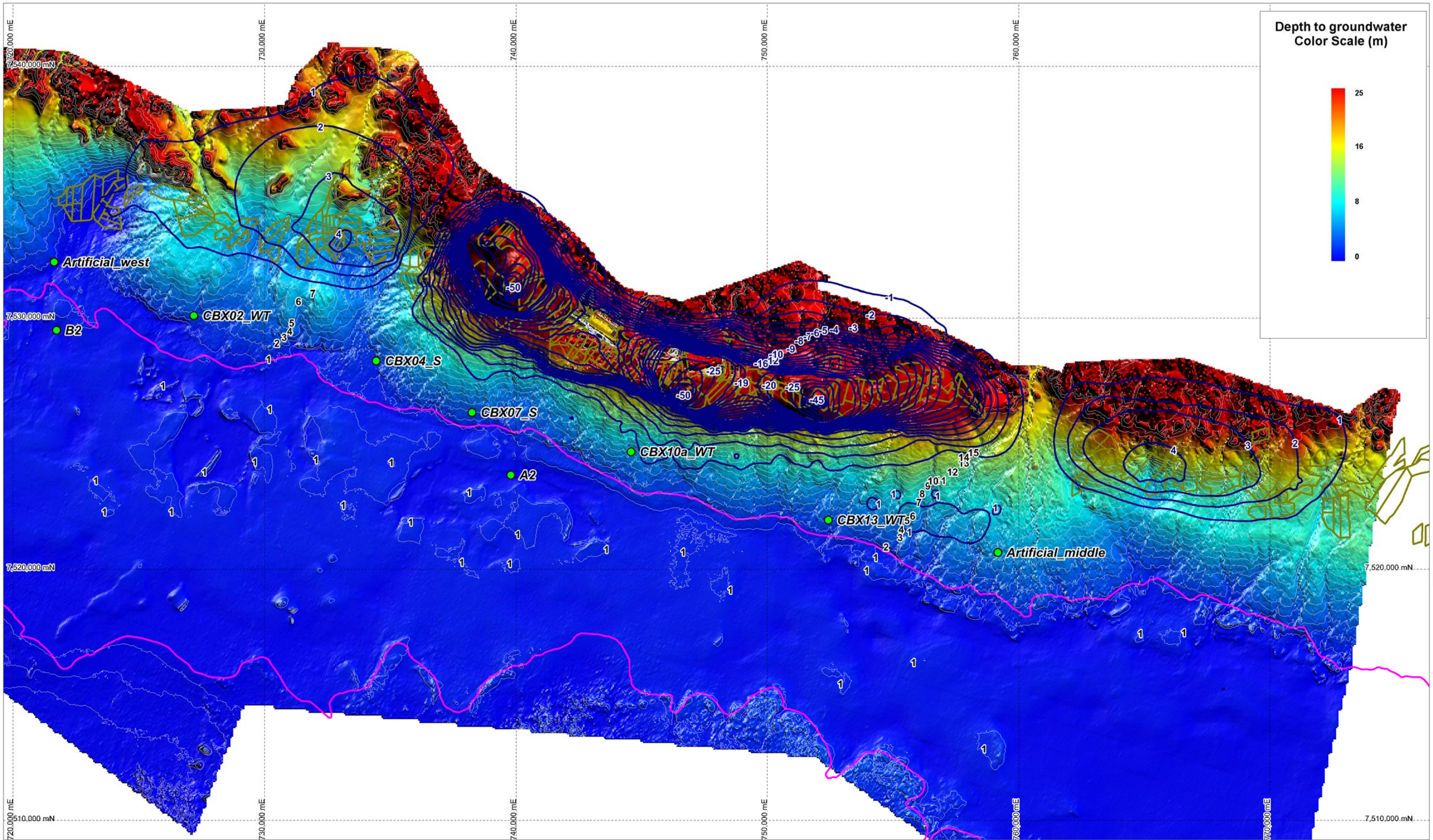
Yr 3 Groundwater Level Change from Baseline & Depth to Groundwater WET Climate Simulation

Author: B. Willis-Jones	Date:29/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000


Depth to groundwater
Color Scale (m)
25
16
8
0
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Artificial_west
CBX02_WT
B2
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location
Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 4 Groundwater Level Change
from Baseline & Depth
to Groundwater
WET Climate Simulation
Author: B. Willis-Jones
Date:29/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000



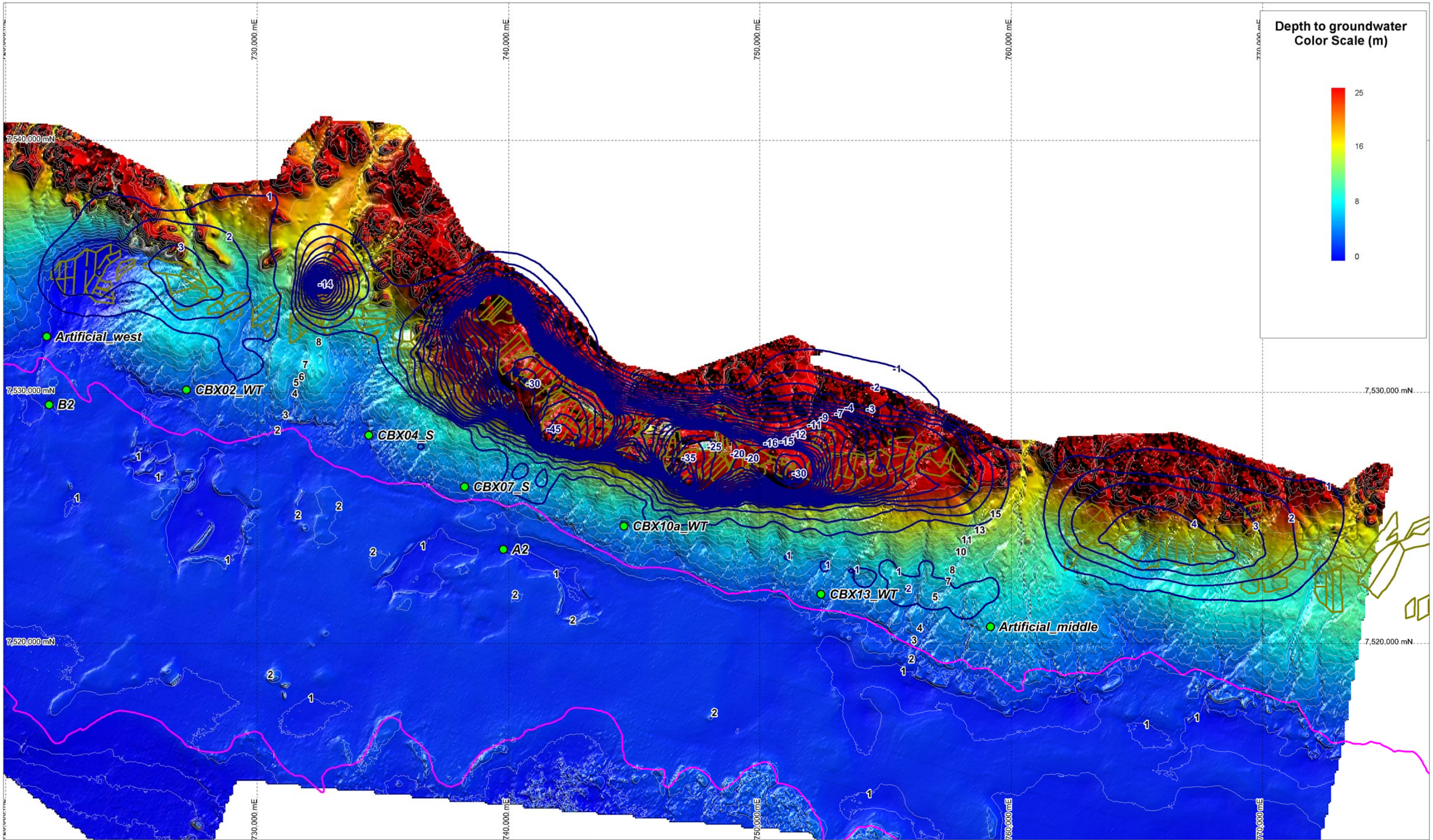
Depth to groundwater Color Scale (m)
25
16
8
0
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Artificial_west
CBX02_WT
B2
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 5 Groundwater Level Change from Baseline & Depth to Groundwater WET Climate Simulation
Author: B. Willis-Jones
Date:29/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000



Fortescue Metals Group Ltd

Yr 6 Groundwater Level Change from Baseline & Depth to Groundwater WET Climate Simulation

Author: B. Willis-Jones	Date:29/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000



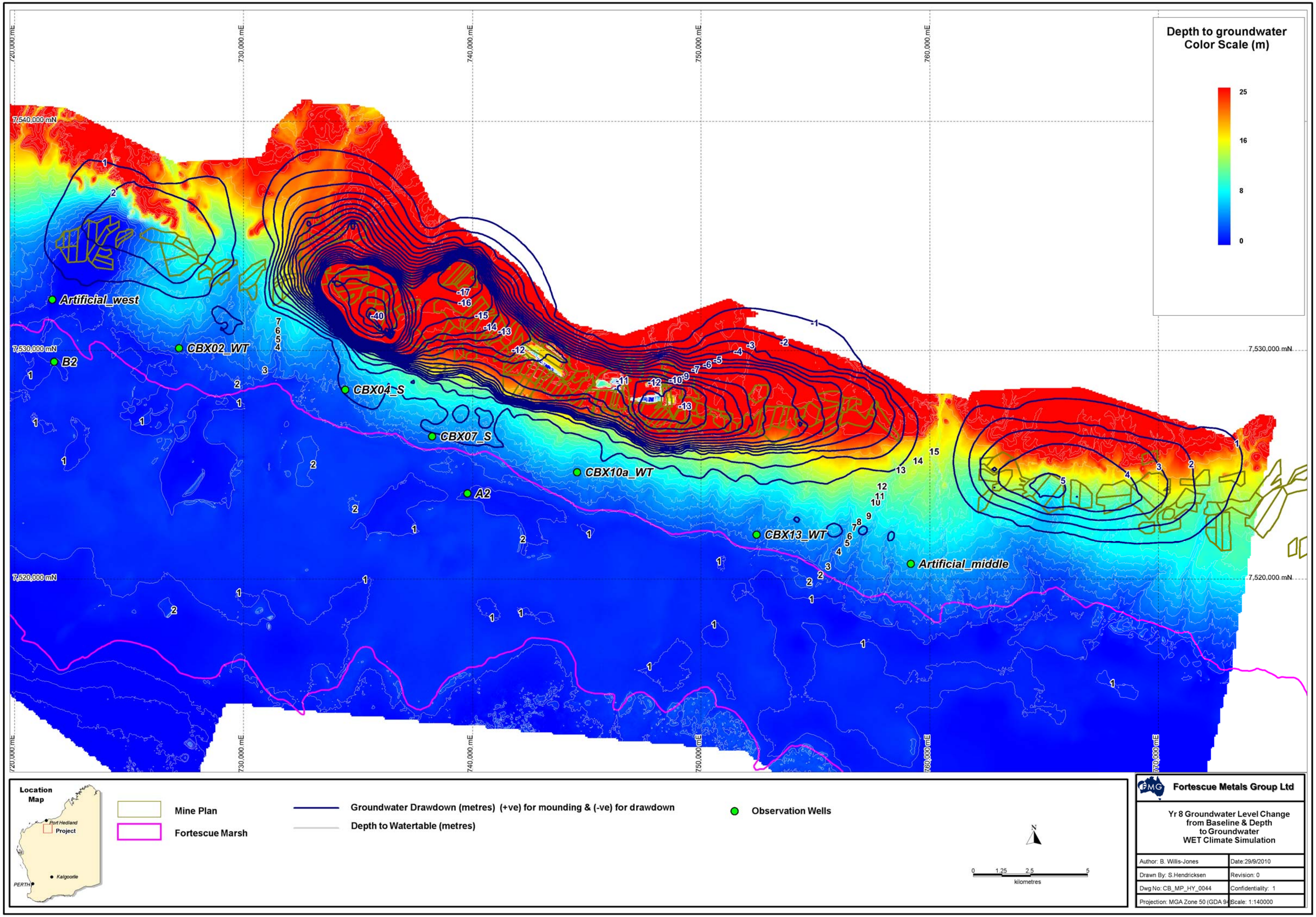
Mine Plan	Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Fortescue Marsh	Depth to Watertable (metres)
Observation Wells	

0 1.25 2.5 5
kilometres

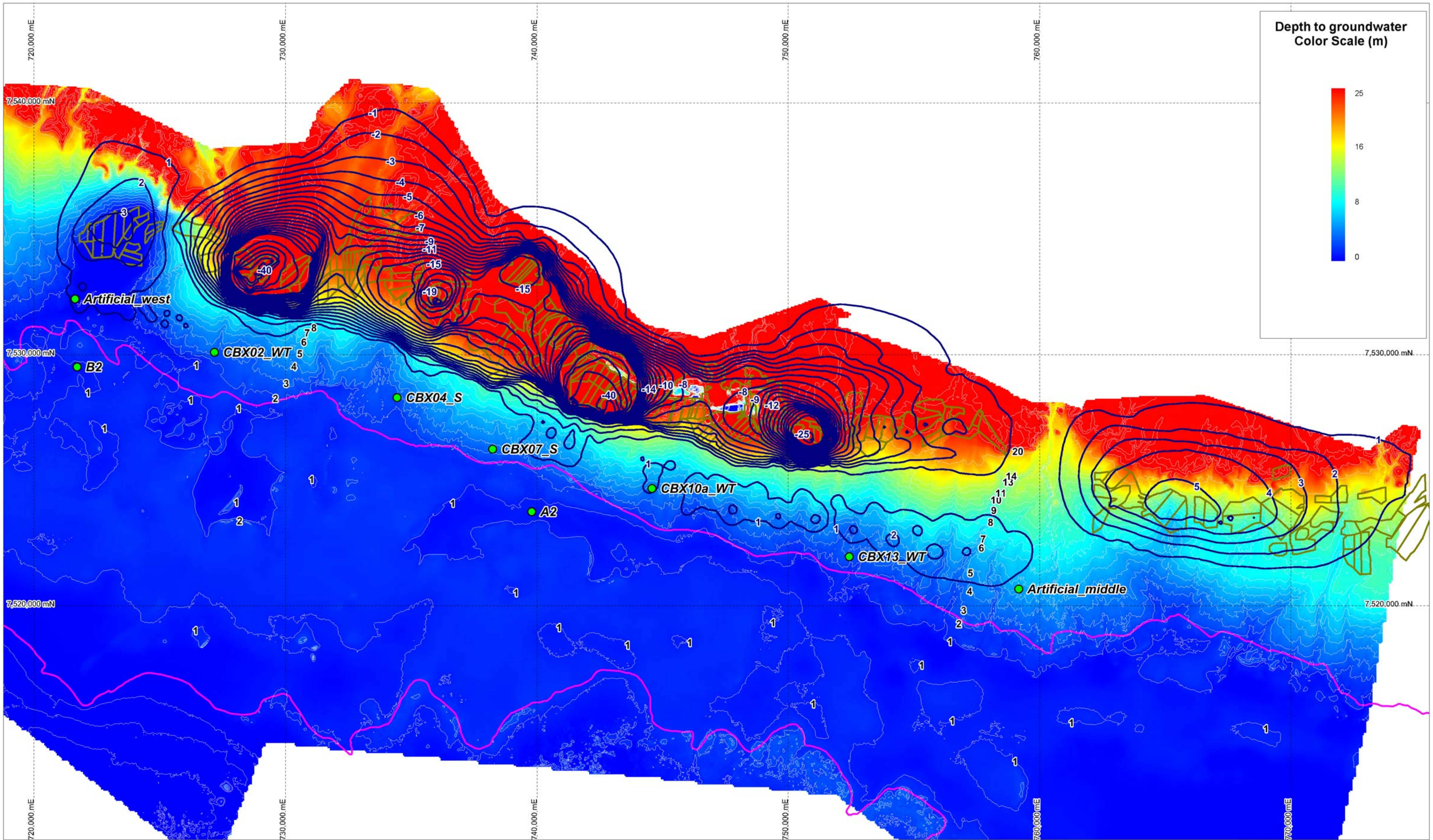
Fortescue Metals Group Ltd

Yr 7 Groundwater Level Change
from Baseline & Depth
to Groundwater
WET Climate Simulation

Author: B. Willis-Jones	Date:29/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000



Depth to groundwater Color Scale (m)
25
16
8
0
Artificial_west
B2
CBX02_WT
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 8 Groundwater Level Change from Baseline & Depth to Groundwater WET Climate Simulation
Author: B. Willis-Jones
Date:29/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000



Location Map

Port Hedland
Project
Kalgoorlie
PERTH

Mine Plan

Fortescue Marsh

Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown

Depth to Watertable (metres)

Observation Wells

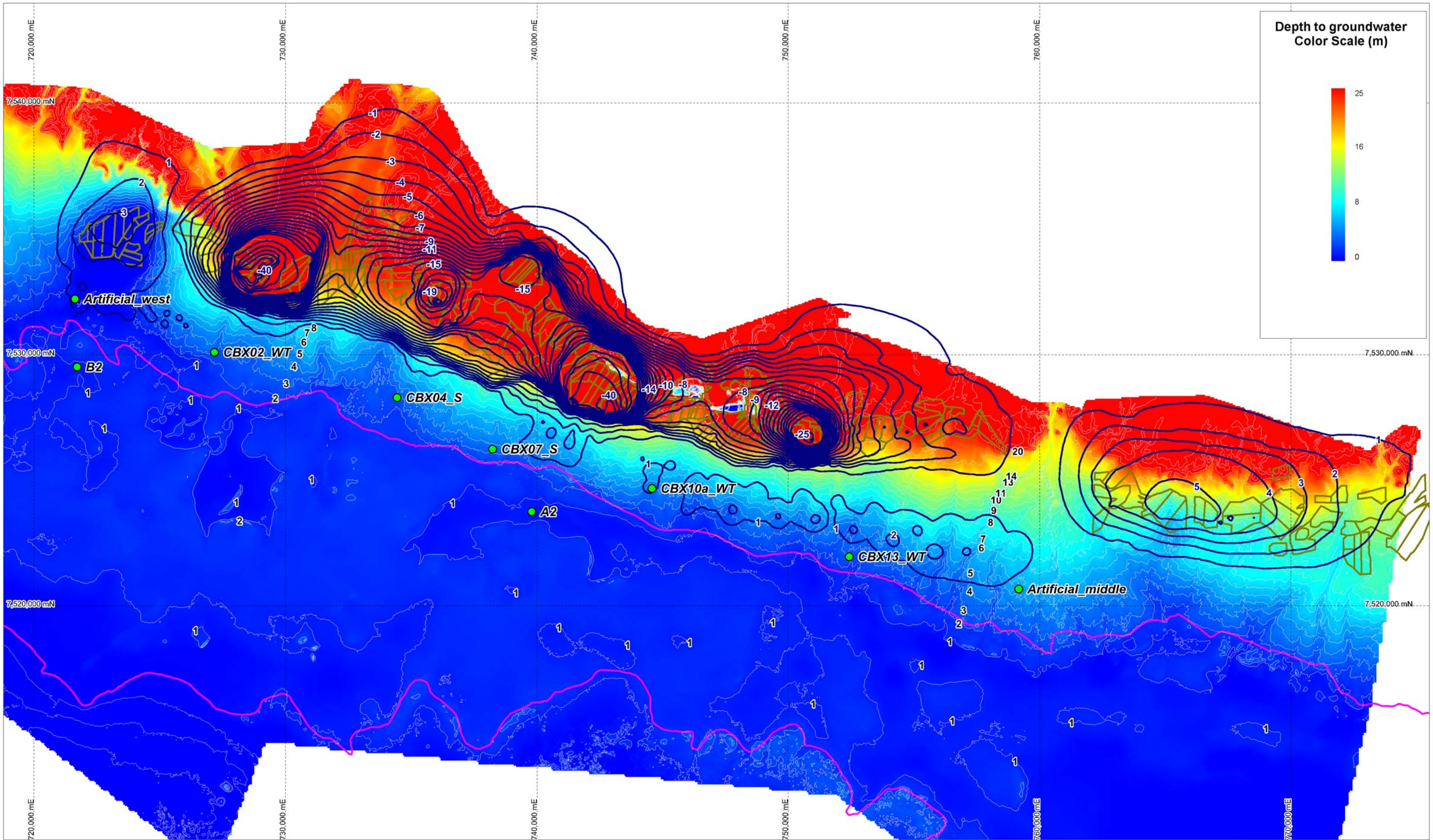
N

0 1.25 2.5 5
kilometres

Fortescue Metals Group Ltd

Yr 9 Groundwater Level Change
from Baseline & Depth
to Groundwater
WET Climate Simulation

Author: B. Willis-Jones	Date:29/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94	Scale: 1:140000



Mine Plan

Fortescue Marsh

Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown

Depth to Watertable (metres)

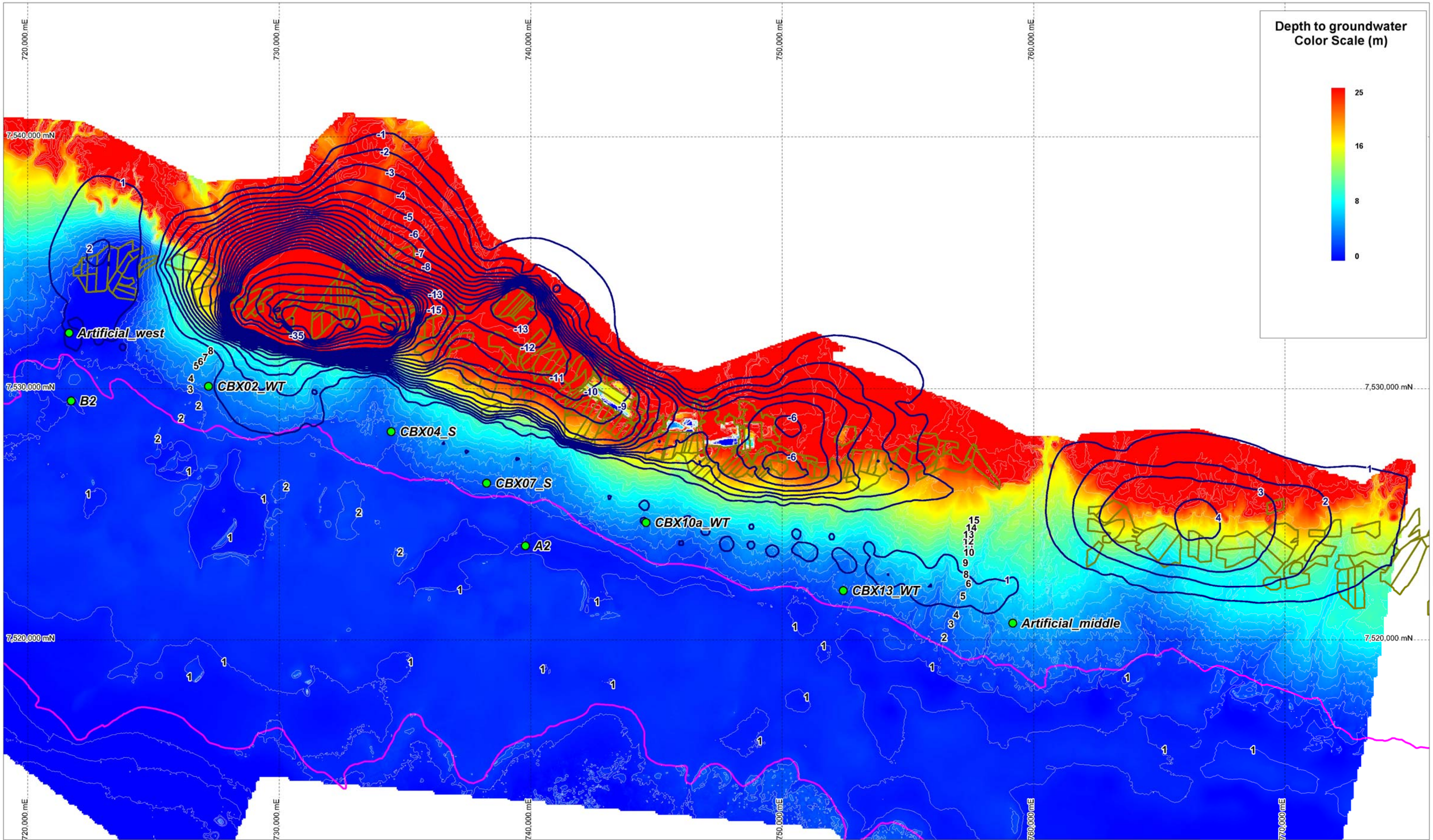
Observation Wells

0 1.25 2.5 5
kilometres

Fortescue Metals Group Ltd

Yr 9 Groundwater Level Change from Baseline & Depth to Groundwater WET Climate Simulation

Author: B. Willis-Jones	Date:29/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000



Mine Plan

Fortescue Marsh

Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown

Depth to Watertable (metres)

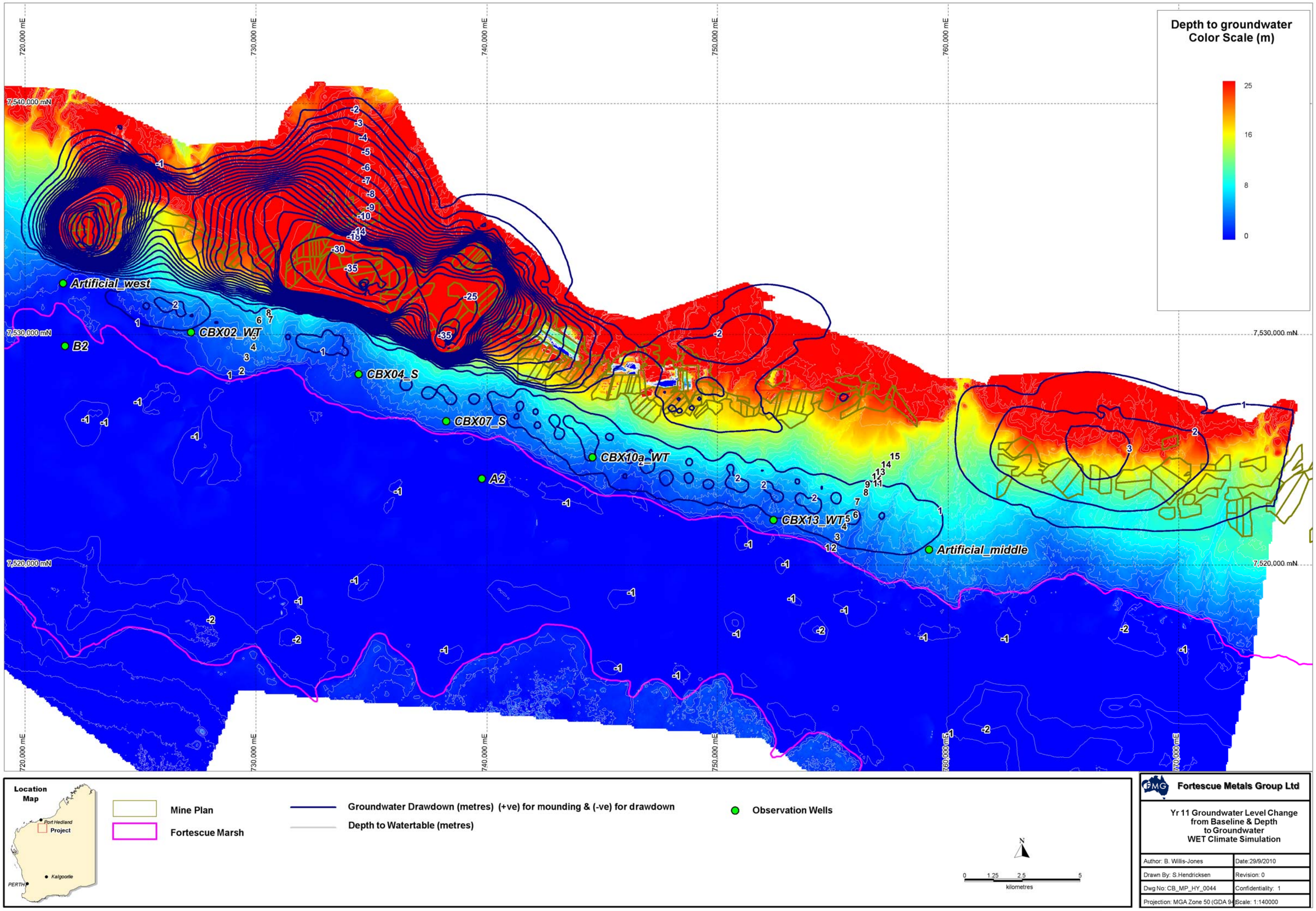
Observation Wells

0 1.25 2.5 5
kilometres

Fortescue Metals Group Ltd

Yr 10 Groundwater Level Change from Baseline & Depth to Groundwater WET Climate Simulation

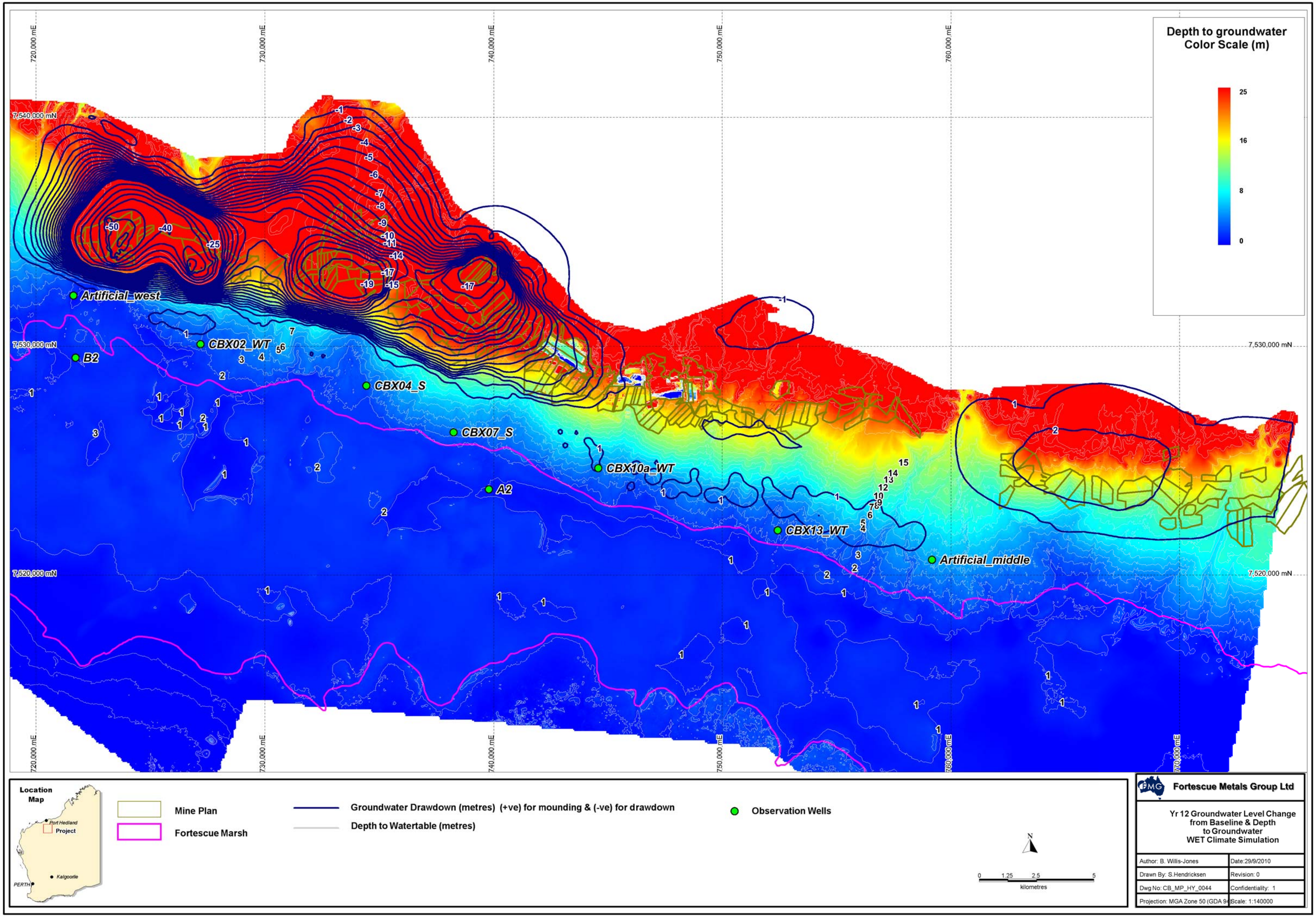
Author: B. Willis-Jones	Date:29/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000



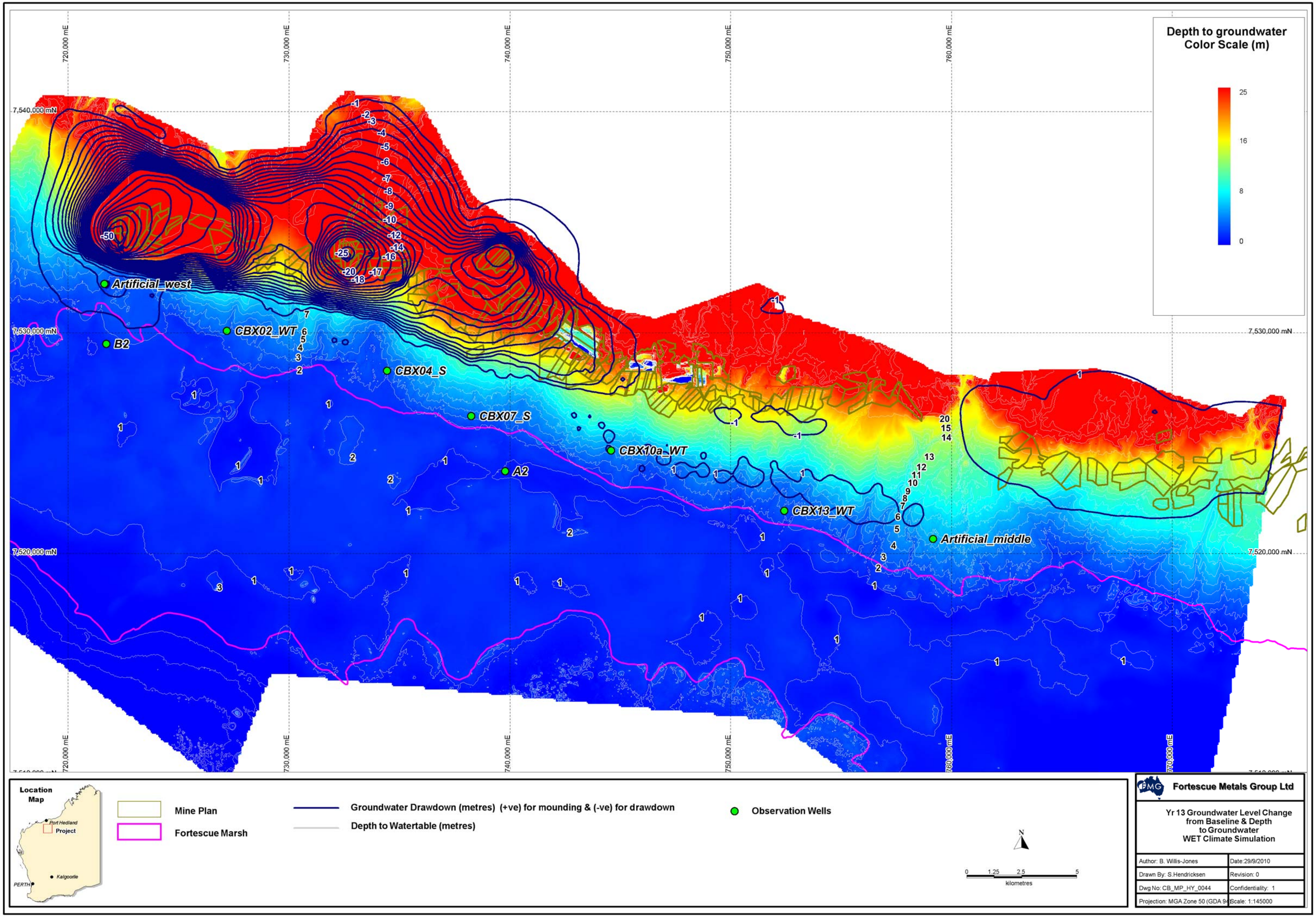
Fortescue Metals Group Ltd

Yr 11 Groundwater Level Change from Baseline & Depth to Groundwater WET Climate Simulation

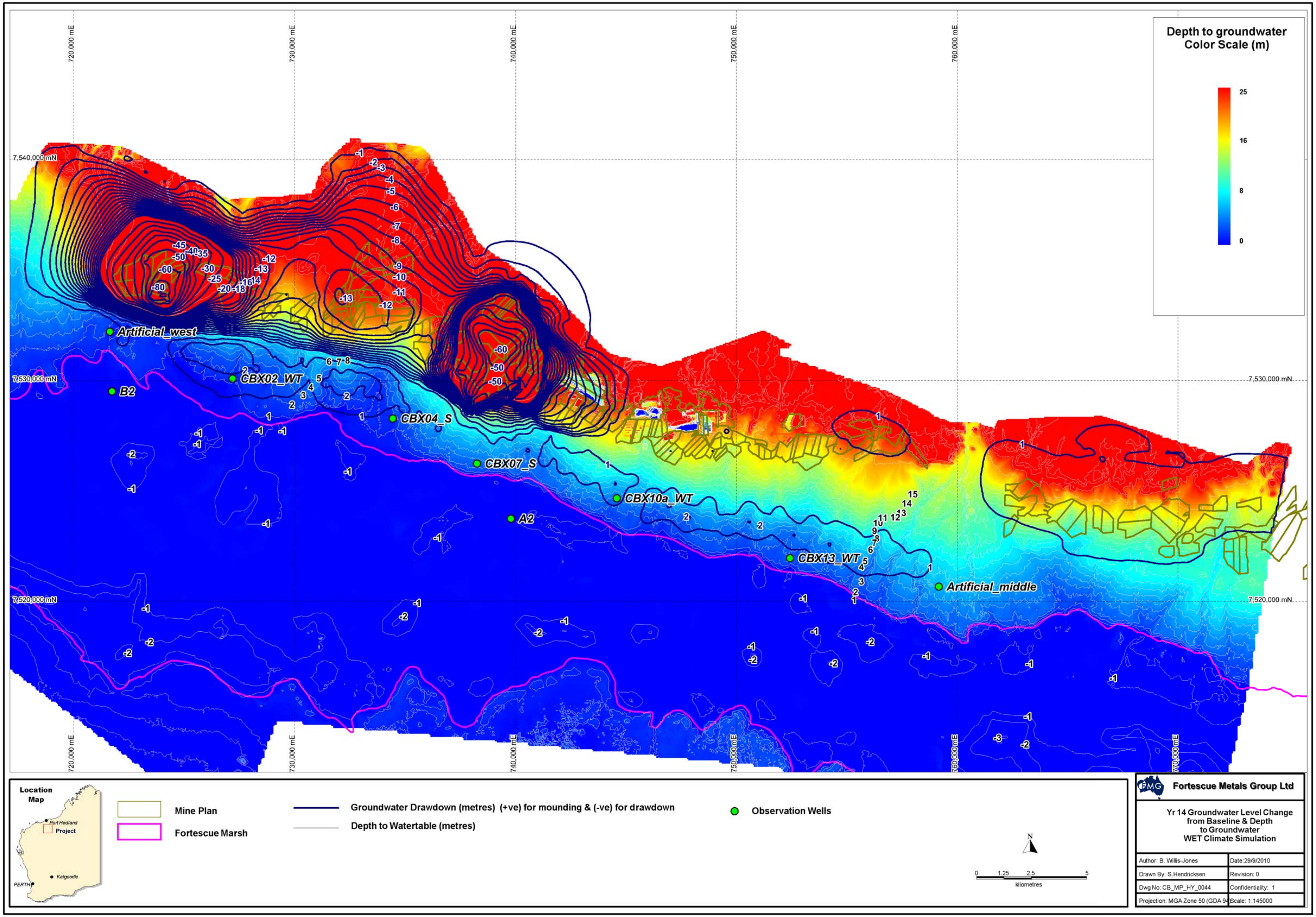
Author: B. Willis-Jones	Date:29/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000



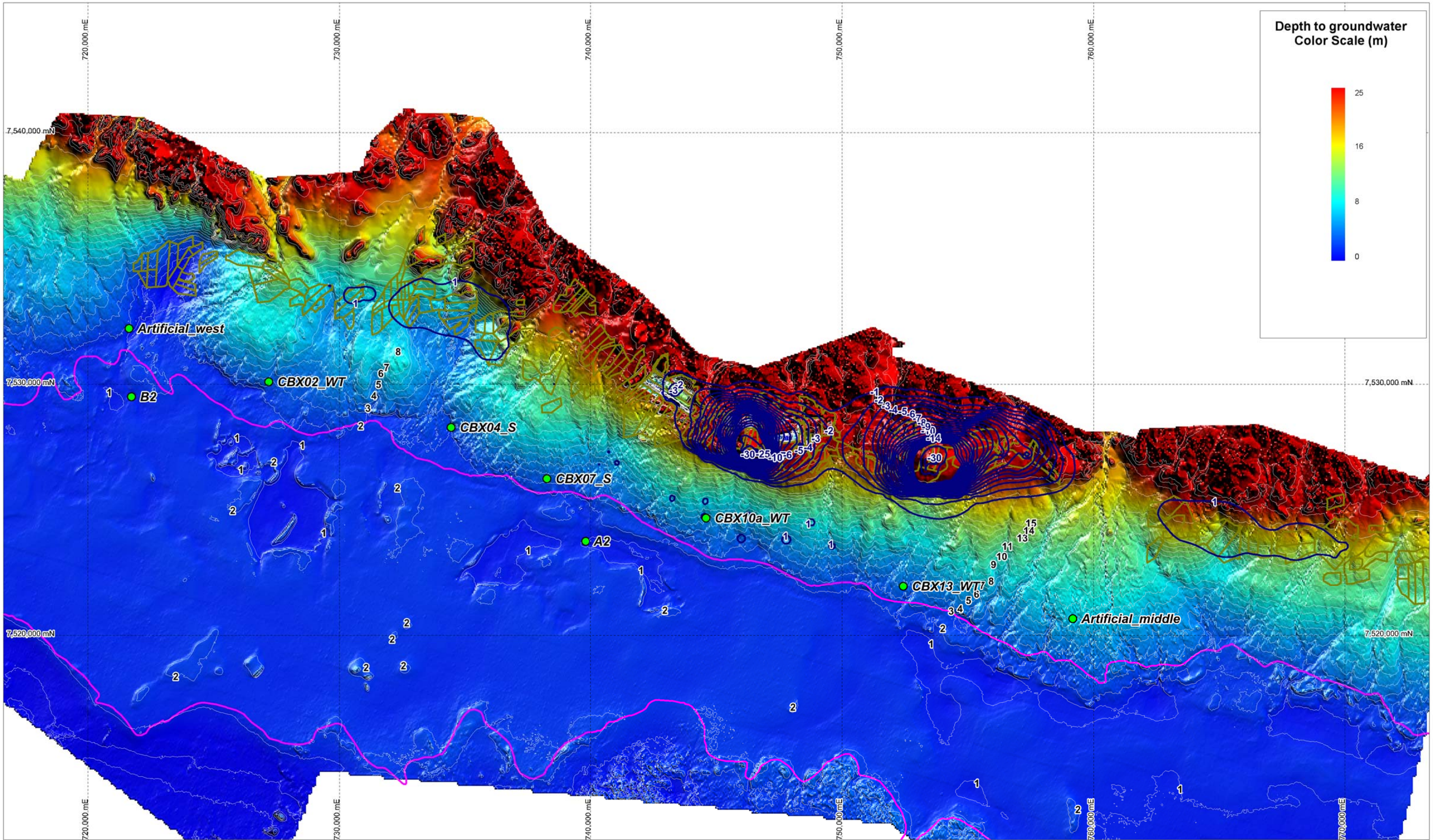
Depth to groundwater Color Scale (m)
25
16
8
0
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Artificial_west
B2
CBX02_WT
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 12 Groundwater Level Change from Baseline & Depth to Groundwater WET Climate Simulation
Author: B. Willis-Jones
Date:29/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000



Depth to groundwater Color Scale (m)
25
16
8
0
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Artificial_west
B2
CBX02_WT
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 13 Groundwater Level Change from Baseline & Depth to Groundwater WET Climate Simulation
Author: B. Willis-Jones
Date:29/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:145000



Depth to groundwater Color Scale (m)
25
16
8
0
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Artificial_west
CBX02_WT
B2
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 14 Groundwater Level Change from Baseline & Depth to Groundwater WET Climate Simulation
Author: B. Willis-Jones
Date:29/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:145000



Location Map

Legend	
Mine Plan	Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Fortescue Marsh	Depth to Watertable (metres)
Observation Wells	

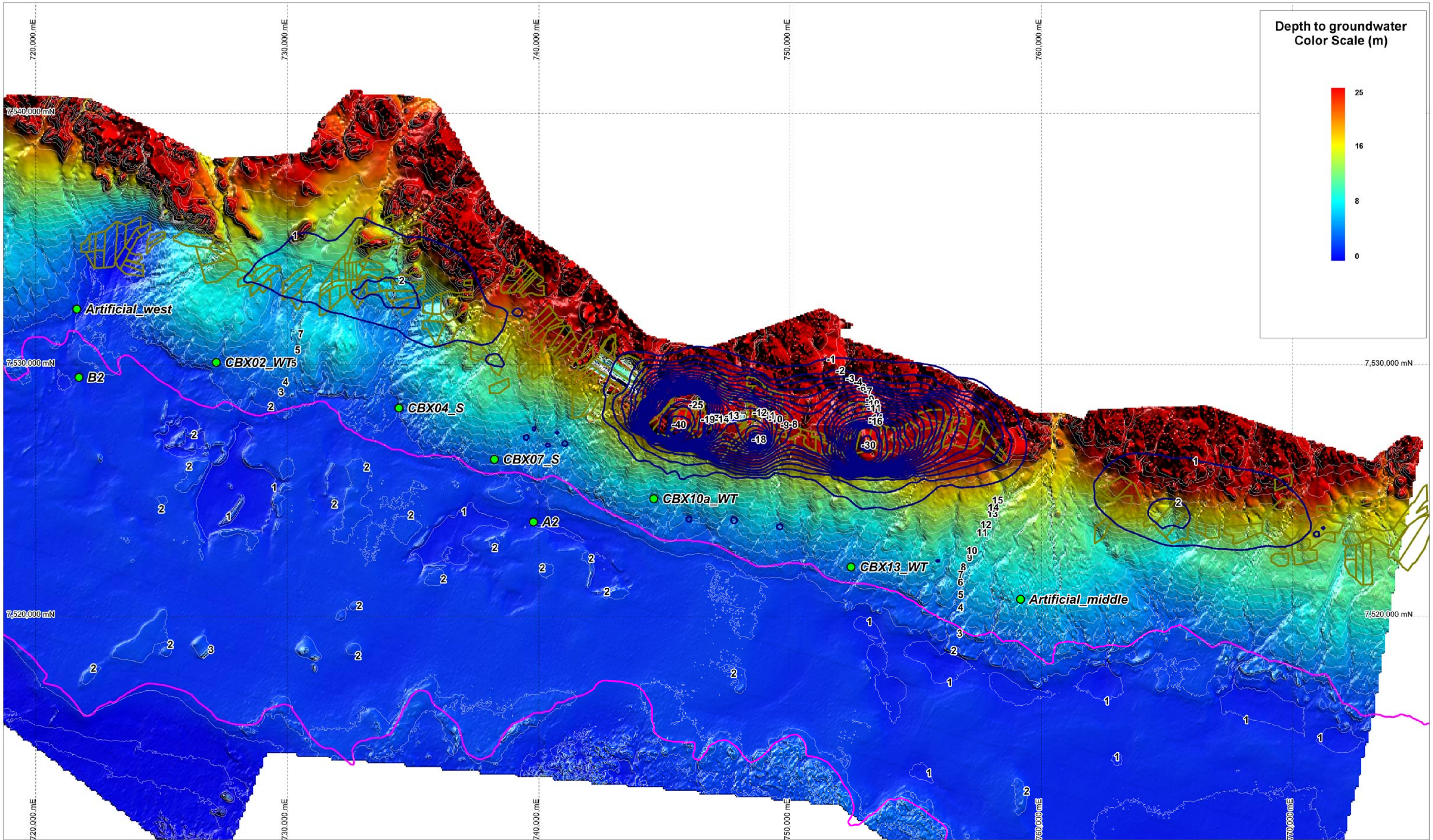
N

0 1.25 2.5 5
kilometres

Fortescue Metals Group Ltd

Yr 1 Groundwater Level Change from Baseline & Depth to Groundwater DRY Climate Simulation

Author: B. Willis-Jones	Date:29/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000



Location Map

Port Hedland

Project

Kalgoorlie

PERTH

Mine Plan

Fortescue Marsh

Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown

Depth to Watertable (metres)

Observation Wells

N

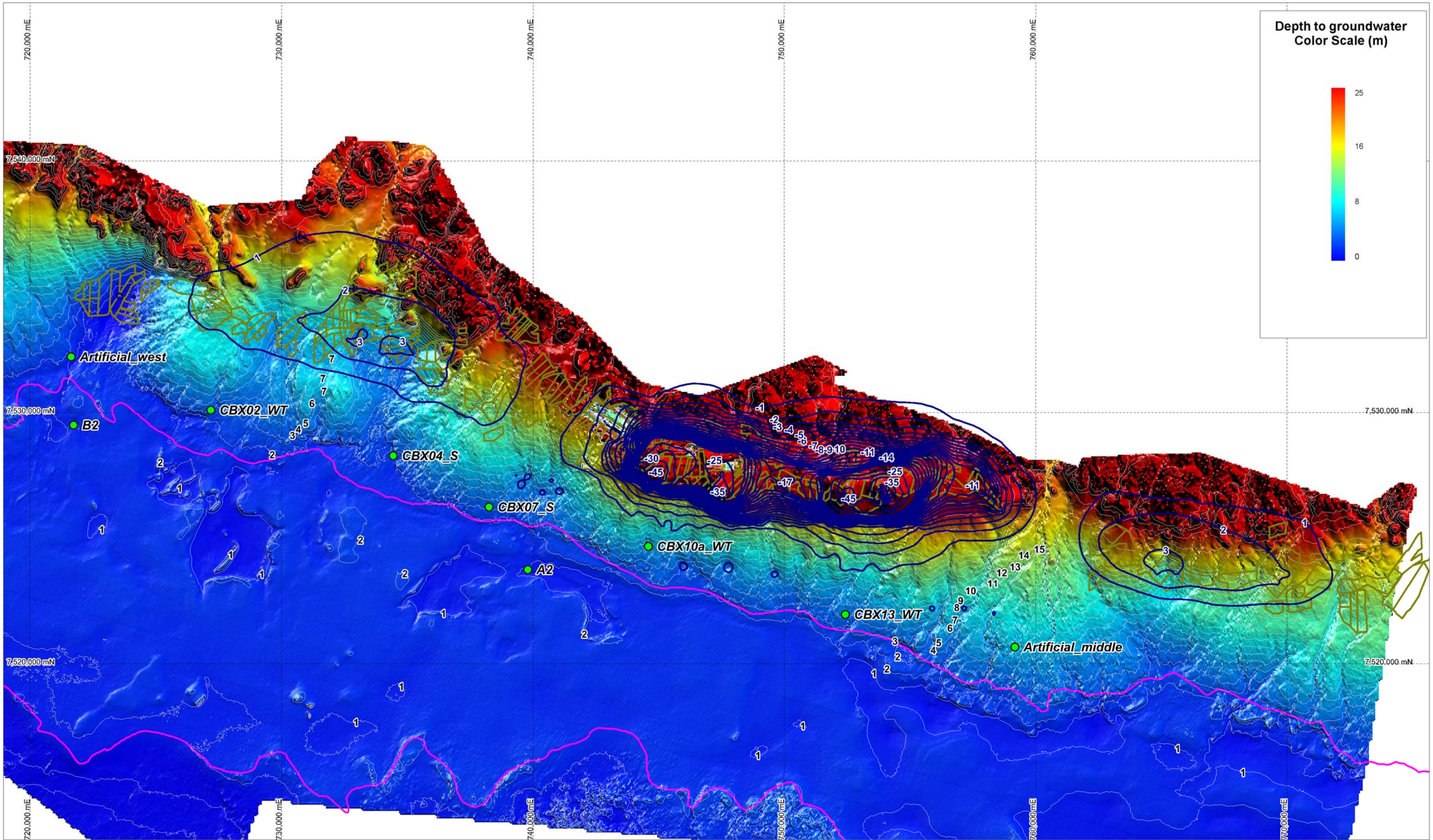
0 1.25 2.5 5

kilometres

Fortescue Metals Group Ltd

Yr 2Groundwater Level Change from Baseline & Depth to Groundwater DRY Climate Simulation

Author: B. Willis-Jones	Date:29/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000



Mine Plan

Fortescue Marsh

Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown

Depth to Watertable (metres)

Observation Wells

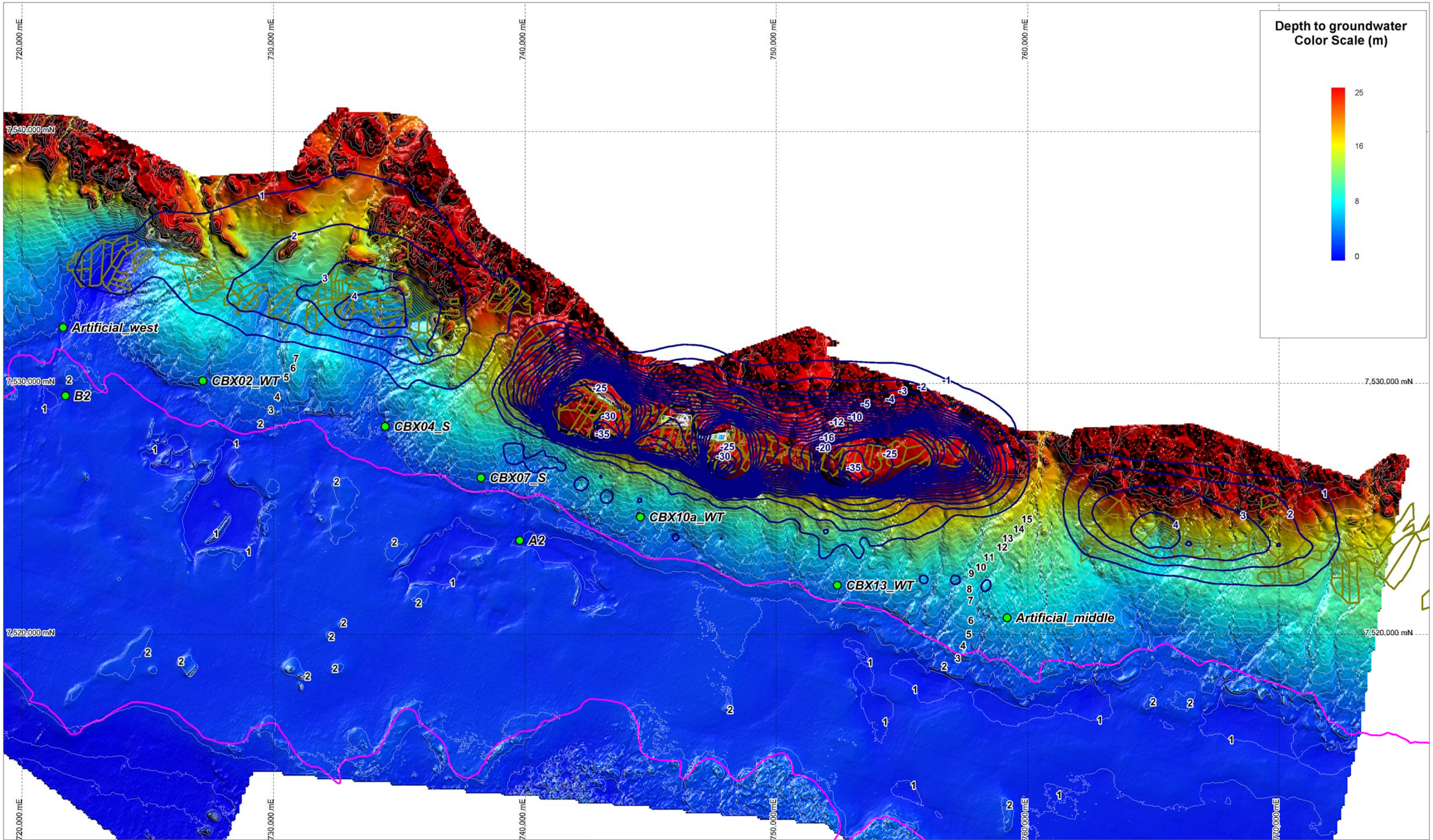
N

0 1.25 2.5 5
kilometres

Fortescue Metals Group Ltd

Yr 3 Groundwater Level Change from Baseline & Depth to Groundwater DRY Climate Simulation

Author: B. Willis-Jones	Date:29/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94	Scale: 1:140000



Mine Plan

Fortescue Marsh

Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown

Depth to Watertable (metres)

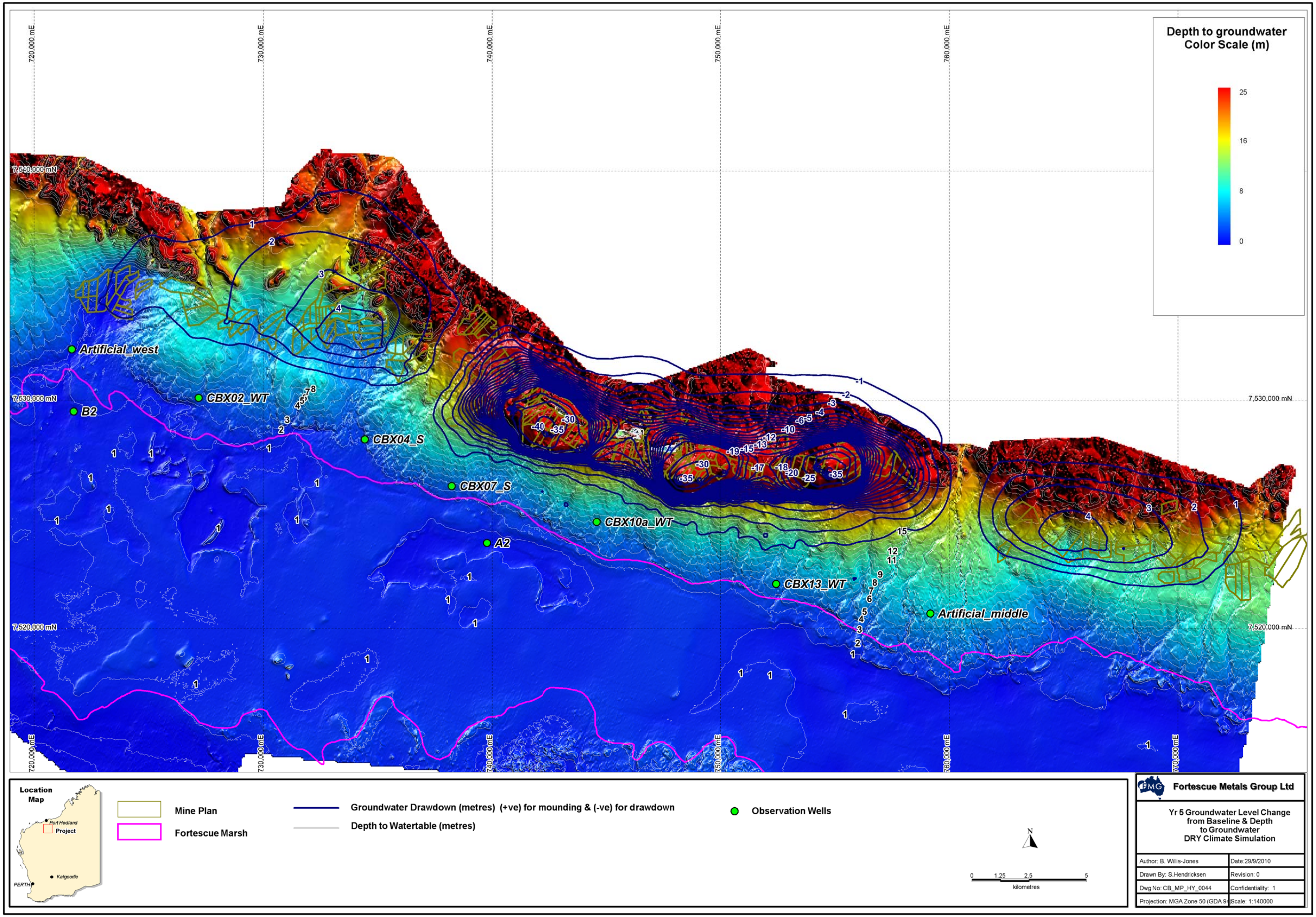
Observation Wells

0 1.25 2.5 5
kilometres

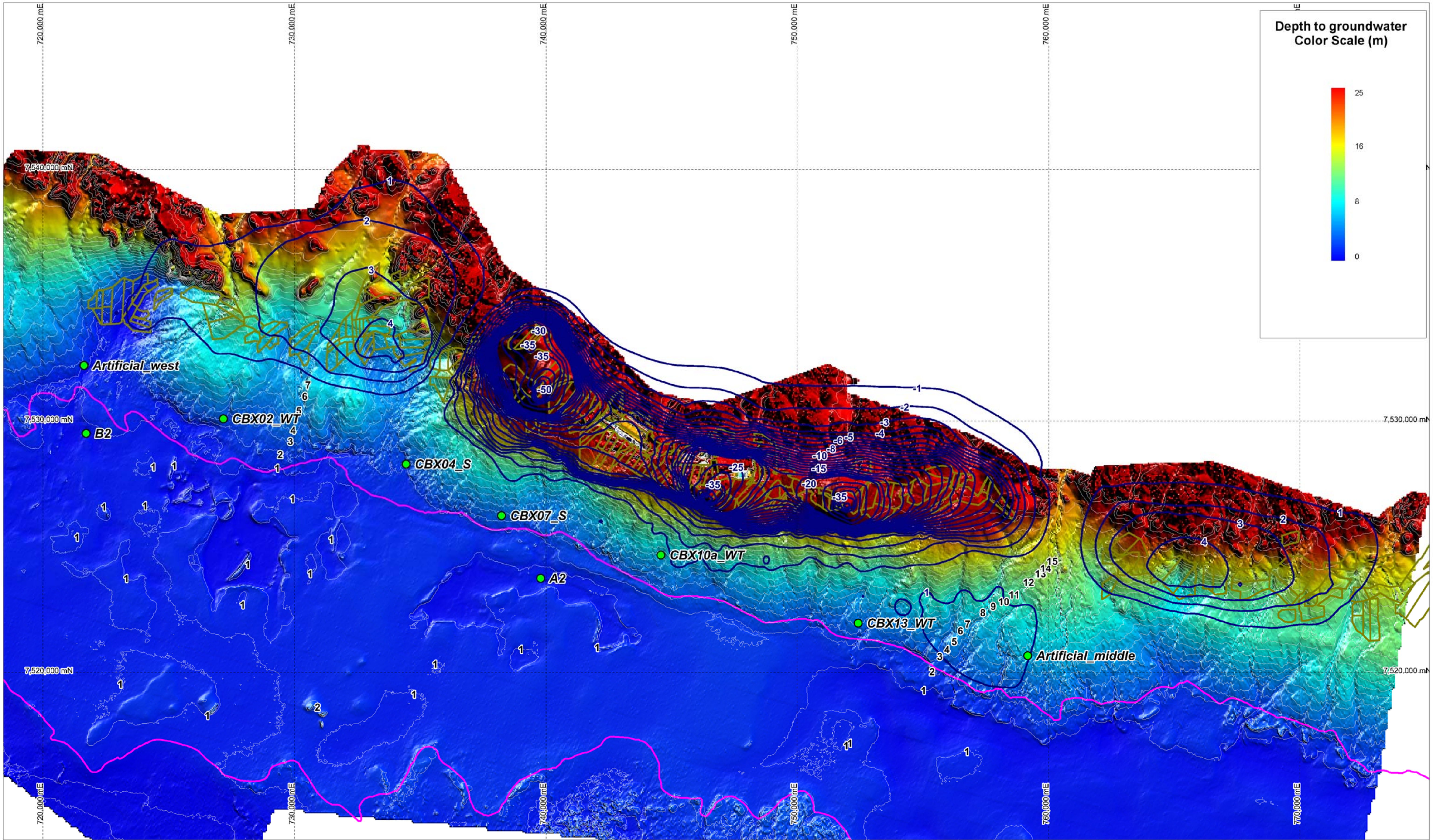
Fortescue Metals Group Ltd

Yr 4 Groundwater Level Change from Baseline & Depth to Groundwater DRY Climate Simulation

Author: B. Willis-Jones	Date:29/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000



Depth to groundwater
Color Scale (m)
25
16
8
0
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Artificial_west
B2
CBX02_WT
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location
Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0
1.25
2.5
5
kilometres
Fortescue Metals Group Ltd
Yr 5 Groundwater Level Change
from Baseline & Depth
to Groundwater
DRY Climate Simulation
Author: B. Willis-Jones
Date:29/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000



Mine Plan

Fortescue Marsh

Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown

Depth to Watertable (metres)

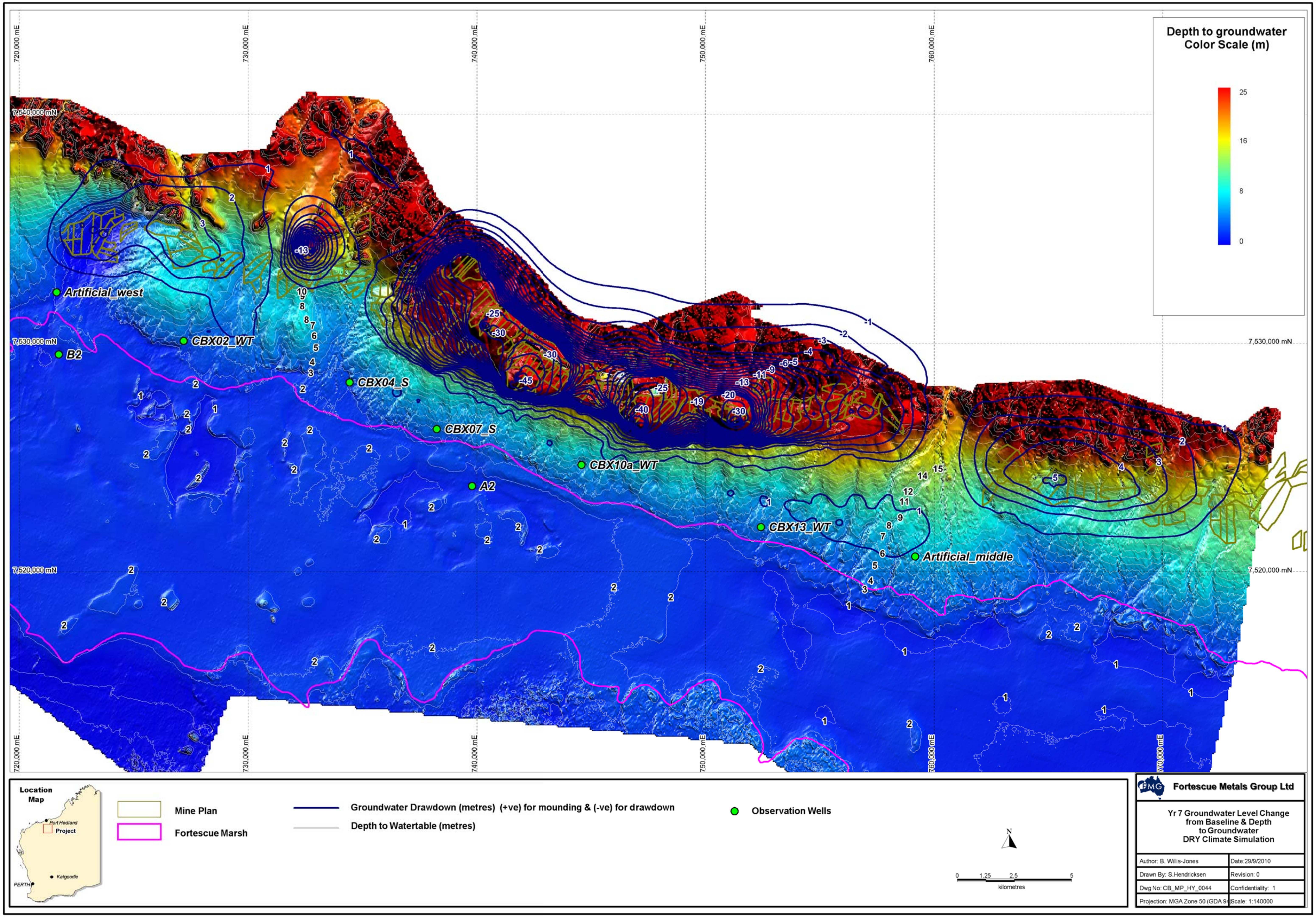
Observation Wells

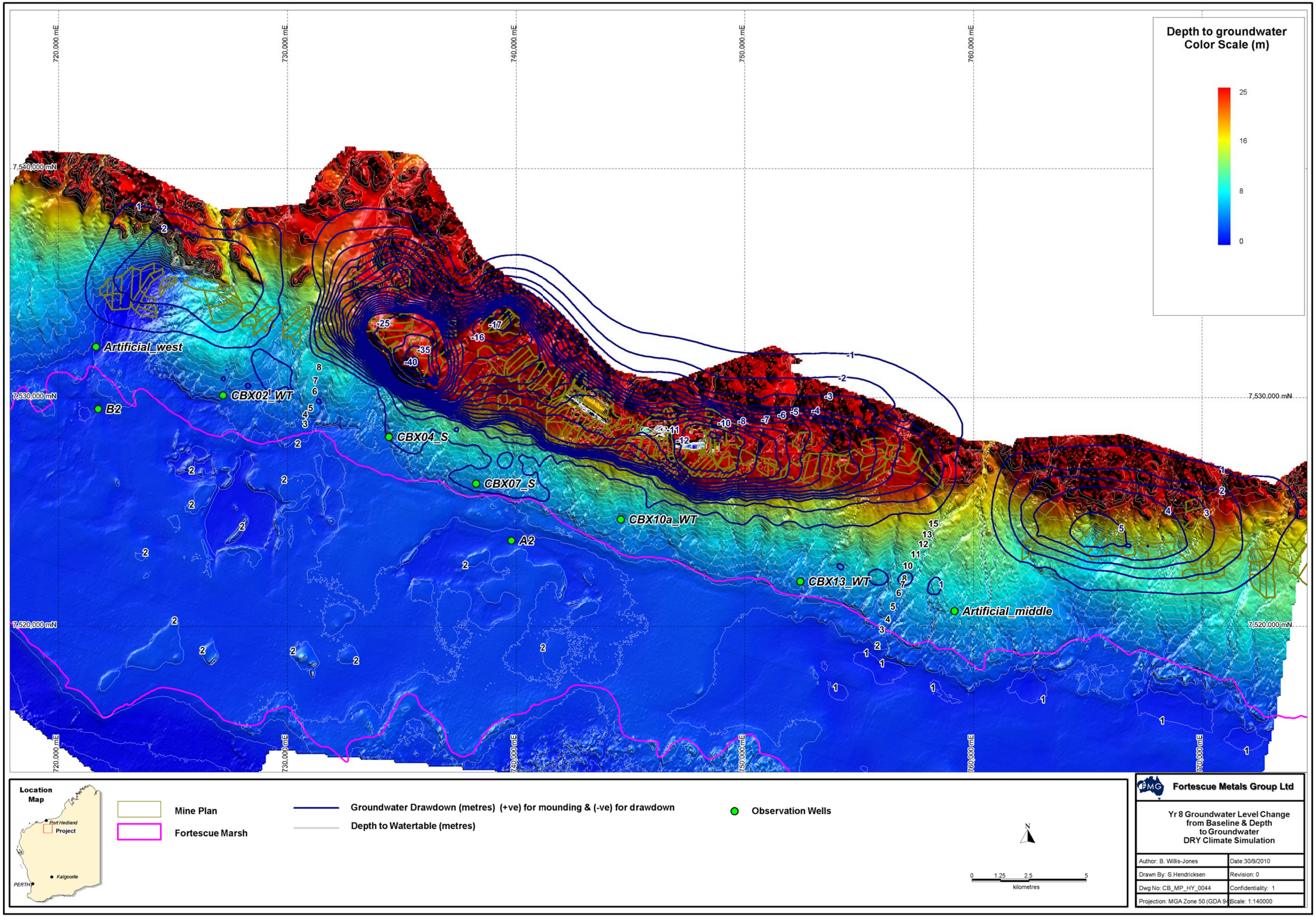
0 1.25 2.5 5
kilometres

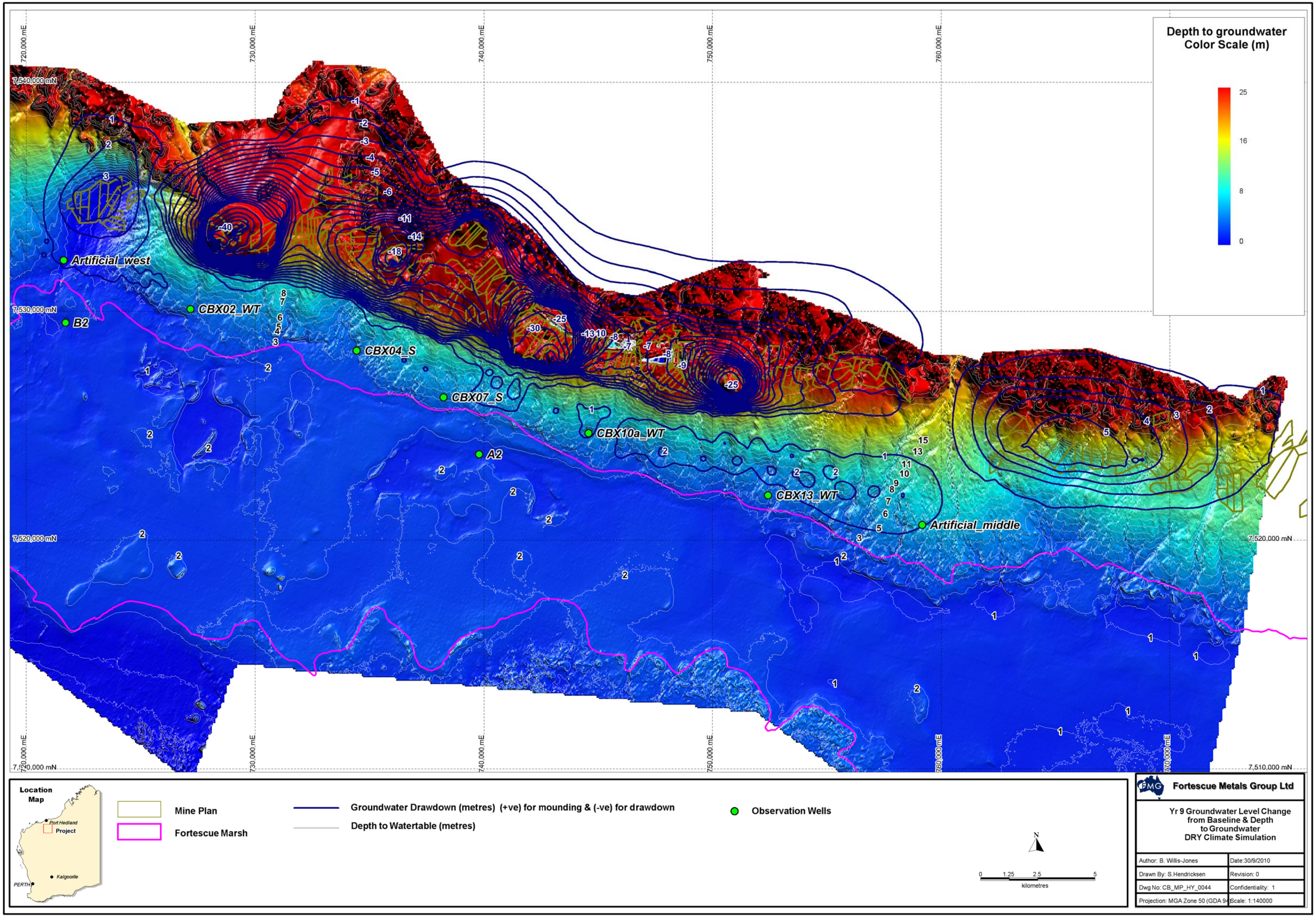
Fortescue Metals Group Ltd

Yr 6 Groundwater Level Change from Baseline & Depth to Groundwater DRY Climate Simulation

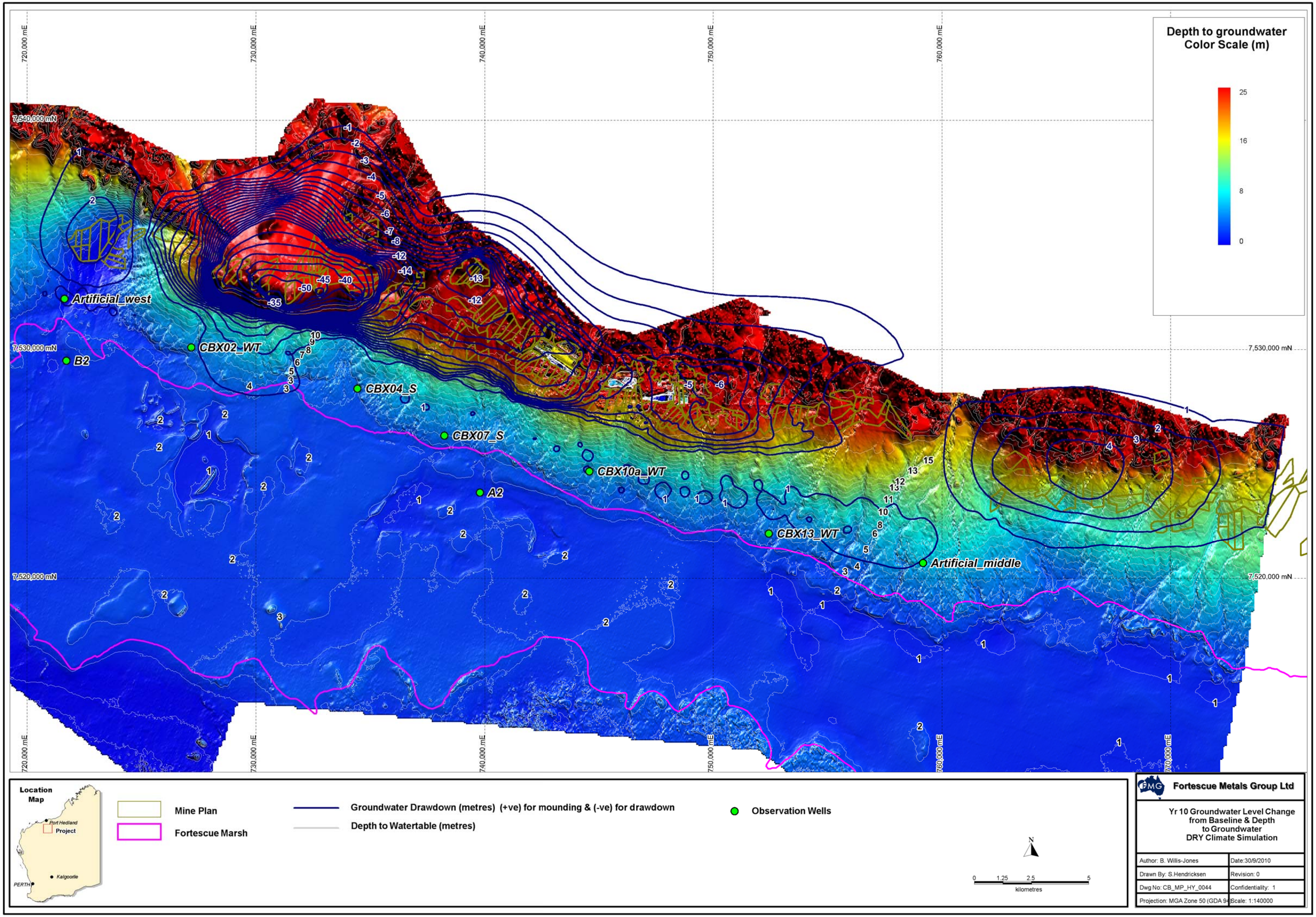
Author: B. Willis-Jones	Date:29/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000

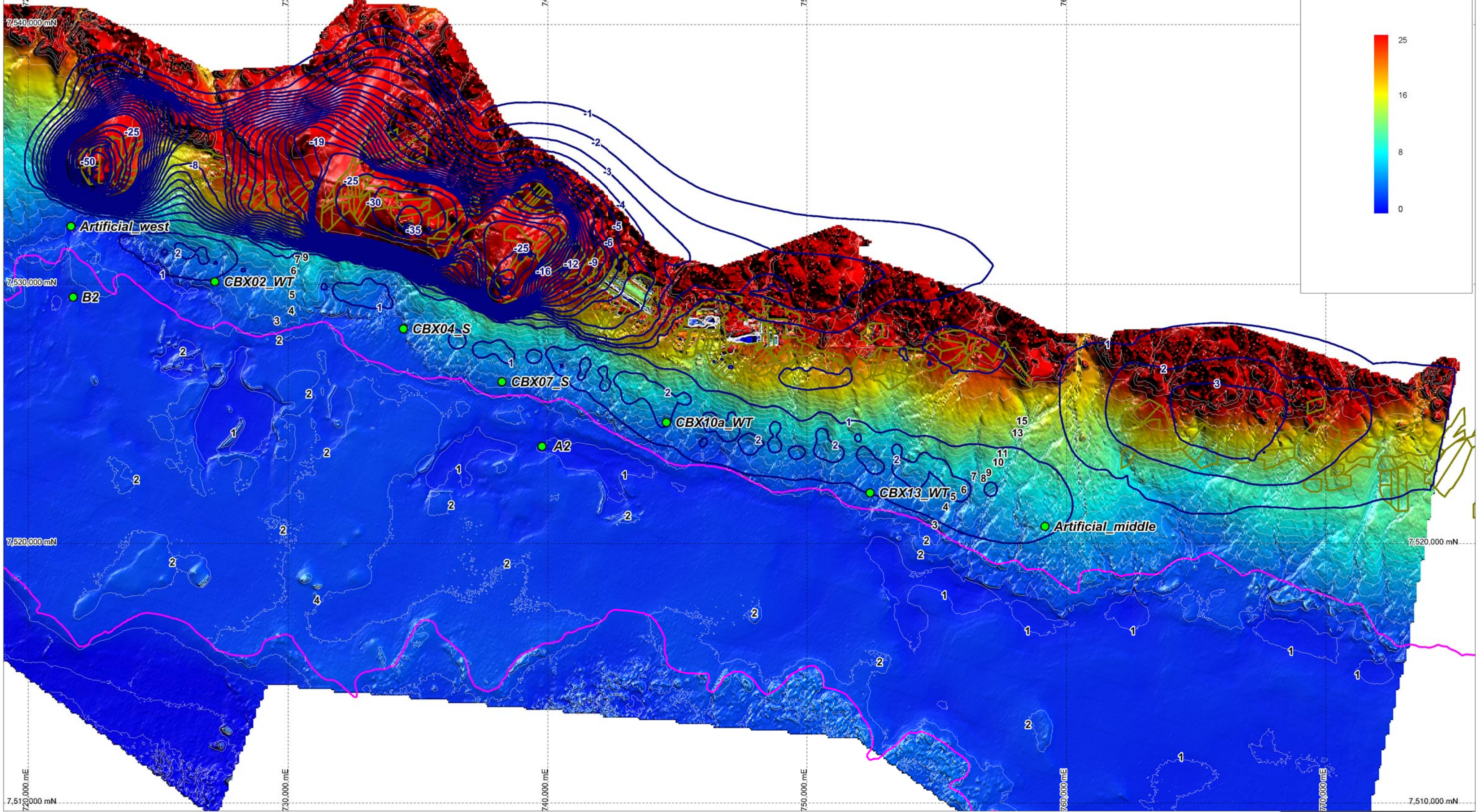

Depth to groundwater
Color Scale (m)
25
16
8
0
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Artificial_west
CBX02_WT
B2
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location
Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 7 Groundwater Level Change
from Baseline & Depth
to Groundwater
DRY Climate Simulation
Author: B. Willis-Jones
Date:29/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94
Scale: 1:140000


Depth to groundwater
Color Scale (m)
25
16
8
0
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Artificial_west
B2
CBX02_WT
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 8 Groundwater Level Change from Baseline & Depth to Groundwater DRY Climate Simulation
Author: B. Willis-Jones
Date:30/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94
Scale: 1:140000



Depth to groundwater Color Scale (m)
25
16
8
0
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
7,510,000 mN
Artificial_west
B2
CBX02_WT
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 9 Groundwater Level Change from Baseline & Depth to Groundwater DRY Climate Simulation
Author: B. Willis-Jones
Date:30/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000


Depth to groundwater
Color Scale (m)
25
16
8
0
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Artificial_west
CBX02_WT
B2
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location
Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0
1.25
2.5
5
kilometres
Fortescue Metals Group Ltd
Yr 10 Groundwater Level Change
from Baseline & Depth
to Groundwater
DRY Climate Simulation
Author: B. Willis-Jones
Date:30/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000



Location Map

Port Hedland

Project

Kalgoorlie

PERTH

Mine Plan

Fortescue Marsh

Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown

Depth to Watertable (metres)

Observation Wells

N

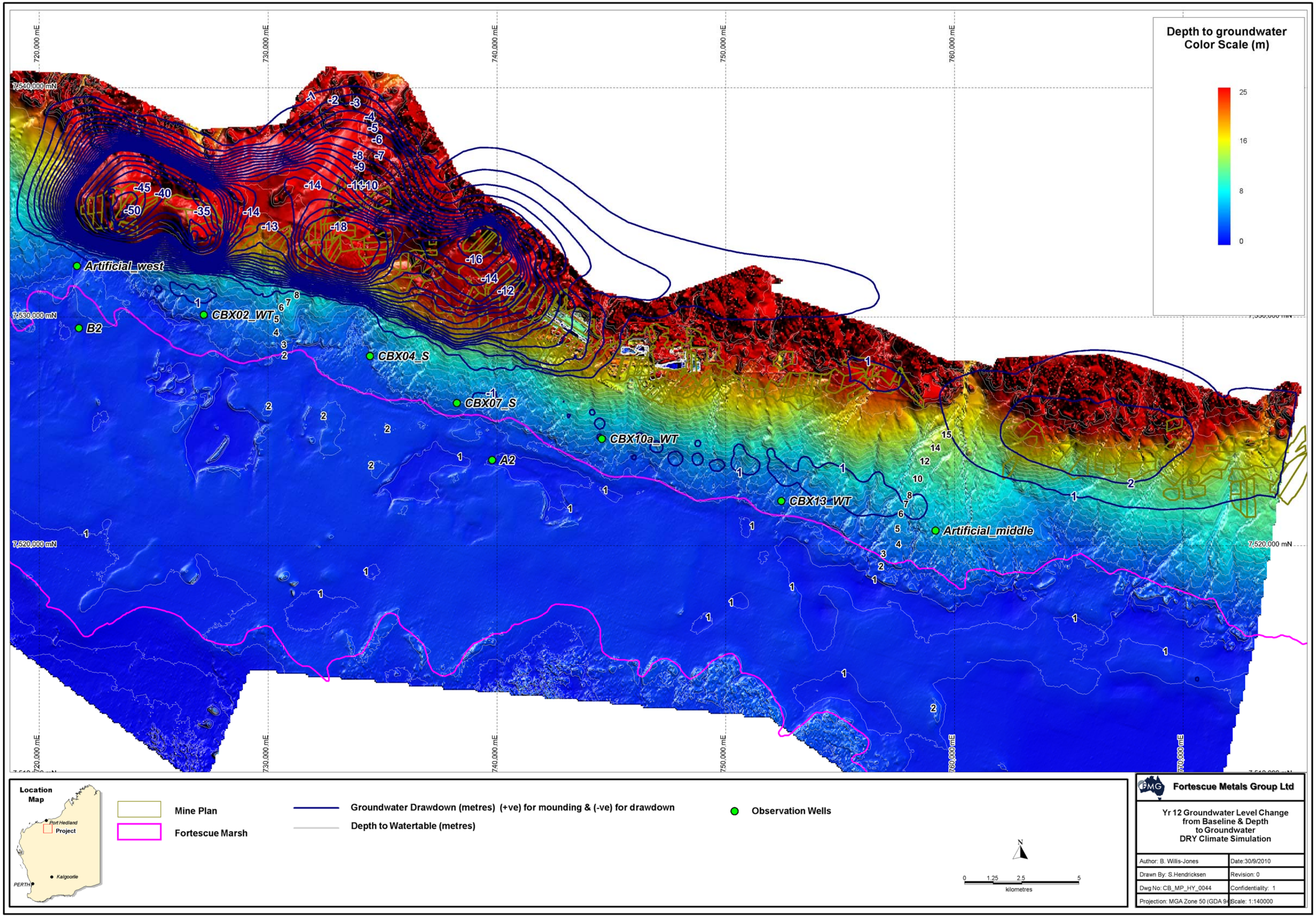
0 1.25 2.5 5

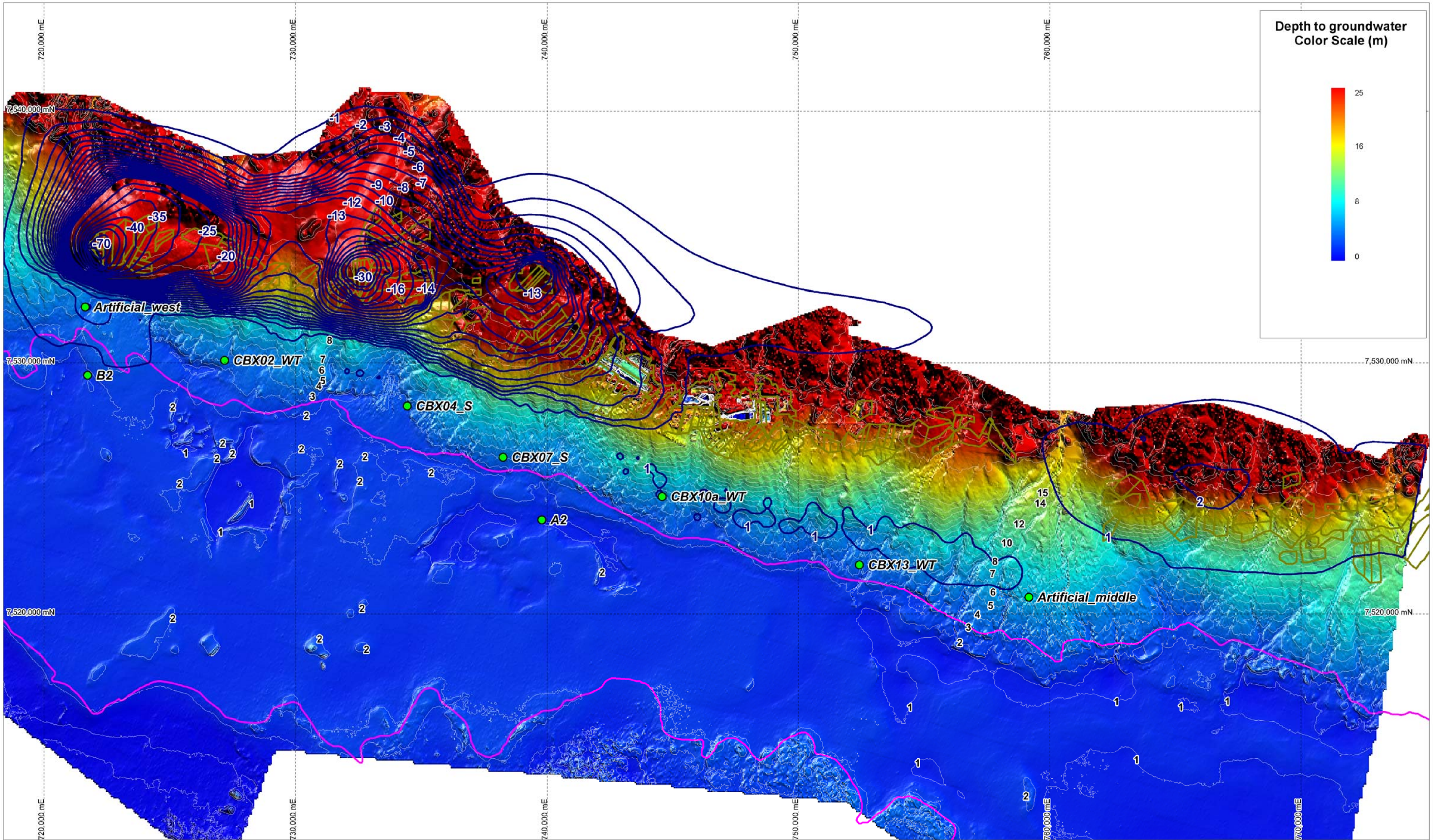
kilometres

Fortescue Metals Group Ltd

Yr 11 Groundwater Level Change from Baseline & Depth to Groundwater DRY Climate Simulation

Author: B. Willis-Jones	Date:30/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94	Scale: 1:140000


Depth to groundwater
Color Scale (m)
25
16
8
0
720,000 mE
730,000 mE
740,000 mE
750,000 mE
760,000 mE
770,000 mE
7,540,000 mN
7,530,000 mN
7,520,000 mN
Artificial_west
B2
CBX02_WT
CBX04_S
CBX07_S
CBX10a_WT
A2
CBX13_WT
Artificial_middle
Location Map
Port Hedland
Project
Kalgoorlie
PERTH
Mine Plan
Fortescue Marsh
Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Depth to Watertable (metres)
Observation Wells
N
0 1.25 2.5 5
kilometres
Fortescue Metals Group Ltd
Yr 12 Groundwater Level Change from Baseline & Depth to Groundwater DRY Climate Simulation
Author: B. Willis-Jones
Date:30/9/2010
Drawn By: S.Hendricksen
Revision: 0
Dwg No: CB_MP_HY_0044
Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)
Scale: 1:140000



Location Map

Port Hedland

Project

Kalgoorlie

PERTH

Legend	
Mine Plan	Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown
Fortescue Marsh	Depth to Watertable (metres)
Observation Wells	

N

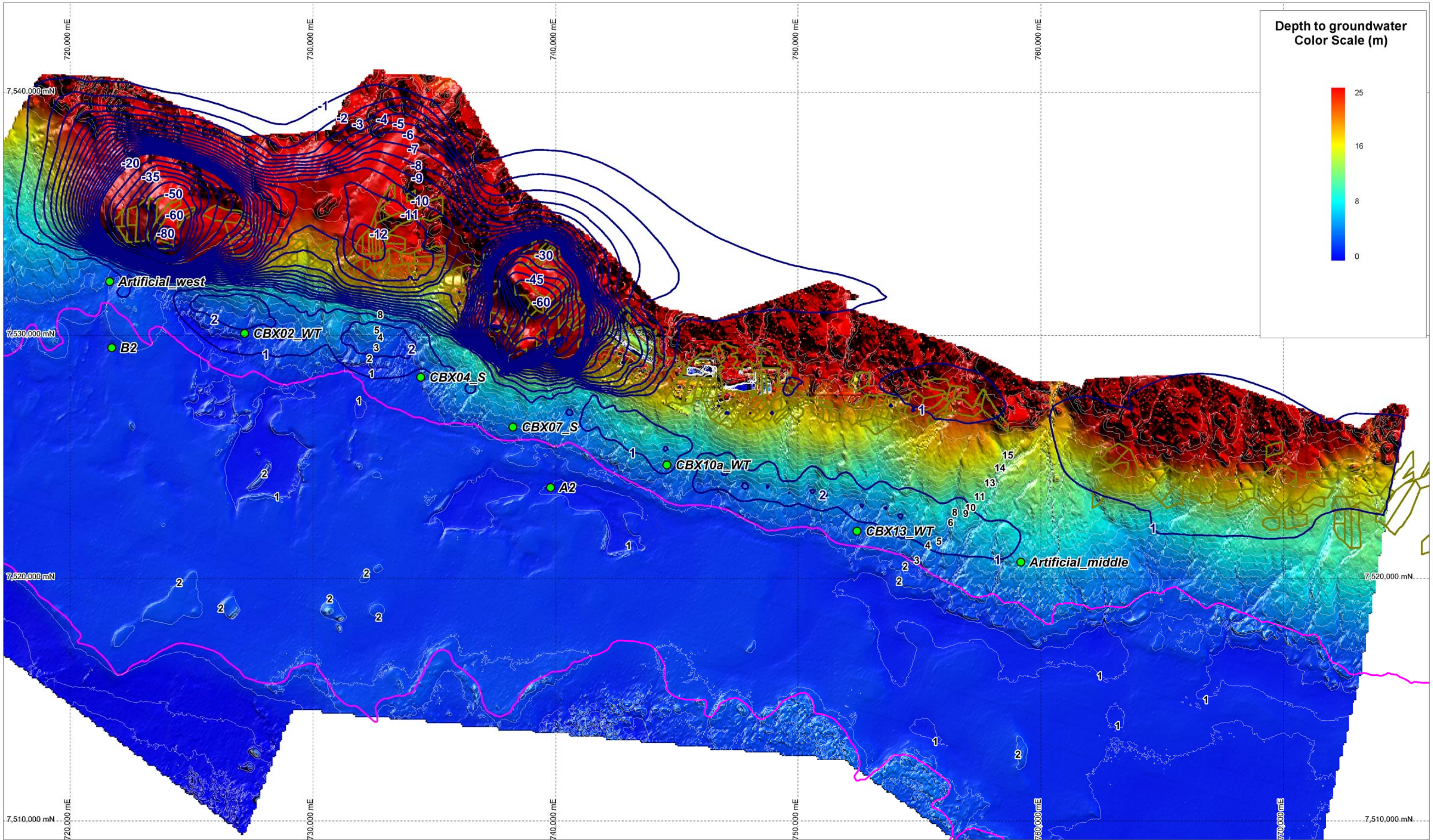
0 1.25 2.5 5

kilometres

Fortescue Metals Group Ltd

Yr 13 Groundwater Level Change from Baseline & Depth to Groundwater DRY Climate Simulation

Author: B. Willis-Jones	Date:30/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94	Scale: 1:140000



Mine Plan

Fortescue Marsh

Groundwater Drawdown (metres) (+ve) for mounding & (-ve) for drawdown

Depth to Watertable (metres)

Observation Wells

N

0 1.25 2.5 5
kilometres

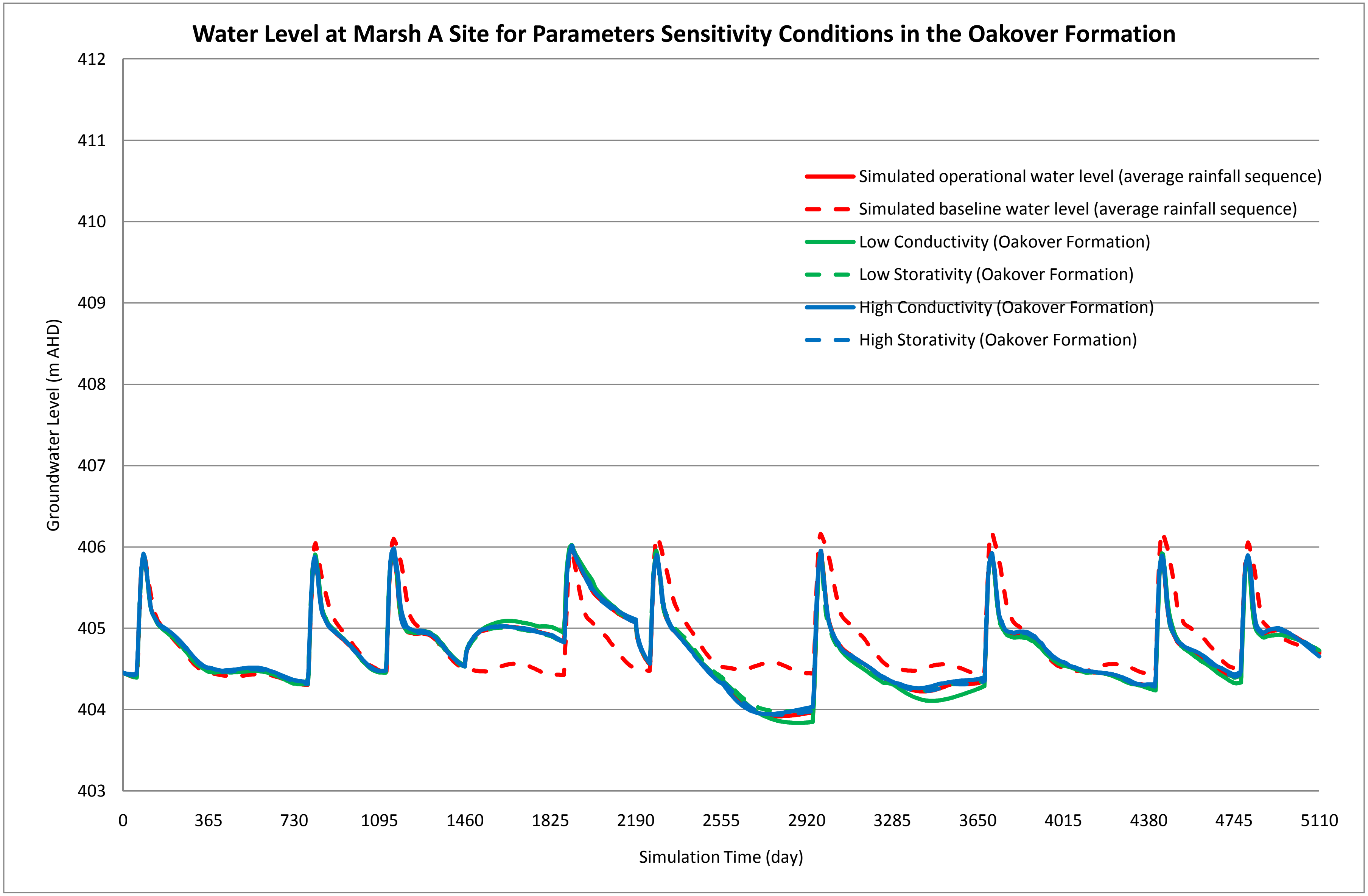
Fortescue Metals Group Ltd

Yr 14 Groundwater Level Change from Baseline & Depth to Groundwater DRY Climate Simulation

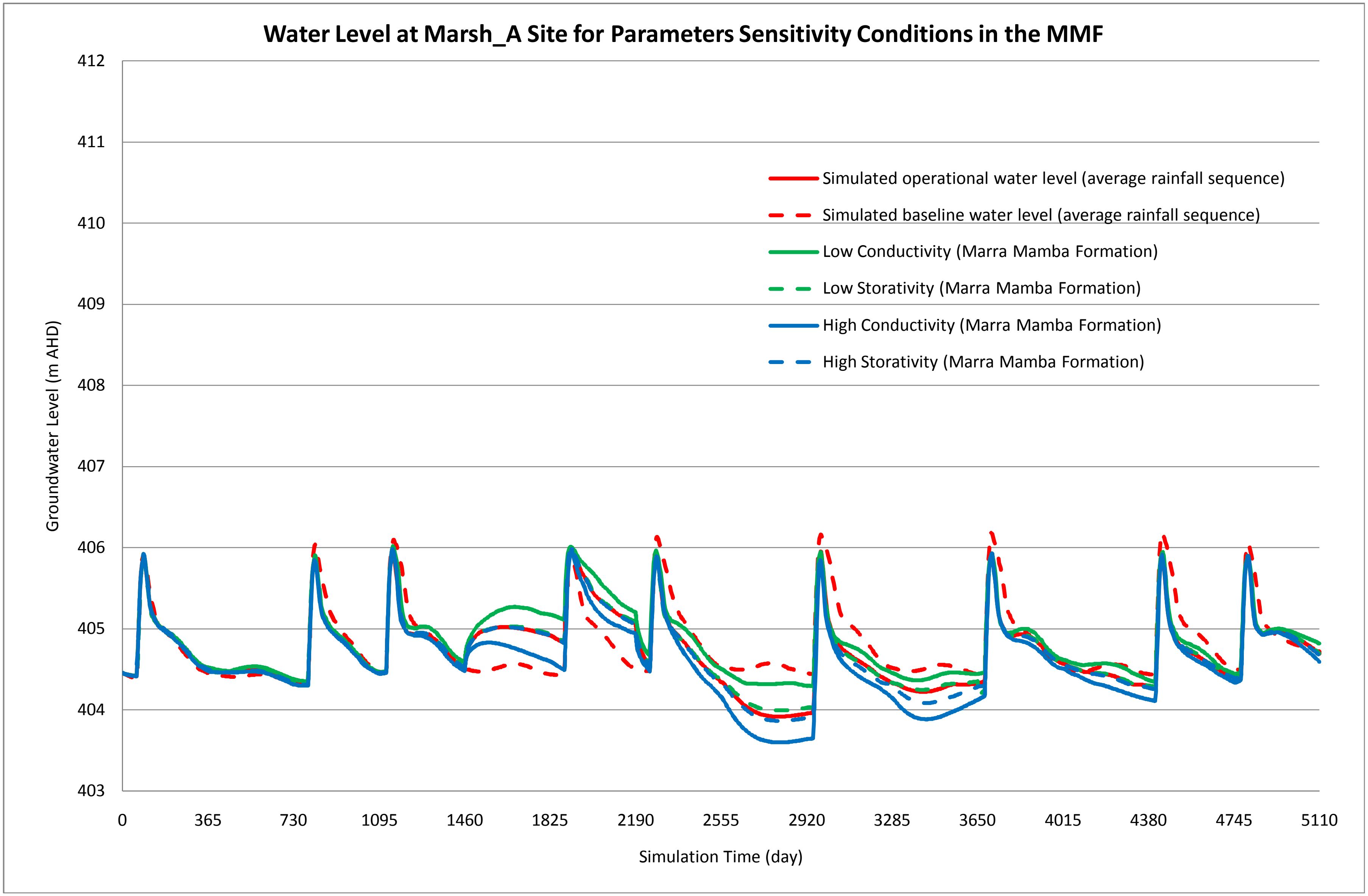
Author: B. Willis-Jones	Date:30/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:145000

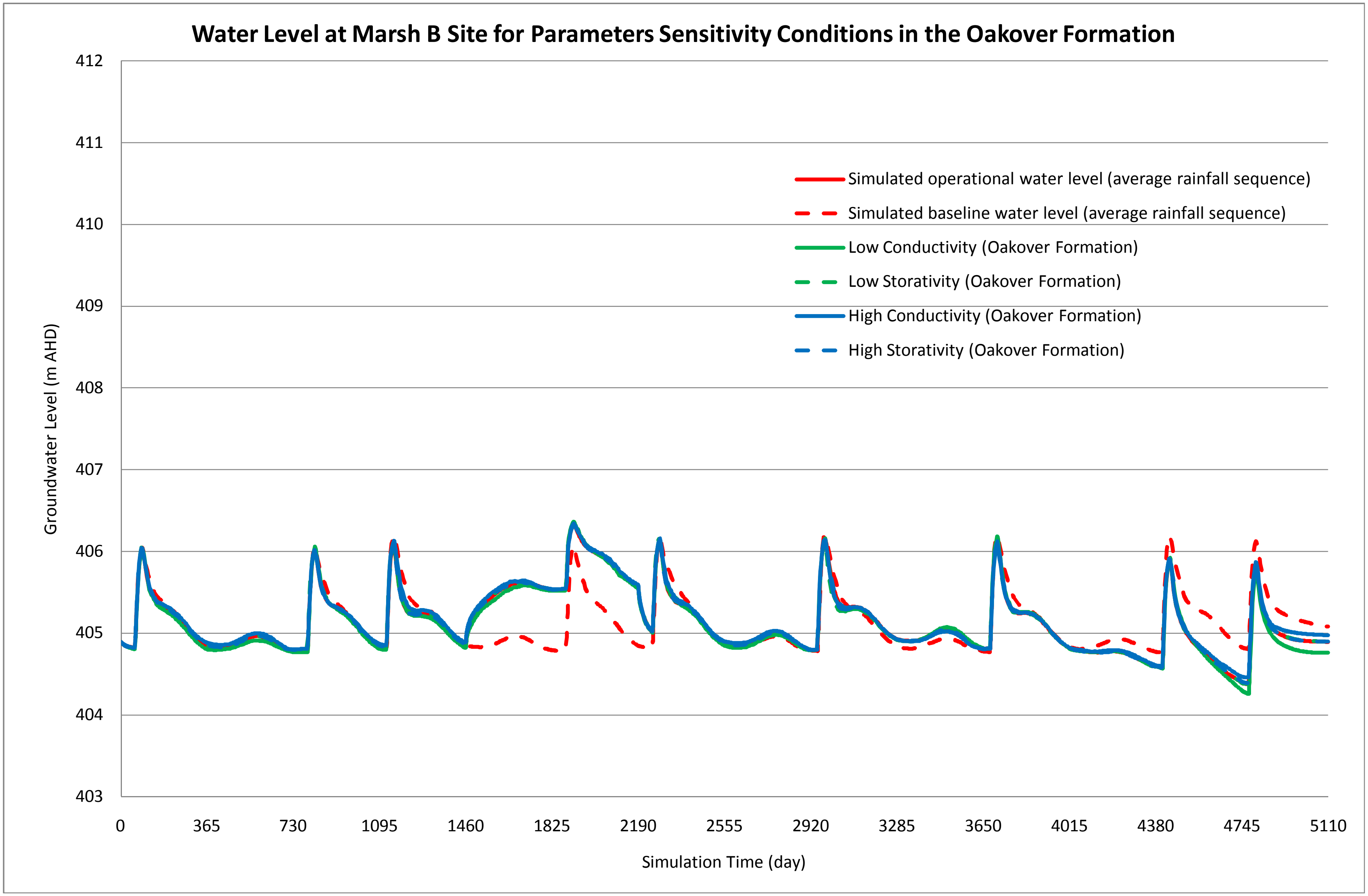
Appendix H.

Parameter Sensitivity and Uncertainty Analysis

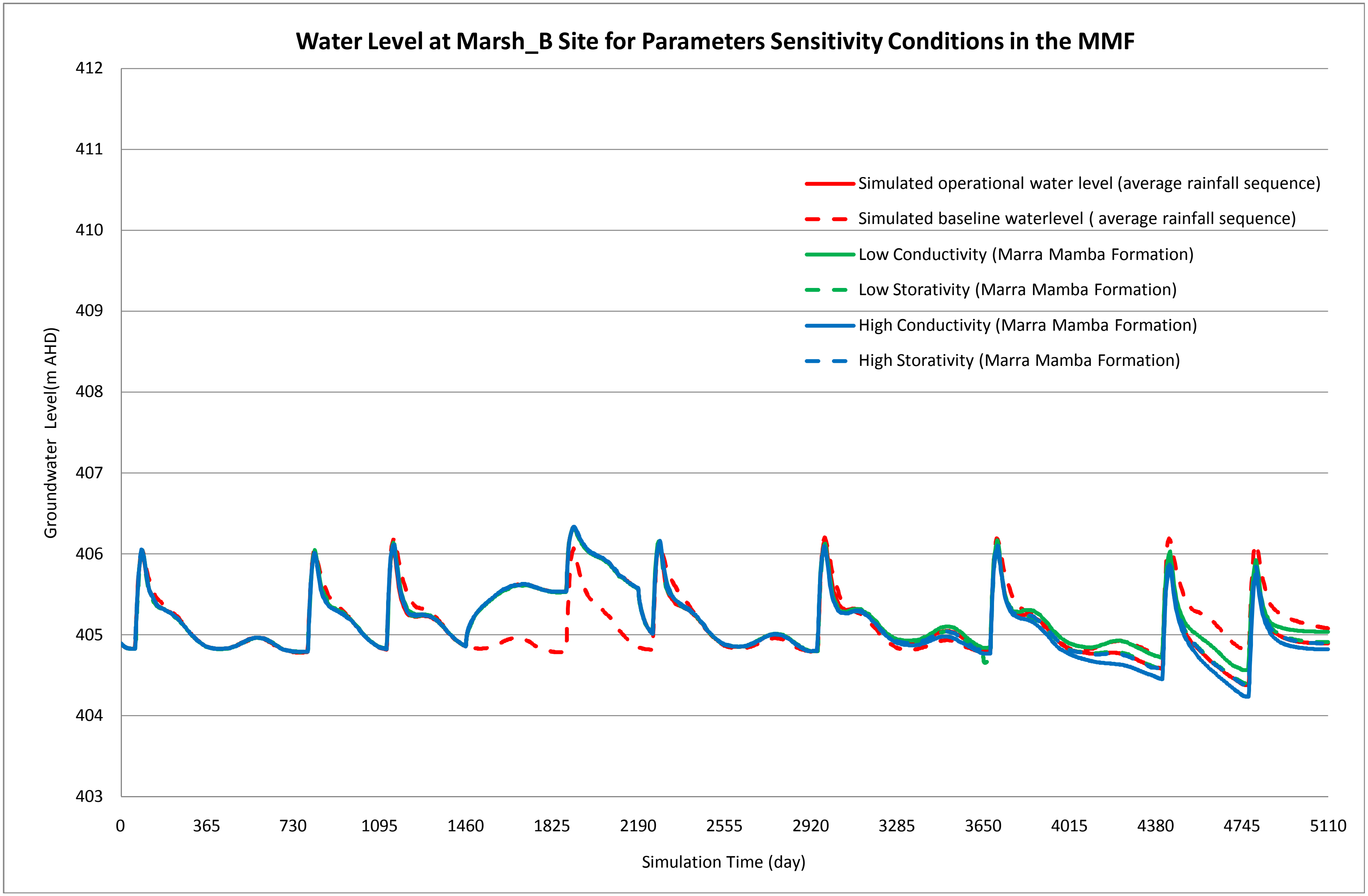


Water Level at Marsh A Site for Parameters Sensitivity Conditions in the Oakover Formation
Groundwater Level (m AHD)
412
411
410
409
408
407
406
405
404
403
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Simulated operational water level (average rainfall sequence)
Simulated baseline water level (average rainfall sequence)
Low Conductivity (Oakover Formation)
Low Storativity (Oakover Formation)
High Conductivity (Oakover Formation)
High Storativity (Oakover Formation)

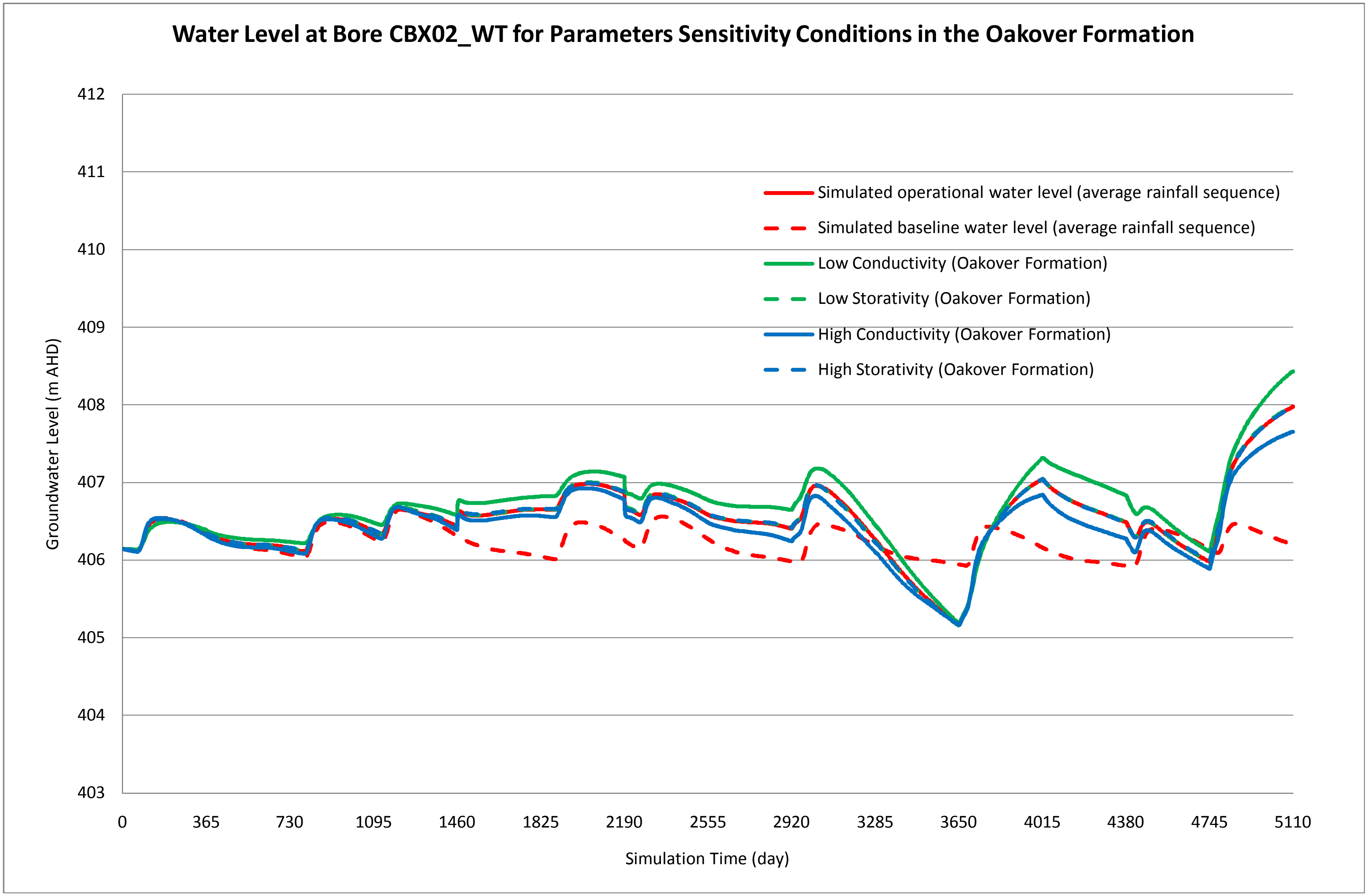

Water Level at Marsh_A Site for Parameters Sensitivity Conditions in the MMF
Groundwater Level (m AHD)
412
411
410
409
408
407
406
405
404
403
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Simulated operational water level (average rainfall sequence)
Simulated baseline water level (average rainfall sequence)
Low Conductivity (Marra Mamba Formation)
Low Storativity (Marra Mamba Formation)
High Conductivity (Marra Mamba Formation)
High Storativity (Marra Mamba Formation)



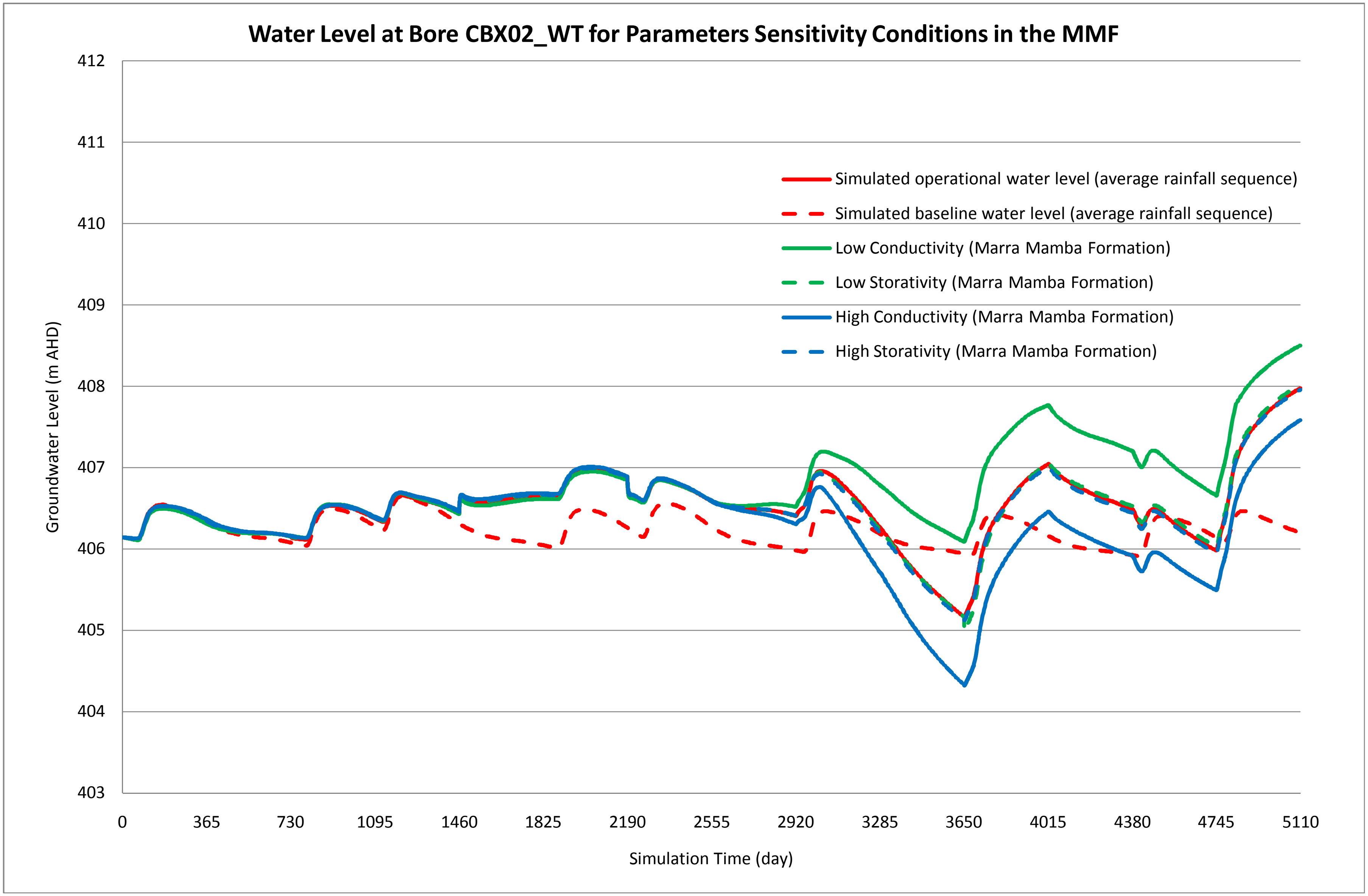
Water Level at Marsh B Site for Parameters Sensitivity Conditions in the Oakover Formation
Groundwater Level (m AHD)
412
411
410
409
408
407
406
405
404
403
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Simulated operational water level (average rainfall sequence)
Simulated baseline water level (average rainfall sequence)
Low Conductivity (Oakover Formation)
Low Storativity (Oakover Formation)
High Conductivity (Oakover Formation)
High Storativity (Oakover Formation)

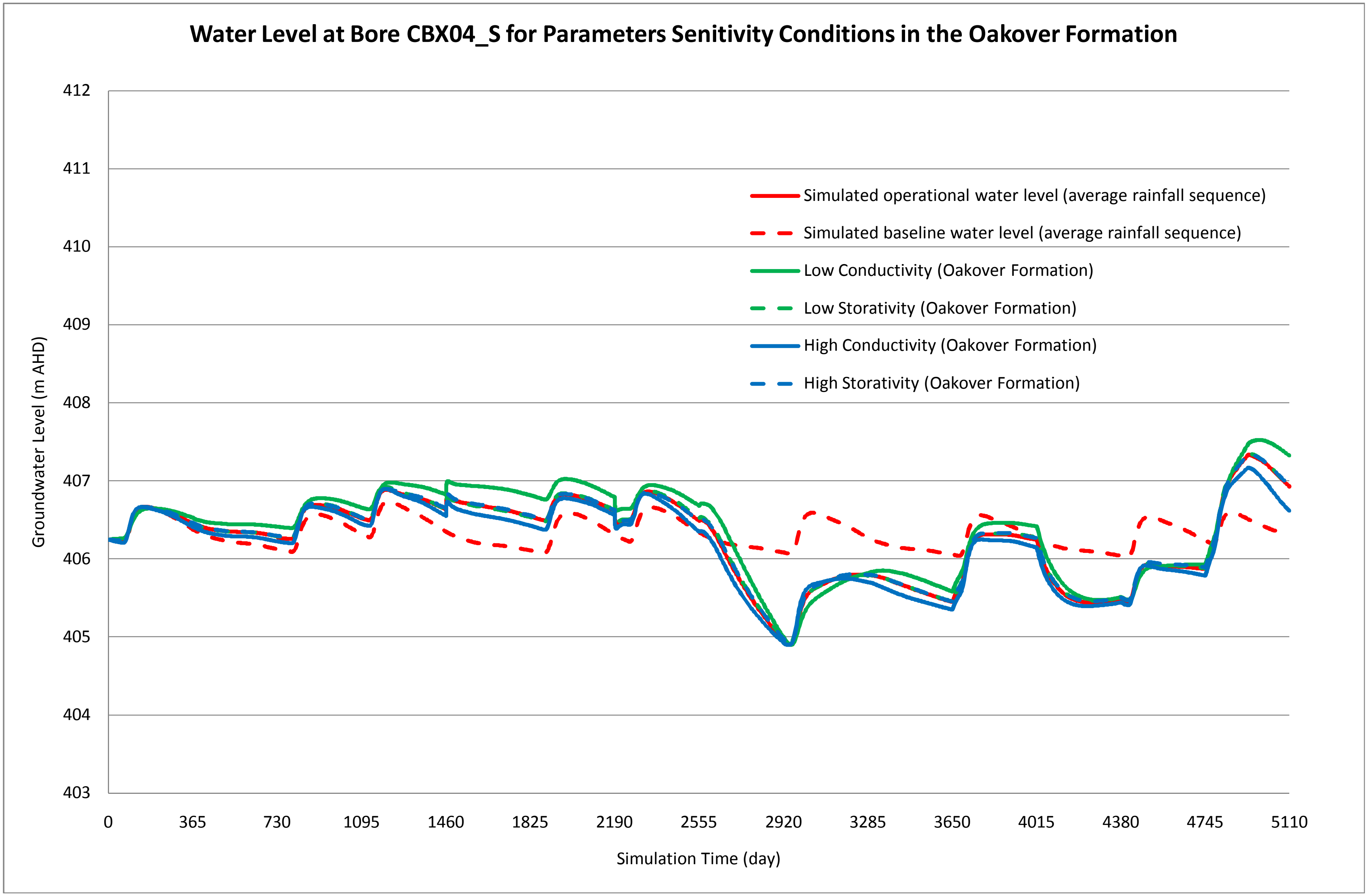


Water Level at Marsh_B Site for Parameters Sensitivity Conditions in the MMF
Groundwater Level(m AHD)
412
411
410
409
408
407
406
405
404
403
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Simulated operational water level (average rainfall sequence)
Simulated baseline waterlevel (average rainfall sequence)
Low Conductivity (Marra Mamba Formation)
Low Storativity (Marra Mamba Formation)
High Conductivity (Marra Mamba Formation)
High Storativity (Marra Mamba Formation)

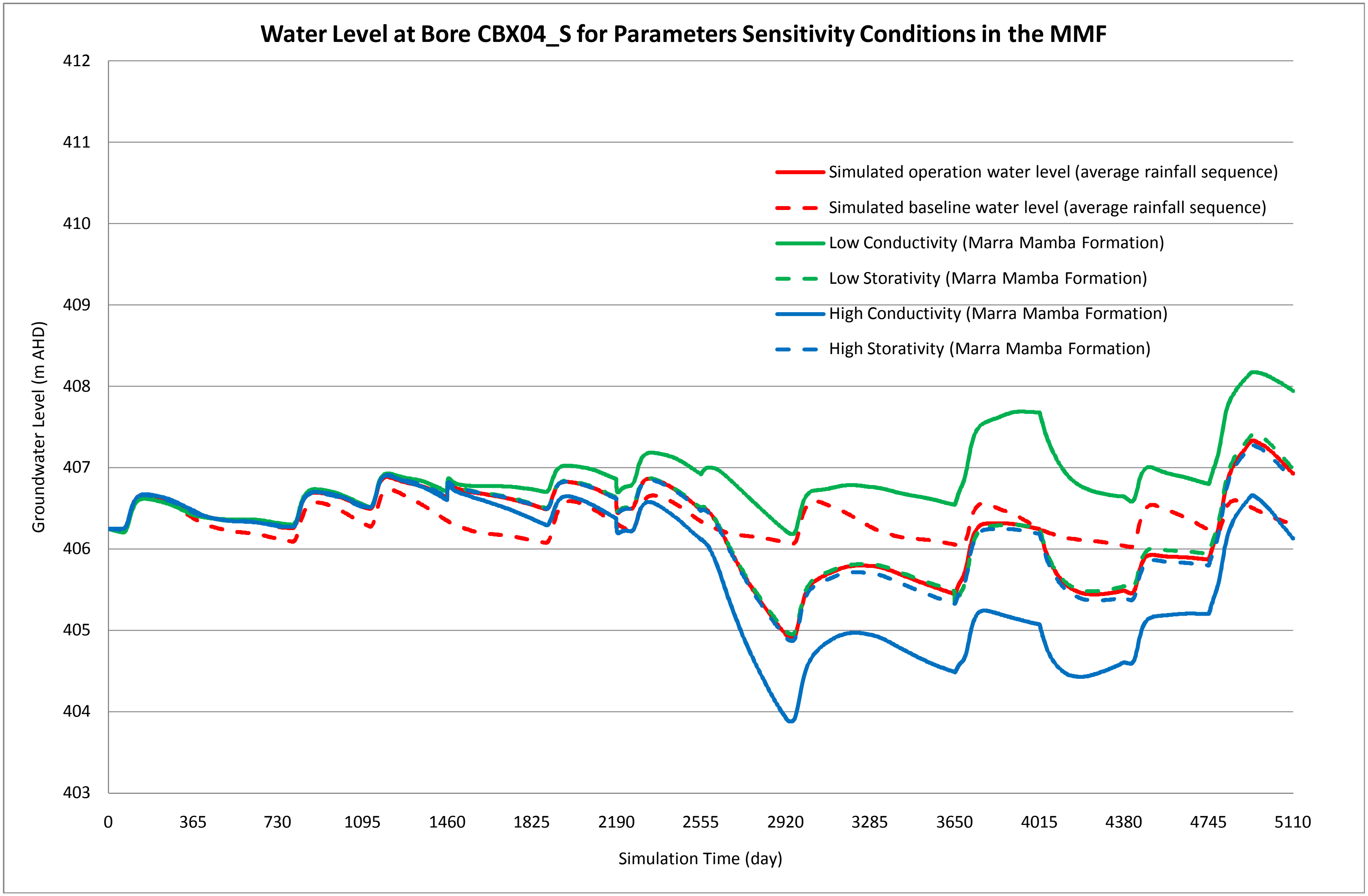


Water Level at Bore CBX02_WT for Parameters Sensitivity Conditions in the Oakover Formation
412
411
410
409
408
407
406
405
404
403
Groundwater Level (m AHD)
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Simulated operational water level (average rainfall sequence)
Simulated baseline water level (average rainfall sequence)
Low Conductivity (Oakover Formation)
Low Storativity (Oakover Formation)
High Conductivity (Oakover Formation)
High Storativity (Oakover Formation)

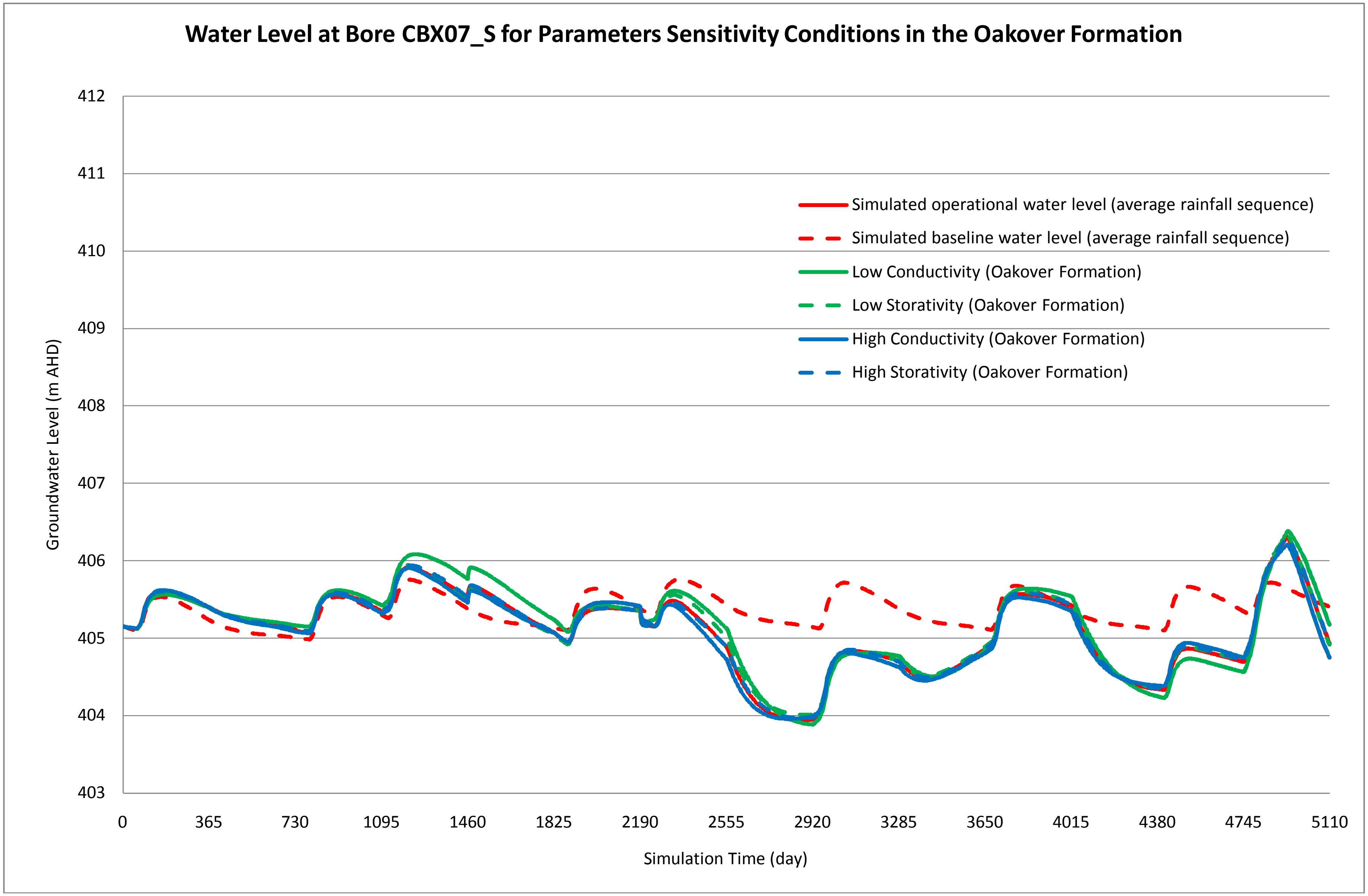

Water Level at Bore CBX02_WT for Parameters Sensitivity Conditions in the MMF
Groundwater Level (m AHD)
412
411
410
409
408
407
406
405
404
403
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Simulated operational water level (average rainfall sequence)
Simulated baseline water level (average rainfall sequence)
Low Conductivity (Marra Mamba Formation)
Low Storativity (Marra Mamba Formation)
High Conductivity (Marra Mamba Formation)
High Storativity (Marra Mamba Formation)

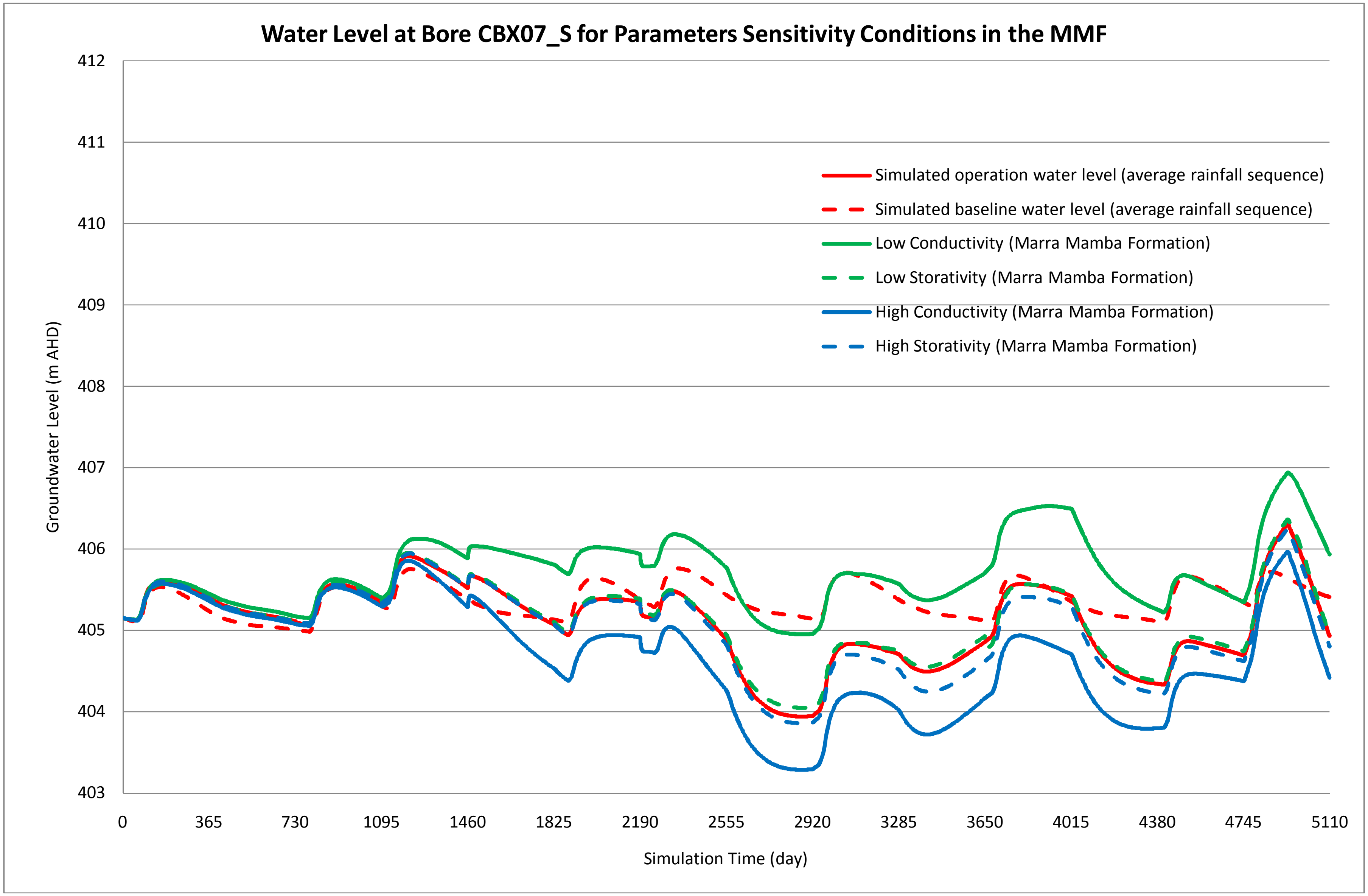


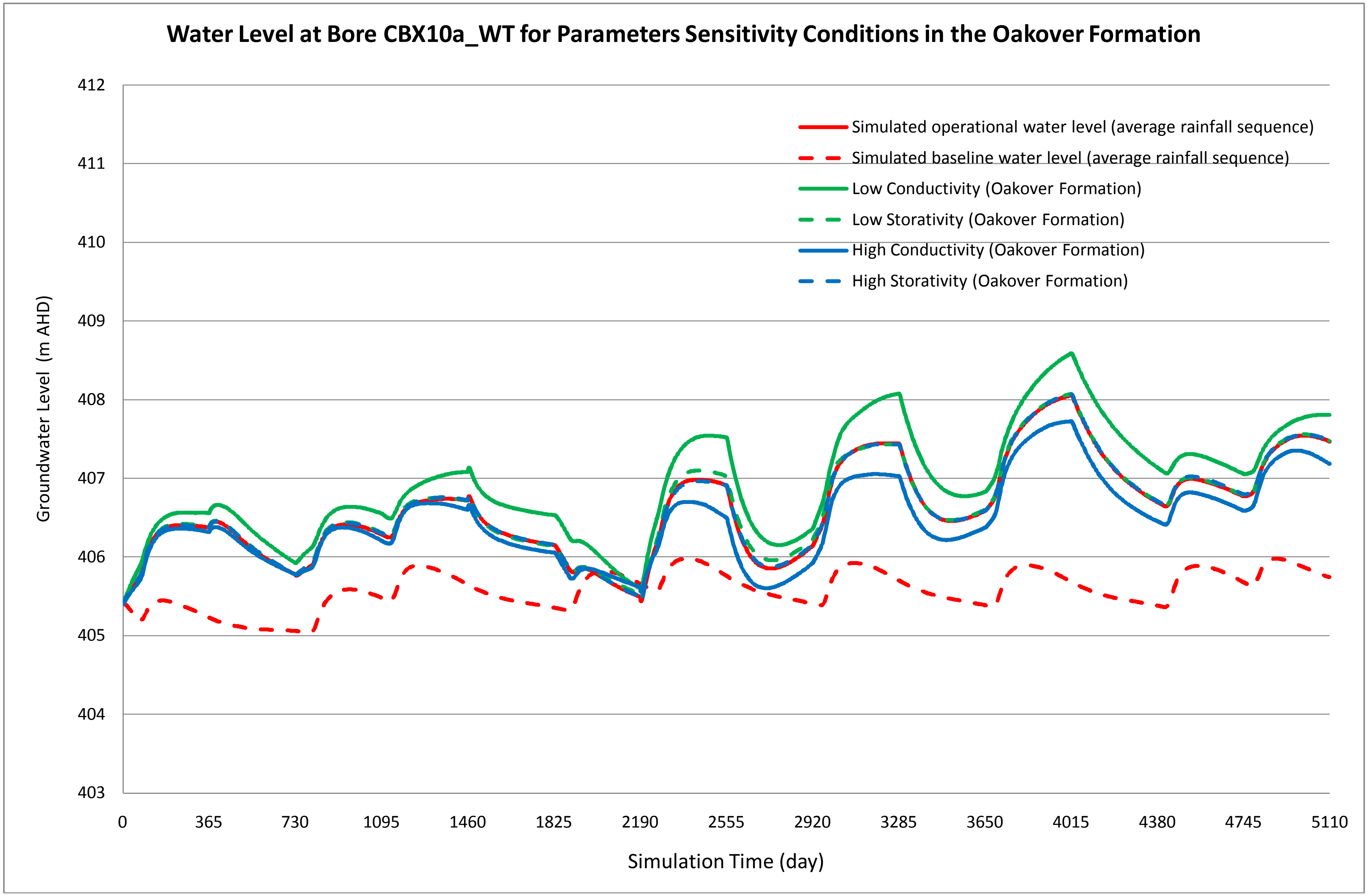
Water Level at Bore CBX04_S for Parameters Senitivity Conditions in the Oakover Formation
412
411
410
409
408
407
406
405
404
403
Groundwater Level (m AHD)
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Simulated operational water level (average rainfall sequence)
Simulated baseline water level (average rainfall sequence)
Low Conductivity (Oakover Formation)
Low Storativity (Oakover Formation)
High Conductivity (Oakover Formation)
High Storativity (Oakover Formation)

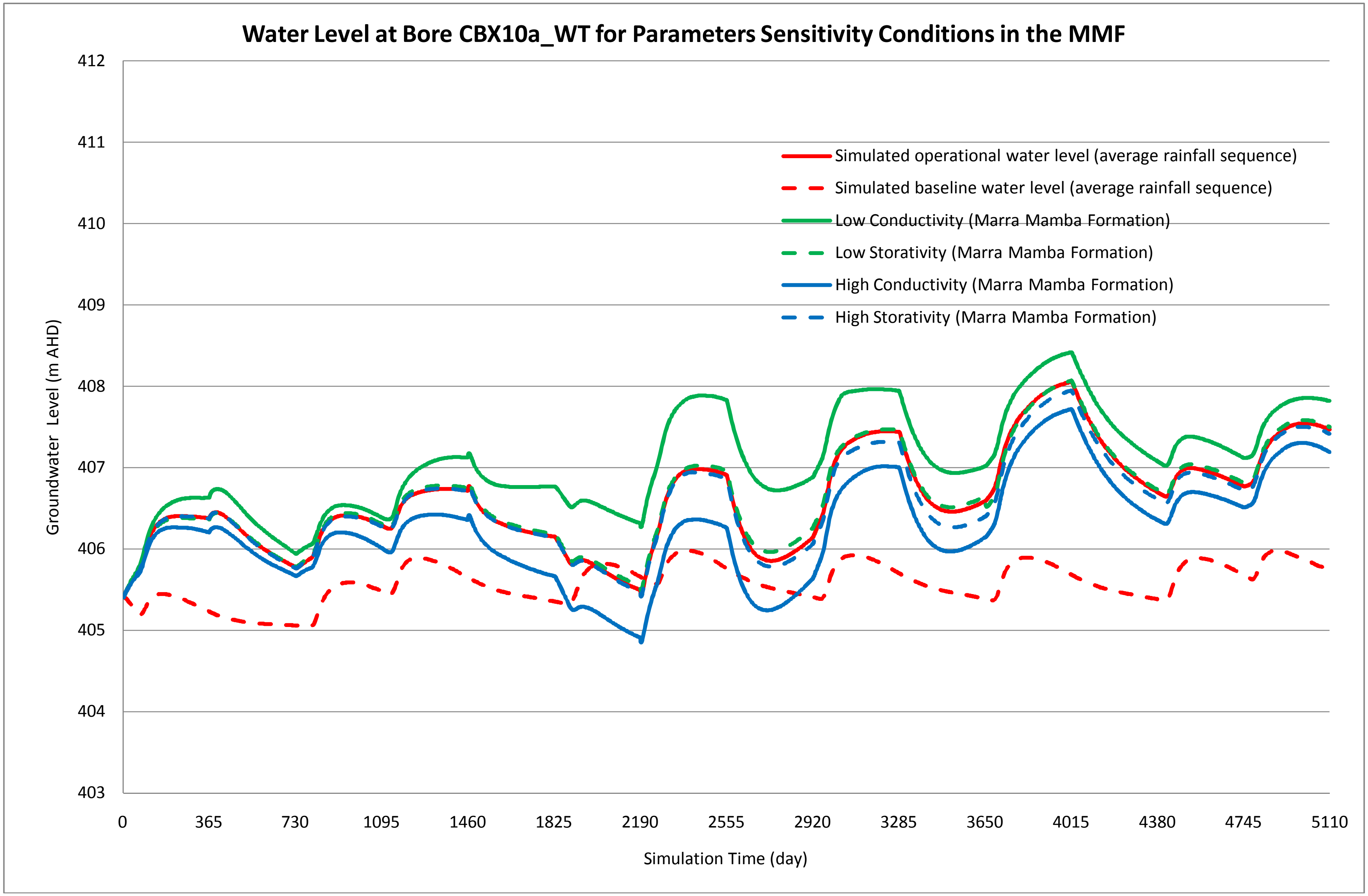


Water Level at Bore CBX04_S for Parameters Sensitivity Conditions in the MMF
Groundwater Level (m AHD)
412
411
410
409
408
407
406
405
404
403
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Simulated operation water level (average rainfall sequence)
Simulated baseline water level (average rainfall sequence)
Low Conductivity (Marra Mamba Formation)
Low Storativity (Marra Mamba Formation)
High Conductivity (Marra Mamba Formation)
High Storativity (Marra Mamba Formation)

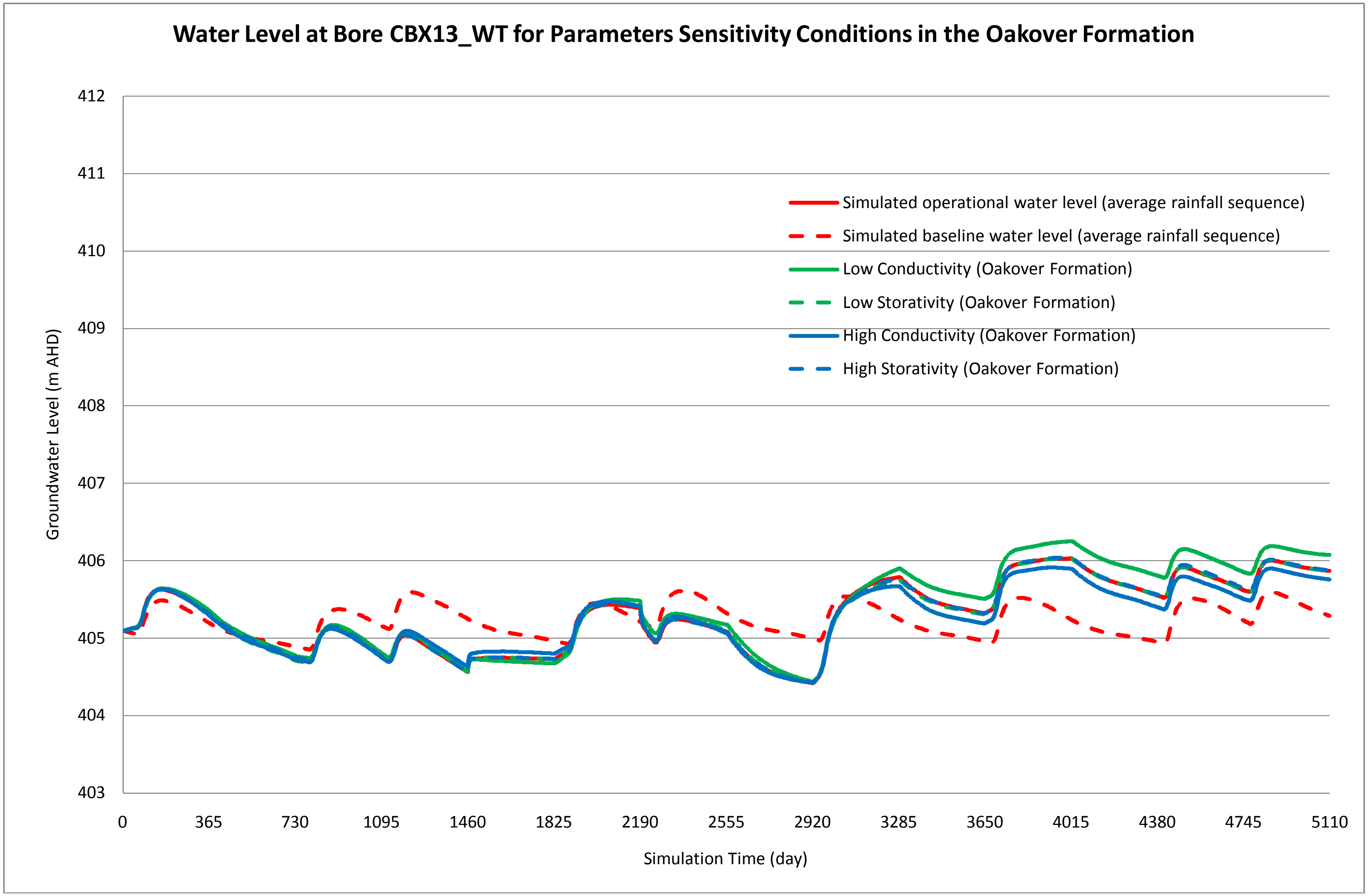

Water Level at Bore CBX07_S for Parameters Sensitivity Conditions in the Oakover Formation
Groundwater Level (m AHD)
412
411
410
409
408
407
406
405
404
403
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Simulated operational water level (average rainfall sequence)
Simulated baseline water level (average rainfall sequence)
Low Conductivity (Oakover Formation)
Low Storativity (Oakover Formation)
High Conductivity (Oakover Formation)
High Storativity (Oakover Formation)

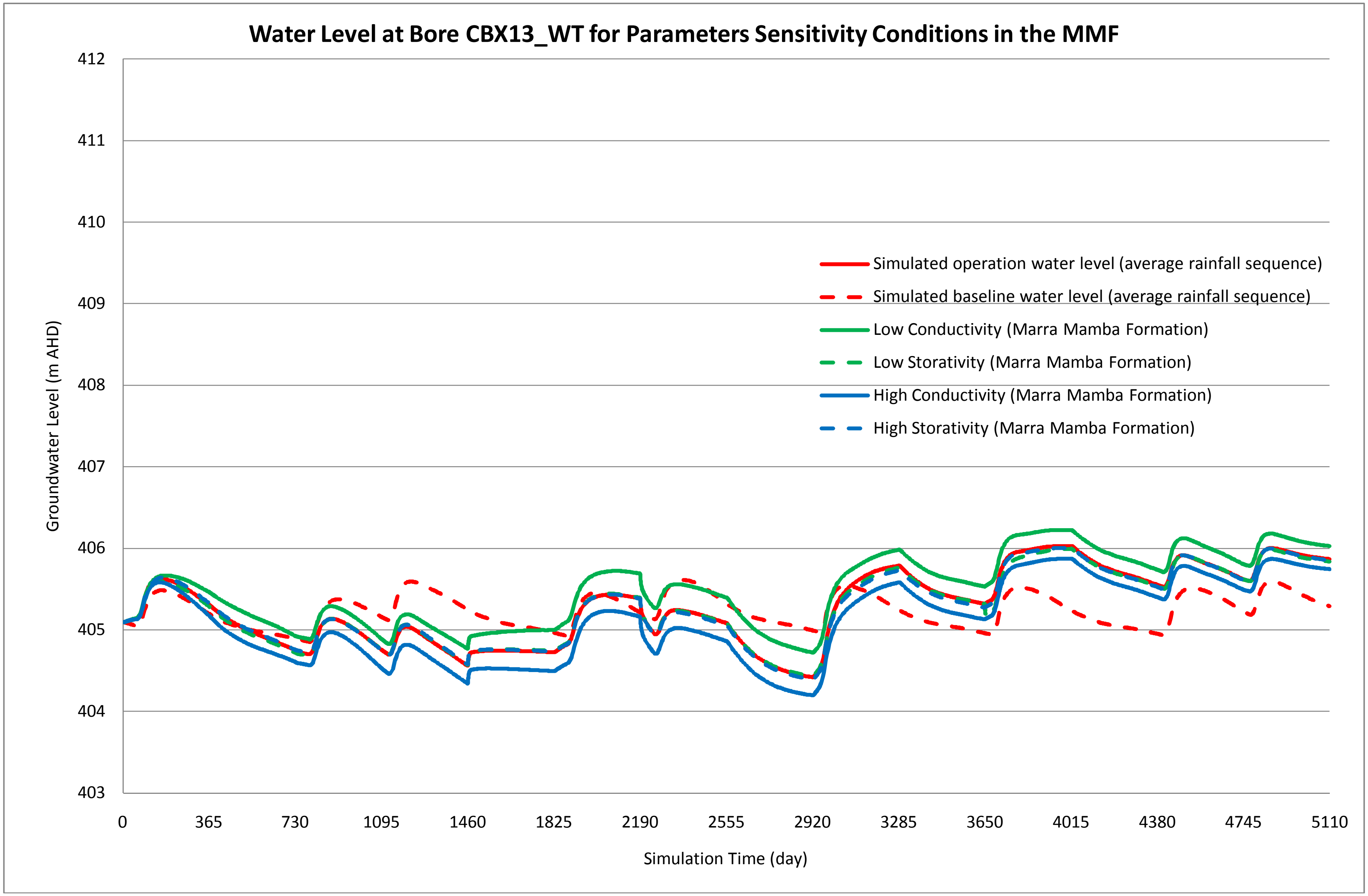

Water Level at Bore CBX07_S for Parameters Sensitivity Conditions in the MMF
Groundwater Level (m AHD)
412
411
410
409
408
407
406
405
404
403
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Simulated operation water level (average rainfall sequence)
Simulated baseline water level (average rainfall sequence)
Low Conductivity (Marra Mamba Formation)
Low Storativity (Marra Mamba Formation)
High Conductivity (Marra Mamba Formation)
High Storativity (Marra Mamba Formation)


Water Level at Bore CBX10a_WT for Parameters Sensitivity Conditions in the Oakover Formation
Groundwater Level (m AHD)
Simulation Time (day)
Simulated operational water level (average rainfall sequence)
Simulated baseline water level (average rainfall sequence)
Low Conductivity (Oakover Formation)
Low Storativity (Oakover Formation)
High Conductivity (Oakover Formation)
High Storativity (Oakover Formation)
412
411
410
409
408
407
406
405
404
403
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110



Water Level at Bore CBX10a_WT for Parameters Sensitivity Conditions in the MMF
412
411
410
409
408
407
406
405
404
403
Groundwater Level (m AHD)
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Simulated operational water level (average rainfall sequence)
Simulated baseline water level (average rainfall sequence)
Low Conductivity (Marra Mamba Formation)
Low Storativity (Marra Mamba Formation)
High Conductivity (Marra Mamba Formation)
High Storativity (Marra Mamba Formation)

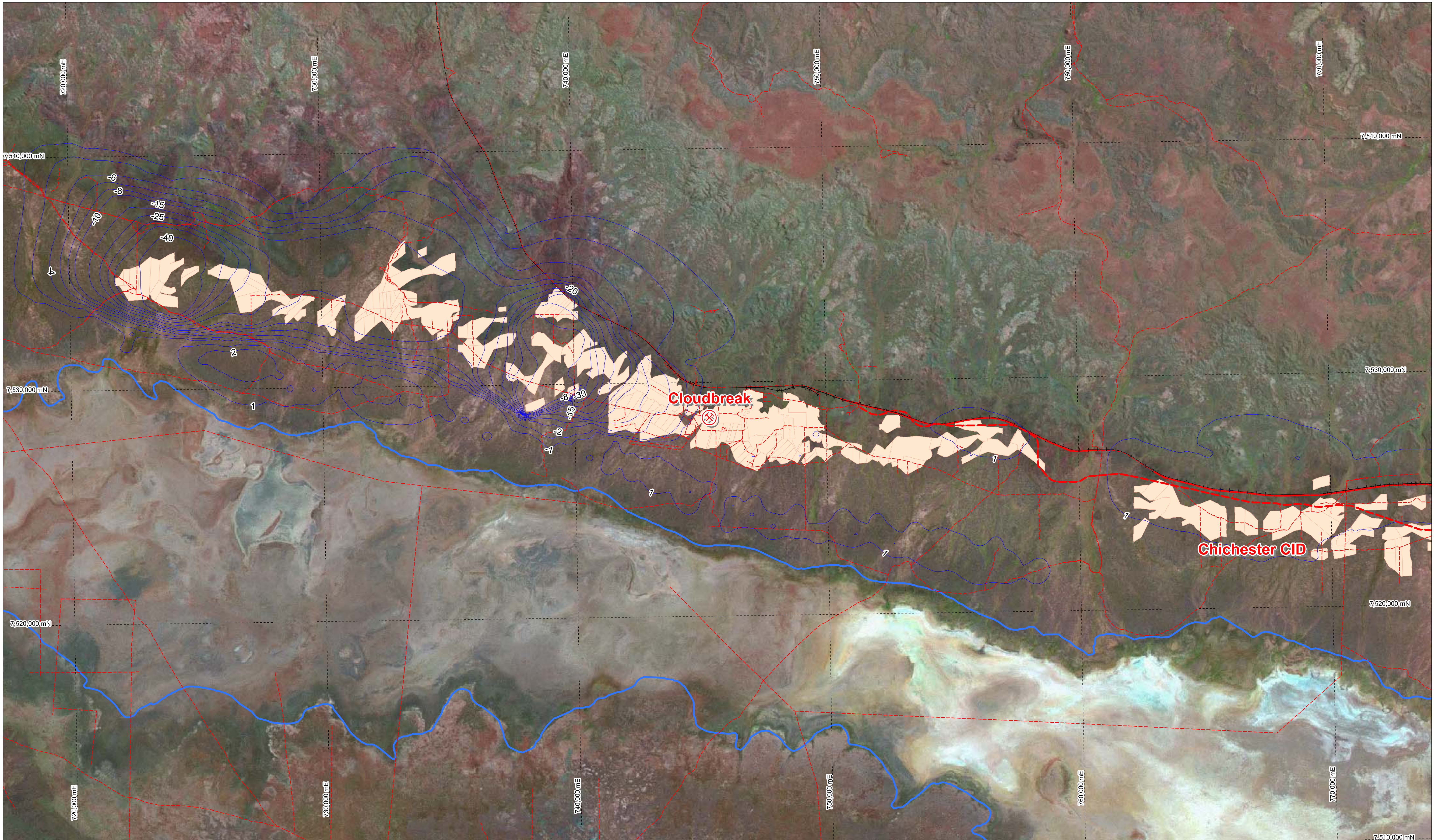

Water Level at Bore CBX13_WT for Parameters Sensitivity Conditions in the Oakover Formation
Groundwater Level (m AHD)
412
411
410
409
408
407
406
405
404
403
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Simulated operational water level (average rainfall sequence)
Simulated baseline water level (average rainfall sequence)
Low Conductivity (Oakover Formation)
Low Storativity (Oakover Formation)
High Conductivity (Oakover Formation)
High Storativity (Oakover Formation)

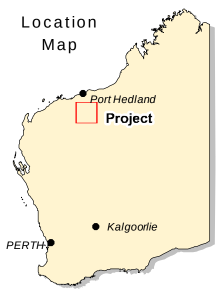


Water Level at Bore CBX13_WT for Parameters Sensitivity Conditions in the MMF
412
411
410
409
408
407
406
405
404
403
Groundwater Level (m AHD)
0
365
730
1095
1460
1825
2190
2555
2920
3285
3650
4015
4380
4745
5110
Simulation Time (day)
Simulated operation water level (average rainfall sequence)
Simulated baseline water level (average rainfall sequence)
Low Conductivity (Marra Mamba Formation)
Low Storativity (Marra Mamba Formation)
High Conductivity (Marra Mamba Formation)
High Storativity (Marra Mamba Formation)

Appendix I.

Post Mining Water Level Recovery Analysis





Mine Sequence

Fortescue Marsh Boundary

drawdown (-ve) and mounding (+ve) in meters

Existing Roads/Tracks

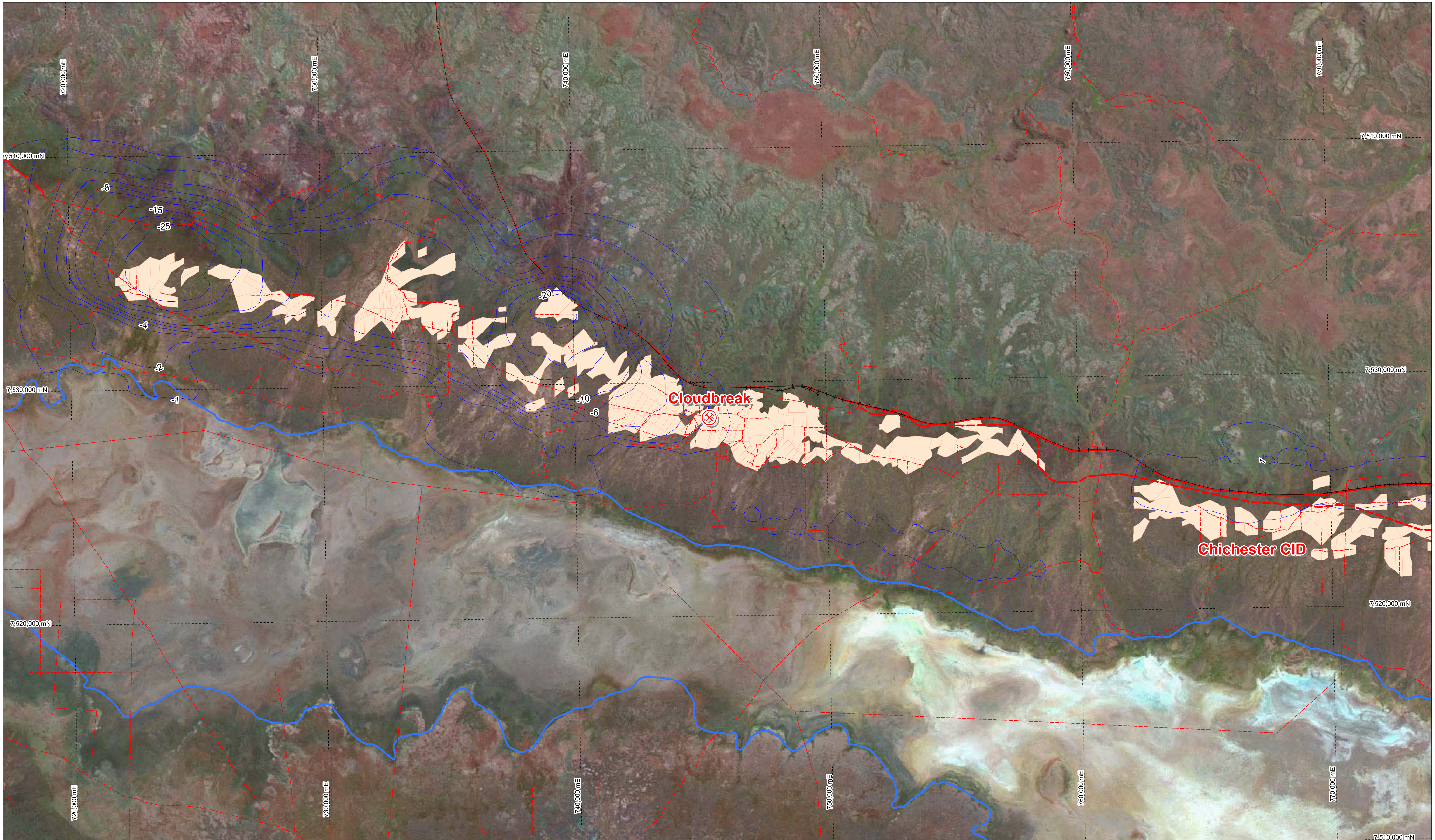
N

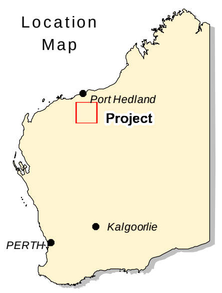
0 1.25 2.5 5
kilometres

Fortescue Metals Group Ltd

Drawdown at End of Mining

Author: B. Willis-Jones	Date:9/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000





Mine Sequence

Fortescue Marsh Boundary

drawdown (-ve) and mounding (+ve) in meters

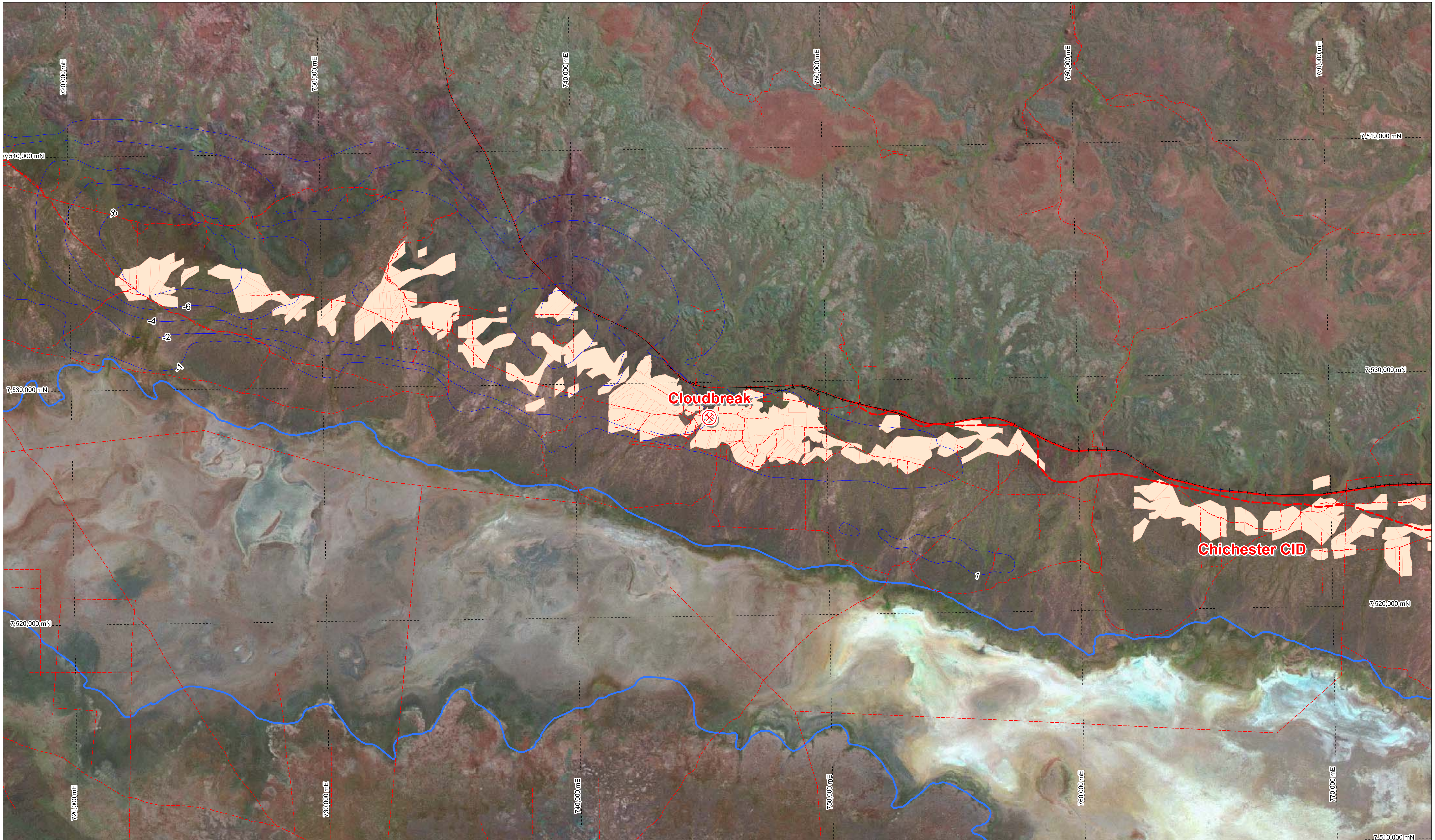
Existing Roads/Tracks

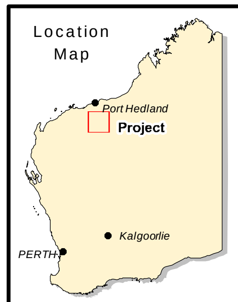
0 1.25 2.5 5
kilometres

Fortescue Metals Group Ltd

Residual Drawdown at 1 Year Post Mining

Author: B. Willis-Jones	Date:9/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000





Legend	
Mine Sequence	drawdown (-ve) and mounding (+ve) in meters
Fortescue Marsh Boundary	Existing Roads/Tracks

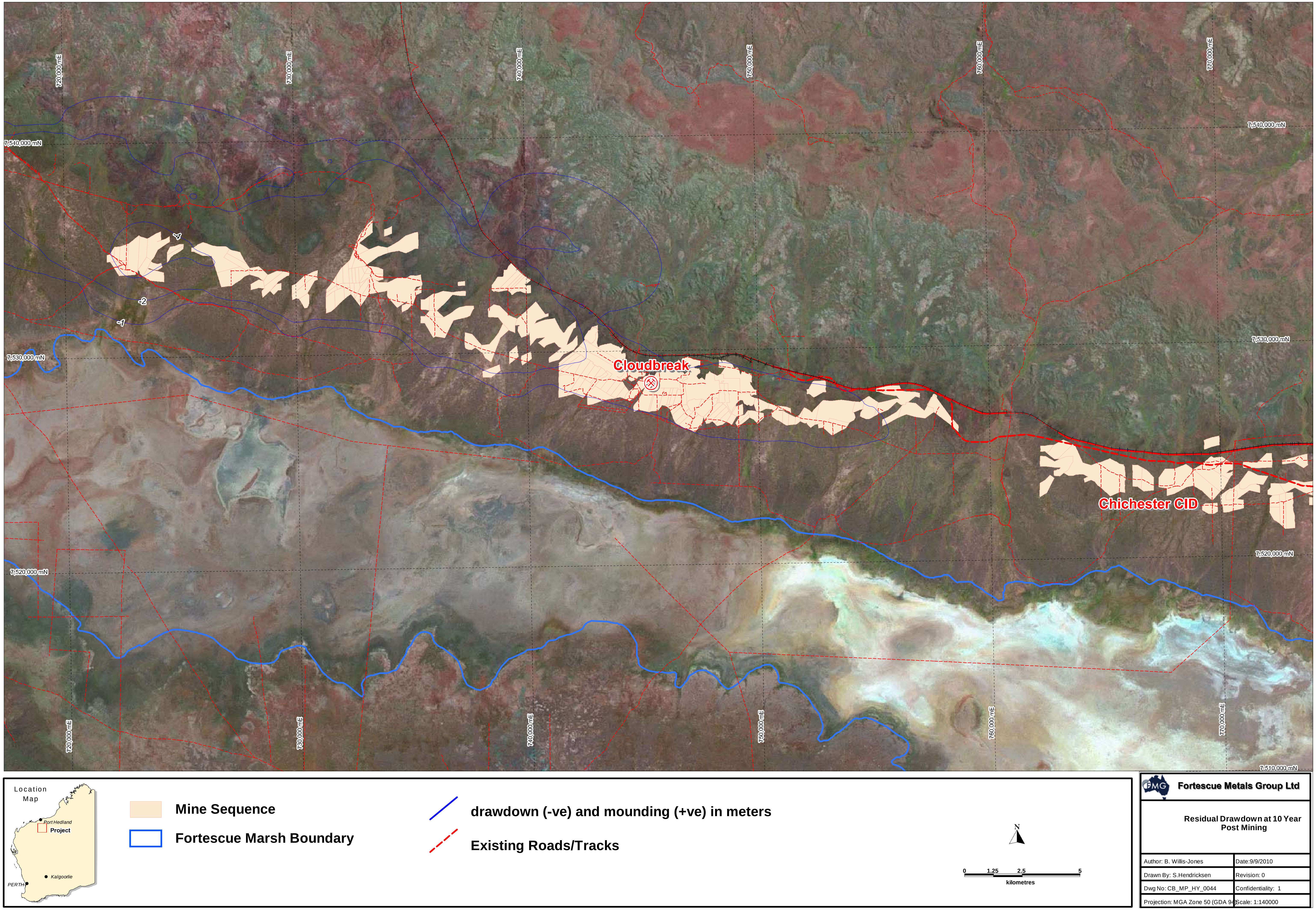
N

0 1.25 2.5 5
kilometres

Fortescue Metals Group Ltd

Residual Drawdown at 5 Year Post Mining

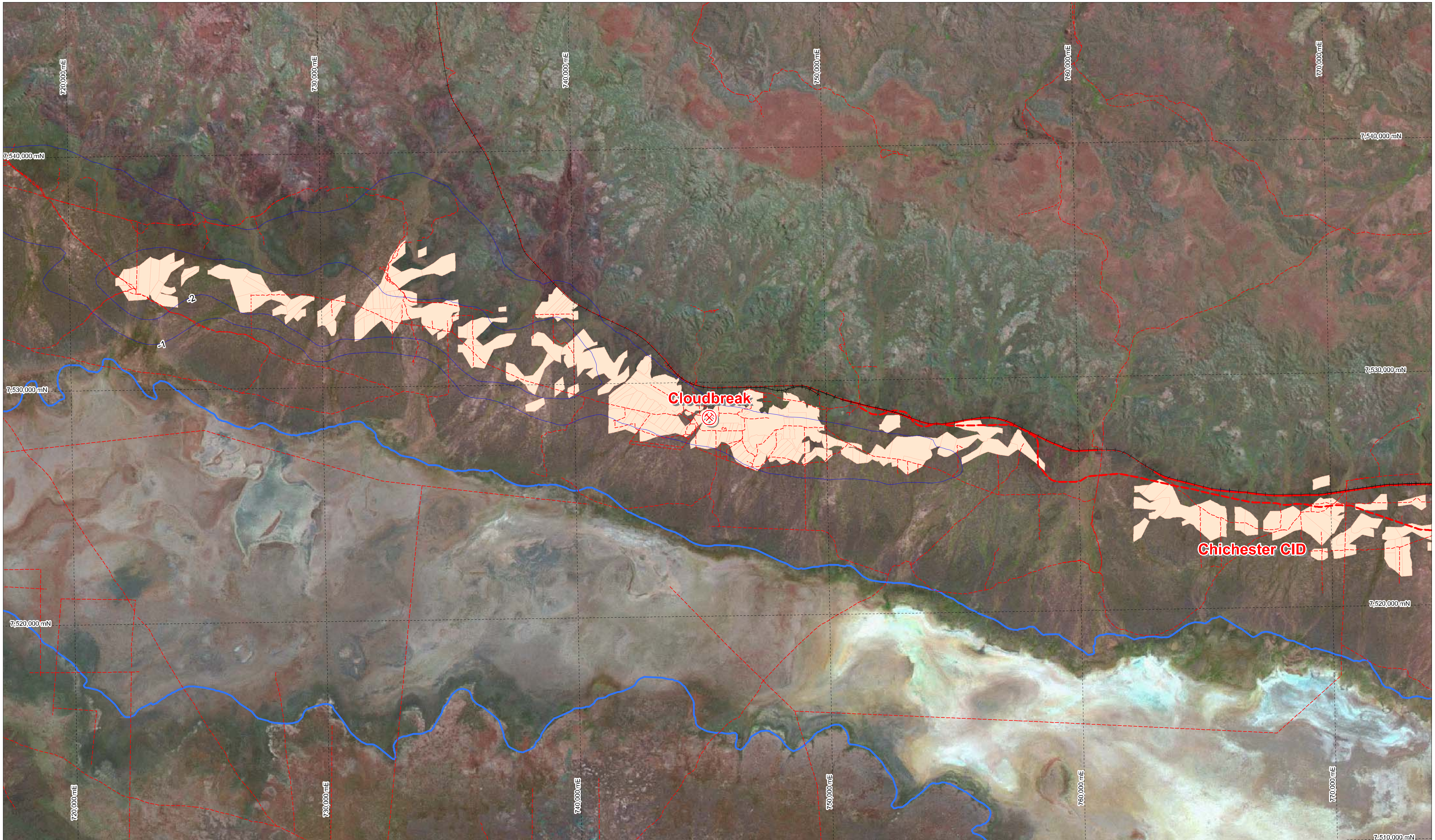
Author: B. Willis-Jones	Date:9/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000



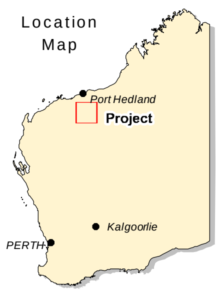
Fortescue Metals Group Ltd

Residual Drawdown at 10 Year Post Mining

Author: B. Willis-Jones	Date:9/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000



Location Map



Mine Sequence

Fortescue Marsh Boundary

drawdown (-ve) and mounding (+ve) in meters

Existing Roads/Tracks

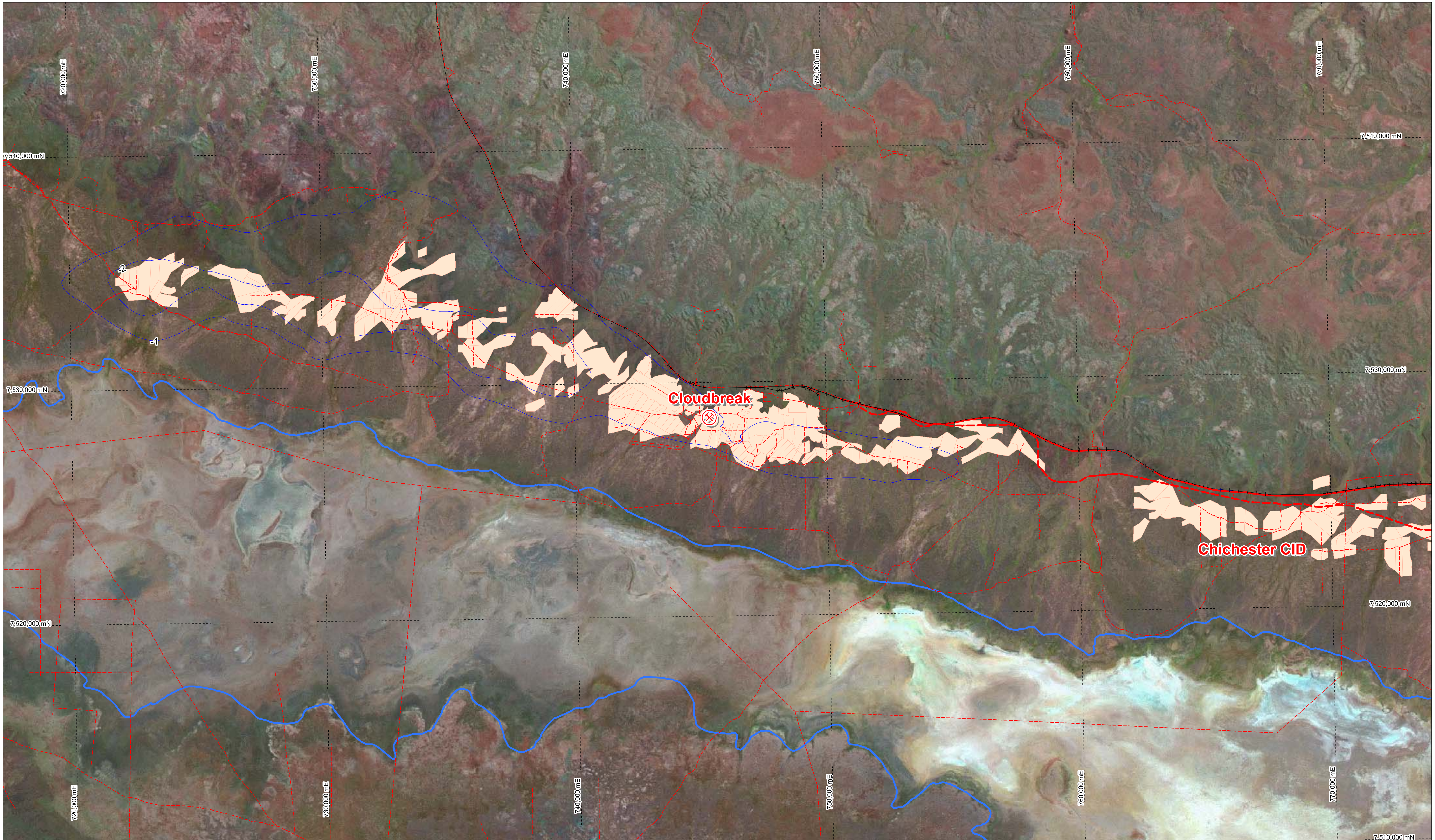
N

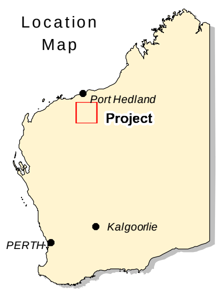
0 1.25 2.5 5
kilometres

Fortescue Metals Group Ltd

Residual Drawdown at 20 Year Post Mining

Author: B. Willis-Jones	Date:9/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94	Scale: 1:140000





Mine Sequence

Fortescue Marsh Boundary

drawdown (-ve) and mounding (+ve) in meters

Existing Roads/Tracks

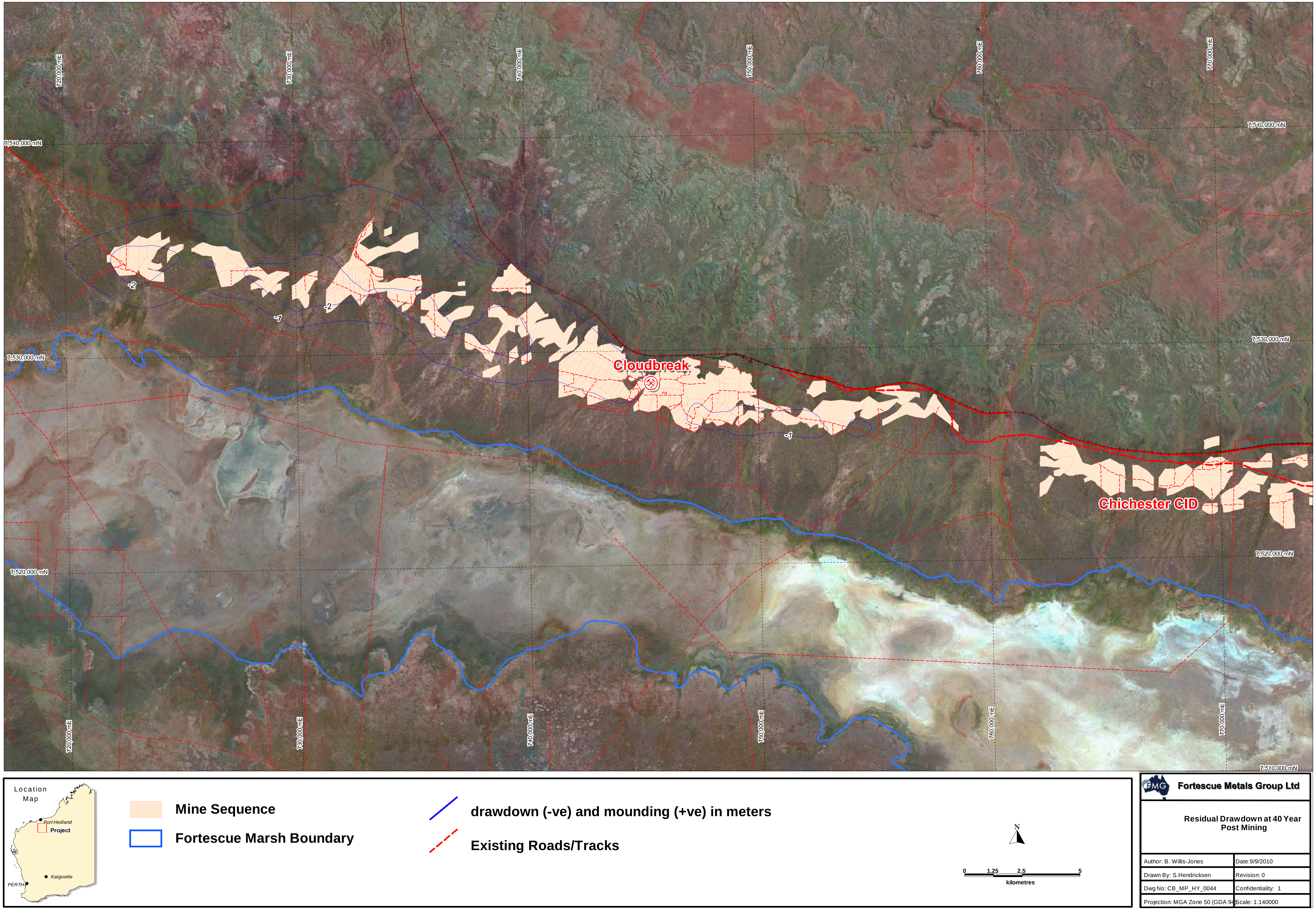
N

0 1.25 2.5 5
kilometres

Fortescue Metals Group Ltd

Residual Drawdown at 30 Year Post Mining

Author: B. Willis-Jones	Date:9/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000



Fortescue Metals Group Ltd

Residual Drawdown at 40 Year Post Mining

Author: B. Willis-Jones	Date:9/9/2010
Drawn By: S.Hendricksen	Revision: 0
Dwg No: CB_MP_HY_0044	Confidentiality: 1
Projection: MGA Zone 50 (GDA 94)	Scale: 1:140000